

UREA SYNTHESIS USING GREEN AMMONIA TECHNOLOGY

K2

UNIVERSITI KEBANGSAAN MALAYSIA

UREA SYNTHESIS USING GREEN AMMONIA TECHNOLOGY

K2

AZRUL ZULHILMI BIN AHMAD ROSLI	(A172752)
NURZULAIKHA BINTI ZULKARNAIN	(A173895)
NUR IFFA BINTI RIZUAN	(A173952)
AERRY TING WEI HUAN	(A174141)
SURIYA VATHI A/P SUBRAMANIAN	(A174271)

FACULTY OF ENGINEERING AND BUILT ENVIRONMENT
UNIVERSITI KEBANGSAAN MALAYSIA
BANGI

2023

SINTESIS UREA DARIPADA TEKNOLOGI AMMONIA HIJAU

K2

AZRUL ZULHILMI BIN AHMAD ROSLI	(A172752)
NURZULAIKHA BINTI ZULKARNAIN	(A173895)
NUR IFFA BINTI RIZUAN	(A173952)
AERRY TING WEI HUAN	(A174141)
SURIYA VATHI A/P SUBRAMANIAN	(A174271)

FAKULTI KEJUTERAAN DAN ALAM BINA
UNIVERSITI KEBANGSAAN MALAYSIA
BANGI

2023

DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

01 July 2023

AZRUL ZULHILMI BIN
AHMAD ROSLI
A173752

NURZULAIKHA BINTI
ZULKARNAIN
A173895

NUR IFFA BINTI RIZUAN
A173952

AERRY TING WEI HUAN
A174141

SURIYA VATHI A/P
SUBRAMANIAN
A174271

ACKNOWLEDGEMENT

Praise is to God, the most gracious, the most merciful. Thank you for giving us the strength and spirit to complete this report – Urea Synthesis from Green Ammonia Technology. Here, we wish to express our highest gratitude and appreciation to some important people who have given us their big hand in accomplishing our project. Primarily, we would like to extend appreciation to all people for helping and contributing ideas while conducting this study.

First and foremost, we would like to acknowledge the guidance and advice of PM Noorhisham Tan Kofli and Dr. Peer Mohamed as our group supervisors and Mr, Tan Chung Chuan from ExxonMobil as our industrial supervisor. Besides, we would like to extend heartfelt gratitude to Ir. Dr. Nor Yuliana Yuhana, Dr. Muhammad Zulhaziman Mat Salleh, PM Dr. Mohd Shahbudin Mastar @ Masdar, and Dr. Nur Tantiyani Ali Othman the coordinators of this subject for giving us suggestions throughout the project.

Also, we would like to express our highest gratitude to our parents for giving us all the moral support when we really need one. Thank you very much and may God bless your help. Lastly, we would like to thank all our course mates and seniors, and those who are involved in helping us in this project directly and indirectly. Without all the help, it is impossible for us to complete this project. Your kindness and cooperation are highly appreciated. Just words alone cannot illustrate how much we thank you all.

Thank you.

EXECUTIVE SUMMARY

In this design project, a Urea Synthesis using Green Ammonia Technology is proposed. Urea, commonly known as carbamide, is the diamide of carbonic acid. Research shows that the global demand for urea market can reach 190 million tonnes in 2021 and is expected to achieve a healthy CAGR of 4.15% from 2022 to 2035 due to high usage of urea. Thus conceptual plant will produce 17550 tonne/year urea which is going to fill 0.05% deficiency of world's demand urea. The working days of 352 days and 24 hour a day in operating of the plant of urea with 14 days maintenances.

Urea synthesis using green ammonia technology uses power-to-urea technology which is from solar power as electrical supply. First, tap water undergoes water purification to provide the necessary deionized water quality to the process. This is required to meet the specification of PEM electrolyser. After water purification, water will undergo electrolysis through PEM electrolyser to produce oxygen and hydrogen. Then, hydrogen and nitrogen enter the catalytic packed bed reactor by using a magnetic induction with the presence of nanocatalyst to produce ammonia. Next, ammonia is produced and go to urea synthesis along with carbon dioxide to synthesis urea at plug flow reactor. Urea, ammonium carbamate, and excess ammonia will go to stripper for decomposition of ammonium carbamate. Then, excess ammonium carbamate will flow to the decomposition unit for further decomposing it to ammonia and carbon dioxide. Then, urea will flow to the evaporator to evaporate some water and then into granulator to the achieve desired purity in granule form.

In this work, mass and energy balance are conducted, along with the simulation using Symmetry®. Heat exchanger network is designed to minimize the waste of energy from the plant. Heat integration and pinch analysis are applied with the aim at reducing the energy consumption of the process and maximizing the recovery of heat energy. The total energy recovery in the plant is 52.28%. The resulting process flow diagram after heat integration provides a clear visualization of the heat exchange between the hot and cold streams in the plant, which helps to identify areas where energy can be saved and reduced for the overall energy consumption.

Piping and instrumentation diagram (P&ID) is drawn to show the valve and control used in optimization of plant. Degree of freedom is obtained in determining the number of controllers required for each unit operation. Suitable pipe size is also determined for every stream. This is important for a chemical plant to ensure smooth and safe operations can be achieved.

In the production process, there are three types of waste that are generated and needs to be treated which are solid residual, wastewater and waste gas. The waste should be treated according to Environment Quality Act (EQA) 1974 and others related law. Wastewater treatment plant consists of 4 stages which is pre-treatment, primary treatment, secondary treatment and sludge treatment. The purpose of these treatments is to reduce the value of COD and BOD concentration in wastewater according to Standard B.

For the plant layout, a suitable location is required to build up the production plant. After analysing many factors such as raw material availability, transportation facilities, availability of utilities and infrastructure, labour supply, site characteristics and waste disposal, a location in Tanjung Langsat Industrial Area, Pasir Gudang, Johor is chosen as a location for the plant. The proposed available land is be 7 acres which cost of RM 1.47 million. The reason that this location is chosen due to high availability of raw materials, power and water supply. As for the arrangement of the components in site location, the manufacturing units are placed near to the control room as it operated at an extreme condition which require a proper attention. For utilities, it is placed nears to the processing equipment for ready supply of utilities to give the most economics run. Raw material, product and by-product storage are located near to the loading bay to ease the retrieving of raw materials and storing the product. There are 3 assembly points identified to allow personnels gathers in case of emergency.

For industrial safety, hazard identification is performed in order to protect workers', workplaces', properties, and the environment's health and safety. The hazard properties for each of the material is identified by referring to the material safety data sheet (MSDS). Legislative requirements is determined to follow and obey the rule that has been stated and enforced by Malaysian government such as Environmental Quality Act 1974, Occupational Safety and Health Act 1994 and Factory and Machinery Act 1976. The hazard case studies need to be identified to evaluate the risk and to prevent any potential accidents such as accident of ammonia leakage. HIRARC analysis is used to determine the equipment units associated with the highest risk. HAZOP study is carried out on the main unit operation to determine the necessary safety actions..

Economic analysis is carried out to find the profitability of the production plant. From the analysis, the total capital investment is RM 455.58 million, total product cost is RM 1588.39 million and the depreciation charge is RM 25.13 million. The profitability analysis is performed to evaluate the economic return and its profit. From the calculation it is shown that the return of investment for the plant production is 60%, the payback period, PBP is 1.8 years, and the net return is RM 181.73 million, net present value, NPV is RM 605.79 million and the discounted cash flow rate of return, DCFRR is 55%. These values indicate that the plant is profitable and favourable.

On the other hand, detailed design of unit equipment involved in the plant production process have been carried out. For each unit equipment, design specifications, material selection and equipment features are performed. Mechanical design and drawing for reactors, separators and utilities have been done by using AutoCAD®. The designed units pass the stress analysis and elastic stability tests, proving that the designs are safe.

TABLE OF CONTENTS

	Page
DECLARATION	iii
ACKNOWLEDGEMENT	iv
EXECUTIVE SUMMARY	v
TABLE OF CONTENTS	vii
LIST OF TABLES	xvii
LIST OF ILLUSTRATIONS	xxvii
LIST OF ABBREVIATIONS	xxxii
CHAPTER I INTRODUCTION	
1.1 Introduction	1
1.2 Physical and Chemical Properties	2
1.3 Application of Urea	4
CHAPTER II ECONOMIC ASPECT	
2.1 Supply and Demand of Urea	5
2.2 Future Market Potential	6
2.3 Availability of Raw material	6
2.4 List of Companies Producing Urea	7
2.5 Price of Raw Material and Products	8
2.6 Plant Capacity	8
CHAPTER III PROCESS DESIGN CONCEPT	
3.1 Process Overview	10
3.2 Process Design Level 1	10
3.2.1 Process Selection Consideration	11
3.2.2 Process Description	14
3.2.3 Mode of Operation	15
3.2.4 Stoichiometry Reaction	15
3.2.5 Design Constraint	16
3.2.6 Selectivity Vs Conversion	18
3.3 Process Design Level 2	18
3.3.1 Synthesis of Input-Output Structure	19

3.3.2	Process Output Destination	19
3.3.3	Design Capacity	20
3.3.4	Overall Material Balance	20
3.3.5	Economic Potential Analysis Level 2	21
3.4	Process Design Level 3	22
3.4.1	Number of Reactor	23
3.4.2	Number of Recycle Stream	23
3.4.3	Reactor Selection	24
3.4.4	Reactor Heat Effect	24
3.4.5	Reactor Sizing	27
3.4.6	Reactor Cost	30
3.4.7	Cost of Compressors	32
3.4.8	Economic Potential Analysis Level 3	35
3.5	Process Design Level 4	37
3.5.1	Preliminary Design of Phase Separator, PS-101	38
3.5.2	Preliminary Design of Stripper, S-101	40
3.5.3	Preliminary Design of Decomposer, DP-101	45
3.5.4	Preliminary Design of Evaporator, EV-101	49
3.5.5	Economic Potential Analysis Level 4	52
3.6	Urea Synthesis From Green Ammonia Technology	53
3.6.1	Process Description of Whole Process	53
3.6.2	Process Flow Diagram	57
3.7	Mass Balance and Energy Balance	57
3.7.1	Mass Balance	57
3.7.2	Energy Balance	69
3.7.3	Energy balance on Condenser, CD-101	79
3.7.4	Comparison of Mass Balance by Manual Calculation and Symmetry® Calculation	80
CHAPTER IV HEAT INTEGRATION		
4.1	Introduction	83
4.2	Pinch Analysis	83
4.2.1	Data Extraction	83
4.2.2	Interval Temperature	84
4.2.3	Heat Relationship	84
4.2.4	Heat Balance	85
4.2.5	Heat Cascade	86
4.2.6	Heat Exchanger Network (HEN)	87
4.2.7	Total Heat Recovery	89
4.3	Process Flow Diagram after Heat Integration	90

CHAPTER V	PROCESS CONTROL AND INSTRUMENTATION	
5.1	Introduction	91
	5.1.1 Process Control Analysis	91
	5.1.2 Type of Instrumentations	93
5.2	Control Configuration of Unit Operation	93
	5.2.1 Control System of Storage Tank, ST-101	94
	5.2.2 Control System of Storage Tank, ST-102	96
	5.2.3 Control System of Electrolyser, E-101	98
	5.2.4 Control System of Catalytic Packed Bed Reactor, R-101	101
	5.2.5 Control System of Phase Separator, PS-101	103
	5.2.6 Control System of Cooler, CL-101	106
	5.2.7 Control System of Heater, H-101	108
	5.2.8 Control System of Plug Flow Reactor, R-102	109
	5.2.9 Control System of Stripper, S-101	112
	5.2.10 Control System of Decomposer, DP-101	115
	5.2.11 Control System of Evaporator, EV-101	118
	5.2.12 Control System of Granulator, G-101	120
	5.2.13 Control System of Condenser, C-101	122
5.3	Pressure Relief System	124
5.4	Piping System Design	124
	5.4.1 Piping for Liquid Flow	125
	5.4.2 Piping for Vapour Flow	125
	5.4.3 Piping for Mixture Flow	126
CHAPTER VI	WASTE MANAGEMENT	
6.1	Introduction	131
6.2	Waste Generation	131
6.3	Laws and Regulations Related	132
	6.3.1 Environmental Quality (Scheduled Wastes) Regulations 2005	133
	6.3.2 Environmental Quality (Industrial Effluent) Regulations 2009	135
	6.3.3 Environmental Quality (Clean Air) Regulations 2014	137
	6.3.4 Solid Waste and Public Cleansing Management (Scheme for Commercial, Industrial and Institutional Solid Waste) Regulations 2018.	139
	6.3.5 Occupational Safety Health Act (OSHA)	139
6.4	Wastewater Characterization	140
	6.4.1 Chemical Oxygen Demand (COD)	140
	6.4.2 Biochemical Oxygen Demand (BOD)	140
	6.4.3 Summary	141

6.5	Wastewater Treatment	141
6.5.1	Pre-treatment	141
6.5.2	Primary Treatment	143
6.5.3	Secondary Treatment	145
6.5.4	Sludge Treatment	148
6.5.5	BOD, COD, dan SS After Treatment	151
6.5.6	Process Flow Diagram of Wastewater Treatment	151
6.6	Solid Waste Management	151
6.7	Waste Gas Treatment	152
6.7.1	Waste Gas Treatment	153
6.7.2	Gas Stack Design	154
6.8	Waste Minimization	155
CHAPTER VII PLANT LAYOUT		
7.1	Introduction	157
7.2	Plant Location and Layout	157
7.3	Site Location Factors	157
7.3.1	Raw Material Availability	158
7.3.2	Transportation Facilities	158
7.3.3	Availability of Utilities and Infrastructure	159
7.3.4	Labour Supply	159
7.3.5	Site Characteristics	159
7.3.6	Waste Disposal	159
7.4	Suggestion fo Plant Location	160
7.5	Quantitative Factor Rating	161
7.6	Selection of The Site Location	163
7.7	Plant Layout	164
CHAPTER VIII INDUSTRIAL SAFETY		
8.1	Introduction	166
8.2	Hazard Identification	166
8.3	Legistaltive Requirements	170
8.3.1	Occupational Safety and Health Act 1994 (Act 514)	170
8.4	Concept of Hazard System	172
8.5	Hazard Case Studies	176
8.5.1	Ammonia Leakage at Vijaipur, India	176
8.5.2	Urea Synthesis Reactor Exploded at Pingyin, China	177

8.6	Hazard and Operability Study (HAZOP)	177
8.7	Hazard Identification, Risk Assessment, and Risk Control (HIRARC)	178
8.8	Discussion on The hirarc Assessment Result	179
CHAPTER IX ECONOMIC ANALYSIS		
9.1	Introduction	181
9.2	Estimation of Total Capital Investment, C_{tc}	181
	9.2.1 Fixed Capital Investment, C_{fc}	182
	9.2.2 Land Capital, Cl_c	186
	9.2.3 Working Capital, C_{wc}	186
	9.2.4 Summary of Total Investment Cost	187
9.3	Estimation of Total Product Cost, C_{tpc}	187
	9.3.1 Cost of Manufacturing (Com)	187
	9.3.2 General Expenses (Ge)	193
	9.3.3 Total Product Cost (C_{tpc})	193
9.4	Depreciation, A_D	194
9.5	Profitability Analysis	194
	9.5.1 Method That Do Not Consider the Time Value of Money	195
	9.5.2 Method That Considers the Time Value of Money	199
	9.5.3 Justifications on Profitability Analysis	202
9.6	Breakeven Analysis	202
9.7	Sensitivity Analysis	204
	9.7.1 Sensitivity Analysis of Urea	204
	9.7.2 Sensitivity Analysis of Oxygen	204
	9.7.3 Overall Sensitivity Analysis	205
CHAPTER X DETAIL DESIGN		
10.1	Storage Tank, ST-101	206
	10.1.1 Introduction	206
	10.1.2 Dimension of Storage Tank, ST-101	206
	10.1.3 Summary of Detail Design of Storage Tank, ST-101	208
10.2	Storage Tank, ST-102	208
	10.2.1 Introduction	209
	10.2.2 Dimension of Storage Tank, ST-101	209
	10.2.3 Summary of Detail Design of Storage Tank, ST-102	211

10.3	Activated Carbon Filter, AF-101	211
10.3.1	Introduction	212
10.3.2	Summary of Detail Design of Activated Carbon Filter, AF-101	212
10.4	Electrodeionization, ED-101	213
10.4.1	Introduction	213
10.4.2	Power Requirement	215
10.4.3	Balance of Plant (BOP)	216
10.5	Heater, H-101	216
10.5.1	Introduction	216
10.5.2	Heat Load	219
10.5.3	Tube-side Coefficient	220
10.5.4	Shell-side Coefficient	221
10.5.5	Overall Heat Transfer Coefficient	224
10.5.6	Tube-side Pressure Drop	225
10.5.7	Shell-side Pressure Drop	226
10.5.8	Summary of Detail Design of Heater, H-101	226
10.6	PEM Electrolyser, E-101	227
10.6.1	Introduction	227
10.6.2	Specification	228
10.6.3	Power Requirements	228
10.6.4	Balance of Plant (BOP)	229
10.7	Demister, D-101	229
10.7.1	Introduction	229
10.8	Demister, D-102	232
10.8.1	Introduction	232
10.9	Cooler, CL-106	235
10.9.1	Introduction	235
10.9.2	Dimension of Cooler, CL-106	236
10.9.3	Summary of Detail Design of Cooler, CL-106	241
10.10	Cooler, CL-101	242
10.10.1	Summary of Detail Design of Cooler, CL-101	242
10.11	Cooler, CL-102	243
10.11.1	Summary of Detail Design of Cooler, CL-102	243
10.12	Cooler, CL-103	244
10.12.1	Summary of Detail Design of Cooler, CL-103	245
10.13	Cooler, CL-104	246
10.13.1	Summary of Detail Design of Cooler, CL-104	246
10.14	Cooler, CL-105	247

	10.14.1 Summary of Detail Design of Cooler, CL-105	247
10.15	Cooler, CL-107	248
	10.15.1 Summary of Detail Design of Cooler, CL-107	248
10.16	Packed Bed Reactor, R-101	249
	10.16.1 Introduction	249
	10.16.2 Material Selection	250
	10.16.3 Design Specification	251
	10.16.4 Design of Cooling Jacket	251
	10.16.5 Design of Catalyst Bed	254
	10.16.6 Design of Catalyst Plate	255
	10.16.7 Heat Transfer Coefficient	255
	10.16.8 Summary of Detail Design of Packed Bed Reactor, R-101	256
10.17	Phase Separator, SP-101	257
	10.17.1 Introduction	257
	10.17.2 Operating Condition of Two-Phase Separator, PS-101	258
	10.17.3 Isothermal Flash calculation	259
	10.17.4 Sizing of Phase Separator, PS-101	261
	10.17.5 Summary of Phase Separator, PS-101	265
10.18	Plug Flow Reactor, R-102	266
	10.18.1 Introduction	266
	10.18.2 Reactor Properties	266
	10.18.3 Design Parameters	267
	10.18.4 Sieve Plates	269
	10.18.5 Summary of Detail Design of Plug-Flow Reactor, R-102	270
10.19	Stripper, S-101	270
	10.19.1 Introduction	270
	10.19.2 Design Specification	270
	10.19.3 Number of Theoretical stages	273
	10.19.4 Number of Actual Stages	274
	10.19.5 Diameter and Height of Column	275
	10.19.6 Summary of Detail Design of Stripper, S-101	277
10.20	Heat Exchanger, HE-101	278
	10.20.1 Introduction	278
	10.20.2 Design Specification of Heat Exchanger, HE-101	279
10.21	Heat Exchanger, HE-102	280
	10.21.1 Introduction	280
10.22	Decomposer, DP-101	281
	10.22.1 Introduction	281
	10.22.2 Design Specification	282

	10.22.3 Number of Theoretical Stages	283
	10.22.4 Number of Actual Stages	285
	10.22.5 Diameter and Height of Column	286
	10.22.6 Summary of Detail Design of Decomposer, D-101	288
10.23	Evaporator, EV-101	289
	10.23.1 Introduction	289
	10.23.2 Operation of Evaporator	290
	10.23.3 Area of Heat Transfer	291
	10.23.4 Steam Consumption	292
	10.23.5 Summary of Detail Design of Evaporator, EV-101	293
10.24	Granulator, G-101	293
	10.24.1 Introduction	293
	10.24.2 Design Specification	294
10.25	Condenser, CD-101	297
	10.25.1 Introduction	297
	10.25.2 Temperature Profile of Condenser, CD-101	299
	10.25.3 Specification of Condenser, CD-101	300
	10.25.4 Tube side Coefficient	303
	10.25.5 Shell side Coefficient	303
	10.25.6 Overall Coefficient	305
	10.25.7 Pressure Drops at Tube side	306
	10.25.8 Shell-side Pressure Drop	306
	10.25.9 Summary of Detail Design of Condenser, CD-101	307

CHAPTER XI MECHANICAL DRAWING

11.1	Packed Bed Reactor, R-101	309
	11.1.1 Introduction	309
	11.1.2 Design Specification	309
	11.1.3 Design Pressure	311
	11.1.4 Minimum Wall Thickness	311
	11.1.5 Maximum Allowable Working Pressure (MAWP)	312
	11.1.6 Design of Jacket	313
	11.1.7 Combine Loading Analysis	314
	11.1.8 Vessel Support	322
	11.1.9 Flange Joint	329
11.2	Phase Separator, PS-101	331
	11.2.1 Introduction	331
	11.2.2 Material Selection	332
	11.2.3 Design Specification	333
	11.2.4 Determination of Wall Thickness	334

11.2.5	Maximum Allowable Working Pressure (MAWP _{vessel}) of Phase Separator, PS-101	338
11.2.6	Combined Loading of Phase Separator, PS-101	339
11.2.7	Vessel support	344
11.2.8	Bolted flanged joints	346
11.2.9	Summary of Mechanical Design of Phase Separator, PS-101	348
11.3	Plug Flow Reactor, R-101	349
11.3.1	Introduction	349
11.3.2	Design Specification	350
11.3.3	Detailed Design of R-102	351
11.3.4	Design Pressure	352
11.3.5	Minimum Wall Thickness	352
11.3.6	Summary of Maximum Allowable Working Pressure, MAWP	353
11.3.7	Design of Heating Jacket	354
11.3.8	Sieve Plates	358
11.3.9	Combined Loading Analysis	359
11.3.10	Weight of the Plates	364
11.3.11	Insulation Weight	364
11.3.12	Total weight	364
11.3.13	Vessel Support	365
11.3.14	Base Ring and Anchors Bolts Design	368
11.3.15	Design of Flanged Joints	373
11.3.16	Summary of Mechanical Design of Plug Flow Reactor, R-102	375
11.4	Cooler, CL-106	376
11.4.1	Introduction	376
11.4.2	Design Pressure	377
11.4.3	Minimum Wall Thickness	378
11.4.4	Allowable Working Pressure, MAWP _{vessel}	379
11.4.5	Combined Loading Analysis	380
11.4.6	Design of Vessel Supports	384
11.4.7	Design of Flanged Joints	386
11.4.8	Summary of Mechanical Design of Cooler, CL- 106	387
11.5	Condenser, CD-101	388
11.5.1	Design Specification	388
11.5.2	Design Pressure	389
11.5.3	Minimum Wall Thickness	390
11.5.4	Maximum Allowable Working Pressure (MAWP)	391
11.5.5	Combined Loading	393
11.5.6	Flanged Joint	398
11.5.7	Summary of Mechanical Design of Condenser, CD-101	399

REFERENCE	401	
Appendix A	Mass and Energy Balance, and Simulation	408
Appendix B	Process Flow Diagram and Piping, Insturmentation Diagram and Plan Layout	425
Appendix C	Industrial Safety	432
Appendix D	Details Design and Mechanical Design	465
Appendix E	Mechanical Drawing	490
Appendix F	Material Safety data Sheet (MSDS)	495

LIST OF TABLES

Table No.		Page
Table 1.1	Physical and chemical properties of water, nitrogen, and carbon dioxide.	2
Table 1.2	Physical and chemical properties of urea	2
Table 1.3	Physical and chemical properties of oxygen	3
Table 1.4	Physical and chemical properties of ammonia, and ammonium carbamate	4
Table 2.1	Comparison of carbon dioxide supplier in Malaysia	6
Table 2.2	Comparison of nitrogen supplier in Malaysia	7
Table 2.3	List of global company producing urea	7
Table 2.4	List of local company producing urea	7
Table 2.5	Price of raw material and products	8
Table 2.6	Amount of the raw material needed in a year	8
Table 3.1	Comparison between all the pathways.	11
Table 3.2	Comparison between types of electrolysis	12
Table 3.3	Comparison between types of ammonia production method	13
Table 3.4	Categories of each component in urea synthesis	20
Table 3.5	Overall mass balance	20
Table 3.6	Cost of raw materials and products	21
Table 3.7	Data for economy potential of process design level 2	22
Table 3.8	Detail operating conditions of each reactor	23
Table 3.9	Adiabatic temperature for Catalytic Packed Bed Reactor, R-101	25
Table 3.10	Adiabatic temperature for Plug Flow Reactor, R-102	26
Table 3.11	Dimension of R-101	28
Table 3.12	Dimension of R-102	30

Table 3.13	Marshall and Swift index by year	31
Table 3.14	Annual cost of catalytic packed bed reactor, R-101 based on conversion	32
Table 3.15	Annual cost of plug flow reactor, R-102 based on conversion	32
Table 3.16	Summary of compressors parameter	33
Table 3.17	Installation and annually cost C-101	34
Table 3.18	Installation and annually cost C-102	34
Table 3.19	Installation and annually cost C-103	35
Table 3.20	Installation and annually cost C-104	35
Table 3.21	Data for economy potential level 3	36
Table 3.22	Summary calculation of phase separator, PS-101	39
Table 3.23	Summary calculation of stripper, ST-101	44
Table 3.24	Summary calculation of decomposer, DP-101	49
Table 3.25	Summary calculation of evaporator, EV-101	51
Table 3.26	Data for economy potential level 4	52
Table 3.27	Mass balance on Storage Tank, ST-102	58
Table 3.28	Mass balance on Electrolyser, E-101	59
Table 3.29	Mass balance on Demister, D-101	60
Table 3.30	Mass balance on Demister, D-102	61
Table 3.31	Mass balance on Catalytic Packed Bed Reactor, R-101	62
Table 3.32	Mass balance on Phase Separator, PS-101	63
Table 3.33	Mass balance on Plug Flow Reactor, R-102	64
Table 3.34	Mass balance on Stripper, S-101	65
Table 3.35	Mass balance on Decomposer, DP-101	66
Table 3.36	Mass balance on Evaporator, EV-101	67
Table 3.37	Mass balance on Granulator, G-101	68

Table 3.38	Overall mass balance	69
Table 3.39	Specific heat of formation and specific heat capacity for each component	70
Table 3.40	Energy balance on Electrolyser, E-101	71
Table 3.41	Energy balance on Catalytic Packed Bed Reactor, R-101	72
Table 3.42	Energy balance on Plug Flow Reactor, R-102	74
Table 3.43	Energy balance on Stripper, S-101	75
Table 3.44	Energy balance on Decomposer, DP-101	76
Table 3.45	Energy balance on Evaporator, EV-101	78
Table 3.46	Energy balance on Granulator G-101	79
Table 3.47	Energy balance on Condenser CD-101	79
Table 3.48	Mass balance comparison of unit operations by Symmetry®	81
Table 3.49	Overall mass balance comparison by Symmetry®	82
Table 4.1	Process data for each utility unit	83
Table 4.2	Interval temperature for $\Delta T_{min} = 20 \text{ }^{\circ}\text{C}$	84
Table 4.3	Heat balance at each interval temperature	85
Table 4.4	Heat cascade iteration calculation method	86
Table 4.5	Summary of heat cascade	87
Table 4.6	Total energy recovery	90
Table 5.1	Types of instrumentation and objectives	92
Table 5.2	Letter code for instrument symbols	93
Table 5.3	Degree of freedom for each unit	94
Table 5.4	Control strategy of storage tank, ST-101	96
Table 5.5	Control strategy of storage tank, ST-102	98
Table 5.6	Control configurations of electrolyser, E-101	100
Table 5.7	Control strategy of catalytic packed bed reactor, R-101	102

Table 5.8	Control strategy of phase separator, PS-101	105
Table 5.9	Control strategy of cooler, CL-101	107
Table 5.10	Control configurations of heater, H-101	109
Table 5.11	Control strategy of plug flow reactor R-102	111
Table 5.12	Control strategy of stripper, S-101	114
Table 5.13	Control strategy of decomposer DP-101	117
Table 5.14	Control strategy of evaporator, EV-101	119
Table 5.15	Control strategy of granulator G-101	121
Table 5.16	Control strategy of condenser CD-101	123
Table 5.17	Types of relief valves	124
Table 5.18	Pipe sizing for liquid stream	128
Table 5.19	Pipe sizing for vapour stream	129
Table 5.20	Pipe sizing for mixture stream	130
Table 6.1	Solid waste composition	132
Table 6.2	Wastewater composition	132
Table 6.3	Waste gas composition	132
Table 6.4	Scheduled wastes of potential incompatibility in Group 1	134
Table 6.5	Scheduled wastes of potential incompatibility in Group 3	134
Table 6.6	Acceptable condition for discharge of industrial/mixed effluent	136
Table 6.7	Acceptable COD for discharge of industrial effluent	136
Table 6.8	Acceptable COD for discharge of industrial effluent	137
Table 6.9	Limit value of chemical and petrochemical industry in all size	138
Table 6.10	New Malaysia Ambient Air Quality Standard	138
Table 6.11	Concentration carbon dioxide in the production	139
Table 6.12	Summary of waste characteristics of plant after wastewater treatment	151

Table 6.13	Air quality standard under Environmental Quality (Clean Air) Regulations (Amendment) 2014	152
Table 6.14	Treated gas specifications	153
Table 6.15	Waste minimization	155
Table 7.1	Characteristics of proposed plant location	160
Table 7.2	Weightage for evaluation of location criteria for plant	162
Table 7.3	Quantitative factor rating for location decision	162
Table 8.1	Hazard properties	167
Table 8.2	Inventory of the hazardous material	169
Table 8.3	Control of Industrial Major Hazards Regulation (CIMAH) 1996	171
Table 8.4	Hazard system based on the overall production process	172
Table 8.5	Hazard system based on the selected process	173
Table 8.6	Quantitative rating of the likelihood of an occurrence	178
Table 8.7	Quantitative rating of the severity of a hazard	178
Table 8.8	Risk matrix in HIRARC Assessment	179
Table 8.9	Description of risk matrix in HIRARC Assessment	179
Table 9.1	Parameter of calculation of purchased equipment cost	183
Table 9.2	Purchased equipment cost and installation cost	184
Table 9.3	Direct cost estimation	185
Table 9.4	Indirect cost estimation	185
Table 9.5	Summary of total capital investment	187
Table 9.6	Cost of raw material	188
Table 9.7	Labour requirement	189
Table 9.8	Operating labour cost estimation	190
Table 9.9	Summary of variable production cost	191
Table 9.10	Fixed charges cost estimation	192

Table 9.11	Summary of general expenses	193
Table 9.12	Summary of project investment	195
Table 9.13	ROI, PBP and net return estimation	198
Table 9.14	Summary of NPV estimation	200
Table 9.15	Summary of DCFRR estimation	201
Table 9.16	Summary of profitability analysis	202
Table 9.17	Sensitivity analysis of urea	204
Table 9.18	Sensitivity analysis of urea	204
Table 10.1	Volumetric flowrate of water for ST-101	207
Table 10.2	Summary of detailed design for storage tanks, ST-101	208
Table 10.3	Mass flowrate of deionize water for ST-102	209
Table 10.4	Volumetric flowrate of deionize water for ST-102	210
Table 10.5	Summary of detailed design for storage tanks, ST-101	211
Table 10.6	Summary of design specification for AF-101	212
Table 10.7	Model reference and its volumetric flowrate	214
Table 10.8	General design data for EDI module	215
Table 10.9	Physical properties of heating steam and process stream for heater unit H-101	217
Table 10.10	Pitch constants	221
Table 10.11	Detail design tube-side coefficient of Heater, H-101	226
Table 10.12	Detail design shell-side coefficient of Heater, H-101	227
Table 10.13	Composition of inlet and outlet components in electrolyser, E-101	228
Table 10.14	Properties of vapour and liquid in D-101	230
Table 10.15	Properties of vapour and liquid in D-101	233
Table 10.16	Physical properties of gases (ammonia and carbon dioxide) and cooling water	235
Table 10.17	Summary of cooler, CL-106	241

Table 10.18	Summary of cooler, CL-101	242
Table 10.19	Summary of cooler, CL-102	243
Table 10.20	Summary of cooler, CL-103	245
Table 10.21	Summary of cooler, CL-104	246
Table 10.22	Summary of cooler, CL-105	247
Table 10.23	Summary of cooler, CL-107	248
Table 10.24	Design information of R-101	250
Table 10.25	Dimension of R-101 in different measurement units	251
Table 10.26	Information on carbon steel SA-537	252
Table 10.27	Summary of detailed design for R-101	256
Table 10.28	Equations for single-stage flash vaporization and partial condensation operations	258
Table 10.29	Feed composition of Phase Separator, PS-101	259
Table 10.30	Feed mole fraction and K-value of phase separator, PS-101	259
Table 10.31	Summary of product flow from phase separator, PS-101	261
Table 10.32	Properties of product stream for PS-101	261
Table 10.33	Summary detailed design of Phase Separator, PS-101	265
Table 10.34	Properties of Plug Flow Reactor, R-102	266
Table 10.35	Summary of Design for Plug Flow Reactor, R-102	270
Table 10.36	Summary of chemical properties and flowrate of components in Stripper, S-101	271
Table 10.37	Summary chemical properties and flowrate of components in S-101	272
Table 10.38	Summary of detailed design Stripper, S-101	278
Table 10.39	Physical properties of the product stream and cooling water in Heat Exchanger, HE-101	279
Table 10.40	Summary of design specification for Heat Exchanger, HE-101	279

Table 10.41	Physical properties of the product stream and cooling water in Heat Exchanger, HE-102	280
Table 10.42	Summary of design specification for Heat Exchanger, HE-102	281
Table 10.43	Summary of chemical properties and flowrate of components in Decomposer, DP-101	282
Table 10.44	Summary chemical properties and flowrate of components in D-101	283
Table 10.45	Summary of detailed design Decomposer, D-101	288
Table 10.46	Parameter of Evaporator, EV-101	291
Table 10.47	Detail design of Evaporator, E-101	293
Table 10.48	Composition of components in condenser, CD-101	300
Table 10.49	Physical properties of Condenser, CD-101	300
Table 10.50	Overall specifications of Condenser, CD-101	307
Table 10.51	Shell side specifications of Condenser, CD-101	307
Table 10.52	Tube side specifications of condenser, CD-101	308
Table 11.1	Design specifications of Packed Bed Reactor, R-101	310
Table 11.2	Dimension of Packed Bed Reactor, R-101	310
Table 11.3	Design pressure of each part of Packed Bed Reactor, R-101	311
Table 11.4	Minimum wall thickness of each part of Packed Bed Reactor, R-101	311
Table 11.5	Nominal thickness of stainless-steel type 316 SA-204	312
Table 11.6	MAWP _{vessel} calculation result for each part of R-101	313
Table 11.7	Summary of parameters in the analysis of primary stresses in the design of Packed Bed Reactor R-101	320
Table 11.8	Summary of parameters in the analysis of elastic stability in the design of Packed Bed Reactor, R-101	322
Table 11.9	Anchor bolt chain design	327
Table 11.10	Summary of parameters in the design of vessel support for the design of Packed Bed Reactor, R-101	328

Table 11.11	Dimension of each flange on Packed Bed Reactor, R-101	330
Table 11.12	Mass flow rates in each stream	331
Table 11.13	Minimum wall thickness of each part	337
Table 11.14	Conditions for bracket and leg supports	345
Table 11.15	Dimension of carbon steel pipe legs	346
Table 11.16	D_{optimum} of pipe connection for each stream	347
Table 11.17	Dimension in mm of flanges at each stream	347
Table 11.18	Dimension in mm of slip-on and blind flanges	348
Table 11.19	Summary results for the design of PS-101	349
Table 11.20	Operating condition and design parameters of Plug Flow Reactors, R-102	350
Table 11.21	Dimensions of Plug Flow Reactors, R-102	351
Table 11.22	New design pressure for Plug Flow Reactors, R-102	352
Table 11.23	Properties of Therminol 66	355
Table 11.24	Summary of Combined Stress	361
Table 11.25	Summary of total weight of vessel	364
Table 11.26	Skirt design for Plug Flow Reactor, R-102	368
Table 11.27	Summary of base ring and anchor bolt design	372
Table 11.28	Anchor bolt chair design	373
Table 11.29	Welding neck flanges	374
Table 11.30	Summary of mechanical design of Plug Flow Reactor, R-102	375
Table 11.31	Condition of CL-106	376
Table 11.32	Dimensions value of the saddle	386
Table 11.33	Dimensions value of welding-neck flanges	387
Table 11.34	Summary of mechanical design CL-106	387
Table 11.35	Specification of condenser, CD-101	389

Table 11.36	MAWP _{part} and pressure at top of condenser, CD-101	392
Table 11.37	Summary of primary stress in the condenser, CD-101	395
Table 11.38	Dimension of saddle design of condenser, CD-101	398
Table 11.39	Dimension welding neck flange for each connection in condenser, CD-101	399
Table 11.40	Summary of mechanical design for condenser, CD-101	399
Table 11.41	First table in specific objective for Chapter II	426
Table 11.42	First table in specific objective for Chapter II	427
Table 11.43	First table in specific objective for Chapter II	428
Table 11.44	First table in specific objective for Chapter II	429
Table 11.45	First table in specific objective for Chapter II	430
Table 11.46	First table in specific objective for Chapter II	431

LIST OF ILLUSTRATIONS

Figure No.		Page
Figure 1.1	Molecular structure of urea	1
Figure 2.1	Demand and supply of urea from 2019 to 2035	5
Figure 3.1	Simplified block diagram for urea synthesis using green ammonia technology	10
Figure 3.2	Design constraints	17
Figure 3.3	Selectivity of each component against conversion	18
Figure 3.4	Input and Output Structure for Urea Synthesis	19
Figure 3.5	Potential economy curve of process design level 2	22
Figure 3.6	Process design concept diagram level 3	23
Figure 3.7	Graph of adiabatic temperature against conversion for Catalytic Packed Bed Reactor, R-101	26
Figure 3.8	Graph of adiabatic temperature against conversion for Plug Flow Reactor, R-102	27
Figure 3.9	Volume of R-101 against conversion	29
Figure 3.10	Volume of R-102 against conversion	30
Figure 3.11	Potential economy curve for design level 3	37
Figure 3.12	Process design concept level 4	37
Figure 3.13	Potential economy curve for design level 4	53
Figure 3.14	Storage Tank, ST-102	58
Figure 3.15	Electrolyser, E-101	59
Figure 3.16	Demister, D-101	60
Figure 3.17	Demister, D-102	61
Figure 3.18	Catalytic Packed Bed Reactor, R-101	62
Figure 3.19	Phase Separator, PS-101	63
Figure 3.20	Plug Flow Reactor, R-102	64

Figure 3.21	Stripper, S-101	65
Figure 3.22	Decomposer, DP-101	66
Figure 3.23	Evaporator, EV-101	67
Figure 3.24	Granulator, G-101	68
Figure 3.25	Overall process	68
Figure 3.26	Electrolyser, E-101	71
Figure 3.27	Catalytic Packed Bed Reactor, R-101	72
Figure 3.28	Plug Flow Reactor, R-102	73
Figure 3.29	Stripper, S-101	75
Figure 3.30	Decomposer, DP-101	76
Figure 3.31	Evaporator, EV-101	77
Figure 3.32	Granulator, G-101	78
Figure 3.33	Condenser, CD-101	79
Figure 3.34	Process Flow Diagram in the Symmetry ®	81
Figure 4.1	Relationship between T_{int} with hot and cold streams	85
Figure 4.2	Heat cascade	87
Figure 4.3	Grid heat exchanger network	88
Figure 4.4	Heat exchanger network above pinch point	88
Figure 4.5	Heat exchanger network below pinch point	89
Figure 5.1	Control configurations of storage tank, ST-101	96
Figure 5.2	Control configurations of storage tank, ST-102	98
Figure 5.3	Control configurations of electrolyser, E-101	100
Figure 5.4	Control configurations of catalytic packed bed reactor, R-101	102
Figure 5.5	Control configurations of phase separator, PS-101	105
Figure 5.6	Control configurations of cooler, CL-101	107
Figure 5.7	Control configurations of heater, H-101	109

Figure 5.8	Control configurations of plug flow reactor R-102	111
Figure 5.9	Control configurations of stripper, S-101	114
Figure 5.10	Control configuration of decomposer DP-101	117
Figure 5.11	Control configurations of evaporator, EV-101	119
Figure 5.12	Control configuration of granulator G-101	121
Figure 5.13	Control configuration of condenser CD-101	123
Figure 7.1	The available industrial land in Tanjung Langsat.	163
Figure 8.1	The fracture on the urea reactor cylinder	177
Figure 8.2	Summary of the rating of risk in HIRARC assessment	180
Figure 9.1	General break-even analysis	203
Figure 9.2	Specific break-even analysis	203
Figure 9.3	Overall sensitivity analysis	205
Figure 10.1	Storage tank, ST-101	206
Figure 10.2	Storage tank, ST-102	209
Figure 10.3	Schematic diagram of Activated Carbon Filter AF-101	212
Figure 10.4	Schematic diagram of Electrodeionization module, ED-101	213
Figure 10.5	Set of chambers of electrodeionization (EDI)	214
Figure 10.6	Process of electrodeionization (EDI)	214
Figure 10.7	Schematic diagram of Heater, H-101	216
Figure 10.8	Temperature profile of heater, H-101	219
Figure 10.9	Diagram of tube-side heat transfer factor.	221
Figure 10.10	Diagram of shell-bundle clearance	222
Figure 10.11	Diagram of shell side hot transfer friction	223
Figure 10.12	Diagram of tube side friction factors	225
Figure 10.13	Diagram of shell side friction factors	226
Figure 10.14	Diagram of demister, D-101	230

Figure 10.15	Stainless steel knitted mesh	232
Figure 10.16	Diagram of demister, D-101	232
Figure 10.17	Schematic diagram of CL-106	235
Figure 10.18	Temperature profile of cooler, CL-106	236
Figure 10.19	Schematic diagram of Packed Bed Reactor, R-101	250
Figure 10.20	Type 1 jacket	252
Figure 10.21	Jacket closure type (b-1)	252
Figure 10.22	Phase separator, PS-101	257
Figure 10.23	Typical proportion of vertical liquid-vapor separator	263
Figure 10.24	Dimension of phase separator, PS-101	265
Figure 10.25	Schematic diagram of Plug Flow Reactor, R-102	266
Figure 10.26	Schematic diagram of Stripper, S-101	271
Figure 10.27	Liquid-Vapor Flow Factor	276
Figure 10.28	Schematic diagram of Heat Exchange HE-101	279
Figure 10.29	Schematic diagram of Decomposer, DP-101	282
Figure 10.30	Liquid-Vapor Flow Factor	287
Figure 10.31	Calandria type evaporator	290
Figure 10.32	Schematic diagram of Evaporator, EV-101	291
Figure 10.33	Schematic diagram of Granulator, G-101	294
Figure 10.34	Diagram of rotary atomizer	294
Figure 10.35	Working principal of condenser	298
Figure 10.36	Schematic diagram of Condenser, CD-101	299
Figure 10.37	Temperature profile of condenser, C-102	299
Figure 10.38	Temperature profile of Condenser, CD-101	302
Figure 11.1	Schematic diagram of Packed Bed Reactor, R-101	310
Figure 11.2	Welding neck flange	330
Figure 11.3	Schematic diagram of Phase Separator, PS-101	331

Figure 11.4	Dimension of Phase Separator, PS-101	332
Figure 11.5	Schematic diagram of torispherical head	333
Figure 11.6	Height of each part in ft	335
Figure 11.7	Dimension of the designed bracket	345
Figure 11.8	Lap-joint flange	347
Figure 11.9	(a) Slip-on flange (b) Blind flange	348
Figure 11.10	Schematic diagram of Plug Flow Reactor, R-102	350
Figure 11.11	Type 1 jacket	354
Figure 11.12	Type (b-1) jacket closure	354
Figure 11.13	Diagram of tube side friction factors	357
Figure 11.14	Type of skirt	365
Figure 11.15	Double Plate with Gusset	369
Figure 11.16	Base ring and Anchor bolt	373
Figure 11.17	Steel welding neck flanges	374
Figure 11.18	Schematic diagram of saddle support	384
Figure 11.19	Diagram of saddle support	384
Figure 11.20	Dimension of saddle	386
Figure 11.21	Diagram of welding-neck flanges	387
Figure 11.22	Dimension of welding-neck flanges	387

LIST OF ABBREVIATIONS

UKM	Universiti Kebangsaan Malaysia
PEM	Proton Exchange Membrane
AWE	Alkaline Water Electrolysis
SOEC	Solid Oxide Electrolysis
NH ₃	Ammonia
H ₂	Hydrogen
N ₂	Nitrogen
NH ₂ CO ₂ NH ₄	Ammonium Carbamate
N ₂ H ₂ CONH ₂	Urea
H ₂ O	Water
CO ₂	Carbon Dioxide
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
SS	Suspended Solid

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

Urea, commonly known as carbamide, is the diamide of carbonic acid. It is a nitrogenous compound containing a carbonyl group connected to two amine groups with a chemical formula of $\text{CH}_4\text{N}_2\text{O}$. It is also a naturally occurring chemical formed by the metabolism of proteins and is widely distributed in mammalian urine. Urea exists in colourless crystalline form which has no scent, non-toxic and highly soluble in water (American Chemical Society 2021). Figure 1.1 shows the molecular structure of urea.

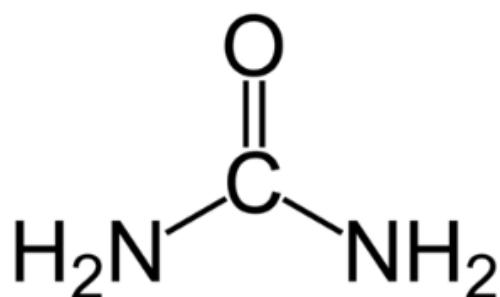


Figure 1.1 Molecular structure of urea

Source: Manisha 2009

Urea is most commonly used as nitrogen fertilizer, as well as a vital raw material for the production of polymers and pharmaceuticals. It is in high demand as a fertilizer since it has the highest nitrogen content of all industrial compounds. It is especially beneficial due to its high nitrogen concentration, the ability to be applied as a solid in granular form and the ability to be dissolved in solutions with other plant nutrients due

to its very high solubility in water. Urea is produced by the exothermic reaction between ammonia and carbon dioxide (American Chemical Society 2021).

1.2 PHYSICAL AND CHEMICAL PROPERTIES

a. Raw Material

The raw material used in this urea synthesis using green technology is water, nitrogen, and carbon dioxide. Table 1.1 shows the physical and chemical properties of water, nitrogen, and carbon dioxide.

Table 1.1 Physical and chemical properties of water, nitrogen, and carbon dioxide.

Physical and Chemical Properties	Water	Nitrogen	Carbon Dioxide
Molecular formula	H ₂ O	N ₂	CO ₂
Molecular weight (g/mol)	18	28	44
Appearance	Colourless liquid	Colourless gas	Colourless gas
Odour	Odourless	Odourless	Odourless
Density (g/cm ³)	1	0.967	1.53
pH	7	5.5 – 7.2	N/A
Melting point (°C)	0	-210	-56.5
Boiling point (°C)	100	-196	-78.46
Solubility	Completely miscible	Soluble in water	Soluble in water
Viscosity (Pa·s)	1 x 10 ⁻³	7	0.015 x 10 ⁻³
Toxicity	Nontoxic	Nontoxic	Little

Source: National Center for Biotechnology Information.(2021)

b. Main-Product

The main product of this production is urea. Table 1.2 shows the physical and chemical properties of urea.

Table 1.2 Physical and chemical properties of urea

Physical and Chemical Properties	Value/Properties
Molecular formula	CH ₄ N ₂ O
Molecular weight (g/mol)	60.06

Appearance	Colourless solid
Odour	Odourless
Density (g/cm3)	1.32
pH	4 – 8
Melting point (°C)	133
Boiling point (°C)	135
Solubility	Soluble in water
Viscosity	No viscosity
Toxicity	No toxicity

Source: National Center for Biotechnology Information (2021)

c. By-Product

The by-product of this production is oxygen. Table 1.3 shows the physical and chemical properties of oxygen.

Table 1.3 Physical and chemical properties of oxygen

Physical and Chemical Properties	Oxygen
Molecular formula	O ₂
Molecular weight (g/mol)	32
Appearance	Colourless gas
Odour	Odourless
Density (g/cm3)	1.1
pH	N/A
Melting point (°C)	-218.4
Boiling point (°C)	-183
Solubility	Soluble in water
Viscosity (Pa·s)	N/A
Toxicity	Nontoxic

Source: National Center for Biotechnology Information.(2021)

d. Intermediate Product

The by-product of this production is ammonia, and ammonium carbamate. Table 1.4 shows the physical and chemical properties of ammonia, and ammonium carbamate.

Table 1.4 Physical and chemical properties of ammonia, and ammonium carbamate

Physical and Chemical Properties	Ammonia	Ammonium Carbamate
Molecular formula	NH ₃	NH ₂ CO ₂ NH ₄
Molecular weight (g/mol)	17.03	78.071
Appearance	Colourless gas	White crystalline solid
Odour	Pungent smell	Pungent smell
Density (g/cm ³)	0.88	1.6
pH	11 – 13	N/A
Melting point (°C)	-77.73	60
Boiling point (°C)	-33.34	251
Solubility	Soluble in water	Soluble in water
Viscosity (Pa·s)	9.18 x 10 ⁻⁶	N/A
Toxicity	Highly toxic	Highly toxic

Source: National Center for Biotechnology Information.(2021)

1.3 APPLICATION OF UREA

Urea is a chemical that is widely used in agricultural sector, chemical industry, medical and other commercial uses. In our plant design project, the urea produced is used in the chemical industry as a raw material to synthesize a variety of significant chemicals such as a variety of polymers particularly urea-formaldehyde resins. Besides, urea is used as a starting material in the production of several adhesives including urea-formaldehyde and urea-melamine-formaldehyde, which are used in marine plywood.

Urea is also used as a raw ingredient in the production of other chemicals like potassium cyanate, which is used as an industrial feedstock. Furthermore, urea can be used to produce urea nitrate, which is an explosive material that is used in the mining and construction industries (Company 2022).

CHAPTER II

ECONOMIC ASPECT

2.1 SUPPLY AND DEMAND OF UREA

Research shows that the global demand for urea market can reach 190 million tonnes in 2021 and is expected to achieve a healthy CAGR of 4.15% from 2022 to 2035 (ChemAnalyst 2021). Due to its high usage of urea, the supply of urea is increasing every year starting from 2021 until 2032. The global urea market value was USD 107.28 billion and USD 129.52 billion in 2021 and 2022 respectively. The global urea supply is expected to expand at a compound growth rate (CAGR) of 2.2% during the forecast period from 2022 until 2029 (Anon 2022). It is also expected to expand at a CAGR of 2.3% from 2029 until 2032 (Singh 2021). However, the global market supply and demand displayed a decline of 2.3% in 2020 as compared to 2019 due to Covid 19 impact. Figure 2.1 shows the global supply and demand of urea between year 2019 until forecast period 2035.

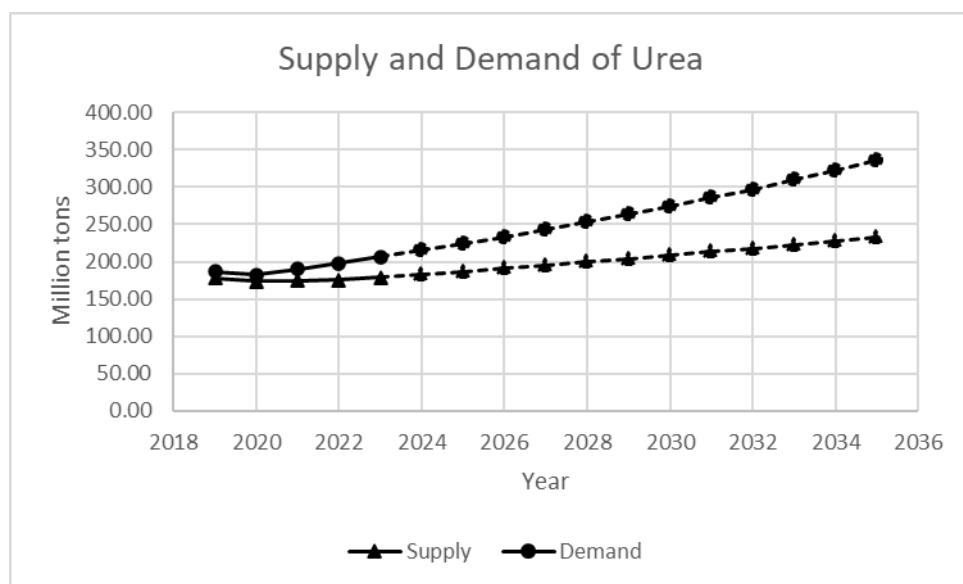


Figure 2.1 Demand and supply of urea from 2019 to 2035

Source: Urea Market Research Report 2022

2.2 FUTURE MARKET POTENTIAL

The global urea market size is projected to reach RM 7.12 billion (USD 150.61 billion) by 2029 (Fortune Business Insights 2022). Urea is widely used in agriculture as fertilizer, feed additives, plastics, and pharmaceutical industries. Besides, urea also offers a potential alternative fuel source as it is low cost and mass manufactured.

There are few top urea companies that are expanding their application to the automotive sector as urea applications expand in exhaust systems and tanks of diesel-powered automobiles. Asia Pacific region holds the largest share in the Urea market and then followed by North America (Chemanalyst 2021). India is the top country in urea production where it produces 24.6 million tons per year that accounts for 37.63% of world's urea production. In 2022, the world's total urea production was 64.4 million tons (Knoema.com 2021)

Currently, there are few projects and studies on blue ammonia and green ammonia technology for future sustainability to reduce environmental impact. This type of urea could reduce carbon dioxide emission in which its demand will continuously increase in future.

2.3 AVAILABILITY OF RAW MATERIAL

The production of urea will use green ammonia technology. Green ammonia technology will be synthesis using electrolysis and Haber-Bosh process (Wenliang et al 2022). The raw material used in production is CO₂, N₂, and water. H₂ gas will be produced by electrolysis of water and be used in ammonia synthesis. Table 2.1 and Table 2.2 below shows the comparison between suppliers of raw materials.

Table 2.1 Comparison of carbon dioxide supplier in Malaysia

Properties	Location	Price (RM/ton)	Reference
Air Gas Technology	Taman Kota Masai, Johor Bahru	8120.00	AirProduct 2022

Bee Hua Industrial Gases Sdn Bhd	Ulu Tiram, Johor	8500.00	AllGases 2022
----------------------------------	------------------	---------	---------------

Table 2.2 Comparison of nitrogen supplier in Malaysia

Properties	Location	Price (RM/ton)	Reference
Air Gas Technology	Taman Kota Masai, Johor Bahru	2622.00	AirProduct 2022
Bee Hua Industrial Gases Sdn Bhd	Ulu Tiram, Johor	2800.00	AllGases 2022

The water supply will get from Syarikat Air Johor Bahru Sdn Bhd with prices RM 3.30 per ton (Ranhill SAJ 2022).

2.4 LIST OF COMPANIES PRODUCING UREA

The PT Pupuk Kalimantan Timur, CF Industries Holdings, Inc and Yara Urea Granulation Plant are some key players in the global urea industry. Since the capacity for the majority of companies is limited, Table 2.3 below shows a list of only a few companies in the world that manufacture urea.

Table 2.3 List of global company producing urea

Company	Location	Plant capacity (Mtonnes/year)	Source
PT Pupuk Kalimantan Timur	Indonesia	3.43	Pupuk Kaltim. 2022
Saudi Arabian Fertilizer Company	Saudi Arabia	2.60	Saudi Arabian Fertilizer Company. n.d.
CF Industries Holdings, Inc.	United States	2.40	CF Industries Holdings Annual Report 2022. 2022
Engro Fertilisers Limited	Pakistan	1.30	Brouwer, M. 2022
Yara Urea Granulation Plant	Netherlands	0.73	Yara Urea Granulation Plant Maire Tecnimont. n.d.

Table 2.4 List of local company producing urea

Company	Location	Plant capacity (Mtonnes/year)	Source
Petronas Chemicals Group Bhd	Sipitang, Sabah	1.20	Chong, R. 2021

Petronas Chemicals Fertiliser Kedah Sdn. Bhd.	Kuala Muda, Kedah	1.40	Chong,R. 2021
--	----------------------	------	------------------

2.5 PRICE OF RAW MATERIAL AND PRODUCTS

Our main product is urea in solid phase while our by-product is oxygen gas. The raw materials that used in this production to produce urea is water, nitrogen gas and carbon dioxide gas. The price of each of the raw materials and product is shown in Table 2.5 below.

Table 2.5 Price of raw material and products

Component	Price (RM/ton)	Reference
Urea	22000	Indexmundi 2022
Oxygen gas	68370	PharmaCompass 2022
Water	3.30	Ranhill SAJ 2022
Nitrogen gas	2622	Air Gas Technology 2022
Carbon dioxide gas	8120	Air Gas Technology 2022

2.6 PLANT CAPACITY

The production capacity was given which is 50MT/day. The main raw material which is nitrogen, hydrogen and carbon dioxide need to be supplied to the plant to produce 17550 tonne/year of urea. The calculation of the amount needed is based on the stoichiometry of the overall equation. Table 2.6 show the amount for the raw material needed in a year is shown.

Table 2.6 Amount of the raw material needed in a year

Raw material	Mass flowrate (metric tonne/year)
Nitrogen	13831.20
Hydrogen	26520.18
Carbon dioxide	26257.61

Based on the production capacity of urea which is 17550 tonne/year, in the coming year of 2025, our company is going to fill 0.05% deficiency of the world's demand for urea. The calculation is as shown below:

Production time a day = 24 hours

Maintenance = 14 days/ year

$$\begin{aligned}\text{Production time per year} &= (365 - 14) \text{ days} \times 24 \text{ hours} \\ &= 8424 \text{ hours}\end{aligned}$$

The plant will operate 24 hours for 351 days in a year.

$$\begin{aligned}\text{Deficiency} &= \text{Demand} - \text{Supply} \\ &= 223.56 \text{ Mtonnes/year} - 186.95 \text{ Mtonnes/year} \\ &= 36.60 \text{ Mtonnes/year}\end{aligned}$$

Plant capacity = percentage x deficiency

$$\begin{aligned}17550 \text{ tonne/year} &= \text{percentage} \times 36600000 \text{ tonne/year} \\ \text{percentage} &= 0.0005 \times 100\% \\ &= 0.05\%\end{aligned}$$

According to Table 2.3 and Table 2.4, our production capacity is the smallest compared to the listed company and going to fill the 0.05% of the world's demand for urea.

CHAPTER III

PROCESS DESIGN CONCEPT

3.1 PROCESS OVERVIEW

In the production of urea from green ammonia technology, nitrogen, water and carbon dioxide was used as raw materials. Figure 3.1 shows the simplified block diagram for urea synthesis using green ammonia technology.

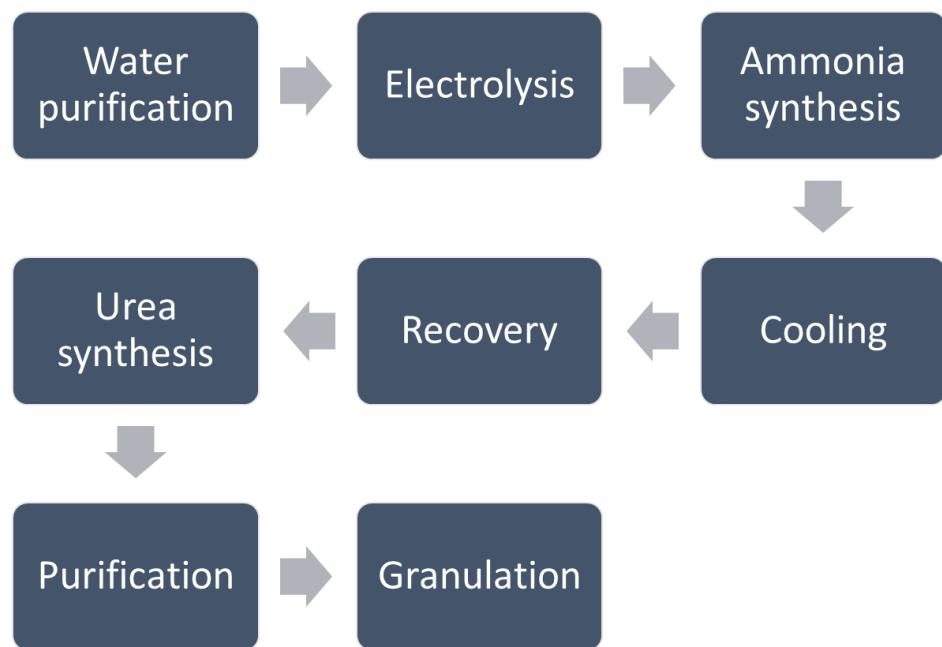


Figure 3.1 Simplified block diagram for urea synthesis using green ammonia technology

3.2 PROCESS DESIGN LEVEL 1

In process design level 1, before starting the process synthesis, information on design and process selection are determined. The main objective for this level is defining

chemical reaction involved, raw material required, and product formed, reaction stoichiometric, design of constraint and catalyst used.

3.2.1 Process Selection Consideration

Process selection considerations is to ensure the production process selected with the highest priority and according to the scope requirements or objective. The objective of this plant design is to produce the urea from green ammonia technology. So, the production process for ammonia needs to be 100% renewable and carbon-free. Then, the purity of urea should at least 99.5% for commercial-grade and stored as a crystalline and granular variant. The process selection will be discussed are urea, ammonia, and electrolysis.

a. Process Selection of Urea Production

There are a lot of pathways can be used to produce urea from ammonia which are coal-to-urea, methane-to-urea, and power-to-urea. Table 3.1 shows the comparison between all the pathways.

Table 3.1 Comparison between all the pathways.

Properties	Power-to-Urea	Coal-to-Urea	Methane-to-Urea	Biomass-to-Urea	References
Raw material	Water	Coal	Methane	Empty Fruit Bunch (EFB)	Wenliang et al. (2022) & Ajiwibowo et al. (2019)
Process	Using renewable energy like solar power, wind power, and biogas power.	Combustion of coal to produce CO ₂ and energy.	Methanation process.	Undergo process supercritical water gasification (SCWG) and syngas chemical looping (SCL).	Wenliang et al. (2022) & Ajiwibowo et al. (2019)
Green ammonia technology	Yes	No	No	Yes	Wenliang et al. (2022) & Ajiwibowo et al. (2019)
Carbon free	Yes, no CO ₂ was produced during ammonia synthesis.	No, combustion will produce CO ₂	No, when methane reacted with water it will produce H ₂ ,	Yes, SCWG consist of methanation which will produce CO ₂ .	Wenliang et al. (2022) & Ajiwibowo et al. (2019)

CO ₂ and CO ₂					
System efficiency	74%	N/A	61%	44%	Wenliang et al. (2022)
Maturity	Mature	Mature	Mature	Demonstration	Wenliang et al. (2022) & Ajiwibowo et al. (2019)

The suitable pathway was chosen is power-to-urea because it is using green technology which solar power energy, has the higher system efficiency, zero net carbon, and it has been practiced widely in real-life.

b. Process Selection of Electrolysis

There are several types of electrolysis of water can be used to produced H₂. The three types of electrolysis are alkaline water electrolysis, (AWE), proton exchange membrane electrolysis (PEM), and solid oxide electrolysis (SOEC). PEM is chosen due to several reason and it was shown in Table 3.2.

Table 3.2 Comparison between types of electrolysis

Properties	Alkaline water electrolysis (AWE)	Proton exchange membrane electrolysis (PEM)	Solid oxide electrolysis (SOEC)	References
Energy consumption, kWh/Nm ³	4.5	3.8	2.6	Wenliang et al. (2022)
Hydrogen production, kg/h	134	196	233	RBN Energy LLC 2022
Capital cost, \$kW ⁻¹	1000 - 1200	1860 - 2320	>2000	Schmidt et al. (2017)
Maturity	Mature	Commercial for small scale industry	Demonstration in the laboratory	Schmidt et al. (2017)
Operating temperature, °C	60 - 80	50 - 80	650 - 800	Schmidt et al. (2017)
Operating pressure, bar	<30	<200	<25	Schmidt et al. (2017)
Lifetime, h	60,000 – 90,000	20,000 – 60,000	<10,000	Schmidt et al. (2017)

From Table 3.2, PEM and AWE have a low operating temperature to others electrolysis. Low temperatures and low pressure are required for green technology to

ensure that the amount of energy utilized is minimal. PEM was chosen due to compact design, low maintenance, and don't use any liquid chemical solution as the electrolyte compared to AWE which use potassium hydroxide solution in most cases (Nel Hydrogen, 2021). PEM electrolysis is the best method for producing hydrogen utilising extra renewable energy since it has a quick ramp-up and ramp-down capability and a large dynamic working range of 0–100%.

Multistack techniques are utilised to adjust the hydrogen production rate to client needs by utilising PEM technology, which can work over a wide range of current density. The PEM water electrolysis unit has the essential flexibility thanks to the use of many stacks rather than a single monostack. According to the Millet et al. (2018), there three types of PEM stack in the market which are PEM monostack, PEM quadristack, and PEM tristack. The selection of PEM types will depend on amount of hydrogen need to produce.

It may be desirable to remove one PEM stack from the cluster for maintenance purposes without stopping the service. Configurations with independent power supplies are preferred in that scenario. When PEM stacks are connected in parallel, one unit can be removed from the cluster by using an equivalent-impedance unit instead. When water is given in series, the mass flow needs to be high enough to keep the biphasic mixture adequately hydrated. It was better to ensure the PEM stack in parallel form (Millet et al. 2018)

c. Process Selection of Ammonia Synthesis

There are several methods to produce ammonia which are Haber-Bosch process, thermochemical cycle, and electromagnetic induction. Table 3.3 shows the comparison between types of ammonia production method.

Table 3.3 Comparison between types of ammonia production method

Type of process	Raw material	Operating condition	Advantages	Disadvantages	References
Haber-Bosch Process	Nitrogen, and Hydrogen	400-650°C 200-350 bar	Highly efficient process and	High energy usage. High GHG	Cong et al. (2019)

			active under optimum conditions of temperature and pressure. Carbon-free process & energy efficiency.	emission and high energy usage due to high operating pressure and temperature when using methane as feedstock.	
Thermochemical cycle	Aluminum Oxide and Nitrogen	1500°C 1 bar	Low energy consumption and produce ammonia directly from carbonized material instead of pure hydrogen.	High operating temperature leading to limited heat sources and materials	Juanza et al. (2019)
Electromagnetic induction method	Nitrogen, Hydrogen, and manganese zinc ferrite, $Mn_{0.8}Zn_{0.2}Fe_2O_4$ as nanocatalyst	28°C 1 bar	Low energy uses due to low temperature and pressure. Therefore, activation energy is 30% lower than process with no magnetic field, thus make the reaction faster. Carbon-free process & energy efficiency.	Demonstration in the laboratory and pilot scale.	Yahya (2018) & Qureshi et al. (2022)

Electromagnetic induction method was chosen as process unit. This is because it has the lowest energy usage and carbon free technology which can minimize the environmental pollution.

3.2.2 Process Description

Urea synthesis using green ammonia technology is using power-to-urea technology which is solar power as electrical supply. First, tap water will undergo water purification unit to provide the necessary deionized water to the process (Bessarabov & Millet 2018). This is because to meet requirement for PEM electrolyser. After water

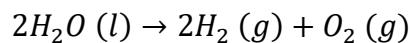
purification, water will undergo electrolysis through PEM electrolyser to produce oxygen and hydrogen. Then, hydrogen and nitrogen will enter the catalytic packed bed reactor by using magnetic induction with presence of manganese zinc ferrite as nanocatalyst to produce ammonia. Next, ammonia produced will go to urea synthesis along with carbon dioxide to synthesis urea at plug flow reactor. Urea, ammonium carbamate, and excess ammonia will go to stripper for decomposition of ammonium carbamate. Then, excess ammonium carbamate will flow to decomposition for further decompose it to ammonia and carbon dioxide. Then, urea will flow to evaporator to evaporate some water and granulator to achieve desired purity in granule form.

3.2.3 Mode of Operation

Our process is continuous process. It is because our plant undergoes 24 hours operation and shutdown only 14 days for maintenance. For the demand, we have steady market demand from 2019 till 2035 which is the trend of demand market shows increasing demand in every year. Our production has longer lifetime and can sustain longer based on the increasing in demand. During the production of urea, there not many impurities in the process so it was better using continuous process compared to batch process. This is because, the maintenance duration can be reduced and increase rate of processing. Then, with higher rate plant capacity which is 2096.68 kg/hr, using batch process is not efficient because it will need more reactor.

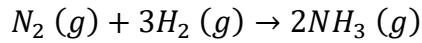
3.2.4 Stoichiometry Reaction

First reaction is water splitting which produce hydrogen and oxygen by using electrolysis process.

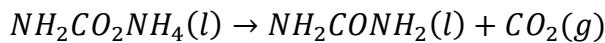
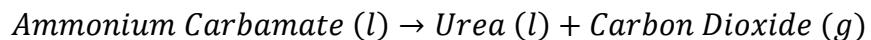
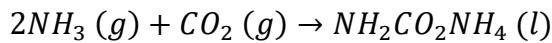
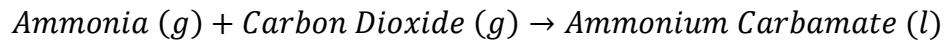


After water splitting, hydrogen will undergo ammonia synthesis while oxygen will be sold to other companies. Hydrogen will react with nitrogen to produce ammonia.

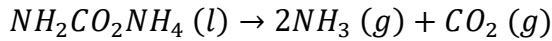
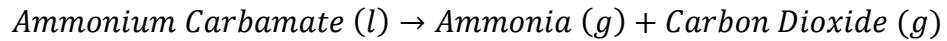




Then, ammonia will react with carbon dioxide to produce ammonium carbamate and undergo further reactions to produce urea.



Next, excess ammonium carbamate will undergo decomposition in the stripper and decomposer to produce ammonia and carbon dioxide.



3.2.5 Design Constraint

Design constraint are conditions that must be met for project to be successful. Design constraints may help to reduce the possibilities while choosing a project. Although at times it may seem like a disadvantage, but it makes the project into shape and takes on specific requirements (Robb 2022). It is to make sure the safety and efficiency of the project. There are two types of design constraints which are external constraints and internal constraints. Figure 3.2 shows the design constraints for external and internal.

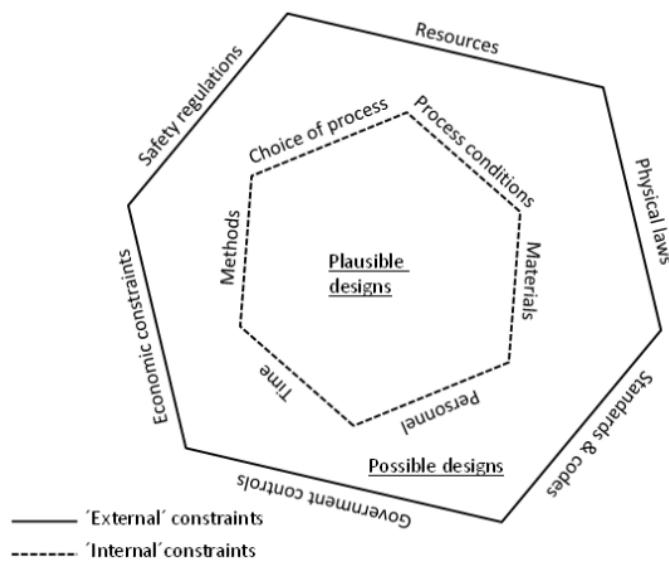


Figure 3.2 Design constraints

Source: Karvonen et al. 2015

External constraints are those that the designer cannot control, such as those related to the economy, health, or a natural disaster. From health aspects, Covid-19 pandemic have changed the work styles of every industry including this urea industry. Quarantine guidelines will arise some problem like absenteeism, so addition of workforce will be required. These may eventually cause productivity to drop if new work procedures are implemented at workplaces to guarantee employee health adequacy and social isolation, as well as altered skilling for multi-role coverages or the introduction of new product lines and procedures. With increasing number of workers, it will affect financial of the company. According to Statista 2021, inflation in Malaysia will be up to 2.47% and it will affect resources whether from cost or availability. From standards and codes, there are so many law that need to be complied such as Factory and Machinery act 1967 (Act 139), Environmental Quality Act 1974 (Act 127), Occupational Safety and Health Act 1994 (Act 514). And Petroleum (Safety Measure) Act 1984 (Act 302). All these acts should be followed to make sure the production can run smoothly.

Internal constraints are limitations that the designer has control over, such as method, process conditions, choice of process, personnel, materials, and time. At here, the boundary conditions have been set up which is production only can use green

ammonia technology which is zero net carbon production. The choice of process of ammonia synthesis shouldn't have any carbon production like using biomass gasification. Typically, ammonia production will use Haber-Bosch process which is required high temperature and pressure. As a safety precaution, an emergency pressure relief system as well as other appropriate safety measures must be implemented. As a next step in overcoming the constraint, process controls are applied. Then, every machine should have their own personnel to make sure the machine can run efficiently.

3.2.6 Selectivity Vs Conversion

Selectivity of each component can be determined with the following equation:

$$\text{Selectivity, } S_i = \frac{\text{Concentration of Product Form}}{\text{Concentration of Limiting Reactant Consumed}} = \frac{c_i}{c_{A_0}x} \quad \dots(3.1)$$

In order to determine the conversion and selectivity of reactants and products, Polymath ODE Solver is employed. The graph of selectivity against conversion for ammonia synthesis and urea synthesis is presented in Figure 3.3. The graph is created to find the best conversion rate with the most selectivity for the intended product.

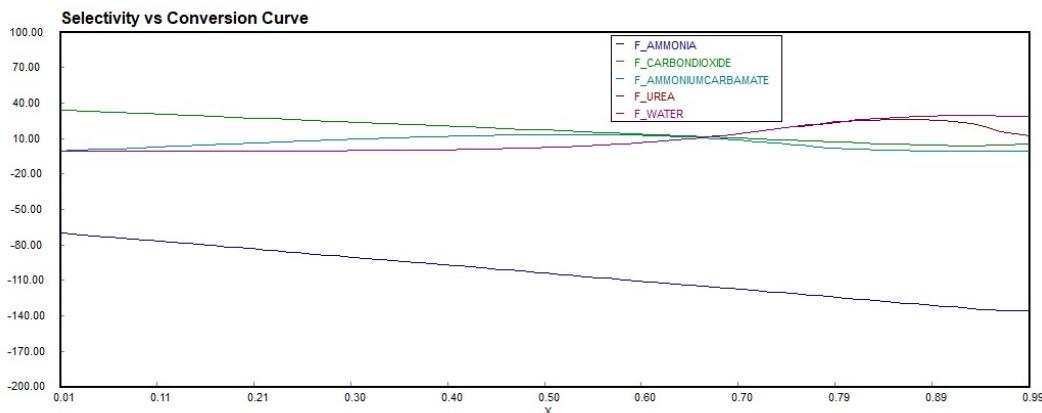


Figure 3.3 Selectivity of each component against conversion

3.3 PROCESS DESIGN LEVEL 2

In the process design level 2, development of input-output structure of the process. At here, the destination code of each product, excess reactant, waste and by product are

decided. Design capacities are constructed for each raw material and product. The overall mass balances are performed and the economic potential involving limiting reactants are shown.

3.3.1 Synthesis of Input-Output Structure

A simple black-box structure known as an input-output structure can relate the reactants and products used in a process. It is also utilized in industry as an indication to determine the gross profit of a production plant. As a result, the process can identify the types of reactants used as well as the end results, which include the primary product, a by-product, and wastes. Figure 3.4 below shows the input-output structure of urea synthesis.

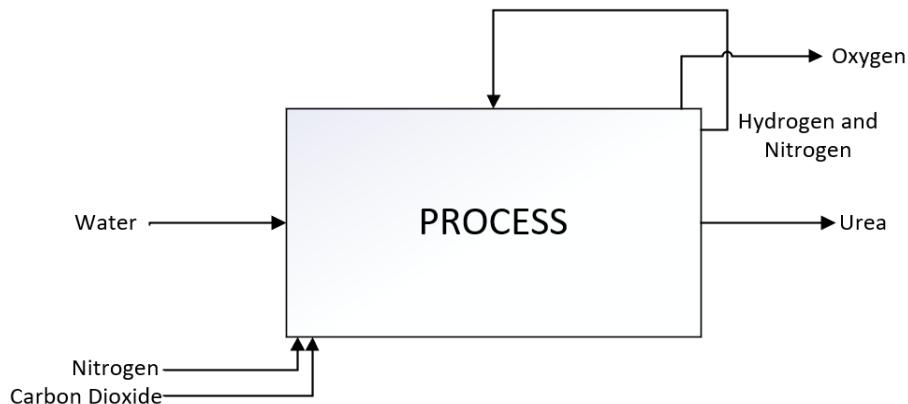


Figure 3.4 Input and Output Structure for Urea Synthesis

3.3.2 Process Output Destination

To determine their respective output destinations, an analysis is done to determine whether the output components are heavy or light. The standard utilised was propylene, and each output product's boiling point was compared to propylene's at -47.6°C. Output components were divided into light and heavy categories based on their boiling points. Light components had boiling points below propylene, while heavy components have boiling points above propylene. Table 3.4 shows categories of each component in the production.

Table 3.4 Categories of each component in urea synthesis

Component	Normal Boiling Point (°C)	Light / Heavy	Destination code
Hydrogen	-251	Light	Recycle & Purge
Water	100	Heavy	Waste
Urea	135	Heavy	Primary product
Oxygen	- 183	Light	By-product
Carbon Dioxide	-78.5	Light	Purge
Nitrogen	-195.8	Light	Recycle & Purge
Ammonia	-33.34	Heavy	Recycle

Source: Process Engineer's Tools 2022

3.3.3 Design Capacity

Design capacity of the plant is selected based on the supply and demand of urea globally. Plant capacity is calculated according to the 0.05% shortage of global deficiency in future of the market by producing 2095 kg/hr. Assume that the period of plant shut down for maintenance is 14 days, thus the project will operate for 351 days per year.

3.3.4 Overall Material Balance

Based on the product capacity 2083.33 kg/h, an overall material balance is calculated to perform the flowrate of input and output for urea production. Table 3.5 shows flowrate of input-output urea production.

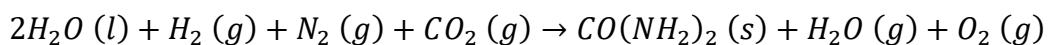


Table 3.5 Overall mass balance

Carbamate							
Carbon Dioxide	0	0	3117	0	1511.55	79.56	0
Urea	0	0	0	0	0	0	2083.33
Total	3148.17	1641.88	3117	2796.35	2242.8	773.39	2095.86

Total inlet mass flowrate = Total outlet mass flowrate

7907.05 kg/h \approx 7908.39 kg/h (Balanced)

3.3.5 Economic Potential Analysis Level 2

Function for potential economic for level 2, f_{PE2} , can be calculated based on the feed composition and feed flow rate. It is calculated to determine the gross profit obtained from the production. The general equation used to calculate f_{PE2} is shown below, and the cost of raw materials and product is shown in Table 3.6.

$$f_{PE2} = \text{Cost for main product} + \text{Cost for by product} - \text{Cost of raw material}$$

$$f_{PE2} = C_U F_U + C_O F_O - C_W F_W - C_N F_N - C_A F_A$$

Where:

C = cost

F = Flowrate

U = urea

O = oxygen gas

W = water

N = nitrogen gas

A = carbon dioxide

Table 3.6 Cost of raw materials and products

Component	Price (RM/kg)
Urea	22.00
Oxygen gas	68.37
Water	0.00330
Nitrogen gas	2.62
Carbon dioxide gas	8.12

Results for data economic potential level 2 based on conversion are shown in Table 3.7 and Figure 3.5.

Table 3.7 Data for economy potential of process design level 2

Conversion	f_{PE2} (RM million/year)
0.1	77.8
0.2	226.5
0.3	276.0
0.4	300.8
0.5	315.7
0.6	325.6
0.7	332.6
0.8	337.9
0.9	342.1
1.0	345.4

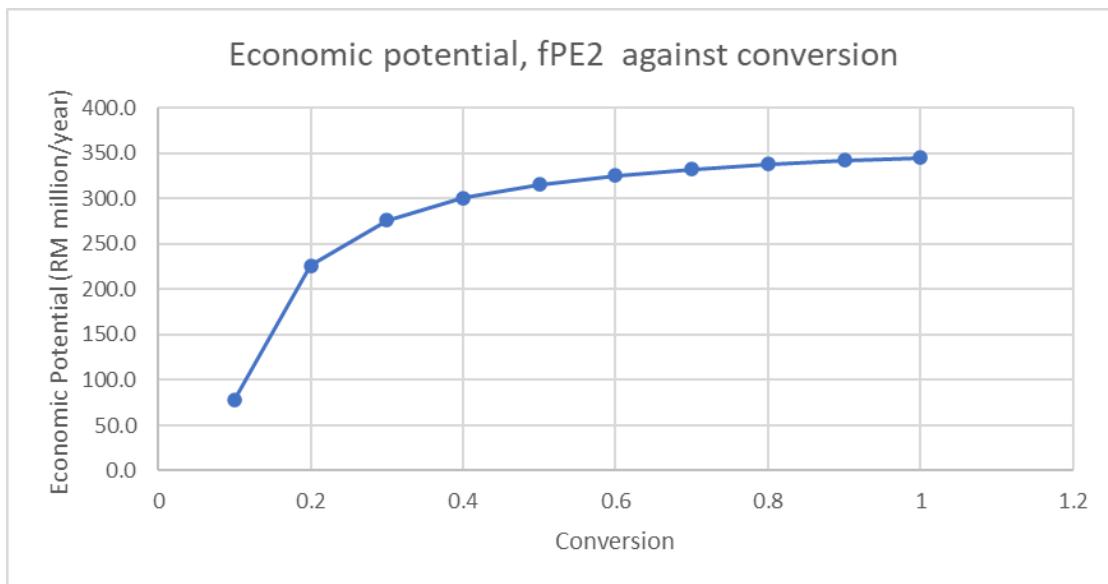


Figure 3.5 Potential economy curve of process design level 2

3.4 PROCESS DESIGN LEVEL 3

Process design level 3 describes the synthesis of recycle structure and designing the reactors that used in the process. Design variables that need to be determined in process design level 3 are number and types of reactors, compressor design, heat management

of reactor and economic potential level 3. The process design concept diagram level 3 including reactor system and separation is shown in Figure 3.6.

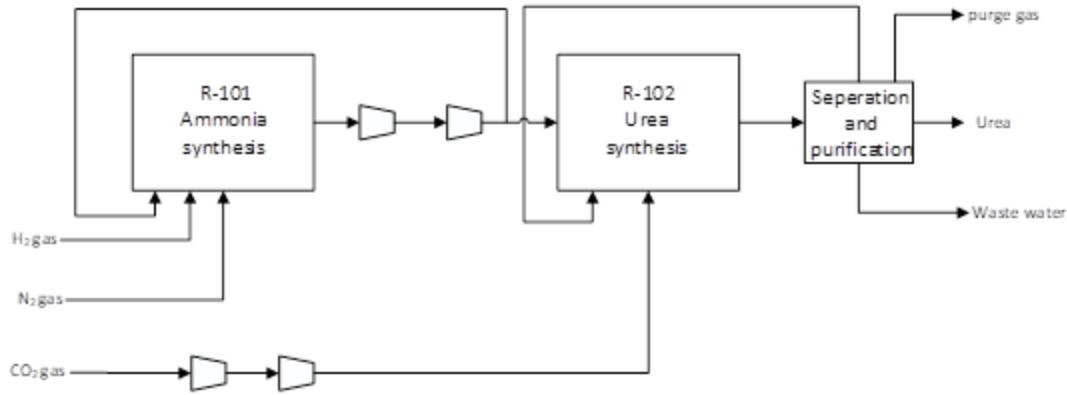


Figure 3.6 Process design concept diagram level 3

3.4.1 Number of Reactor

There are two main reactions occur in the production of urea from ammonia. Hence the whole production process requires two different reactions in order to complete it. Firstly, nitrogen gas and hydrogen gas will enter reactor 1, R-101 to produce ammonia gas. Then, liquid ammonia will react with carbon dioxide gas in reactor 2, R-102 to produce urea, which is the main product along with the by-products such as ammonium carbamate, water, and unreacted ammonia. The detail operating conditions for the respective process involve in each reactor are shown in Table 3.8 below.

Table 3.8 Detail operating conditions of each reactor

Unit Operation	Process	Temperature (°C)	Pressure (bar)	Catalyst
R-102	Ammonia synthesis	28	1	Mn _{0.8} Zn _{0.2} O ₄
R-103	Urea synthesis	180	140	-

3.4.2 Number of Recycle Stream

Recyclable streams are critical for reducing waste and costs associated with unreacted reactants. Extra raw materials required for process optimization must be recycled to reduce costs and needless waste. In urea manufacturing from green ammonia, there are three recycling streams are present. First, Water from demister D-101 and D-102 will

recycle back to storage tank, ST-102. Then, hydrogen gas is relatively expensive as a raw material. Therefore, the unreacted hydrogen gas in the process is recycled back to the reactor to save cost. Excess nitrogen and hydrogen from the phase separator, PS-101 will be recycled back into R-101. Next, excess ammonia, carbon dioxide and decomposition product from stripper, S-101 will recycle back to R-102 to increase the conversion.

3.4.3 Reactor Selection

Reactor used for reactor, R-101 is catalytic packed bed reactor with the inducing magnet. Inducing magnetic field can lower the condition operation for ammonia synthesis (Yahya 2018). For reactor, R-102, plug flow reactor was used to increase the rate of conversion with recycle stream.

3.4.4 Reactor Heat Effect

The heat effect of the R-101, and R-102 reactor is calculated. The heat effect of a reactor is used to determine whether heat is emitted or absorbed during a reaction in the reactor. If the reaction is carried out adiabatically, no heat will be added into the reactor and no heat will be removed from the reactor during the reaction. Meanwhile, isothermal heat condition will be added into the reactor in order to keep the constant temperature of contents inside the reactor. The equation below is used to calculate the adiabatic temperature:

$$\sum_{j=1}^N n_j \Delta H_{rxn,j}^{in} + \sum_{i=1}^M P_i C_{pi}(T_a - T_m) - \sum_{k=1}^K F_k C_{pk}(T_m - T_m) = 0 \quad \dots(3.2)$$

Where;

$\Delta H_{rxn,j}^{in}$ = Heat of reaction at inlet temperature for reaction j

C_{pi} = Mean specific heat capacity for each feed components I including reactants, impurities and recycled products

T_a = Adiabatic temperature of reactor

C_{pk} = Mean specific heat for each product components k including reactants, impurities, and products from reaction

T_m = Inlet temperature of reactor

$$T_a = \frac{x[-\Delta H_{rxn}^0(T_R)] + \sum \theta_i C_{pi} T_m + X \Delta C_p T_R}{\sum \theta_i C_{pi} + X \Delta C_p} \dots(3.3)$$

Where;

ΔH_{rxn}^0 = Heat of reaction at reference temperature

C_{pi} = Specific heat for each product, i which includes reactant and impurities

T_a = Adiabatic temperature

T_m = Inlet temperature of reactor

X = Conversion

θ_i = Ratio of reactant i to limiting reactant

The reaction is exothermic when adiabatic temperature increases with increasing conversion. Thus, isothermal reactor condition is suitable to be used to ensure that reaction occurs favourably and prevent runaway reaction from happening. Then, the reaction is endothermic when adiabatic temperature decreases with increasing conversion. Therefore, adiabatic reactor condition is suitable to be used to ensure that reaction occurs favourably and prevent runaway reaction from happening. Table 3.9 and Figure 3.7 below show the result of adiabatic temperature for catalytic packed bed reactor, R-101. Table 3.10 and Figure 3.8 below show the result of adiabatic temperature for plug flow reactor, R-102.

Table 3.9 Adiabatic temperature for Catalytic Packed Bed Reactor, R-101

Conversion	Adiabatic Temperature, T_a (K)
0.1	317.04
0.2	332.93
0.3	348.82
0.4	364.71
0.5	380.60
0.6	396.48
0.7	412.37

0.8	428.26
0.9	444.15
1	460.04

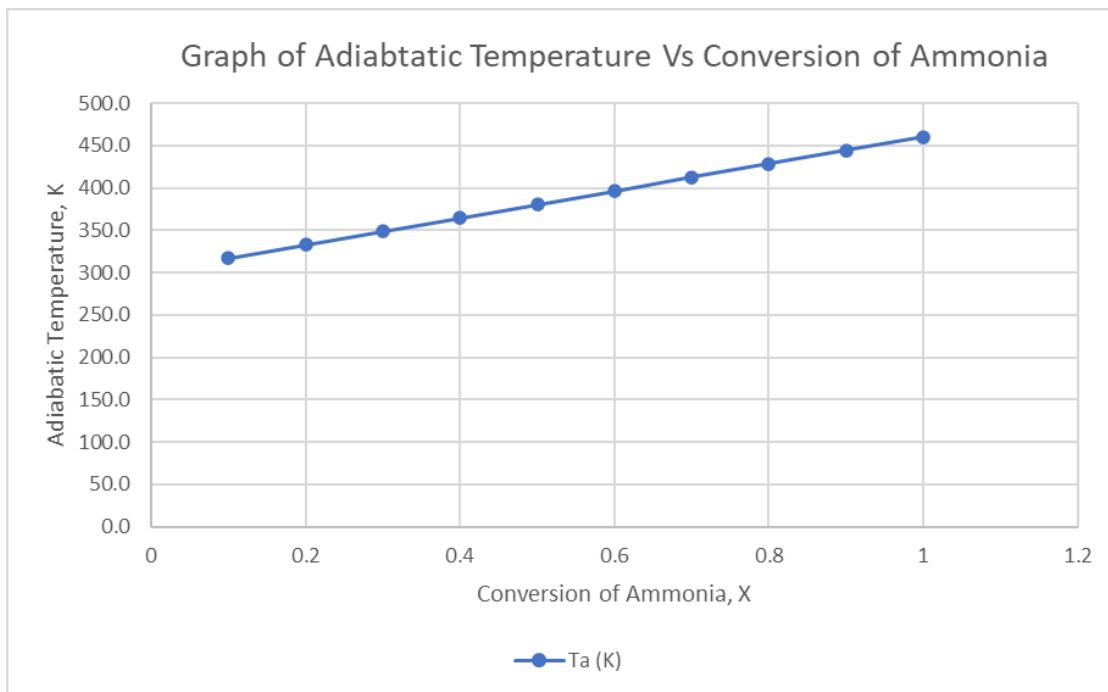


Figure 3.7 Graph of adiabatic temperature against conversion for Catalytic Packed Bed Reactor, R-101

Table 3.10 Adiabatic temperature for Plug Flow Reactor, R-102

Conversion	Adiabatic Temperature, T_a (K)
0.1	450.92
0.2	448.68
0.3	446.45
0.4	444.22
0.5	441.98
0.6	439.75
0.7	437.52
0.8	435.28
0.9	433.05
1	430.82

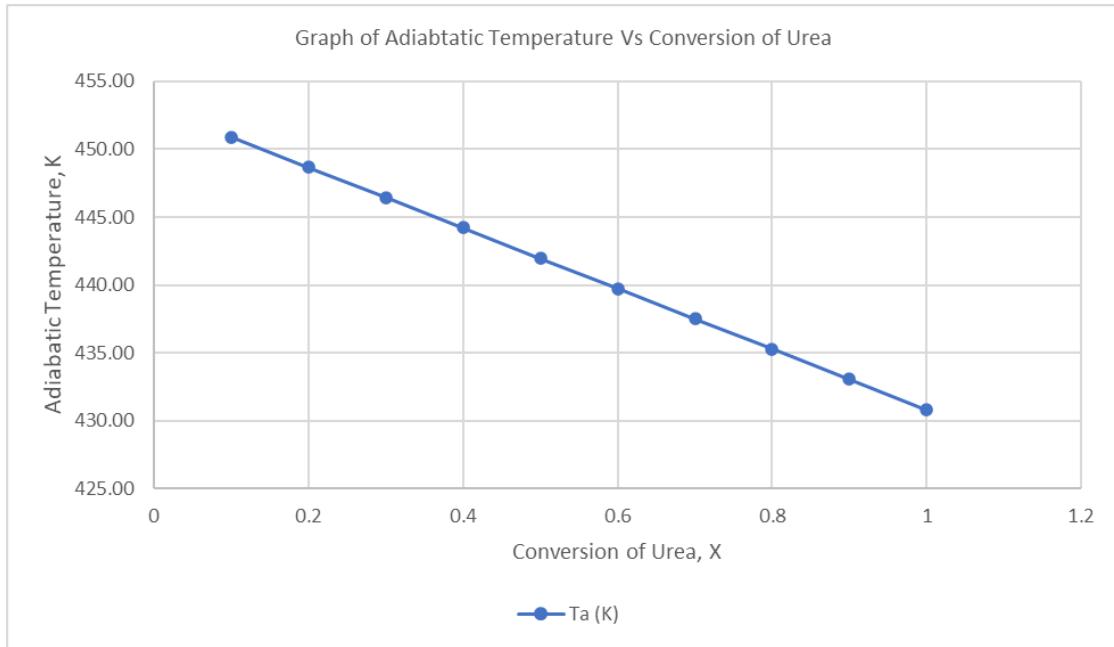


Figure 3.8 Graph of adiabatic temperature against conversion for Plug Flow Reactor, R-102

From Figure 3.7 and Figure 3.8, the reaction inside the catalytic packed bed reactor, R-101 is exothermic while for plug flow reactor, R-102 is endothermic.

3.4.5 Reactor Sizing

Reactor sizing is necessary to determine for the estimation of reactor cost. For urea production from green ammonia technology, two reactors are needed which are the packed bed reactor (R-101) for ammonia synthesis and plug flow reactor (R-102) for urea synthesis. Design of equation of each type reactors listed as below.

a. Catalytic Packed Bed Reactor, R-101

Since there is solid catalyst involves in the ammonia synthesis reaction, the volume of the packed bed reactor used is designed by using equation as shown below.

$$\text{Design equation: } V = \int_0^X \frac{F_{AO}}{\rho_c(1-\varepsilon)(-r_A)} dX_A$$

Where:

V = Volume of reactor, m^3

X = Conversion of reactant

ϵ = Voidage of catalyst

r_A = Rate of reaction

F_{AO} = Initial molar flow rate of component, kmole/h

ρ = Density of catalyst, kg/m³

To determine the dimension of each reactor, a few assumptions are made.

- i. The reactor is cylindrical in shape
- ii. Length to diameter ratio of reactor is 3 where $\frac{L}{D} = 3$
- iii. Length of reactor, $L=3D$
- iv. Volume of a cylinder, $V = \frac{1}{4}\pi D^2 L = 14\pi D^2(3D)$
- v. Diameter of reactor, $D = \sqrt[3]{\frac{4V}{3\pi}}$

Table 3.11 Dimension of R-101

Conversion, X	Volume, V (m ³)	Diameter, D (m)	Height, H (m)
0.1	0.59	0.63	1.89
0.2	1.88	0.93	2.78
0.3	5.32	1.31	3.94
0.4	9.46	1.59	4.77
0.5	13.86	1.80	5.41
0.6	21.28	2.08	6.25
0.7	27.81	2.28	6.83
0.8	36.81	2.50	7.50
0.9	49.57	2.76	8.28
1.0	61.17	2.96	8.88

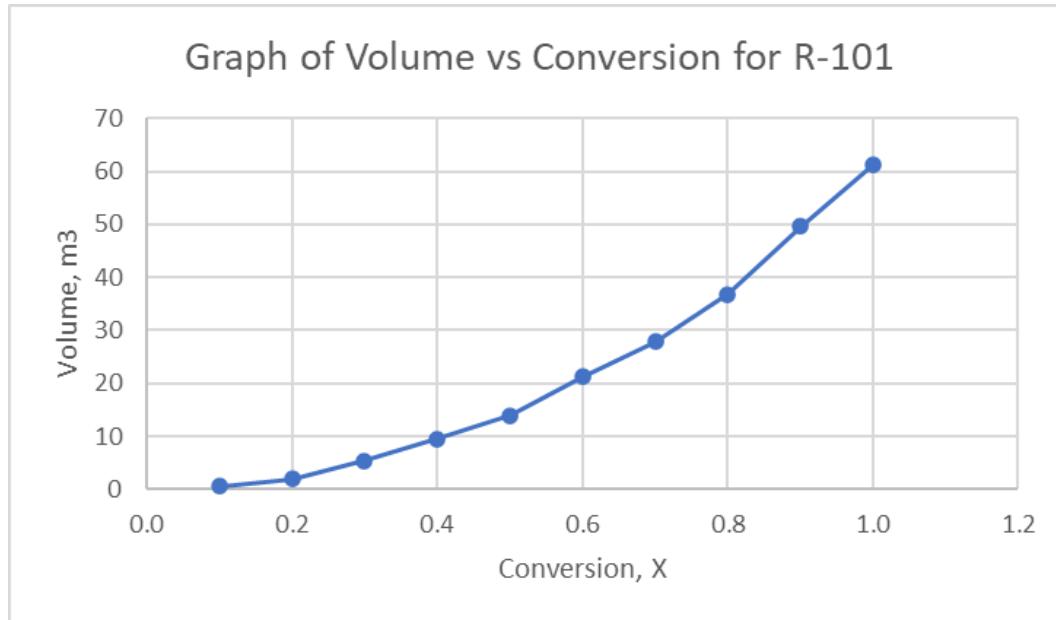


Figure 3.9 Volume of R-101 against conversion

b. Plug Flow Reactor, R-102

Plug flow reactor with 10 number of sieve trays is used to avoid back mixing and to make sure gaseous CO₂ not escape from reactor but must react in the lower part of reactor.

Design equation: $V = F_{AO} \int_0^X \frac{dX}{-r_A}$

Where:

V : Volume of reactor, m³

X : Conversion of reactant

F_{AO} : Initial molar flow rate of component, kmol/h

r_A : Rate of reaction

To determine the dimension of each reactor, a few assumptions are made.

- i. The reactor is cylindrical in shape
- ii. Length to diameter ratio of reactor is 3 where $\frac{L}{D} = 3$
- iii. Length of reactor, L=3D
- iv. Volume of a cylinder, $V = \frac{1}{4}\pi D^2 L = 14\pi D^2(3D)$

v. Diameter of reactor, $D = \sqrt[3]{\frac{4V}{3\pi}}$

Table 3.12 Dimension of R-102

Conversion, X	Volume, V (m ³)	Diameter, D (m)	Height, H (m)
0.1	0.75	0.68	2.05
0.2	1.67	0.89	2.67
0.3	2.80	1.06	3.18
0.4	4.21	1.21	3.64
0.5	6.00	1.37	4.10
0.6	8.34	1.52	4.57
0.7	11.56	1.70	5.10
0.8	16.37	1.91	5.73
0.9	25.08	2.20	6.60
1.0	36.10	2.48	7.45

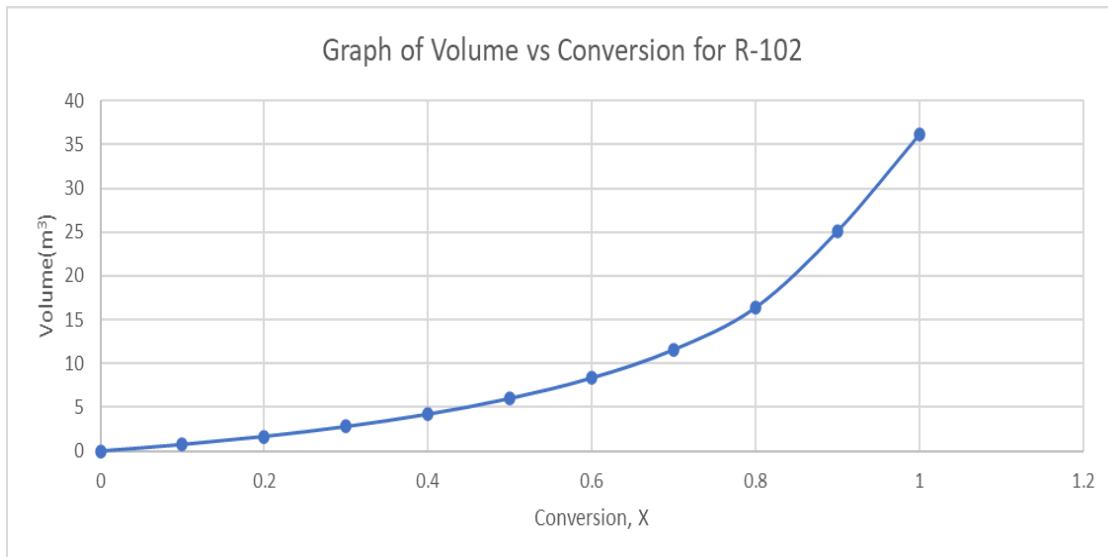


Figure 3.10 Volume of R-102 against conversion

3.4.6 Reactor Cost

Installation and annual cost of a reactor can be calculated by using the following equation:

Installation cost of reactor:

$$K_r = \left(\frac{I_{MSK}}{I_{MSD}} \right) 7775.3 D^{1.066} L_R^{0.82} [2.18 + F_M F_P] F_I$$

Annual cost of reactor:

$$K_{rt} = \left(\frac{I_{MSK}}{I_{MSD}} \right) \left(\frac{7775.3}{3} \right) D^{1.066} L_R^{0.82} [2.18 + F_M F_P] F_I$$

Where,

I_{MSK} = Present Marshall and Swift index

I_{MSD} = Past Marshall and Swift index

D = Diameter of reactor

L_R = Length of reactor

F_M = Design material factor

F_P = Pressure factor

F_I = Installation factor

The index of Marshall and Swift by year is as shown in Table 3.13.

Table 3.13 Marshall and Swift index by year

Year	Index
2011	1476.7
2012	1536.5
2013	1552.8
2014	1566.9
2015	1598.1
2016	1582.3
2017	1593.7
2018	1638.2
2019	1716.2
2020	1729.4
2021	1773.4

Source: Marshall Swift Valuation Services 2021

The design material factor, F_M is 3.75 as the material used for both reactors are stainless steel while pressure factor, F_P is assumed to be 1. Table 3.14 and Table 3.15 show the annual cost of catalytic packed bed reactor, R-101 and plug flow reactor, R-102 respectively.

Table 3.14 Annual cost of catalytic packed bed reactor, R-101 based on conversion

Conversion, X	Volume (m ³)	Diameter (m)	Length (m)	K _{rt} (RM/year)
0.1	0.59	0.63	1.89	140615.41
0.2	1.88	0.93	2.78	319374.29
0.3	5.32	1.31	3.94	519582.10
0.4	9.46	1.59	4.77	803568.72
0.5	13.86	1.80	5.41	1063827.49
0.6	21.28	2.08	6.25	1406870.80
0.7	27.81	2.28	6.83	1624062.96
0.8	36.81	2.50	7.50	1913035.97
0.9	49.57	2.76	8.28	2227582.72
1.0	61.17	2.96	8.88	2647681.03

Table 3.15 Annual cost of plug flow reactor, R-102 based on conversion

Conversion, X	Volume (m ³)	Diameter (m)	Length (m)	K _{rt} (RM/year)
0.1	0.75	0.68	2.05	305720.22
0.2	1.67	0.89	2.67	505259.50
0.3	2.80	1.06	3.18	699604.87
0.4	4.21	1.21	3.64	904966.77
0.5	6.00	1.37	4.10	1131203.76
0.6	8.34	1.52	4.57	1390937.42
0.7	11.56	1.70	5.10	1707378.32
0.8	16.37	1.91	5.73	2126088.78
0.9	25.08	2.20	6.60	2778606.48
1.0	36.10	2.48	7.45	3627501.23

3.4.7 Cost of Compressors

Compressor C-101 and C-102 are a multiple compressor that used to increase the pressure from 1 bar to 140 bar. Compressor C-101 is used to compress the output R-101 from 1 bar to 46 bar while C-102 increase the pressure from 46 bar to 140 bar into

plug flow reactor, R-102 so that the reaction in R-102 can occur. Compressor C-103 and C-104 are used to compress the carbon dioxide gas from 1 bar to 140 bar into R-102. Table 3.16 show the summary of the compressors parameter used in the process plant.

Table 3.16 Summary of compressors parameter

Compressor	C-101	C-102	C-103	C-104
Inlet pressure (bar)	1	46	1	46
Outlet pressure (bar)	46	140	46	135
Inlet temperature (°C)	28	20	25	50
Outlet temperature (°C)	50	40	50	100
Present Marshall and Swift index, I_{MSK}	1773.4	1773.4	1773.4	1773.4
Past Marshall and Swift Index, I_{MSD}	280	280	280	280

The power that is used to compress the gas phase from pressure 1 to pressure 2 in C-101, C-102, C-103 and C-104 can be calculated by using the equation shown below. Table 3.17, Table 3.18, Table 3.19, and Table 3.20 show the annual and installation cost of compressor, C-101, C-102, C-103 and C-104 respectively.

Power, W:

$$-W = R_G \frac{nZRT_1}{(n-1)} [(P_2/P_1)^{\frac{n-1}{n}} - 1]$$

Installation cost, K_{pk}

$$K_{pk} = \frac{I_{MSK}}{I_{MSD}} 8.74 (2.11 + F_d) F_I \left(\frac{W}{\eta}\right)^{0.82}$$

Annually cost, K_{pt}

$$K_{pt} = \frac{I_{MSK}}{3I_{MSD}} 8.74 (2.11 + F_d) \left(\frac{W}{\eta}\right)^{0.82} + \frac{W}{\eta} C_p (8150)$$

Where,

W	= Power to compress gas using compressor (kW)
R _G	= Flowrate of the stream
n	= Polytrophic index
Z	= compressibility coefficient
R	= gas constant
T ₁	= inlet temperature
P ₁	= inlet pressure
P ₂	= outlet pressure
F _d	= Design factor
η	= Compressor efficiency
C _p	= Power cost (RM/year)

Table 3.17 Installation and annually cost C-101

Conversion, X	R _G (mol/s)	Power (W)	Power (kW)	K _{pk} (RM million/year)	K _{pt} (RM million/year)
0.1	811.1	11273875.8	11273.9	0.71	63.3
0.2	405.6	5636937.9	5636.9	0.40	31.7
0.3	270.4	3757958.6	3758.0	0.29	21.1
0.4	202.8	2818468.9	2818.5	0.23	15.8
0.5	162.2	2254775.2	2254.8	0.19	12.7
0.6	135.2	1878979.3	1879.0	0.16	10.6
0.7	115.9	1610553.7	1610.6	0.14	9.1
0.8	101.4	1409234.5	1409.2	0.13	7.9
0.9	90.1	1252652.9	1252.7	0.12	7.04
1.0	81.11	1127387.58	1127.39	0.11	6.34

Table 3.18 Installation and annually cost C-102

Conversion, X	R _G (mol/s)	Power (W)	Power (kW)	K _{pk} (RM million/year)	K _{pt} (RM million/year)
0.1	811.10	1774855.03	1774.86	0.16	9.98
0.2	405.55	887427.51	887.43	0.09	4.99
0.3	270.37	591618.34	591.62	0.06	3.33
0.4	202.78	443713.76	443.71	0.05	2.50
0.5	162.22	354971.01	354.97	0.04	2.00
0.6	135.18	295809.17	295.81	0.04	1.67
0.7	115.87	253550.72	253.55	0.03	1.43

0.8	101.39	221856.88	221.86	0.03	1.25
0.9	90.12	197206.11	197.21	0.03	1.11
1.0	81.11	177485.50	177.49	0.02	1.00

Table 3.19 Installation and annually cost C-103

Conversion, X	R _G (mol/s)	Power (W)	Power (kW)	K _{pk} (RM million/year)	K _{pt} (RM million/year)
0.1	196.70	2706793.65	2706.79	0.22	15.2
0.2	98.35	1353396.83	1353.40	0.13	7.6
0.3	65.57	902264.55	902.26	0.09	5.08
0.4	49.18	676698.41	676.70	0.07	3.81
0.5	39.34	541358.73	541.36	0.06	3.05
0.6	32.78	451132.28	451.13	0.05	2.54
0.7	28.10	386684.81	386.68	0.04	2.18
0.8	24.59	338349.21	338.35	0.04	1.90
0.9	21.86	300754.85	300.75	0.04	1.69
1.0	19.67	270679.37	270.68	0.03	1.52

Table 3.20 Installation and annually cost C-104

Conversion, X	R _G (mol/s)	Power (W)	Power (kW)	K _{pk} (RM million/year)	K _{pt} (RM million/year)
0.1	196.70	455633.75	455.63	0.05	2.56
0.2	98.35	227816.87	227.82	0.03	1.28
0.3	65.57	151877.92	151.88	0.02	0.86
0.4	49.18	113908.44	113.91	0.02	0.64
0.5	39.34	91126.75	91.13	0.01	0.51
0.6	32.78	75938.96	75.94	0.01	0.43
0.7	28.10	65090.54	65.09	0.01	0.37
0.8	24.59	56954.22	56.95	0.01	0.32
0.9	21.86	50625.97	50.63	0.01	0.29
1.0	19.67	45563.37	45.56	0.01	0.26

3.4.8 Economic Potential Analysis Level 3

The economy potential for level 3, f_{PE3} is given by

$$f_{PE3} = f_{PE2} - K_{rt} - K_{pt}$$

Where,

f_{PE2} = Economy potential for level 2

K_{rt} = Annual cost of reactors

K_{pt} = Annual cost of compressors

The result of economy potential of level 3 is shown below in Table 3.21.

Table 3.21 Data for economy potential level 3

Conversion, X	f_{PE2} (RM million/year)	f_{PE3} (RM million/year)
0.1	77.84	-13.70
0.2	226.47	180.09
0.3	276.02	244.42
0.4	300.79	276.29
0.5	315.65	295.22
0.6	325.56	307.57
0.7	332.64	316.28
0.8	337.95	322.51
0.9	342.08	326.94
1.0	345.38	329.98

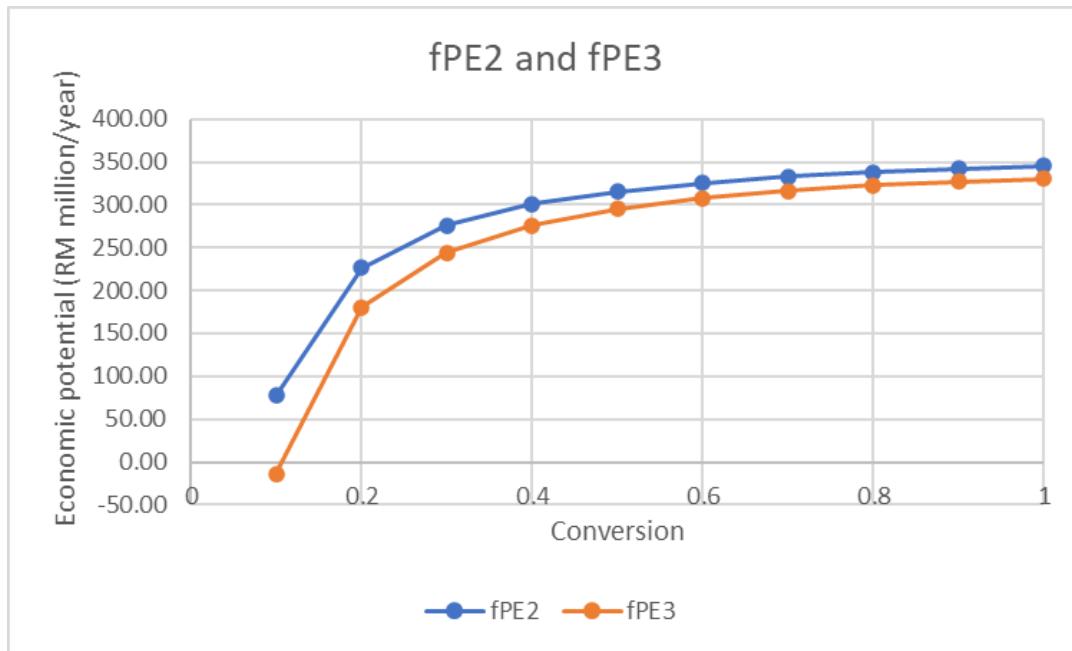


Figure 3.11 Potential economy curve for design level 3

3.5 PROCESS DESIGN LEVEL 4

Process design level 4 encompasses all separation units used throughout the process. Separation is the process of separating two or more mixtures to obtain a product of high purity. Separation units are crucial in any process that involves the removal of impurities, reactant recycling, or further purification of the product. The separation units involved in the production are phase separator, stripper, decomposer and evaporator.

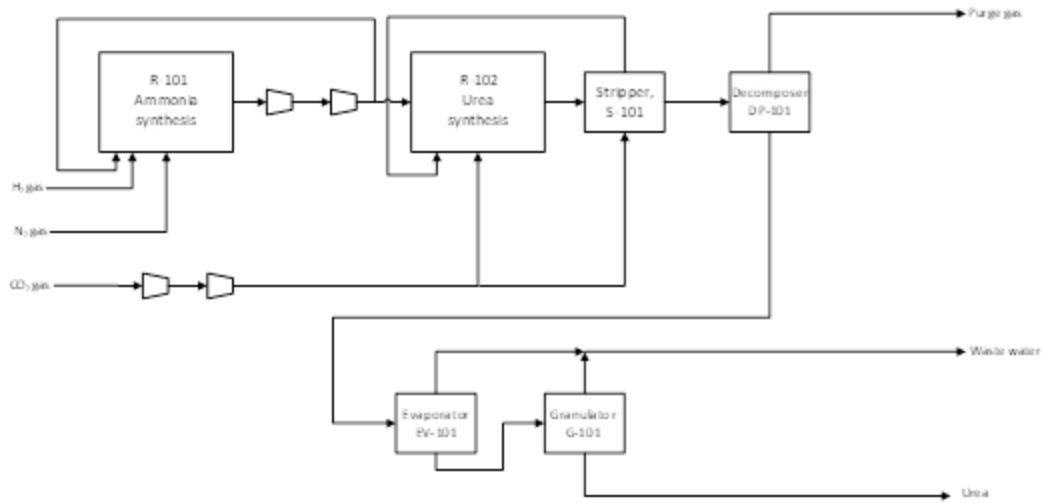


Figure 3.12 Process design concept level 4

3.5.1 Preliminary Design of Phase Separator, PS-101

Phase separator is used to perform liquid-gas separation process. Gas product will be discharged through the upper gas stream, meanwhile liquid product will be transferred to the bottom stream. Phase separator, PS-101 is used to separate the unreacted gas reactant which are nitrogen and hydrogen back to the reactor, R-101 from gas-liquid mixture.

a. Design calculations

The calculation of minimum vessel diameter shown as below:

$$D_V = \sqrt{\frac{4V_v}{\pi u_s}}$$

Where,

D_V : Minimum vessel diameter, m

V_v : Gas or vapour volumetric flow rate, m^3/s

u_s : u_t if a demister pad is used and 0.15 u_t for separator without demister pad

The calculation of settling velocity of the liquid droplets shown as below:

$$u_t = 0.07 \left[\frac{\rho_L - \rho_V}{\rho_V} \right]^{\frac{1}{2}}$$

Where,

u_t = Settling velocity, m/s

ρ_L = Liquid density, kg/m^3

ρ_V = Vapour density, kg/m^3

Hold-up volume, V_s (m^3) = liquid volumetric flowrate (m^3/s) \times time (s)

Liquid depth required, h_v (m) = $\frac{\text{hold-up volume } (\text{m}^3)}{\text{vessel cross-sectional area } (\text{m}^2)}$

$$\text{Vessel height, } h \text{ (m)} = h_v + D_v + \frac{D_v}{2} + \text{height of demister pad (0.4 m)}$$

b. Costing

The annual cost of the phase separator, K_{rt} can be calculated based on the equation below:

$$K_{rt} = \left(\frac{l_{MSK}}{l_{MSD}}\right) \frac{7775.3}{3} D^{1.066} L_R^{0.802} (218 + F_M F_P) F_I$$

The installation cost of the phase separator, K_r can be calculated based on the equation below:

$$K_r = \left(\frac{l_{MSK}}{l_{MSD}}\right) 7775.3 D^{1.066} L_R^{0.802} (218 + F_M F_P) F_I$$

Where,

l_{MSK} = Marshall and Swift Index of construction year 2022

l_{MSD} = Past Marshall and Swift Index year 2021

D = Diameter of phase separator

L_R = Length of phase separator

F_M = Construction factor

F_P = Pressure factor

F_I = Installation cost index in Malaysia

Table 3.22 shows the summary calculation of phase separator, PS-101.

Table 3.22 Summary calculation of phase separator, PS-101

Conversion, X	Diameter, D_v (m)	Height, h_v (m)	Annual cost, K_{rt} (RM)	Installation cost, K_r (RM)
0.1	0.21	0.99	7719.75	23159.24
0.2	0.29	1.12	12347.29	37041.88
0.3	0.36	1.22	16426.76	49280.27
0.4	0.41	1.30	20216.16	60648.47

0.5	0.46	1.37	23816.96	71450.88
0.6	0.51	1.44	27281.81	81845.44
0.7	0.55	1.45	30642.30	91926.90
0.8	0.58	1.56	33919.16	101757.49
0.9	0.62	1.61	37126.94	111380.83
1.0	0.65	1.66	40276.29	120828.87

3.5.2 Preliminary Design of Stripper, S-101

Stripper, S-101 is used to separate the ammonium carbamate and carbon dioxide from the rest of the output of reactor, R-102. Ammonium carbamate will decompose to carbon dioxide and ammonia gas and will recycle back to reactor, R-102. The operating condition of S-101 is 180°C and 140 bar.

a. Design calculation

The equations used to conduct the design calculations for the stripper are summarized below.

i. Number of theoretical stages (Robbins 2011)

$$\text{Equilibrium constant, } K = \frac{\text{Total gas flow rate } (\frac{\text{kmole}}{\text{h}})}{\text{Total liquid flow rate } (\frac{\text{kmole}}{\text{h}})}$$

Stripping factor, S

$$S = \frac{K}{\left(\frac{L}{V}\right)}$$

Where,

L = Liquid flowrate, kmol/h

V = Vapour flowrate, kmol/h

$$N = \frac{\ln \left(\frac{x_f}{x_b} \left(1 - \frac{1}{S} \right) + \frac{1}{S} \right)}{\ln S} = 2 \text{ stages}$$

Where,

- N = Number of theoretical stages
- x_f = Feed concentration (mole fraction), kmol/m³
- x_b : Effluent concentration (mole fraction), kmol/m³

ii. Number of actual stages (Duss & Taylor 2018)

Number of transfer unit in gas, N_G ,

$$N_G = N_L = 0.936\mu_L^{-0.25}$$

Based on Lamm & Jarboe 2021, the liquid viscosity, μ_L is between 0.2 to 1.6 cP.

$$N_G = N_L = 0.936(1.6)^{-0.25} = 0.83$$

Where,

- N_L = Number of transfer unit in liquid
- μ_L = Liquid viscosity, cP

Overall transfer unit for gas phase, N_{OG}

$$\frac{1}{N_{OG}} = \frac{1}{N_G} + \frac{S}{N_L}$$

$$N_{OG} = \frac{1}{\frac{1}{N_G} + \frac{S}{N_L}}$$

Murphree point efficiency on a tray, η_{point}

$$\eta_{point} = 1 - e^{-N_{OG}}$$

Murphree tray efficiency, η_{tray}

$$n_{tray} = \frac{e^{S \times n_{point}} - 1}{S}$$

Column efficiency, n_{column}

$$n_{column} = \frac{\ln[1 + n_{tray}(S - 1)]}{\ln S}$$

Number of actual stages, N_a ,

$$N_a = \frac{N_t}{n_{column}}$$

= 4 stages

iii. Diameter of stripper

Calculation formula diameter and height of stripper:

Based on Towler & Sinnott 2013,

Liquid-vapour flow factor, F_{LV}

$$F_{LV} = \frac{L_w}{V_w} \sqrt{\frac{\rho_v}{\rho_l}}$$

Where,

L_w = Liquid mass flowrate, kg/s

V_w = Vapour mass flowrate, kg/s

ρ_v = Vapour density, kg/m³

ρ_l = Liquid density, kg/m³

Plate spacing, I_t is normally be used is 0.61m or 24 inch.

By referring Figure 11.5.3 from Geankoplis, 2014, $K_1 = 0.07 \text{ ft/s}$

Allowable vapor velocity, V_{\max}

$$V_{\max} = K \left(\frac{\sigma}{20} \right)^{0.2} \sqrt{\frac{\rho_L - \rho_V}{\rho_V}}$$

$$= 0.0574 \text{ m/s}$$

Multiplying the above by 0.8 for 80% flooding to get V_{actual}

Net area required, A_n

$$A_n = \frac{V}{\frac{\rho_V}{V_{\text{actual}}}}$$

$$= 1.64 \text{ m}^2$$

Column cross sectional area, $A_c = A_n / 0.8 = 2.1 \text{ m}^2$

iv. Diameter of stripper

$$D = \sqrt{\frac{4 \times A_c}{\pi}}$$

$$= 1.62 \text{ m}$$

v. Height of stripper

$$H = (N_a) I_t$$

$$= 2.44 \text{ m}$$

b. Costing

Installation cost for stripper:

$$K_m = \frac{I_{MSK}}{I_{MSD}} \left(7775.3 \times D^{1.066} \times L_R^{0.82} (2.18 + F_M F_P) F_I + 3329.2 (A_C^{0.65}) \right)$$

Annual cost for stripper:

$$K_{mt} = \frac{I_{MSK}}{I_{MSD}} \left(\frac{7775.3}{3} \times D^{1.066} \times L_R^{0.82} (2.18 + F_M F_P) F_I + 3329.2 (A_C^{0.65}) \right)$$

Where,

D = Diameter of stripper

L = Height of the stripper

F_M = Construction factor

F_P = Pressure factor

F_I = Installation cost index in Malaysia

I_{MSK} = Present Marshall and Swift Index

I_{MSD} = Past Marshall and Swift Index

Table 3.23 shows the summary calculation of stripper, ST-101

Table 3.23 Summary calculation of stripper, ST-101

Conversion, X	Diameter, D (m)	Height, H (m)	Annually cost, K _{rt} (RM/year)	Installation cost, K _r (RM/year)
0.1	0.61	1.83	40568	121705
0.2	0.86	3.05	89239	267716
0.3	1.06	3.05	110767	332300
0.4	1.22	3.05	129122	387367
0.5	1.37	3.05	145430	436290
0.6	1.50	2.44	133473	400418
0.7	1.62	2.44	144902	434706
0.8	1.73	2.44	155591	466773

0.9	1.83	2.44	165672	497015
1.0	1.93	1.83	138416	415249

3.5.3 Preliminary Design of Decomposer, DP-101

The mixture of urea, ammonia carbamate and water, ammonia and carbon dioxide at 120°C and 3 bar will enter decomposer. At here, further decomposition of ammonium carbamate will take place and ammonia and carbon dioxide will purge out from the plant through stream 40. Then, the urea solution that consist of urea, water and less amount of carbon dioxide and ammonia will enter evaporator (EV-101) at stream 42 for water removal.

a. Design calculation

The equations used to conduct the design calculations for the decomposer are summarized below.

i. Number of theoretical stages

Stripping factor, S

$$S = \frac{K}{\left(\frac{L}{V}\right)} = 2$$

Where,

K = Equilibrium constant = Vapour mole fraction/ liquid mole fraction

L = Liquid flowrate, kmol/h

V = Vapour flowrate, kmol/h

$$N = \frac{\ln \left(\frac{x_f}{x_b} [(S - 1) + 1] \right)}{\ln S} + 1$$

$$= \frac{\ln \left(\frac{69.37}{83.84} [(2 - 1) + 1] \right)}{\ln 2} + 1 = 4 \text{ stages}$$

Where,

- N = Number of theoretical stages
 x_f = Feed concentration (mole fraction), kmol/m³
 x_b = Effluent concentration (mole fraction), kmol/m³

ii. Number of actual stages

Number of transfer unit in gas, N_G ,

$$N_G = N_L = 0.936\mu_L^{-0.25}$$

Based on Lamm & Jarboe 2021, the liquid viscosity, μ_L is between 0.2 to 1.6 cP.

$$N_G = N_L = 0.936(1.6)^{-0.25} = 0.83$$

Where,

- N_L = Number of transfer unit in liquid
 μ_L = Liquid viscosity, cP

Overall transfer unit for gas phase, N_{OG}

$$\frac{1}{N_{OG}} = \frac{1}{N_G} + \frac{S}{N_L}$$

$$N_{OG} = \frac{1}{\frac{1}{N_G} + \frac{S}{N_L}} = \frac{1}{\frac{1}{0.832} + \frac{2}{0.832}} = 0.244$$

Murphree point efficiency on a tray, η_{point}

$$\eta_{point} = 1 - e^{-N_{OG}}$$

$$\eta_{point} = 1 - e^{-0.2435} = 0.216$$

Murphree tray efficiency, η_{tray}

$$\eta_{tray} = \frac{e^{S \times \eta_{point}} - 1}{S}$$

$$\eta_{tray} = \frac{e^{2 \times 0.2161} - 1}{2} = 0.3$$

Column efficiency, n_{column}

$$n_{column} = \frac{\ln[1 + n_{tray}(S - 1)]}{\ln S}$$

$$= 0.383$$

Number of actual stages, N_a ,

$$N_a = \frac{N_t}{n_{column}}$$

$$= 4.187 \approx 4 \text{ stages}$$

iii. Diameter of column

Calculation formula diameter and height of column:

Based on Towler & Sinnott 2019,

Liquid-vapour flow factor, F_{LV}

$$F_{LV} = \frac{L_w}{V_w} \sqrt{\frac{\rho_v}{\rho_L}}$$

$$F_{LV} = \frac{0.75}{0.67} \sqrt{\frac{35.93}{1247.71}} = 0.191$$

Where,

L_w = Liquid mass flowrate, kg/s

V_w = Liquid mass flowrate, kg/s

ρ_v = Vapour density, kg/m³

ρ_L = Liquid density, kg/m³

Plate spacing, I_t is normally be used is 0.61m

By referring Figure 11.27, $K_1 = 0.013$

Flooding velocity, u_f

$$u_f = K_1 \sqrt{\frac{\rho_L - \rho_V}{\rho_L}}$$

$$= 0.07 \frac{m}{s}$$

Net area required, A_n

$$A_n = \frac{X_b}{u_n}$$

$$= 3.09 m^2$$

Assuming column cross-sectional area, A_c occupies 20% of cross-sectional area=
 $A_n/0.80$

$$A_c = 3.865$$

iv. Diameter of decomposer

$$D = \sqrt{\frac{4 \times A_c}{\pi}}$$

$$= 2.22 m$$

v. Height of decomposer

$$H = (N_a)I_t$$

$$= 2.55 m$$

b. Costing

Installation cost for decomposer:

$$K_m = \frac{I_{MSK}}{I_{MSD}} \left(7775.3 \times D^{1.066} \times L_R^{0.82} (2.18 + F_M F_P) F_I + 3329.2 (A_C^{0.65}) \right)$$

Annual cost for decomposer:

$$K_{mt} = \frac{I_{MSK}}{I_{MSD}} \left(\frac{7775.3}{3} \times D^{1.066} \times L_R^{0.82} (2.18 + F_M F_P) F_I + 3329.2 (A_C^{0.65}) \right)$$

Where,

D = Diameter of the distillation column

L = Height of the distillation column

F_M = Construction factor

F_P = Pressure factor

F_I = Installation cost index in Malaysia

I_{MSK} = Present Marshall and Swift Index

I_{MSD} = Past Marshall and Swift Index

Table 3.24 shows the summary calculation of decomposer, DP-101.

Table 3.24 Summary calculation of decomposer, DP-101

Conversion,X	Diameter, D (m)	Height, H (m)	Installation Cost, K _M (RM/year)	Annual Cost, K _M (RM/year)
0.1	0.70	4.87	104933.57	314800.71
0.2	0.99	2.28	81492.32	244476.96
0.3	1.21	2.13	95666.27	286998.82
0.4	1.40	2.06	108548.88	325646.63
0.5	1.57	2.04	121226.23	363678.68
0.6	1.72	2.05	134330.83	402992.49
0.7	1.86	2.10	148348.35	445045.06
0.8	1.98	2.17	163732.06	491196.17
0.9	2.10	3.54	260261.81	780785.43
1.0	2.22	2.48	205777.95	617333.85

3.5.4 Preliminary Design of Evaporator, EV-101

Evaporator, EV-101 is used to remove the excess water, ammonia and carbon dioxide from urea solution to obtain a more concentrated urea solution.

a. Design calculations

The calculation of minimum vessel diameter shown as below:

$$D_V = \sqrt{\frac{4V_v}{\pi u_s}}$$

Where,

D_V = Minimum vessel diameter, m

V_v = Gas or vapour volumetric flow rate, m^3/s

u_s = u_t if a demister pad is used and 0.15 u_t for separator without demister pad

The calculation of settling velocity of the liquid droplets shown as below:

$$u_t = 0.07 \left[\frac{\rho_L - \rho_V}{\rho_V} \right]^{\frac{1}{2}}$$

Where,

u_t = Settling velocity, m/s

ρ_L = Liquid density, kg/m^3

ρ_V = vapour density, kg/m^3

Hold-up volume, V_s (m^3) = liquid volumetric flowrate (m^3/s) \times time (s)

Liquid depth required, h_v (m) = $\frac{\text{hold-up volume } (\text{m}^3)}{\text{vessel cross-sectional area } (\text{m}^2)}$

Vessel height, h (m) = $h_v + D_V + \frac{D_V}{2} + \text{height of demister pad } (0.4 \text{ m})$

b. Costing

The annual cost of the evaporator, K_{rt} can be calculated based on the equation below:

$$K_{rt} = \left(\frac{l_{MSK}}{l_{MSD}}\right) \frac{7775.3}{3} D^{1.066} L_R^{0.802} (218 + F_M F_P) F_I$$

The installation cost of the evaporator, K_r can be calculated based on the equation below:

$$K_r = \left(\frac{l_{MSK}}{l_{MSD}}\right) 7775.3 D^{1.066} L_R^{0.802} (218 + F_M F_P) F_I$$

Where,

l_{MSK} = Marshall and Swift Index of construction year 2022

l_{MSD} = Past Marshall and Swift Index year 2021

D = Diameter of evaporator

L_R = Length of evaporator

F_M = Construction factor

F_P = Pressure factor

F_I = Installation cost index in Malaysia

Table 3.25 shows the summary calculation of evaporator, EV-101.

Table 3.25 Summary calculation of evaporator, EV-101

Conversion, X	Diameter, D_v (m)	Height, h_v (m)	Annual cost, K_{rt} (RM)	Installation cost, K_r (RM)
0.1	1.58	2.78	157056.70	471170.09
0.2	2.23	3.76	291233.85	873701.54
0.3	2.73	4.51	419874.65	1259623.96
0.4	3.16	5.14	545241.83	1635725.49
0.5	3.53	5.70	668309.31	2004927.94
0.6	3.87	6.21	789616.56	2368849.67
0.7	4.18	6.67	909504.52	2728513.55
0.8	4.46	7.10	1028207.29	3084621.88
0.9	4.73	7.51	1145895.08	3437685.25
1.0	4.99	7.89	1262696.90	3788090.71

3.5.5 Economic Potential Analysis Level 4

The economy potential for level 3, f_{PE3} is given by

$$f_{PE3} = f_{PE2} - K_{rt} - K_{pt}$$

Where,

f_{PE2} = Economy potential for level 2

K_{rt} = Annual cost of reactors

The economy potential for level 4, f_{PE4} is given by

$$f_{PE4} = f_{PE3} - \text{Total cost of separation unit}$$

Where,

f_{PE3} = Economy potential for level 3

Table 3.26 Data for economy potential level 4

Conversion, X	f_{PE3} (RM million/year)	Total cost of separation unit (RM million/year)	f_{PE4} (RM million/year)
0.1	-13.70	1.63	-25.33
0.2	180.09	2.03	168.05
0.3	244.42	2.53	231.89
0.4	276.29	2.98	263.31
0.5	295.22	3.41	281.82
0.6	307.57	3.55	294.02
0.7	316.28	3.94	302.35
0.8	322.51	4.33	308.18
0.9	326.94	5.52	311.42
1.0	329.98	4.83	315.15

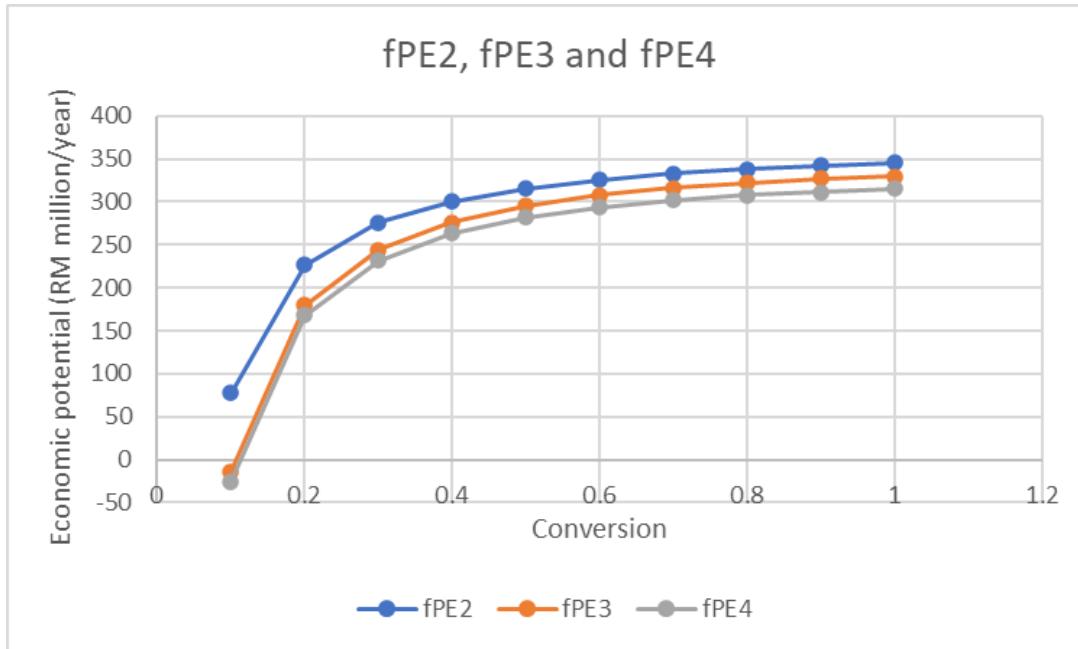


Figure 3.13 Potential economy curve for design level 4

3.6 UREA SYNTHESIS FROM GREEN AMMONIA TECHNOLOGY

The raw material being used is water, nitrogen, and carbon dioxide. Water will split into the hydrogen and oxygen, and oxygen will be sold to other companies while hydrogen will be used in ammonia synthesis along with nitrogen. Then, ammonia will react with carbon dioxide will produce urea and ammonium carbamate as by-product.

3.6.1 Process Description of Whole Process

a. Water Purification

Tap water will transfer to the storage tank (ST-101) at room temperature (28°C and 1 bar) through stream 2. The function of storage tank (ST-101) is to store the water if short of water supply. Then, water will flow into activated carbon filter (AF-101) through stream 4 to remove the odour, 99% impurities, and ensure low number of Total Organic Carbon (TOC). Then, from stream 5 water will enter electrodeionization modules to deionize the water.

b. Electrolysis

Deionize water will enter the storage tank (ST-102) at stream 6. Before entering PEM electrolyser (E-101), deionize water from storage tank (ST-102) will be heated up from 28°C to 80°C. Deionize water will enter the electrolysis through stream 9 with operation conditions 80°C and 15 bar (Saebea 2019). Water splitting will occur at here (E-101) which produce hydrogen gas (H₂) at cathode and oxygen gas (O₂) at anode with 96% conversion. The stoichiometry equation for this reaction is:

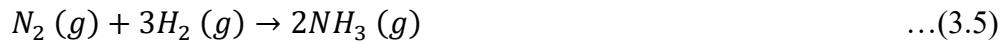


H₂O: Water, N₂: Nitrogen, H₂: Hydrogen

The limiting reactant at here is water. Oxygen and hydrogen gas will enter their own demister (D-101 and D-102) through stream 10 and 11. The operating condition at stream 10 for oxygen is 80°C and 2 bar while at stream 11 for hydrogen gas is 80°C and 10 bar. Function of demister to trap moisture in vapour and recycle it back to storage tank (ST-102). Oxygen will be by-product at stream 14 and hydrogen gas will be used in for ammonia synthesis. Oxygen gas will be cooling down to room temperature (28°C) before going out from plant through stream 15 and it will be sold.

c. Ammonia Synthesis

Hydrogen gas from demister (D-102) will be cool down to room temperature (28°C) and will enter the catalytic packed bed reactor (R-101) through stream 17. Nitrogen gas will enter the reactor (R-101) through stream 18 at room temperature (28°C). The operating condition in R-101 is 28°C and 1 bar. This process will use magnetic induction and assisted by the presence of manganese zinc ferrite, Mn_{0.8}Zn_{0.2}O₄ as nanocatalyst. The advantage of inducing the magnetic field with presence of nanocatalyst on R-101 are the activation energy is 30% lower than process with absence of magnetic field, thus make the reaction faster and low energy used. Besides that, magnetizing the nanocatalyst ease the exchange and pairing of electrons between adsorbed gases and the catalyst's surface (Qureshi et al. 2022). The stoichiometry of the reaction is:



N₂: Nitrogen, H₂: Hydrogen, NH₃: Ammonia

Limiting reactant for this process is nitrogen with conversion of ammonia synthesis is 25% (Qureshi et al. 2022). Excess hydrogen and nitrogen will go out from reactor (R-101) through stream 19 with temperature 28°C and 1 bar along with ammonia. Before entering the phase separator, the gas mixture will undergo compression to achieve 140 bar pressure and it will increase the temperature of gas mixture to 40°C. The gas mixture will enter phase separator (PS-101) at stream 22 and operating conditions of phase separator is 40°C and 140 bar. Function of phase separator (PS-101) is to separate between ammonia in liquid form, and hydrogen and nitrogen in gas form. Hydrogen and nitrogen gas will be recycled back to reactor (R-101) through stream 23 with temperature 40°C and 135 bar. Then, ammonia will flow out from bottom of phase separator (PS-101) at stream 25 with temperature 80°C and 135 bar.

d. Urea Synthesis

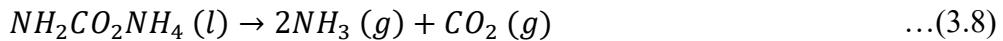
Ammonia from phase separator (PS-101) will be heating up to 180°C before entering plug flow reactor (R-102) at stream 26. Carbon dioxide will enter the plug flow reactor at stream 31 but it will be compress and heating up to 180°C and 140 bar. The operation condition of urea synthesis is 180°C and 140 bar and two reactions will take place in the reactor (R-102). The conversion for both conversion is 77% and the stoichiometry equation for this reaction is:



NH₃: Ammonia, CO₂: Carbon Dioxide, NH₂CO₂NH₄: Ammonium Carbamate, NH₂CONH₂: Urea

Limiting of the process is ammonia and ammonium carbamate for reaction 1 and 2 respectively. During urea synthesis, ammonium carbamate will be produced along with ammonia, and excess ammonia and carbon dioxide. The mixture will go out from reactor (R-102) through stream 33 and go to stripper (S-101) for decomposition of

ammonium carbamate. Ammonium carbamate will be decomposed to ammonia and carbon dioxide at conversion 80%. Carbon dioxide will enter the stripper (S-101) through stream 32 to support required amount of carbon dioxide for the process and act as a stripping agent. The operating condition of stripper is 180°C and 140 bar. The stoichiometry for the reaction is:



NH₂CO₂NH₄: Ammonium Carbamate, NH₃: Ammonia, CO₂: Carbon Dioxide

Ammonia gas and carbon dioxide gas will recycle back to the reactor (R-102) through top outlet of stripper (S-101). Excess ammonium carbamate, urea and water will go out from stripper (S-101) through stream 37 because their phase condition is mixture of vapor and liquid due to operating condition.

e. Purification

After stripping process, the mixture is cooling down to 120°C and 3 bar before entering the decomposer (DP-101) through stream 39. At here, further decomposition of ammonium carbamate will take place and ammonia and carbon dioxide will purge out from the plant. The stoichiometry of reaction is at equation ... (3.8) with 100% conversion. Then, urea will enter evaporator (EV-101) at stream 42 to evaporate some water in the urea with efficiency 97.3%. The inlet stream of evaporator is 110°C and 2 bar. The temperature of the steam in the evaporator (EV-101) is 115°C and 2 bar.

f. Granulation

Urea from the evaporator (EV-101) is cooling down to 100°C and 1.5 bar and enter the granulator (G-101) through stream 45. Hot air will enter the granulator to dry the remaining water in the urea from the spray dryer with hot air temperature is 115°C. Then, the water vapour from evaporator (EV-101) and granulator (G-101) will enter the condenser (CD-101) at stream 47 to be condense to liquid. This is because water vapour needs to change the phase to water liquid before discharge from the plant. The granule

form of urea from granulator (G-101) with temperature 115°C will enter tray conveyer that cooling down the urea to room temperature. Then, urea ready to be packed.

3.6.2 Process Flow Diagram

The process flow diagram is shown at Appendix B.

3.7 MASS BALANCE AND ENERGY BALANCE

A mass balance also known as a material balance is an application of conservation of mass to the analysis of physical system. We can identify mass flows which might have been unknown, or difficult to measure by according for material entering or leaving a system. The exact conservation law used in the analysis of the system depend on the context of the problem at all revolve around mass conservation as a matter that cannot disappeared or be created spontaneously (Arie Gumilar 2009).

3.7.1 Mass Balance

Mass balance of the whole process was calculated using stoichiometry and equation below:

$$\sum x_o N_o - \sum x_i N_i = \sum ar_k \quad \dots(3.9)$$

a. Mass Balance of Storage Tank ST-102

Deionized water from electro deionization, ED-101 through stream 6 and the recycled water from demister (D-101 and D-102) through stream 12 and 13 will enter the storage tank, ST-102. The purpose of ST-102 is to store the water to provide ready supply of deionized water for electrolyser through stream 7.

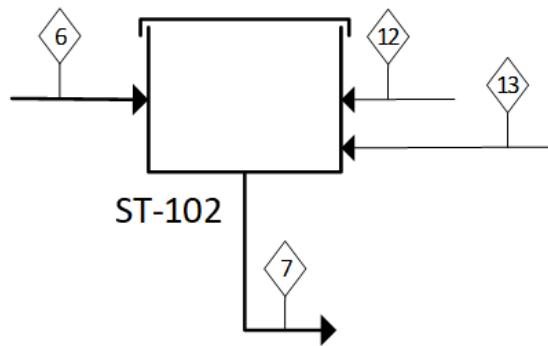


Figure 3.14 Storage Tank, ST-102

Table 3.27 Mass balance on Storage Tank, ST-102

Component	Mass flowrate (kg/hr)			
	Inlet stream 6	Inlet stream 12	Inlet stream 13	Outlet stream 7
Water	3148.17	57.07	47.98	3253.22
Total	3148.17	57.07	47.98	3253.22

Total inlet mass flowrate = Total outlet mass flowrate

$$3253.22 \text{ kg/h} = 3253.33 \text{ kg/h} \text{ (Balanced)}$$

b. Mass balance of Electrolyser E-101

Deionize water will enter the electrolysis through stream 9 with operation conditions 80°C and 15 bar (Saebea 2019). Water splitting will occur at here (E-101) which produce hydrogen gas (H₂) at cathode and oxygen gas (O₂) at anode with 96% conversion.



H₂O: Water, N₂: Nitrogen, H₂: Hydrogen

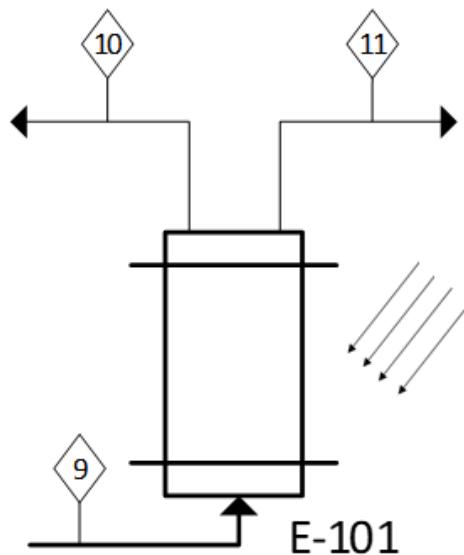


Figure 3.15 Electrolyser, E-101

Table 3.28 Mass balance on Electrolyser, E-101

Component	Mass flowrate (kg/hr)		
	Inlet stream 9	Outlet stream 10	Inlet stream 11
Water	3253.22	57.07	47.98
Hydrogen	0	0	351.83
Oxygen	0	2796.34	0
Total	3253.22	2853.41	399.81

Total inlet mass flowrate = Total outlet mass flowrate

$$3253.22 \text{ kg/h} = 3253.22 \text{ kg/h} \text{ (Balanced)}$$

c. Mass balance of Demister D-101

The oxygen gas from E-101 will enter the D-101 through stream 10 at 80°C and 2 bar. The D-101 will trap the moisture in vapour and recycle back the water to ST-102.

The oxygen at high purity will go out through stream 14 as by product and it will be sold.

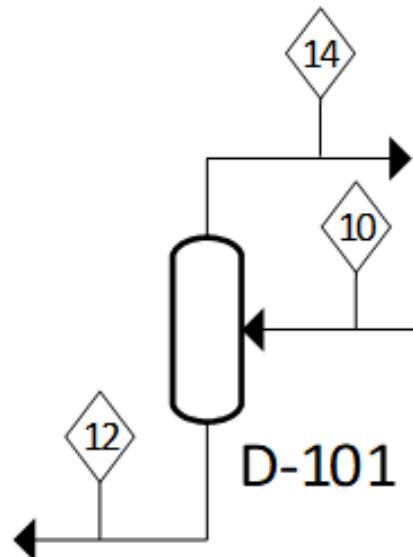


Figure 3.16 Demister, D-101

Table 3.29 Mass balance on Demister, D-101

Component	Mass flowrate (kg/hr)		
	Inlet stream 10	Outlet stream 14	Inlet stream 12
Water	57.07	0	57.07
Oxygen	2796.34	2796.35	0
Total	2853.41	2796.35	57.07

Total inlet mass flowrate = Total outlet mass flowrate

$$2853.41 \text{ kg/h} = 2853.42 \text{ kg/h} \text{ (Balanced)}$$

d. Mass balance of Demister, D-102

The hydrogen gas from E-101 will enter the D-101 through stream 11 at 80°C and 10 bar. The D-101 will trap the moisture in vapour and recycle back the water to ST-102 at stream 12. The product, hydrogen will be used for ammonia synthesis at R-101.

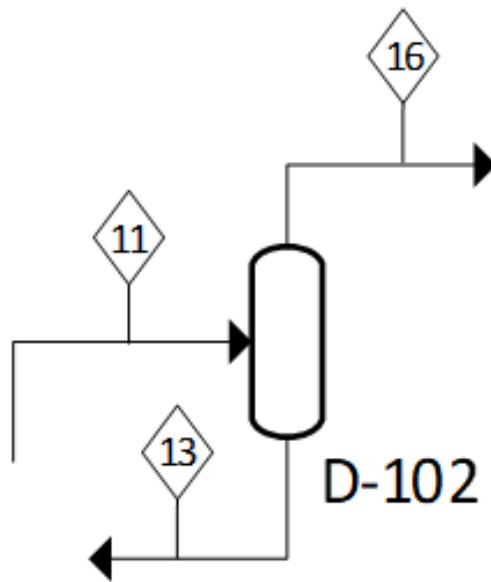


Figure 3.17 Demister, D-102

Table 3.30 Mass balance on Demister, D-102

Component	Mass flowrate (kg/hr)		
	Inlet stream 11	Outlet stream 13	Inlet stream 16
Water	47.98	47.98	0
Hydrogen	351.83	0	351.83
Total	399.81	47.98	351.83

Total inlet mass flowrate = Total outlet mass flowrate

$$399.81 \text{ kg/h} = 399.81 \text{ kg/h} \text{ (Balanced)}$$

e. Mass Balance on Catalytic Packed Bed Reactor R-101

Hydrogen gas from electrolysis will enter the reactor at 28°C and 1 bar. Nitrogen will react with hydrogen with catalyst Mn_{0.8}Zn₂Fe₄ at 28°C and 1 bar. Ammonia and excess hydrogen and nitrogen will go out from reactor to phase separator.



N₂: Nitrogen, H₂: Hydrogen, NH₃: Ammonia

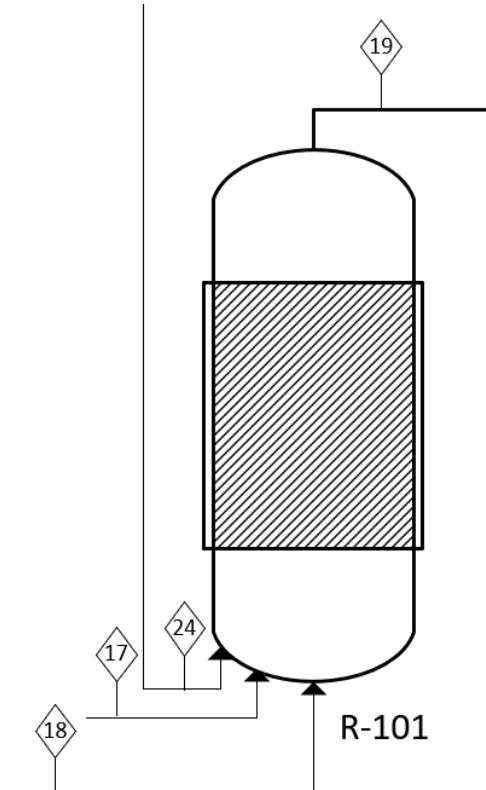


Figure 3.18 Catalytic Packed Bed Reactor, R-101

Table 3.31 Mass balance on Catalytic Packed Bed Reactor, R-101

Component	Mass flowrate (kg/hr)			
	Inlet stream 17	Inlet stream 18	Inlet stream 24	Outlet stream 19
Nitrogen	0	1641.88	1231.96	1231.96
Hydrogen	351.83	0	263.99	263.99
Ammonia	0	0	0	1993.71
Total	351.83	1641.88	1495.95	3489.66

Total inlet mass flowrate = Total outlet mass flowrate

$$3489.66 \text{ kg/h} = 3489.66 \text{ kg/h} \text{ (Balanced)}$$

f. Mass Balance on Phase Separator, PS-101

After cooling the mixture from reactor (R-101), the mixture will separate inside the phase separator between vapour and liquid at 40°C and 140 bar. Hydrogen and nitrogen will go out from the top of phase separator and recycle back to reactor (R-101) while ammonia will from bottom of phase separator.

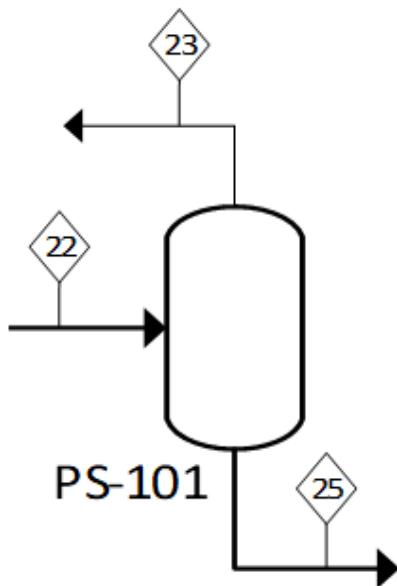


Figure 3.19 Phase Separator, PS-101

Table 3.32 Mass balance on Phase Separator, PS-101

Component	Mass flowrate (kg/hr)		
	Inlet stream 22	Outlet stream 23	Outlet stream 25
Nitrogen	1231.96	1231.96	0
Hydrogen	263.99	263.99	0
Ammonia	1993.71	0	1993.71
Total	3489.66	1495.95	1993.71

Total inlet mass flowrate = Total outlet mass flowrate

$$3489.66 \text{ kg/h} = 3489.66 \text{ kg/h} \text{ (Balanced)}$$

g. Mass Balance on Plug Flow Reactor, R-102

The ammonia gas that has been separated in PS-101 will flow into the plug flow reactor where the primary product will produce. Carbon dioxide gas from stream 31 enter R-102 and it will react with ammonia gas to produce urea, ammonium carbamate, water, unreacted ammonia gas and also unreacted carbon dioxide gas at stream 33. The conversion of this reaction is around 75% - 82% and this Plug Flow Reactor operates at 180°C and 140 bar. The unreacted ammonia and carbon dioxide gas from stripper will recycle back to R-102 to prevent from wastage and maintain the air quality in the environment.



NH₃: Ammonia, CO₂: Carbon Dioxide, NH₂CO₂NH₄: Ammonium

Carbamate, NH₂CONH₂: Urea

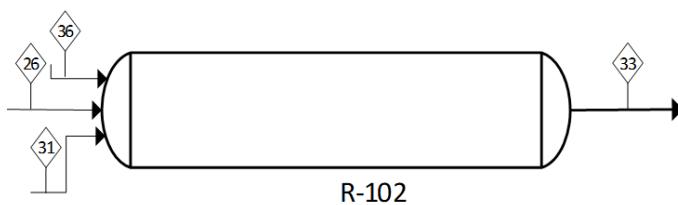


Figure 3.20 Plug Flow Reactor, R-102

Table 3.33 Mass balance on Plug Flow Reactor, R-102

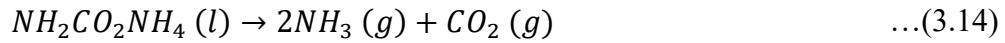
Component	Mass flowrate (kg/hr)			
	Inlet stream 26	Inlet stream 31	Inlet stream 36	Outlet stream 33
Ammonia	1993.71	0	282.36	742
Carbon dioxide	0	2994	864.84	1877
Ammonium carbamate	0	0	0	808.82
Water	0	0	0	624.93
Urea	0	0	0	2083.33
Total	1993.71	2994	1147.2	6135.75

$$\text{Total inlet mass flowrate} = \text{Total outlet mass flowrate}$$

$$6134.91 \text{ kg/h} = 6135.75 \text{ kg/h} \text{ (Balanced)}$$

h. Mass Balance on Stripper, S-101

The solution from R-102 at stream 34 will flow into S-101 to decompose the ammonium carbamate into ammonia and carbon dioxide gas. The stripping agent in this unit is carbon dioxide and this unit operates at 180°C and 140 bar. The conversion of the ammonium carbamate is only 80% where the remaining 20% will fully decompose at the next unit operation, which is decomposer, DP-101. The ammonia and carbon dioxide gas that has been separated will recycle back to R-102 to proceed the reaction to produce molten urea.



NH₂CO₂NH₄: Ammonium Carbamate, NH₃: Ammonia, CO₂: Carbon Dioxide

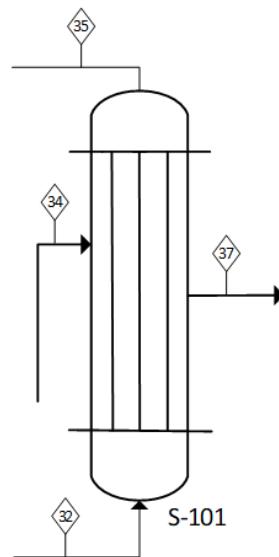


Figure 3.21 Stripper, S-101

Table 3.34 Mass balance on Stripper, S-101

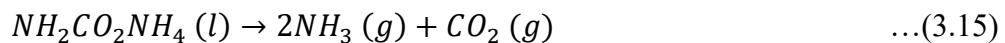
Component	Mass flowrate (kg/hr)			
	Inlet stream 32	Inlet stream 34	Outlet stream 35	Outlet stream 37
Ammonia	0	742	282.36	742
Carbon dioxide	123	1877	864.84	1500
Ammonium carbamate	0	808.82	0	161.61
Water	0	624.93	0	624.93
Urea	0	2083.33	0	2083.33
Total	123	6135.75	1147.2	5111.87

Total inlet mass flowrate = Total outlet mass flowrate

$$6258.75 \text{ kg/h} = 6259.07 \text{ kg/h} \text{ (Balanced)}$$

i. Mass Balance on Decomposer, DP-101

The remaining ammonium carbamate will decompose to carbon dioxide and ammonia at 120°C and 3 bar. 2% of carbon dioxide and ammonia will dissolve in the water and remaining will be purge out.



NH₂CO₂NH₄: Ammonium Carbamate, NH₃: Ammonia, CO₂: Carbon Dioxide

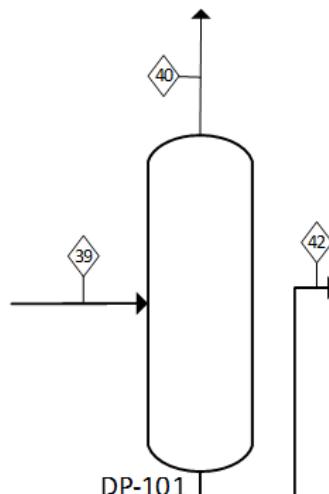


Figure 3.22 Decomposer, DP-101

Table 3.35 Mass balance on Decomposer, DP-101

Component	Mass flowrate (kg/hr)		
	Inlet stream 39	Outlet stream 40	Outlet stream 42
Ammonia	742	741.25	81.25
Carbon dioxide	1500	1511.55	79.56
Ammonium carbamate	161.61		
Water	624.93		624.93
Urea	2083.33		2083.33
Total	5111.87	2242.8	2869.07

Total inlet mass flowrate = Total outlet mass flowrate

$$5111.87 \text{ kg/h} = 5111.87 \text{ kg/h} \text{ (Balanced)}$$

j. Mass Balance on Evaporator EV-101

With efficiency 97.3% (Xing et al. 2020), water will evaporate from the product to achieve desired purity.

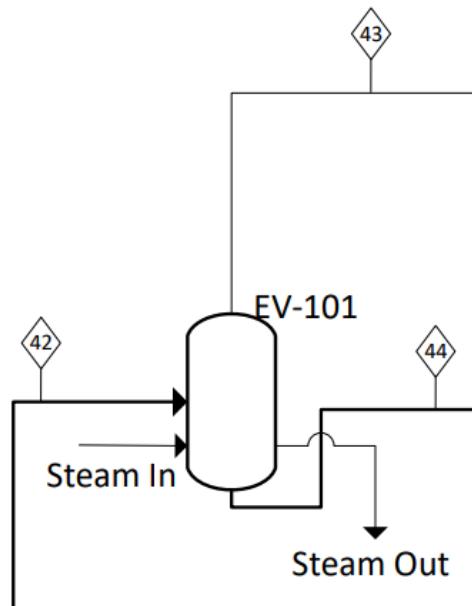


Figure 3.23 Evaporator, EV-101

Table 3.36 Mass balance on Evaporator, EV-101

Component	Mass flowrate (kg/hr)		
	Inlet stream 42	Outlet stream 43	Outlet stream 44
Ammonia	81.25	81.25	
Carbon dioxide	79.56	79.56	
Water	624.93	436.27	188.66
Urea	2083.33		2083.33
Total	2869.07	597.08	2271.99

$$\text{Total inlet mass flowrate} = \text{Total outlet mass flowrate}$$

$$2869.07 \text{ kg/h} = 2869.07 \text{ kg/h} \text{ (Balanced)}$$

k. Mass Balance on Granulator G-101

Urea will change the physical appearance from liquid to granule by using hot air.

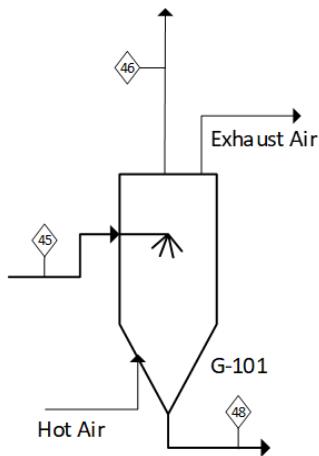


Figure 3.24 Granulator, G-101

Table 3.37 Mass balance on Granulator, G-101

Component	Mass flowrate (kg/hr)		
	Inlet stream 45	Outlet stream 46	Outlet stream 48
Water	188.66	176.31	12.35
Urea	2083.33		2083.33
Total	2271.99	176.31	2095.68

Total inlet mass flowrate = Total outlet mass flowrate

$$2271.99 \text{ kg/h} = 2271.99 \text{ kg/h} \text{ (Balanced)}$$

I. Overall Mass Balance

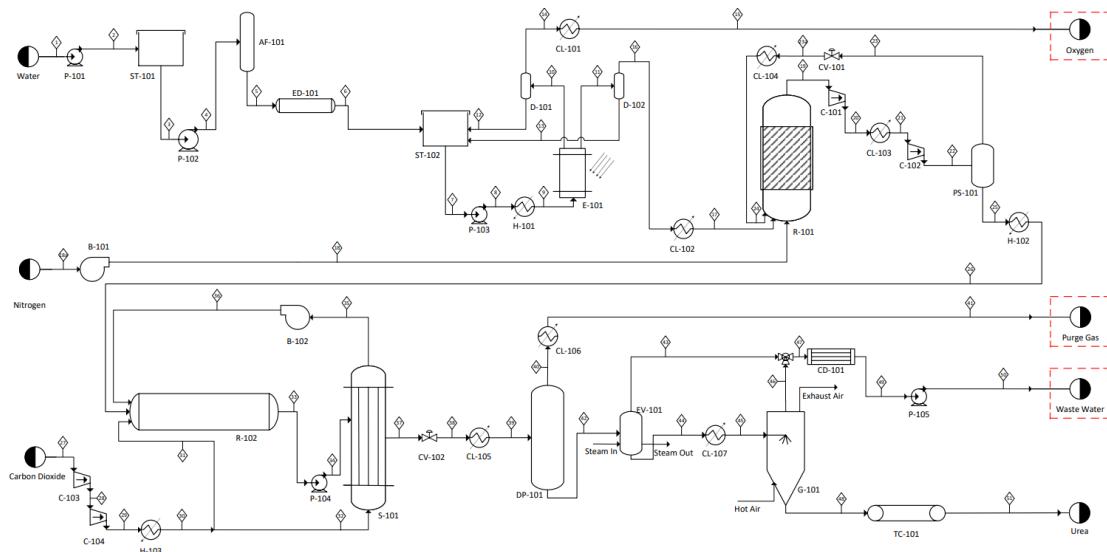


Figure 3.25 Overall process

Table 3.38 Overall mass balance

Component	Mass flowrate (kg/hr)						
	Inlet stream 1	Inlet stream 18	Inlet stream 27	Outlet stream 15	Outlet stream 41	Outlet stream 50	Outlet stream 51
Water	Water	3148.17	0	0	0	0	612.58
Oxygen	Oxygen	0	0	0	2796.35	0	0
Hydrogen	Hydrogen	0	0	0	0	0	0
Nitrogen	Nitrogen	0	1641.88	0	0	0	0
Ammonia	Ammonia	0	0	0	0	731.25	81.25
Ammonium Carbamate	Ammonium Carbamate	0	0	0	0	0	0
Carbon Dioxide	Carbon Dioxide	0	0	3117	0	1511.55	79.56
Urea	Urea	0	0	0	0	0	0
Total	Total	3148.17	1641.88	3117	2796.35	2242.8	773.39

Total inlet mass flowrate = Total outlet mass flowrate

$$7907.05 \text{ kg/h} \approx 7908.39 \text{ kg/h} \text{ (Balanced)}$$

Full calculation at Appendix A.

3.7.2 Energy Balance

Energy balance is the relationship between energy in and energy out. Energy balance is applied to calculate the energy that is required in the system and the energy released or absorbed during the process. If heat is being released to the surrounding, hence it is exothermic reaction and if heat is being absorbed during the reaction, then it is an endothermic reaction. The assumption that we consider during the energy balance calculation are:

- The flow in the unit processing is at steady state
- Potential energy, and kinetic energy is negligible, and work is done by the system because unit processing is in closed system.
- The reference temperature is 25°C

Enthalpy change in each component is important to determine the overall heat change. The molar enthalpy change of a component can be calculated using formula below:

$$\Delta \hat{H} = \int_{T_1}^{T_2} C_p dt$$

Where,

C_p = the molar heat capacity of the component

T_1 = reference temperature

T_2 = inlet or outlet temperature

List of formula used:

$$\text{Inlet enthalpy, } \Delta H_{ix} = \int_{T_1}^{T_2} C_p dt$$

$$\text{Outlet enthalpy, } \Delta H_{ox} = \int_{T_1}^{T_2} C_p dt$$

$$\text{Total input enthalphy, } H_i = \sum N_{ix} \Delta H_{ix}$$

$$\text{Total output enthalphy, } H_o = \sum N_{ox} \Delta H_{ox}$$

Hence, to obtain Q in which it can be defined as energy transferred to or from the system as heat:

$$Q = \sum H_o - \sum H_{in} + r \sum H_{rxn}$$

Table 3.39 below shows the specific heat of formation and specific heat capacity for each component involved in the production of urea.

Table 3.39 Specific heat of formation and specific heat capacity for each component

Component	C_p (kJ/kmol. K)	H_f (kJ/mol)
Ammonia	35.91 (Gas), 80.8 (Liquid)	-46190
Hydrogen gas	28.87	0
Nitrogen gas	29.07	0
Urea	92.79	-0.333
Carbon dioxide	37.17 (Gas), 2.538 (Liquid)	-393520
Water	75.24	-285820

Ammonium carbamate	130.38	-151.88
Oxygen	29.41	0

Energy balance for each unit operations that involved with temperature changes is calculated as below.

a. **Energy balance on Electrolyser, E-101**

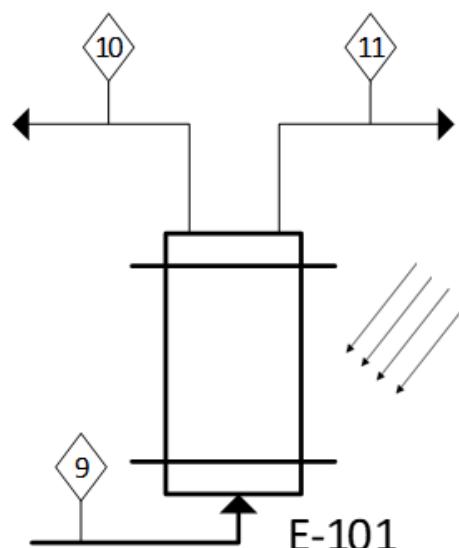


Figure 3.26 Electrolyser, E-101

Table 3.40 Energy balance on Electrolyser, E-101

Components	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mol)		
Inlet stream 9			Outlet stream 10			Outlet stream 11		
Hydrogen	0	0	0	0	174.52	1587.85		
Oxygen	0	0	174.77	1617.55	0	0		
Water	73.92	4138.2	1.30	4138.2	1.09	4138.2		

Enthalpy of reaction:

$$\Delta H_{rxn} = 0 \frac{kJ}{mol}$$

Enthalpy change of inlet stream = $\Delta H_i = 305.895$

Enthalpy change of outlet stream = $N_i \Delta H_{in} = 569.701$

$$\begin{aligned}
 Q &= E_{out} - E_{in} + r \sum \Delta H_{rxn} \\
 &= (\hat{H}_{10N_{10}} + \hat{H}_{11N_{11}}) - (\hat{H}_9N_9) + r\Delta H_{rxn} \\
 &= 263805.346 \text{ kJ/hr} \\
 &= 73.28 \text{ kW (endothermic)}
 \end{aligned}$$

b. Energy balance on Catalytic Packed Bed Reactor, R-101

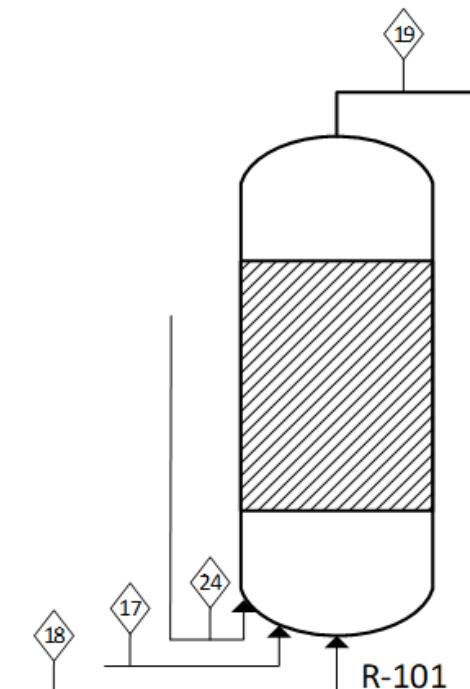
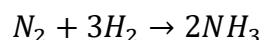


Figure 3.27 Catalytic Packed Bed Reactor, R-101

Table 3.41 Energy balance on Catalytic Packed Bed Reactor, R-101

Components	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mole)	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mole)	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mole)	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mole)
	Inlet stream 17			Inlet stream 18			Inlet stream 24	
Hydrogen	174.52	86.61	0	0	130.95	86.61	130.95	86.61
Nitrogen	0	0	117.22	87.21	87.96	87.21	87.96	87.21
Ammonia	0	0	0	0		0	117.06	111
	Outlet stream 19							

The chemical equation involved is:



Rate of reaction, $r = 14.64 \text{ kmole/h}$

Enthalpy of reaction:

$$\Delta H_{rxn} = -92.380 \frac{\text{kJ}}{\text{mol}}$$

$$\text{Enthalpy change of inlet stream} = \Delta H_i = 443.505 \frac{\text{kJ}}{\text{mol}}$$

$$\text{Enthalpy change of outlet stream} = N_i \Delta H_{in} = 320.062 \frac{\text{kJ}}{\text{mol}}$$

$$\begin{aligned} Q &= E_{out} - E_{in} + r \sum \Delta H_{rxn} \\ &= \hat{H}_{19}N_{19} - (\hat{H}_{17}N_{17} + \hat{H}_{18}N_{18} + \hat{H}_{24}N_{24}) + r\Delta H_{rxn} \\ &= -1364787.47 \text{ kJ/hr} \\ &= -379.11 \text{ kW (exothermic)} \end{aligned}$$

c. Energy balance on Plug Flow Reactor, R-102

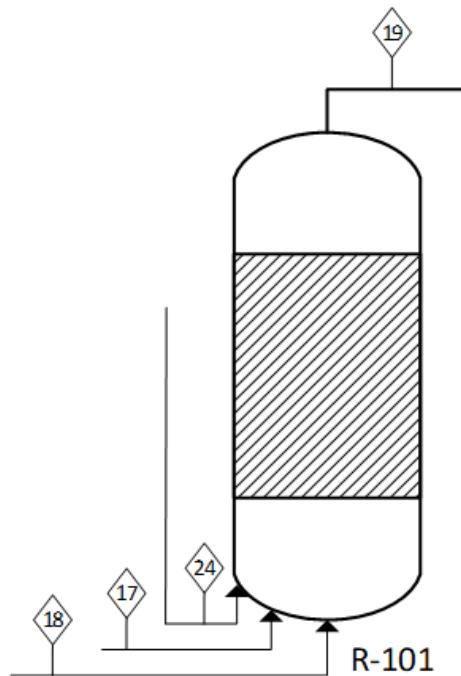
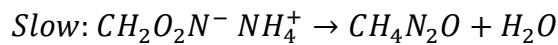
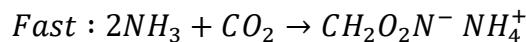


Figure 3.28 Plug Flow Reactor, R-102

Table 3.42 Energy balance on Plug Flow Reactor, R-102

Components	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mol)
Inlet stream 26		Inlet stream 31			Inlet stream 36		Inlet stream 33	
Carbon dioxide	0	0	68.03	5761.35	19.69	5761.35	42.65	5761.35
Carbamate	0		0	0	0	0	10.36	20305
Ammonia	87.96	12524	0	0	16.58	12524	43.57	12524
Water	0	0	0	0	0	0	14.20	11662.2
Urea	0	0	0	0	0	0	34.69	14382.4
								5

The chemical equation involved is:



Rate of reaction, r₁ = 45.04 kmole/h

Rate of reaction, r₂ = 34.68 kmole/h

Enthalpy of reaction:

$$\Delta H_{rxn\ 1} = -21878.10 \frac{\text{kJ}}{\text{mol}}$$

$$\Delta H_{rxn\ 2} = -9907.00 \frac{\text{kJ}}{\text{mol}}$$

$$\text{Enthalpy change of inlet stream} = \Delta H_i = 1310.138 \frac{\text{kJ}}{\text{mol}}$$

$$\text{Enthalpy change of outlet stream} = N_i \Delta H_{in} = 1666.282 \frac{\text{kJ}}{\text{mol}}$$

$$\begin{aligned} Q &= E_{out} - E_{in} + r \sum \Delta H_{rxn} \\ &= (\hat{H}_{33}\text{N}_{33}) - (\hat{H}_{26}\text{N}_{26} + \hat{H}_{31}\text{N}_{31} + \hat{H}_{36}\text{N}_{36}) + r\Delta H_{rxn} \\ &= -12327257.54 \text{ kJ/hr} \\ &= -3424.24 \text{ kW (exothermic)} \end{aligned}$$

d. Energy balance on Stripper, S-101

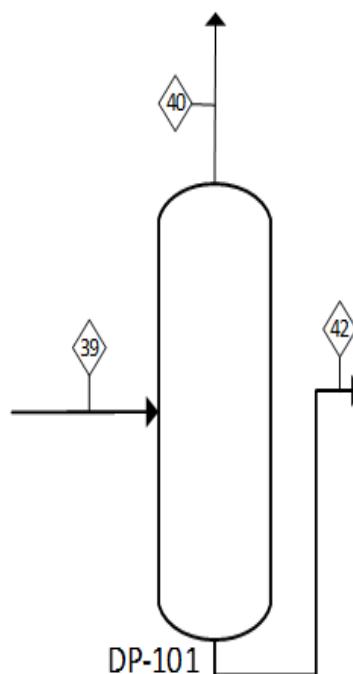
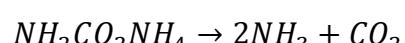


Figure 3.29 Stripper, S-101

Table 3.43 Energy balance on Stripper, S-101

Components	Molar flow rate, N (kmole/hr)	Enthalpy, H_{in} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H_{in} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H_{in} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H_{in} (kJ/mol)
Inlet stream 32		Inlet stream 34			Outlet stream 35		Outlet stream 37	
Carbon dioxide	2.79	5761	42.66	5761.35	19.65	5761.35	34.08	5761.35
Carbamate	0	0	10.36	20305	0	0	2.07	20305
Ammonia	0	0	43.57	5566.05	16.58	5566.05	43.57	5566.05
Water	0	0	34.68	11662.2	0	0	34.68	11662.2
Urea	0	0	34.68	14382.4	0	0	34.68	14382.4
				5				5

The chemical equation involved is:



Rate of reaction, $r = 8.29$ kmole/h

Enthalpy of reaction:

$$\Delta H_{rxn} = -334.04 \frac{kJ}{mol}$$

$$\text{Enthalpy change of inlet stream} = \Delta H_i = 63438.05 \frac{kJ}{mol}$$

$$\text{Enthalpy change of outlet stream} = \Delta H_o = 69004.45 \frac{kJ}{mol}$$

$$\begin{aligned} Q &= E_{out} - E_{in} + r \sum \Delta H_{rxn} \\ &= (\hat{H}_{35}N_{35} + \hat{H}_{37}N_{37}) - (\hat{H}_{32}N_{32} + \hat{H}_{34}N_{34}) + r\Delta H_{rxn} \\ &= -2797530.963 \text{ kJ/hr} \\ &= -777.09 \text{ kW (exothermic)} \end{aligned}$$

e. Energy balance on Decomposer, DP-101

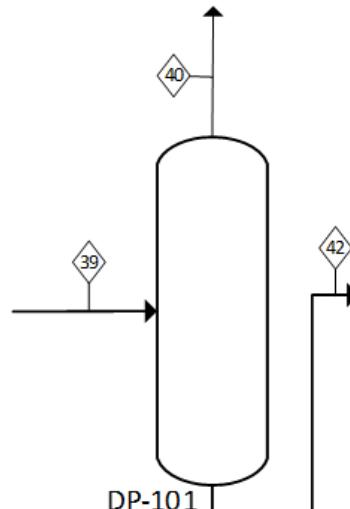
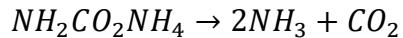


Figure 3.30 Decomposer, DP-101

Table 3.44 Energy balance on Decomposer, DP-101

Components	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mol)	
Inlet stream 39			Outlet stream 40			Outlet stream 42	
Carbon dioxide	34.08	3531.15	36.15	3159.45	0	0	
Carbamate	2.07	12084.28	0	0	0	0	
Ammonia	43.57	3411.45	47.71	3052.35	0	0	
Water	34.68	7147.80	0	0	34.68	6395.40	
Urea	34.68	8815.05	0	0	34.68	7887.15	

The chemical equation involved is:



Rate of reaction, $r = 2.07 \text{ kmole/h}$

Enthalpy of reaction:

$$\Delta H_{rxn} = -334.04 \frac{kJ}{mol}$$

$$\text{Enthalpy change of inlet stream} = \Delta H_i = 34989.73 \frac{kJ}{mol}$$

$$\text{Enthalpy change of outlet stream} = \Delta H_o = 20494.35 \frac{kJ}{mol}$$

$$\begin{aligned} Q &= E_{out} - E_{in} + r \sum \Delta H_{rxn} \\ &= (\hat{H}_{40}N_{40} + \hat{H}_{42}N_{42}) - (\hat{H}_{39}N_{39}) + r\Delta H_{rxn} \\ &= -783886.788 \text{ kJ/hr} \\ &= -217.75 \text{ kW (exothermic)} \end{aligned}$$

f. Energy balance on Evaporator, EV-101

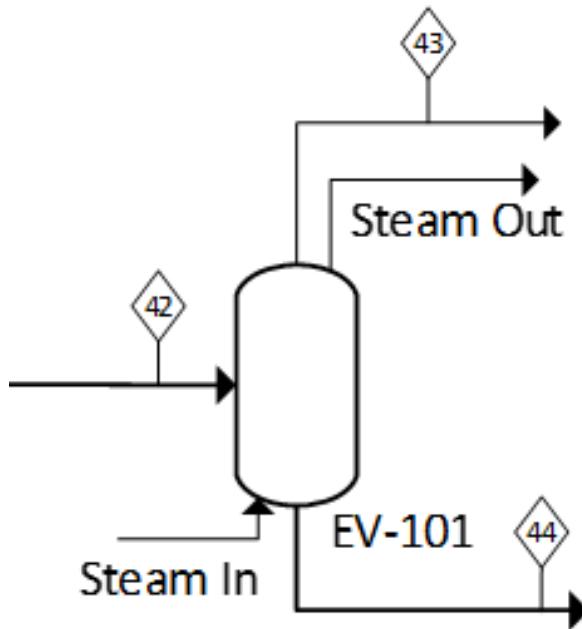


Figure 3.31 Evaporator, EV-101

Table 3.45 Energy balance on Evaporator, EV-101

Components	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H _{in} (kJ/mol)		
Inlet stream 42			Outlet stream 43			Outlet stream 44		
Water	34.68	6395.4	24.21	11573.25	10.47	11286		
Urea	34.68	7887.15	0	0	34.68	13918.5		

Enthalpy change of inlet stream = $\Delta H_i = 14282.55 \frac{kJ}{mol}$

Enthalpy change of outlet stream = $\Delta H_o = 36777.75 \frac{kJ}{mol}$

$$\begin{aligned}
 Q &= E_{out} - E_{in} \\
 &= (\hat{H}_{43}N_{43} + \hat{H}_{44}N_{44}) - (\hat{H}_{42}N_{42}) \\
 &= 385727.546 \text{ kJ/hr} \\
 &= 107.147 \text{ kW (endothermic)}
 \end{aligned}$$

g. Energy balance on Granulator, G-101

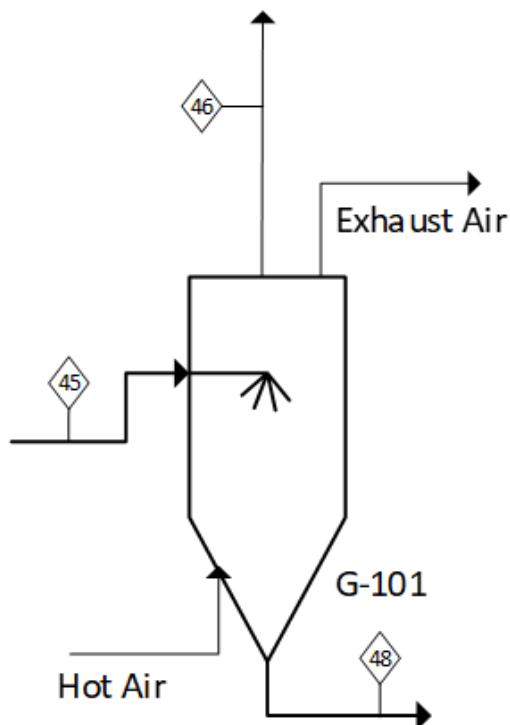


Figure 3.32 Granulator, G-101

Table 3.46 Energy balance on Granulator G-101

Components	Molar flowrate, N (kmole/hr)	Enthalpy, H_{in} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H_{out} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H_{out} (kJ/mol)
Inlet stream 45				Outlet stream 46		Outlet Stream 48
Water	10.47	5643	9.78	6943.95	0.69	6842.34
Urea	34.68	6959.25	0	0	34.68	8351.1

$$\text{Enthalpy change of inlet stream} = \Delta H_i = 12602.25 \frac{\text{kJ}}{\text{mol}}$$

$$\text{Enthalpy change of outlet stream} = \Delta H_o = 22137.39 \frac{\text{kJ}}{\text{mol}}$$

$$\begin{aligned} Q &= E_{out} - E_{in} \\ &= (\hat{H}_{46}N_{46} + \hat{H}_{48}N_{48}) - (\hat{H}_{45}N_{45}) \\ &= 61820.19 \text{ kJ/hr} \\ &= 17.17 \text{ kW (endothermic)} \end{aligned}$$

3.7.3 Energy balance on Condenser, CD-101

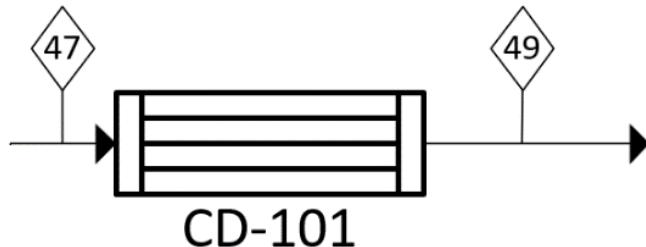


Figure 3.33 Condenser, CD-101

Temperature reference = 298.15 K

Temperature operating = 413.15 K

Table 3.47 Energy balance on Condenser CD-101

Components	Molar flowrate, N (kmole/hr)	Enthalpy, H_{in} (kJ/mol)	Molar flow rate, N (kmole/hr)	Enthalpy, H_{out} (kJ/mol)
Inlet stream 47		Outlet stream 49		
Water	33.99	8872.82	33.99	225.72

$$\text{Enthalpy change of inlet stream} = \Delta H_i = 8872.82 \frac{\text{kJ}}{\text{mol}}$$

$$\text{Enthalpy change of outlet stream} = \Delta H_o = 225.72 \frac{\text{kJ}}{\text{mol}}$$

$$\begin{aligned}
 Q &= E_{out} - E_{in} \\
 &= (\hat{H}_{49}N_{49}) - (\hat{H}_{47}N_{47}) \\
 &= - 293915.097 \text{ kJ/hr} \\
 &= - 81.64 \text{ kW (exothermic)}
 \end{aligned}$$

3.7.4 Comparison of Mass Balance by Manual Calculation and Symmetry® Calculation

Comparisons can be made between the calculations done manually and the results simulated by Symmetry®. From the results, we can notice that the final mass of products that we get from manual calculation is different from Symmetry® simulation. These differences occur because Symmetry® uses more accurate method to solve the equation during simulation at every stream in the process while manual calculations had simplified a lot of calculations in the process. The equation used are:

$$\text{Percentage error (\%)} = \frac{|Simulation - Manual|}{Simulation} \times 100\% \quad \dots(3.16)$$

The following section shows the comparison of the mass balance between manual calculation and Symmetry® calculation. The percentage of error is calculated and recorded down on the table for each unit operations. Figure 3.34 shows the process flow diagram in the Symmetry®.

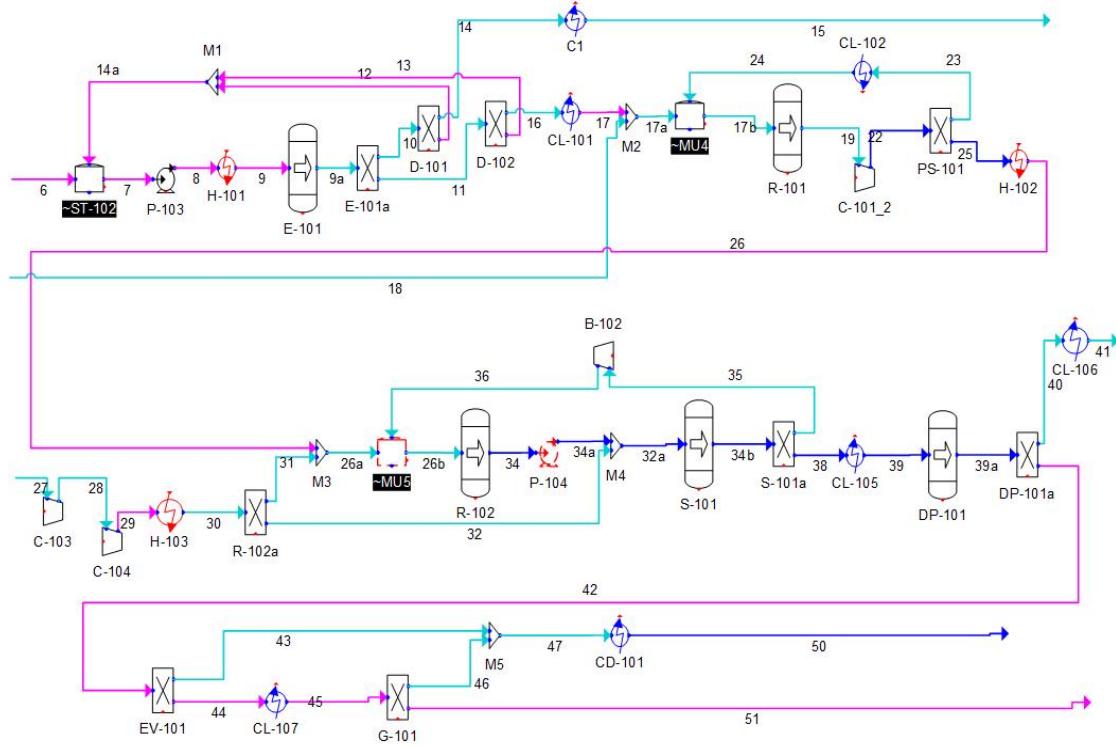


Figure 3.34 Process Flow Diagram in the Symmetry ®

Table 3.48 Mass balance comparison of unit operations by Symmetry®

Unit operation	Outlet stream	Manual calculation (kg/h)	Simulation calculation (kg/h)	Percentage of error (%)
Electrolysis, E-101	Stream 10	2853.41	2853.84	0.02
	Stream 11	399.81	400.38	0.14
Catalytic Packed Bed Reactor, R-101	Stream 19	1993.71	1747.13	14.11
Phase Separator, PS-101	Stream 23	1495.95	1495.95	
	Stream 25	1993.71	1747.13	14.11
Plug Flow Reactor, R-102	Stream 33	6136.08	5746.45	6.78
Stripper, ST-101	Stream 35	1147.2	1005.32	14.11
	Stream 37	511.87	4864.13	5.09
Decomposer, DP-101	Stream 40	2242.80	2017.66	11.16
	Stream 42	2869.07	2846.47	0.79
Evaporator, EV-101	Stream 43	597.08	744.50	19.81
	Stream 44	2271.99	2101.97	8.09
Granulator, G-101	Stream 46	176.31	169.55	3.99
	Stream 48	2095.68	2095.22	0.02

Table 3.48 and Table 3.49 shows overall mass balance and mass balance comparison of unit operations by Symmetry®.

Table 3.49 Overall mass balance comparison by Symmetry®

Stream	Manual calculation (kg/h)	Simulation calculation (kg/h)	Percentage of error (%)
Input stream 01	3148.17	3148.17	0
Input stream 18	1641.88	1641.88	0
Input stream 27	3117	3117	0
Outlet stream 15	2796.35	2796.45	0.01
Outlet stream 41	2242.8	2017.66	11.16
Outlet stream 50	773.39	751.25	2.95
Outlet stream 51	2095.68	2095.22	0.02

Overall percentage of error for this plant is 2.02%. The complete comparisons are shown in the Appendix A.

CHAPTER IV

HEAT INTEGRATION

4.1 INTRODUCTION

When developing a process, the application of the heat integration technique helps to minimise energy usage and maximise heat recovery. One of the most effective and widely utilised methods for heat exchanger networks is pinch technology. Heat should not be transferred across the pinch point that typically exists between the hot stream and cold stream curves. Both the temperature-enthalpy diagram and problem table technique are used to identify the pinch point. When compared to the temperature-enthalpy diagram, the problem table method can produce a more precise value hence it is employed.

4.2 PINCH ANALYSIS

4.2.1 Data Extraction

Based on our process flow diagram, there are 7 utilities involved for the pinch analysis which are 4 hot streams and 3 cold streams. Each stream is heated or cooled from a source temperature, T_s , to a target temperature, T_t . Table 4.1 shows the data extraction for each utility stream.

Table 4.1 Process data for each utility unit

No.	Stream No.	Type	Specific Heat Capacity, CP (kW°C)	Source Temperature, T_s (°C)	Target Temperature, T_t (°C)	T Change, ΔT (°C)	Heat Load, Q (kW)
1	8	Cold	3.779	28	80	52	196.52
2	14	Hot	0.721	70	28	42	30.28
3	16	Hot	1.410	70	28	42	59.23
4	20	Hot	2.632	50	20	30	78.97
5	23	Hot	1.414	40	28	12	16.97

6	25	Cold	1.218	80	180	100	121.84
7	29	Cold	0.847	100	180	80	67.74
8	38	Hot	2.437	180	120	60	146.21
9	40	Hot	0.929	110	28	82	76.16
10	43	Hot	0.507	175	28	147	74.50
11	44	Hot	0.994	175	100	75	74.55

4.2.2 Interval Temperature

In problem table method, the actual stream temperature T_{act} is converted into interval temperature T_{int} using equations (4.1) and (4.2) as shown below.

$$\text{Hot stream: } T_{int} = T_{act} - \frac{1}{2}\Delta T_{min} \quad \dots(4.1)$$

$$\text{Cold stream: } T_{int} = T_{act} + \frac{1}{2}\Delta T_{min} \quad \dots(4.2)$$

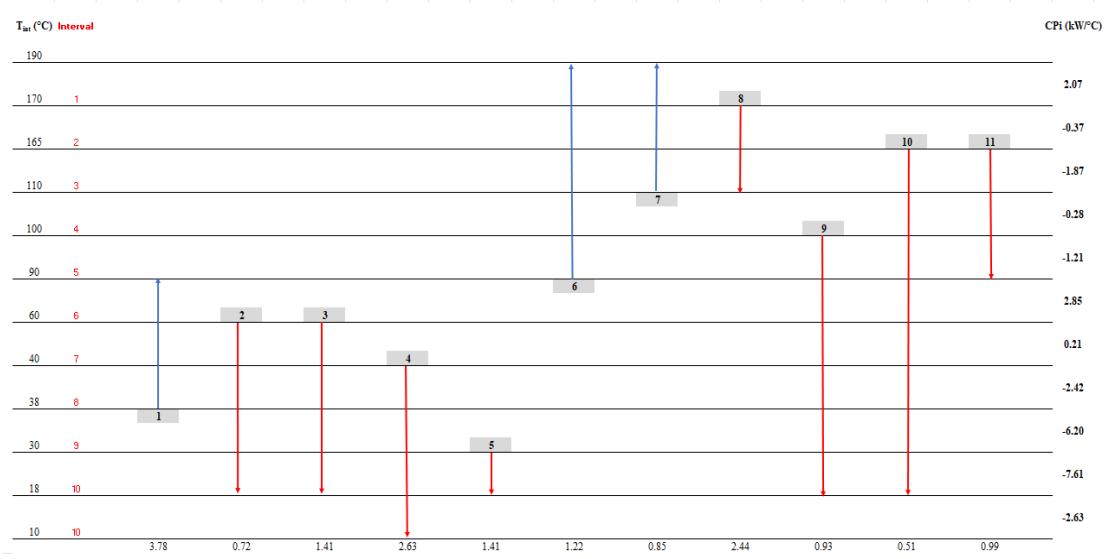
Where $\Delta T_{min} = 20^{\circ}\text{C}$

Table 4.2 Interval temperature for $\Delta T_{min} = 20^{\circ}\text{C}$

No.	Stream No.	Type	Actual Temperature, Ts/Tt ($^{\circ}\text{C}$)	Interval Temperature Change, +/-	Interval Temperature, Ts/Tt ($^{\circ}\text{C}$)
1	8	Cold	28/80	(+)	38/90
2	14	Hot	70/28	(-)	60/18
3	16	Hot	70/28	(-)	60/18
4	20	Hot	50/20	(-)	40/10
5	23	Hot	40/28	(-)	30/18
6	25	Cold	80/180	(+)	90/190
7	29	Cold	100/180	(+)	110/190
8	38	Hot	180/120	(-)	170/110
9	40	Hot	110/28	(-)	100/18
10	43	Hot	175/28	(-)	165/18
11	44	Hot	175/100	(-)	165/90

4.2.3 Heat Relationship

Figure 4.1 below shows the relationship between interval temperature with hot and cold streams.

Figure 4.1 Relationship between T_{int} with hot and cold streams

4.2.4 Heat Balance

Based on the heat relationship in Figure 4.1, heat balance for each utility stream can be determined using the formula as stated below.

$$\Delta H_i = (\Sigma Cp_C - \Sigma Cp_H)_i \Delta T_i \quad \dots(4.3)$$

Table 4.3 Heat balance at each interval temperature

Interval Temperature, T_{int} (°C)	Interval, i	Change in Interval Temperature, ΔT_{int} (°C)	Interval Heat Load, CP_i (kW/°C)	Heat Balance, ΔH_i (kW)	Excess/Deficient Heat
190	-	-	-	-	-
170	1	20	2.07	41.40	Deficient
165	2	5	-0.37	-1.85	Excess
110	3	55	-1.87	-102.85	Excess
100	4	10	-0.28	-2.80	Excess
90	5	10	-1.21	-12.10	Excess
60	6	30	2.85	85.50	Deficient
40	7	20	0.21	4.20	Deficient
38	8	2	-2.42	-4.84	Excess
30	9	8	-6.20	-49.60	Excess
18	10	12	-7.61	-91.32	Excess
10	11	8	-2.63	-21.04	Excess

4.2.5 Heat Cascade

Heat cascade is performed to determine the pinch point and pinch temperature which is the temperature interval where heat is equal to zero. The heat introduced to the top when pinch point is created is the minimum heat required for hot utility process, $Q_{H\min}$. While the heat at the bottom, known as $Q_{C\min}$, is the minimum heat required for cold utility process. Table 4.4 shows the iteration calculation method of heat cascade, while Figure 4.2 shows the visualization of heat cascade.

Table 4.4 Heat cascade iteration calculation method

Interval Temperature, Tint (°C)	Heat Balance, ΔH (kW)	1st iteration, ΔH (kW)	2nd iteration, ΔH (kW)
190	-	0	41.40
170	41.40	-41.40	0.00
165	-1.85	-39.55	1.85
110	-102.85	63.30	104.70
100	-2.80	66.10	107.50
90	-12.10	78.20	119.60
60	85.50	-7.30	34.10
40	4.20	-11.50	29.90
38	-4.84	-6.66	34.74
30	-49.60	42.94	84.34
18	-91.32	134.26	175.66
10	-21.04	155.30	196.70

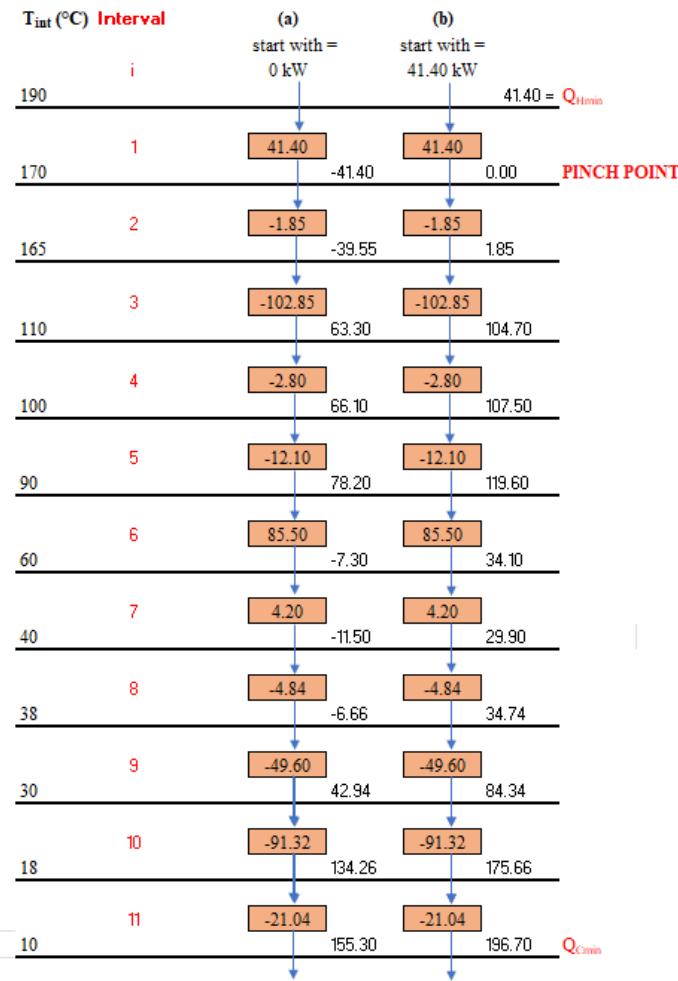


Figure 4.2 Heat cascade

Table 4.5 Summary of heat cascade

Summary of Heat Cascade	Values
Minimum required heat for hot utility process, Q_{Hmin}	41.40 kW
Minimum required heat for cold utility process, Q_{Cmin}	196.70 kW
ΔT_{min}	20°C
Pinch temperature (interval)	170°C
Pinch temperature for hot stream	180°C
Pinch temperature for cold stream	160°C

4.2.6 Heat Exchanger Network (HEN)

The heat exchanger network is represented as a grid, as illustrated in Figure 4.3. The process streams are represented by horizontal lines. Cold streams are drawn from right to left, while hot streams are drawn from left to right.

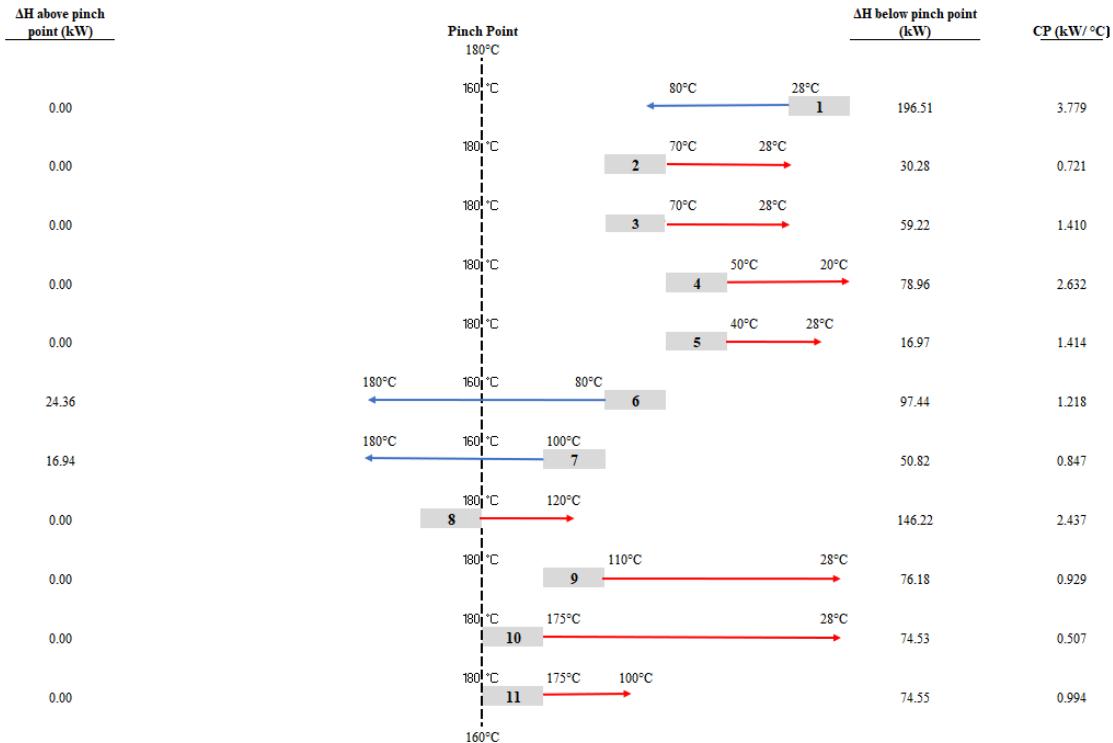


Figure 4.3 Grid heat exchanger network

Network design is only performed when the representation grid is divided into below pinch and above pinch. There are some requirements that need to be adhered to when performing heat exchange. For above pinch, the heat capacity of hot stream must be lower or equal to cold stream ($CP_H \leq CP_C$) with only hot utilities allowed. For below pinch, the heat capacity of hot stream must be greater or equal to cold stream ($CP_H \geq CP_C$) with only cold utilities allowed. Figure 4.4 and Figure 4.5 show the heat exchanger network above pinch point and below pinch point, respectively.

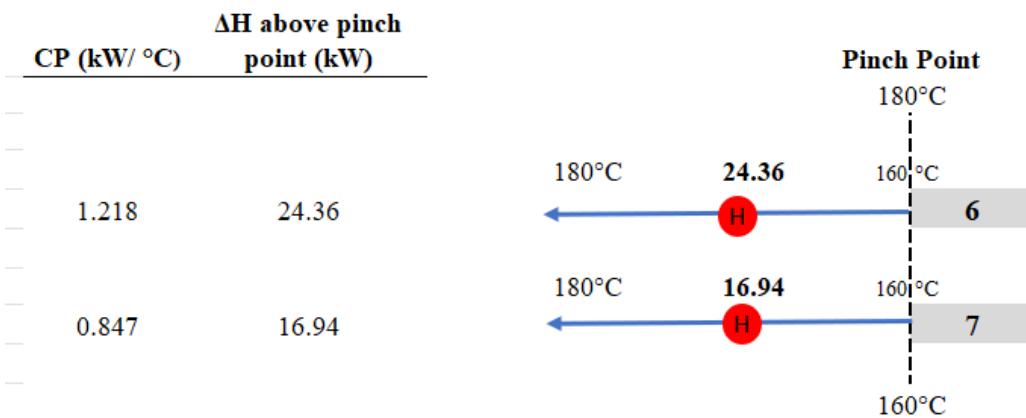


Figure 4.4 Heat exchanger network above pinch point

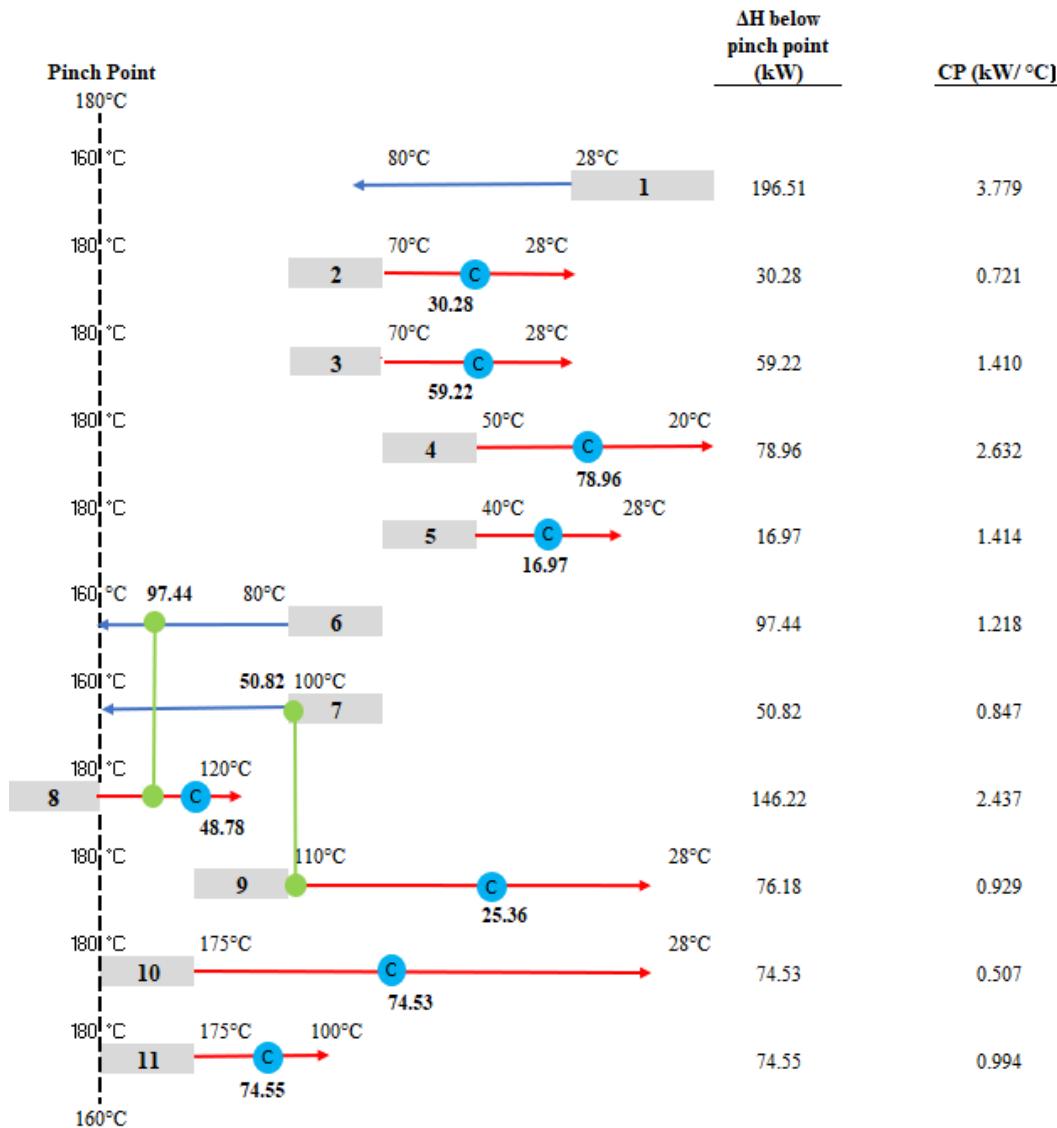


Figure 4.5 Heat exchanger network below pinch point

4.2.7 Total Heat Recovery

The total energy recovery is the energy saved after optimizing the heat exchanger network by performing pinch analysis. The percentage of total energy recovery can be calculated by the formula shown as below:

...(4.4)

Percentage of energy recovery (%)

$$= \frac{\text{Total energy before heat integration} - \text{Total energy after heat integration}}{\text{Total energy before heat integration}} \times 100\%$$

Table 4.6 Total energy recovery

Energy Requirement (kW)		Total Energy Recovery (%)
Before integration	After integration	
942.98	449.95	52.28

Hence, 52.28% of energy is recovered from the application of heat integration in the production plant.

4.3 PROCESS FLOW DIAGRAM AFTER HEAT INTEGRATION

Process flow diagram (PFD) after heat integration for urea synthesis is shown in Appendix B.

CHAPTER V

PROCESS CONTROL AND INSTRUMENTATION

5.1 INTRODUCTION

The piping and instrumentation diagram (P&ID) is drawn to show the instrumentation and piping details for plant equipment, including valve and fittings and their arrangement as well. In this chapter, basic instrumentation and control systems for ethanol production plant are introduced. Safety aspects such as the installation of pressure relief valves are also shown in this chapter. This is important to a chemical plant to ensure smooth and safe operations can be achieved. One of the steps during process design of a chemical plant is the development of control systems. In this step a chemical engineer will look into the degree of freedom, control objectives, manipulated variables, measured outputs as well as the control structure connecting manipulations and measurements.

The processes in any plant must be controlled within a safe limit. Any variation of the process variable from the designed value may affect the product quality. In more serious cases, the deviation may also cause dangerous situation such as equipment failure and explosion. Therefore, all important process parameters must be monitored and controlled within a safety limit. As soon as deviation occurs, it can be detected immediately, and corrective actions can be taken automatically. The remaining of this chapter will focus on control configuration of every unit operation in glycerol carbonate producing plant.

5.1.1 Process Control Analysis

Process control analysis refers to the study of transient behaviour of the process while process control refers to the use of process dynamics to alleviate the effect of

undesirable process behaviour. This chapter's major goal is to choose a unit operation and create a control configuration that will keep the system's process at the desired operating condition (Corinne Bernstein n.d.). Before the piping and instrumentation diagram is prepared, a simple analysis is carried out to determine the requirement of process control and type of controller on each unit operation of the production plant. Each unit operations in urea plant need to be controlled in order to ensure the operations of the plant are safe and within control.

According to Sinnott 2009, the primary objectives when specifying instrumentation and control schemes are:

- i. Safe plant operation
- ii. To ensure the process variables within known safe operating limits.
- iii. To provide interlocks and alarms to prevent dangerous operating procedures.
- iv. To detect any dangerous situations as they develop and to provide alarms and automatic shutdown systems.
- v. To maintain the product quality at specified standards.
- vi. To achieve the designed production rate.
- vii. To maintain the steady operation with minimal operator intervention.
- viii. To operate at efficient low cost and commensurate with the other objectives

The process control design has been applied to the storage tank, ST-101, electrolyser, E-101, demister, cooler, heater, catalytic packed bed reactor, R-101, phase separator, PS-101, plug flow reactor, R-102, stripper, S-101, decomposer, DP-101, evaporator, EV-101, condenser, CD-101, and granulator, G-101. Table 5.1 shows the types of configurations for different types of controllers and its objectives.

Table 5.1 Types of instrumentation and objectives

Parameter	Instrumentation	Objective
Temperature	Temperature transmitter (TT)	Detect the temperature and send signal to TC.
	Temperature control (TC)	Control the opening of valve after receiving signal from TT to achieve the temperature set point of the vessel.
Pressure	Pressure transmitter (PT)	Detect the pressure and send signal to PC.

	Pressure control (PC)	Control the opening of valve after receiving signal from PT to achieve the pressure set point of the vessel.
Level	Level transmitter (LT)	Detect the level and send signal to LC.
	Level control (LC)	Control the opening of valve after receiving signal from LT to achieve the level set point of the vessel.
Flowrate	Flowrate transmitter (FT)	Detect the flowrate and send signal to FC.
	Flowrate control (FC)	Control the opening of valve after receiving signal from FT to achieve the flowrate set point of the vessel.

5.1.2 Type of Instrumentations

Depending on the control objectives, the controller used in the unit operation can be either feed-forward control or feedback control. Function of instrumentation is used to control and monitor in process throughout the plant operation. In the drawing, the instrumentation 87 is always denoted with special symbols and letters and each of them has separate meaning. The controller is very important as the controlled variable is influenced by some disturbance and the variable deviates from the set point. Table 5.2 shows the symbol and letter used in the production for different types of controllers.

Table 5.2 Letter code for instrument symbols

Measurable Variable	First Letter	Indicating only	Recording	Controller			Final Control Element
				Indicating	Blind	Transmitter	
Temperature	T	TI	TRC	TIC	TC	TT	TV
Pressure	P	PI	PRC	PIC	PC	PT	PV
Level	L	LI	LRC	LIC	LC	LT	LV
Flow rate	F	FI	FRC	FIC	AC	FT	FV
Flow ratio	FF	FFI	FFRC	FFIC	FFC	FFT	FFV

5.2 CONTROL CONFIGURATION OF UNIT OPERATION

Every unit operation of the urea production plant is controlled by several objectives. Instrumentations implemented are of basic requirements to ensure a safe and smooth production process. Table 5.3 shows the degree of freedom for each unit.

Table 5.3 Degree of freedom for each unit

Unit operations	Degree of Freedom	Controller
Storage Tank, ST-101	1	▪ Level
Electrolyser, E-101	3	▪ Temperature ▪ Pressure ▪ Flowrate
Catalytic Packed Bed Reactor, R-101	2	▪ Temperature ▪ Flowrate
Phase Separator, PS-101	3	▪ Temperature ▪ Pressure ▪ Flowrate
Cooler, CL-101	1	▪ Temperature
Heater, H-101	1	▪ Temperature
Plug Flow Reactor, R-102	3	▪ Temperature ▪ Pressure ▪ Flowrate
Stripper, S-101	1	▪ Temperature
Decomposer, DP-101	1	▪ Temperature
Evaporator, EV-101	3	▪ Temperature ▪ Level ▪ Flowrate
Condenser, CD-101	1	▪ Temperature
Granulator, G-101	1	▪ Temperature

5.2.1 Control System of Storage Tank, ST-101

a. Total mass balance:

$$\rho \left(\frac{\partial V}{\partial t} \right) = \sum \rho F_i - \sum \rho F_o$$

$$\rho \left(\frac{\partial V}{\partial t} \right) = \rho_2 F_2 - \rho_3 F_3$$

b. Total energy balance:

$$\rho C_p V \left(\frac{\partial V}{\partial t} \right) = \rho C_p F_i (T_i - T_o) - UA(T - T_c) + Q$$

$$\rho C_p V \left(\frac{\partial V}{\partial t} \right) = C_p F_2 T_2 - C_p F_3 T_3 - UA(T - T_c) + Q$$

c. Degree of freedom

Parameter: $\rho, U, A, T = 4$

Number of variables, $N_V: F_2, F_3, T_2, T_3 = 4$

Number of equations, $N_E : 2$

Degree of Freedom, $N_F = N_V - N_E = 4 - 2 = 2$

Output variables: $F_3, T_3, = 2$

Input variable: $F_2, T_2 = 2$

Manipulated variable: F_2

Disturbances, $N_D: T_2 = 1$

Control Degree of freedom = $N_F - N_D = 2 - 1 = 1$

Number of controllers needed = 1

d. Controllers Needed

i. Level controller

e. Control Configuration and Strategy

After all the above aspects have been calculated, the finalized storage tank, ST-101 has determined as shown in Figure 5.1 and the control strategy on storage tank, ST-101 is summarized in Table 5.4.

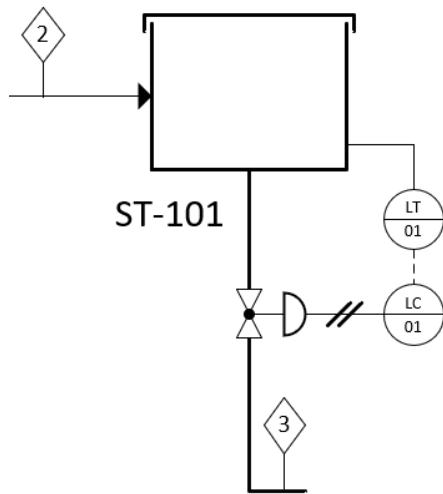


Figure 5.1 Control configurations of storage tank, ST-101

Table 5.4 Control strategy of storage tank, ST-101

Type of controller	Control objectives	Control variable	Manipulated variable	Control Action	Types of valves
Level	To control the level inside the storage tank to avoid overflow	Level of fluid within storage tank	Outlet flow rate of the storage tank in stream 3	Increase valve opening when the level is over the maximum allowable limit	Globe valve that control the flowrate of liquid more precisely

5.2.2 Control System of Storage Tank, ST-102

a. Total mass balance:

$$\rho \left(\frac{\partial V}{\partial t} \right) = \sum \rho F_i - \sum \rho F_o$$

$$\rho \left(\frac{\partial V}{\partial t} \right) = (\rho_6 F_6 + \rho_{12} F_{12} + \rho_{11}) - \rho_7 F_7$$

b. Total energy balance:

$$\rho C_p V \left(\frac{\partial V}{\partial t} \right) = \rho C_p F_i (T_i - T_o) - UA(T - T_c) + Q$$

$$\rho C_p V \left(\frac{\partial V}{\partial t} \right) = C_p F_6 T_6 + C_p F_{11} T_{11} + C_p F_{12} T_{12} - C_p F_7 T_7 - UA(T - T_c) + Q$$

c. Degree of freedom

Parameter: $\rho, U, A, T = 4$

Number of variables, $N_V: F_6, F_{12}, F_{11}, F_7, T_6, T_{11}, T_{12}, T_7 = 8$

Number of equations, $N_E : 2$

Degree of Freedom, $N_F = N_V - N_E = 8 - 2 = 6$

Output variables: $F_7, T_7, = 2$

Input variable: $F_6, F_{12}, F_{11}, T_6, T_{11}, T_{12} = 6$

Manipulated variable: F_6

Disturbances, $N_D: F_{12}, F_{11}, T_6, T_{11}, T_{12} = 6$

Control Degree of freedom = $N_F - N_D = 6 - 5 = 1$

Number of controllers needed = 1

d. Controllers Needed

i. Level controller

e. Control Configuration and Strategy

After all the above aspects have been calculated, the finalized storage tank, ST-102 has determined as shown in Figure 5.2 and the control strategy on storage tank, ST-102 is summarized in Table 5.5.

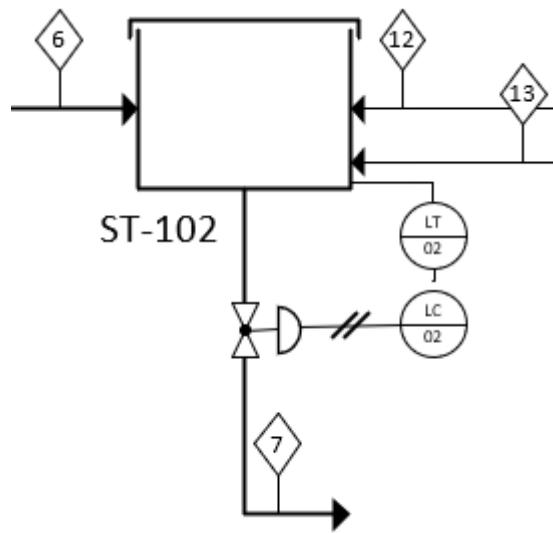


Figure 5.2 Control configurations of storage tank, ST-102

Table 5.5 Control strategy of storage tank, ST-102

Type of controller	Control objectives	Control variable	Manipulated variable	Control Action	Types of valve
Level	To control the level inside the storage tank to avoid overflow	Level of fluid within storage tank	Outlet flow rate of the storage tank in stream 7	Increase valve opening when the level is over the maximum allowable limit	Glove valve that controls the flowrate of liquid more precisely

5.2.3 Control System of Electrolyser, E-101

a. Total Mass Balance

$$\rho \left(\frac{\partial V}{\partial t} \right) = \sum \rho F_i - \sum \rho F_o$$

$$\rho \left(\frac{\partial V}{\partial t} \right) = (\rho_9 F_9) - (\rho_{10} F_{10} + \rho_{11} F_{11})$$

b. Total Energy Balance

$$\rho C_p V \left(\frac{\partial T}{\partial t} \right) = \rho C_p F_i (T_i - T_o) - UA(T - T_c) + Q$$

$$\rho C_p V \left(\frac{\partial T}{\partial t} \right) = C_p F_9 T_9 - C_p F_{10} T_{10} - C_p F_{11} T_{11} - UA(T - T_c) + Q$$

c. Design of Volume

$$V = \pi r^2 h$$

d. Degree of Freedom

Parameter: $\rho, U, A, T = 4$

Number of variables, $N_V: F_9, F_{10}, F_{11}, T_9, T_{10}, T_{11}, Q, V = 8$

Number of equations, $N_E : 3$

Degree of Freedom, $N_F = N_V - N_E = 8 - 3 = 5$

Output variables: $F_{10}, F_{11}, T_{10}, T_{11}, V = 6$

Input variable: $F_9, T_9, Q = 3$

Manipulated variable: Q

Disturbances, $N_D: F_9, T_9 = 2$

Control Degree of freedom = $N_F - N_D = 5 - 2 = 3$

Number of controllers needed = 3

e. Controllers Needed

1. Pressure controller
2. Temperature controller
3. Flowrate controller

f. Control Configuration and Strategy

After all the above aspects have been calculated, the finalized electrolyser, E-101 has determined as shown in Figure 5.3 and the control strategy on electrolyser, E-101 is summarized in Table 5.6.

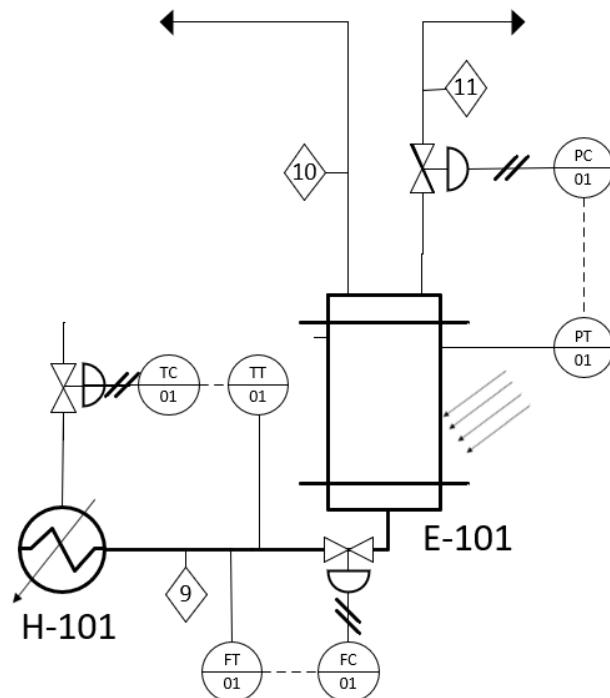


Figure 5.3 Control configurations of electrolyser, E-101

Table 5.6 Control configurations of electrolyser, E-101

Type of controller	Control objectives	Control variable	Manipulated variable	Control Action	Types of valve
Temperature	To control the temperature of the electrolyser, E-101 at a set point of 80°C	Temperature of the electrolyser at set point of 80°C	Inlet flowrate of cooling water in	Temperature transmitter (TT) sense the temperature changes in the electrolyser and send signal to temperature controller (TC). Then, TC will manipulate the valve opening of cooling water inlet. When T<SP, valve opening will decrease while when T>SP, valve opening will increase	Gate valve because low-pressure for water-cooling stream
Pressure	To maintain the pressure of the electrolyser, E-101 at 15atm	Pressure of the electrolyser at set point of 15 atm	Outlet flowrate at stream 11	Pressure transmitter (PT) sense the pressure changes in stripper and send signal to pressure controller (PC). PC will manipulate the valve opening of outlet stream	Butterfly valve because it has good control of gas flow

Flowrate	To maintain the flowrate of inlet streams to a set point of 3253.22 kg/h to avoid overflow	Flowrate of feed of stream 9 (SP= 3253.22 kg/h)	Flowrate inlet of electrolyser	Flowrate transmitter will detect the flowrate at inlet stream and send signal to the controller. If the flowrate is higher than the set point, then the valve opening is decreased. If the flowrate is below set point, the valve opening is increased	Gate valve because of low fluid resistance
----------	--	---	--------------------------------	--	--

5.2.4 Control System of Catalytic Packed Bed Reactor, R-101

a. Total Mass Balance

$$\rho \left(\frac{dV}{dt} \right) = \sum \rho F_i - \sum \rho F_o$$

$$\rho \left(\frac{dV}{dt} \right) = \sum \rho F_{17} + \sum \rho F_{18} + \sum \rho F_{24} - \sum \rho F_{19}$$

b. Energy Balance

$$V\rho C \left(\frac{dT}{dt} \right) = FC(T_i - T)Q$$

$$V\rho C_p \left(\frac{dT}{dt} \right) = F_{17}C_pT_{17} + F_{18}C_pT_{18} + F_{18}C_pT_{24} - F_{19}C_pT_{19} - UA(T - T_c) + Q$$

c. Volume of Cylinder

$$V = \pi r^2 h$$

d. Degree of Freedom

Number of variables : 11 ($F_{17}, F_{18}, F_{24}, F_{19}, T_{17}, T_{18}, T_{24}, T_c, V, Q$)

Number of equations : 3

Number of disturbances : 6 ($F_{17}, F_{18}, F_{24}, T_{17}, T_{18}, T_{24}$)

Degree of freedom : $11 - 3 - 6 = 2$

Number of controllers needed: 2 controllers

e. **Controller Needed**

- i. Flowrate controller (nitrogen)
- ii. Temperature controller

f. **Control Configurations and Strategy**

After all the above aspects have been calculated, the finalized catalytic packed bed reactor, R-101 has determined as shown in Figure 5.4 and the control strategy on catalytic packed bed reactor, R-101 is summarized in Table 5.7.

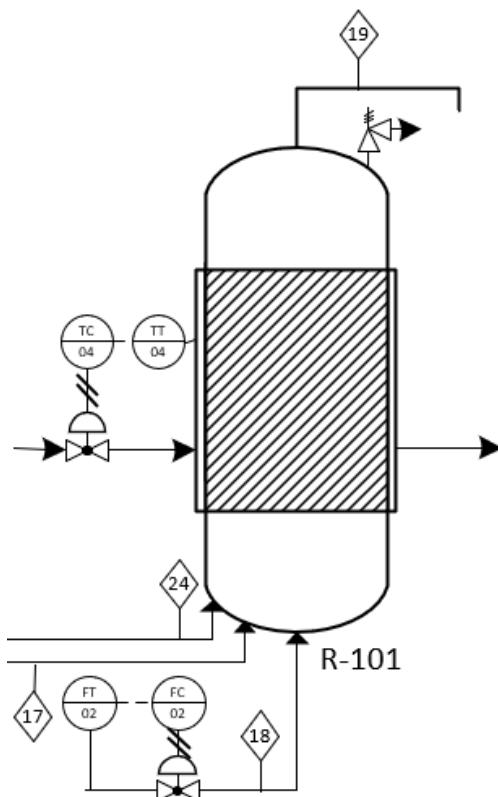


Figure 5.4 Control configurations of catalytic packed bed reactor, R-101

Table 5.7 Control strategy of catalytic packed bed reactor, R-101

Type of controller	Control Objective	Control Variable	Manipulated Variable	Control Action	Type of Valve
Temperature	To maintain	Control the	Inlet flowrate	Temperature	Globe

the temperature of the reactor ($T = 28^\circ\text{C}$)	reactor temperature	of cooling water into the cooling jacket	transmitter sends signal to temperature controller and control the valve of cooling water. Valve opening will be increased as temperature of reactor increases to let more flowrate of cooling water to reduce the temperature of reactor. While valve opening will be decreased when temperature of reactor decreases to let less flowrate of cooling water to maintain the temperature of reactor in set point.	valve - control the flowrate of liquid more precisely
Flowrate	To maintain the flowrate of inlet stream 18 (1641.88 kg/h)	Level of nitrogen in the reactor	Inlet stream 18	Flowrate transmitter sends signal to flowrate controller and control the valve. Valve opening will be decreased as flowrate stream to reactor increases while valve opening will be increased as flowrate of reactor decreases.

5.2.5 Control System of Phase Separator, PS-101

a. Total Mass Balance

$$\rho \left(\frac{dV}{dt} \right) = \sum \rho F_i - \sum \rho F_o$$

$$\rho \left(\frac{dV}{dt} \right) = \sum \rho F_{22} - \sum \rho F_{23} - \sum \rho F_{25}$$

b. Energy Balance

$$V\rho C \left(\frac{dT}{dt} \right) = FC(T_i - T)Q$$

$$V\rho C_p \left(\frac{dT}{dt} \right) = F_{22}C_pT_{22} - F_{23}C_pT_{23} - F_{25}C_pT_{25} - UA(T - T_c) + Q$$

c. Degree of Freedom

Number of variables : 7 ($F_{22}, F_{23}, F_{25}, T_{22}, T_{23}, T_{25}, Q$)

Number of equations : 2

Number of disturbances : 2 (F_{22}, T_{22})

Degree of freedom : $7 - 2 - 2 = 3$

Number of controllers needed: 3 controllers

d. Controller Needed

- i. Flowrate controller
- ii. Temperature controller
- iii. Pressure

e. Control Configuration and Strategy

After all the above aspects have been calculated, the finalized phase separator, PS-101 has determined as shown in Figure 5.5 and the control strategy on phase separator, PS-101 is summarized in Table 5.8.

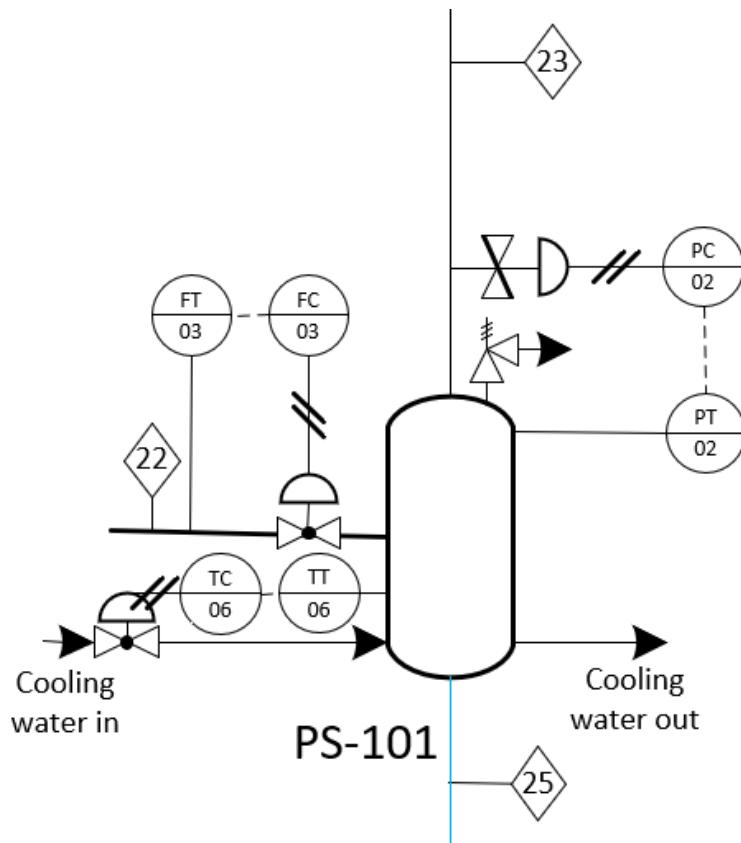


Figure 5.5 Control configurations of phase separator, PS-101

Table 5.8 Control strategy of phase separator, PS-101

Type of controller	Control Objective	Control Variable	Manipulated Variable	Control Action	Type of Valve
Temperature	To maintain the temperature of phase separator	Temperature of phase separator (PS= 40°C)	Flowrate of cooling water into the phase separator	Temperature transmitter sends signal to temperature controller and control the valve of cooling water. Valve opening will be increased as temperature of phase separator increases to let more flowrate of cooling water to reduce the temperature of phase separator.	Globe valve - control the flowrate of liquid more precisely
Flowrate	To maintain the flowrate of inlet streams to avoid overflow	Flowrate of the stream 22 (PS= 3499.66 kg/h)	Flowrate inlet of phase separator	Flowrate transmitter sends signal to flowrate controller and control the valve. Valve opening will be decreased as flowrate stream to phase separator increases while valve	Globe valve - control the flowrate of liquid more precisely

Pressure	To maintain the pressure of phase separator.	Pressure of the phase separator. (PS=140 bar)	Flowrate of stream 23	opening will be increased as flowrate of phase separator decreases.	Pressure transmitter sends signal to pressure controller and control the valve. Valve opening will be increased as pressure of phase separator increases while valve opening will be decreased as pressure of phase separator decreases.	Butterfly valve- good control of gas flow
----------	--	--	-----------------------	---	--	---

5.2.6 Control System of Cooler, CL-101

a. Total Mass Balance

$$\rho \left(\frac{dV}{dt} \right) = \sum \rho F_i - \sum \rho F_o$$

$$\rho \left(\frac{dV}{dt} \right) = \sum \rho F_{16} - \sum \rho F_{17}$$

b. Energy Balance

$$V\rho C \left(\frac{dT}{dt} \right) = FC(T_i - T)Q$$

$$V\rho C_p \left(\frac{dT}{dt} \right) = F_{16}C_pT_{16} - F_{17}C_pT_{17} - UA(T - T_c) + Q$$

c. Volume of Cylinder

$$V = \pi r^2 h$$

d. Degree of Freedom

Number of variables : 5 ($F_{16}, F_{17}, T_{16}, T_{17}, T_c, Q$)

Number of equations : 2

Number of disturbances : 2 (F_{16}, T_{16})

Degree of freedom : $5 - 2 - 2 = 1$

Number of controllers needed: 1 controller

e. Controller Needed

- i. Temperature controller

f. Control Configuration and Strategy

After all the above aspects have been calculated, the finalized cooler, CL-101 has determined as shown in Figure 5.6 and the control strategy on cooler, CL-101 is summarized in Table 5.9.

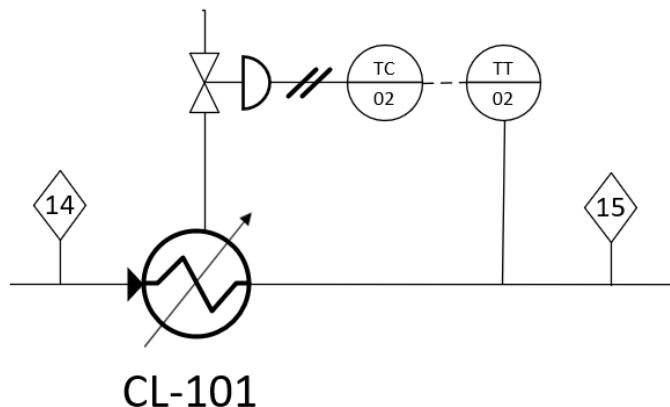


Figure 5.6 Control configurations of cooler, CL-101

Table 5.9 Control strategy of cooler, CL-101

Type of controller	Control Objective	Control Variable	Manipulated Variable	Control Action	Type of Valve
Temperature	To control the outlet temperature of process fluid at desired temperature.	Process fluid outlet temperature	Flow rate of service fluid.	Any deviation in temperature of process fluid at heat exchanger outlet will be detected. Signal will be transmitted to TRC which will send signal to regulate the valve opening at service fluid stream to manipulate the flow rate of service fluid.	Gate valve

5.2.7 Control System of Heater, H-101

a. Total Mass Balance

$$\rho \left(\frac{\partial V}{\partial t} \right) = \sum \rho F_i - \sum \rho F_o$$

$$\rho \left(\frac{\partial V}{\partial t} \right) = \rho_8 F_8 - \rho_9 F_9$$

b. Total Energy Balance:

$$\rho C_p V \left(\frac{\partial V}{\partial t} \right) = \rho C_p F_i (T_i - T_o) - UA(T - T_c) + Q$$

$$\rho C_p V \left(\frac{\partial V}{\partial t} \right) = C_p F_8 T_8 - C_p F_9 T_9 - UA(T - T_c) + Q$$

c. Degree of freedom

Parameter: $\rho, U, A, T = 4$

Number of variables, $N_V: F_9, F_8, T_9, T_8, Q, F_S, T_S = 7$

Number of equations, $N_E : 2$

Degree of Freedom, $N_F = N_V - N_E = 7 - 2 = 5$

Output variables: $F_9, T_9, = 2$

Input variable: $F_8, T_8, Q, F_S, T_S = 3$

Manipulated variable: F_S

Disturbances, $N_D: F_8, T_8, Q, T_S = 4$

Control Degree of freedom = $N_F - N_D = 5 - 4 = 1$

Number of controllers needed = 1

d. Controllers needed

1. Temperature controller

e. Control Configuration and Strategy

After all the above aspects have been calculated, the finalized heater, H-101 has determined as shown in Figure 5.7 and the control strategy on heater, H-101 is summarized in Table 5.10.

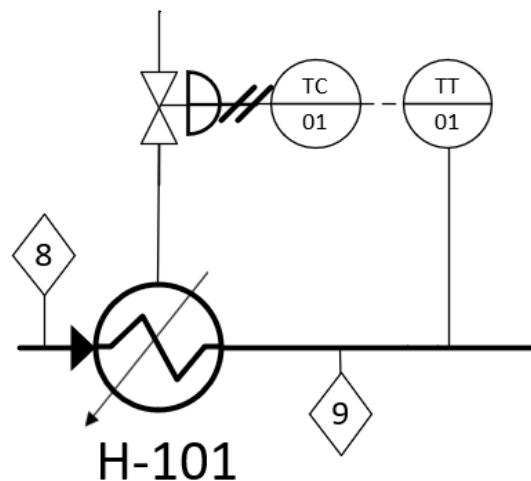


Figure 5.7 Control configurations of heater, H-101

Table 5.10 Control configurations of heater, H-101

Type of controller	Control objectives	Control variable	Manipulated variable	Control Action	Types of valve
Temperature	To control the temperature of heater, H-101 at a set point of 80°C	Temperature of the heater at set point of 80°C	Inlet flowrate of cooling water in	Temperature transmitter (TT) sense the temperature changes in the electrolyser and send signal to temperature controller (TC). Then, TC will manipulate the valve opening of cooling water inlet. When T< SP, valve opening will decrease while when T>SP, valve opening will increase	Gate valve because low-pressure for water-cooling stream

5.2.8 Control System of Plug Flow Reactor, R-102

a. v Total Mass Balance

$$\rho \left(\frac{\partial V}{\partial t} \right) = \sum \rho F_i - \sum \rho F_o$$

$$\rho \left(\frac{\partial V}{\partial t} \right) = \sum \rho F_{26} + \sum \rho F_{31} + \sum \rho F_{36} - \sum \rho F_{33}$$

b. Energy Balance

$$V\rho C_p \left(\frac{dT}{dt} \right) = FC_p(T_i - T_o)Q$$

$$V\rho C_p \left(\frac{dT}{dt} \right) = F_{26}C_pT_{26} + F_{31}C_pT_{31} + F_{36}C_pT_{36} - F_{33}C_pT_{33} - UA(T_i - T_o) + Q$$

c. Volume of horizontal cylinder

$$V = \pi r^2 h$$

d. Ideal gas equation

$$PV = nRT$$

e. Degree of freedom

Since V, ρ, C_p, R are constant

Number of variables : 9 ($F_{26}, F_{31}, F_{36}, F_{33}, T, Q, r, h, P$)

Number of equations : 4

Number of disturbances : 2 (F, T)

Degree of freedom : $9 - 4 - 2 = 3$

Number of controllers needed: 3 controllers

f. Controller needed

- i. Temperature controller
- ii. Pressure controller
- iii. Flowrate controller (maintain conversion)

g. Control Configuration and Strategy

After all the above aspects have been calculated, the finalized plug flow reactor, R-102 has determined as shown in Figure 5.8 and the control strategy on plug flow reactor, R-102 is summarized in Table 5.11.

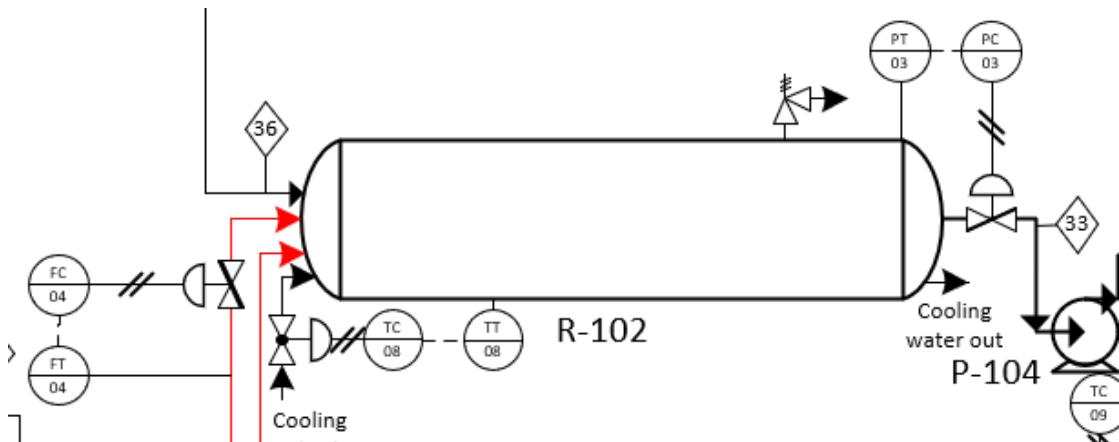


Figure 5.8 Control configurations of plug flow reactor R-102

Table 5.11 Control strategy of plug flow reactor R-102

Type of controller	Control Objective	Control variable	Manipulated variable	Control Action	Type of valve
Temperature	To control the temperature of reactor R-102	Temperature of reactor R-102 (Set point: 180°C)	Inlet flowrate of cooling water	Temperature transmitter sends signal to temperature controller and control the valve of cooling water. Valve opening will be increased as temperature of reactor increases to let more flowrate of cooling water to reduce the temperature of reactor. While valve opening will be decreased when temperature of reactor decreases to let less flowrate of cooling water to maintain the temperature of reactor in set	Globe valve - control the flowrate of liquid more precisely

Pressure	To control the pressure of reactor	Pressure of reactor R-102 (Set point: 140 bar)	Outlet gas flowrate of stream 33	Pressure transmitter sends signal to pressure controller and control the valve. Valve opening will be increased as pressure of reactor increases while valve opening will be decreased as pressure of reactor decreases	Butterfly valve - good control of gas flow
Flowrate	To control the flowrate of inlet stream 26	Flowrate of the stream 26 (Set point: 1994 kg/h)	Inlet flowrate of stream 26	Flowrate transmitter sends signal to flowrate controller and control the valve. Valve opening will be decreased as flowrate stream to reactor increases while valve opening will be increased as flowrate stream to reactor decreases.	Butterfly valve - good control of gas flow

5.2.9 Control System of Stripper, S-101

a. Total Mass Balance

$$\rho \left(\frac{\partial V}{\partial t} \right) = \sum \rho F_i - \sum \rho F_o$$

$$\rho \left(\frac{\partial V}{\partial t} \right) = (\rho_{32} F_{32} + \rho_{34} F_{34}) - (\rho_{35} F_{35} + \rho_{37} F_{37})$$

b. Total Energy Balance

$$\rho C_p V \left(\frac{\partial V}{\partial t} \right) = \rho C_p F_i (T_i - T_o) - UA(T - T_c) + Q$$

$$\rho C_p V \left(\frac{\partial V}{\partial t} \right) = C_p F_{32} T_{32} + C_p F_{34} T_{34} - C_p F_{35} T_{35} - C_p F_{37} T_{37} - UA(T - T_c) + Q$$

c. Design of Volume

$$V = \pi r^2 h_1 + \frac{4}{3} \pi r^3$$

d. Ideal Gas Law

$$PV = nRT$$

e. Degree of freedom

Parameter: $\rho, U, A, T = 4$

Number of variables, $N_V: F_{32}, F_{34}, F_{35}, F_{37}, T_{34}, T_{32}, T_{35}, T_{37}, Q, V = 10$

Number of equations, $N_E : 4$

Degree of Freedom, $N_F = N_V - N_E = 10 - 4 = 6$

Output variables: $F_{35}, F_{37}, T_{35}, T_{37}, V, Q = 6$

Input variable: $F_{32}, F_{34}, T_{34}, T_{32} = 4$

Manipulated variable: F_{34}

Disturbances, $N_D: F_{32}, T_{34}, T_{32} = 3$

Control Degree of freedom = $N_F - N_D = 6 - 3 = 3$

Number of controllers needed = 3

f. Controllers Needed

1. Pressure controller
2. Temperature controller
3. Flowrate controller

g. Control Configuration and Strategy

After all the above aspects have been calculated, the finalized stripper, S-101 has determined as shown in Figure 5.9 and the control strategy on stripper, S-101 is summarized in Table 5.12.

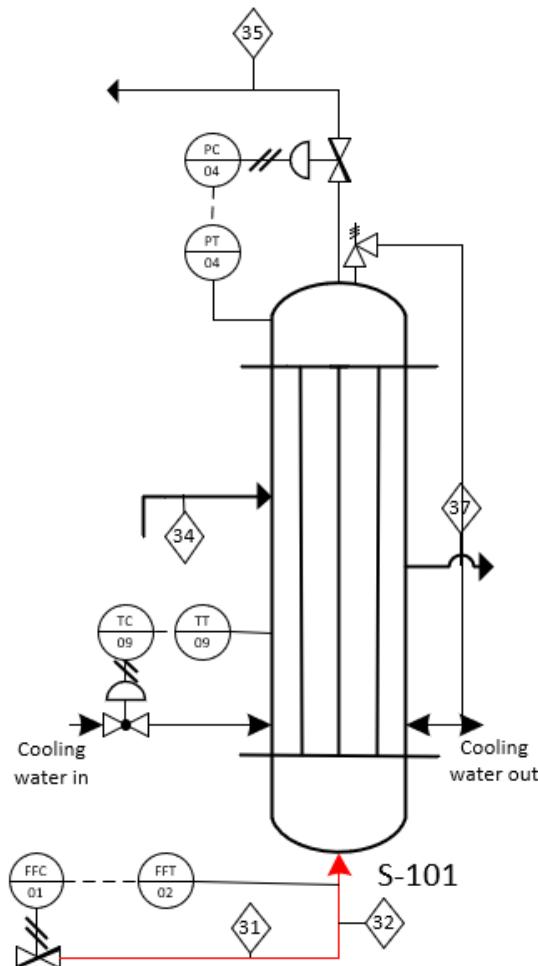


Figure 5.9 Control configurations of stripper, S-101

Table 5.12 Control strategy of stripper, S-101

Type of controller	Control objectives	Control variable	Manipulated variable	Control Action	Types of valves
Temperature	To control the temperature of stripper, S-101 at a set point of 180°C	Temperature of the reactor at set point of 180°C	Inlet flowrate of cooling water	Temperature transmitter (TT) sense the temperature changes in the stripper and send signal to temperature controller (TC). Then, TC will manipulate the valve opening of cooling water inlet. When T<SP, valve opening will decrease while when T>SP, valve opening will increase	Globe valve because it is good at regulating the flowrate of liquid

Pressure	To maintain the pressure of the stripper, S-101 at 140 atm	Pressure of the stripper at set point of 140 atm	Outlet flowrate at stream 35	Pressure transmitter (PT) sense the pressure changes in stripper and send signal to pressure controller (PC). PC will manipulate the valve opening of outlet stream decomposer. When P>SP, valve opening increase. When P<SP valve opening decrease.	Butterfly valve because good shut-off ability, minimum pressure drops, better seal, minimum resistance to flow and suitable for vapor flow
Flowrate	To maintain the flowrate of inlet streams to a set point of 6136.08 kg/h to avoid overflow	Flowrate of feed of stream 34 (SP= 6136.08 kg/h)	Flowrate inlet of stripper	Flowrate transmitter will detect the flowrate at inlet stream and send signal to the controller. If the flowrate is higher than the set point, then the valve opening is decreased. If the flowrate is below set point, the valve opening is increased	Butterfly valve because it has good control of gas flow

5.2.10 Control System of Decomposer, DP-101

a. Total mass balance

$$\rho \left(\frac{\partial V}{\partial t} \right) = \sum \rho F_i - \sum \rho F_o$$

$$\rho \left(\frac{\partial V}{\partial t} \right) = \sum \rho F_{40} - \sum \rho F_{41} - \sum \rho F_{44}$$

b. Energy Balance

$$V\rho C_p \left(\frac{dT}{dt} \right) = FC_p(T_i - T_o)Q$$

$$V\rho C_p \left(\frac{dT}{dt} \right) = F_{40}C_pT_{40} - F_{41}C_pT_{41} - F_{44}C_pT_{44} - UA(T_i - T_o) + Q$$

c. Volume of cylinder

$$V = \pi r^2 h$$

d. Ideal gas equation

$$PV = nRT$$

e. Degree of freedom

Since V, ρ , C_p , R are constant

Number of variables : 7 ($F_{40}, F_{41}, F_{44}, T_i, T_o, Q, P$)

Number of equations : 4

Number of disturbances : 2 (F, T)

Degree of freedom : $7-4-2 = 1$

Number of controllers needed: 1 controller

f. Controller needed

i. Temperature controller

g. Control Configuration and Strategy

After all the above aspects have been calculated, the finalized decomposer, DP-101 has determined as shown in Figure 5.10 and the control strategy on decomposer, DP-101 is summarized in Table 5.13.

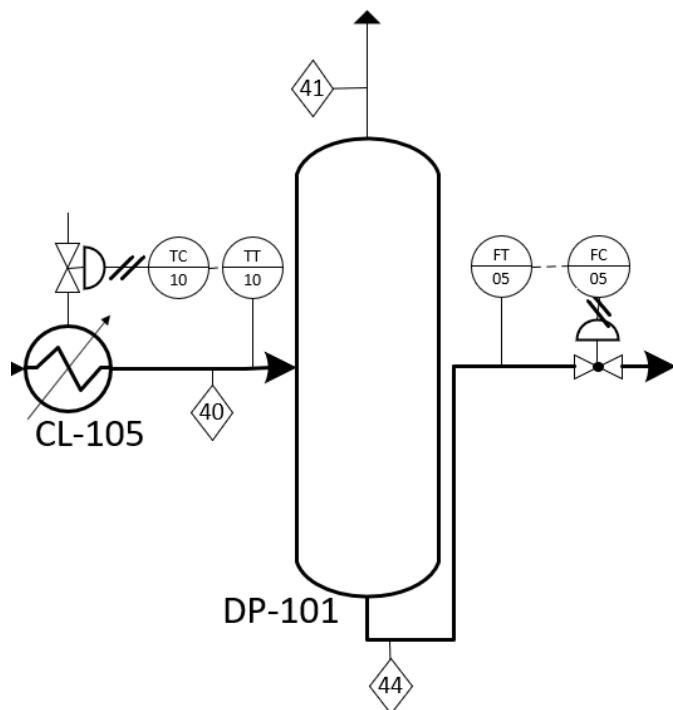


Figure 5.10 Control configuration of decomposer DP-101

Table 5.13 Control strategy of decomposer DP-101

Type of controller	Control Objective	Control variable	Manipulated variable	Control Action	Type of valve
Temperature	To control the operating temperature of decomposer	Temperature of decomposer DP-101 (Set point: 120°C)	Inlet flowrate of cooling water	Temperature transmitter sends signal to temperature controller and control the valve of cooling water. Valve opening will be increased as temperature of reactor increases to let more flowrate of cooling water to reduce the temperature of reactor. While valve opening will be decreased when temperature of reactor decreases to let less flowrate of cooling water to maintain the temperature of reactor in set	Globe valve - control the flowrate of liquid more precisely

point.

5.2.11 Control System of Evaporator, EV-101

a. Total Mass Balance

$$\rho \left(\frac{dV}{dt} \right) = \sum \rho F_i - \sum \rho F_o$$

$$\rho \left(\frac{dV}{dt} \right) = \sum \rho F_{42} + \sum \rho F_{43} - \sum \rho F_{44}$$

b. Energy Balance

$$V\rho C \left(\frac{dT}{dt} \right) = FC(T_i - T)Q$$

$$V\rho C_p \left(\frac{dT}{dt} \right) = F_{42}C_pT_{42} - F_{43}C_pT_{43} - F_{44}C_pT_{44} - UA(T - T_c) + Q$$

c. Component Balance

- i. Total component balance A: $V\left(\frac{dCA}{dt}\right) = F_{42}(C_{A2} - C_{A1})$
- ii. Total component balance A: $V\left(\frac{dCB}{dt}\right) = F_{42}(C_{B2} - C_{B1})$

d. Degree of Freedom

Number of variables : 10 ($F_{42}, F_{43}, F_{44}, T_{42}, T_{43}, T_{44}, Q, C_A, C_B, C_C$)

Number of equations : 4

Number of disturbances : 3 (F_{42}, T_{42}, C_A)

Degree of freedom : $10 - 4 - 3 = 3$

Number of controllers needed: 3 controllers

e. Controller Needed

- i. Flowrate controller
- ii. Level controller
- iii. Temperature controller

f. Control Configuration and Strategy

After all the above aspects have been calculated, the finalized evaporator, EV-101 has determined as shown in Figure 5.11 and the control strategy on evaporator, EV-101 is summarized in Table 5.14.

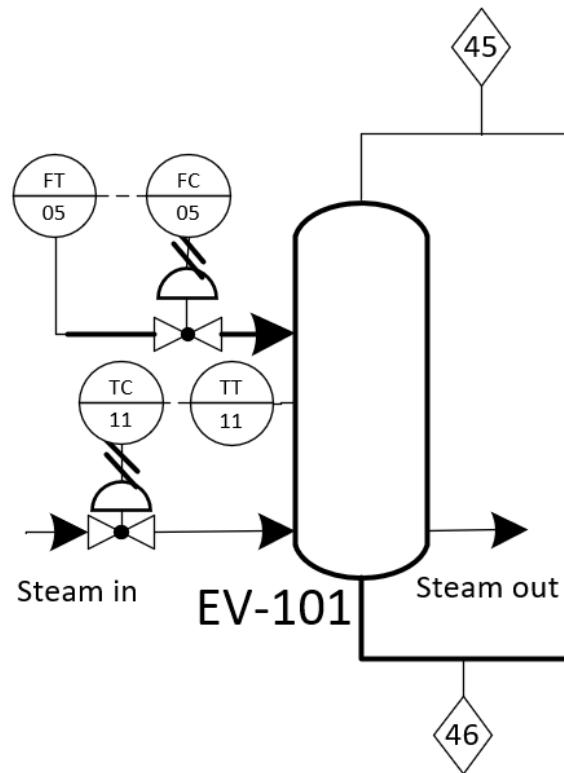


Figure 5.11 Control configurations of evaporator, EV-101

Table 5.14 Control strategy of evaporator, EV-101

Type of controller	Control Objective	Control Variable	Manipulated Variable	Control Action	Type of Valve
Temperature	To ensure temperature do not exceed urea boiling point.	Temperature of phase separator ($T = 110^{\circ}\text{C}$)	Flowrate of cooling water into the evaporator	Temperature transmitter sends signal to temperature controller and control the valve of cooling water. Valve opening will be increased as temperature of phase separator increases to let more flowrate of cooling water to reduce the temperature of evaporator.	Globe valve - control the flowrate of liquid more precisely

Flowrate	To maintain the flowrate of inlet streams to avoid overflow	Flowrate of the stream 42 (E= 2083.33 kg/h)	Flowrate inlet of mixture	Flowrate transmitter sends signal to flowrate controller and control the valve. Valve opening will be decreased as flowrate stream to evaporator increases while valve opening will be increased as flowrate of evaporator decreases.	Globe valve - control the flowrate of liquid more precisely
Level	To avoid volume of component in evaporator exist volume of evaporator	Volume of reactor	Outlet flow rate in stream 44	Level transmitters give signal to controller when volume changes. The controller open or close valve at the bottom stream	Globe valve - control the flowrate of liquid more precisely

5.2.12 Control System of Granulator, G-101

a. Total mass balance

$$\rho \left(\frac{\partial V}{\partial t} \right) = \sum \rho F_i - \sum \rho F_o$$

$$\rho \left(\frac{\partial V}{\partial t} \right) = \sum \rho F_{47} - \sum \rho F_{48} - \sum \rho F_{50}$$

b. Energy Balance

$$V\rho C_p \left(\frac{dT}{dt} \right) = FC_p(T_i - T_o)Q$$

$$V\rho C_p \left(\frac{dT}{dt} \right) = F_{47}C_pT_{47} - F_{48}C_pT_{48} - F_{50}C_pT_{50} - UA(T_i - T_o) + Q$$

c. Volume of cylinder

$$V = \pi r^2 h$$

d. Degree of freedom

Since V, ρ, C_p, R are constant

Number of variables : 6 ($F_{47}, F_{48}, F_{50}, T_i, T_o, Q$)

Number of equations : 3
 Number of disturbances : 2 (F, T)
 Degree of freedom : $6 - 3 - 2 = 1$
 Number of controllers needed: 1 controller

e. **Controller needed**

- i. Temperature controller

f. **Control Configuration and Strategy**

After all the above aspects have been calculated, the finalized granulator, G-101 has determined as shown in Figure 5.12 and the control strategy on granulator, G-101 is summarized in Table 5.15.

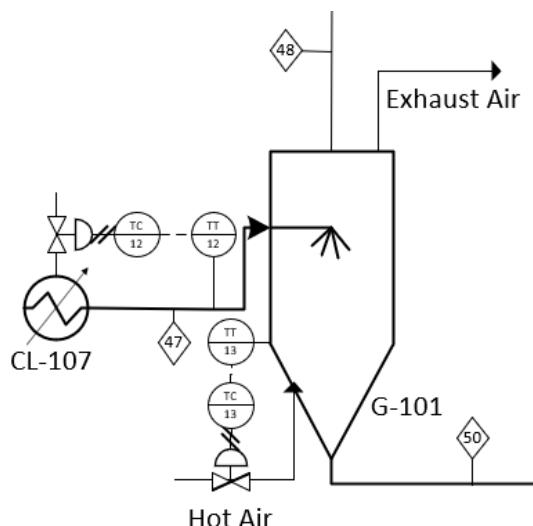


Figure 5.12 Control configuration of granulator G-101

Table 5.15 Control strategy of granulator G-101

Type of controller	Control Objective	Control variable	Manipulated variable	Control Action	Type of valve
Temperature	To control the operating temperature of granulator	Temperature of granulator G-101 (Set point: 115°C)	Inlet flowrate of hot air	The temperature of hot air in granulator is detected. A signal is sent to the temperature controller. The measured temperature is then compared to the set point. If there is any different from the set	Butterfly valve - Good control of gas flow

point, a signal will be sent to the final element which is control valve and the valve opening is regulated

5.2.13 Control System of Condenser, C-101

a. Total mass balance

$$\rho \left(\frac{\partial V}{\partial t} \right) = \sum \rho F_i - \sum \rho F_o$$

$$\rho \left(\frac{\partial V}{\partial t} \right) = \sum \rho F_{49} - \sum \rho F_{51}$$

b. Energy Balance

$$V\rho C_p \left(\frac{dT}{dt} \right) = FC_p(T_i - T_o)Q$$

$$V\rho C_p \left(\frac{dT}{dt} \right) = F_{49}C_pT_{49} - F_{51}C_pT_{51} - UA(T_i - T_o) + Q$$

c. Degree of freedom

Since V, ρ, C_p , are constant

Number of variables : 5 ($F_{49}, F_{51}, T_i, T_o, Q$)

Number of equations : 2

Number of disturbances : 2 (F, T)

Degree of freedom : $5-2-2 = 1$

Number of controllers needed: 1 controller

d. Controller needed

i. Temperature controller

e. Control Configuration and Strategy

After all the above aspects have been calculated, the finalized condenser, CD-101 has determined as shown in Figure 5.13 and the control strategy on condenser, CD-101 is summarized in Table 5.16.

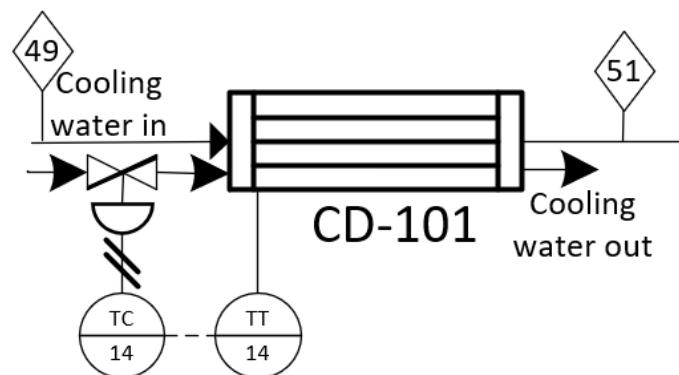


Figure 5.13 Control configuration of condenser CD-101

Table 5.16 Control strategy of condenser CD-101

Type of controller	Control Objective	Control variable	Manipulated variable	Control Action	Type of valve
Temperature	To control the operating temperature of condenser	Temperature of condenser CD-101 (Set point: 140°C)	Inlet flowrate of cooling water	Temperature transmitter sends signal to temperature controller and control the valve of cooling water. Valve opening will be increased as temperature of reactor increases to let more flowrate of cooling water to reduce the temperature of reactor. While valve opening will be decreased when temperature of reactor decreases to let less flowrate of cooling water to maintain the temperature of reactor in set	Butterfly valve - Good control of gas flow

point.

5.3 PRESSURE RELIEF SYSTEM

A pressure relief system is the system that is used to control the pressure from exceeding the limit that is set. It is basically a safety precaution system that is practiced in the industry to protect the vessels. The type of relief valve is summarised in Table 5.17.

Table 5.17 Types of relief valves

Location	Type of Valve	Phase	Application	Flow Destination
Catalytic Packed Bed Reactor, R-101	Spring loaded pressure valve	Vapour	To avoid overpressure inside the R-101	Flow to vent
Phase Separator, PS-101	Spring loaded pressure valve	Vapour	To avoid overpressure inside the PS-101	Flow to vent
Plug Flow Reactor, R-102	Spring loaded pressure valve	Vapour	To avoid overpressure inside the R-102	Flow to vent
Stripper, S-101	Spring loaded pressure valve	Vapour	To avoid overpressure inside the S-101	Flow to vent

5.4 PIPING SYSTEM DESIGN

Piping system in a plant or facility is responsible for transporting fluids or gases from one location to another. It is made up of various components such as pipes, fittings, flanges and pipe support. In the design of a piping system, several factors must be considered to ensure efficient and safe transportation of fluids or gases throughout the plant. This includes the use of appropriate materials, such as carbon steel or stainless steel and determining the appropriate pipe diameter for each stream in the plant process based on market standards and calculated optimum diameter. In this specific plant design project, stainless steel Schedule 40 is chosen due to its high resistance to corrosion and ease of fabrication. Furthermore, stainless steel pipes are able to withstand high pressures and temperatures, making them suitable for use in a wide range of industrial applications. They are also easy to clean and maintain, which is important for maintaining the integrity of the process and ensuring the safety of the plant. There

are three types of fluid flow that can occur in a plant which are liquid flow, vapour flow and mixture flow.

5.4.1 Piping for Liquid Flow

The optimal diameter of the pipelines transferring liquid made of stainless steel is calculated based on the formula below. Table 5.18 summarizes the calculated pipe dimensions for the liquid stream.

$$d_{opt} = 293G^{0.52}\rho^{-0.37}$$

Where,

d_{opt} = optimum diameter, m

G = liquid flowrate, kg/s

ρ = liquid density, kg/m³

5.4.2 Piping for Vapour Flow

In order to determine pipe size for vapour flow, the velocity of the vapour is calculated using the equation as shown below:

$$U = \sqrt{\frac{RT}{M}}$$

Where,

R = gas constant (8.314 J/mol K)

T = stream temperature, K

M = molecular weight of the vapour, g/mol

While the cross-sectional area and inside diameter of the pipe are calculated using the equation below:

$$A = \frac{Q}{\rho U}$$

$$D = \sqrt{\frac{4A}{\pi}}$$

Where,

Q = vapour flowrate, kg/s

ρ = vapour density, kg/m³

U = vapour velocity, m/s

Table 5.19 summarizes the calculated pipe dimensions for the vapour stream.

5.4.3 Piping for Mixture Flow

Pipes transporting gas and liquid in two-phase flow should be sized primarily based on flow velocity. Flow velocity should be kept at least below fluid erosional velocity. The velocity above which erosion may occur can be determined by the empirical equation below:

$$V_e = \frac{C}{\sqrt{\rho_m}}$$

Where,

V_e = Fluid erosional velocity (m/s)

C = Empirical constant (100 for continuous service)

ρ = Gas/liquid mixture density (kg/m³)

After determining fluid erosional velocity, the minimum cross-sectional area required to avoid fluid erosion is then calculated using the equation below:

$$A = \frac{9.35G + \left(\frac{ZRT}{21.25P} \right)}{V_e}$$

Where,

G = mixture flow rate, kg/s

Z = compressibility factor

R = gas/liquid ratio

T = operating temperature, K

P = operating pressure, kPa

Table 5.20 summarizes the calculated pipe dimensions for the mixture stream.

Table 5.18 Pipe sizing for liquid stream

Stream	Flowrate, G (kg/s)	Density, ρ (kg/m ³)	Optimum diameter, D _{opt} (mm)	Optimum diameter, D _{opt} (inch)	Nominal diameter, D _{nominal} (inch)	Outer diameter, D _{out} (inch)	Thickness, t (inch)	Inner diameter, D _{in} (inch)
1	0.87	997.0	21.24	0.83	1.000	1.32	0.133	1.18
2	0.87	997.0	21.24	0.83	1.000	1.32	0.133	1.18
3	0.87	997.0	21.24	0.83	1.000	1.32	0.133	1.18
4	0.87	997.0	21.24	0.83	1.000	1.32	0.133	1.18
5	0.87	997.0	21.24	0.83	1.000	1.32	0.133	1.18
6	0.87	997.0	21.24	0.83	1.000	1.32	0.133	1.18
7	0.90	997.0	21.60	0.84	1.000	1.32	0.133	1.18
8	0.90	997.0	21.60	0.84	1.000	1.32	0.133	1.18
9	0.90	997.0	21.60	0.84	1.000	1.32	0.133	1.18
12	0.02	997.0	2.64	0.10	0.125	0.41	0.068	0.34
13	0.01	997.0	2.41	0.09	0.125	0.41	0.068	0.34
25	0.55	682.6	19.27	0.75	0.750	1.05	0.113	0.94
44	0.75	1096.2	18.96	0.74	0.750	1.05	0.113	0.94
46	0.63	1115.3	17.19	0.67	0.750	1.05	0.113	0.94
47	0.63	1115.3	17.19	0.67	0.750	1.05	0.113	0.94
51	0.17	997.0	9.07	0.35	0.375	0.68	0.091	0.58
52	0.17	997.0	9.07	0.35	0.375	0.68	0.091	0.58

Table 5.19 Pipe sizing for vapour stream

Stream	Temperature, T (K)	Flowrate, G (kg/s)	Density, ρ (kg/m ³)	Area, A (m ²)	Optimum diameter, D _{opt} (m)	Optimum diameter, D _{opt} (inch)	Nominal diameter, D _{nominal} (inch)	Outer diameter, D _{out} (inch)	Thickness, t (inch)	Inner diameter, D _{in} (inch)
10	353.15	0.79	1.41	0.059	0.27	10.76	12.0	12.750	0.375	12.375
11	353.15	0.11	0.14	0.021	0.16	6.39	8.0	8.625	0.322	8.303
14	343.15	0.78	1.43	0.058	0.27	10.66	12.0	12.750	0.375	12.375
15	301.15	0.78	1.43	0.061	0.28	11.01	12.0	12.750	0.375	12.375
16	343.15	0.10	0.08	0.032	0.20	7.99	8.0	8.625	0.322	8.303
17	301.15	0.10	0.08	0.035	0.21	8.26	10.0	10.750	0.365	10.385
18	301.15	0.46	1.25	0.039	0.22	8.73	10.0	10.750	0.365	10.385
18a	301.15	0.46	1.25	0.039	0.22	8.73	10.0	10.750	0.365	10.385
19	301.15	0.97	0.94	0.085	0.33	12.95	12.0	12.750	0.375	12.375
20	323.15	0.97	0.94	0.082	0.32	12.72	12.0	12.750	0.375	12.375
21	293.15	0.97	0.94	0.086	0.33	13.04	12.0	12.750	0.375	12.375
23	313.15	0.42	1.04	0.041	0.23	9.04	10.0	10.750	0.365	10.385
23a	313.15	0.42	1.04	0.041	0.23	9.04	10.0	10.750	0.365	10.385
24	301.15	0.42	1.04	0.042	0.23	9.13	10.0	10.750	0.365	10.385
26	453.15	0.55	0.86	0.043	0.23	9.24	10.0	10.750	0.365	10.385
27	298.15	0.87	1.87	0.062	0.28	11.03	12.0	12.750	0.375	12.375
28	323.15	0.87	1.87	0.059	0.27	10.81	12.0	12.750	0.375	12.375
29	373.15	0.87	1.87	0.055	0.26	10.43	12.0	12.750	0.375	12.375
30	453.15	0.87	1.87	0.050	0.25	9.94	10.0	10.750	0.365	10.385

31	453.15	0.83	1.87	0.049	0.25	9.74	10.0	10.750	0.365	10.385
32	453.15	0.03	1.87	0.002	0.05	1.97	2.0	2.375	0.154	2.221
35	453.15	0.32	1.62	0.021	0.16	6.48	8.0	8.625	0.322	8.303
36	453.15	0.32	1.62	0.021	0.16	6.48	8.0	8.625	0.322	8.303
41	383.15	0.67	1.53	0.051	0.26	10.06	10.0	10.750	0.365	10.385
42	328.45	0.67	1.53	0.055	0.27	10.46	12.0	12.750	0.375	12.375
43	301.15	0.67	1.53	0.058	0.27	10.69	12.0	12.750	0.375	12.375
45	448.15	0.12	0.60	0.014	0.13	5.26	6.0	6.625	0.280	6.345
48	388.15	0.05	0.60	0.006	0.09	3.47	3.5	4.000	0.226	3.774
49	413.15	0.17	0.60	0.021	0.16	6.37	8.0	8.625	0.322	8.303

Table 5.20 Pipe sizing for mixture stream

Stream	Pressure, P (kPa)	Temperature, T (K)	Flowrate, G (kg/s)	Density, ρ (kg/m ³)	Optimum diameter, D_{opt} (m)	Optimum diameter, D_{opt} (inch)	Nominal diameter, $D_{nominal}$ (inch)	Outer diameter, D_{out} (inch)	Thickness, t (inch)	Inner diameter, D_{in} (inch)
22	14000	313.15	0.97	0.94	0.24	9.46	10	10.75	0.365	10.39
33	13500	453.15	1.70	748.86	0.32	12.54	14	14.00	0.437	13.56
34	14000	453.15	1.70	748.86	0.32	12.54	14	14.00	0.437	13.56
37	13500	453.15	1.42	625.08	0.41	16.19	18	18.00	0.562	17.44
37	300	453.15	1.42	625.08	0.41	16.26	18	18.00	0.562	17.44
39	300	413.17	1.42	625.08	0.41	16.26	18	18.00	0.562	17.44
40	300	393.15	1.42	625.08	0.41	16.25	18	18.00	0.562	17.44

CHAPTER VI

WASTE MANAGEMENT

6.1 INTRODUCTION

Waste management is the process of controlling waste from the time it is created until it is finally disposed of. The three current industrial waste management strategies are source reduction by in-plant modification, waste recovery/recycling, and waste treatment by detoxifying, neutralising, or destroying the undesirable substances. The first two options which are plant modification and waste recovery/recycling are the most promising waste management strategies. In fact, one very enticing option is waste recovery. Different disposal and management techniques are used for solid, liquid, and gaseous wastes. Waste management strives to reduce waste's detrimental impact on the environment, human health, and aesthetics (Kosseva 2011).

6.2 WASTE GENERATION

In the production process, there are three types of waste generated that needs to be treated which are solid residual, wastewater and waste gas. Solid waste is generated from the maintenance of activated carbon filter (AF-101) and accumulation of solid at electrode of PEM electrolyser (E-101). While wastewater is generated from the condensation of water vapor from evaporator (EV-101) and granulator (G-101) which then combined to discharge through stream 50. For waste gas, it is discharged from decomposer (DP-101) by stream 41. Table 6.1, Table 6.2 and Table 6.3 shows the flowrate (kg/hr) and composition of each stream according to the type of waste presence.

Table 6.1 Solid waste composition

Stream	Component	Flowrate (kg/h)
AF-101	Activated carbon	No flowrate since they are only collected during maintenance processes
E-101	Accumulation of solid catalyst at electrode of electrolyser	

Table 6.2 Wastewater composition

Stream	Component	Flowrate (kg/h)
50	Water	612.58
	Ammonia	81.25
	Carbon dioxide	79.56
	Total	773.39

Table 6.3 Waste gas composition

Stream	Component	Flowrate (kg/h)
41	Ammonia	731.25
	Carbon dioxide	1511.54
	Total	2242.79

6.3 RELATED LAWS AND REGULATIONS

Industries are expected to pre-treat the waste before it is discharged. Untreated effluent can't be discharged in open channels from industries. Recovered water must comply with direct discharge requirements before discharge into the sea after treatment. In Malaysia, all waste produced from industrial activity must comply to a few environmental acts and regulations.

Environment Quality Act (EQA) 1974 is the key legislation of Malaysian Environmental legislation and some of the regulation standards are revised by the Department of Environment (DOE), Malaysia. This Act establishes guidelines for pollution prevention, reduction, control, and enhancement. It is divided into the following parts:

- i. Preliminary
- ii. Administration
- iii. Licenses
- iv. Prohibition

- v. Control of Pollution
- vi. Appeal and Appeal Board
- vii. Miscellaneous

Powers and functions relevant to the protection of the environment are shared by the Director General of Environmental Quality and the Minister charged with the responsibility for environment protection. In the process of production of aviation fuel, the laws and regulations that need to be followed are:

- i. Environmental Quality (Scheduled Wastes) Regulations 2005
- ii. Environmental Quality (Industrial Effluent) Regulations 2009
- iii. Environmental Quality (Clean Air) Regulations 2014

There are also another acts related to the waste management that is related in this project which is Act 672 – Solid Waste and Public Cleansing Management Act 2007 and Occupational Safety Health Act (OSHA). It focused on Solid Waste and Public Cleansing Management (Scheme for Commercial, Industrial and Institutional Solid Waste) Regulations 2018.

6.3.1 Environmental Quality (Scheduled Wastes) Regulations 2005

These regulations are about managing the hazardous material. In this project, there are wastes that are classified under First Schedule and Fourth Schedule. According to Regulation 2 (interpretation), "scheduled waste" means any waste falling within the categories of waste listed in the First Schedule and "incompatible scheduled waste" means a scheduled waste specified in the Fourth Schedule which, when mixed, will create a dangerous situation through the generation of heat, fire, explosion or release of toxic substances (EQA 1974).

Regulations 9 (Scheduled waste storage) stated any person may store scheduled waste produced by him for 180 days or less after production provided that the quantity of scheduled waste collected on site shall not exceed 20 metric tons (EQA 1974). The material was listed in First Schedule is under SW 2 which is waste containing mainly inorganic constituents that may contain metals and organic matter. The scheduled waste

presence in this project is classified as SW 202 and SW 204. SW 2020 namely catalyst waste which is $Mn_{0.8}Zn_{0.2}O_4$ that used in ammonia synthesis. Then, SW 204 is sludge containing one or more metals including chromium, copper, nickel, zinc, lead, cadmium, aluminum, tin, vanadium and beryllium. The metal in this project comes from titanium electrode at PEM electrolyser.

Fourth Schedule refers to scheduled wastes with potential incompatibility. The mixing of a waste in Group A with a waste in Group B may have the following potential consequences. Table 6.4 shows the waste produce during production, treatment, and maintenance in the plant.

Table 6.4 Scheduled wastes of potential incompatibility in Group 1

Group 1-A	Group 1-B
Alkaline caustic liquids	Acid sludge
Alkaline cleaner	Chemical cleaners
Alkaline corrosive liquid	Electrolyte, acid
Caustic wastewater	Etching acid, liquid or solvent
Lime sludge and other corrosive alkalies	Pickling liquor and other corrosive acid
	Spent acid and spent mixed acid

Source: Environmental Quality (Scheduled Wastes) Regulations 2005

During the maintenance and cleaning process, there are more than one chemical cleaner will be used depending on the type of the equipment used. There are four main industrial cleaning chemicals which are strong alkali cleaning agents, medium alkali cleaning agents, mild alkali chemical solution, and strong acid (*Royal Building Cleaning Ltd.*, 2017). Every chemical cleaner have their own properties, usage and risk and they are different for one another. Table 6.5 shows the waste produce during production, treatment, and maintenance.

Table 6.5 Scheduled wastes of potential incompatibility in Group 3

Group 3-A	Group 3-B
Magnesium, and zink power and other reactive metals and metal hydrides/	Any waste in Group 1-A or 1-B

Source: Environmental Quality (Scheduled Wastes) Regulations 2005

The waste in Group-1-B is chemical cleaners using during cleaning process which are ethylen-diamine-tetra-acetic-acid (EDTA), oxalic acid, citric acid, and ascorbic acid (Drexler 2017). When Group 3-A which is metal waste from the catalyst and equipment react with Group 3-B, the release of toxic substances in case of fire or explosion will happen.

In normal practice, scheduled wastes are stored in the following containers which are bunghole drum (steel/plastic), open top drum (steel/plastic) with cover and clamp, intermediate bulk container, corrugated box or carton box, and flexible intermedia bulk containers (FIBCs), jumbo bags, bulk bags and polypropylene big bags. Containers containing residues of chemicals or scheduled wastes which are not compatible to the waste to be stored should be properly rinsed prior to usage. The solution generated from the rinsing activity should be contained and characterized prior to treatment or disposal at sites as approved by the Department of Environment (EQA 1974).

6.3.2 Environmental Quality (Industrial Effluent) Regulations 2009

Industrial effluent refers to any waste in the form of liquid or wastewater generated from manufacturing process including the treatment of water for water supply or any activity occurring at any industrial premises while mixed effluent refers to any waste in the form of liquid or wastewater containing both industrial effluent and sewage. Based on the Malaysian Environmental Legislation, the key legislation which is Environmental Quality (Industrial Effluent) Regulations 2009. The effluent condition should be following the standard of regulation. Standard A is applicable to any discharges into any inland water within catchment areas listed in the Third Schedule while Standard B is applicable to any other inland waters or Malaysian waters.

In this process, the wastewater treatment plant follows Standard B as the nearest discharge area is at Sungai Tiram and it is not in Sixth Schedule. Sixth Schedule is the area identified at the catchment for Standard A. Then, Fourth Schedule is a method for the analysis of industrial effluents or mixed effluents. Table 6.6 shows the acceptable condition for discharge of industrial/mixed effluent.

Table 6.6 Acceptable condition for discharge of industrial/mixed effluent

Parameter	Unit	Standard A	Standard B
(1)	(2)	(3)	(4)
(i) Temperature	°C	40	40
(ii) pH Value		6.0-9.0	5.5-9.0
(iii) BOD at 20°C	mg/L	20	50
(iv) Suspended Solids	mg/L	50	100
(v) Zink	mg/L	2.0	2.0
(vi) Colour	ADMI*	100	200

*ADMI – American Dye Manufacturers Institute

Source: Environmental Quality (Industrial Effluent) Regulations 2009

Next, Seventh Schedule is explained about an acceptable condition for the disposal of industrial effluents containing chemical oxygen requirements (COD) for a specific sector or industry. Table 6.7 shows acceptable COD for discharge of industrial effluent.

Table 6.7 Acceptable COD for discharge of industrial effluent

	(1)	(2)	(3)	(4)
	Industry	Unit	Standard A	Standard B
(a)	Pulp and paper industry			
(i)	Pulp mill	mg/L	80	350
(ii)	Paper mill (recycled)	mg/L	80	250
(iii)	Pulp and paper mill	mg/L	80	300
(b)	Textile industry	mg/L	80	250
(c)	Fermentation and distillery industry	mg/L	400	400
(d)	Other industries	mg/L	80	200

Source: Environmental Quality (Industrial Effluent) Regulations 2009

Then, Eighth Schedule is an acceptable condition for the disposal of mixed effluents containing chemical oxygen demand (COD). Table 6.8 shows acceptable conditions for discharge of industrial effluent or mixed effluent.

Table 6.8 Acceptable COD for discharge of industrial effluent

(1) Unit	(2) Standard A	(3) Standard B
mg/L	80	200

In conclusion, all the discharge parameters should be followed Standard B. It can be Fourth, Seventh or Eighth Schedule, depends on effluent types.

6.3.3 Environmental Quality (Clean Air) Regulations 2014

Clean Air Regulations 2014 aims to regulate emissions of air pollutants from industrial activities. CAR 2014 replaces the Environmental Quality (Clean Air) Regulations 1978. Ammonia and carbon dioxide gas are discharged to the surrounding during the production.

According to regulation 2 (interpretation), "air impurities" includes smoke, soot, dust, ash (including fly ash), cinders, grit, solid particles of any kind inclusive of particulates, gases, fumes, mist, odours and radioactive substance which are generated as a result of combustion of fuel and the like, or a result of the use of electricity as a heat source, or a result of synthesis, resolution or any other treatment and any other substance which may be designated by the Minister as those which are liable to affect adversely the human health or the living environment. Then, "process" means any action, operation, conversion, or treatment embracing chemical, industrial, manufacturing or processing factors, methods or forms including furnaces, ovens, retorts, kettles, converters, cupolas, kilns, crucibles, stills, dryers, roasters, separator filters, reboilers, columns, classifiers, screens, quenchers, cookers, digesters, towers, washers, scrubbers, mills, condensers or absorbers.

Regulations 21 (Date of compliance) stated that every new facility shall comply with Standard C so this plant will follow this Standard. Ammonia was classified as Noxious and Offensive Substances (Regulations 32) at Third Schedule. Table 6.9 shows the limit value of chemical and petrochemical industry in all sizes.

Table 6.9 Limit value of chemical and petrochemical industry in all size

Pollutant	Limit value	Monitoring
Ammonia (NH ₃)	76 mg/m ³	Periodic

Source: Environmental Quality (Clean Air) Regulations 2014

Ammonia release from the plant after gas treatment is 20.37 ppm so ammonia is not exceed the limit value. Periodic monitoring will be done to control the release of ammonia gas from the plant.

Then, New Ambient Air Quality Standard was established to replace the older Malaysia Ambient Air Quality Guideline that has been used since 1989. The New Ambient Air Quality Standard adopts 6 air pollutants criteria that include 5 existing air pollutants which are particulate matter with the size of less than 10 micron (PM₁₀), sulfur dioxide (SO₂), carbon monoxide (CO), nitrogen dioxide (NO), and ground level ozone (O₃) as well as 1 additional parameter which is particulate matter with the size of less than 25 micron (PM_{2.5}). The air pollutants concentration limit will be strengthened in stages until 2020. There are 3 interim targets set which include interim target 1 (IT-1) in 2015, interim target 2 (IT-2) in 2018 and the full implementation of the standard in 2020. Table 6.10 shows the New Malaysia Ambient Air Quality Standard.

Table 6.10 New Malaysia Ambient Air Quality Standard

Pollutants	Averaging Time	Ambient Air Quality Standard		
		IT-1 (2015) µg/m ³	IT-2 (2018) µg/m ³	Standard (2020) µg/m ³
Particulate Matter with the size of less than 10 micron (PM ₁₀)	1 Year	50	45	40
	24 Hour	150	120	100
Particulate Matter with the size of less than 2.5 micron (PM _{2.5})	1 Year	35	25	15
	24 Hour	75	50	35
Sulfur Dioxide (SO ₂)	1 Hour	350	300	250
	24 Hour	105	90	80
Nitrogen Level Ozone (NO ₂)	1 Hour	320	300	280
	24 Hour	75	75	70
Ground Level Ozone (O ₃)	1 Hour	200	200	180

	8 Hour	120	120	100
*Carbon Monoxide (CO)	1 Hour	35	35	30
	8 Hour	10	10	10

*mg/m³

6.3.4 Solid Waste and Public Cleansing Management (Scheme for Commercial, Industrial and Institutional Solid Waste) Regulations 2018.

This regulation is relating to handling the commercial, industrial, or institutional solid waste. Solid waste generated in this process is the filter from activated carbon column. Industrial solid was generated means any person who generated any industrial solid waste and include any person who generates any industrial solid waste during any temporary activity. Then, residual solid waste means any industrial solid waste is not reused, recycled, or composted and can be placed in a receptacle. Every plant will have storage site whether it is located inside or outside the premises where industrial solid waste is stored before collection. According to the First Schedule at Regulation 3, the local authority for scheme area of the plant location is under Pasir Gudang Municipal Council with 132.2 Km².

6.3.5 Occupational Safety Health Act (OSHA)

In the manufacturing plant, our waste gas is carbon dioxide (CO₂) and ammonia (NH₃). The CO₂ concentration is determined by comparing the minimum limit set by the Occupational Safety Health Act (OSHA) to decide if it is safe to eliminate or needs to be treated before gas waste is released. The carbon dioxide concentration is shown in Table 6.11.

Table 6.11 Concentration carbon dioxide in the production

Component	Mass Flowrate (kg/hr)	Concentration of CO ₂ (mg/L)	Concentration of CO ₂ (ppm)
Carbon Dioxide (CO ₂)	1511.55	1260.30	707.41

According to OSHA 1994 act, the standard for permissible limit is less than 5000 ppm. The concentration of CO₂ in this plant is not exceed the limit.

6.4 WASTEWATER CHARACTERIZATION

Before being released into the environment, wastewater needs to be treated effectively to remove impurities and pollutants. The effluent discharge must be within the established environmental regulatory limit. In this production plant of urea, the parameters that are taken into considerations are chemical oxygen demand (COD) and biochemical oxygen demand (BOD). By treating wastewater according to the Environmental Quality (Industrial Effluent) Regulations 2009, the COD and BOD levels should be lowered.

6.4.1 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is the amount of oxygen consumed under specified conditions in the chemical oxidation of the organics and oxidizable inorganics in wastewater. Prior to discharge, COD testing is essential for determining the quality of the effluent and wastewater. If the COD value is high, it indicates that the sample contains a lot of oxidizable organic material, which will reduced the amount of dissolved oxygen. In the production of urea plant, the COD value for wastewater is 3520 mg/L (Gupta et al. 2005).

6.4.2 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand (BOD) refers to the amount of oxygen utilized by microorganism in performing oxidation. It should be noted that COD levels are always higher than BOD values. BOD/COD ratio for untreated municipal wastewater typically range from 0.3 to 0.8. Therefore, the BOD value are calculated by using the equation below.

$$BOD = 0.3 \times COD \quad \dots(6.1)$$

$$\text{BOD of wastewater} = 0.3 \times 3520 \text{ mg/L}$$

$$= 1056 \text{ mg/L}$$

6.4.3 Summary

The COD value from wastewater of urea plant is 3520 mg/L while the BOD value calculated is 1056 mg/L. The wastewater discharge limit should be in compliance with Standard B as the discharge point is at Sungai Tiram, Pasir Gudang which is located near to this proposed plant. Both COD and BOD of the waste stream exceeds the discharge limit of Standard B effluent according to the Environmental Quality (Industry Effluent) Regulations 2009, which are 200 mg/L and 50 mg/L, respectively. Hence, treatment needs to be done to treat the wastewater until it complies the regulation prior to discharge.

6.5 WASTEWATER TREATMENT

Wastewater treatment plant consists of 4 stages which is pre-treatment, primary treatment, secondary treatment and sludge treatment. The purpose of these treatments is to reduce the value of COD and BOD concentration in wastewater. The pretreatment technique used in this plant is equalization, continue with primary treatment that involve coagulation and flocculation and sedimentation tank, secondary treatment involves aeration tank and secondary clarifier and sludge treatment consist of storage tank (sludge thickening) and press filter (sludge dewatering).

6.5.1 Pre-treatment

The wastewater from the process plant needs to be pre-treated to remove large objects and non-degradable materials.

a. Equalization Tank (E-101)

Equalization is the first step for wastewater treatment process in our plant. The purpose of this unit is to minimize chemical treatment and flow surge to chemical treatments. Besides, it also stabilizes the pH and reduce peaks and flows in wastewater discharges from the production plant and pollutant loadings. The typical hydraulic retention time (HRT) is 12 hours. An efficiency of 30% removal of BOD and COD respectively are taken for equalization tank.

i. Design

Inlet flowrate, $F = 773.39 \text{ kg/hr} + 25.13 \text{ kg/hr} = 798.52 \text{ kg/hr}$

$$\begin{aligned}\text{Volumetric flowrate, } Q &= \frac{\text{Inlet flowrate, } F}{1000} \\ &= \frac{798.52 \text{ kg/hr}}{1000} \\ &= 0.799 \text{ m}^3/\text{h}\end{aligned}$$

By considering a safety factor 1.2,

$$\begin{aligned}\text{New volumetric flowrate, } Q &= \text{Old } Q \times \text{safety factor} \\ &= 0.799 \text{ m}^3/\text{h} \times 1.2 \\ &= 0.959 \text{ m}^3/\text{h} \\ &= 23.016 \text{ m}^3/\text{d}\end{aligned}$$

Since $HRT = 12 \text{ hr} = \tau$

$$\begin{aligned}\text{Volume of tank, } V &= Q\tau \\ &= 23.016 \text{ m}^3/\text{d} \times \frac{12}{24} \text{ day} \\ &= 11.508 \text{ m}^3\end{aligned}$$

ii. Dimension

Since the shape of tank is rectangular and the depth is 2.97 m (Equalization and Water Storage Tanks Tank (HDPE) Specifications, 2017).

$$V = \text{depth} \times \text{length} \times \text{width}$$

$$11.508 \text{ m}^3 = 2.97 \times \text{length} \times \text{width}$$

$$\text{Length} = 1.97 \text{ m}$$

$$\text{Width} = 1.97 \text{ m}$$

iii. Efficiency of removal

$$\text{BOD (residual)} = 1056 \text{ mg/L} \times 0.70 = 739.2 \text{ mg/L}$$

$$\text{COD (residual)} = 3520 \text{ mg/L} \times 0.70 = 2464 \text{ mg/L}$$

6.5.2 Primary Treatment

Primary treatment is a physio-chemical process that involves the addition of coagulant and flocculant to remove suspended solid matter in wastewater. In this process wastewater flow will slow down and the suspended solid will settle at bottom by gravity where this settle called as sludge.

a. Coagulation and Flocculation Tank (CF-101)

Coagulation and flocculation tank is used to separate the suspended solid in wastewater that come from cleaning process of reactor that utilized catalyst. The process aided with addition of coagulant which is Aluminum Sulfate (Alum) that will coagulate the colloid particles in the wastewater to form floc and float on the surface of water. This technique also will reduce the concentration of BOD, COD and SS. The typical hydraulic retention time (HRT) is 2.5 hours (Ismail et al. 2012). An efficiency of 20% removal of BOD and COD respectively are taken and 65% removal efficiency of SS are taken for this unit.

i. Design

$$\text{Inlet flowrate, } F = 798.52 \text{ kg/hr}$$

$$\text{Volumetric flowrate, } Q = 23.016 \text{ m}^3/\text{d}$$

$$\text{Since HRT} = 2.5 \text{ hr} = \tau$$

$$\begin{aligned}\text{Volume of tank, } V &= Q\tau \\ &= 23.016 \text{ m}^3/\text{d} \times \frac{2.5}{24} \text{ day} \\ &= 2.40 \text{ m}^3\end{aligned}$$

ii. Dimension

Since the shape of tank is rectangular and the depth is 1.4 m (Coagulation and Flocculation Tank, 2017)

$$V = \text{depth} \times \text{length} \times \text{width}$$

$$2.40 \text{ m}^3 = 1.4 \times \text{length} \times \text{width}$$

$$\text{Length} = 1.31 \text{ m}$$

Width = 1.31 m

iii. Amount of Alum needed.

In coagulation and flocculation tank, 50 mg/L alum needed (Mudassir et al. 2017).

$$\begin{aligned}\text{Volumetric flowrate, } Q &= 23.016 \text{ m}^3/\text{d} \\ &= 23016 \text{ L/d}\end{aligned}$$

$$\begin{aligned}\text{Flowrate of Alum} &= 23016 \text{ L/d} \times 50\text{mg/L} \\ &= 1.15 \text{ kg/day} \\ &= 0.05 \text{ kg/hr}\end{aligned}$$

iv. Removal efficiency

$$\text{BOD (residual)} = 739.2 \text{ mg/L} \times 0.80 = 591.36 \text{ mg/L}$$

$$\text{COD (residual)} = 2464 \text{ mg/L} \times 0.80 = 1971.2 \text{ mg/L}$$

$$\text{SS (residual)} = 180 \text{ mg/L} \times 0.35 = 63 \text{ mg/L}$$

b. Sedimentation

Sedimentation is used to reduce the velocity of the wastewater flow and to allow the floc to settle by gravity. This technique also will reduce the concentration of BOD, COD and SS. The typical hydraulic retention time (HRT) is 1.5 hours (Minimum Standards for Sedimentation Tank Design - King County, 2021). An efficiency of 30% removal of BOD and COD respectively are taken and 70% removal efficiency of SS are taken for this unit.

i. Design

$$\text{Inlet flowrate, } F = 808.52 \text{ kg/hr}$$

$$\begin{aligned}\text{Volumetric flowrate, } Q &= \frac{\text{Inlet flowrate, } F}{1000} \\ &= \frac{808.52 \text{ kg/hr}}{1000} \\ &= 0.809 \text{ m}^3/\text{h}\end{aligned}$$

By considering a safety factor 1.2,

$$\begin{aligned}\text{New volumetric flowrate, } Q &= \text{Old } Q \times \text{safety factor} \\ &= 0.809 \text{ m}^3/\text{h} \times 1.2 \\ &= 0.971 \text{ m}^3/\text{h} \\ &= 23.300 \text{ m}^3/\text{d}\end{aligned}$$

Since HRT = 1.5 hr = τ

$$\begin{aligned}\text{Volume of tank, } V &= Q\tau \\ &= 23.300 \text{ m}^3/\text{d} \times \frac{1.5}{24} \text{ day} \\ &= 1.46 \text{ m}^3\end{aligned}$$

ii. Dimension

Since the shape of tank is rectangular and the depth is 1.4 m (Coagulation and Flocculation Tank, 2017)

$$V = \text{depth} \times \text{length} \times \text{width}$$

$$1.46 \text{ m}^3 = 1.46 \times \text{length} \times \text{width}$$

$$\text{Length} = 1 \text{ m}$$

$$\text{Width} = 1 \text{ m}$$

iii. Removal efficiency

$$\text{BOD (residual)} = 591.36 \text{ mg/L} \times 0.70 = 414.00 \text{ mg/L}$$

$$\text{COD (residual)} = 1971.2 \text{ mg/L} \times 0.70 = 1379.84 \text{ mg/L}$$

$$\text{SS (residual)} = 63 \text{ mg/L} \times 0.30 = 18.90 \text{ mg/L}$$

6.5.3 Secondary Treatment

V Primary treatment is biological process to eliminate the contaminants in wastewater through biological aerobic and anaerobic process

a. Aeration Tank, A-101

Aeration tank is an activated sludge process where air will be added into the water to encourage microbial growth. The purpose is to reduce the BOD and COD in the wastewater. The typical hydraulic retention time (HRT) is 8 hours. An efficiency of 95% removal of BOD and COD respectively are taken for aeration tank.

i. Design

$$\text{Inlet flowrate, } F = 777.51 \text{ kg/hr}$$

$$\begin{aligned}\text{Volumetric flowrate, } Q &= \frac{\text{Inlet flowrate, } F}{1000} \\ &= \frac{777.51 \text{ kg/hr}}{1000} \\ &= 0.778 \text{ m}^3/\text{h}\end{aligned}$$

By considering a safety factor 1.2,

$$\text{New volumetric flowrate, } Q = \text{Old } Q \times \text{safety factor}$$

$$\begin{aligned}&= 0.778 \text{ m}^3/\text{h} \times 1.2 \\ &= 0.934 \text{ m}^3/\text{h} \\ &= 22.416 \text{ m}^3/\text{d}\end{aligned}$$

Since HRT = 1.5 hr = τ

$$\text{Volume of tank, } V = Q\tau$$

$$\begin{aligned}&= 22.416 \text{ m}^3/\text{d} \times \frac{8}{24} \text{ day} \\ &= 7.472 \text{ m}^3\end{aligned}$$

ii. Dimension

Since the shape of tank is rectangular,

$$V = \text{depth} \times \text{length} \times \text{width}$$

$$7.472 \text{ m}^3 = \text{depth} \times 3.00 \times \text{width}$$

$$\text{Length} = 3.00 \text{ m (Rahman 2016)}$$

$$\text{Width} = 1.58 \text{ m}$$

$$\text{Width} = 1.58 \text{ m}$$

iii. Flowrate of air

In aeration tank, Standard Oxygen Transfer Efficiency (SOTE) is 20%

$$\begin{aligned}\text{Flowrate of air} &= \frac{\text{BOD value}}{\text{oxygen}} \\ &= \frac{414.0}{0.20} \\ &= 2070 \text{ kg/h}\end{aligned}$$

iv. Amount of activated sludge needed.

In aeration tank, feed to mass ratio (F:M ratio) is 0.2 (Nalco Water Handbook 2nd ed. 1998).

$$\begin{aligned}\text{F:M} &= \frac{\text{BOD value}}{\text{amount of activated sludge}} \\ 0.45 &= \frac{414.0 \text{ mg/L}}{\text{amount of activated sludge}}\end{aligned}$$

Amount of activated sludge = 920 mg/L

v. Removal efficiency

$$\text{BOD (residual)} = 414.00 \text{ mg/L} \times 0.05 = 20.70 \text{ mg/L}$$

$$\text{COD (residual)} = 1379.84 \text{ mg/L} \times 0.05 = 68.99 \text{ mg/L}$$

b. Clarifier, C-101

Clarifier is biological treatment process with main goal of returning sludge. During this stage, the solid particles and suspended solid is removed by clarification and thickening by using clarifier where it will settle at bottom in the form of activated sludge. The typical hydraulic retention time (HRT) is 4 hours (Clarifier Design Criteria, 2016). An efficiency of 40% removal of BOD and COD respectively are taken while efficiency removal of SS is 80%

i. Design

$$\text{Inlet flowrate, F} = 812.65 \text{ kg/hr}$$

$$\begin{aligned}
 \text{Volumetric flowrate, } Q &= \frac{\text{Inlet flowrate, } F}{1000} \\
 &= \frac{812.65 \text{ kg/hr}}{1000} \\
 &= 0.813 \text{ m}^3/\text{h}
 \end{aligned}$$

By considering a safety factor 1.2,

$$\begin{aligned}
 \text{New volumetric flowrate, } Q &= \text{Old } Q \times \text{safety factor} \\
 &= 0.813 \text{ m}^3/\text{h} \times 1.2 \\
 &= 0.976 \text{ m}^3/\text{h} \\
 &= 23.424 \text{ m}^3/\text{d}
 \end{aligned}$$

Since HRT = 4 hr = τ

$$\begin{aligned}
 \text{Volume of tank, } V &= Q\tau \\
 &= 23.424 \text{ m}^3/\text{d} \times \frac{4}{24} \text{ day} \\
 &= 3.904 \text{ m}^3
 \end{aligned}$$

ii. Dimension

Since the shape of tank is cylindrical, radius assumed to be 1.00 m

$$\begin{aligned}
 \text{Volume of clarifier tank} &= \pi r^2 h \\
 3.904 \text{ m}^3 &= \pi 1^2 h \\
 H &= 1.24 \text{ m}
 \end{aligned}$$

Removal efficiency

$$\text{BOD (residual)} = 20.70 \text{ mg/L} \times 0.60 = 12.42 \text{ mg/L}$$

$$\text{COD (residual)} = 68.99 \text{ mg/L} \times 0.60 = 41.394 \text{ mg/L}$$

$$\text{SS (residual)} = 18.90 \text{ mg/L} \times 0.20 = 3.78 \text{ mg/L}$$

6.5.4 Sludge Treatment

v Sludge treatment are the process for managing the sludge. The purpose of this process is to reduce odors, remove water and to reduce volume.

a. Sludge Thickening (ST-101)

This purpose of this unit is to increase the solid concentration. The typical hydraulic retention time (HRT) is 24 hours (Suez's Degremont. 2019). An efficiency of 10% removal of BOD and COD respectively are taken while efficiency removal of SS is 20%.

i. Design

$$\begin{aligned}\text{Inlet flowrate, } F &= 102.69 \text{ kg/hr} \\ \text{Volumetric flowrate, } Q &= \frac{\text{Inlet flowrate, } F}{1000} \\ &= \frac{102.69 \text{ kg/hr}}{1000} \\ &= 0.103 \text{ m}^3/\text{h}\end{aligned}$$

By considering a safety factor 1.2,

$$\begin{aligned}\text{New volumetric flowrate, } Q &= \text{Old } Q \times \text{safety factor} \\ &= 0.103 \text{ m}^3/\text{h} \times 1.2 \\ &= 0.124 \text{ m}^3/\text{h} \\ &= 2.976 \text{ m}^3/\text{d}\end{aligned}$$

Since HRT = 24 hr = τ

$$\begin{aligned}\text{Volume of tank, } V &= Q\tau \\ &= 2.976 \text{ m}^3/\text{d} \times \frac{24}{24} \text{ day} \\ &= 2.976 \text{ m}^3\end{aligned}$$

ii. Dimension

Since the shape of tank is cylindrical, radius assumed to be 1.00 m

$$\begin{aligned}\text{Volume of clarifier tank} &= \pi r^2 h \\ 3.976 \text{ m}^3 &= \pi 1^2 h \\ H &= 1.27 \text{ m}\end{aligned}$$

Removal efficiency

$$\text{BOD (residual)} = 12.42 \text{ mg/L} \times 0.90 = 11.18 \text{ mg/L}$$

$$\text{COD (residual)} = 41.394 \text{ mg/L} \times 0.90 = 37.25 \text{ mg/L}$$

$$\text{SS (residual)} = 3.78 \text{ mg/L} \times 0.80 = 3.02 \text{ mg/L}$$

b. Press filter (PF-101)

The amount of sludge collected from the sludge is assumed to be 2.0% from suspended solid and 2% from sedimentation. An efficiency of 10% removal of BOD and COD respectively are taken while efficiency removal of SS is 15%.

i. Design

$$\text{Inlet flowrate, } F = 87.58 \text{ kg/hr}$$

$$\begin{aligned}\text{Volumetric flowrate, } Q &= \frac{\text{Inlet flowrate, } F}{1000} \\ &= \frac{87.58 \text{ kg/hr}}{1000} \\ &= 0.088 \text{ m}^3/\text{h}\end{aligned}$$

By considering a safety factor 1.2,

$$\begin{aligned}\text{New volumetric flowrate, } Q &= \text{Old } Q \times \text{safety factor} \\ &= 0.088 \text{ m}^3/\text{h} \times 1.2 \\ &= 0.106 \text{ m}^3/\text{h} \\ &= 2.544 \text{ m}^3/\text{d}\end{aligned}$$

Since HRT = 22 hr = τ

$$\begin{aligned}\text{Volume of tank, } V &= Q\tau \\ &= 2.544 \text{ m}^3/\text{d} \times \frac{22}{24} \text{ day} \\ &= 2.332 \text{ m}^3\end{aligned}$$

ii. Dimension

Since the shape of tank is cylindrical, radius assumed to be 1.00 m

$$\text{Volume of clarifier tank} = \pi r^2 h$$

$$2.332 \text{ m}^3 = \pi 1^2 h$$

$$H = 1.0 \text{ m}$$

Removal efficiency

$$\text{BOD (residual)} = 11.18 \text{ mg/L} \times 0.90 = 10.06 \text{ mg/L}$$

$$\text{COD (residual)} = 37.25 \text{ mg/L} \times 0.90 = 33.53 \text{ mg/L}$$

$$\text{SS (residual)} = 3.02 \text{ mg/L} \times 0.85 = 2.57 \text{ mg/L}$$

6.5.5 BOD, COD, dan SS After Treatment

The wastewater from effluent of urea synthesis from green ammonia technology is undergo a wastewater treatment plant to lower down the BOD, COD and SS values in order to meet the standard B requirements from Environmental Quality (Industrial Effluent) Regulations 2009. Table 6.12 shows the summary of waste characteristics of plant after wastewater treatment.

Table 6.12 Summary of waste characteristics of plant after wastewater treatment

Parameter	Effluent from stream 50	Treated effluent	Standard B	Efficiency (%)
Temperature	28°C	28°C	40°C	-
BOD	1056	12.42	50	98.82
COD	3520	42.39	200	98.80
SS	180	3.78	100	97.90

From table above, all the treatment effluent is following the guidelines from EQA. According to Standard B, the effluent can be discharge nearest discharge area which Sungai Tiram. The overall efficiency of the wastewater treatment plant is 98.51%.

6.5.6 Process Flow Diagram of Wastewater Treatment

The process flow diagram is shown at Appendix B.

6.6 SOLID WASTE MANAGEMENT

There are solid wastes in our plant that will be generated from the maintenance of activated carbon filter from the process and gas treatment such as replacing of the

carbon filter, and accumulation of solid at electrode of PEM electrolyser (E-101). Based on the Environmental Quality (Scheduled Wastes) Regulations 2005, the waste generated during the maintenance process falls under the category of SW 202.

In normal practice, scheduled wastes are stored in the following containers which are bunghole drum (steel/plastic), open top drum (steel/plastic) with cover and clamp, intermediate bulk container, corrugated box or carton box, and flexible intermedia bulk containers (FIBCs), jumbo bags, bulk bags and polypropylene big bags. The quantity of the wastes should be taken into consideration to estimate the appropriate size and strength of container to avoid over spilling or container breakage. The container used should be in good condition which free from any damage such as tear or hole. Assigning specific containers for specific wastes will allow the containers to be reused without further washing/cleaning.

Hence, the containers of scheduled wastes shall be clearly labelled in accordance with their types applicable to its category. The solid waste will be collected and sent to by third parties such as Cenviro Kualiti Alam Sdn. Bhd. for further disposal.

6.7 WASTE GAS TREATMENT

The urea production plant generates gaseous waste that includes carbon dioxide and ammonia gas. The concentration of the gaseous waste is evaluated to decide whether it is safe to release or if it needs to be treated first by comparing it with the standard limits set by the Malaysian guidelines for air quality. Table 6.13 shows the standard limits for clean air that were relevant to this urea synthesis process.

Table 6.13 Air quality standard under Environmental Quality (Clean Air) Regulations (Amendment) 2014

Pollutant	Limit value (ppm)
Ammonia	111
Carbon dioxide	400

Source: National Attorney General's Chambers 2014

6.7.1 Waste Gas Treatment

The concentration of carbon dioxide releases is calculated as:

$$C_{CO_2} = \frac{1511.55 \text{ kg}}{\text{hr}} \times \frac{1.87 \text{ kg}}{\text{m}^3} \times \frac{\text{hr}}{2242.80 \text{ kg}} \times \frac{(1 \times 10^6) \text{ mg}}{\text{kg}} \times \frac{0.001 \text{ m}^3}{\text{L}} = 1260.30 \text{ mg/L}$$

$$C_{CO_2, \text{1 hour}} = \left(\frac{22.4}{MW} \right) \left(\frac{T}{273} \right) \left(\frac{1}{P} \right) C = \left(\frac{22.4}{44} \right) \left(\frac{28+273}{273} \right) \left(\frac{1}{1} \right) (1260.30) = 707.41 \text{ ppm}$$

As $C_{CO_2, \text{1 hour}} = 707.41 \text{ ppm} > 400 \text{ ppm}$, hence carbon dioxide needs to be treated.

The concentration of ammonia releases is calculated as:

$$C_{NH_3} = \frac{731.25 \text{ kg}}{\text{hr}} \times \frac{0.86 \text{ kg}}{\text{m}^3} \times \frac{\text{hr}}{2242.80 \text{ kg}} \times \frac{(1 \times 10^6) \text{ mg}}{\text{kg}} \times \frac{0.001 \text{ m}^3}{\text{L}} = 280.40 \text{ mg/L}$$

$$C_{NH_3, \text{1 hour}} = \left(\frac{22.4}{MW} \right) \left(\frac{T}{273} \right) \left(\frac{1}{P} \right) C = \left(\frac{22.4}{17} \right) \left(\frac{28+273}{273} \right) \left(\frac{1}{1} \right) (280.40) = 407.36 \text{ ppm}$$

As $C_{NH_3, \text{1 hour}} = 407.36 \text{ ppm} > 111 \text{ ppm}$, hence ammonia needs to be treated.

Since the concentration of carbon dioxide and ammonia have exceeded the limit value listed in the guidelines, hence the gases must be treated. To address concerns such as air pollution and the greenhouse effect, an adsorption technique using activated carbon will be employed to decrease their concentration prior to discharge. This method can effectively reduce the concentration of carbon dioxide and ammonia up to 95% (Vlaanderen 2020). Additionally, the adsorption technique can be used to treat both acidic and alkaline gases. Table 6.14 shows the treated gas specifications after adsorption.

Table 6.14 Treated gas specifications

Component	Initial concentration (ppm)	Final concentration (ppm)
Carbon dioxide	707.41	35.37
Ammonia	407.36	20.37

After the waste gas is treated, the final concentration of the waste gases is below the limit established by the Environmental Quality (Clean Air) Regulation 2014. This means that the gas can be safely discharged into the atmosphere through a gas stack.

6.7.2 Gas Stack Design

The effective stack height, H_e , is a crucial factor in stack design as it determines the height at which pollutants are released into the atmosphere. The effective stack height is the total of the actual stack height, H_s and the plume rise, Δh . This relationship is represented by the equation $H_e = H_s + \Delta h$.

The height of the plume can be calculated by using Holland's formula:

$$\Delta h = \frac{v_s d}{u} [1.5 + (2.68 \times 10^{-2})P \left(\frac{T_s - T_a}{T_s} \right) d]$$

Where Δh is plume height (m), v_s is stack velocity (m/s), d is stack diameter (m), u is wind speed (m/s), P is pressure (kPa), T_s is stack temperature (K) and T_a is air temperature (K).

Detail for gas stack design:

Wind speed, $u = 3.09$ m/s

Stack velocity, $v_s = 2.5$ m/s

Pressure, $P = 100$ kPa

Air temperature, $T_a = 301.15$ K

Stack temperature, $T_s = 423.15$ K

Height, $H_s = 30$ m

Diameter, $d = 1$ m

Plume rise, $\Delta h =$

$$\Delta h = \frac{(2.5)(1)}{3.09} \left[1.5 + (2.68 \times 10^{-2})(100) \left(\frac{423.15 - 301.15}{423.15} \right) (1) \right]$$

$$= 1.84 \text{ m}$$

Effective stack height, $H_e = 31.84 \text{ m}$

Hence, the final stack height will be 31.84 m which is approximately 32 m. By building the stack at that height, we can ensure that the concentration of hazardous material at ground level is safe.

6.8 WASTE MINIMIZATION

Waste minimization refers to the use of source reduction and environmentally sound recycling methods prior to energy recovery, treatment, or disposal of wastes. Source reduction, often known as pollution prevention, refers to any strategy that decreases the usage of hazardous materials in manufacturing processes by reducing or eliminating waste formation at the source. Recycling is the process of recovering value from things after they have been manufactured. The reuse or recovery of in-process materials or materials generated as by-products that can be further treated on site or transported offsite to reclaim value is referred to as recycling. Table 6.15 shows the waste minimization can be done in the production plant.

Table 6.15 Waste minimization

Concept of waste minimization	Steps
Source elimination	Eliminate carbon dioxide gas
Recycling	Recycle ammonia and carbon dioxide gas
Treatment	Wastewater treatment
Disposal	Disposal sludge

The ammonia gas waste can be reduced by eliminating some of the ammonia gas used in the reaction. The usage of ammonia gas can be reduced by limiting the CO₂ used during urea synthesis and stripping process. Therefore, the unused ammonia and CO₂ can be recycled back to the reactors where the reactions occurred. Wastewater treatment is done to treat the wastewater before it is discharged to the environment. Wastewater treatment starts with equalization, followed by coagulation and flocculation and sedimentation for primary treatment, aeration and clarification for secondary

treatment, and sludge thickener and dewatering for sludge treatment. Sludge created during wastewater treatment is no longer helpful to the process and is thus disposed of in accordance with the Environmental Quality (Industrial Effluent) Regulations 2009.

CHAPTER VII

PLANT LAYOUT

7.1 INTRODUCTION

An ideal location for a plant is one the most important factor to a successful business. Suitable location is required to build up the production plant. A proper decision making and future planning will determine either a long term positive or negative effects towards the production plant.

7.2 PLANT LOCATION AND LAYOUT

Site selection for industrial construction is a study to determine the most convenient location for a plant's location which considers many factors that meet the objectives of the company to provide the highest profitability of the operation (Prince Manufacturing 2021). For strategic growth, a reasonable decision must be taken since it will have a long-term impact either positive or negative on the manufacturing process. Some factors must be considered before the construction to ensure that the operation can run smoothly. The overall urea production might be affected by location of the plant and site. Hence, the plant must be strategically positioned to meet the requirements.

7.3 SITE LOCATION FACTORS

The following factors must be met when choosing a location for this urea production facility. There are:

- i. raw material availability
- ii. transportation facilities
- iii. availability of utilities and infrastructure
- iv. labour supply

- v. site characteristics
- vi. waste disposal.

7.3.1 Raw Material Availability

To make a profit, Companies should strive to enhance their raw material management practices since raw materials are crucial to the manufacturing process. Availability to raw materials is one of the most important considerations among many other factors. Companies must be able to maintain raw material inventories to ensure a continuous flow of production with acceptable quality, proper timeliness, and cost-effectiveness. Too many inventories would be detrimental to the businesses since they would have to spend a significant amount of money and resources on the inventorying process. As a result, it is important to locate a production facility near the most accessible raw materials. The objective of the company is to lower the cost of shipping of raw materials and storage facilities (Smriti Chand 2019).

7.3.2 Transportation Facilities

Transport is critical to the continuous supply of raw materials to industry and the delivery of commodities to final customers. It also aided the expansion of large-scale businesses by enabling the entrance and outflow of raw materials and finished commodities. Transport enables businesses to alter the supply of commodities at various locations in response to changing demand. Price fluctuations are therefore kept to a minimum (Knowledge Team 2021). Depending on the number of raw materials and final products, a suitable method of transportation, such as rail, road, water transportation (through rivers, canals, or the sea), and air transportation, is chosen, as location of the plant. It should be recognised that transportation expenses should remain reasonably low in comparison to overall production costs. Transport facilities are also important to workers since they allow them to get to their workstations quickly. Public transit and accessibility to a major thoroughfare are only a few of the mobility choices available to employees on a regular basis.

7.3.3 Availability of Utilities and Infrastructure

The location of urea production, especially from green ammonia should have proper supply of water and electricity. Hence, the location of the company should be somewhere that is accessible to water and electricity supply. Construction of companies in rural areas will be quite challenging to those facilities. Rural construction may make supplying the plant challenging. In this case, industrial parks are desirable since they may provide modern services such as water and both physical and electrical infrastructure because chemical operations require a large volume of water for the process. Furthermore, power is required for electrolysis processes, motors, illumination, and everyday activities (Schwalger. 2019). Infrastructure such as hospitals, clinics, schools, fire stations, and a nice residential neighbourhood should be positioned near the industrial site so that consumers and workers have easy access to it.

7.3.4 Labour Supply

The location of the company should be near to residential area and universities that will have internship students so that the plant can operate with readily available labour. It is because workers are important to operate the plant effectively.

7.3.5 Site Characteristics

Site characterization is a part of the greater process of determining the acceptability of long-term repository performance (Brusseau 2019). Besides, to its basic availability, the type of the landform, whether uneven, level, or steeply sloping, determines the localization of the industry. The characteristics of a site location, such as its size, shape, accessibility, and, in the case of a geographical location, landforms, soil and ground conditions, and climate, all contribute to the context it provides.

7.3.6 Waste Disposal

The location for industry should be allocated based on the waste that will be produced to ease the disposal of the waste in the correct way. If there was solid waste, the location should be near a landfill or other treatment area. If the waste is not properly disposed

of, it may contaminate the soil, the air, and the water and affect people's health, including the wellbeing of the staff at your company.

7.4 SUGGESTION FO PLANT LOCATION

Based on our plant design, three locations are chosen for consideration, which are:

- i. Lumut Industrial Park Land, Sitiawan
- ii. Tanjung Langsat Industrial Land, Pasir Gudang, Johor
- iii. Industrial Land Kemenia, Sarawak.

Table 7.1 below shows the characteristics of each location and the mark analysis which is used to assess the locations.

Table 7.1 Characteristics of proposed plant location

Location/ Site Location Requirement	Lumut Industrial Park, Sitiawan	Tanjung Langsat Industrial Area, Pasir Gudang	Industrial Land Kemenia, Sarawak
Map			
Price (per acre)	RM 1,907,136	RM 1,470,150	RM 900,00
Available Land (Acres)	11.2	7	3.92
Raw material Supply location	Linde Malaysia Sdn Bhd, Ipoh (73km) Southern Industrial Gas (70km)	Air Gas Technology Sdn Bhd (10km) Bee Hua Industrial Gases Sdn Bhd (38km)	Southern Industrial Gas Sdn. Bhd. (14.2 km)
Power supply	Chenderoh Hydroelectric Power Plant, Chenderoh Lake (114km) Sungai Siput Large Scale Solar Power Plant (136 km)	Empangan Gunung Pulai (78km) Solar Farm Uitm Masai (25km)	Murum Hydro Power Generation Sdn. Bhd. (179.4 km)
Water supply	Lembaga Air Perak (7km)	Syarikat Air Johor Sdn Bhd (10km)	Jabatan Bekalan Air Luar Bandar Bintulu Divisional

			(1.9 km)
Transport Facilities	79km to Sultan Azlan Shah Airport	Senai International Airport (60 km)	Bintulu Airport (18.8 km)
Port Location	Lumut Maritime Terminal (0.5km) Lumut Port (15km)	Johor Port Pasir Gudang (9km) Tanjung Langsat Port (6.3km)	Bintulu Port (14.2 km)
Availability of labor	Resident of Mulia Resident of Bakti	Residents of Sri Aman Residents of Pasir Putih	Taman Kemenra Raya Taman Kemenra Sutera
Availability of Utilities and Infrastructure	Electric Supply Water Supply Near to hospital, school, and resident area	Electric Supply Water Supply Near to hospital, school, and resident area	Electric Supply Water Supply Near to hospital, school, and resident area
Nearby river	Manjung River (9.2km) Setiawan River (5km)	Pahlawan River (2.1km) Jonglak River (6.7 km) Perapat River (5.5. km)	Kemenra River (24.4 km)
Railway Facilities	Batu Gajah Railway Station (69km)	Terminal of Pasir Gudang, KTMB (12.4 km)	Not available
Roadway facilities	Lumut Highway (20km) WCE Autobahn (25km)	Pasir Gudang Highway (28.3 km) Senai Desaru Highway (51km)	Pan Borneo Highway (5 km)
Population	156,234	231, 832	114,058
Site characteristics	Barren and flat land type Some big firms exist in the neighborhood like H&R ChemPharm Asia Sdn Bhd and PGEO Edible Oils Sdn. Bhd. (Lumut Division) (14202-V)	Medium-Heavy Industrial land, flat and barren land. Some big firms exist in the neighborhood like MSM Sugar Refinery, Eternal Materials Sdn Bhd Plant	Flat industrial land
Waste disposal	Standard B	Standard B	Standard B
Type of industrial area	Medium and heavy industrial area	Medium industrial area	Medium industrial area

7.5 QUANTITATIVE FACTOR RATING

The selection amongst the three locations is eventually made based on the scoring method's highest value. The table below displays the weightage and score system for site selection. Based on the factor weights as displayed in the Table 7.2 below, the score value is distributed based on Table 7.3.

Table 7.2 Weightage for evaluation of location criteria for plant

Factors (Marks)	5-4	3	0-2
Land area	Sufficient for further expansion	Sufficient	Insufficient
Price	Cheap	Acceptable	Expensive
Raw material supply	Within distance of 50km	Within distance less than 100km	Within distance more than 100km
Power supply	Sufficient and low cost	Medium amount and cost	Insufficient and high cost
Water supply	Within distance of 50km	Within distance less than 100km	Within distance more than 100km
Transport facilities	Complete	Medium	Less
Port location	Distance less than 50km	Distance less than 100Km	Distance more than 100Km
Availability of labor	More than 100,000	More than 50,000	Less than 50,000
Availability of Utilities and Infrastructure	Complete	Medium	Less

Table 7.3 Quantitative factor rating for location decision

Factors	Factor Weight Rating (Weight %)	Merit Rating					
		Puncak Alam Industrial Park Land		Tanjung Langsat Industrial Area		Industrial Land Kemena, Sarawak	
		Rating	Total	Rating	Total	Rating	Total
Land area	0.08	4	0.32	4	0.32	4	0.32
Price	0.10	4	0.40	5	0.50	4	0.40
Raw material supply	0.20	3	0.60	5	1.00	5	1.00
Power supply	0.10	3	0.30	5	0.50	3	0.30
Water supply	0.10	2	0.20	4	0.40	2	0.20
Transport facilities	0.08	4	0.32	2	0.16	4	0.32
Port location	0.07	1	0.07	3	0.21	3	0.21
Availability of labor	0.12	4	0.48	5	0.60	3	0.36
Availability of Utilities and Infrastructure	0.15	3	0.45	4	0.60	4	0.60
Total	-	3.14	-	4.29	-	3.71	

7.6 SELECTION OF THE SITE LOCATION

Selection of the site location is depending on the quantitative factor rating. From Table 7.3 Tanjung Langsat Industrial Area, Pasir Gudang in Johor is chosen as the plant due to number of reasons. Figure 7.1 shows the available industrial land in Tanjung Langsat, Johor.



Figure 7.1 The available industrial land in Tanjung Langsat.

Source: Google Maps (2022)

The proposed available land area will be 7 acres which costs RM 1.47 million. The high availability of raw materials, power and water supply also makes Tanjung Langsat Industrial Area the most suitable plant location. The power supply source is from the green technology which is using solar power from Solar Farm Uitm Masai. Additionally, it is 60 km from Senai International Airport while 6.3 km from Tanjung Langsat Port and 9 km from Johor Port Pasir Gudang. This enables the export of products via air and marine transportation services. Furthermore, the plant can be conveniently operated thanks to the site's proximity to important utilities or infrastructure and easy access to railway and roadway facilities. In a nutshell, Tanjung

Langsat Industrial Area met the essential requirements that could have a significant impact on the plant's productivity and sustainability.

7.7 PLANT LAYOUT

The location that we chose for our production is at Tanjung Langsat Industrial Area, Pasir Gudang, Johor. The area of the land is 5 acres. Plant layout is the effective arrangement for the industrial facilities, building, equipment in a plant. It is very important for the arrangement of all the component in the site layout to maximize the production at minimum cost.

The manufacturing unit like reactor, stripper, decomposer, and evaporator is better to place near to the control room so that it can be operated nicely. It is because that equipment operates at extreme conditions like high temperature which required proper attention from the operator. However, since the control room should be in the safer place and far away from the hazardous processes, so it is located adjacent to the processing area.

For the utilities room, the utilities like heater and cooler placed near to processing area. It is placed near to processing equipment for ready supply of utilities to give the most economics run of pipes to and from the process units. At production plant, there are some future expansion spaces on pipe alleys for future needs and service pipes oversized to allow future requirements. The administrative areas that include canteen, surau, car park, medical Center, fire station, power supply located in the other site of plant to keep away from hazardous processes to protect personnel from hazard. It is located near to main gate and have access to the roads. Each building had their access to the road. Laboratory and M&E workshop located beside production plant to ease the maintenance work.

Raw material and product and byproduct storage located near to loading bay which is at second gate. It is to ease the retrieving of raw material and to store the finished product. Meanwhile, the waste treatment plant is built near to production plant so that all the waste effluent stream can be directed to waste treatment plant easily. Wind direction is an important criterion to be considered. The wind direction of this

industrial area is southeast. So, the laboratory, administrative building, canteen and surau is placed in the northeast so that these building safe from fire. There are 3 assembly point to allow people gather during emergency. Flare is located at the end of site to prevent personnel hazard. The plan layout can be seen at Appendix B.

CHAPTER VIII

INDUSTRIAL SAFETY

8.1 INTRODUCTION

During the production phase of urea, any potential hazards that may occur in the plant will be identified in this chapter. Hazard is measured on the basis of the chemical, the operation of the device and its operating condition.

8.2 HAZARD IDENTIFICATION

Hazard identification is the first step in the risk assessment. Based on Hart (2021), hazardous materials are chemicals or substances that are classified as physical or health hazards. It needs to be identified in order to protect workers', workplaces', properties', and the environment's health and safety. Each hazard has its own set of side effects and damage potential. The sources of hazard include toxicity properties, flammability, reactivity, corrosiveness, and explosiveness. This information is based on material safety data sheets (MSDS). Table 8.1 below shows the hazard analysis, hazardous properties, and exposure limits for the materials used. Table 8.2 shows the inventory of the hazardous material.

Table 8.1 Hazard properties

Materials	Hazard analysis (NFPA rating)	Hazardous properties					Exposure limits (based on OSHA(PEL), United States)
		Toxicity	Flammability	Reactivity	Corrosiveness	Explosiveness	
Oxygen	Health: 3 Flammability: 0	Non-toxic	Non-flammable but can initiate fire or explosions or may increase the combustibility or oxidation rate of materials.	Powerful oxidiser, reacts exothermically with many materials, reacts with phosphine, hydrazine, hydrogen sulfide, ethers, alcohols, and hydrocarbons, reacts violently with reducing agents.	N/A	May explode if heated.	N/A
Hydrogen	Health: 0 Flammability: 4 Reactivity: 0	Non-toxic	Extremely flammable	Very reactive. Can combines with many elements to form hydrides.	Has a large influence on the corrosion of a stainless steel.	Can be explosive at concentrations of 18.3 – 59%.	Must not exceed 20 ppm
Nitrogen	Health: 0 Flammability: 0 Reactivity: 0	Non-toxic	Non-flammable	Can react violently with lithium, neodymium, titanium or magnesium to form nitrides under certain condition.	Non-corrosive	N/A	N/A
Ammonia	Health: 3 Flammability: 1 Reactivity: 0	toxic	Slight flammable gas	Reacts with oxidizing gases such as chlorine, bromine and other halogens. Reacts with acid and reducing agents.	Corrosive	If flames are accidentally extinguished, they may re-ignite explosively.	50 ppm averaged over an 8 hour work day
Ammonium carbamate	Health: 2 Flammability: 0	Non-toxic	Non-flammable	N/A	Highly corrosive	N/A	50 ppm averaged over an 8 hour

	Reactivity: 0						
Carbon dioxide	Health: 2 Flammability: 0 Reactivity: 0	High concentrations may cause rapid deterioration of the circulatory system.	Non-flammable	N/A	N/A	Heat of fire can build pressure in container and cause it to rupture	5000 ppm as an 8 hour time weighted average
Urea	Health: 0 Flammability: 0 Reactivity: 0	N/A	Non-flammable	Not reactive under ambient conditions	Non-corrosive	N/A	N/A

Table 8.2 Inventory of the hazardous material

Materials	Storage	Handling	Amount	Description amount
Oxygen	Keep in well-ventilated area	Never use oil or grease on the valves or regulators of an oxygen cylinder. It easily results in an explosion.	Pipeline 15 = 2796.35 kg/h	2796.35 kg/h oxygen is a by-product from electrolysis process and will be sell.
Nitrogen	The cylinder must be protected from direct sunlight, and mechanical damage.	Put on personal protective equipment (PPE). Always keep in place a removable valve cover while moving the cylinder. Never attempt to lift a cylinder by its cap as the cap is to protect the valve. The containers must be protected from any physical damage.	Pipeline 18 = 1641.88 kg/h	1641.88 kg/h nitrogen gas will be used and act as reactant at PBR, R-101 for ammonia synthesis.
Ammonia	Store in a well-ventilated area. Store the containers upright to keep them from falling or being knocked over. Install valve protection cap.	Put on personal protective equipment (PPE). Do not breath gas and avoid all contact with skin, eyes or clothing. Keep away from heat, hot surfaces and ignition sources. Use only non-sparking tools. Do not insert any object into cap openings that will make it damage and leak.	Pipeline 43 = 812.5 kg/h	812.5 kg/h ammonia gas will come out from decomposer, DP-101.
Carbon Dioxide	Store in well-ventilated area. Stored containers should be periodically checked for general conditions and leakage. Make sure that container valve guards in place.	Put on personal protective equipment (PPE) Protect containers from physical damage. Do not remove the labels provided by the supplier for the identification of the content. Do not eat, drink or smoke when using it.	Pipeline 27 = 3117 kg/h	3117 kg/h carbon dioxide act as reactant for urea synthesis at PFR, R-102 and stripping agent at stripper, S-101.
Urea	Store in well-ventilated area and well-sealed containers. Avoid storage near extreme heat and open flame	Put on personal protective equipment (PPE). Avoid contact with eyes, skin and clothing.	Pipeline 53 = 2095.68 kg/h	2095.68 kg/h granule urea which is the main product will be formed and will be sell.

8.3 LEGISTALTIVE REQUIREMENTS

In Malaysia, all chemical plant needs to follow and obeys the rules that has been stated and enforced by Malaysian government. The regulations, acts, rules and order are regulated under the Department of Occupational Safety and Health (DOSH) and Department of Environment (DOE), must be followed to ensure the safety, health and welfare of people at work and residents nearby. DOSH is under the Ministry of Human Resource while DOE is under Ministry of Natural Resources and Environment. There are three main legal requirements that need to be followed which are Environmental Quality Act 1974 (Act 127), Occupational Safety and Health Act 1994 (Act 514) and Factory and Machinery Act 1976 (Act 139).

8.3.1 Occupational Safety and Health Act 1994 (Act 514)

The Occupational Safety and Health Act (OSHA) 1994 is only implemented during the construction and operation stage of a project. According to the act, it shall be the duty of every employer and every self-employed person to ensure, so far as is practicable, the safety, health and welfare at work of all his employees and it shall be the duty of every employer and every self-employed person to conduct his undertaking in such manner as to ensure, not being his employees, who may be affected thereby are not thereby exposed to risks to their safety or health.

There is other regulation under OSHA 1994 that known as Control of Industrial Major Accident Hazards (CIMAH) that was introduced in 1996. It states that every manufacturer who undertakes an industrial activity shall as soon as he becomes aware of an imminent danger which may affect the safety of persons or the environment, take immediate action to rectify the situation and establish and maintain a good management system for controlling any major accident. Table 8.3 shows the application of Control of Industrial Major Hazards Regulation 1996 (CIMAH) to prevent people, property and environment from industrial major accident and mitigate the consequence of major accident.

Table 8.3 Control of Industrial Major Hazards Regulation (CIMAH) 1996

Category	Legal requirements	Applications
On-site emergency plan	OSHA 1994 [ACT 514] P.U. (A) 39/1996 (CIMAH Regulations 1996) PART IV Regulation 18	<ul style="list-style-type: none"> After consulting a Competent Person, manufacturer who has control of an industrial activity shall prepare and keep an up-to-date and adequate on-site emergency plan detailing how major accidents are to be dealt with on the site on which the industrial activity is carried on Manufacturer must ensure that the on-site emergency plan prepared in pursuance of sub regulation (1) is constantly updated to any material change made in the industrial activity and every person on the site who is affected by the plan is informed of its relevant provisions Manufacturer must prepare and submit the on-site emergency plan to the Director General at least three months before the commencement of the industrial activity
Off-site emergency plan	OSHA 1994 [ACT 514] P.U. (A) 39/1996 (CIMAH Regulations 1996) PART IV Regulation 21	<ul style="list-style-type: none"> Manufacturer must control of an industrial activity shall inform the local authority or port authority of the area that our industrial activity is considered capable of producing a major accident hazard and of the need for the preparation of an off-site emergency plan for the area surrounding the site which may be likely to be affected by a major accident. Off-site emergency plan should be practice and prepare in printed form for employees' knowledge
Demonstration of safe operation	OSHA 1994 [ACT 514] P.U. (A) 39/1996 (CIMAH Regulations 1996) Part III Regulation 10	<ul style="list-style-type: none"> Major hazard accidents must be identified, and the working person shall know the hazard information, training and equipment to ensure their safety
Information to the public	OSHA 1994 [ACT 514] P.U. (A) 39/1996 (CIMAH Regulations 1996) PART IV Regulation 22	Manufacturer must ensure that persons outside the site who are likely to be in an area which, in the opinion of the Director General, is likely to be affected by a major accident occurring at the site
Report on industrial activity	OSHA 1994 [ACT 514] P.U. (A) 39/1996 (CIMAH Regulations 1996) PART IV Regulation 14	<ul style="list-style-type: none"> Report prepared according to Schedule 6 (Sub regulation 14(1) and 15(1)) Information relating to every hazardous substance involved in the activity in relevant quantity as listed in Schedule 2 Information relating to the installation Information relating to the system of management for controlling the industrial activity Information relating to a potential major accident in the form of risk assessment
Application (Hazardous substance)	OSHA 1994 [ACT 514] P.U. (A) 39/1996 (CIMAH Regulations 1996) PART IV Regulation 12	<ul style="list-style-type: none"> Listing and identify hazardous substance on schedule 1 or schedule 2 Listing and label information of all hazardous and non-hazardous material and equipment Keep all hazardous in close and tight container with suitable wall storage material

Apart from that, guidelines on hazard identification, risk assessment and risk control (HIRARC) were introduced. The purpose of this guideline is to provide a systematic and objective approach to assessing hazards and their associated risks that will provide an objective measure of an identified hazard as well as provide a method to control the risk. According to HIRARC guidelines also, risk control shall be implemented at the source of the hazard, engineering control, administrative control, and personal protective equipment (PPE).

8.4 CONCEPT OF HAZARD SYSTEM

Hazard is defined as a chemical or physical condition that has the potential for causing fatality or injury to people or damage to property and the environment. In the process industry, hazard can be categorized as chemical hazard, thermodynamic hazard, mechanical hazard, health hazard, electrical and electromagnetic hazard. According to Marshall and Ruhemann (2001), the occurrence of the unwanted event is due to the realization of a “hazard system”. A hazard system mainly consists of hazard source, receptors, transmission paths and barriers. Table 8.4 shows the hazard system based on the overall production process while Table 8.5 shows the hazard system based on the selected process.

Table 8.4 Hazard system based on the overall production process

Component	Definition	Examples
Source	It has the capacity to be realized at many different levels of severity.	<ul style="list-style-type: none"> ▪ Reactor ▪ Pressure vessel such as phase separator and stripper ▪ Utilities such as heater and cooler ▪ Evaporator
Receptors	Suffer harm due to the realization of hazard.	<ul style="list-style-type: none"> ▪ Voluntary receptors – Operators of the equipment and workers at the production plant site ▪ Involuntary receptors – Residents and school children nearby the plant
Transmission paths	A medium via which the consequence of a hazard is “transferred” from the source to the receptor.	<ul style="list-style-type: none"> ▪ Thermal radiation transmission from explosion accident ▪ Dispersion in the air ▪ Leakage of chemical to nearby river or drainage system
Barriers	Physical and non-physical means planned to prevent, control, mitigate undesired event or accident	<ul style="list-style-type: none"> ▪ Physical barriers – Explosion proof control room ▪ Non-physical barriers – Scheduled inspection and maintenance, emergency response plan and training for operators

Table 8.5 Hazard system based on the selected process

Hazard Source	Hazard Category	Hazard Description	Transmission Path	Receptors	Barriers (Physical)	Barriers (Non-physical)
PEM electrolyser, E-101 producing oxygen and hydrogen gas	<ul style="list-style-type: none"> ▪ Chemical hazard ▪ Health hazard 	<ul style="list-style-type: none"> ▪ May explode if heated ▪ Oxygen is non-flammable, but readily supports combustion ▪ Hydrogen is a very flammable gas and may cause fires and explosions if leaked 	<ul style="list-style-type: none"> ▪ Thermal radiation transmission ▪ Dispersion in the air ▪ Leakage of hazardous chemicals 	<ul style="list-style-type: none"> ▪ Operators on duty ▪ Workers at plant site ▪ Residents nearby 	<ul style="list-style-type: none"> ▪ Personal protective equipment for operators ▪ Wall of unit operations housing the R-101 ▪ Explosion proof control room 	<ul style="list-style-type: none"> ▪ Regular maintenance and operation unit inspection ▪ Training for operators ▪ Emergency Response Plan (ERP)
Catalytic packed bed reactor, R-101 containing nitrogen and hydrogen gas	<ul style="list-style-type: none"> ▪ Chemical hazard ▪ Health hazard 	<ul style="list-style-type: none"> ▪ May explode if heated ▪ May displace oxygen and cause rapid suffocation ▪ Contact with rapidly expanding gas may cause burns or frostbite ▪ Hydrogen is a very flammable gas and may cause fires and explosions if leaked 	<ul style="list-style-type: none"> ▪ Thermal radiation transmission ▪ Dispersion in the air ▪ Leakage of hazardous chemicals 	<ul style="list-style-type: none"> ▪ Operators on duty ▪ Workers at plant site ▪ Residents nearby 	<ul style="list-style-type: none"> ▪ Personal protective equipment for operators ▪ Explosion proof control room 	<ul style="list-style-type: none"> ▪ Regular maintenance and operation unit inspection ▪ Training for operators ▪ Emergency Response Plan (ERP)
Phase separator, PS-101 separates flammable gas and liquid at high pressure	<ul style="list-style-type: none"> ▪ Chemical hazard ▪ Health hazard 	<ul style="list-style-type: none"> ▪ May cause vessel rupture due to high operating pressure ▪ Leakage of hazardous chemicals that may have high flammability 	<ul style="list-style-type: none"> ▪ Thermal radiation transmission ▪ Dispersion in the air ▪ Overpressure ▪ Leakage of hazardous chemicals 	<ul style="list-style-type: none"> ▪ Operators on duty ▪ Workers at plant site ▪ Residents nearby 	<ul style="list-style-type: none"> ▪ Personal protective equipment for operators ▪ Explosion proof control room 	<ul style="list-style-type: none"> ▪ Regular maintenance and operation unit inspection ▪ Training for operators ▪ Emergency Response Plan (ERP)
Plug flow reactor, R-102 containing	▪ Thermodynamic hazard	▪ May cause vessel rupture due to high	▪ Thermal radiation transmission	▪ Operators on duty	▪ Personal protective	<ul style="list-style-type: none"> ▪ Regular maintenance and

flammable gas which operates at high temperature and pressure	<ul style="list-style-type: none"> ▪ Chemical hazard ▪ Health hazard 	<ul style="list-style-type: none"> ▪ operating temperature and pressure ▪ Leakage of hazardous chemicals that may have high flammability ▪ Explosion may occur if the temperature and pressure exceed the limit that reactor can hold 	<ul style="list-style-type: none"> ▪ Dispersion in the air ▪ Overpressure ▪ Leakage of hazardous chemicals 	<ul style="list-style-type: none"> ▪ Workers at plant site ▪ Residents nearby 	<ul style="list-style-type: none"> ▪ equipment for operators ▪ Explosion proof control room 	<ul style="list-style-type: none"> ▪ operation unit inspection ▪ Training for operators ▪ Emergency Response Plan (ERP)
Stripper, S-101 containing flammable gas which operates at high temperature and pressure	<ul style="list-style-type: none"> ▪ Thermodynamic hazard ▪ Chemical hazard ▪ Health hazard 	<ul style="list-style-type: none"> ▪ May cause vessel rupture due to high operating temperature and pressure ▪ Leakage of hazardous chemicals that may have high flammability ▪ Explosion may occur if the temperature and pressure exceed the limit that vessel can hold 	<ul style="list-style-type: none"> ▪ Thermal radiation transmission ▪ Dispersion in the air ▪ Overpressure ▪ Leakage of hazardous chemicals 	<ul style="list-style-type: none"> ▪ Operators on duty ▪ Workers at plant site ▪ Residents nearby 	<ul style="list-style-type: none"> ▪ Personal protective equipment for operators ▪ Explosion proof control room 	<ul style="list-style-type: none"> ▪ Regular maintenance and operation unit inspection ▪ Training for operators ▪ Emergency Response Plan (ERP)
Decomposer, DP-101 containing flammable gas which operates at high temperature and pressure	<ul style="list-style-type: none"> ▪ Thermodynamic hazard ▪ Chemical hazard ▪ Health hazard 	<ul style="list-style-type: none"> ▪ May cause vessel rupture due to high operating temperature and pressure ▪ Leakage of hazardous chemicals that may have high flammability ▪ Explosion may occur if the temperature and pressure exceed the limit that vessel can hold 	<ul style="list-style-type: none"> ▪ Thermal radiation transmission ▪ Dispersion in the air ▪ Overpressure ▪ Leakage of hazardous chemicals 	<ul style="list-style-type: none"> ▪ Operators on duty ▪ Workers at plant site ▪ Residents nearby 	<ul style="list-style-type: none"> ▪ Personal protective equipment for operators ▪ Explosion proof control room 	<ul style="list-style-type: none"> ▪ Regular maintenance and operation unit inspection ▪ Training for operators ▪ Emergency Response Plan (ERP)

Evaporator, EV-101 containing hot steam at high temperature	<ul style="list-style-type: none"> ▪ Thermodynamic hazard ▪ Health hazard 	<ul style="list-style-type: none"> ▪ Explosion may occur if the temperature exceeds the limit that evaporator can hold 	<ul style="list-style-type: none"> ▪ Thermal radiation transmission 	<ul style="list-style-type: none"> ▪ Operators on duty ▪ Workers at plant site ▪ Residents nearby 	<ul style="list-style-type: none"> ▪ Personal protective equipment for operators ▪ Explosion proof control room 	<ul style="list-style-type: none"> ▪ Regular maintenance and operation unit inspection ▪ Training for operators ▪ Emergency Response Plan (ERP)
Maintenance and cleaning process	<ul style="list-style-type: none"> ▪ Physical hazard ▪ Chemical hazard ▪ Health hazard 	<ul style="list-style-type: none"> ▪ Falling from height which may cause physical injury and even death ▪ Inhalation of toxic gases which may cause difficulty in breathing and even death ▪ Slippery or wet floor which may cause physical injury 	<ul style="list-style-type: none"> ▪ Physical contact 	<ul style="list-style-type: none"> ▪ Operators on duty ▪ Workers at plant site 	<ul style="list-style-type: none"> ▪ Personal protective equipment for operators 	<ul style="list-style-type: none"> ▪ Regular maintenance and operation unit inspection ▪ Training for operators and workers ▪ Emergency Response Plan (ERP)

8.5 HAZARD CASE STUDIES

Most accidents in urea manufacturing plants are due to the possibility of ammonia release and explosions due to the formation of gaseous mixtures in reactors. The hazard case needs to be learnt to evaluate the risk and prevent any potential accidents from happening by taking lessons from the accident that have happened before.

8.5.1 Ammonia Leakage at Vijaipur, India

On 26 August 1992, the pressure drop was seen in the outlet stream of the ammonia pump before entering the urea reactor. During the investigation, it was discovered that the safety valve located at the discharge end of the pump was defective. Because of that, the safety valve was replaced by the eight employees. While it was being replaced, the isolation valve that stopped the liquid flow from the mainline failed. At a pressure of 23 kg/sq cm, liquid ammonia burst out, vaporizing in seconds to form suffocating clouds of deadly gas (Vania 2009). Some people were utterly soaked in the liquified ammonia. Consequently, eleven persons died, and ten were injured even though their colleagues had tried to diffuse the gas with water spray.

After the ammonia gas was released, the emergency siren was activated, but no one followed the responsibility outlined in the onsite emergency plan. Not just that, the nearest fire call point was broken to notify the fire department about the accident. Luckily, the first fire tender arrived three minutes after the accident happened. When the accident had been controlled, the cause of the valve failure was investigated, and it was discovered that the isolation valve collar had broken, allowing the valve spindle to move upward. Because of that, the isolation valve collar was broken, resulting in ammonia leakage (Baboo 2018).

The lesson that can learn from this incident is to make sure that the valves have been marked correctly with identified numbers. Next, everyone in the plant needs to strictly follow the emergency plan to avoid and reduce the effect and impact of the accident. The escape route from the ammonia pump platform should be increased to facilitate the person's escape.

8.5.2 Urea Synthesis Reactor Exploded at Pingyin, China

On 21 March 2005, a urea synthesis plant at Pingyi county, Shandong province, urea synthesis reactor exploded, killing four persons, and seriously injuring 32 people. The company had losses of up to 30 million RMB Yuan or 4.3 million US dollars due to this accident. The most probable cause of the explosion is the severe stress corrosion cracking (SCC) lengthened 900 mm in the longitudinal direction and penetrated all layers in the urea reactor, as shown in Figure 8.1.

When SCC happened, the liner was unable to withstand the heavy load of internal pressure and resulting in tearing destruction, leading the medium in the reactor to leak rapidly, and the boiling liquid expansion vapour explosion occurred. The urea synthesis reactor wall is multi-layered, and each cylinder in the reactor distributes the leak detection steam. Some reason for SCC fracture is because of the looseness of the connection thread between leak detection nozzles and the alkali ions in leak detection steam were concentrated in the gaps between multilayer plates of the reactor (Wang et al. 2009).



Figure 8.1 The fracture on the urea reactor cylinder

Source: Wang et al. 2009

8.6 HAZARD AND OPERABILITY STUDY (HAZOP)

Hazard and operability analysis (HAZOP) is a method for analysing, evaluating, and managing risks. The HAZOP's goal is to figure out how the system or plant deviates from the design intent, creating a risk to people and equipment, as well as causing operational issues. It is a procedures or changes for eliminating or reducing the

probability of operating deviations. The HAZOP studies are conducted on the major equipment in the plant which includes electrolyser (E-101), catalytic packed bed reactor (R-101), phase separator (PS-101), plug flow reactor (R-102), and stripper (S-101). It can be seen at Appendix C.

8.7 HAZARD IDENTIFICATION, RISK ASSESSMENT, AND RISK CONTROL (HIRARC)

The Hazard Identification, Risk Assessment, and Risk Control (HIRARC) Assessment is a required risk assessment under the Occupational Safety and Health Act 1994 (Act 154) for employers to ensure that their workplaces are safe for employees and others associated with the production plant. It is used to identify any factors that may cause harm in the production plant and to implement preventive measures to control these risks. A qualitative analysis is used to describe the potential severity and likelihood of hazards using words. The HIRARC Guidelines by DOSH Malaysia also provide quantitative ratings for both the likelihood of an occurrence and the severity of a hazard, as shown in Table 8.6 and Table 8.7, respectively.

Table 8.6 Quantitative rating of the likelihood of an occurrence

Likelihood	Example	Rating
Most likely	The most likely result of the hazard/ event being realized	5
Possible	Has a good chance of occurring and is not unusual	4
Conceivable	Might be occur at sometimes in the future	3
Remote	Has not been known to occur after many years	2
Inconceivable	Is practically impossible and has never occurred	1

Table 8.7 Quantitative rating of the severity of a hazard

Severity	Example	Rating
Catastrophic	Numerous fatalities, irrecoverable property damage and productivity	5
Fatal	Approximately one single fatality major property damage if hazard is realized	4
Serious	Non-fatal injury, permanent disability	3
Minor	Disability but not permanent injury	2
Negligible	Minor abrasions, bruise, cuts, first aid type injury	1

Relative risk can be calculated by using the formula as below.

$$\text{Rating of Likelihood} \times \text{Rating of Severity} = \text{Relative Rating of Risk}$$

The calculated relative rating of risk can be analyzed and determine its severity by using the risk matrix as shown in Table 8.8 together with the explanation of each level as in Table 8.9 below with the colour in the risk matrix indicates the risk level, whereby red colour indicates high risk level, yellow colour indicates medium risk level, and green colour indicates low risk level.

Table 8.8 Risk matrix in HIRARC Assessment

Likelihood (L)	Severity (S)				
	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

Table 8.9 Description of risk matrix in HIRARC Assessment

Risk	Description	Action
15-25	High	A HIGH risk requires immediate action to control the hazard as detailed in the hierarchy of control. Actions taken must be documented on the risk assessment form including date for completion.
5-12	Medium	A MEDIUM risk required a planned approach to control the hazard and applies temporary measure if required. Actions taken must be documented on the risk assessment from which includes the date for completion.
1-4	Low	A risk identified as LOW may be considered as acceptable and further reduction may not be necessary. However, if the risk can be resolved quickly and efficiently, control measures should be implemented and recorded.

The HIRARC studies are conducted on the major equipment in the plant which includes electrolyser (E-101), catalytic packed bed reactor (R-101), phase separator (PS-101), plug flow reactor (R-102), and stripper (S-101). It can be seen at Appendix C.

8.8 DISCUSSION ON THE HIRARC ASSESSMENT RESULT

The HIRARC assessment is conducted based on the five major equipment that involved in the production plant. Based on the results of the HIRARC assessment, a total of 25 potential hazards were identified from the respective major equipment in the plant. Figure 8.2 shows the summary of the rating of risk in HIRARC assessment.

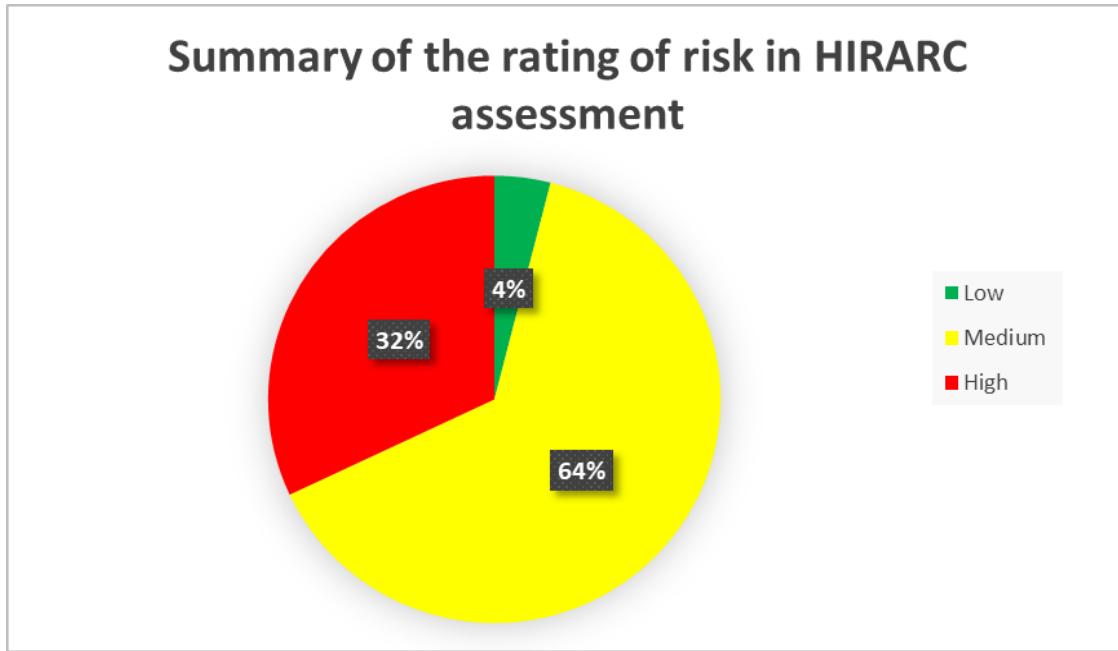


Figure 8.2 Summary of the rating of risk in HIRARC assessment

Among the 25 hazards identified in the overall plant, there are 16 (64%) medium risk potential hazards, 8 (32%) are high risk potential hazards and 1 (4%) are low risk potential hazards. The majority of risks, 64% are classified as medium risk which is 16 medium risk level among the total 25 risk rating. This requires risk planning to identify, prioritize and manage these risks as well as implementing temporary measures if necessary. Actions taken should be documented on the risk assessment form including the completion date. Besides, there are also 32% high risk levels identified, which is 8 high risk level among the total 25 risk rating. Therefore, immediate action is necessary to control these hazards, as detailed in the hierarchy of control. These actions should also be documented on the risk assessment form. To reduce risks as much as possible, it is important to implement recommended control measures based on the HIRARC Guidelines, including engineering controls, administrative controls and personal protective equipment (PPE). The safety level in the production plant can also be improved through the establishment of good working procedures, regular OSH training for workers and ongoing safety campaigns. Lastly, there is only 1 low risk level among the 25-risk rating, which can be considered acceptable and may not require further reduction. However, if these risks can be quickly and efficiently addressed, control measures should be implemented and recorded to prevent potential hazards in the future.

CHAPTER IX

ECONOMIC ANALYSIS

9.1 INTRODUCTION

Economic analysis is one of the key elements in determining the profitability of new plant and it can predict how profitable the facility will be. A few factors in economic analysis must be determined, including return on investment (ROI), payback time, net present value (NPV), internal rate of return, and discounted cash flow rate of return (DCFRR).

9.2 ESTIMATION OF TOTAL CAPITAL INVESTMENT, CT_C

Before an industrial plant can be designed and put into operation, a large amount of money must be available to pay for all the necessary machinery and equipment, the facility's construction site, utility services, buildings, facilities, and start-up costs for starting the plant operation. Total Capital Investment is the sum of fixed capital investment, the working capital and capital to purchased land for the plant.

$$C_{TC} = C_{FC} + C_{WC} + C_L$$

Where,

C_{TC} = Total capital investment

C_{FC} = Fixed capital investment

C_{WC} = Working capital

C_L = Capital to purchase land for the plant

9.2.1 Fixed Capital Investment, C_{FC}

Fixed capital investment may be divided into two components which are manufacturing fixed capital investment (direct cost) or non-manufacturing fixed capital investment (indirect cost). It also can be summarized as the equation below.

$$\text{Fixed Capital Investment, } C_{FC} = \text{Direct costs} + \text{Indirect costs}$$

Total costs of site preparation, foundation, all supporting vessels and equipment, piping, instrumentation, insulation, and auxiliary facilities expenditures are referred as direct costs. While any plant expenses that are not directly connected to a process operation or construction overhead are referred as indirect costs.

a. Direct cost

Direct cost is the capital necessary for the installed process equipment including all elements that are required for full operation such as site preparations, foundations, all supporting vessels and equipment, piping, instrumentation, insulation, auxiliary facilities and so on. In our plant, the equipment that are needed to run the process has shown in table 9.1. Formula to calculate the purchased equipment cost is shown below.

$$C_e = a + bS^n \quad \dots(9.1)$$

Where,

a, b = constant

S = Size of parameter

n = Exponent for that type of equipment

The parameter for the formula of purchased equipment cost is tabulated in Table 9.1 below.

Table 9.1 Parameter of calculation of purchased equipment cost

Equipments	Unit for size, S	Quantity	a	b	n	S
Pump	Flow litre/s	7	3300	48	1.2	500
Storage tank	Capacity, m ³	2	5700	70	0.7	4000
Activated carbon filter, AF-101	Capacity, m ²	1	76000	54000	0.5	1.4
Electrodionization module, ED-101	Volume, m ³	1	61500	32500	0.8	75.16
Heater	m ²	1	28000	54	1.2	20
PEM Electrolyser, E-101	Volume, m ³	1	61500	32500	0.8	78.43
Demister	Capacity, m ³	2	76000	54000	0.5	1.4
Cooler	m ²	7	28000	54	1.2	20
Blower	m ³ /hr	4	4200	27	0.8	5000
Catalytic packed bed reactor, R-101	Volume, m ³	1	14000	15400	0.7	100
Plug flow reactor, R-102	Shell mass, kg	1	-2500	200	0.6	69200
Compressor	Drive power, kW	4	8400	3100	0.6	29000
Phase separator, PS-101	Shell mass, kg	1	11600	34	0.85	1702.94
Stripper, S-101	Shell mass, kg	1	-400	230	0.6	69200
Decomposer, DP-101	Area, m ²	1	-45000	56000	0.3	180
Evaporator, EV-101	Area, m ²	1	17000	13500	0.6	640
Granulator, G-101	Evap rate kg/hr	1	190000	180	0.9	4000
Condenser, CD-101	m ²	1	28000	54	1.2	20
Conveyer, TC-101	Length, m	1	41000	730	1.0	10
Heat exchanger	m ²	2	28000	54	1.2	20
Waste Treatment Plant						
Equalization tank	m ³	1	5800	1600	0.7	21.14
Coagulation and Flocculation Tank	m ³	1	5800	1600	0.7	1.4
Sludge tank	m ³	1	5800	1600	0.7	21.06
Aeration tank	m ³	1	5800	1600	0.7	52.78
Clarifier	m ³	1	5800	1600	0.7	42.30
Storage tank	m ³	1	5700	70	0.7	4000
Press filter	m ³	1	5800	1600	0.7	1.4

Sumber: Towler & Sinnott 2013

The cost of purchased equipment that are calculated based on the equation 1 is then used to calculate the purchased equipment cost at present time by using the formula below. The purchased equipment cost is then converted into Malaysian Ringgit.

$$\text{Purchased equipment cost at present time, } C_s = C_D \left(\frac{I_s}{I_D} \right) \quad \dots(9.2)$$

Where,

C = Cost of the item

I_s = Cost index for current time

I_D = Cost index for past time

Based on the Marshall Swift Valuation Services 2018, the Marshall Swift Index in 2010 and 2022 is 1446.5 and 2121.1 respectively. The direct cost for the plant is summarized in Table 9.2 and Table 9.3 below.

Table 9.2 Purchased equipment cost and installation cost

Equipments	Current purchased equipment cost, C_s (RM million)	Installation factor (%)	Installation cost (RM million)
Pump	5.97	0.4	2.39
Storage tank	0.37	0.63	0.23
Activated carbon filter, AF-101	0.90	0.47	0.42
Electrodionization module, ED-101	6.99	0.69	4.82
Heater	0.19	0.3	0.06
PEM Electrolyser, E-101	7.22	0.3	2.17
Demister	1.79	0.25	0.45
Cooler	1.34	0.3	0.40
Blower	0.74	0.25	0.18
Catalytic packed bed reactor, R-101	2.57	0.3	0.77
Plug flow reactor, R-102	1.01	0.3	0.30
Compressor	38.02	0.49	18.63
Phase separator, PS-101	0.20	0.25	0.05
Stripper, S-101	1.18	0.3	0.35
Decomposer, DP-101	1.42	0.25	0.35
Evaporator, EV-101	4.28	0.3	1.29

Granulator, G-101	3.23	0.3	0.97
Condenser, CD-101	0.19	0.3	0.06
Conveyer, TC-101	0.31	0.4	0.12
Heat exchanger	0.38	0.3	0.12
Waste Treatment Plant	0.62	0.6	0.37
Total	7894		34.52

Table 9.3 Direct cost estimation

Components	Percentage of Purchased Equipment Cost (%)	Cost (RM million)
Purchased equipment (delivered)	-	78.94
Purchased equipment installation	-	34.52
Insulation	9	7.10
Instruments and controls (installed)	13	10.26
Piping (installed)	31	24.47
Electrical systems (installed)	40	31.58
Buildings (including services)	47	37.10
Yard improvements	15	11.84
Service facilities (installed)	55	43.42
Total		279.23

b. Indirect cost

Indirect cost is the capital required for all plant elements that are not directly related to the process operation and construction overheads. The construction overhead cost includes engineering expenses, miscellaneous construction costs, contractor's fees and contingencies, field office and supervision expenses, and home office expenses,. The indirect cost for the plant is summarized in the Table 9.4 below.

Table 9.4 Indirect cost estimation

Components	Percentage of Direct-Equipment Cost (%)	Cost (RM million)
Engineering and supervision	8	22.34
Legal expenses	4	11.17
Construction expenses	10	27.92

Contractor's fee	5	13.96
Contingencies	8	22.34
Total		97.73

c. Fixed capital investment, C_{FC}

$$\begin{aligned} \text{Fixed capital investment, } C_{FC} &= \text{Direct cost} + \text{Indirect cost} \\ &= \text{RM } 279.23 \text{ million} + \text{RM } 97.73 \text{ million} \\ &= \text{RM } 376.96 \text{ million} \end{aligned}$$

9.2.2 Land Capital, C_{LC}

Land capital is referring as the capital to purchase land for the site to construct the plant. The selected plant location is at Tanjung Langsat Industrial Area, Pasir Gudang, Johor. The plant size is estimated in 7 acres and the cost of land is RM1,470,150 per acre. Land capital is calculated as below:

$$\begin{aligned} \text{Land capital, } C_{LC} &= \text{RM } 1,470,150 \times 7 \text{ acres} \\ &= \text{RM } 10.29 \text{ million} \end{aligned}$$

9.2.3 Working Capital, C_{WC}

Working capital is the money needed to start up a plant. In other words, working capital is refers to funds used to purchase raw materials and supplies to be kept as stock, finished products in stock and semi-finished materials in the process of being manufactured, accounts receivable, cash kept on hand for monthly payment of operating expenses, such as salaries, wages and raw material and supplies purchases, accounts payable and taxes payable. The working capital in the plant is 15% of the total capital investment (Towler & Sinnott 2013).

$$C_{WC} = 0.15 C_{TC}$$

$$C_{WC} = 0.15 (C_{FC} + C_L + C_{WC})$$

$$0.85C_{WC} = 0.15C_{FC} + 0.15C_L$$

$$0.85 C_{WC} = 0.15(\text{RM } 376.96 \text{ million}) + 0.15(\text{RM } 10.29 \text{ million})$$

Working capital, C_{WC} = RM 68.34 million

9.2.4 Summary of Total Investment Cost

Table 9.5 shows the summary of total capital investment which includes fixed capital investment, land capital and working capital.

Table 9.5 Summary of total capital investment

Types	Cost (RM million)
Fixed capital investment, C_{FC}	376.96
Land capital, C_{LC}	10.29
Working capital, C_{WC}	68.34
Total capital investment, C_{TC}	455.58

9.3 ESTIMATION OF TOTAL PRODUCT COST, C_{TPC}

Total product cost is the total costs of operating the plant, selling the products, recovering the capital investment and contributing to corporate functions such as management and research and development. Total cost is divided into two categories which are manufacturing costs and general expenses. Total product cost can be calculated by using the formula below:

$$\text{Total product cost} = \text{Manufacturing cost} + \text{General expenses}$$

9.3.1 Cost of Manufacturing (Com)

Manufacturing costs is all costs that are directly related to a manufacturing process or the physical equipment of a process plant itself. The manufacturing costs are divided into three categories which are variable production costs, fixed charges and plant overhead costs. Manufacturing costs can be calculated by using the formula below:

$$\text{Manufacturing cost} = \text{Variable production costs} + \text{Fixed charges} + \text{Plant overhead cost}$$

a. Variable production cost

Variable production costs are the costs that include expenses directly associated with the manufacturing operation. Variable production costs include the costs of raw materials, direct operating labour, utilities, operating supervisory and clerical assistance, plant maintenance and repairs, operating supplies, laboratory charges, patents and royalties.

i. Raw material

The raw materials that are used in the production plant are water, nitrogen gas and carbon dioxide gas. The cost of these raw materials is tabulated in the Table 9.6 below.

Table 9.6 Cost of raw material

Raw material	Mass flowrate (kg/hr)	Mass flowrate (kg/year)	Price per unit (RM/kg)	Price (RM million/year)
Water	3148.17	26520184.08	0.003	0.09
Nitrogen	1641.88	13831197.12	2.622	36.27
Carbon dioxide	3117.00	26257608.00	8.120	213.21
Total	7907.05	66608989.20	10.745	715.73

ii. Utilities

The cost for utilities, such as steam, electricity, process and cooling water, compressed air, natural gas, waste treatment and disposal, varies widely depending on the amount required, plant location, and source. Utility costs for chemical processes plant is usually approximately 15 to 20 percent of the total product cost (Peters & Timmerhaus 1991). In our plant, the utility costs are approximately 15 percent of the total product cost due to the plant have recycling systems.

$$\text{Utilities cost} = 0.15 C_{TPC}$$

iii. Operating Labour

Operating labour may be divided into both skilled and unskilled labour. In calculating the cost of operating labour, the number of workers and the number of shifts that are needed in each equipment is determined. The cost of operating labour is listed in Table 9.7 and Table 9.8.

Table 9.7 Labour requirement

Equipments	Number of equipment	Operators per shift per equipment	Operators per shift
Pump	7	0.00	0.00
Storage tank	2	0.00	0.00
Activated carbon filter, AF-101	1	0.00	0.00
Electrodionization module, ED-101	1	0.00	0.00
Heater	1	0.50	0.50
PEM Electrolyser, E-101	1	0.50	0.50
Demister	2	0.00	0.00
Cooler	7	0.10	0.70
Blower	4	0.20	0.80
Catalytic packed bed reactor, R-101	1	0.50	0.50
Plug flow reactor, R-102	1	0.50	0.50
Compressor	4	0.15	0.60
Phase separator, PS-101	1	0.35	0.35
Stripper, S-101	1	0.35	0.35
Decomposer, DP-101	1	0.35	0.35
Evaporator, EV-101	1	0.25	0.25
Granulator, G-101	1	1.00	1.00
Condenser, CD-101	1	0.10	0.10
Conveyer, TC-101	1	0.00	0.00
Heat exchanger	2	0.10	0.20
Waste Treatment Plant	1	2.00	2.00
Total Labour			8.70 (9 labour)

Table 9.8 Operating labour cost estimation

Condition	Value/Unit
Operation hour per day	24
Operation hour in one year	8424
Shift per day	2
Hour per shift	12
Total shift per year	702
Number of shifts per week per operator	6
Number of shifts per year per operator	301
Operator required per shift	2.33
Total operator per shift	9.0
Total operating labour (per day)	20.99
Labour monthly salary (RM/month)	1500
Total labour monthly salary (RM month)	21000
Cost of total operating labour (RM million/year)	0.252

iv. Operating supervision and clerical assistance

Operating supervision and clerical assistance are required in a manufacturing operation plant. These operating supervision and clerical assistance are closely related to the total amount of operating labour, complexity of the operation and product quality standards. The operating supervision and clerical assistance cost is about 15 percent of the operating labour cost (Peters & Timmerhaus 1991).

$$\text{Operating supervision and clerical assistance cost} = 0.15 \text{ (operating labour cost)}$$

v. Maintenance and repairs

Maintenance and repairs are one of the crucial expenses required to maintain the plant in a good repair regardless of the amount of production. Maintenance costs include the cost of replacing or repairing parts and equipment as well as the cost of labour needed to carry out the maintenance work. In our plant, the maintenance and repairs cost are 6 percent of the fixed-capital investment (Peters & Timmerhaus 1991).

$$\text{Maintenance and repairs cost} = 0.06 C_{FC}$$

vi. Operating supplies

Operating supplies such as charts, lubricants, and test chemicals are things required during plant operation but it cannot be considered as raw materials or maintenance and repair materials. The operating supplies cost in our plant is 15 percent of the total cost for maintenance and repairs (Peters & Timmerhaus 1991).

Operating supplies = 0.15 (Maintenance and repairs cost)

vii. Laboratory charges

Laboratory charges cost is used for the laboratory tests in the plant which can control the operation of the plant and maintain the quality of the product. The laboratory charges cost in our plant is 20 percent of the operating labour cost (Peters & Timmerhaus 1991).

Laboratory charges = 0.20 (Operating labour cost)

viii. Patents and royalties

The cost of using inventions owned by others is reflected in patents and royalties, which must be paid based on the volume of content generated. Despite the fact that the company involved in the operation already had the original patent, there are some costs associated with the development and acquisition of the patent that are also counted as the cost of patents and royalties. The cost of patents and royalties in our plant is 3 percent of the total product cost (Peters & Timmerhaus 1991).

Patents and royalties = 0.03 (Total product cost)

The summary of variable production cost is tabulated in Table 9.9.

Table 9.9 Summary of variable production cost

Parameter	Cost factor	Equation cost (RM million)	Cost (RM million)
Raw material	-	715.13	715.13
Utilities	0.15 C _{TPC}	0.15 C _{TPC}	238.26

Operating labour	-	0.252	0.252
Operating supervision and clerical assistance	0.15 (Operating labour)	0.0378	0.0378
Maintenance and repairs	0.06 C _{FC}	22.62	22.62
Operating supplies	0.15 (Maintenance and repairs)	3.3926	3.3926
Laboratory charges	0.20 (Operating labour)	0.0504	0.0504
Patents and royalties	0.03 C _{TPC}	0.03 C _{TPC}	47.65
Variable production cost			1027.99

b. Fixed charges

Fixed charges are the cost that change little or not at all with the amount of production. Fixed charges include the local taxes, insurance and interest. Table 9.10 show the cost of fixed charges.

Table 9.10 Fixed charges cost estimation

Parameter	Cost factor	Cost (RM million)
Local taxes	0.04 C _{FC}	15.08
Insurance	0.01 C _{FC}	3.77
Financing (Interest)	0.1 C _{FC}	37.70
Fixed charges cost		56.54

c. Plant overhead cost

Plant overhead cost is the cost required for routine plant services such as nonmanufacturing machinery, equipment and buildings. The plant overhead cost for chemical plants is about 50 to 70 percent of the total cost for operating labour, operating supervision and clerical assistance and maintenance and repairs. In our plant, the plant overhead cost is 50 percent of the total cost for operating labour, operating supervision and clerical assistance and maintenance and repairs.

Plant overhead cost = 0.50 (Operating labour + operating supervision and clerical assistance + maintenance and repairs)

Plant overhead cost = 0.50 (0.252+0.0378+22.62)

Plant overhead cost = RM 11.45 million

Manufacturing cost is calculated in the equation below.

$$\begin{aligned}
 \text{Manufacturing cost} &= \text{Variable production cost} + \text{fixed charges} + \text{plant overhead cost} \\
 &= \text{RM } 1027.99 \text{ million} + \text{RM } 56.54 \text{ million} + \text{RM } 11.45 \text{ million} \\
 &= \text{RM } 1095.99 \text{ million}
 \end{aligned}$$

9.3.2 General Expenses (Ge)

General expenses can be classified into administrative costs, distribution and marketing cost and research and development cost. Table 9.11 shows summary of general expenses in our plant.

Table 9.11 Summary of general expenses

Parameter	Cost factor	Cost (RM million)
Administrative cost	0.06 C _{TPC}	95.30
Distribution and marketing cost	0.20 C _{TPC}	317.68
Research and development cost	0.05 C _{TPC}	79.42
Total General Expenses		492.40

9.3.3 Total Product Cost (C_{tpc})

Total product cost of our production plant is calculated as below:

$$C_{TPC} = \text{Manufacturing cost} + \text{General Expenses}$$

$$= \text{RM } 1095.99 \text{ million} + \text{RM } 492.40 \text{ million}$$

$$= \text{RM } 1588.39 \text{ million}$$

9.4 DEPRECIATION, A_D

Depreciation can be defined as decrease in value for a fixed asset throughout the usual life of the material possessions. Machinery, equipment, and currency are some examples of assets that are likely to depreciate over time. In this calculation, straight line depreciation method is used as it is the simplest method and easy to understand (Peters & Timmerhaus 1991). In this method, it is assumed that the value of the assets decreases linearly with time. The formula to calculate the depreciation is shown below.

$$A_D = \frac{C_{FC} - S}{n}$$

Where,

C_{FC} = fixed capital investment

S = salvage value of plant at end of service life

N = service life of the plant (years)

Salvage value is typically estimated based on the conditions at the time the plant is put into use, and this factor cannot be predicted with fully accuracy. Engineers usually neglect the value and assumed it as zero due to difficulties involved in making reliable estimates of the salvage value (Peters & Timmerhaus 1991).

$$\begin{aligned} A_D &= \frac{(376.96 - 0)}{15} \\ &= \text{RM } 25.13 \text{ million/year} \end{aligned}$$

9.5 PROFITABILITY ANALYSIS

The profitability analysis is one of the components that is crucial for administrator to forecast the profitability of a proposal. This analysis of profitability can predict whether the company can gain the profit, how much profit it can make and when the profit can be gained. In the profitability analysis, there are two classifications which are the methods that do not consider the time value of money and the methods that consider the time value of money. Table 9.12 shows the summary of project investment.

Table 9.12 Summary of project investment

Parameter	Value
Full production capacity (kg/year)	41211977.04
Fixed capital investment, C_{FC} (RM million)	376.96
Working capital (RM million)	68.34
Land capital (RM million)	10.29
Total capital investment (RM million)	455.58
Total product cost at full capacity	1588.39
Design life (years)	15
Taxation rate	25
Salvage value	0
Annual depreciation cost (RM million/year)	25.13
Minimum acceptable rate of return, $M_{a,r}$	16%
Selling price of oxygen (RM/kg)	68.37
Selling price of urea (RM/kg)	22

9.5.1 Method That Do Not Consider the Time Value of Money

a. Return on Investment (ROI)

The return of investment is the ratio of profit to investment. The most common return of investment is using net profit and total capital investment. The equation of return of investment is shown below.

$$\text{Return on Investment, } ROI = \frac{N_{p,ave}}{C_{TC}} \times 100\%$$

Where,

$N_{p,ave}$ = average net profit

C_{TC} = Total capital investment

$$\text{Return on Investment, } ROI = \frac{N_{p,ave}}{C_{TC}} \times 100\% = \frac{271.60}{455.58} \times 100\% = 60.0\%$$

The ROI obtained is then compared with minimum acceptable rate of return, MARR. In our plant, the value of MARR is selected as 16% which is in the category of

new product or process in a new application. Since the calculation ROI is 60 % and it is greater than the MARR = 16%, thus the project offers an acceptable rate of return.

b. Payback period (PBP)

The payback period is the length of time necessary for the total return to equal the capital investment. The initial fixed-capital investment and annual cash flow are usually used in payback period. The equation of payback period is shown below.

$$PBP = \frac{V + A_x}{A_j}$$

Where,

V = manufacturing fixed capital investment

A_x = non-manufacturing fixed capital investment

A_j = Annual cash flow

$$\begin{aligned} PBP &= RM\ 455.58\text{ million} / RM\ 254.54\text{ million} \\ &= 1.80\text{ years} \end{aligned}$$

The PBP obtained is then compared with reference PBP with the equation below. If the payback period is less than the reference PBP, the PBP is acceptable.

$$PBP_{ref} = \frac{0.85}{M_{ar} + \left(\frac{0.85}{n}\right)} = \frac{0.85}{0.16 + \left(\frac{0.85}{15}\right)} = 3.92\text{ years}$$

Since the calculated PBP value shown above is 1.80 years which is lower than reference PBP = 3.92 years, thus this project is acceptable.

c. Net return, R_n

Net return is a profitability measure which the amount of cash flow over and above that required to meet the minimum acceptable rate of return and recover the total capital investment. The calculation of net return is shown below

$$\begin{aligned}
 R_{n,ave} &= N_{p,ave} - M_{a,r} C_{TC} \\
 &= 254.62 - (0.16 \times 455.58) \\
 &= \text{RM } 181.73 \text{ million}
 \end{aligned}$$

The fact that the net return obtained is positive value, means that the project will actually generate more cash flow than is required to pay back the investment and produce a return that matches the minimum acceptable rate. Therefore, it is earning at a rate greater than the minimum acceptable rate. The summary of return of investment, payback period and net return estimation is shown in Table 9.13. According to the calculation above,

- i. ROI = 60% and it is greater than MARR = 16%
- ii. PBP = 1.80 years and it is less than PBP_{ref} = 3.92 years
- iii. Net return = RM 181.73 million and it is positive value.

As a conclusion, the plant design project is generally attractive to the investor.

Table 9.13 ROI, PBP and net return estimation

Year	Production rate	Expenditure (RM million)	Income (RM million)	Gross profit (RM million)	Depreciation (RM million)	Taxable income (RM million)	Tax payable (RM million)	Net profit (RM million)	Non-Discounted Cash flow (RM million)
0	0	455.58	0.00	-455.58	0.00	-455.58	-113.90	-341.69	-455.58
1	0.5	794.20	999.47	205.27	25.13	180.14	45.04	135.11	160.24
2	0.9	1429.55	1799.05	369.49	25.13	344.36	86.09	258.27	283.40
3	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19
4	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19
5	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19
6	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19
7	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19
8	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19
9	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19
10	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19
11	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19
12	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19
13	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19
14	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19
15	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19

9.5.2 Method That Considers the Time Value of Money

There are two classifications in the methods that consider the time value of money which are Net Present Value (NPV) and Discounted Cash Flow Rate of Return (DCFRR).

a. Net present value (NPV)

Net present value is the total present value of a time series of cash flow. If the NPV value of a project at the minimum acceptable rate of return, M_{ar} is positive, then the project is said to earn a return greater than M_{ar} and is attractive. The NPV value of the project can be calculated by using the equation below.

$$NPV = \sum_{j=1}^n f_{di,j} [A_j + rec_j + d_j] - \sum_{j=1}^n f_{di,j} C_j$$

Where,

A_j = Cash flow in year j

$f_{di,j}$ = Selected present worth factor for the cash flow with interest rate i in year j

rec_j = return earning in year j

d_j = Depreciation charge in year j

C_j = Total capital investment in year

Table 9.14 shows the NPV estimation of the project which the NPV value of the project is RM 605.79 million at minimum acceptable rate of return, MARR = 0.16 and the value is positive.

b. Discounted Cash Flow Rate of Return, DCFRR

Discounted cash flow rate of return is the return obtained from an investment in which all investments and cash flows are discounted. It is determined by setting the NPV equal to zero. Table 9.14 and Table 9.15 shows the summary of NPV estimation and DCFRR estimation of the project.

Table 9.14 Summary of NPV estimation

Year	Production rate	Expenditure (RM million)	Income (RM million)	Gross profit (RM million)	Depreciation (RM million)	Taxable income (RM million)	Tax payable (RM million)	Net profit (RM million)	Cash Flow (RM million)	Discounted Factor (RM million)	Discounted Cash Flow (RM million)	Cumulative Discounted Cash (RM million)
0	0	455.58	0.00	-455.58	0.00	-455.58	-113.90	-341.69	-455.58	1.00	-455.58	-455.58
1	0.5	794.20	999.47	205.27	25.13	180.14	45.04	135.11	160.24	0.86	138.14	-317.45
2	0.9	1429.55	1799.05	369.49	25.13	344.36	86.09	258.27	283.40	0.74	210.61	-106.83
3	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.64	201.29	94.46
4	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.55	173.53	267.99
5	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.48	149.59	417.58
6	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.41	128.96	546.54
7	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.35	111.17	657.71
8	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.31	95.84	753.55
9	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.26	82.62	836.16
10	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.23	71.22	907.39
11	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.20	61.40	968.79
12	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.17	52.93	1021.72
13	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.15	45.63	1067.35
14	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.13	39.34	1106.68
15	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.11	33.91	1140.59

Table 9.15 Summary of DCFRR estimation

Year	Production rate	Expenditure (RM million)	Income (RM million)	Gross profit (RM million)	Depreciation (RM million)	Taxable income (RM million)	Tax payable (RM million)	Net profit (RM million)	Cash Flow (RM million)	Discounted Factor (RM million)	Discounted Cash Flow (RM million)	Cumulative Discounted Cash (RM million)
0	0	455.58	0.00	-455.58	0.00	-455.58	-113.90	-341.69	-455.58	1.00	-455.58	-455.58
1	0.5	794.20	999.47	205.27	25.13	180.14	45.04	135.11	160.24	0.644	103.187	-352.40
2	0.9	1429.55	1799.05	369.49	25.13	344.36	86.09	258.27	283.40	0.415	117.522	-234.88
3	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.267	83.901	-150.97
4	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.172	54.029	-96.95
5	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.111	34.792	-62.15
6	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.071	22.405	-39.75
7	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.046	14.428	-25.32
8	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.030	9.291	-16.03
9	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.019	5.983	-10.05
10	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.012	3.853	-6.19
11	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.008	2.481	-3.71
12	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.005	1.598	-2.12
13	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.003	1.029	-1.09
14	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.002	0.663	-0.42
15	1	1588.39	1998.94	410.55	25.13	385.42	96.35	289.06	314.19	0.001	0.427	0.00

9.5.3 Justifications on Profitability Analysis

Table 9.16 show the summary of profitability analysis of our plant.

Table 9.16 Summary of profitability analysis

Parameter	Value	Conclusion
Return on investment, ROI	60%	The ROI value is higher than $M_{ar} = 16\%$. Thus, the project is profitable
Payback period, PBP	1.80 years	The PBP value is lower than $PBP_{ref} = 3.92$ years, which is acceptable
Net Return, R_n	RM 181.73 million	The R_n value is positive. Thus, the project is profitable
Net present value, NPV	RM 605.79 million	The NPV value is positive. Thus, the project is profitable
Net Discounted Cash Flow Rate of Return, DCFRR	55%	The DCFRR is higher than $M_{ar}= 16\%$. Thus, the plant is viable.

9.6 BREAK EVEN ANALYSIS

Break-even analysis is an accounting process that determines when a company, or a product will become profitable. Break-even point is a point where the total cost equals to the total revenue or in another word where the net income or profit is zero (Towler & Sinnott 2013). Figure 9.1 shows the graph of the general break-even analysis. From the graph, the year of break-even point can be identified. The point where the expenditure is intersects with income is called break-even point and the year for break-even point is approximately 1 year.

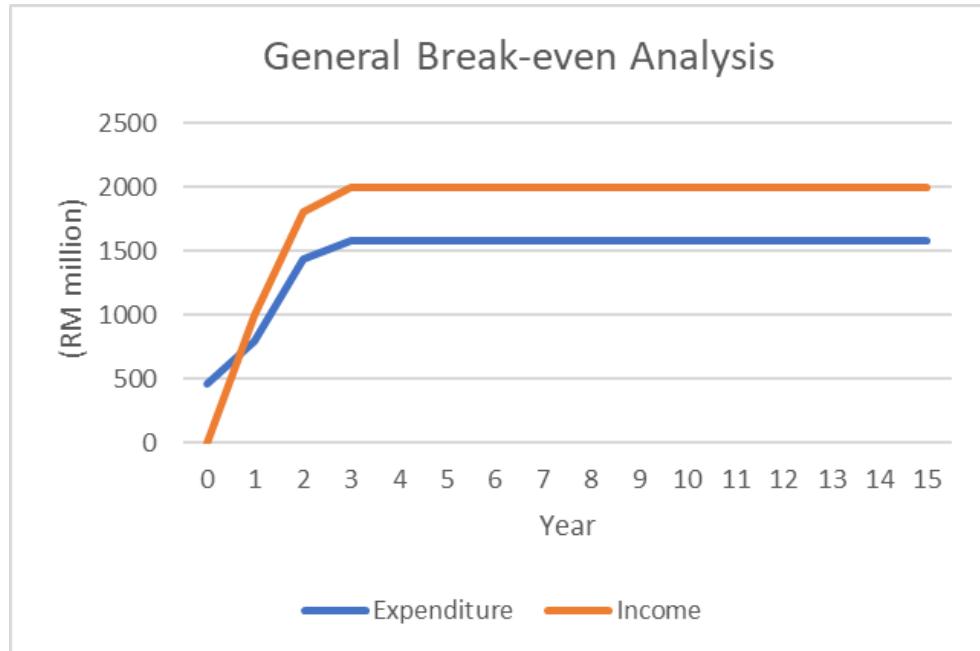


Figure 9.1 General break-even analysis

The graph of the specific break-even analysis for the process is shown in Figure 9.2 below. For this plant, the proposed or desired plant capacity is 17550 tonnes/year. Since the break-even point at Figure 9.2 is approximately at 7000 tonnes/year which is lower than the desired plant capacity, so the plant is profitable and favourable.

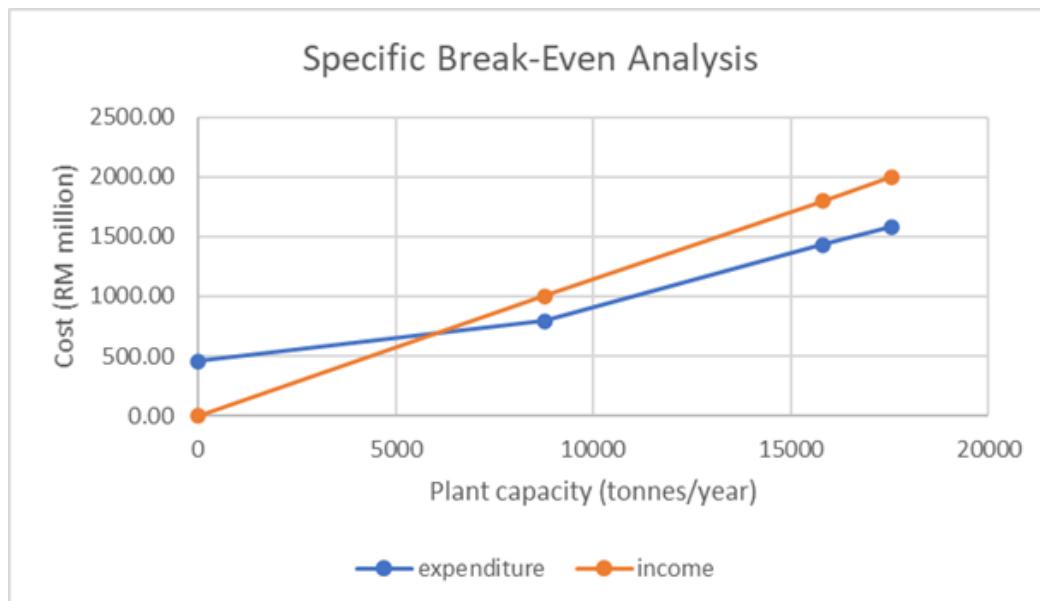


Figure 9.2 Specific break-even analysis

9.7 SENTIVITY ANALYSIS

The effects of forecast uncertainty on the viability of a project can be examined by using a sensitivity analysis (Towler & Sinnott 2013). The sensitivity analysis can also be used as predictions of the prices by increasing and decreasing the price of the main product and also by-product (Kenton 2022).

9.7.1 Sensitivity Analysis of Urea

The sensitivity analysis of urea is shown in Table 9.17 below. Based on the table below, a suitable selling price for urea is RM 22/kg.

Table 9.17 Sensitivity analysis of urea

Cost (RM/kg)		Full capacity of urea (kg/year)			
388388183.04	15000000	16000000	17654008.32	18000000	19000000
5	75000000	80000000	88270041.6	90000000	95000000
10	150000000	160000000	176540083.2	180000000	190000000
22	330000000	352000000	388388183	396000000	418000000
25	375000000	400000000	441350208	450000000	475000000
30	450000000	480000000	529620249.6	540000000	570000000

9.7.2 Sensitivity Analysis of Oxygen

The sensitivity analysis of oxygen gas is shown in Table 9.18 below. Based on the table below, a suitable selling price for oxygen gas is RM 22/kg.

Table 9.18 Sensitivity analysis of urea

Cost (RM/kg)		Full capacity of urea (kg/year)			
1610554650.59	10000000	20000000	23556452.4	40000000	50000000
50	500000000	1000000000	1177822620	2000000000	2500000000
60	600000000	1200000000	1413387144	2400000000	3000000000
68.37	683700000	1367400000	1610554651	2734800000	3418500000
80	800000000	1600000000	1884516192	3200000000	4000000000
90	900000000	1800000000	2120080716	3600000000	4500000000

9.7.3 Overall Sensitivity Analysis

From the overall sensitivity analysis, other parameters involved in the project can be analysed. Figure 9.3 below shows the overall sensitivity analysis of the project.

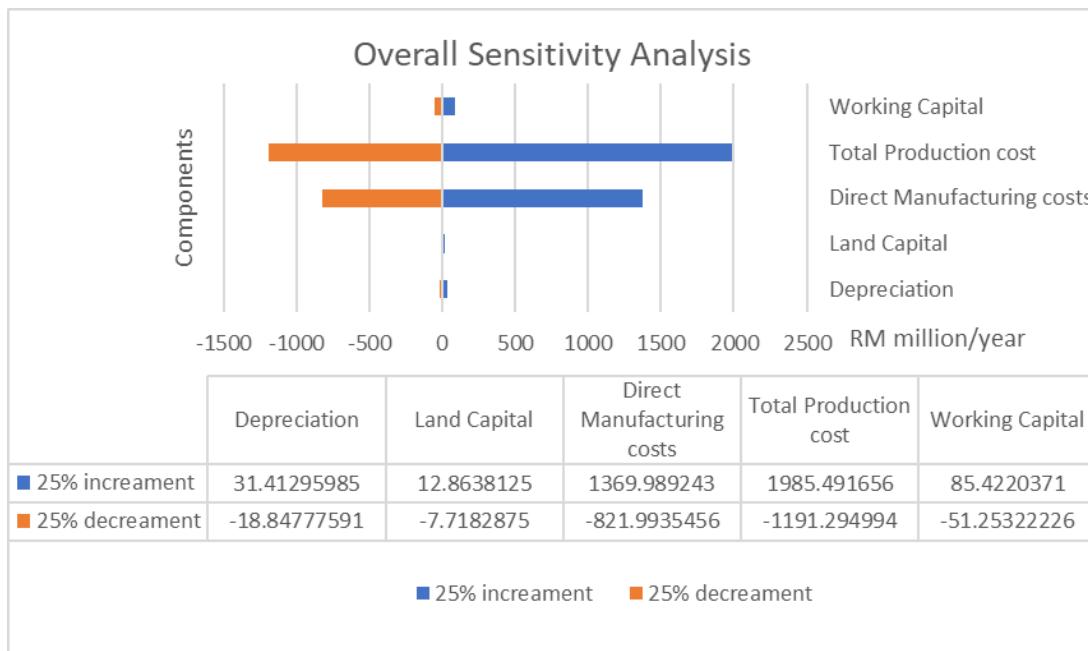


Figure 9.3 Overall sensitivity analysis

CHAPTER X

DETAIL DESIGN

10.1 STORAGE TANK, ST-101

Designed by: Nurzulaikha binti Zulkarnian (A173895)

10.1.1 Introduction

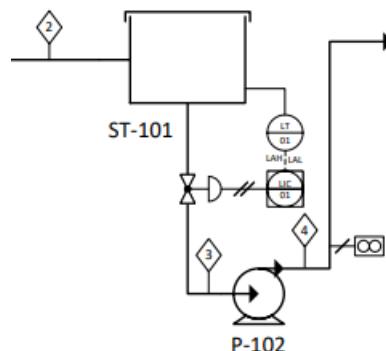


Figure 10.1 Storage tank, ST-101

Tap water will transfer to the storage tank (ST-101) at room temperature (28°C and 1.5 bar) through stream 2. Since the plant operate continuously, the storage tank will take precaution by store the water if short of water supply occur. Then, water will flow out through stream 3 and flow into activated carbon filter (AF-101) for next process.

10.1.2 Dimension of Storage Tank, ST-101

As water is the main component flowing in and out of the storage tank, with the flowrate of 3148.17 kg/hr. the volumetric flowrate is then calculated for both inlet and outlet stream of the storage tank.

Operation of the storage tank should be fully understood before determining the working volume of the tank. It takes 5 hours for the tap water flow into the tank and takes 2 hours for the tap water to flow out from the tank. Hence, the accumulation of the volume in the tank would be the working volume of the tank.

Table 10.1 Volumetric flowrate of water for ST-101

Component	Mass flowrate (kg/hr)	Density (kg/m³)	Volumetric flowrate (m³/hr)
Tap water	3148.17	997	3.158
Total	3148.17		3.158

Assumptions:

- i. The valve of the outlet stream of the tank would remain close until the tank reached a limit point.
- ii. The time for the storage tank to reach the maximum volume accumulation is 2 hours.
- iii. The valve of the outlet stream will remain closed until the tap water flowing into the tank for at least 2 hours.

Working volume is calculated as shown below:

$$v_w = 3.158 \frac{m^3}{hr} \times 2 \text{ hr} = 6.316 m^3$$

By giving 20% allowance for safety factor,

Volume of the holding tank,

$$v = v_w \times 1.2$$

$$= 6.316 m^3 \times 1.2$$

$$= 7.579 m^3$$

The common ratio of the height, H to diameter, D for storage tank is 1:1 to 1.5:1.
By taking H to D ratio of 1.5:1

$$\frac{H}{D} = 1.5; H = 1.5D$$

$$v = \frac{\pi D^2 H}{4} = \frac{\pi D^2 (1.5D)}{4} = \frac{1.5D^3 \pi}{4}$$

$$7.579 = \frac{1.5D^3 \pi}{4}$$

$$D = 1.860 \text{ m}$$

$$H = 1.5D = 2.790 \text{ m}$$

10.1.3 Summary of Detail Design of Storage Tank, ST-101

The summary of the detailed design of storage tank, ST-101 is tabulated in Table 10.2 as follows:

Table 10.2 Summary of detailed design for storage tanks, ST-101

Parameter	Value
Operating pressure	1.5 bar
Operating temperature	28 °C
Volume of tank, v	7.579 m ³
Height of tank, H	2.790 m
Diameter of tank, D	1.860 m

10.2 STORAGE TANK, ST-102

Designed by: Nurzulaikha binti Zulkarnian (A173895)

10.2.1 Introduction

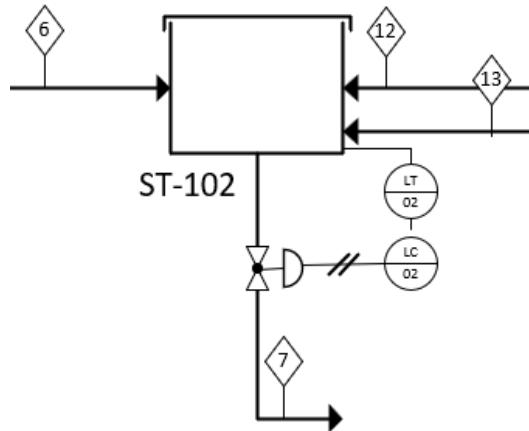


Figure 10.2 Storage tank, ST-102

Deionize water will enter the storage tank (ST-102) at stream 6. Deionize water that flows out from both demister, D-101 and D-102 will recycle back into ST-102 at stream 12 and 13 respectively. Deionize water will flow out through stream 7 and flow into PEM electrolyser for the next process. Operating conditions for ST-102 is 30°C and 1 bar. The main role of ST-102 is to act as an intermediate storage where the changes of flow rate occur and to prevent from waste of material.

Table 10.3 Mass flowrate of deionize water for ST-102

Component	Inlet stream 6	Inlet stream 12	Inlet stream 13	Outlet stream 7
Water (kg/h)	3148.17	57.07	47.98	3253.22
Total (kg/h)	3148.17	57.07	47.98	3253.22

10.2.2 Dimension of Storage Tank, ST-101

As water is the main component flowing in and out of the storage tank, with the flowrate of 3253.22 kg/hr. The volumetric flowrate is then calculated for both inlet and outlet stream of the storage tank.

Operation of the storage tank should be fully understood before determining the working volume of the tank. It takes 5 hours for the deionize water flow into the tank

and takes 2 hours for the deionize water to flow out from the tank. Hence, the accumulation of the volume in the tank would be the working volume of the tank.

Table 10.4 Volumetric flowrate of deionize water for ST-102

Component	Mass flowrate (kg/hr)	Density (kg/m³)	Volumetric flowrate (m³/hr)
Deionize water	3253.22	997	3.263
Total	3253.22		3.263

Assumptions:

- i. The valve of the outlet stream of the tank would remain close until the tank reached a limit point.
- ii. The time for the storage tank to reach the maximum volume accumulation is 2 hours.
- iii. The valve of the outlet stream will remain closed until the tap water flowing into the tank for at least 2 hours.

Working volume is calculated as shown below:

$$v_w = 3.263 \frac{m^3}{hr} \times 2 \text{ hr} = 6.526 m^3$$

By giving 20% allowance for safety factor,

Volume of the holding tank,

$$v = v_w \times 1.2$$

$$= 6.526 m^3 \times 1.2$$

$$= 7.831 m^3$$

The common ratio of the height, H to diameter, D for storage tank is 1:1 to 1.5:1.
By taking H to D ratio of 1.5:1

$$\frac{H}{D} = 1.5; H = 1.5D$$

$$v = \frac{\pi D^2 H}{4} = \frac{\pi D^2 (1.5D)}{4} = \frac{1.5D^3 \pi}{4}$$

$$7.831 = \frac{1.5D^3 \pi}{4}$$

$$D = 1.880 \text{ m}$$

$$H = 1.5D = 2.820 \text{ m}$$

10.2.3 Summary of Detail Design of Storage Tank, ST-102

The summary of the detailed design of storage tank, ST-101 is tabulated in Table 10.5 as follows:

Table 10.5 Summary of detailed design for storage tanks, ST-101

Parameter	Value
Operating pressure	1 bar
Operating temperature	30 °C
Volume of tank, v	7.831 m ³
Height of tank, H	2.820 m
Diameter of tank, D	1.880 m

10.3 ACTIVATED CARBON FILTER, AF-101

Designed by: Aerry Ting Wei Huan (A174141)

10.3.1 Introduction

Activated carbon filter which also known as activated charcoal filter, is a type of filter commonly used for air and water purification. It is made from carbonaceous materials such as charcoal or coal, which have been treated to create a highly porous structure. In our plant, the activated carbon filter (AF-101) is used to remove the odour, 99% of impurities and ensure low number of Total Organic Carbon (TOC) from water that flow through stream 4. It operates at 28°C and 3 bar. Figure 10.1 shows the schematic diagram of activated carbon filter (AF-101).

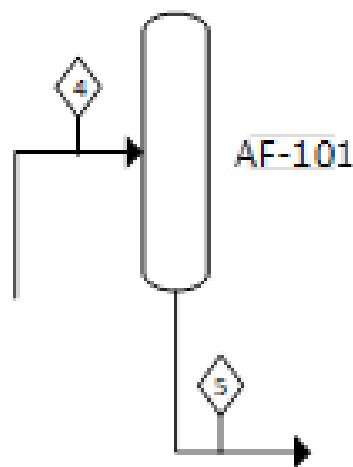


Figure 10.3 Schematic diagram of Activated Carbon Filter AF-101

The detailed design calculation steps involved for activated carbon filter (AF-101) is shown in Appendix D.

10.3.2 Summary of Detail Design of Activated Carbon Filter, AF-101

Table 10.6 shows the summary of design specification for AF-101.

Table 10.6 Summary of design specification for AF-101

Parameter	Value
Volumetric flowrate, m ³ /hr	3.158
Filter area, m ²	1.519
Height, m	3.780
Diameter, m	1.391
Volume, m	5.741

Amount of activated carbon, kg	861.27
--------------------------------	--------

10.4 ELECTRODEIONIZATION, ED-101

Designed by: Nurzulaikha binti Zulkarnain (A173895)

10.4.1 Introduction

Water that has been filtered in Activated Carbon Filter (AF-101) will flow into ED-101 through stream 5 to deionize the water. The operating condition in this unit is 28°C and 2.5 bar. Water is the main component flowing in and out of the electrodeionization module, with the flowrate of 3148.17 kg/hr. Figure 10.4 shows schematic diagram of electrodeionization module, ED-101.

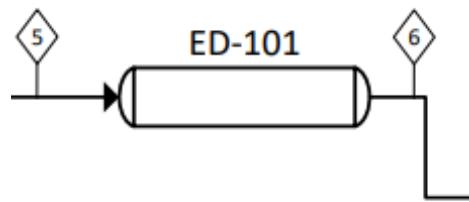


Figure 10.4 Schematic diagram of Electrodeionization module, ED-101

Electrodeionization (EDI) is an electrically driven water treatment technology that uses electricity, ion exchange membranes and resin to remove ionized species from water. EDI removes ions and other charged species from water, for example salts and organic acids.

The EDI module consists of a set of chambers filled with ion exchange resins and separated by ion-exchange membranes. Water enters the module, where an applied electrical field at right-angles to the flow forces ions to move through the resins and across the membranes. These impurity ions are not permanently bound to the media but instead are collected into concentrate streams which can be directed to drain or recycled. The deionized product water can be used directly or undergo further treatment for enhanced water purity. Figure 10.5 and Figure 10.7 shows the typical set of chambers of electrodeionization (EDI) and process of electrodionization (EDI) respectively.

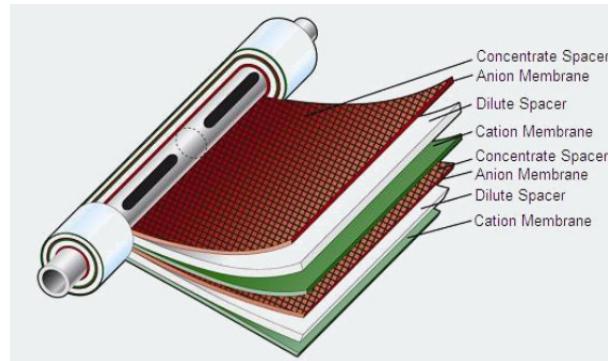


Figure 10.5 Set of chambers of electrodeionization (EDI)

Source: Lenntech 2023

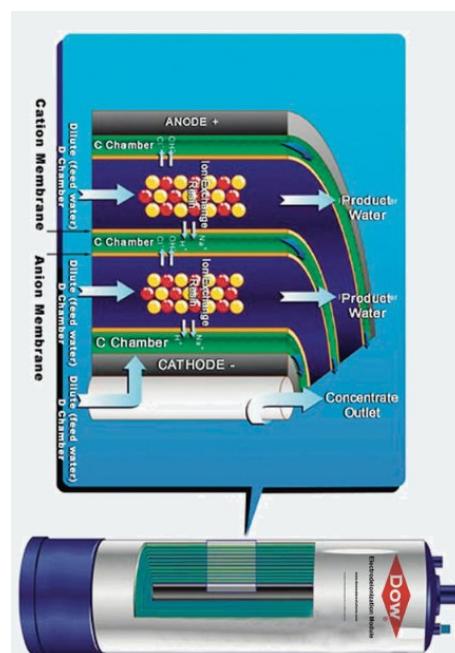


Figure 10.6 Process of electrodeionization (EDI)

Source: Lenntech 2023

Lenntech has been chosen for design the electrodionization module. Lenntech's electrodionization plants are built with conventional plate-and-frame arrangement EDI modules capable of treating several flows. Table 10.7 shows the model reference and its volumetric flowrate. Since the volumetric flowrate of ED-101 is $3.22 \text{ m}^3/\text{h}$, therefore, model LT-EDI-Polix-5 has been chosen for ED-101 module.

Table 10.7 Model reference and its volumetric flowrate

Model reference	Flow
LT-EDI-Polix-5	$2-5 \text{ m}^3/\text{h}$

LT-EDI-Polix-10	5-10 m ³ /h
LT-EDI-Polix-20	10-20 m ³ /h
LT-EDI-Polix-40	20-40 m ³ /h
LT-EDI-Polix-60	40-60 m ³ /h
LT-EDI-Polix-100	60-100 m ³ /h

Source: Lenntech 2023

Table 10.8 show the general design data for Electrodeionization (EDI) module

Table 10.8 General design data for EDI module

Parameters	Value
Feed water maximum conductivity	40 µS/cm
Feed water maximum hardness	< 1 ppm
Demi/ultra-pure water quality	8-18 MΩ
Recovery	90-95 %

Source: Lenntech 2023

10.4.2 Power Requirement

$$\text{Water production rate} = \frac{3148.17 \text{ kg}}{1 \text{ h}} \times \frac{1000 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ mol}}{18.02 \text{ g}} \times \frac{1 \text{ h}}{3600 \text{ s}} = 48.529 \text{ mol/s}$$

Given average energy consumption at stack 0.05 kWh/m³

Average energy consumption at stack = 0.05 kWh/m³ = 180 kJ/m³

By assuming Faraday efficiency as 90%

$$\begin{aligned} \text{Power requirements} &= \frac{\text{molar flowrate of water} \times \text{average energy consumption}}{\text{faraday efficiency}} \\ &= \frac{48.529 \times 180000}{0.9} \\ &= 9706 \text{ kW} \end{aligned}$$

The power required for the electrodeionization module is 9706 kW

10.4.3 Balance of Plant (BOP)

BOP refers to all the components and systems other than the main power-producing unit like the stack in an electrodeionization module that are necessary for the operation and functioning of the overall system. The purpose of the BOP is to ensure the proper functioning and efficiency of the power generation system as a whole. It provides the necessary support and control systems to enable the main unit to operate optimally and deliver the desired output. The BOP power requirement can vary depending on the specific design and configuration of the electrodeionization system. However, as a rough estimate, the BOP power requirement is typically around 10-15% of the stack power (Noriko Hikosaka Behling, 2013).

By assuming the BOP power requirements is 10% of stack power

$$\text{BOP power requirements} = 0.10 \times \text{power}$$

$$= 0.10 \times 9706 \text{ kW}$$

$$= 970.6 \text{ kW}$$

10.5 HEATER, H-101

Designed by: Azrul Zulhilmi bin Ahmad Rosli (A173752)

10.5.1 Introduction

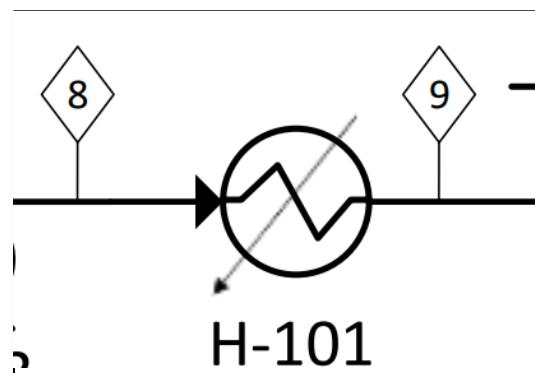


Figure 10.7 Schematic diagram of Heater, H-101

Figure 10.7 shows the heater H-101 used in our process plant. High temperature steam is used to increase the temperature of the liquid in stream 8 which contains water from 28°C to 80°C. Table 10.9 show physical properties of heater, H-101.

Table 10.9 Physical properties of heating steam and process stream for heater unit H-101

Physical properties	Shell (Steam)	Tube (Stream 8)
Temperature, °C	T _{in} = 109.33 T _{out} = 80	T _{in} = 28 T _{out} = 80
Heat Capacity, C _p (kJ/kg°C)	1.99	4.18
Viscosity, μ (mNs/m ²)	0.15	0.89
Density, ρ (kg/m ³)	0.6266	1000
Thermal Conductivity, (kW/m°C)	0.048	0.61

The inlet temperature used for the heating steam is calculated using this formula,

$$Q = m(C_{p(water)})(\Delta T)$$

$$Q = 3253.22(3600)(4.184)(5)$$

$$Q = 2.548 \times 10^9$$

So,

$$T_{steam} = \frac{Q}{mC_{p(steam)}}$$

$$T_{steam} = \frac{2.548 \times 10^9}{3253.22(3600)(1.99)}$$

$$T_{steam} = 109.33^\circ\text{C}$$

Assumption:

- Only the thermal design will be considered and illustrates Kern's Method.

- The operation of the shell and tube heat exchanger is counter-current flow.
- The process stream will be put in tube to ensure better heat transfer.
- Temperature correction factor: one shell pass; two or more even tube passes

Log mean temperature difference:

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}}$$

$$\Delta T_{lm} = \frac{(25 - 80) - (80 - 109.33)}{\ln \frac{(25 - 80)}{(80 - 109.33)}}$$

$$\Delta T_{lm} = 39.589^\circ\text{C}$$

Dimension temperature ratio:

$$R = \frac{T_1 - T_2}{t_2 - t_1}$$

$$R = \frac{28 - 80}{80 - 109.33}$$

$$R = 0.564$$

$$S = \frac{t_2 - t_1}{T_1 - T_2}$$

$$S = \frac{80 - 109.33}{28 - 80}$$

$$S = 0.639$$

Mean temperature:

$$\Delta T_m = F_t \Delta T_{lm} = (0.85)(39.589) = 33.65^\circ\text{C}$$

Figure 10.8 shows temperature profile of heater, H-101.

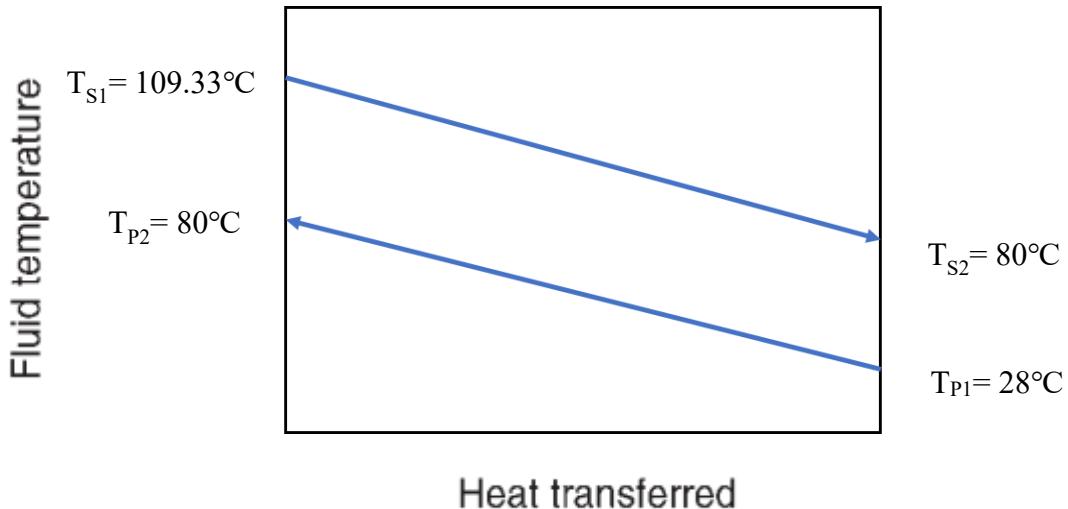


Figure 10.8 Temperature profile of heater, H-101

10.5.2 Heat Load

Mixture flowrate: 3253.22 kg/h

$$Q = mC_p \Delta T$$

$$= (3253.22)(4.18)(80028)(1/3600) = 196.422 \text{ kW}$$

$$Q_{\text{mixture}} = Q_{\text{heating}}$$

$$\text{Hence, } Q_{\text{heating}} = 196.422 \text{ kW} = mC_p \Delta T$$

$$196.422 \text{ kW} = m(4.187)(109.33 - 80)$$

$$m_{\text{steam}} = 3.365 \text{ kg/s} = 12115.126 \text{ kg/hr}$$

Assumption of U, assume $U = 1500 \text{ W/m}^2\text{°C}$

Area required: $Q = UA\Delta T_m$

$$A = 3.891 \text{ m}^2$$

10.5.3 Tube-side Coefficient

Select 25.4 mm outside diameter, d_o , 19.86 mm inside diameter, d_i , 0.0317 m long, triangular pitch, 1.83 of length, $1.25d_o$ copper.

$$\text{Surface area of one tube, } A = \pi d_o L = \pi(25.4 \times 10^{-3})(1.83) = 0.146 \text{ m}^2$$

Number of tubes required,

$$N_T = \frac{\text{area of required}}{\text{area of one tube}}$$

$$N_T = \frac{3.891}{0.146} = 27 \text{ tubes}$$

$$\text{Cross-sectional area, one tube} = \pi(0.0198)^2 = 0.000309 \text{ m}^2$$

$$\text{Total tubes area, } A_t = 27(0.000309) = 0.00837 \text{ m}^2$$

$$\text{Tube velocity, } u_t = \frac{0.904}{1000(0.146)} = 0.00619 \text{ ms}^{-1}$$

Assume tube passes is 4

$$\text{So overall } u_t = 4(0.00619) = 0.02476 \text{ ms}^{-1}$$

$$\begin{aligned} \text{Coefficient water in tube, } h_i &= 4200(1.35 + (0.02 \times T_m)(u_t^{0.8})(d_i^{0.2})) \\ &= 4200(1.35 + (0.02 \times 54)(0.02476^{0.8})(0.019862^{0.2})) \\ &= 1159.204 \text{ W/m}^2\text{C} \end{aligned}$$

$$\text{Reynolds number, } Re = \frac{d_i u_t \rho}{\mu} = \frac{1000(0.0247)(0.01986)}{0.89} = 0.5524$$

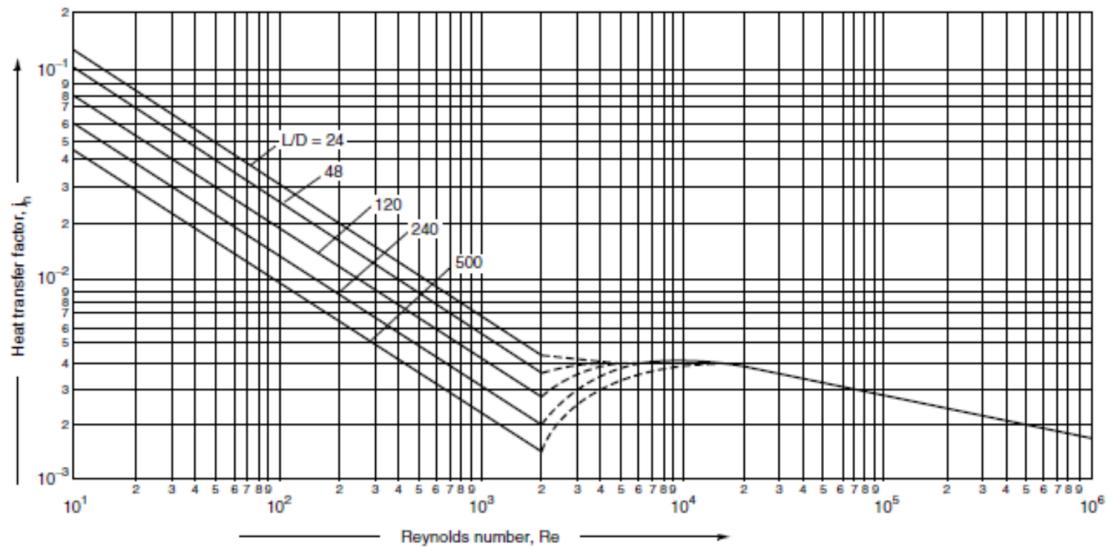


Figure 10.9 Diagram of tube-side heat transfer factor.

Source: RK Sinnott 2019

From Figure 10.9, $j_f = 8$

10.5.4 Shell-side Coefficient

Assume triangular pitch, $P_t = 1.25(0.0254) = 0.03175$

Table 10.10 Pitch constants

No. passes	1	2	4	6	8
K_1	0.319	0.249	0.175	0.0743	0.0365
n_1	2.142	2.207	2.285	2.499	2.675

Source: RK Sinnott 2019

From Table 10.10, for 4 passes, triangular pitch,

$$K_1 = 0.0175 \text{ and } n_1 = 2.285$$

$$\text{Diameter bundle, } D_b = D_o \left(\frac{N_t}{K_1} \right)^{\frac{1}{n_1}} = (0.0254) \left(\frac{27}{0.0175} \right)^{\frac{1}{2.285}} = 0.631 \text{ m}$$

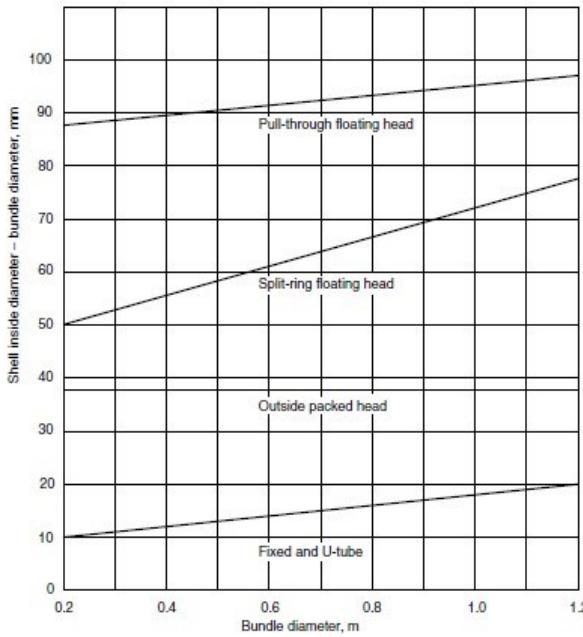


Figure 10.10. Shell-bundle clearance

Figure 10.10 Diagram of shell-bundle clearance

Source: RK Sinnott 2019

From Figure 10.10, for pull-through floating head, clearance = 92mm = 0.092

$$\text{Shell diameter, } D_s = 0.092 + 0.631 = 0.7232 \text{ m}$$

Baffle spacing, use 25% cut baffles

$$l_b = 0.25(0.7232) = 0.181 \text{ m}$$

$$\text{Area of shell, } A_s = \frac{(p_t - d_o)D_s l_b}{p_t} = \frac{(0.03175 - 0.0254)(0.7232)(0.1808)}{0.03175} = 0.0131 \text{ m}^2$$

$$\text{Shell mass velocity, } G_s = \frac{W_s}{A_s} = \frac{3.365}{0.0131} = 257.38 \text{ kg/m}^2\text{s}$$

Equivalent diameter,

$$d_e = \frac{1.1}{d_o} (p_t^2 - 0.917 d_o^2) = \frac{1.1}{0.0254} (0.03175^2 - 0.917(0.0254)^2)$$

$$= 0.01804 \text{ m}$$

$$\text{Reynolds number, } \text{Re} = \frac{d_e(G_s)}{\mu} = \frac{0.01804(257.38)}{0.15} = 30946.264$$

$$\text{Prandlt number, } \text{Pr} = \frac{c_p \mu}{k} = \frac{1.99(0.15)}{0.048} = 6.129$$

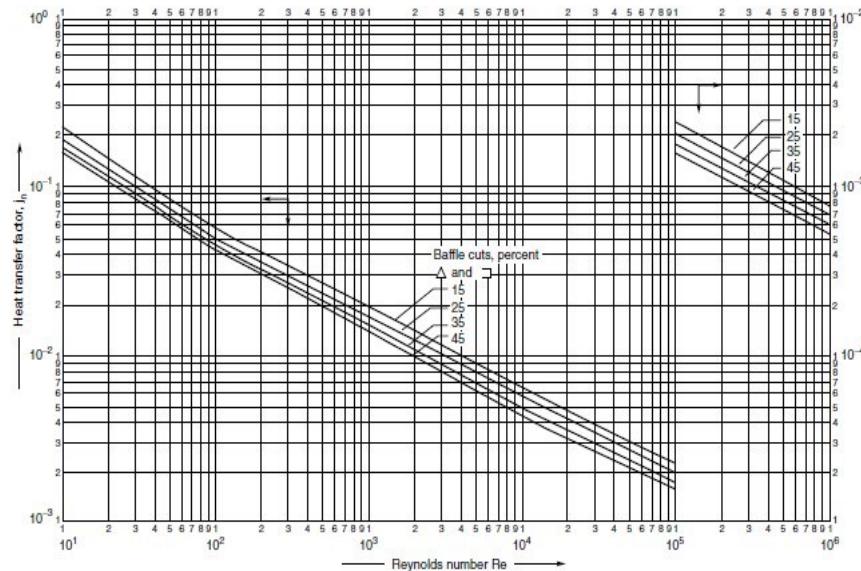


Figure 10.11 Diagram of shell side hot transfer friction

Source: RK Sinnott 2019

From Figure 10.11, $j_h = 0.0035$

$$\text{Nusselt number, } N_u = R_e(j_h) \left(P_r^{\frac{1}{3}} \right) = 30946.254(0.0035) \left(6.219^{\frac{1}{3}} \right) = 199.18$$

Shell-side heat transfer coefficient, h_s

$$h_s = \frac{k(N_u)}{d_e}$$

$$h_s = \frac{0.048(199.18)}{0.01804}$$

$$h_s = 530.106$$

10.5.5 Overall Heat Transfer Coefficient

$$\begin{aligned}
 \text{Overall coefficient } h_t &= \frac{1}{\left(\left(\frac{1}{h_s}\right) + \left(\frac{d_o}{d_i}\right)\left(\frac{1}{h_i}\right) + \left(\frac{d_o \left(\ln\left(\frac{d_o}{d_i}\right)\right)}{2}\right)(k_i)\right)50000} \\
 &= \frac{1}{\left(\left(\frac{1}{530.106}\right) + \left(\frac{0.0254}{0.01986}\right)\left(\frac{1}{1159.20}\right) + \left(\frac{0.0254 \left(\ln\left(\frac{0.0254}{0.01986}\right)\right)}{2}\right)(0.477)\right)50000} \\
 &= 11161980.2 \text{ W/m}^2\text{°C} \\
 U_o &= \left(\frac{h_t - U_{assume}}{U_{assume}} \right) 100 \\
 U_o &= \left(\frac{11161980.2 - 1500}{1500} \right) 100 \\
 &= 744032.015 \text{ W/m}^2\text{°C}
 \end{aligned}$$

This value is well above the initial estimate; therefore the design has adequate area for the duty required.

10.5.6 Tube-side Pressure Drop

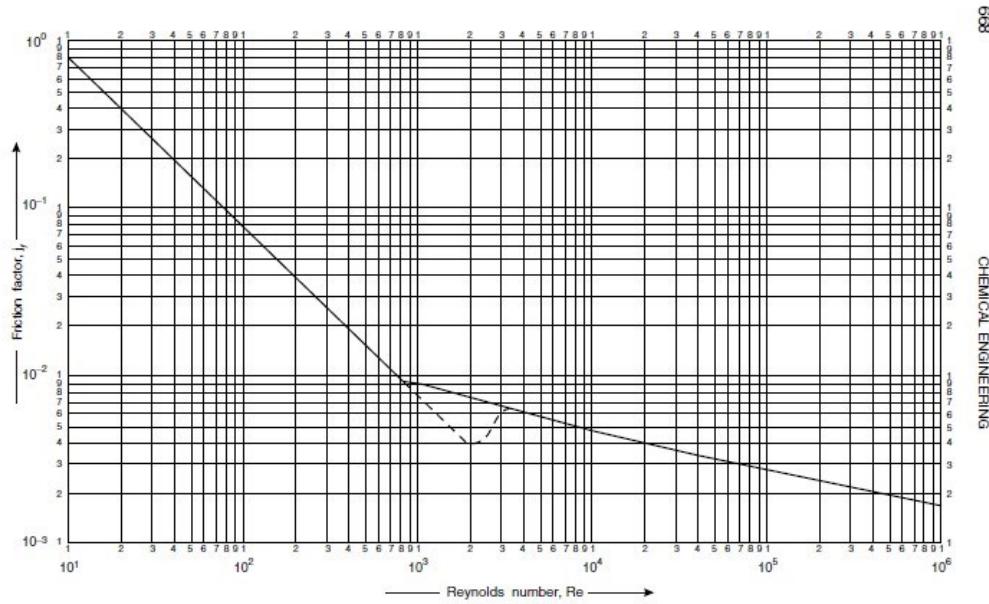


Figure 10.12. Tube side friction factors

Source: RK Sinnott 2019

From Figure 10.12, $j_f = 8$

$$\Delta P_t = 8j_f \left(\frac{L'}{d_i} \right) \left(\frac{\rho \mu_t^2}{2} \right)$$

$$L' = L_{assume} - 0.05 = 1.83 - 0.05 = 1.78m$$

$$\Delta P_t = 8(8) \left(\frac{1.78}{0.01986} \right) \left(\frac{(1000)(0.00619)^2}{2} \right)$$

$$\Delta P_t = 9587146.44 \text{ Pa.s}$$

10.5.7 Shell-side Pressure Drop

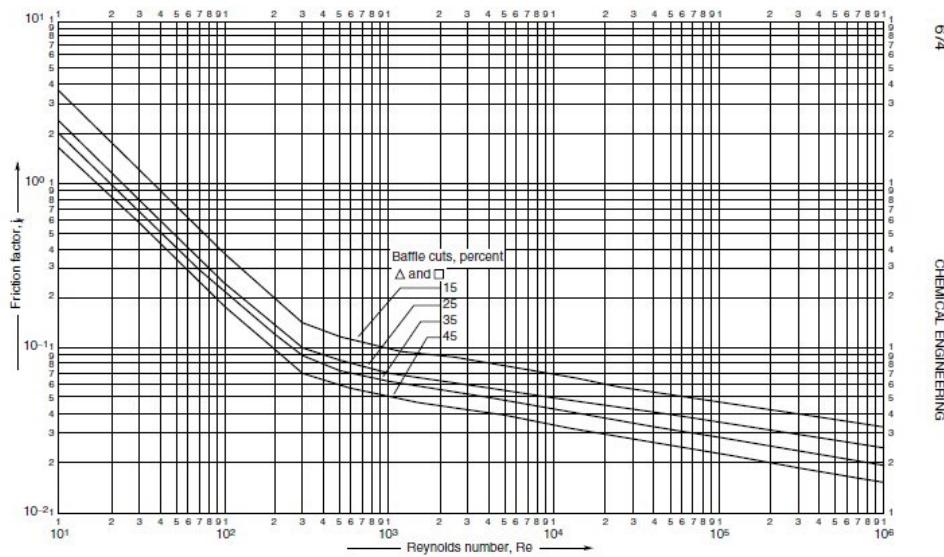


Figure 10.13. Shell-side friction factors, segmental baffles

Figure 10.13 Diagram of shell side friction factors

Source: RK Sinnott 2019

From Figure 10.13, $j_h = 0.0035$

$$\Delta P_s = \frac{8(0.035) \left(\frac{d_s}{d_e}\right) \left(\frac{L}{l_b}\right) \left(\frac{\rho(\mu_s^2)}{2}\right)}{1000}$$

$$\Delta P_s = \frac{8(0.035) \left(\frac{0.723}{0.018}\right) \left(\frac{1.83}{0.181}\right) \left(\frac{1000(419.758^2)}{2}\right)}{1000}$$

$$\Delta P_s = 9587146.44 \text{ Pa.s}$$

10.5.8 Summary of Detail Design of Heater, H-101

Table 10.11 and Table 10.12 show the summary of the calculation for design of heater, H-101.

Table 10.11 Detail design tube-side coefficient of Heater, H-101

Parameter	Values
Triangular pitch	1.25
Outer diameter, d_o (mm)	25.4

Inner diameter, d_i (mm)	19.862
Length of tube, L (mm)	1.83
Area, A (m^2)	3.891
Area of one tube, A_t (m^2)	0.146
Number of tubes	27
Number of tubes passes	4
Linear fluid velocity, u_t (ms^{-1})	0.0247
Heat transfer coefficient, h_i ($W/m^2\circ C$)	1159.20
Pressure drop, P (kPa)	1.757

Table 10.12 Detail design shell-side coefficient of Heater, H-101

Parameter	Values
Number of shell passes	2
Bundle diameter, D_b (mm)	631.19
Shell diameter, D_s (mm)	723.19
Baffle cut (%)	25
Tube pitch (mm)	31.75
Equivalent diameter, d_e (mm)	18.04
Mass velocity, G_s (kg/m^2s)	257.38
Heat transfer coefficient, h_s ($W/m^2\circ C$)	530.11
Pressure drop, P (kPa)	9587.15
Overall heat transfer coefficient, U_o ($W/m^2\circ C$)	11161980.23

10.6 PEM ELECTROLYSER, E-101

Designed by: Suriya Vathi A/P Subramanian (A174271)

10.6.1 Introduction

Electrolyser is a device that utilises electricity to electrolyze water or other components into their constituent elements. Electrolysis is a chemical process that occurs when an electric current flows through a material, causing it to disintegrate into its constituents. In the instance of water electrolysis, an electrolyser splits water molecules into hydrogen and oxygen gases using an electric current. The hydrogen gas can be kept as a compressed gas or as a liquefied gas. The oxygen produced is either discharged back

into the atmosphere or collected and stored for use in other industrial operations (Accelera, 2023).

10.6.2 Specification

In urea manufacturing, this unit operate at 80°C at stream 9 at operating pressure of 15 bar. Deionize water will enter the electrolysis through stream 9 with operation conditions 80°C and 15 bar (Saebea 2019). Water splitting will occur at here (E-101) which produce hydrogen gas (H₂) at cathode and oxygen gas (O₂) at anode with 96% conversion. Amount of water required is 3253.22 kg/hr where it will produce 351.83 kg/hr hydrogen. The chemical equation involved is as below:

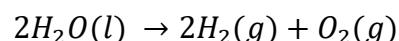


Table 10.13 Composition of inlet and outlet components in electrolyser, E-101

Components	Flowrate (kg/hr)		
	Inlet		Outlet
	Stream 9	Stream 10	
Water	3253.22	51.07	79.962
Hydrogen	0	0	351.83
Oxygen	0	2796.34	0

10.6.3 Power Requirements

$$\text{Hydrogen production rate} = \frac{351.83 \text{ kg/h}}{1000 \text{ g/kg}} \times \frac{1 \text{ mol}}{2\text{g}} \times \frac{1}{3600\text{s}} = 0.0488 \text{ moles/s}$$

Given average power consumption at stack 4.5 kWh/Nm³ (Nel Hydrogen, 2018)

Average power consumption at stack = 4.5 kWh/Nm³ = 16200 kJ/ Nm³

By assuming Faraday efficiency as 90%

$$\text{Power requirements} = \frac{\text{molar flowrate of hydrogen gas} \times \text{average power consumption}}{\text{faraday efficiency}}$$

$$= \frac{0.0488 \times 16200000}{0.9}$$

$$= 874.22 \text{ kW}$$

The power required for the electrolyser is 874.22 kW

10.6.4 Balance of Plant (BOP)

BOP refers to all the components and systems other than the main power-producing unit like the stack in an electrolyser that are necessary for the operation and functioning of the overall system. The purpose of the BOP is to ensure the proper functioning and efficiency of the power generation system as a whole. It provides the necessary support and control systems to enable the main unit to operate optimally and deliver the desired output. The BOP power requirement can vary depending on the specific design and configuration of the electrolyser system. However, as a rough estimate, the BOP power requirement is typically around 10-15% of the stack power (Noriko Hikosaka Behling, 2013).

By assuming the BOP power requirements is 10% of stack power

$$\text{BOP power requirements} = 0.10 \times \text{power}$$

$$= 0.10 \times 874.22 \text{ kW}$$

$$= 87.42 \text{ kW}$$

The purity of electrolyser used in this process could produce hydrogen gas at 99.9995% purity demand (Nel Hydrogen, 2018).

10.7 DEMISTER, D-101

Designed by: Nur Iffa binti Rizuan (A173952)

10.7.1 Introduction

According to Utami Ledyana et al. 2020, demister or also known as mist eliminator can be defined as a mechanical separation of liquids from gases. After electrolyser, the oxygen gas that contains moisture will enter demister, D-101 to separate the water which is moisture from the oxygen gas before it is been released as by-products. D-101

contains a demister pad that will separate the water from the oxygen gas. Figure 10.14 below shows the schematic diagram of D-101. Table 10.14 shows the properties of vapour and liquid streams that enter at stream 10 and leave at stream 14 for oxygen and stream 12 for water.

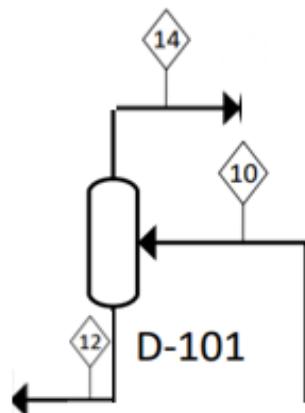


Figure 10.14 Diagram of demister, D-101

Table 10.14 Properties of vapour and liquid in D-101

Properties	Vapour (Oxygen gas)	Liquid (Water)
Mass flowrate (kg/hr)	2796.34	57.07
Density (kg/m ³)	1.2	971
Volumetric flowrate (m ³ /s)	0.932	0.00016

Settling velocity, $u_t = 0.07 \times \sqrt{\left(\frac{\rho_L - \rho_v}{\rho_v}\right)}$ where ρ_L = liquid density (kg/m³), ρ_v = vapour density (kg/m³),

$$= 0.07 \times \sqrt{\left(\frac{971 - 1.2}{1.2}\right)}$$

$$u_t = 1.99 \text{ m/s}$$

Since the operating pressure is lower than 20 bar, $L_v/ D_v = 3$. The liquid height is set at half of the vessel diameter for preliminary design.

Liquid height inside the demister, $h_v = D_v/2$

$$\text{Cross sectional area for vapour flow, } A_V = \frac{\pi D_V^2}{4} \times 0.5$$

$$= 0.3927 D_V^2 \text{ m}^2$$

$$\text{Vapour velocity, } u_v = \frac{Q_v}{A_v} = (0.932/0.3927 D_V^2) = 2.3733 D_V^{-2} \text{ m/s}$$

$$\text{Vapour residence time, } t_v = \frac{h_v}{u_t} = 0.2513 D_V$$

$$\text{Actual residence time, } t_a = \frac{L_v}{u_v} = \frac{3D_v}{2.3733 D_V^{-2}} = 1.2639 D_V^3$$

For satisfactory separation, residence time required = residence time actual

$$0.2513 D_V = 1.2639 D_V^3$$

$$\text{Diameter vessel, } D_V = 0.44 \text{ m}$$

$$\text{Liquid cross sectional area, } A_L = \frac{\pi D_v^2}{4} \times 0.5$$

$$= 0.07603 \text{ m}^2$$

$$\text{Length of vessel, } L_V = 3 \times D_V = 1.32 \text{ m}$$

$$\text{Holdup volume, } V_h = A_L \times L_V = 0.1004 \text{ m}^3$$

$$\text{Holdup time, } t_h = \frac{\text{Liquid volume}}{\text{Liquid flow rate}} = (0.1004/0.00016) = 614.7 \text{ s} = 11 \text{ min}$$

The type of demister pad that is used is stainless steel demister pad with co-knit mesh as shown in Figure 10.15 because it provides finer targets, remove finer droplets and has high separation efficiency (Road 2005). The values calculated is satisfied as the holdup time is more than the minimum holdup time which is 10 minutes.



Figure 10.15 Stainless steel knitted mesh

Source: (Wiremesh 2019)

10.8 DEMISTER, D-102

Designed by: Nur Iffa binti Rizuan (A173952)

10.8.1 Introduction

After electrolyser, the hydrogen gas that contains moisture will enter another demister, D-102 to separate the water which is moisture from the hydrogen gas before it enters the packed bed reactor as one of the reactants to produce ammonia gas. D-102 contains demister pad that will separate the water from the hydrogen gas. Figure 10.16 below shows the schematic diagram of D-102. Table 10.15 shows the properties of vapour and liquid streams that enter at stream 11 and leave at stream 16 for hydrogen and stream 13 for water.

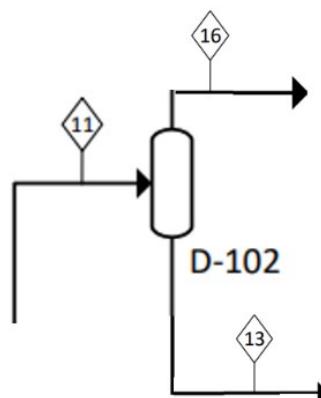


Figure 10.16 Diagram of demister, D-101

Table 10.15 Properties of vapour and liquid in D-101

Properties	Vapour (Oxygen gas)	Liquid (Water)
Mass flowrate (kg/hr)	351.83	47.98
Density (kg/m ³)	0.0686	971
Volumetric flowrate (m ³ /s)	0.007	0.000014

Settling velocity, $u_t = 0.07 \times \sqrt{\left(\frac{\rho_L - \rho_v}{\rho_v}\right)}$ where ρ_L = liquid density (kg/m³), ρ_v = vapour density (kg/m³),

$$= 0.07 \times \sqrt{\left(\frac{971 - 0.0686}{0.0686}\right)}$$

$$u_t = 8.33 \text{ m/s}$$

Since the operating pressure is lower than 20 bar, $L_v / D_v = 3$. The liquid height is set at half of the vessel diameter for preliminary design.

Liquid height inside the demister, $h_v = D_v / 2$

Cross sectional area for vapour flow, $A_v = \frac{\pi D_v^2}{4} \times 0.5$

$$= 0.3927 D_v^2 \text{ m}^2$$

Vapour velocity, $u_v = \frac{Q_v}{A_v} = (0.007 / 0.3927 D_v^2) = 0.0171 D_v^{-2} \text{ m/s}$

Vapour residence time, $t_v = \frac{h_v}{u_t} = 0.06 D_v$

Actual residence time, $t_a = \frac{L_v}{u_v} = \frac{3D_v}{0.0171 D_v^{-2}} = 175.72 D_v^3$

For satisfactory separation, residence time required = residence time actual

$$0.06 D_v = 175.72 D_v^3$$

Diameter vessel, $D_V = 0.018 \text{ m}$

$$\text{Liquid cross-sectional area, } A_L = \frac{\pi D_V^2}{4} \times 0.5$$

$$= 0.00025 \text{ m}^2$$

Length of vessel, $L_V = 3 \times D_V = 0.054 \text{ m}$

Holdup volume, $V_h = A_L \times L_V = 0.000014 \text{ m}^3$

$$\text{Holdup time, } t_h = \frac{\text{Liquid volume}}{\text{Liquid flow rate}} = (0.000014 / 0.000014) = 1 \text{ s} = 0.0167 \text{ min}$$

The value is not satisfied as the holdup time is less than the minimum holdup time value which is 10 minutes. Therefore, the liquid volume need to be increased by increasing the diameter of the vessel by using a factor.

$$\text{Factor} = \sqrt{\frac{10}{t_h}} = \sqrt{\frac{10}{0.0167}} = 24.47$$

New diameter vessel, $D_V = 24.47 \times 0.018 = 0.44 \text{ m}$

New liquid cross sectional area, $A_L = 0.0763 \text{ m}^2$

New length of vessel, $L_V = 3 \times 0.44 = 1.32 \text{ m}$

New holdup volume, $V_h = 0.1008 \text{ m}^3$

New holdup time, $t_h = 1008.07 \text{ s} = 17 \text{ min.}$

The type of demister pad that is used in D-102 is same as D-101 as shown in Figure 10.15 which is stainless steel demister pad with co-knit mesh as it provides finer targets, remove finer droplets and has high separation efficiency (Road 2005). The values

calculated is satisfied as the holdup time is more than the minimum holdup time which is 10 minutes.

10.9 COOLER, CL-106

Designed by: Nur Iffa binti Rizuan (A173952)

10.9.1 Introduction

The outlet of the decomposer, D-101 which consists of ammonia and carbon dioxide gas will be fed to CL-106 for the cooling process from temperature 55.3°C to 28°C before it will be treated and removed. The type of cooler used is shell and heat exchanger as it is a well-established design, easily cleaned and can be constructed from a wide range of materials. Figure 10.17 shows the schematic diagram of CL-106 while Table 10.16 shows the physical properties of the gases (ammonia and carbon dioxide) and cooling water that act as cooling agent.

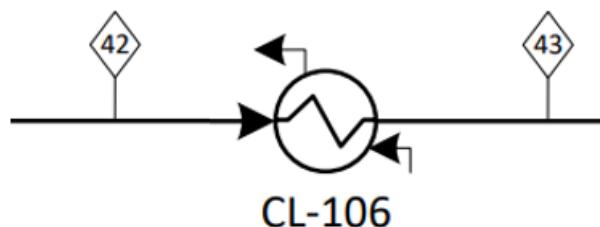


Figure 10.17 Schematic diagram of CL-106

Table 10.16 Physical properties of gases (ammonia and carbon dioxide) and cooling water

Properties	Tube side fluid		Cooling water (Shell side fluid)
	Ammonia gas	Carbon dioxide gas	
Density (kg/m ³)	0.73	1.98	999.07
Specific heat capacity (kJ/kg°C)	2.2	0.846	4.18
Viscosity (Pa.s)	1×10^{-5}	15.08×10^{-6}	0.0010
Thermal conductivity (W/m°C)	0.0244	0.0169	0.598

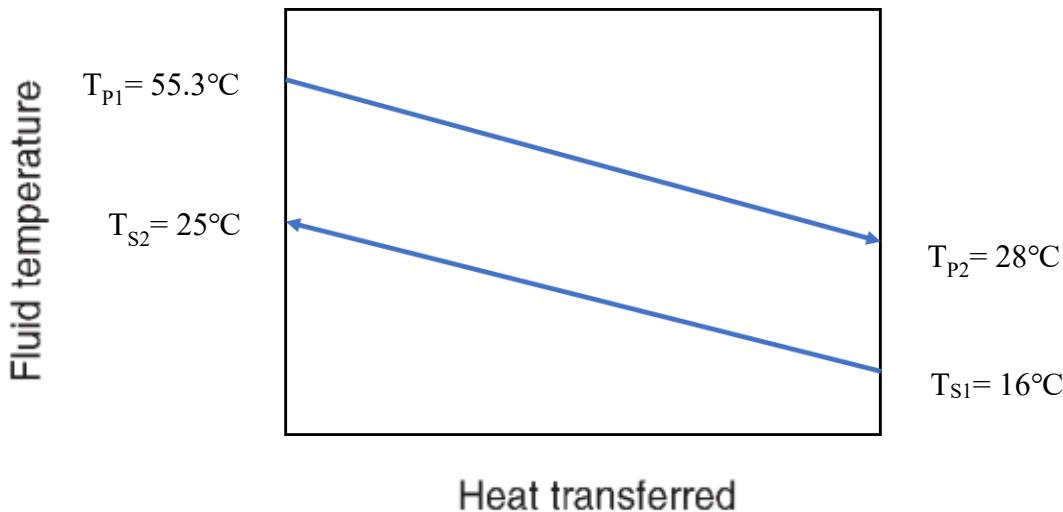


Figure 10.18 Temperature profile of cooler, CL-106

10.9.2 Dimension of Cooler, CL-106

Kern's method is used and assuming that no phase change happens in the unit. The ammonia and carbon dioxide gas will flow at the tube side as the gases are corrosive and the cost can be reduced. Counter current flow configuration is selected because it has higher thermal efficiency compared to co-current flow as shown in Figure 10.18.

a. Required mass flowrate of cooling water (cooling agent)

$$Q_{\text{process}} = Q_{\text{service}}$$

$$(mc_p \Delta T)_{\text{process}} = (mc_p \Delta T)_{\text{service}}$$

$$\frac{2242.8}{3600} \times 3.046 \times (55.3 - 28) = m \times 4.18 \times (25 - 16)$$

$$m_{\text{cooling water}} = 1.38 \text{ kg/s}$$

b. Log mean T difference (LMTD, ΔT_{lm})

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}}$$

$$= \frac{(55.3-25)-(28-16)}{\ln \frac{(55.3-25)}{(28-16)}}$$

$$= 19.8^{\circ}\text{C}$$

c. LMTD, ΔT_{lm} correction factor, F_T and true temperature difference

$$\Delta T_m = F_T \Delta T_{lm}$$

$$R = \frac{(T_1 - T_2)}{(t_2 - t_1)}$$

$$= \frac{(T_1 - T_2)}{(t_2 - t_1)}$$

$$R = 3.03$$

$$S = \frac{(t_2 - t_1)}{(T_1 - T_2)}$$

$$= \frac{(25-16)}{(55.3-16)}$$

$$S = 0.23$$

By referring Towler & Sinnott 2013 from figure 12.19 in the book, $F_T = 0.9$

$$\Delta T_m = 17.82^{\circ}\text{C}$$

By referring Table 12.1 (hot fluid: gases, cold fluid: water) from Towler & Sinnott 2013, overall heat transfer coefficient, $U_o = 160 \text{ W/m}^2\text{ }^{\circ}\text{C}$.

d. Number of tubes, N_t

$$N_t = \frac{A}{A_t}; A_t = \pi D L; Q = UA\Delta T_m$$

$$A = 18.17 \text{ m}^2$$

Assuming the outside diameter of tube, $D_o = 20 \text{ mm}$, length of the tube = 3.66m , wall thickness = 1.6 mm and inside diameter of tube, $D_i = 18.4 \text{ mm}$. Based on the Towler & Sinnott 2013, the smaller tube diameter are preferred for most duties as it will be more compact and much cheaper tube. It also stated that the longer tubes will reduce the shell diameter and therefore cheaper exchanger.

Tube arrangement: Triangular pitch and 2 pass as it gives higher heat transfer compared to square pitch (Towler & Sinnott 2013).

$$\text{Tube pitch, } P_t : 1.25D_o = 1.25(20) = 25\text{mm}$$

$$\text{Surface area of one tube, } A_t = \pi D L = 0.229 \text{ m}^2$$

$$\text{Number of tubes, } N_t = A/A_t = 18.17/0.229 = 79.3 \approx 80$$

$$N_t \text{ per pass} = 80/4 = 40$$

$$\text{Cross section area for one tube, } A_c = \frac{\pi}{4} (D_i)^2 = \frac{\pi}{4} (18.4)^2 = 0.002659 \text{ m}^2$$

$$\text{Areas per pass: } 40 \times 0.002659 = 0.10636 \text{ m}^2$$

$$\text{Volumetric flow} = (2242.8/3600) \times (1/2.71) = 0.2299 \text{ m}^3/\text{s}$$

$$\text{Tube side velocity, } u_t = \frac{\text{volumetric flow}}{\text{area per pass}} = 2.2 \text{ m/s}$$

$$\text{Reynold number of tube side, } Re = \frac{\rho v_t D_i}{\mu} = 4374.04$$

$$\text{Prandtl number of tube side, } Pr = \frac{C_p \mu}{k_f} = \frac{(3.046 \times 1000) \times (2.508 \times 10^{-5})}{0.0413} = 1.85$$

$$L/D_o = 4.88/0.02 = 183$$

By referring Figure 12.2.3 from Towler & Sinnott 2013, heat transfer coefficient, $j_h = 4.2 \times 10^{-2}$

$$\text{Heat transfer coefficient for tube side, } h_i = 4200(1.35+0.02t)\left(\frac{u_t}{D_i}\right)^{0.8}$$

$$= 4200(1.35+0.02((41.65)\left(\frac{2.2^{0.8}}{0.0184^{0.2}}\right)) = 3830.6 \text{ W/m}^2\text{C.}$$

e. Shell side coefficient

$$\text{Bundle diameter, } D_b = D_o \left(\frac{N_t}{k}\right)^{1/n}$$

By referring to Table 12.4 in Towler & Sinnott 2013 with 2 passes, $k_1 = 0.249$, $n_1 = 2.207$

$$D_b = 0.3 \text{ m or } 300\text{mm}$$

$$\text{Shell diameter, } D_s = D_B + C$$

From Figure 12.10, Towler & Sinnott 2013, using split-ring floating head type, the shell/bundle clearance value is 55mm or 0.055mm

$$D_s = 0.3 + 0.055 = 0.355 \approx 0.4\text{m}$$

$$\text{The optimum baffle spacing, } I_B = 0.5 * D_s = 0.2\text{m}$$

$$\text{Tube pitch, } p_t = 25\text{mm or } 0.025\text{m}$$

$$\text{Cross section area, } A_s = \frac{(p_t - D_o)D_s I_B}{p_t} = 0.0016 \text{ m}^2$$

$$\text{Shell side mass flux (mass velocity), } G_s = W_s/A_s = 1.38/0.0016 = 862.5 \text{ kg/m}^2\text{s}$$

$$\text{Linear velocity shell, } u_s = G_s/\rho = 862.5/999.07 = 0.86\text{m/s}$$

Shell side equivalent diameter, $D_e = (1.10/D_o)(p_t^2 - 0.917D_o^2) = 0.014m$

Reynold's number of shell side, $Re = \frac{G_s D_e}{\mu} = 12075$

Prandlt number, $P_r = \frac{C_p \mu}{k} = 6.99$

By referring to Figure 12.29 from Towler & Sinnott 2013,

Baffle cut = 25%

Heat transfer factor, $j_h = 0.0059$

Heat transfer coefficient, $h_i = \frac{j_h R_e P_r^{0.33} k}{D_i} = 4398.45 W/m^2 \text{ }^\circ C$

f. Overall heat transfer coefficient:

Stainless steel, thermal conductivity = 16 W/m°C

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{1}{h_{od}} + \frac{D_o \ln \frac{D_o}{D_I}}{2k_w} + \frac{D_o}{D_I} \left(\frac{1}{h_i} + \frac{1}{h_{id}} \right)$$

where,

h_{od} = outside dirt coefficient (fouling factor) = 6000 W/m²°C

h_{id} = inside dirt coefficient = 5000 W/m²°C

$h_o = h_i$ at shell side = 4398.45 W/m²°C

$h_i = h_i$ at tube side = 3830.6 W/m²°C

$U_o = 1055.64$ W/m²°C

Pressure drop for fluid flow in tube, $\Delta P_t = N_p \left[8j_f \left(\frac{L}{D_i} \right) + 2.5 \right] \frac{\rho u_t^2}{2}$

By referring to Figure 12.24 (Towler & Sinnott, 2013) for $Re = 4374.04$, friction factor, $j_f = 0.006$

$\Delta P_t = 45.31 \text{ kPa}$ (The value is still in the range based on Haslego 2010, which is from 30 until 60 kPa so the value achieved is acceptable)

Pressure drop for fluid flow in shell, $\Delta P_s = 8j_f \left(\frac{D_s}{D_e}\right) \left(\frac{L}{I_B}\right) \left(\frac{\rho u_s^2}{2}\right)$

$\Delta P_s = 61.82 \text{ kPa}$ (The value is still in the range based on Mukherjee 2015, which is from 49 kPa until 68.6 kPa so the value achieved is acceptable.)

10.9.3 Summary of Detail Design of Cooler, CL-106

Table 10.17 Summary of cooler, CL-106

Properties	CL-106
Mass flowrate for cooling agent (kg/s)	1.38
Mass flowrate for process fluid(kg/s)	0.623
Log mean temperature difference, ΔT_{lm} ($^{\circ}\text{C}$)	19.8
ΔT_{lm} correction factor, F_t	0.9
True temperature difference, ΔT_m ($^{\circ}\text{C}$)	17.82
Heat transfer, Q (kW)	51.81
Type of flow	Counter current flow
Tube Side coefficient	Ammonia and carbon dioxide (From 55.3$^{\circ}\text{C}$ to 28$^{\circ}\text{C}$)
Heat transfer surface area, A (m^2)	18.17
Outside diameter of tube, D_o (m)	0.02
Inside diameter of tube, D_i (m)	0.0184
Length of tube,L (m)	3.66
Tube arrangement	Triangular pitch with 2 passes
Tube pitch, p_t (m)	0.025
Surface area of one tube, A_t (m^2)	0.229
Number of tubes, N_t	80
Tube side velocity, u_t (m/s)	2.2
Reynolds number, Re	4374.04
Prandlt number,Pr	1.85
Heat transfer coefficient, h_i ($\text{W}/\text{m}^2\text{ }^{\circ}\text{C}$)	3830.6

Shell side coefficient	Cooling water (cooling agent)
Bundle diameter, D_b (m)	0.3
Shell diameter, D_s (m)	0.4
Optimum baffle spacing, I_B (m)	0.2
Cross section area, A_s	0.0016
Shell side mass flux(mass velocity), G_s ($\text{kg}/\text{m}^2\text{s}$)	862.5
Linear velocity shell, u_s (m/s)	0.86
Shell side equivalent diameter, D_e (m)	0.014
Reynolds number, Re	12075
Prandlt number, Pr	6.99
Baffle cut (%)	25
Heat transfer coefficient, h_i ($\text{W}/\text{m}^2\text{C}$)	4398.45
Overall heat transfer coefficient, U_o ($\text{W}/\text{m}^2\text{C}$)	1055.64
Pressure drop for fluid flow in tube, ΔP_t (kPa)	45.31
Pressure drop for fluid flow in shell, ΔP_s (kPa)	61.82

10.10 COOLER, CL-101

Designed by: Nur Iffa binti Rizuan (A173952)

10.10.1 Summary of Detail Design of Cooler, CL-101

Table 10.18 Summary of cooler, CL-101

Properties	CL-101
Mass flowrate for cooling agent (kg/s)	0.4787
Mass flowrate for process fluid(kg/s)	0.7768
Log mean temperature difference, ΔT_{lm} ($^{\circ}\text{C}$)	24.02
ΔT_{lm} correction factor, F_t	0.7
True temperature difference, ΔT_m ($^{\circ}\text{C}$)	16.82
Heat transfer, Q (kW)	30.01
Type of flow	Counter current flow
Tube Side coefficient	Cooling water (cooling agent)
Heat transfer surface area, A (m^2)	11.16
Outside diameter of tube, D_o (m)	0.02
Inside diameter of tube, D_i (m)	0.0184
Length of tube,L (m)	3.66
Tube arrangement	Triangular pitch with 2 passes

Tube pitch, p_t (m)	0.025
Surface area of one tube, A_t (m^2)	0.227
Number of tubes, N_t	50
Tube side velocity, u_t (m/s)	1.04
Reynolds number, Re	1916.25
Prandlt number, Pr	6.99
Heat transfer coefficient, h_i ($W/m^2\text{°C}$)	1737.71
Shell side coefficient	Oxygen (From 70°C to 28°C)
Bundle diameter, D_b (m)	0.22
Shell diameter, D_s (m)	0.3
Optimum baffle spacing, I_B (m)	0.14
Cross section area, A_s	0.01
Shell side mass flux(mass velocity), G_s ($kg/m^2\text{s}$)	0.77
Linear velocity shell, u_s (m/s)	0.7
Shell side equivalent diameter, D_e (m)	0.0142
Reynolds number, Re	506
Prandlt number, Pr	0.763
Baffle cut (%)	25
Heat transfer coefficient, h_i ($W/m^2\text{°C}$)	165.34
Overall heat transfer coefficient, U_o ($W/m^2\text{°C}$)	180.65
Pressure drop for fluid flow in tube, ΔP_t (kPa)	31.1
Pressure drop for fluid flow in shell, ΔP_s (kPa)	66.58

10.11 COOLER, CL-102

Designed by: Nur Iffa binti Rizuan (A173952)

10.11.1 Summary of Detail Design of Cooler, CL-102

Table 10.19 Summary of cooler, CL-102

Properties	CL-102
Mass flowrate for cooling agent (kg/s)	0.9414
Mass flowrate for process fluid(kg/s)	0.0977
Log mean temperature difference, ΔT_{lm} (°C)	24.02
ΔT_{lm} correction factor, F_t	0.7
True temperature difference, ΔT_m (°C)	16.82
Heat transfer, Q (kW)	59.02

Type of flow	Counter current flow
Tube Side coefficient	Cooling water (Cooling agent)
Heat transfer surface area, A (m^2)	21.94
Outside diameter of tube, D_o (m)	0.02
Inside diameter of tube, D_i (m)	0.0184
Length of tube,L (m)	3.66
Tube arrangement	Triangular pitch with 2 passes
Tube pitch, p_t (m)	0.025
Surface area of one tube, A_t (m^2)	0.23
Number of tubes, N_t	96
Tube side velocity, u_t (m/s)	1.02
Reynolds number, Re	1871.86
Prandlt number,Pr	6.99
Heat transfer coefficient, h_i ($\text{W}/\text{m}^2\text{°C}$)	1705.43
Shell side coefficient	Hydrogen (From 70°C to 28°C)
Bundle diameter, D_b (m)	0.297
Shell diameter, D_s (m)	0.4
Optimum baffle spacing, I_B (m)	0.2
Cross section area, A_s	0.01
Shell side mass flux(mass velocity), G_s ($\text{kg}/\text{m}^2\text{s}$)	0.7977
Linear velocity shell, u_s (m/s)	1.06
Shell side equivalent diameter, D_e (m)	0.0142
Reynolds number, Re	12051.2
Prandlt number, Pr	0.0751
Baffle cut (%)	25
Heat transfer coefficient, h_i ($\text{W}/\text{m}^2\text{°C}$)	903.05
Overall heat transfer coefficient, U_o ($\text{W}/\text{m}^2\text{°C}$)	64.65
Pressure drop for fluid flow in tube, ΔP_t (kPa)	55.6
Pressure drop for fluid flow in shell, ΔP_s (kPa)	68.04

10.12 COOLER, CL-103

Designed by: Nur Iffa binti Rizuan (A173952)

10.12.1 Summary of Detail Design of Cooler, CL-103

Table 10.20 Summary of cooler, CL-103

Properties	CL-103
Mass flowrate for cooling agent (kg/s)	4.54
Mass flowrate for process fluid(kg/s)	0.97
Log mean temperature difference, ΔT_{lm} ($^{\circ}$ C)	11.46
ΔT_{lm} correction factor, F_t	0.84
True temperature difference, ΔT_m ($^{\circ}$ C)	9.63
Heat transfer, Q (kW)	170.8
Type of flow	Counter current flow
Tube Side coefficient	Hydrogen, nitrogen and ammonia (From 50°C to 20°C)
Heat transfer surface area, A (m^2)	11.09
Outside diameter of tube, D_o (m)	0.02
Inside diameter of tube, D_i (m)	0.0184
Length of tube,L (m)	3.66
Tube arrangement	Triangular pitch with 2 passes
Tube pitch, p_t (m)	0.025
Surface area of one tube, A_t (m^2)	0.23
Number of tubes, N_t	48
Tube side velocity, u_t (m/s)	2.39
Reynolds number, Re	352.45
Prandlt number,Pr	0.949
Heat transfer coefficient, h_i (W/ m^2 $^{\circ}$ C)	3849.37
Shell side coefficient	Cooling water (cooling agent)
Bundle diameter, D_b (m)	0.22
Shell diameter, D_s (m)	0.3
Optimum baffle spacing, I_B (m)	0.13
Cross section area, A_s	0.01
Shell side mass flux(mass velocity), G_s (kg/ m^2 s)	969.35
Linear velocity shell, u_s (m/s)	0.97
Shell side equivalent diameter, D_e (m)	0.014
Reynolds number, Re	13765.74
Prandlt number, Pr	6.99
Baffle cut (%)	25
Heat transfer coefficient, h_i (W/ m^2 $^{\circ}$ C)	5014.32
Overall heat transfer coefficient, U_o (W/ m^2 $^{\circ}$ C)	150.67

Pressure drop for fluid flow in tube, ΔP_t (kPa)	39.44
Pressure drop for fluid flow in shell, ΔP_s (kPa)	67.87

10.13 COOLER, CL-104

Designed by: Nur Iffa binti Rizuan (A173952)

10.13.1 Summary of Detail Design of Cooler, CL-104

Table 10.21 Summary of cooler, CL-104

Properties	CL-104
Mass flowrate for cooling agent (kg/s)	1.91
Mass flowrate for process fluid(kg/s)	0.42
Log mean temperature difference, ΔT_{lm} ($^{\circ}$ C)	13.44
ΔT_{lm} correction factor, F_t	0.91
True temperature difference, ΔT_m ($^{\circ}$ C)	12.23
Heat transfer, Q (kW)	71.71
Type of flow	Counter current flow
Tube Side coefficient	Cooling water (cooling agent)
Heat transfer surface area, A (m^2)	36.63
Outside diameter of tube, D_o (m)	0.02
Inside diameter of tube, D_i (m)	0.0184
Length of tube,L (m)	3.66
Tube arrangement	Triangular pitch with 2 passes
Tube pitch, p_t (m)	0.025
Surface area of one tube, A_t (m^2)	0.227
Number of tubes, N_t	162
Tube side velocity, u_t (m/s)	1.21
Reynolds number, Re	22200
Prandlt number,Pr	6.99
Heat transfer coefficient, h_i (W/ m^2 $^{\circ}$ C)	1911.36
Shell side coefficient	Hydrogen and nitrogen (From 40$^{\circ}$C to 28$^{\circ}$C)
Bundle diameter, D_b (m)	0.38
Shell diameter, D_s (m)	0.4
Optimum baffle spacing, I_B (m)	0.22
Cross section area, A_s	0.02
Shell side mass flux(mass velocity), G_s (kg/ m^2 s)	0.2078

Linear velocity shell, u_s (m/s)	2.8
Shell side equivalent diameter, D_e (m)	0.01
Reynolds number, Re	313.89
Prandlt number, Pr	0.751
Baffle cut (%)	25
Heat transfer coefficient, h_i (W/m ² °C)	754.3
Overall heat transfer coefficient, U_o (W/m ² °C)	172
Pressure drop for fluid flow in tube, ΔP_t (kPa)	41.73
Pressure drop for fluid flow in shell, ΔP_s (kPa)	52.44

10.14 COOLER, CL-105

Designed by: Nur Iffa binti Rizuan (A173952)

10.14.1 Summary of Detail Design of Cooler, CL-105

Table 10.22 Summary of cooler, CL-105

Properties	CL-105
Mass flowrate for cooling agent (kg/s)	2.41
Mass flowrate for process fluid(kg/s)	1.42
Log mean temperature difference, ΔT_{lm} (°C)	109
ΔT_{lm} correction factor, F_t	0.9
True temperature difference, ΔT_m (°C)	98.94
Heat transfer, Q (kW)	45.75
Type of flow	Counter current flow
Tube Side coefficient	Ammonia, ammonia carbamate, carbon dioxide, water, urea (From 140.02°C to 120°C)
Heat transfer surface area, A (m ²)	2.89
Outside diameter of tube, D_o (m)	0.02
Inside diameter of tube, D_i (m)	0.0184
Length of tube,L (m)	3.66
Tube arrangement	Triangular pitch with 2 passes
Tube pitch, p_t (m)	0.025
Surface area of one tube, A_t (m ²)	0.227
Number of tubes, N_t	14
Tube side velocity, u_t (m/s)	0.12
Reynolds number, Re	16003.3

Prandlt number, Pr	0.886
Heat transfer coefficient, h_i (W/m ² °C)	655.51
Shell side coefficient	Cooling water as cooling agent
Bundle diameter, D_b (m)	0.12
Shell diameter, D_s (m)	0.3
Optimum baffle spacing, I_B (m)	0.13
Cross section area, A_s	0.01
Shell side mass flux(mass velocity), G_s (kg/m ² s)	240.64
Linear velocity shell, u_s (m/s)	0.24
Shell side equivalent diameter, D_e (m)	0.0142
Reynolds number, Re	3417.34
Prandlt number, Pr	6.99
Baffle cut (%)	25
Heat transfer coefficient, h_i (W/m ² °C)	2109.83
Overall heat transfer coefficient, U_o (W/m ² °C)	63.06
Pressure drop for fluid flow in tube, ΔP_t (kPa)	40

10.15 COOLER, CL-107

Designed by: Nur Iffa binti Rizuan (A173952)

10.15.1 Summary of Detail Design of Cooler, CL-107

Table 10.23 Summary of cooler, CL-107

Properties	CL-107
Mass flowrate for cooling agent (kg/s)	1.52
Mass flowrate for process fluid(kg/s)	0.63
Log mean temperature difference, ΔT_{lm} (°C)	114.44
ΔT_{lm} correction factor, F_t	0.95
True temperature difference, ΔT_m (°C)	108.72
Heat transfer, Q (kW)	63.38
Type of flow	Counter current flow
Tube Side coefficient	Urea and water (From 175°C to 100°C)
Heat transfer surface area, A (m ²)	3.64
Outside diameter of tube, D_o (m)	0.02
Inside diameter of tube, D_i (m)	0.0184
Length of tube,L (m)	3.66

Tube arrangement	Triangular pitch with 2 passes
Tube pitch, p_t (m)	0.025
Surface area of one tube, A_t (m^2)	0.227
Number of tubes, N_t	16
Tube side velocity, u_t (m/s)	0.26
Reynolds number, Re	7730
Prandlt number, Pr	5.36
Heat transfer coefficient, h_i ($W/m^2\text{°C}$)	1315.96
Shell side coefficient	Cooling water (cooling agent)
Bundle diameter, D_b (m)	0.13
Shell diameter, D_s (m)	0.3
Optimum baffle spacing, I_B (m)	0.13
Cross section area, A_s	0.001
Shell side mass flux(mass velocity), G_s ($kg/m^2\text{s}$)	242.6
Linear velocity shell, u_s (m/s)	2.43
Shell side equivalent diameter, D_e (m)	0.0142
Reynolds number, Re	3445
Prandlt number, Pr	6.99
Baffle cut (%)	25
Heat transfer coefficient, h_i ($W/m^2\text{°C}$)	2020.65
Overall heat transfer coefficient, U_o ($W/m^2\text{°C}$)	66.4
Pressure drop for fluid flow in tube, ΔP_t (kPa)	44
Pressure drop for fluid flow in shell, ΔP_s (kPa)	66.8

10.16 PACKED BED REACTOR, R-101

Designed by: Aerry Ting Wei Huan (A174141)

10.16.1 Introduction

Packed bed reactor is applied to reactor R-101 in the production of urea from ammonia. It comprises of a cylindrical vessel with solid packing that creates large surface area for contact between reactants and a catalyst. Hydrogen gas will enter the catalytic packed bed reactor R-101 through stream 17. While nitrogen will enter the R-101 through stream 18 at room temperature (28°C). The operating condition of the ammonia synthesis is 28°C and 1 bar with manganese zinc ferrite ($Mn_{0.8}Zn_{0.2}O_4$) as nanocatalyst. Figure 10.19 below show the schematic diagram of R-101.

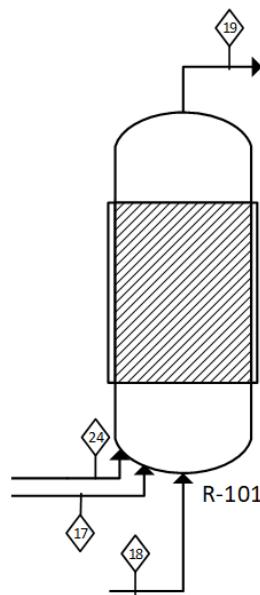


Figure 10.19 Schematic diagram of Packed Bed Reactor, R-101

10.16.2 Material Selection

The operating condition for R-101 is 1 bar operating pressure with temperature at 28°C. The material used for construction of reactor R-101 is austenitic stainless-steel type 316L with specification number of SA-240 and UNS number of S32950. Advantage of stainless-steel type 316L is high durability and high oxidation resistance property. 316L stainless steel has low carbon content that can reduce risk of chrome carbide precipitation. The composition of SA-240 stainless steel is 26% chromium, 4% nickel, 1% molybdenum and 1% nitrogen. High chromium content can increase the vessel resistance to oxidation process. Additional of molybdenum composition can help to increase corrosion resistance and pitting resistance. Table 10.24 shows the design information of R-101.

Table 10.24 Design information of R-101

Type of information	Operating selection and condition
Operating pressure	1 bar
Operating temperature	28°C
Material	Stainless-steel type 316L
Specification number	SA-240
UNS number	S32950
Material composition	26Cr-4Ni-Mo-N

Maximum allowable stress	26600 psi
Joint efficiency	1.0

10.16.3 Design Specification

Height to diameter ratio of 3:1 is applied to the design of vertical layout reactor R-101. This ratio is an optimum value for the design of packed bed reactor dimension. Large height to diameter ratio such as 4:1 and 5:1 is good in term of heat transport mechanism but costly due to large pressure drop (Andrigo et al. 1999). Table 10.25 below shows calculated dimension of R-101 in different measurement units. Further calculation details are shown in Appendix D.

Table 10.25 Dimension of R-101 in different measurement units

Part	Value (m)	Value (ft)	Value (In)
Ellipsoidal 2:1 top head height	0.740	2.429	29.144
Cylindrical shell height	7.399	24.278	291.318
Ellipsoidal 2:1 bottom head height	0.740	2.429	29.144
Vessel height	8.880	29.135	349.606
Vessel internal diameter	2.961	9.715	116.576
Vessel internal radius	1.481	4.858	58.288

10.16.4 Design of Cooling Jacket

Based on the calculation of energy balance in R-101 as shown in section 3.7.2, approximately 379.11 kW of heat of reaction released to the surrounding. It can be classified as exothermic reaction. Cooling jacket is required to install at R-101 to maintain the operating temperature of reactor and prevent excessive heat energy loss to the surrounding. Based on 2010 ASME Boiler & Pressure Vessel Code VIII Division, Type 1 jacket is selected whereby jacket will be confined entirely to the cylindrical shell as shown in Figure 10.2. Closure of the jacket selected is type (b-1) as shown in Figure 10.21.

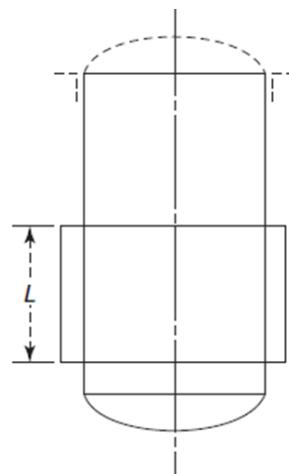


Figure 10.20 Type 1 jacket

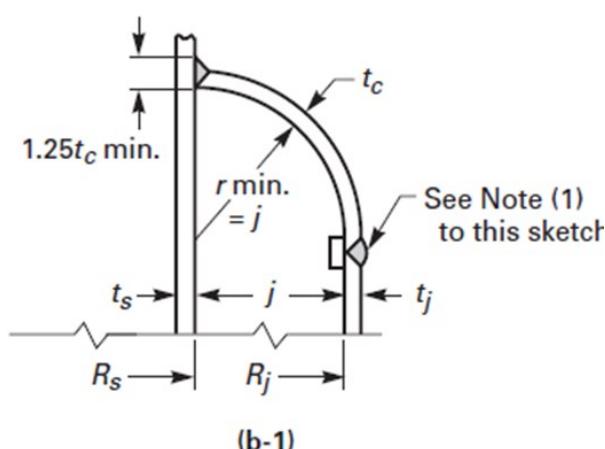


Figure 10.21 Jacket closure type (b-1)

Carbon steel with specification number of SA-537 become the main construction material of cooling jacket for R-101. Since the cooling water will supplied and flow entirely throughout the jacket, the consideration of corrosion properties not so severe and normal carbon steel material can be proposed. Table 10.26 shows the information of carbon steel SA-537 based on ASME 2010.

Table 10.26 Information on carbon steel SA-537

Type of information	Value
Specification number	SA-537
UNS number	K12437
Maximum allowable stress	21000 psi

Cooling water is the cooling agent supplied to the jacket installed at the reactor R-101. The cooling water will face temperature changes from initial inlet temperature 10°C to outlet temperature 25°C. The mass flow rate of cooling water is 6.041 kg/s as calculated shown as below.

$$m_c = \frac{379.11 \times 10^3}{4184(25 - 10)} = 6.041 \text{ kg/s}$$

Spiral wound baffle jacket is selected in the design of cooling jacket and applied to Type 1 jacket from ASME code reference. This jacket can be known as conventional jacket. Conventional jacket allows the lowest pressure drop condition compared to the other jackets and high heat transfer area. Conventional jacket often used for small vessel design and suit to small volume size of reactor R-101. The spacing between the jacket and vessel wall will varied based on the size of vessel. Since reactor R-101 can be considered as small vessel, the typical spacing is 50 mm.

There are few assumptions to be made in the calculation:

Jacket space, J = 2 in = 50.8 mm

Vessel diameter = 2.961 m

Internal design pressure, P = 1 bar = 14504 psi

Maximum allowable stress, S = 21000 psi

Height of jacket = 2.5 m

The baffle forms a continuous spiral channel, section 75 mm × 200 mm

$$\text{Number of spiral} = \frac{\text{Height of jacket}}{\text{Pitch}} = \frac{2.50}{200 \times 10^{-3}} = 13$$

$$\text{Length of channel} = 13 \times \pi \times 2.961 = 120.93 \text{ m}$$

$$\text{Cross sectional area of channel} = (75 \times 200) \times 10^{-6} = 15 \times 10^{-3} \text{ m}^2$$

$$\text{Hydraulic mean diameter, } d_e = \frac{4 \times \text{cross-sectional area}}{\text{wetted perimeter}} = \frac{(4)(75)(200)}{2(75+200)} = 109 \text{ mm}$$

Pressure drop is calculated to determine whether the design of cooling jacket is feasible or not.

Velocity of cooling water through channel, $u_c = \frac{\text{mass flow}}{\text{density} \times \text{area}} = \frac{6.041}{(997)(0.015)} = 0.404 \text{ m/s}$

$$\text{Reynolds number, } \text{Re} = \frac{d_e u_c \rho}{\mu} = \frac{(109 \times 10^{-3})(0.404)(997)}{0.001002} = 43844.20$$

From Figure 12.24 ASME code booklet, friction factor, $j_f = 3.50 \times 10^{-3}$

$$\text{Pressure drop, } \Delta P = 8j_f \left(\frac{L}{D_e}\right) \rho \frac{u_c^2}{2} = (8)(3.50 \times 10^{-3}) \left(\frac{120.93}{109 \times 10^{-3}}\right) (997) \left(\frac{0.404^2}{2}\right) = 2.53 \text{ kPa}$$

The cooling jacket design is acceptable since pressure drop calculated is small.

10.16.5 Design of Catalyst Bed

In reactor R-101, manganese zinc ferrite ($\text{Mn}_{0.8}\text{Zn}_{0.2}\text{O}_4$) as nanocatalyst is used to increase the rate reaction between hydrogen and nitrogen gas. The ratio height of cylindrical shell reactor to catalyst bed reactor is 1.2 : 1, height of preheating zone and cooling zone is same (Jiang et al. 2015)

$$\text{Height of catalyst bed, } H_{bed} = \frac{H_{shell}}{1.20} = \frac{7.399}{1.20} = 6.166 \text{ m}$$

$$\text{Height of preheating zone} = \frac{7.399 - 6.166}{2} = 0.617 \text{ m}$$

$$\text{Height of cooling zone} = 0.617 \text{ m}$$

$$\text{Diameter of catalyst bed} = \text{diameter of reactor} = 2.961 \text{ m}$$

$$\text{Volume of catalyst in the catalyst bed} = \frac{\pi D_{bed}^2 H_{bed}}{4} = \frac{\pi (2.961)^2 (6.166)}{4} = 42.46 \text{ m}^3$$

Voidage of manganese zinc ferrite catalyst, $\epsilon = 0.4$

Density of calcium oxide catalyst, $\rho = 4800 \text{ kg/m}^3$

$$\text{Weight of catalyst} = \rho V(1 - \epsilon) = (4800)(42.46)(1 - 0.4) = 122284.80 \text{ kg}$$

10.16.6 Design of Catalyst Plate

Plate diameter = 2.961 m

Plate area, $A_c = 6.89 \text{ m}^2$

Downcorner area, $A_d = 0.12A_c = 0.12(6.89) = 0.827 \text{ m}^2$

Active area, $A_a = A_c - 2A_d = 6.89 - 2(0.827) = 5.236 \text{ m}^2$

Holes area, $A_h = 10\%A_a = 0.524 \text{ m}^2$

Holes size of diameter (typically 5mm hole size is used), $d_h = 0.005 \text{ m}$

Plate thickness for SA-516 Grade 70 is 0.546 inch (13.88mm)

Area of one hole = $\frac{\pi}{4}(d_h)^2 = 1.96 \times 10^{-5} \text{ m}^2$

Number of holes = area of holes/area of 1 hole = 26687 holes

10.16.7 Heat Transfer Coefficient

The internal heat-transfer coefficients will increase when the vessel was packed by the catalyst. The tube-side heat transfer coefficient for a packed tube can be estimated using the correlations from Leva et al. (1951).

For heating, $\frac{h_i d_t}{\lambda_f} = 0.813 \left(\frac{\rho_f u d_p}{\mu} \right)^{0.9} e^{-6d_p/d_t}$

$$\text{For cooling, } \frac{h_i d_t}{\lambda_f} = 3.50 \left(\frac{\rho_f u d_p}{\mu} \right)^{0.7} e^{-4.6 d_p / d_t}$$

Where,

h_i = heat transfer coefficient for packed tube

d_t = tube diameter

λ_f = fluid thermal conductivity

ρ_f = fluid density, kg/m³

u = superficial velocity, m/s

d_p = particle effective diameter, m

μ = fluid viscosity, Ns/m²

$$h_i = [0.813 \left(\frac{1.27(8.44)(0.005)}{0.00267} \right)^{0.9} e^{-6(0.005)/2.961} \times \frac{0.16}{2.961}] = 6.47 \text{ W/m}^2 \text{ } ^\circ\text{C (heating)}$$

$$h_i = [3.50 \left(\frac{1.27(8.44)(0.005)}{0.00267} \right)^{0.9} e^{-4.6(0.005)/2.961} \times \frac{0.16}{2.961}] = 2.79 \text{ W/m}^2 \text{ } ^\circ\text{C (heating)}$$

10.16.8 Summary of Detail Design of Packed Bed Reactor, R-101

The detailed design for R-101 has been computed and summarized as shown in Table 10.4.

Table 10.27 Summary of detailed design for R-101

Parameter	Unit	Values
Type of reactor	-	Packed bed reactor
Reactor volume	m ³	61.17
Reactor diameter	m	2.961
Reactor height	m	8.880
Catalyst bed height	m	6.166
Catalyst plate diameter	m	2.961
Catalyst plate downcomer area	m ²	0.827
Catalyst plate active area	m ²	5.236
Pressure drop	kPa	2.530

10.17 PHASE SEPARATOR, SP-101

Designed by: Nurzulaikha binti Zulkarnain (A173895)

10.17.1 Introduction

Two phase separator or also known as flash column is used to separate gases and liquid from the mixture stream. The mixture products from R-101 which consists of excess hydrogen and nitrogen gas along with ammonia liquid will flow into PS-101 at stream 22. Operating conditions of PS-101 is 40°C and 140 bar. Function of PS-101 is to separate between ammonia in liquid form, and hydrogen and nitrogen in gas form. Hydrogen and nitrogen gas will be recycled back to R-101 through stream 23 while ammonia liquid will flow out from bottom of PS-101 at stream 25.

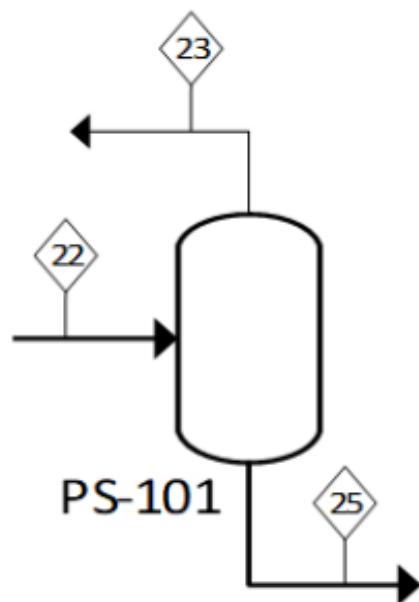


Figure 10.22 Phase separator, PS-101

PS-101 is isothermal phase separator where the temperature and pressure are constant throughout the process. From Seader & Henley (1999), if the equilibrium temperature and pressure of a multicomponent mixture are specified, values of the remaining $2C + 5$ variables are determined from the same number of equations in Table 10.28.

Table 10.28 Equations for single-stage flash vaporization and partial condensation operations

Equation		Number of equations
$P_v = P_L$	(Mechanical equilibrium)	1
$T_v = T_L$	(Thermal equilibrium)	1
$y_i = K_i x_i$	(Phase equilibrium)	C
$Fz_i = V y_i + L x_i$	(Component material balance)	C
$F = V + L$	(Total material balance)	1
$h_F F + Q = h_v V + h_L L$	(Energy balance)	1
$\sum_i y_i - \sum_i x_i = 0$	(Summations)	1
		$\xi = 2C + 5$

Source: Seader & Henley 1999

10.17.2 Operating Condition of Two-Phase Separator, PS-101

Two phase separator, PS-101 will be operating at temperature 40°C and 140 bar. Flash operation is assumed to be isothermal with constant temperature and pressure and the K-value is independent of feed composition. Rachford and Rice equation will help to the solution when K-value is independent of composition. Rachford and Rice equation state:

$$f(\varphi) = \sum_{i=1}^C \frac{z_i(1 - K_i)}{1 + \varphi(K_i - 1)} = 0$$

where φ is vapor fraction which is the ratio between vapor flowrate and feed flowrate (V/F). Liquid fraction is given by:

$$x_i = \frac{z_i}{1 + \varphi(K_i - 1)}$$

and vapor fraction is given by

$$y_i = \frac{z_i K_i}{1 + \varphi(K_i - 1)} = x_i K_i$$

The feed stream composition of PS-101 is stated in Table 10.29.

Table 10.29 Feed composition of Phase Separator, PS-101

Component	Molar flowrate (kmol/hr)	Liquid fraction, x_i	Vapor fraction, y_i
Hydrogen	130.95	0.004	0.177
Nitrogen	43.97	0.002	0.824
Ammonia	117.06	0.994	0.000

Total molar flowrate of the feed at stream 22 is 291.98 kmol/hr. By using the above information, feed mole fraction and K value is calculated and shown in Table 10.30.

Table 10.30 Feed mole fraction and K-value of phase separator, PS-101

Component	Feed mole fraction, z_i	$K_i = y_i/x_i$
Hydrogen	0.0756	44.25
Nitrogen	0.3530	412.00
Ammonia	0.5713	0.00

10.17.3 Isothermal Flash calculation

Rachford and Rice equation will be used in calculation of PS-101. Existence of vapor fraction, φ should be verified before designing PS-101. Since there are K-value that are more than 1 and also less than 1, check must be made for $f(0)$ and $f(1)$ to see if the mixture is between the bubble and dew points and to ensure that flash can occur.

From the Rachford and Rice equation,

$$f(\varphi) = \sum_{i=1}^C \frac{z_i(1 - K_i)}{1 + \varphi(K_i - 1)} = 0$$

Hence,

$$f(0) = \frac{0.0756(1 - 44.25)}{1 + (0)(44.25 - 1)} + \frac{0.3530(1 - 412)}{1 + (0)(412 - 1)} + \frac{0.5713(1 - 0)}{1 + (0)(0 - 1)}$$

$$f(0) = -147.78$$

and

$$f(1) = \frac{0.0756(1 - 44.25)}{1 + (1)(44.25 - 1)} + \frac{0.3530(1 - 412)}{1 + (1)(412 - 1)} + \frac{0.5713(1 - 0)}{1 + (1)(0 - 1)}$$

$$f(1) = 305.47$$

Since $f(0)$ is less than 0, the mixture is above the bubble point, and $f(1)$ is more than 0, the mixture is below the dew point. These conditions allow flashing to occur. To compute the value of vapour fraction, φ , Rachford and Rice equation will be used again as following.

$$f(\varphi) = 0 = \frac{0.0756(1 - 44.25)}{1 + (\varphi)(44.25 - 1)} + \frac{0.3530(1 - 412)}{1 + (\varphi)(412 - 1)} + \frac{0.5713(1 - 0)}{1 + (\varphi)(0 - 1)}$$

$$\varphi = 0.425$$

The value determined from the calculation for φ is 0.425. To determine the value of vapor and liquid flowrate, vapor fraction equation is used where,

$$\varphi = \frac{V}{F}$$

Hence, the vapor flowrate can be computed as

$$V = F\varphi = (291.98)(0.425) = 124.09 \text{ kmol/hr}$$

The liquid flashed is

$$L = F - V = 291.98 - 124.09 = 167.89 \text{ kmol/hr}$$

The summary of composition for product stream is listed in Table 10.31 below.

Table 10.31 Summary of product flow from phase separator, PS-101

Component	Vapor fraction, y_i	Vapor flowrate (kmol/h)	Liquid fraction, x_i	Liquid flowrate (kmol/h)
Hydrogen	0.177	131.341	0.004	3.956
Nitrogen	0.824	43.992	0.002	0.142
Ammonia	0.000	0.000	0.994	116.361

10.17.4 Sizing of Phase Separator, PS-101

From the isothermal flash calculation, the value of molar flowrate of the flashed product has been determined. The properties of the product stream are shown in Table 10.32.

Table 10.32 Properties of product stream for PS-101

Properties	Liquid	Vapor
Total molar flowrate (kmol/hr)	167.89	124.09
Molecular weight (kg/kmol)	11.88	12.06
Mass flowrate (kg/h)	1993.71	1495.95
Density (kg/m ³)	195.91	35.93

The properties will be used for the determination of sizing and dimension of phase separator. Sizing of phase separator start with finding value of abscissa ratio, F_{LV} , which is a kinetic energy ratio given by Sherwood, Shipley, and Holloway to correlate packed-column flooding data.

$$F_{LV} = \frac{LM_L}{VM_V} \left(\frac{\rho_V}{\rho_L} \right)^{0.5}$$

where L = Liquid flowrate, kmol/hr

M_L = Molecular weight of liquid, kg/kmol

V = Vapor flowrate, kmol/hr

M_V = Molecular weight of vapor, kg/kmol

ρ_V = Density of vapor, kg/m³

ρ_L = Density of liquid, kg/m³

Hence, the value of F_{LV} is:

$$F_{LV} = \frac{167.89 \times 11.88}{124.09 \times 12.06} \left(\frac{35.93}{195.91} \right)^{0.5}$$

$$F_{LV} = 0.571$$

By taking the plate spacing as 24", and conjunction with the value of F_{LV} , the value of correlation factor for surface tension, C_F is obtained from Figure 6.24 from Separation Process Principle by Seader (2006) as:

$$C_F = 0.2 \text{ ft/s}$$

To calculate the surface tension factor, equation below is used,

$$F_{ST} = \left(\frac{\sigma}{20} \right)^{0.2}$$

$$F_{ST} = \left(\frac{18.1}{20} \right)^{0.2} = 0.9802$$

Capacity parameters of Sounders and Brown, C can be obtained by using the equation as stated below,

$$C = F_{ST} F_F F_{HA} C_F$$

$$\text{where } F_{ST} = \text{surface tension factor} = \left(\frac{\sigma}{20} \right)^{0.2}$$

F_F = foaming factor

$F_{HA} = 1.0$ for $A_h/A_a \geq 0.10$ and $5(A_h/A_a) + 0.5$ for $0.06 \leq A_h/A_a \leq 0.1$

σ = liquid surface tension, dyne/cm

For nonfoaming systems, $F_F = 1.0$; for many absorbers, F_F is 0.75 or less. A_h is the area open to the vapor as it penetrates the liquid on a tray. By taking F_F is 1.0, and F_{HA} as 1.0, value of parameter C can be obtained as,

$$C = (0.9802)(1.0)(1.0)(0.2) = 0.19604 \text{ ft/s}$$

In order to calculate the diameter of the phase separator, settling velocity of the liquid droplets need to be solved first where,

$$U_t = C \left(\frac{\rho_L - \rho_V}{\rho_V} \right)^{1/2}$$

$$U_t = 0.19604 \left(\frac{195.91 - 35.93}{35.93} \right)^{1/2} = 0.4137 \text{ ft/s} = 0.1261 \text{ m/s}$$

For vertical separators, the proposed layout and typical proportion is shown in Figure 10.23.

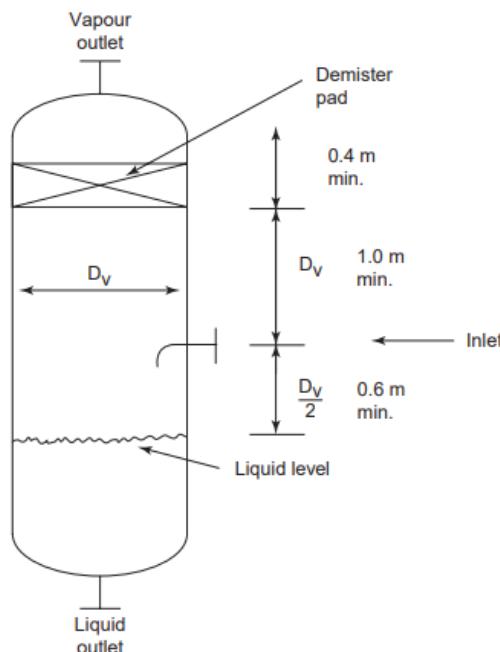


Figure 10.23 Typical proportion of vertical liquid-vapor separator

Source: Towler & Sinnott 2013

Demister pad is used for efficient and economical of entrained liquid droplet from vapour stream. It is used within the process where these liquid droplets can cause problems such as corrosion of equipment, contamination product, damage to instruments and fouling of heat exchanger and catalyst. In this phase separator PS-101

design, it will be excluded since the process around the vessel do not dealing with such problems and will be save cost.

$$\text{Vapor volumetric flowrate, } V_v = \frac{1495.95 \text{ kg/hr}}{35.928 \text{ kg/m}^3} = 41.637 \frac{\text{m}^3}{\text{hr}} = 0.0116 \frac{\text{m}^3}{\text{s}}$$

By applying equation from Towler & Sinnott (2013), the minimum diameter of vessel is

$$D_v = \sqrt{\left(\frac{4V_v}{\pi u_s}\right)}$$

$$D_v = \sqrt{\left(\frac{4(0.0116)}{\pi(0.1261)}\right)} = 1.04 \text{ m}$$

Take the diameter as 1.2 m

$$D_v/2 = 0.6 \text{ m}$$

$$\text{Liquid volumetric flowrate, } V_L = \frac{1993.71 \text{ kg/hr}}{195.911 \text{ kg/m}^3} = 10.18 \frac{\text{m}^3}{\text{hr}} = 0.00283 \frac{\text{m}^3}{\text{s}}$$

Allow for minimum of 10 minutes holdup,

$$\text{Volume held in vessel} = 0.00283 \times (10 \times 60) = 1.698 \text{ m}^3$$

$$\begin{aligned} \text{Liquid depth required, } h_v &= \frac{\text{volume held up}}{\text{vessel cross sectional area}} \\ &= \frac{1.698}{(\pi \times 1.2^2 / 4)} = 0.15 \text{ m} \end{aligned}$$

Increase to 0.3 m to allow space for positioning the controller. Hence the liquid depth is 0.45 m.

So, the total height of the phase separator is $= 1 + 0.6 + 0.45 = 2.05$ m.

Take the vessel height as 2.5 m to increase the efficiency of vapor-liquid separation.

The feed position will be $= h_v + D_v/2 = 0.45 + 0.6 = 1.05$ m.

The dimension of the phase separator can be seen on the following diagram.

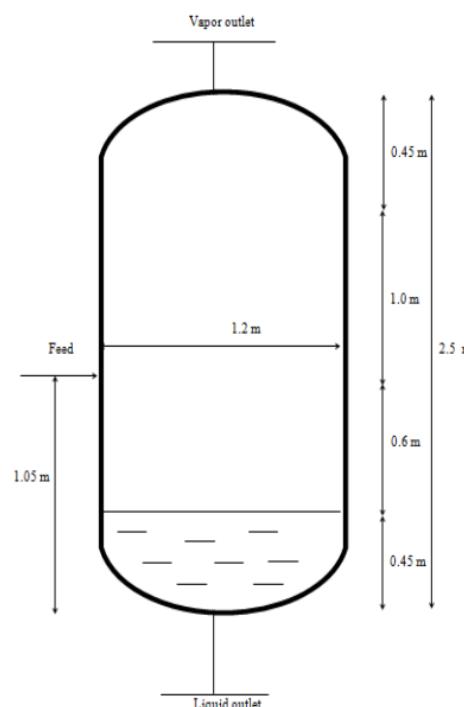


Figure 10.24 Dimension of phase separator, PS-101

10.17.5 Summary of Phase Separator, PS-101

Table 10.33 shows the summary detailed design for phase separator, PS-101

Table 10.33 Summary detailed design of Phase Separator, PS-101

Specification	Value
Settling Velocity, U_t	0.1261 m/s
Vessel diameter, D_v	1.2 m
Vessel height, H	2.5 m
Vessel volume	1.698 m ³

10.18 PLUG FLOW REACTOR, R-102

Designed by: Azrul Zulhilmi bin Ahmad Rosli (A173752)

10.18.1 Introduction

The type of reactor that being used in the production of urea is the plug flow reactor. This plug flow reactor in a vertical shape. Ammonia from packed bed reactor (R-101) will be fed into the reactor along with carbon dioxide at 180°C and 140 bar. Then, urea and other side products will be left the reactor with unreacted feed. There are two main reactions that will occur inside the reactor. Plug flow consists of numbers of plat inside the reactor and the reaction will flow from the bottom to the top. Figure 10.25 show schematic diagram of plug flow reactor.

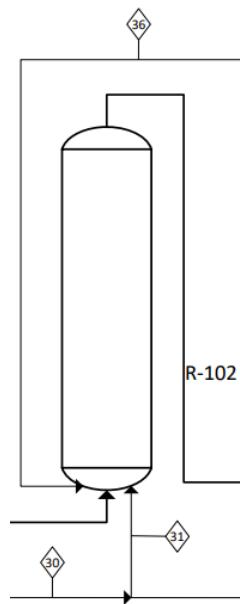


Figure 10.25 Schematic diagram of Plug Flow Reactor, R-102

10.18.2 Reactor Properties

The properties of the down flow reactor are shown in Table 10.34 below.

Table 10.34 Properties of Plug Flow Reactor, R-102

Parameter	Value
Operating Temperature, °C	180

Operating Pressure, bar	140
Feed Flow Rate, kg/h (Ammonia)	1993.71
Feed Flow Rate, kg/h (CO ₂)	2994.00
Feed Flow Rate, kg/h (Recycle)	1147.20
Feed Flow Rate, kg/h (Total)	6134.91
Volumetric Flow Rate, m ³ /h (Ammonia)	6.339
Volumetric Flow Rate, m ³ /h (CO ₂)	13.450
Volumetric Flow Rate, m ³ /h (Recycle)	2.309
Volumetric Flow Rate, m ³ /h (Total)	22.098
Composition of Carbamate	0.13
Catalyst	No

10.18.3 Design Parameters

The volume for R-102 can be calculated using simplified formula of the Washburn equation:

$$\frac{V}{F_{AO}} = \int_0^{x_A} \frac{dx_A}{-r_A}$$

Where,

V: Volume of the fluid flowing through the porous medium

F_{AO}: The flow rate of the fluid

x_A: Length of the porous medium

d_A: Diameter of the pores

r_A: Radius of the pores

By determining the pressure drop across the medium and the fluid's flow rate, the equation can be used to determine the volume of fluid moving through a porous medium. The equation can also be used to determine a porous material's permeability, which is a measurement of how easily a fluid can pass through the medium.

By using a rate law for a first-order reaction (RK Sinnott 2019),

$$-r_A = k_A \cdot C_A$$

$$C_A = C_{AO}(1 - x_A)$$

Where,

r_A : Rate of reaction

k_A : Rate constant

C_A : Concentration of the reactant

The formula of rate of reaction is substituted back into the volume of reactor where:

$$\frac{V}{F_{AO}} = \int_0^{x_A} \frac{dx_A}{k_A \cdot C_{AO} \cdot (1 - x_A)}$$

$$\frac{V \cdot C_{AO}}{F_{AO}} = \frac{1}{k} \int_0^{x_A} \frac{dx_A}{(1 - x_A)}$$

$$\frac{V}{v_O} = \frac{1}{k_A} [-\ln(1 - x_A)]$$

In order to obtain the volume of the reactor, the equilibrium constant, k is calculated using Arrhenius equation (RK Sinnott 2019).

$$k = k_0 \exp\left(-\frac{E}{RT}\right)$$

Where,

$$k = 4.23 \text{ hr}^{-1}$$

So, the volume of reactor is,

$$\frac{V}{22.098} = \frac{1}{4.23} [-\ln(1 - 0.13)]$$

$$V = 0.728 \text{ m}^3$$

The height and diameter of the reactor will be calculated using the following formula.

$$V = \frac{\pi}{4} D^2 H$$

Where,

$$5D = H$$

Thus,

$$0.728 = \frac{\pi}{4} D^2 (5D)$$

$$D^3 = 0.185$$

$$D = 0.570 \text{ m}$$

$$H = 5(0.57) = 2.85 \text{ m}$$

The residence time for R-102 can be calculated using the equation :

$$\tau = \frac{V}{v_0} = \frac{0.728}{22.098} = 0.03 \text{ hr}$$

10.18.4 Sieve Plates

Cost, operating range, efficiency, and pressure drop should be taken into account when comparing the performance of sieve and valve plates and bubble plates. Sieve plates are utilised in this reactor since reactor operating conditions are high. Sieve plates rely on the movement of vapours through the holes to retain the liquid on the plate and cannot operate at very low pressure (Richardson, 2009). The plate spacing will determine the overall height of the column. The typical plate spacing is between 0.5 and 1 meters, and

the building material is 403 stainless steel. For reactors with small reactor diameters, close spacing is used. Then, sieve trays and the spacing between the trays are to be assumed 0.2 m. The numbers of tray needed in the R-102 is based on the height of reactor Thus,

$$N = \frac{H}{spacing} = \frac{2.85}{0.2} = 14.25 \approx 15 \text{ stages}$$

10.18.5 Summary of Detail Design of Plug-Flow Reactor, R-102

Table 10.35 below shows the summary for the detail design of R-102

Table 10.35 Summary of Design for Plug Flow Reactor, R-102

Parameters	Value
Volume	0.728 m ³
Height	2.85 m
Diameter	0.57 m
Residence time	0.03 hr
Number of trays	15

10.19 STRIPPER, S-101

Designed by Suriya Vathi A/P Subramanian (A174271)

10.19.1 Introduction

In urea production, ammonia and carbon dioxide will be brought together in stripper to allow the reaction to occur to produce the mixture urea, ammonia carbamate and water, ammonia, and carbon dioxide at 180°C and 140 bar. Ammonia carbamate will be decomposed to carbon dioxide and ammonia gas where it will be recycled back to reactor, R-102.

10.19.2 Design Specification

Figure 10.26 below shows the inlet and outlets stream for S-101.

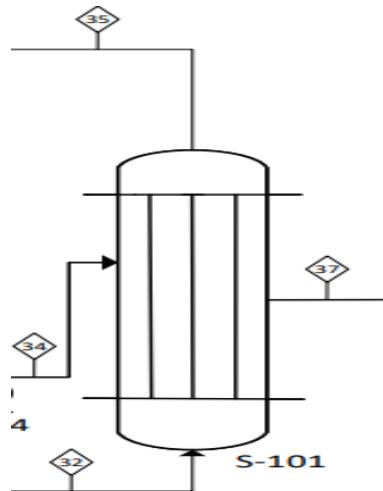


Figure 10.26 Schematic diagram of Stripper, S-101

Table 10.1 Summary of chemical properties and flowrate of components in S-101

Table 10.36 Summary of chemical properties and flowrate of components in Stripper, S-101

Physical properties	Density (kg/m ³)	Viscosity (kg/ms)	Flowrate	Flowrate	Flowrate	Flowrate
			of inlet stream 34	of inlet stream 32	of outlet stream 35	of outlet stream 37
			(kg/h)	(kg/h)	(kg/h)	(kg/h)
Water	305.00	1.5332E-5	613.61	0	0	613.42
Carbon dioxide	382	10.30E-6	1902.18	123	860.40	1482.44
Ammonia carbamate	1380	0.054E-3	797.670	0	0	153.36
Ammonia	153.45	4.52E-9	736.33	0	286.80	766.78
Urea	1320	8.00E-3	2086.27	0	0	2095.87

Table 10.37 Summary chemical properties and flowrate of components in S-101

Components	Feed (Stream 34)			Absorber (Stream 32)			Bottom (Stream 37)			Distillate (Stream 35)		
	Mass Flowrate, F (kg/h)	Molar Flowrate, N (kmole/h)	Mass Fraction, X	Mass Flowrate, F (kg/h)	Molar Flowrate, N (kmole/h)	Mass Fraction, X	Mass Flowrate, F (kg/h)	Molar Flowrate, N (kmole/h)	Mass Fraction, X	Mass Flowrate, F (kg/h)	Molar Flowrate, N (kmole/h)	Mass Fraction, X
Water	613.61	34.05	0.10	0	0	0	613.61	34.05	0.12	0	0	0
Carbon dioxide	1902.18	43.22	0.31	123	2.79	1	1482.44	33.68	0.29	860.40	19.55	0.75
Ammonia Carbamate	797.670	10.22	0.13	0	0	0	153.36	1.96	0.03	0	0	0
Ammonia	736.33	43.24	0.12	0	0	0	766.78	45.03	0.15	286.80	16.84	0.25
Urea	2086.27	34.74	0.34	0	0	0	2095.87	34.90	0.41	0	0	0
Total	6136.08	165.47	1.0	123	2.79	1.0	5111.87	149.62	1.0	1147.20	36.39	1.0

10.19.3 Number of Theoretical stages

Below is the calculation made for this unit based on Chemical Engineering Separations: A Handbook for Students 2021 (Journal of the Air & Waste Management Association, 2012)

$$\text{Equilibrium constant, } K = \frac{\text{Total mole fraction of gas flow } \left(\frac{\text{kmole}}{\text{h}} \right)}{\text{Total mole fraction of liquid flow } \left(\frac{\text{k mole}}{\text{h}} \right)}$$

$$= \frac{\frac{149.62}{165.47 + 2.79}}{\frac{36.39}{149.62 + 36.39}}$$

$$= 4.56$$

Liquid flowrate, L = 149.62 kmole/h

Vapour flowrate, V = 36.39 kmole/h

Stripping factor, S (Robbins. 2011)

$$S = \frac{K}{\left(\frac{L}{V}\right)} = \frac{4.56}{\left(\frac{36.39}{149.62}\right)} = 18.75$$

Where,

K : Equilibrium constant = Vapour mole fraction/ liquid mole fraction

L : Liquid flowrate, kmol/h

V : Vapour flowrate, kmol/h

$$\text{Sum of concentration of feed, } X_f = \sum \frac{\text{Molar flowrate of feed component, kmol/h}}{\frac{\text{Mass of flowrate of feed component, kg/h}}{\text{Density of component, kg/m}^{-3}}}$$

$$= 95.47$$

$$\text{Sum of concentration of bottom, } X_b = \sum \frac{\text{Molar flowrate of bottom component, kmol/h}}{\frac{\text{Mass of flowrate of bottom component, kg/h}}{\text{Density of component, kg/m}^{-3}}}$$

$$= 1034.88$$

$$\text{Number of theoretical stages, } N_t = \frac{\ln\left(\frac{x_f}{x_b}[(S-1)+1]\right)}{\ln S} + 1$$

$$= \frac{\ln\left(\frac{95.47}{1034.88}[(18.75 - 1) + 1]\right)}{\ln 18.75} + 1$$

$$= 1.61 = 2 \text{ stages}$$

Where,

- N : Number of theoretical stages
 x_f : Feed concentration (mole fraction), kmol/m³
 x_b : Effluent concentration (mole fraction), kmol/m³

10.19.4 Number of Actual Stages

Based on Lamm & Jarboe 2021, the liquid viscosity, μ_L is between 0.2 to 1.6 cP.

Liquid viscosity, $\mu_L = 1.6 \text{ cP}$

Number of transfer unit in gas, N_G ,

$$N_G = N_L = 0.936 \mu_L^{-0.25}$$

$$N_G = N_L = 0.936(1.6)^{-0.25} = 0.83$$

Where,

N_L : Number of transfer unit in liquid

μ_L : Liquid viscosity, cP

Overall transfer unit for gas phase, N_{OG}

$$N_{OG} = \frac{1}{\frac{1}{N_G} + \frac{S}{N_L}} = \frac{1}{\frac{1}{0.832} + \frac{18.75}{0.832}} = 0.042$$

Murphree point efficiency on a tray, η_{point}

$$n_{point} = 1 - e^{-N_{OG}}$$

$$n_{point} = 1 - e^{-0.042} = 0.041$$

Murphree tray efficiency, η_{tray}

$$n_{tray} = \frac{e^{S \times n_{point}} - 1}{S}$$

$$n_{tray} = \frac{e^{18.75 \times 0.041} - 1}{18.75} = 0.062$$

Column efficiency, n_{column}

$$n_{column} = \frac{\ln[1 + n_{tray}(S - 1)]}{\ln S}$$

$$= 0.253$$

Number of actual stages, N_a ,

$$N_a = \frac{N_t}{n_{column}}$$

$$= 7.905 \approx 8 \text{ stages}$$

10.19.5 Diameter and Height of Column

Calculation formula diameter and height of column:

Liquid density, $\rho_L = 752.998$

Vapour density, $\rho_V = 324.863$

Liquid mass flowrate, $L_w = \frac{5111.87 \text{ kg/h}}{3600 \text{ s}} = 1.42 \text{ kg/s}$

Vapour mass flowrate, $V_w = \frac{1147.20 \text{ kg/h}}{3600 \text{ s}} = 0.32 \text{ kg/s}$

Based on Towler & Sinnott 2019, liquid-vapour flow factor, F_{LV}

$$F_{LV} = \frac{L_w}{V_w} \sqrt{\frac{\rho_v}{\rho_L}}$$

$$F_{LV} = \frac{1.42}{0.32} \sqrt{\frac{324.863}{752.998}} = 2.915$$

Where,

L_w : Liquid mass flowrate, kg/s

V_w : Liquid mass flowrate, kg/s

ρ_v : Vapour density, kg/m³

ρ_L : Liquid density, kg/m³

Next for plate spacing, I_t is normally be used is 0.61m. By referring Figure 10.30 from Geankoplis, 2014

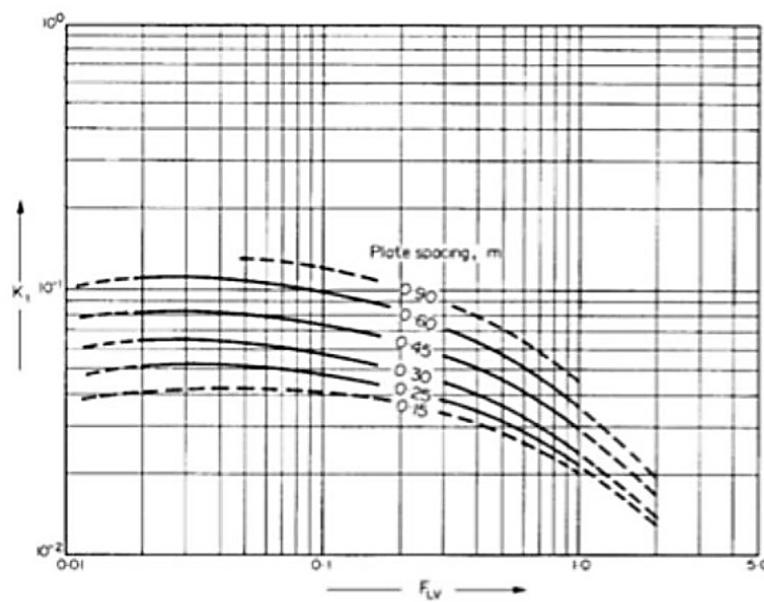


Figure 10.27 Liquid-Vapor Flow Factor

Source: Geankoplis, 2014

K_1 is equal to 0.013

Hence, the flooding velocity, u_f is:

$$u_f = K_1 \sqrt{\frac{\rho_L - \rho_V}{\rho_L}}$$

$$= 0.0098 \frac{m}{s}$$

For design, a value of 80% to 85% of the flooding velocity should be used.

Actual flooding velocity, $u_n = 0.85 u_f$

$$= 0.85 \times 0.0098$$

$$= 0.00833 \text{ m/s}$$

Net area required, $A_n = \frac{x_b}{u_n} = 3.45 \text{ m}^2$

Assuming column cross-sectional area, A_c occupies 20% of cross-sectional area = $A_n/0.80$

$$A_c = 4.313$$

Diameter of stripper,

$$D = \sqrt{\frac{4 \times A_c}{\pi}}$$

$$= 2.34 \text{ m}$$

Height of stripper

$$H = (N_a - 1)I_t$$

$$= 4.27 \text{ m}$$

10.19.6 Summary of Detail Design of Stripper, S-101

Table 10.38 shows the summary of detailed design of S-101

Table 10.38 Summary of detailed design Stripper, S-101

Property	Value	Unit
Liquid molar flowrate, L	149.62	kmol/h
Vapour molar flowrate, V	36.39	kmol/h
Stripping factor, S	18.75	-
Number of theoretical stages, N_t	2	stages
Tray efficiency	0.062	-
Column efficiency	0.253	-
Number or theoretical, N_a	8	stages
Plate spacing, l_t	0.60	m
Actual flooding velocity, u_n	0.00833	m/s
Diameter of column	2.34	m
Height of column, H	4.27	m

10.20 HEAT EXCHANGER, HE-101

Designed by: Aerry Ting Wei Huan (A174141)

10.20.1 Introduction

Shell and tube heat exchanger was the most used type of heat-transfer equipment in chemical process. In this process, heat exchanger (HE-101) as a part of the heat integration as the hot fluid was cold from temperature 180°C to 140.02°C while the cold fluid was heated up to temperature 40°C from 150°C. Kern's method was applied as it was simple and accurate enough for preliminary design calculation. Some assumptions and design specification are determined as follows before the detailed calculation of the construction of heat exchanger, HE-101. Figure 10.28 below show the illustrative diagram of heat exchanger HE-101.

Assumptions

(1) There is no change in specific heat and flow rate of the streams.

(2) The overall heat-transfer coefficient, U is constant.

(3) No heat is losses to surrounding.

10.20.2 Design Specification of Heat Exchanger, HE-101

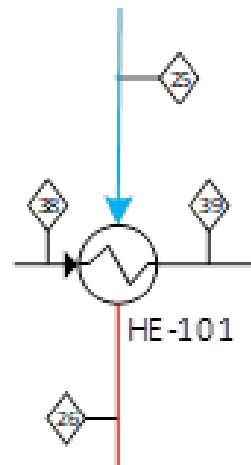


Figure 10.28 Schematic diagram of Heat Exchange HE-101

The detailed design calculation step involved for heat exchanger HE-101 is shown in Appendix D. Table 10.39 below shows the physical properties of the product stream and cooling water while Table 10.40 shows the summary of design specification for HE-101.

Table 10.39 Physical properties of the product stream and cooling water in Heat Exchanger, HE-101

Physical properties	Product stream	Cooling water
Inlet temperature (°C)	180	40
Outlet temperature (°C)	140.02	150
Flowrate (kg/hr)	5111.87	3065.03
Heat capacity, c_p (kJ/kg °C)	2.169	4.187
Density, ρ (kg/m ³)	3.065	997
Thermal conductivity, K (W/m ² °C)	0.208	0.598
Viscosity, η (Ns/m ²)	0.068	0.001

Table 10.40 Summary of design specification for Heat Exchanger, HE-101

Parameter	Value
Tube side	
Outer diameter, d_o (mm)	20
Inner diameter, d_i (mm)	16
Length of tube, L (m)	1.83

Area of one tube, A_t (m ²)	0.115
Number of tubes	42
Number of tube passes	4
Linear fluid viscosity, μ_t (m/s)	0.163
Heat transfer coefficient, h_i (W/m ² °C)	915.55
Pressure drop, ΔP_t (kPa)	6.45
Shell side	
Bundle diameter, D_b (mm)	204.23
Shell diameter, D_s (mm)	275.23
Baffle cut (%)	25
Baffle spacing, l_b (mm)	82.57
Tube pitch, P_t (mm)	25
Equivalent diameter, d_e (mm)	36.63
Heat transfer coefficient, h_s (W/m ² °C)	102.13
Pressure drop, ΔP_s (kPa)	76.32
Overall heat transfer coefficient, U_o (W/m ² °C)	143.46

10.21 HEAT EXCHANGER, HE-102

Designed by: Aerry Ting Wei Huan (A174141)

10.21.1 Introduction

Table 10.3 below shows the physical properties of the product stream and cooling water while Table 10.4 shows the summary of design specification for HE-102.

Table 10.41 Physical properties of the product stream and cooling water in Heat Exchanger, HE-102

Physical properties	Product stream	Cooling water
Inlet temperature (°C)	110	30
Outlet temperature (°C)	55.30	80
Flowrate (kg/hr)	2242.80	2969.33
Heat capacity, c_p (kJ/kg °C)	1.591	4.187
Density, ρ (kg/m ³)	1.347	997
Thermal conductivity, K (W/m ² °C)	0.059	0.598
Viscosity, η (Ns/m ²)	0.006	0.001

Table 10.42 Summary of design specification for Heat Exchanger, HE-102

Parameter	Value
Tube side	
Outer diameter, d_o (mm)	20
Inner diameter, d_i (mm)	16
Length of tube, L (m)	1.83
Area of one tube, A_t (m ²)	0.115
Number of tubes	14
Number of tube passes	4
Linear fluid viscosity, μ_t (m/s)	0.588
Heat transfer coefficient, h_t (W/m ² °C)	2660.87
Pressure drop, ΔP_t (kPa)	17.06
Shell side	
Bundle diameter, D_b (mm)	124.15
Shell diameter, D_s (mm)	195.15
Baffle cut (%)	25
Baffle spacing, l_b (mm)	58.54
Tube pitch, P_t (mm)	25
Equivalent diameter, d_e (mm)	36.63
Heat transfer coefficient, h_s (W/m ² °C)	127.24
Pressure drop, ΔP_s (kPa)	88.24
Overall heat transfer coefficient, U_o (W/m ² °C)	198.46

10.22 DECOMPOSER, DP-101

Designed by Suriya Vathi A/P Subramanian (A174271)

10.22.1 Introduction

After stripper, the mixture urea, ammonia carbamate and water, ammonia, and carbon dioxide will enter decomposer at 120°C and 3 bar. Ammonia carbamate will undergo further decomposition to carbon dioxide and ammonia gas where it will be purged out from the plant through stream 40. Then, the urea solution that consist of urea, water and less amount of carbon dioxide and ammonia will enter evaporator (EV-101) at stream 42 for water removal.

10.22.2 Design Specification

Figure 10.29 below shows the inlet and outlets stream for D-101.

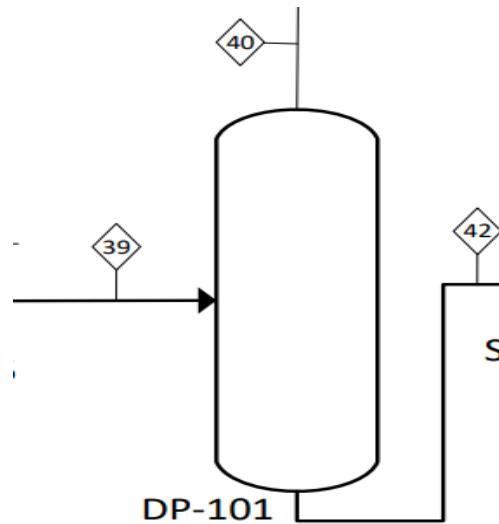


Figure 10.29 Schematic diagram of Decomposer, DP-101

Table 10.43 Summary of chemical properties and flowrate of components in Decomposer, DP-101

Physical properties	Density (kg/m ³)	Viscosity (kg/ms)	Flowrate of	Flowrate of	Flowrate of
			inlet stream 39 (kg/h)	outlet stream 40 (kg/h)	outlet stream 42 (kg/h)
Water	974	1.94E-3	613.61	0	631.195
Carbon dioxide	627	6.5E-5	1482.442	1502.676	86.071
Ammonia carbamate	1437	2.4E-5	153.356	0	0
Ammonia	33.4	1.52E-4	766.781	740.124	86.071
Urea	1266	1.60E-5	2095.867	0	2094.421

Table 10.44 Summary chemical properties and flowrate of components in D-101

Components	Feed (Stream 39)			Bottom (Stream 42)			Distillate (Stream 40)		
	Mass Flowrate, F (kg/h)	Molar Flowrate, N (kmole/h)	Mass Fraction, X	Mass Flowrate, F (kg/h)	Molar Flowrate, N (kmole/h)	Mass Fraction, X	Mass Flowrate, F (kg/h)	Molar Flowrate, N (kmole/h)	Mass Fraction, X
Water	613.61	34.06	0.12	631.195	35.04	0.22	0	0	0
Carbon dioxide	1482.442	33.68	0.29	86.071	1.96	0.03	1502.676	34.144	0.67
Ammonia Carbamate	153.356	1.96	0.03	0	0	0	0	0	0
Ammonia	766.781	45.03	0.15	86.071	5.054	0.03	740.124	43.46	0.33
Urea	2095.867	34.90	0.41	2094.421	34.87	0.73	0	0	0
Total	5111.87	149.63	1.0	2869.07	75.924	1.0	2242.8	77.604	1.0

10.22.3 Number of Theoretical Stages

Below is the calculation made for this unit based on Chemical Engineering Separations: A Handbook for Students 2021 (Journal of the Air & Waste Management Association, 2012)

$$\text{Equilibrium constant, } K = \frac{\text{Total mole fraction of gas flow } \left(\frac{\text{kmole}}{\text{h}} \right)}{\text{Total mole fraction of liquid flow } \left(\frac{\text{k mole}}{\text{h}} \right)}$$

$$= \frac{\frac{77.604}{149.63}}{\frac{75.924}{75.924 + 77.604}}$$

$$= 5.66$$

Liquid flowrate, $L = 75.924 \text{ kmole/h}$

Vapour flowrate, $V = 77.604 \text{ kmole/h}$

Stripping factor, S (Robbins. 2011)

$$S = \frac{K}{\left(\frac{L}{V}\right)} = \frac{5.66}{\left(\frac{75.924}{77.604}\right)} = 6$$

Where,

K : Equilibrium constant = Vapour mole fraction/ liquid mole fraction

L : Liquid flowrate, kmol/h

V : Vapour flowrate, kmol/h

$$\text{Sum of concentration of feed, } X_f = \sum \frac{\frac{\text{Molar flowrate of feed component, kmol/h}}{\text{Mass of flowrate of feed component, kg/h}}}{\text{Density of component, kg/m}^{-3}}$$

$$= 124.41$$

$$\text{Sum of concentration of bottom, } X_b = \sum \frac{\frac{\text{Molar flowrate of bottom component, kmol/h}}{\text{Mass of flowrate of bottom component, kg/h}}}{\text{Density of component, kg/m}^{-3}}$$

$$= 76.75$$

$$\text{Number of theoretical stages, } N_t = \frac{\ln\left(\frac{x_f}{x_b}[(S-1)+1]\right)}{\ln S} + 1$$

$$= \frac{\ln\left(\frac{124.41}{76.75} [(6-1) + 1]\right)}{\ln 6} + 1$$

$$= 2.27 = 2 \text{ stages}$$

Where,

- N : Number of theoretical stages
- x_f : Feed concentration (mole fraction), kmol/m³
- x_b : Effluent concentration (mole fraction), kmol/m³

10.22.4 Number of Actual Stages

Based on Lamm & Jarboe 2021, the liquid viscosity, μ_L is between 0.2 to 1.6 cP.

Liquid viscosity, $\mu_L = 1.6 \text{ cP}$

Number of transfer unit in gas, N_G ,

$$N_G = N_L = 0.936\mu_L^{-0.25}$$

$$N_G = N_L = 0.936(1.6)^{-0.25} = 0.83$$

Where,

- N_L : Number of transfer unit in liquid
- μ_L : Liquid viscosity, cP

Overall transfer unit for gas phase, N_{OG}

$$N_{OG} = \frac{1}{\frac{1}{N_G} + \frac{S}{N_L}} = \frac{1}{\frac{1}{0.832} + \frac{6}{0.832}} = 0.119$$

Murphree point efficiency on a tray, η_{point}

$$\eta_{point} = 1 - e^{-N_{OG}}$$

$$\eta_{point} = 1 - e^{-0.119} = 0.112$$

Murphree tray efficiency, η_{tray}

$$\eta_{tray} = \frac{e^{S \times \eta_{point}} - 1}{S}$$

$$n_{tray} = \frac{e^{6 \times 0.112} - 1}{6} = 0.160$$

Column efficiency, n_{column}

$$n_{column} = \frac{\ln[1 + n_{tray}(S - 1)]}{\ln S}$$

$$= 0.328$$

Number of actual stages, N_a ,

$$N_a = \frac{N_t}{n_{column}}$$

$$= 6.920 \approx 7 \text{ stages}$$

10.22.5 Diameter and Height of Column

Calculation formula diameter and height of column:

Liquid density, $\rho_L = 1158.272 \text{ kg/m}^3$

Vapour density, $\rho_V = 431.11 \text{ kg/m}^3$

Liquid mass flowrate, $L_w = \frac{2869.07 \text{ kg/h}}{3600 \text{ s}} = 0.800 \text{ kg/s}$

Vapour mass flowrate, $V_w = \frac{2242.8 \text{ kg/h}}{3600 \text{ s}} = 0.631 \text{ kg/s}$

Based on Towler & Sinnott 2019, liquid-vapour flow factor, F_{LV}

$$F_{LV} = \frac{L_w}{V_w} \sqrt{\frac{\rho_V}{\rho_L}}$$

$$F_{LV} = \frac{0.80}{0.631} \sqrt{\frac{431.11}{1158.272}} = 0.77$$

Where,

L_w : Liquid mass flowrate, kg/s

V_w : Liquid mass flowrate, kg/s

ρ_v : Vapour density, kg/m³

ρ_L : Liquid density, kg/m³

Plate spacing, I_t is normally be used is 0.61m. By referring Figure 10.2 (Geankoplis, 2014)

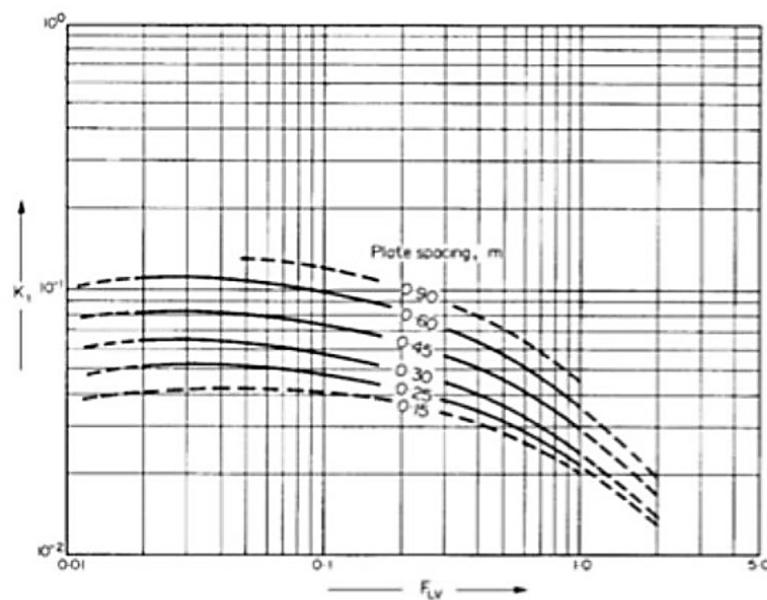


Figure 10.30 Liquid-Vapor Flow Factor

Source: Geankoplis, 2014

K_1 is equal to 0.038

Flooding velocity, u_f

$$u_f = K_1 \sqrt{\frac{\rho_L - \rho_v}{\rho_L}}$$

$$= 0.030 \frac{m}{s}$$

For design, a value of 80% to 85% of the flooding velocity should be used.

Actual flooding velocity, $u_n = 0.85 u_f$

$$= 0.85 \times 0.030$$

$$= 0.026 \text{ m/s}$$

$$\text{Net area required, } A_n = \frac{x_b/3600}{u_n} = 3.0 \text{ m}^2$$

Assuming column cross-sectional area, A_c occupies 20% of cross-sectional area = $A_n/0.80$

$$A_c = 3.75$$

Diameter of stripper,

$$D = \sqrt{\frac{4 \times A_c}{\pi}}$$

$$= 2.19 \text{ m}$$

Height of stripper

$$H = (N_a - 1)I_t$$

$$= 3.60 \text{ m}$$

10.22.6 Summary of Detail Design of Decomposer, D-101

Table 10.45 shows the summary of detailed design of Decomposer, D-101

Table 10.45 Summary of detailed design Decomposer, D-101

Property	Value	Unit
Liquid molar flowrate, L	75.924	kmol/h
Vapour molar flowrate, V	77.604	kmol/h
Stripping factor, S	6	-

Number of theoretical stages, N_t	2	stages
Tray efficiency	0.160	-
Column efficiency	0.328	-
Number of actual, N_a	7	stages
Plate spacing, l_t	0.60	m
Actual flooding velocity, u_n	0.030	m/s
Diameter of column	2.19	m
Height of column, H	3.60	m

10.23 EVAPORATOR, EV-101

Designed by: Azrul Zulhilmi bin Ahmad Rosli (A173752)

10.23.1 Introduction

Evaporation is a separation of a volatile liquid from a non-volatile solid based on the principle of vaporization. The evaporator was used to concentrate the solution before it is being granulated. The short-tube vertical evaporators are used, and it sometimes also known as standard evaporator. Short-tube vertical evaporators are made up of a bundle of short tubes that are contained in a cylindrical shell and range in length from 4 to 10 feet. It is known as Calandria. The feed is injected above the upper tube sheet, and the calandria's steam chest or shell is then filled with steam. In the tubes, the solution is heated and partially vaporised. In a calandria, the centre tube has a larger diameter. Typically, the downcomer area of tubes is estimated to be between 40 and 70 percent of their entire cross-sectional area. The feed rate is much outweighed by the circulation rate through the downcomer/downtake. Normally, the downtake's flow area is roughly equal to the overall tubular flow area (Sindisiwe 2019). Figure 10.31 shows calandria type evaporator.

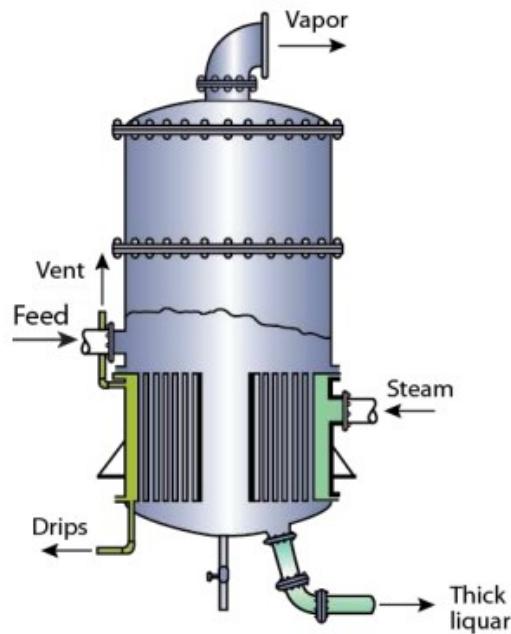


Figure 10.31 Calandria type evaporator

Source: Sindisiwe 2019

10.23.2 Operation of Evaporator

This short-tube vertical evaporator is a single effect evaporator. Feed enters as F at temperature, T_f and saturated steam as S, T_s enters the heat exchanger tube. Condensate steam leaves as condensate. The schematic diagram of single effect evaporator is shown in Figure 10.32 and the material balance in evaporator is tabulated in Figure 10.32

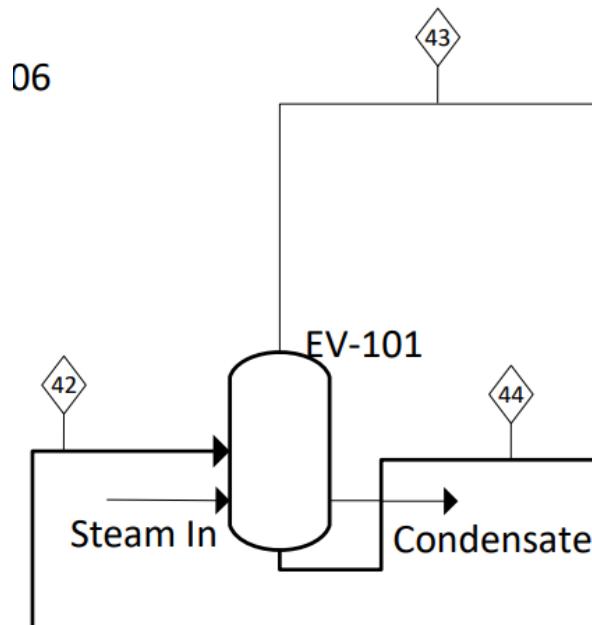


Figure 10.32 Schematic diagram of Evaporator, EV-101

Table 10.46 Parameter of Evaporator, EV-101

Parameter	Value
X_F	0.73
X_L	0.27
Feed, F	2869.07 kg/h
Concentrated liquid, L	631.19 kg/h
Vapor, V	597.08 kg/h
Enthalpy of concentrated liquid, h_L	938.87 kJ/kg
Enthalpy of vapor, h_V	1165.6 kJ/kg
Latent heat of water	3706 kJ/kg
Feed temperature, T_F	110°C
Operating temperature, T_1	175°C

10.23.3 Area of Heat Transfer

At Single effect (Minton, 1988),

- To concentrated feed to 92% solid
- Gauge pressure of steam = 2bar
- Absolute pressure in the vapor space = 2bar
- Overall coefficient = $750-2500 \text{ Wm}^{-2}\text{C}^{-1} = 150-500 \text{ Btu.ft}^{-2}\text{h}^{-1}\text{F}^{-1}$ = assume 1400

- Feed contains = $27/73 = 0.37$
- Thick liquor contains = $8/92 = 0.09$
- Quantity evaporated = $0.37 - 0.09 = 0.28$
 $= 0.28 \times 2869.07 \times 0.73 = 586.44 \text{ kg/hr}$
- Flowrate thick liquid = $2869.07 - 586.44 = 2282.63$ (equation)
 $= 2271.99$ (manual) (assume)
- Boiling point water at 2 bar = 120°C and urea at 2 bar = 185°C so boiling point elevation = 61.5°C

$$q = m_s \lambda_s = (m_f - m)H_v - m_f H_f + mH$$

Where,

q = rate of heat transfer from heating surface to liquid

H_v = specific enthalpy of vapor

H_f = specific enthalpy of thin liquor

H = specific enthalpy of thick liquor

Heat transfer, $q = (2869.07 - 2271.99) 3706 - 2869.07(938.87) + 2271.99 (1165.6)$

$$= 2167326.27 \text{ W}$$

10.23.4 Steam Consumption

Saturated temperature of steam at 4 bar = 2070 kJ/kg

Steam consumption, $S = 2167326.27 / 2070 = 1047.02 \text{ kg/hr}$

Heating surface, $A = 2167326.27 / 1400(175-110) = 23.82 \text{ m}^2$

The economy = $586.44 / 1047.02 = 0.56$

10.23.5 Summary of Detail Design of Evaporator, EV-101

The design of S-101 has been calculated as shown in Appendix D and summarized in Table 10.47.

Table 10.47 Detail design of Evaporator, E-101

Parameter	Values
Duty, Kw	2167.33
Amount of water to be evaporated, kg/hr	586.44
Density of liquid , kg/m ³	1150
Feed flow rate, kg/hr	2869.07
Liquid flow rate, kg/hr	631.19
Vapor flow rate, kg/hr	597.08
Feed composition, X _f	0.73
Liquid composition, X _L	0.27
Area, m ²	23.82
Diameter, m	1.13
Height, m	1.06
Number of tubes	177
Tube outside diameter, mm	26.67
Tube inside diameter, mm	20.93
Total area of tube sheet, m ²	0.92
Tube sheet diameter, m	0.212
Effective tube sheet thickness, mm (include C _A)	5.74
Tube shell thickness, mm	10
Tube wall thickness, mm	10

10.24 GRANULATOR, G-101

Designed by: Nur Iffa binti Rizuan (A173952)

10.24.1 Introduction

The granulator used in this plant has the same concept as the spray dryer. It is used for liquid and dilute slurry feeds. The feed that will be dried is atomized by a rotary atomizer positioned at the top of a vertical cylindrical vessel. Hot air flows up the vessel and dries the droplets. The liquid will be vaporize rapidly from the droplet surface and

particles formed. The advantages of using granulator is it suitable for drying heat sensitive materials and good control of the product particle size (Towler & Sinnott 2013). In this plant, urea and water enter the G-101 to form urea granule. G-101 operate at 1 bar with a temperature of 115°C from hot air supplied.

10.24.2 Design Specification

Figure 10.33 below shows the schematic diagram of granulator G-101

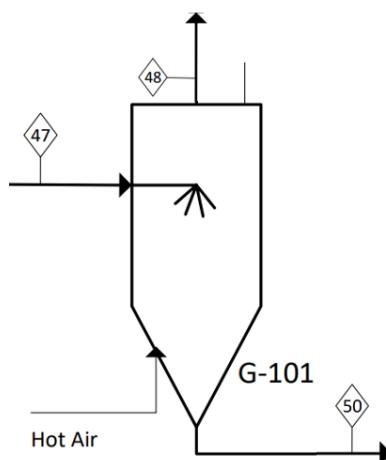


Figure 10.33 Schematic diagram of Granulator, G-101

The type of atomizer used is rotary atomizer as the blockage and clogging tendencies can be negligible (Ratti & Mujumdar 2014). Figure 10.34 below shows the rotary atomizer.

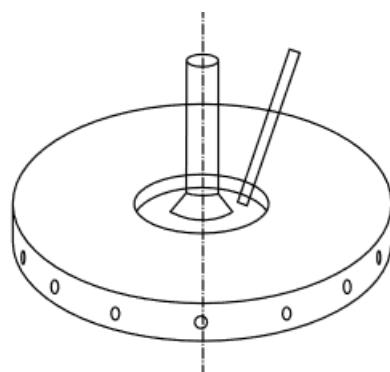


Figure 10.34 Diagram of rotary atomizer

Source: Ratti & Mujumdar 2014

Feed mass flow rate, $M = 2271.99 \text{ kg/h}$

$$= 0.6311 \text{ kg/s}$$

Rotation of speed, N = 16000 rpm

Diameter of wheel, d = 20 cm

Number of vanes = 20

Efficiency, ϵ = 70%

Based on Figure 10.5 from Ratti & Mujumdar 2014, the peripheral velocity, v is 120 m/s

$$\text{Power consumption, } E = \frac{Mv^2}{2\epsilon}$$

$$= \frac{0.6311 \times 120^2}{2 \times 0.7} = 6.5 \text{ kW}$$

$$\text{Droplet size, } D = 1.62 \times 10^{-1} \times N^{-0.44} \times M^{0.21} \times 2d^{-0.39}$$

$$= 1.62 \times 10^{-1} \times 16000^{-0.44} \times 0.6311^{0.21} \times 2(0.2)^{-0.39}$$

$$= 2.97 \text{ mm}$$

The hot air and droplet contact system is counter current as it is good for materials that is heat sensitive. As to maintain the desired purity of urea, so counter current is a good choice.

Net evaporation rate of water = 20.96 kg/h

Moisture removed per kg of hot air = 0.008 kg water/kg air

$$\text{Hot air flow rate, } G_s = \frac{\text{Net evaporation rate of water}}{\text{Moisture removed per kg of hot air}}$$

$$= 20.96 / 0.008 = 2620 \text{ kg/h}$$

Density of water = 1000 kg/m³

Density of urea = 1320 kg/m³

Density of urea particles, $\rho_p = (0.01 \times 1000 + 0.99 \times 1320) = 1316.8 \text{ kg/m}^3$

$$\text{Settling velocity, } v_s = \frac{D^2(\rho_p - \rho_f)g}{18\mu}$$

Where,

ρ_f , density of hot air = 0.91 kg/m³

μ , viscosity of hot air = $22.37 \times 10^{-6} \text{ kg/ms}$

so,

$$v_s = 0.283 \text{ m/s}$$

Operating velocity, $v_a = 2 \times v_s = 0.566 \text{ m/s}$

$$\text{Reynold number} = \frac{Dv_s\rho_p}{\mu} = 4947.6$$

$$\text{Humid volume, } V = 8315 \times \left(\frac{1}{M_a} + \frac{Y}{M_w} \right) \times \left(\frac{T_g + 273.15}{P} \right)$$

Where,

M_a , molecular weight of hot air = 29 g/mol

M_w , molecular weight of water = 18 g/mol

T_g = Temperature of air in °C

P = pressure in N/m²

Y = Humidity of air in kg of moisture / kg of dry air

Humid volume, $V = 1.57 \text{ m}^3/\text{kg dry air}$

$$\text{Column area, } A_c = \frac{G_s \times V}{v_a}$$

$$= 2.02 \text{ m}^2$$

$$\text{Column diameter, } D_c = \sqrt{\frac{4A_c}{\pi}} = 1.6 \text{ m}$$

Residence time, $t_d = 50\sqrt{\text{moles ratio of water to urea in feed}}$

$$= 14 \text{ sec}$$

a. Cylindrical chamber with a conical bottom calculation

Total volume of chamber, $V_t = G_s \times V \times t_d = 15 \text{ m}^3$

Recommended height of cylindrical portion, $h_{cyl} = 0.6 \times D_c = 0.96 \text{ m}$

Volume of the conical portion of chamber, $V_{cone} = V_t - \frac{\pi D_c^2 h_{cyl}}{4} = 13 \text{ m}^3$

Height of cone portion, $h_{cone} = \frac{0.3 \times 4 \times V_{cone}}{\pi D_c^2} = 1.9 \text{ m}$

$\tan \frac{\alpha}{2} = \frac{D_c}{2h_{cone}}$; angle of conical portion chamber, $\alpha = 23^\circ$

10.25 CONDENSER, CD-101

Designed by: Suriya Vathi A/P Subramanian (A174271)

10.25.1 Introduction

In urea production, condenser CD-101 will decrease the temperature of the vapour mixture from 140°C at stream 47 to 28°C at stream 48 at operating pressure of 1 bar. The purpose of the unit in urea production is convert the water vapor in liquid form so that it can be discharge from the plant.

Cooling water used as a coolant in condenser since it has few benefits over other cooling fluids. Firstly, using of cooling water in urea plant enable simple and efficient heat transfer between the urea solution and the cooling water, resulting in a more efficient and effective cooling process. Other than that, cooling water is easily accessible and affordable, making it a cost-effective option. Water also has a high specific heat capacity, which means it can absorb a lot of heat per unit mass, making it

a good coolant. Finally, it is non-toxic and non-flammable, making it an excellent choice for usage in urea plants (Grant, 2022).

Next, the horizontal shell and tube heat exchanger are chosen because it has high heat transfer efficiency as it has large surface area, it designed with removable tube bundles that makes them easy for maintenance and cleaning, it have low pressure drop and low energy requirements, and it can be easily scaled up or down to accommodate changes in production capacity. These advantages make them as versatile choices in urea production plant (Towler & Sinnott, 2013). Cooling water is assigned at tube side of condenser while process fluid is assigned at shell side of condenser. This is because coolant is corrosive. Figure 10.35 below shows the the working principal of condenser and Figure 10.36 below shows the schematic diagram of condenser C-101.

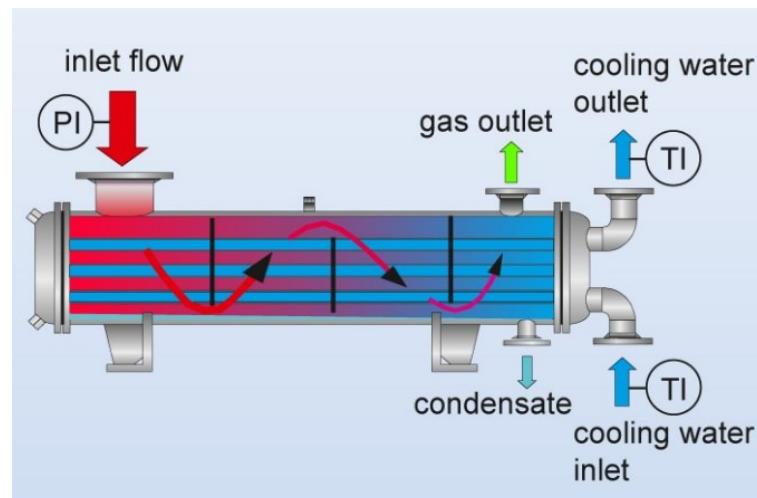


Figure 10.35 Working principal of condenser

Source: Korting, 2023

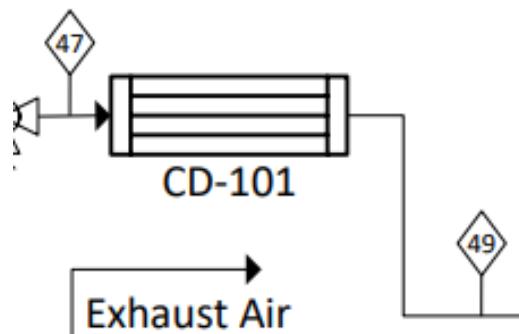


Figure 10.36 Schematic diagram of Condenser, CD-101

10.25.2 Temperature Profile of Condenser, CD-101

Figure 10.37 below shows the temperature profile of condenser, CD-101 where temperature of process fluid reduces from 140°C to 28°C while temperature of cooling water rises from 25°C to 45°C.

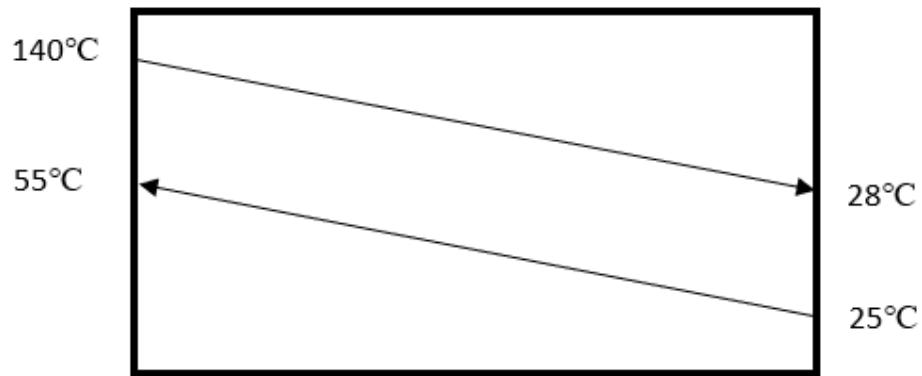


Figure 10.37 Temperature profile of condenser, C-102

The flow of fluid in condenser is counter-current flow where the two fluid flow in parallel to each other but in opposite directions since it will allow the largest change in temperature of both fluids. Table 10.48 below shows the composition of components entering the condenser at stream 44.

Table 10.48 Composition of components in condenser, CD-101

Components	Flowrate (kg/hr)
Water	610.98
Ammonia	85.07
Carbon dioxide	77.34

10.25.3 Specification of Condenser, CD-101

Condenser specifications:

1. Cooling water is assigned to the tube side because of the temperature factor.
2. Use one shell and two tube passes
3. Mixture placed to shell side

Table 10.49 Physical properties of Condenser, CD-101

Physical Properties	Water Utility (Tube)	Process fluid (Shell)
Flowrate (kg/hr)	-	773.39
Density, ρ (kg/m ³)	997	34.44
Viscosity, μ (Ns/m ²)	0.00089	0.000224
Thermal Conductivity, k (W/m °C)	0.6065	0.176
Specific heat capacity (kJ/kg. °C)	4.184	4.16
Inlet temperature (°C)	25	140
Outlet temperature (°C)	55	28

Process fluid flowrate = 779.39 kg/hr

$$= 0.216 \text{ kg/s}$$

Heat load, $Q = mC_p\Delta T$

$$= (0.216 \text{ kg/s})(4.16 \text{ kJ/kg.K})(140-28)$$

$$= 100.87 \text{ kW}$$

Cooling water mass flowrate, \dot{m}

$$\dot{m} = \frac{Q}{C_p \Delta T} = \frac{100.87}{(4.184)(55-25)} = 0.804 \text{ kg/s}$$

Logarithmic mean temperature difference, ΔT_{lm}

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \left(\frac{T_1 - t_2}{T_2 - t_1} \right)} = \frac{(140 - 55) - (28 - 25)}{\ln \left(\frac{140 - 55}{28 - 25} \right)} = 24.52^\circ\text{C}$$

Temperature correction factor, F_t . For temperature correction factor, F_t , the assumptions made are:

1. Equal heat transfer areas in each pass.
2. A constant overall heat transfer coefficient in each pass.
3. The temperature of the shell side fluid in any pass is constant across any cross section.
4. There is no leakage of fluid between shell passes.

Dimensionless temperature ratio:

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{140 - 28}{55 - 25} = 3.73$$

$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{55 - 25}{140 - 25} = 0.261$$

Based on Figure 10.38, the correction factor, F_t for the true temperature difference is determined.

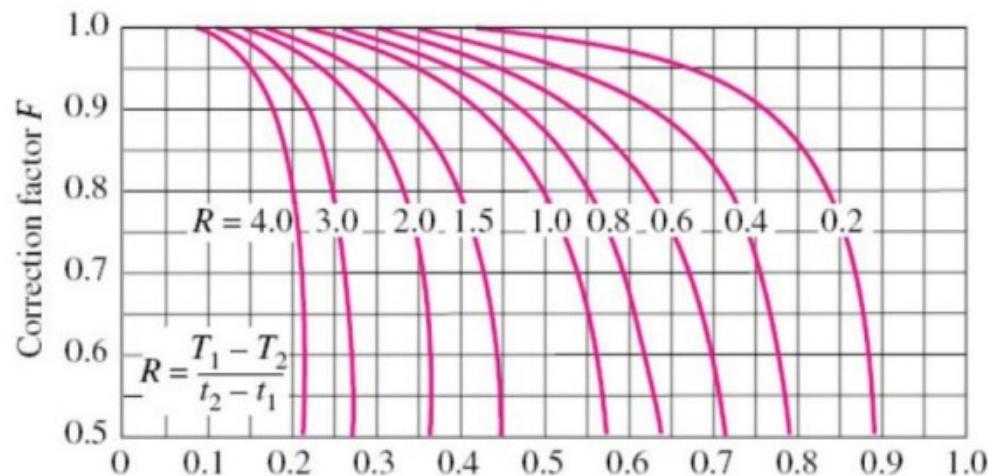


Figure 10.38 Temperature profile of Condenser, CD-101

From correction factor figure, the correction factor (F_t) is 0.75. 1 shell pass and 2 tube passes chosen.

Mean temperature difference.

$$\Delta T_m = F_t \Delta T_{lm} = (0.75) (24.52) = 18.39^\circ\text{C}$$

Overall coefficient, U

By referring (Towler & Sinnott 2013) the overall coefficient used is 800 W/m² .°C

Provisional area, A

$$A = \frac{Q}{U \Delta T_m} = \frac{(100.87 \times 10^3)}{(800)(18.39)} = 6.856$$

The type of material chosen for CD-101 is austenitic stainless steel type 316. It is because it is highly resistant and suitable for high level of structural integrity, (Towler & Sinnott 2013). Other than that, Type 316 that consist of molybdenum will improve the corrosion resistance.

By assuming inside diameter and outside diameter of below:

Length = 2.44 m

Inside diameter, d_i (mm) = 16 mm

Outside diameter, d_o (mm) = 20 mm

Area of one tube, At

Allowing for tube sheet thickness, the length of tube, lo = 2.44m.

$$A_t = \pi D_o L = (\pi)(0.02)(2.44) = 0.153 \text{ m}^2$$

Number of tubes, Nt

$$N_t = \frac{\text{Provisional area, } A}{\text{Area of one tube, } A_t} = \frac{6.856}{0.153} = 45 \text{ tubes}$$

10.25.4 Tube side Coefficient

- i. Mean temperature = $\frac{55+25}{2} = 40$
- ii. Cross sectional area of a tube = $\pi \frac{D_i^2}{4} = (\pi) \left(\frac{(16 \times 10^{-3})^2}{4} \right) = 2.00 \times 10^{-4} \text{ m}^2$
- iii. Tubes per pass = $\frac{45}{2} = 22$
- iv. Total flow area = (Tube per pass) (Tube cross-sectional area)
 - 1. = $(22) \times (0.0002)$
 - 2. = 0.0045 m^2
- v. Water linear velocity, $u_t = \frac{\dot{m}}{\rho A_T} = \frac{0.2165}{(4.184)(0.153)} = 0.338 \text{ m/s}$
- vi. Tube-side heat transfer coefficient,

$$h_i = \frac{4200(1.35+0.02t)u_t^{0.8}}{d_i^{0.2}} = \frac{4200(1.35+(0.02 \times 40))0.135^{0.8}}{(0.016)^{0.2}}$$

$$= 4160.359 \text{ W/m}^2\text{C}$$

10.25.5 Shell side Coefficient

By referring (Towler & Sinnott, 2013), the constant value for 2 tube passes are determined for triangular pitch where $K_1 = 0.249$ and $n_1 = 2.207$

$$\text{Bundle diameter, } D_b = d_o \left(\frac{N_t}{K_1} \right)^{\frac{1}{n_1}} = 20 \left(\frac{45}{0.249} \right)^{\frac{1}{2.207}} = 210.117 \text{ mm}$$

Shell diameter, D_s

Based on Figure 12.10 from the reference book of Towler & Sinnott 2013, the shell bundle diameter can be determined using the obtained value of bundle diameter above for the figure to find the clearance. Split-ring floating head type is used for efficiency, easy cleaning and to reduce shell-side pressure drop. The clearance obtained is 50 mm.

Shell diameter, $D_s = D_b + \text{shell bundle clearance}$

$$= 210.117 + 50 = 260.117 \text{ mm}$$

i. Baffle spacing, l

The optimum spacing chosen is 0.2 times the shell diameter.

$$\text{Baffle spacing, } l_B = \frac{D_s}{0.2} = \frac{260.117}{0.2} = 52.023 \text{ mm}$$

ii. For square pitch,

$$P_t = 1.25(D_o) = 1.25(0.02) = 0.025$$

iii. Crossflow area, A_s

$$A_s = \frac{(P_t - d_o)}{P_t} \times D_s \times l_B = \frac{0.025 - 0.02}{0.025} \times 0.260 \times 10^{-6} \times 0.052 = 0.00271 \text{ m}^2$$

iv. Mass velocity, G_s

$$G_s = \frac{W_s}{A_s} = \frac{0.2165}{0.00271} = 79.99 \text{ kg/m}^2\text{s}$$

v. Linear velocity,

$$u_s = \frac{G_s}{\rho} = \frac{79.99}{34.44} 2.323 \text{ m/}$$

vi. Equivalent diameter, d_e

$$d_e = \frac{1.1}{d_o} (p_t^2 - 0.917 d_o^2) = \frac{1.1}{20} (0.025^2 - 0.917 \times 20^2) = 14.201 \text{ mm}$$

vii. Reynolds number,

$$R_e = \frac{G_s d_e}{\mu} = \frac{79.993 (14.201 \times 10^{-3})}{0.00022} = 5071.37$$

viii. Prandtl number, Pr

$$\text{Pr} = \frac{C_p \mu}{k_f} = \frac{(4.16 \times 10^3)(0.00022)}{0.176} = 5.295$$

ix. Heat transfer factor, j_h

To calculate the value of the heat transfer factor, j_h , the baffle cut must be evaluated. The term baffle cut refers to the dimension of a segmental baffle. The height of the section eliminated to construct the baffle is commonly stated in percentage form as the baffle cut. In general, a baffle reduction between 20 to 25% will provide acceptable heat transfer rates without causing excessive drop. As a result, a baffle reduction of 25% was selected for the condenser, CD-101. When baffle cut = 25% and $Re = 5071.365$ based on Figure 12.29 in Towler & Sinnott 2013 that shows shell-side heat transfer factors:

From figure 8, $j_h = 0.008$ obtained. Shell-side heat transfer coefficient,

$$h_o = \left(\frac{k_f}{d_e} \right) j_h Re^{1/3} \text{Pr}^{1/3}$$

$$= \left(\frac{0.176}{14.201 \times 10^{-3}} \right) (0.008) (5071.37) (5.295)^{1/3} = 887.393 \text{ W/m}^2 \text{ }^\circ\text{C}$$

10.25.6 Overall Coefficient

From (Towler & Sinnott 2013) the conductivity of material for stainless steel, $k_w = 20 \text{ W/m} \cdot \text{ }^\circ\text{C}$. The fouling factor, h_{od} (cooling water) is $5000 \text{ W/m}^2 \text{ }^\circ\text{C}$ and h_{id} is $3000 \text{ W/m}^2 \text{ }^\circ\text{C}$.

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{1}{h_{od}} + \frac{d_o \ln \frac{d_o}{d_i}}{2k_w} + \left(\frac{d_o}{d_i} \right) \left(\frac{1}{h_i} + \frac{1}{h_{id}} \right)$$

Where,

U_o = the overall coefficient based on the outside area of the tube, $\text{W/m}^2 \text{ }^\circ\text{C}$

h_o = outside fluid film coefficient, $\text{W/m}^2 \text{ }^\circ\text{C}$

h_i = inside fluid film coefficient, $\text{W/m}^2 \text{ }^\circ\text{C}$

h_{od} = outside dirt coefficient (fouling factor), $\text{W/m}^2 \text{ }^\circ\text{C}$

h_{id} = inside dirt coefficient, $\text{W/m}^2 \cdot ^\circ\text{C}$

k_w = thermal conductivity of the tube wall material, $\text{W/m} \cdot ^\circ\text{C}$ d_i = tube inside diameter, m

d_o = tube outside diameter, m

so,

$$\frac{1}{U_o} = \frac{1}{887.393} + \frac{1}{5000} + \frac{(0.02)\ln\frac{0.02}{0.016}}{2(20)} + \left(\frac{0.02}{0.016}\right)\left(\frac{1}{4160.36} + \frac{1}{3000}\right)$$

$$U_o = 463.91 \text{ W/m}^2 \cdot ^\circ\text{C}$$

The assumed overall coefficient was $800 \text{ W/m}^2 \cdot ^\circ\text{C}$. The obtained overall coefficient was slightly higher than the assumed one which is $463.91 \text{ W/m}^2 \cdot ^\circ\text{C}$. The percentage difference between these two values is 42.01% .

10.25.7 Pressure Drops at Tube side

$$\text{Reynold number, } Re = \frac{\rho u_t d_i}{\mu} = \frac{(997)(0.33751)(16 \times 10^{-3})}{0.00089} = 6049.44$$

From figure 12.24, j_f is 0.05

$$\begin{aligned} \Delta P_t &= N_p \left[8j_f \left(\frac{L}{d_i} \right) \left(\frac{\mu}{\mu_w} \right)^{-m} + 2.5 \right] \frac{\rho u_t^2}{2} \\ &= 2 \left[8(0.0055) \left(\frac{2.44}{0.016} \right) + 2.5 \right] \frac{(997)(0.338^2)}{2} \\ &= 1046.01 \text{ Pa} = 10.152 \text{ psi} \text{ (Acceptable since it is } < 10 \text{ psi)} \end{aligned}$$

10.25.8 Shell-side Pressure Drop

Reynolds number, $Re = 5071.37$

From figure 19.30, $j_f = 0.008$

$$\Delta P_s = 8j_f \left(\frac{D_s}{d_e} \right) \left(\frac{L}{l_B} \right) \left(\frac{\rho u_s^2}{2} \right) = 8(0.008) \left(\frac{0.260}{0.0142} \right) \left(\frac{2.44}{0.052} \right) \left(\frac{(34.44)(2.323)^2}{2} \right)$$

= 5107.82 Pa = 0.741 psi (Acceptable since it is < 10psi)

10.25.9 Summary of Detail Design of Condenser, CD-101

Table 10.50 Overall specifications of Condenser, CD-101

Overall H-101	Specification
Tube arrangement	Triangular
Exchanger head type	Split-ring floating head
Type of used tube material	Austenitic stainless steel
Thermal conductivity of material, k_w	0.176 W/m ² °C
Baffle cut	25%
Overall heat transfer coefficient, U_o	463.91 W/m ² °C

Table 10.51 Shell side specifications of Condenser, CD-101

Tube side	Specification
Outside diameter, d_o	20×10^{-3} mm
Inside diameter, d_i	16×10^{-3} mm
Length of tube, L	2.44 m
ΔT_{lm}	24.5212 °C
R	3.73
S	0.26
F_t	0.75
Cross sectional area of one tube	0.153 m ²
Linear velocity, u_t	0.338 m/s
Tube coefficient, h_i	4160.36 W/m ² °C
Pressure drop, ΔP_t	0.152 psi

Table 10.52 Tube side specifications of condenser, CD-101

Shell side	Specification
Bundle diameter, D_b	210.12 mm
Shell diameter, D_s	260.12 mm
Baffle spacing, I_b	52.02 mm
Shell area, A_s	0.0027 m ²
Mass velocity, G_s	79.99 kg/m ² s
Linear velocity, u_s	2.32 m/s
Equivalent diameter, d_e	14.201 mm
Shell coefficient, h_o	887.393 W/m ² °C
Pressure drop, ΔP_s	0.741 psi

CHAPTER XI

MECHANICAL DRAWING

11.1 PACKED BED REACTOR, R-101

Design by: Aerry Ting Wei Huan (A174141)

11.1.1 Introduction

Packed bed reactor (R-101) is used to produce ammonia by reaction between nitrogen gas and hydrogen gas with manganese zinc ferrite ($Mn_{0.8}Zn_{0.2}O_4$) as nanocatalyst. A cooling jacket is designed to prevent temperature and heat loss during the reaction. An austenitic stainless-steel type 316L is used as construction material for R-101. This type of stainless steel has a high chromium content for corrosion resistance which enables it to provide the optimum rust protection and thermal stability in a variety of conditions. It is also pitting resistance and has higher rupture stress.

11.1.2 Design Specification

The schematic diagram of the packed bed reactor, R-101 is as shown in Figure 11.1 while its design specifications are listed in Table 11.1.

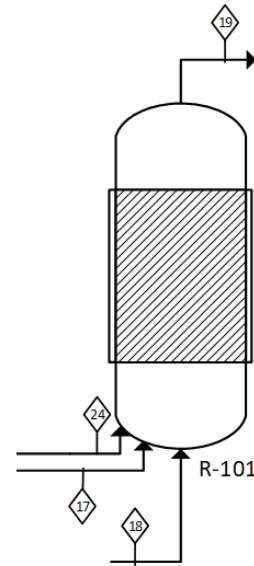


Figure 11.1 Schematic diagram of Packed Bed Reactor, R-101

Table 11.1 Design specifications of Packed Bed Reactor, R-101

Type of information	Operating selection and condition
Operating pressure	1 bar
Operating temperature	28°C
Material	Stainless-steel type 316L
Specification number	SA-240
UNS number	S32950
Material composition	26Cr-4Ni-Mo-N
Maximum allowable stress	26600 psi
Joint efficiency	1.0
Height to diameter ratio	3:1

The volume of reactor R-101 is 61.17 m^3 based on previous calculation done on Section 3.4 Process Design Level 3. The vessel was designed in vertical with two 2:1 ellipsoidal head at top and bottom head. Table 11.2 below shows the calculated dimension of R-101 in different measurement units. Further calculation details are shown in Appendix D.

Table 11.2 Dimension of Packed Bed Reactor, R-101

Part	Value (m)	Value (ft)	Value (In)
Ellipsoidal 2:1 top head height	0.74	2.43	29.14
Cylindrical shell height	7.40	24.28	291.32
Ellipsoidal 2:1 bottom head height	0.74	2.43	29.14
Vessel height	8.88	29.14	349.61
Vessel internal diameter	2.96	9.72	116.58

Vessel internal radius	1.48	4.86	58.29
------------------------	------	------	-------

11.1.3 Design Pressure

Internal pressure was applied to the packed bed reactor, R-101 where the formula for calculating the design pressure is shown as below.

$$P_D = P_o + 0.433h$$

where P_o = operating pressure (gage value) in psi

h = height in ft

10% of safety factor is included to the design pressure value for allowing probable pressure surges up and safety purpose. The formula for calculating design pressure by including 10% safety factor is shown as below.

$$P_J = 1.10 P_D$$

Table 11.3 shows the design pressure of each part of the reactor R-101. Further details of calculations are shown in Appendix D.

Table 11.3 Design pressure of each part of Packed Bed Reactor, R-101

Part	Design pressure, P_D (psi)	Design pressure with 10% safety factor, P_J (psi)
Ellipsoidal 2:1 top head	15.556	17.111
Cylindrical shell	26.068	28.675
Ellipsoidal 2:1 bottom head	27.120	29.832

11.1.4 Minimum Wall Thickness

Table 11.4 shows the minimum wall thickness of each part of the reactor R-101. Further detail calculations are showing at Appendix D.

Table 11.4 Minimum wall thickness of each part of Packed Bed Reactor, R-101

Part	Thickness (in)
Ellipsoidal 2:1 top head	0.0094

Cylindrical shell circumferential stress part	0.0629
Cylindrical shell longitudinal stress part	0.0314
Ellipsoidal 2:1 bottom head	0.0163

From Table 11.4, thickness of cylindrical shell circumferential part is chosen as design thickness, t_{cal} because it has the highest value of minimum thickness among the other part.

$$t_{cal} = 0.0629 \text{ in}$$

Corrosion allowance (CA) of 2mm is considered for the calculation of user thickness since the severe corrosion is not expected (Sinnott 2005b).

$$t_{user} = t_{cal} + CA$$

$$t_{user} = 0.0629 \text{ in} + 2\text{mm} = 0.0629 \text{ in} + 0.0790 \text{ in} = 0.142 \text{ in}$$

Table 11.5 Nominal thickness of stainless-steel type 316 SA-204

Nominal thickness		Stainless-steel type 316 SA 204					
mm	4.763	6.350	7.950	9.525	12.700	15.875	19.050
inch	0.188	0.250	0.313	0.375	0.500	0.625	0.750

Source: Continental Steel & Tube Company USA 2020

From Table 11.5 , nominal thickness of 0.188 in is selected since this thickness value is bigger than user thickness value.

$$t_{min} = t_{nominal} - CA$$

$$t_{min} = 0.188 \text{ in} - 2\text{mm} = 0.188 \text{ in} - 0.079 \text{ in} = 0.109 \text{ in}$$

11.1.5 Maximum Allowable Working Pressure (MAWP)

Maximum allowable working pressure of pressure vessel, MAWP_{vessel} is calculated with internal pressure method by using $t = 0.109 \text{ in}$. Table 11.6 shows MAWP_{vessel} calculation result for each part of R-101. Further detail calculations are shown in Appendix D.

Table 11.6 MAWP_{vessel} calculation result for each part of R-101

Part	Design pressure, P_D (psi)	Pressure at top side (psi)
Ellipsoidal 2:1 top head	49.852	48.800
Cylindrical shell circumferential part	49.805	38.241
Cylindrical shell longitudinal part	99.798	88.234
Ellipsoidal 2:1 bottom head	49.852	37.236

From Table 11.6, the smallest value for pressure at the top is from ellipsoidal bottom head. Hence, MAWP_{vessel} value is 37.236 psi with minimum thickness value of 0.109 in.

11.1.6 Design of Jacket

For maintaining the temperature at 28°C and preventing any heat loss, R-101 is equipped with a cooling jacket. The type 1 jacket which confined entirely to cylindrical shell, is preferred for industry use. From previous section 10.3.3, the jacket space is 50.8 mm (2 inch). The operating pressure of cooling water in jacket is 1 bar (14.504 psi). Type 1 jacket with closure (b-1) is selected as the main design by referring ASME Mandatory Appendix 9 Jacketed Vessel. Carbon steel with specification number of SA-537 is used for main construction material for cooling jacket with maximum allowable stress, S approximately 21000 psi.

Based on ASME Code Appendix 9 Section 9.5 (c)(2), choose of closure (b-1) type must fulfill the criteria that $t_{rc} = t_{rj}$, whereby t_{rc} is required minimum thickness of closure member and t_{rj} is required minimum thickness of outer jacket wall.

The required minimum thickness of the closure of jacket, t_{rc} can be calculated as below.

$$t_{rc} = 0.707 j \sqrt{\frac{P}{S}}$$

where t_{rc} = required minimum thickness of the closure of jacket in inch

j = Jacket space in inch

P = Design pressure of cooling water stream in psi

S = Maximum allowable stress value in psi

$$t_{rc} = 0.707(2) \sqrt{\frac{14.504}{21000}} = 0.037 \text{ in} = 0.944 \text{ mm}$$

Corrosion allowance, CA = 2 mm

Nominal thickness of closure member, $t_c = t_{rc} + CA = 0.944 \text{ mm} + 2 \text{ mm} = 2.944 \text{ mm}$

Minimum corner radius of torus closures, $r_{min} = \text{jacket space} = 50.8 \text{ mm}$

Inside radius of jacket = jacket space = 2 in = 50.8 mm

Weld dimension for attachment of closure member = $0.7t_c = 0.7(2.944) = 2.061 \text{ mm}$

$t_{rj} = t_{rc} = 0.944 \text{ mm}$

Nominal thickness of outer jacket wall, $t_j = t_{rj} + CA = 0.944 \text{ mm} + 2 \text{ mm} = 2.944 \text{ mm}$

11.1.7 Combine Loading Analysis

Besides of pressure factor, the reactor may subject to the major loads and subsidiary loads. The design of reactor should be able to withstand the worst combination loads without failure, and therefore the safety of the reactor is ensured. There are two parts of combine loading analysis, which are analysis of primary stresses and analysis of elastic stability. For the analysis primary stress, the criteria for a safe pressure vessel is $(\Delta\sigma)_{max} < S_{design}$, while for the latter analysis is $\sum \sigma_{compressive} < \sigma_c$ (Sinnott 2005b).

There are some assumptions made in the analysis of combined loading.

1. Liquid level is the same as the length of the column.
2. A safety factor of 10 % is considered.

a. Analysis of primary stresses

For a cylindrical vessel, primary stress is required to achieve static equilibrium. There are four parts in the analysis of primary stresses, which are longitudinal and circumferential stresses, direct stresses, bending stresses and torsional shear stresses.

i. Longitudinal and circumferential stresses

The longitudinal and circumferential stress are due to the internal pressure by the vessel or external pressure to the vessel. With the wall thickness of 2.769 mm, design pressure of 0.1 N/mm², and internal diameter of 2961 mm, the longitudinal stress and circumferential stress can be obtained as follow.

Longitudinal stresses,

$$\sigma_L = \frac{PD_i}{4t} = \frac{(0.1)(2961)}{4(2.769)} = 26.745 \text{ N/mm}^2$$

Circumferential stresses,

$$\sigma_h = \frac{PD_i}{2t} = \frac{(0.1)(2961)}{2(2.769)} = 53.489 \text{ N/mm}^2$$

Where,

σ_L = longitudinal stress in N/mm²

σ_h = circumferential stress in N/mm²

P = pressure in N/mm²

D_i = internal diameter in mm

t = wall thickness in mm

ii. Direct stresses

The direct stress is due to the weight of the vessel, its contents, and any attachment on the vessel, which is the total weight supported by the vessel. The direct stress is tensile for points below the plane of the vessel supports, and compressive for points above the supports.

Direct stress,

$$\sigma_w = \frac{W}{\pi(D_i + t)t}$$

Where,

σ_w = direct stress in N/mm²

W = Total weight in N

D_i = internal diameter in mm

t = wall thickness in mm

For the reactor that is constructed by material of steel, the weight of the shell, W_V is calculated as formula below.

$$W_V = 240 C_V D_m (H_V + 0.8D_m)t = 240(1.08)(2.964)[8.88 + 0.8(2.964)](2.769) \\ = 23929.415 \text{ N}$$

Where,

C_V = a constant of 1.08 for vessels with only few internal fittings

D_m = mean diameter of the vessel in m = $D_i + t \times 10^{-3}$

H_V = Height or length between tangent lines of the cylindrical section in m

t = wall thickness in mm

The weight of cooling jacket for the reactor, W_J can be calculated as below.

$$W_J = 2\pi(R_s + j)t_j\rho g L = 2\pi(1.484 + 0.0508)(0.00294)(7600)(9.81)(2.5) \\ = 5326.88 \text{ N}$$

Where,

R_s = outside radius of inner vessel in m

j = jacket space in m

t_j = nominal thickness of the outer jacket wall in m

ρ = density of material construction of jacket in kg/m³

g = gravitational acceleration in m/s²

L = design length of the jacket section in m

Therefore, the total weight, W_t is $W_V + W_J$, that is 23929.415 N + 5326.88 N = 29256.296 N.

Therefore, the direct stress is calculated as follow.

$$\sigma_w = \frac{W_t}{\pi(D_i + t)t} = \frac{29256.296}{\pi(2961 + 2.769)2.769} = 1.135 \text{ N/mm}^2$$

which the direct stress is compressive.

iii. Bending stresses

The bending stress is resulted from the bending moments when the vessel is subjected to wind loads, earthquake loads, etc. However, the calculation of earthquake loading is not considered since its occurrence is rare in Malaysia.

Bending stress,

$$\sigma_b = \pm \frac{M}{I_V} \left(\frac{D_i}{2} + t \right)$$

Where,

σ_b = bending stress in N/mm²

M = total bending moment in N·mm

I_V = second moment of area of the vessel about the plane bending in mm⁴

D_i = internal diameter in mm

t = wall thickness in mm

The wind load per unit length, W can be calculated by using formula below.

$$W = P_w D_{eff}$$

Where,

P_w = dynamic wind pressure in N/m²

D_{eff} = effective diameter of column which include insulation in m, at which

$$D_{eff} = D_i + 2t = 2.961 + 2(0.00277) = 2.967 \text{ m}$$

For preliminary design, P_w is assumed as 1280 N/m² (Sinnott 2005b). Therefore,

$$W = P_w D_{eff} = (1280)(2.967) = 3797.168 \text{ N/m}$$

The second moment of area of the vessel, I_V can be calculated by using formula below.

$$I_V = \frac{\pi}{64} (D_o^4 - D_i^4) = \frac{\pi}{64} (2966.537^4 - 2961^4) = 2.830 \times 10^{10} \text{ mm}^4$$

Where,

D_o = outer diameter in mm = $D_i + 2t$

D_i = internal diameter in mm

The total bending moment, M_x can be calculated by using formula below.

$$M_x = \frac{Wx^2}{2} = \frac{(3797.168)(8.88)^2}{2} = 1.497 \times 10^5 \text{ N} \cdot \text{m} = 1.497 \times 10^8 \text{ N} \cdot \text{mm}$$

Where,

W = load per unit length in N/m

x = L = distance measured from the free end in m

The bending stress can be calculated as below.

$$\sigma_b = \pm \frac{M}{I_V} \left(\frac{D_i}{2} + t \right) = \pm \frac{1.497 \times 10^8}{2.830 \times 10^{10}} \left(\frac{2961}{2} + 2.769 \right) = \pm 7.846 \text{ N/mm}^4$$

iv. Torsional shear stresses

The torsional shear stress is resulted from torque which is caused by loads offset from vessel axis. The torsional shear stress can be calculated by using the equation below.

$$\tau = \frac{T}{I_p} \left(\frac{D_i}{2} + t \right)$$

Where,

τ = torsional shear stress in N/mm²

T = applied torque

I_p = polar second moment of area

D_i = internal diameter in mm

t = wall thickness in mm

However, the loads are normally small, and therefore the torsional shear stress can be neglected in the preliminary vessel design (Sinnott 2005b).

v. Principal stresses

The principal stresses can be calculated by using equations below.

$$\sigma_1 = \frac{1}{2} \left[\sigma_h + \sigma_z + \sqrt{(\sigma_h - \sigma_z)^2 + 4\tau^2} \right]$$

$$\sigma_2 = \frac{1}{2} \left[\sigma_h + \sigma_z - \sqrt{(\sigma_h - \sigma_z)^2 + 4\tau^2} \right]$$

$$\sigma_3 = 0.5P$$

The third principal stress, σ_3 is negligible for thin-walled vessel. Since the torsional shear stress, τ is negligible, the equations of principal stresses are as below.

$$\sigma_1 = \sigma_h = 53.489 \text{ N/mm}^2$$

$$\sigma_2 = \sigma_z$$

$$\sigma_z (\text{upwind}) = \sigma_L + \sigma_w + \sigma_b = 26.745 + 1.135 + 7.846 = 35.725 \text{ N/mm}^2$$

$$\sigma_z(\text{downwind}) = \sigma_L + \sigma_w - \sigma_b = 26.745 + 1.135 - 7.846 = 20.034 \text{ N/mm}^2$$

$$\sigma_3 = 0 \text{ N/mm}^2$$

vi. Maximum allowable stress intensity

$$(\Delta\sigma)_{\text{upwind}} = \sigma_1 - \sigma_2 = \sigma_h - \sigma_{z,\text{upwind}} = 53.489 - 35.725 = 17.764 \text{ N/mm}^2$$

$$\begin{aligned} (\Delta\sigma)_{\text{downwind}} &= \sigma_1 - \sigma_2 = \sigma_h - \sigma_{z,\text{downwind}} = 53.489 - 20.034 \\ &= 33.455 \text{ N/mm}^2 \end{aligned}$$

The maximum stress intensity, $(\Delta\sigma)_{\max}$ is 33.455 N/mm^2 . According to ASME code Table 1A, the maximum allowable stress, S below the maximum operating temperature in the reactor is 183.448 N/mm^2 . Since $(\Delta\sigma)_{\max} < S_{\text{design}}$, the design of the reactor is considered as safe.

vii. Summary of primary stresses analysis

Table 11.7 below shows the summary of parameters in the analysis of primary stresses in the design of packed bed reactor (R-101).

Table 11.7 Summary of parameters in the analysis of primary stresses in the design of Packed Bed Reactor R-101

Parameters	Values
Minimum wall thickness, t	2.769 mm
Design pressure, P	0.1 N/mm ²
Internal diameter, D_i	2961 mm
Outer diameter, D_o	2966.537 mm
Longitudinal stresses, σ_L	26.745 N/mm ²
Circumferential stresses, σ_h	53.489 N/mm ²
Weight of the shell, W_v	23929.415 N
Weight of the cooling jacket, W_j	5326.881 N
Total weight, W_t	29256.296 N
Mean diameter of the vessel, D_m	2.964 m

Height or length between tangent lines of the cylindrical section, H_V	8.880 m
Direct stresses, σ_w	1.135 N/mm ²
Effective diameter of column, D_{eff}	2.967 m
Dynamic wind pressure, P_w	1280 N/mm ²
Wind load per unit length, W	3797.168 N/m
Second moment of area of the vessel, I_V	2.830×10 ¹⁰ mm ⁴
Total bending moment, M_x	1.497×10 ⁸ N·mm
Bending stress, σ_b	± 7.846 N/mm ²
Torsional shear stress, τ	0 N/mm ²
σ_z (upwind)	35.725 N/mm ²
σ_z (downwind)	20.034 N/mm ²
$(\Delta\sigma)_{upwind}$	17.764 N/mm ²
$(\Delta\sigma)_{downwind}$	33.455 N/mm ²

b. Analysis of elastic stability

The pressure vessel may fail by the elastic instability, which is also known as buckling where the resultant axial stress, σ_z attributed by the combined loading is compressive (Sinnott 2005b). For a curved plate which subjected to an axial compressive load, the critical buckling stress, σ_c (N/mm²) can be calculated as equation below.

$$\sigma_c = \frac{E}{\sqrt{3(1 - \nu^2)}} \left(\frac{t}{R_p} \right)$$

Where,

E = modulus of elasticity in N/mm²

ν = Poisson's ratio

R_p = radius of curvature in mm

t = wall thickness in mm

The equation of critical buckling stress can be used to predict the maximum allowable compressive stress to avoid failure by buckling (Sinnott 2005b). For steel

material at ambient temperature, $E = 200,000 \text{ N/mm}^2$ and safety factor of 12, the equation of critical buckling stress becomes as follow.

$$\sigma_c = 2 \times 10^4 \left(\frac{t}{D_o} \right) = 2 \times 10^4 \left(\frac{2.769}{2966.537} \right) = 18.666 \text{ N/mm}^2$$

The maximum value of the resultant axial stress, $(\sum \sigma_{compressive})$ can be calculated as follow.

$$(\sum \sigma_{compressive}) = \sigma_w + \sigma_b = 1.135 + 7.846 = 8.980 \text{ N/mm}^2$$

Since $(\sum \sigma_{compressive}) < \sigma_c$, the design of the reactor is considered as elastically stable. The design of the reactor is also considered as safe since $(\Delta\sigma)_{max} < S_{design}$. Therefore, it can be concluded that the design of the reactor has fulfilled the requirements for both analysis of primary stresses and analysis of elastic stability.

Table 11.8 below shows the summary of parameters in the analysis of elastic stability in the design of reactor R-101.

Table 11.8 Summary of parameters in the analysis of elastic stability in the design of Packed Bed Reactor, R-101

Parameters	Values
Modulus of elasticity, E	200,000 N/mm ²
Critical buckling stress, σ_c	18.666 N/mm ²
$(\sum \sigma_{compressive})$	8.980 N/mm ²

11.1.8 Vessel Support

The supports of the pressure vessel must be designed to support the weight of the vessels, its contents, and any major loads and subsidiary loads as well. The design of vessel supports should also able to allow easy access to the vessel and fittings for inspection and maintenance (Sinnott 2005b).

Among the various types of vessel support, skirt support is suitable to support the reactor since the skirt support can support tall and vertical column of the reactor. The skirt support is also recommended for vertical vessel as they do not impose concentrated loads on the vessel shell. It is also suitable for tall column which is subjected to wind loading (Sinnott 2005b).

a. Skirt thickness

For the design of skirt, the selected material for skirt is carbon steel with its specification number of SA-516 due to its strongness and durability in supporting the vertical vessel. The carbon steel also has its good ability to weld to the base of the vessel. Straight skirt support with welded flush with the shell are selected. The skirt thickness must be sufficient to withstand the dead-weight loads and bending moments imposed on it by the vessel and it will not be below the vessel pressure loading (Sinnott 2005b).

The maximum dead weight load on the skirt will occur when the vessel is full. The approximate dead weight load, W can be calculated as follow.

$$W = \rho V g = (1000)(61.17)(9.81) = 600077.70 \text{ N}$$

From section 11.1.6 (a) analysis of primary stresses, the total weight of the shell and jacket, $W_t = 29256.296 \text{ N}$

Also, from section 11.1.6 (a) analysis of primary stress, $P_w = 1280 \text{ N/m}^2$ and $D_m = 2.964 \text{ m}$. Therefore, the wind loading, $F_w = P_w D_m = (1280)(2.964) = 3793.624 \text{ N/m}$.

Let the height of the skirt is 1.50 m, the bending moment at the base of the skirt,

$$M_s = F_w \left(\frac{(H_V + H_{skirt})^2}{2} \right) = (3793.624) \left(\frac{(8.88 + 1.50)^2}{2} \right) = 204370.861 \text{ Nm}$$

Since the minimum required thickness should be not less than 6mm, skirt thickness, t_s is set as 6 mm. The bending stress at the skirt,

$$\sigma_{bs} = \frac{4M_s}{\pi(D_s + t_s)t_s D_s} = \frac{4(204370.861 \times 10^3 \text{ Nmm})}{\pi(2961 + 6)(2961)(6)} = 3.699 \text{ N/mm}^2$$

The dead weight stress at the skirt,

$$\sigma_{ws} = \frac{W}{\pi(D_s + t_s)t_s}$$

Where,

M_s = maximum bending moment at the base of the skirt in Nm

W = total weight of the vessel and contents in N

D_s = inside diameter of the skirt at the base, which also same as internal diameter, D_i in mm

t_s = skirt thickness, which also same as wall thickness, t in mm

$$\sigma_{ws}(\text{test}) = \frac{600077.70}{\pi(2961 + 6)(6)} = 8.042 \text{ N/mm}^2$$

$$\sigma_{ws}(\text{operating}) = \frac{29256.296}{\pi(2961 + 6)(6)} = 0.392 \text{ N/mm}^2$$

The resultant stresses in the skirt will be as follow.

$$\begin{aligned} \text{Maximum } \hat{\sigma}_s \text{ (tensile)} &= \sigma_{bs} - \sigma_{ws}(\text{operating}) = 3.699 - 0.392 \\ &= 3.307 \text{ N/mm}^2 \end{aligned}$$

$$\begin{aligned} \text{Maximum } \hat{\sigma}_s \text{ (compressive)} &= \sigma_{bs} + \sigma_{ws}(\text{test}) = 3.699 + 8.042 \\ &= 11.741 \text{ N/mm}^2 \end{aligned}$$

The skirt thickness should under the worst combination of wind and dead weight loading, which by following the criteria below.

$$\sigma_s(\text{tensile}) < S_S E \sin \theta_s$$

$$\sigma_s(\text{compressive}) < 0.125 E_Y \left(\frac{t_s}{D_s} \right) \sin \theta_s$$

Where,

S_S = maximum allowable stress for the skirt material at $T_{\text{ambient}} = 20^\circ\text{C}$

E = weld joint factor

E_Y = modulus of elasticity in N/mm^2

θ_s = base angle of skirt

Maximum allowable stress for the skirt material at $T_{\text{ambient}} = 20^\circ\text{C}$, $S_S = 128.276 \text{ N/mm}^2$

Weld joint factor, $E = 1.0$

Modulus of elasticity, $E_Y = 200,000 \text{ N/mm}^2$

Base angle of skirt, $\theta_s = 90^\circ$ for straight skirt

Therefore,

$$S_S E \sin \theta_s = (128.276)(1.0) \sin(90) = 128.276$$

$$0.125 E_Y \left(\frac{t_s}{D_s} \right) \sin \theta_s = 0.125(200\,000) \left(\frac{6}{2961} \right) \sin(90) = 67.545 \text{ N/mm}^2$$

Since $\sigma_s(\text{tensile}) < S_S E \sin \theta_s$ is $3.307 < 128.276$, and $\sigma_s(\text{compressive}) < 0.125 E_Y \left(\frac{t_s}{D_s} \right) \sin \theta_s$ is $11.741 < 67.545$, both criteria are satisfied. The assumed value of skirt thickness, t_s of 6 mm is acceptable.

b. Base ring and anchor bolt design

The design of base ring and anchor bolt are also important since the loads carried by the skirt are transmitted to the foundation slab by the skirt base ring. The moment produced by the wind or other loads will tend to overturn the vessel. For design of base ring, double plates with gussets is selected, which is also known as chair support. This

type of base ring is strong enough to support the large column of fermenter (Sinnott 2005b).

By assuming the overturning load is shared equally by the anchor bolts, the bolt area that required is as equation below.

$$A_b = \frac{1}{N_b f_b} \left[\frac{4M_s}{D_b} - W_t \right]$$

where

A_b = area of one bolt at the root of the thread in mm²

N_b = number of bolts

f_b = maximum allowable bolt stress in N/mm², at which the typical design value is 125N/mm² or 18,000 psi

M_s = bending moment at the base in Nm

W_t = Total weight of vessel and jacket in N

D_b = bolt circle diameter in m

The number of bolts can be obtained as follow.

Pitch circle diameter, D_b = 2200 mm = 2.2 m

Circumference of bolt circle = 2200π mm

Maximum allowable bolt stress, f_b = 125 N/mm²

Bolt spacing = 600 mm

Minimum number of bolts required = $\frac{2200\pi}{600} = 11.519$

Use the multiple of 4 of the number of bolts, N_b = 12 bolts

Bending moment at the base of the skirt, M_s = 204370.861 Nm

Total weight of the shell and jacket, W_t = 29256.296 N

Therefore,

$$A_b = \frac{1}{N_b f_b} \left[\frac{4M_s}{D_b} - W_t \right] = \frac{1}{(12)(125)} \left[\frac{4(204370.861)}{2.2} - 29256.296 \right] \\ = 228.218 \text{ mm}^2$$

Table 11.9 Anchor bolt chain design

Bolt size (m)	Root area (mm ²)	A	B	C	D	E	F	G
M24	353	45	76	64	13	19	30	36
M30	561	50	76	64	13	25	36	42

Source: (Sinnott 2005b)

Based on Table 11.9, bolt size of M24 is selected, and the area of one bolt at the root, A_b is 353 mm² (Sinnott 2005b). The base ring must be sufficiently wide to distribute the load to the foundation. The total compressive load on the base ring can be calculated as below.

$$F_b = \left[\frac{4M_s}{\pi D_s^2} + \frac{W_t}{\pi D_s} \right] = \left[\frac{4(204370.861)}{\pi(2.961)^2} + \frac{29256.296}{\pi(2.961)} \right] = 32824.281 \text{ N/m}$$

Where,

F_b = compressive load on the base ring in N/m

D_s = skirt diameter in m

Taking the bearing pressure as 5 N/mm², the minimum width of the base ring is as below.

$$L_b = \frac{F_b}{f_c} \times \frac{1}{10^3} = \frac{32824.281}{5 \times 10^3} = 6.565 \text{ mm}$$

where ,

L_b = base ring width in mm

f_c = maximum allowable bearing pressure on the concrete foundation, ranging from 3.5 to 27 N/mm² (500 to 1000 psi)

The required thickness of the base ring is calculated as shown below.

$$t_b = L_r \sqrt{\frac{3f'_c}{f_r}}$$

Where,

L_r = the distance from the edge of the skirt to the outer edge of the ring in mm

t_b = base ring thickness in mm

f'_c = actual bearing pressure in N/mm²

f_r = Allowable design stress in the ring material = 140 N/mm²

Based on Figure 13.30, the anchor bolt chair design, in Sinnott 2005, $B = L_r = 76$ mm

$$\text{Actual width required, } l_b = L_r + t_s + 50 = 76 + 6 + 50 = 132 \text{ mm}$$

Actual bearing pressure on concrete foundation:

$$f'_c = \frac{F_b}{l_b} = \frac{32824.281}{132 \times 10^3} = 0.245 \text{ N/mm}^2$$

Base ring thickness calculated as below.

$$t_b = L_r \sqrt{\frac{3f'_c}{f_r}} = 76 \sqrt{\frac{3(0.245)}{140}} = 5.506 \text{ mm}$$

c. Summary of parameters in design of vessel support for reactor R-103

Table 11.10 below shows the summary of parameters in the design of vessel support for the design of reactor R-101.

Table 11.10 Summary of parameters in the design of vessel support for the design of Packed Bed Reactor, R-101

Parameters	Values
------------	--------

Material	Carbon steel
Specification number	SA-516
Approximate dead weight load, W	600077.70 N
Total weight of the shell and jacket, W_t	29256.296 N
Wind loading, F_w	3793.624 N/m
Bending moment at the base of the skirt, M_s	204370.861 Nm
Skirt thickness, t_s	6 mm
Inside diameter of the skirt at the base, D_s	2961 mm
Bending stress at the skirt, σ_{bs}	3.699 N/mm ²
Dead weight stress at the skirt, $\sigma_{ws}(\text{test})$	8.042 N/mm ²
Dead weight stress at the skirt, $\sigma_{ws}(\text{operating})$	0.392 N/mm ²
Maximum $\hat{\sigma}_s$ (tensile)	3.307 N/mm ²
Maximum $\hat{\sigma}_s$ (compressive)	11.741 N/mm ²
Base angle of skirt, θ_s	90°
Pitch circle diameter, D_b	2.2 m
Circumference of bolt circle	2200π mm
Maximum allowable bolt stress, f_b	125 N/mm ²
Number of bolts, N_b	12
Area of one bolt at the root of the thread, A_b	228.218 mm ²
Selection of bolt size based on Sinnott 2005	M24
A_b based on Sinnott 2005	353 mm ²
Total compressive load on the base ring, F_b	32824.281 N/m
Bearing pressure, f_c	5 N/mm ²
Minimum width of the base ring, L_b	6.565 mm
Actual width required, l_b	132 mm
Distance from the edge of the skirt to the outer edge of the ring, L_r	76 mm
Actual bearing pressure, f'_c	0.245 N/mm ²
Allowable design stress in the ring material, f_r	140 N/mm ²
Base ring thickness, t_b	5.506 mm

11.1.9 Flange Joint

In the designation of reactor, selection of flanged joint is crucial, and it is also a requirement for the design of a reactor. The flanged joints are used for connecting pipes and instruments to the vessel, and also connecting the pipes to other equipment such as pumps and valve (Sinnott 2005b).



Figure 11.2 Welding neck flange

Source: Towler & Sinnott 2013

Among the various types of flanged joints, welding neck flange joint is selected as the design flanged joint in the design of fermenter. The welding neck flange has a long-tapered hub between the flange ring and the welded joint which provides mechanical strength. The long-tapered hub can provide an important reinforcement for use in applications involving high pressure or elevated temperature (Sinnott 2005b). The welding neck flange is also easier to align to the pipe network in which it is installed and results in a stronger weld (Experts 2018).

The dimension of the flange is being selected based on the pipe nominal diameter. For material stream, the flange size is selected based on the piping system design at Chapter V. For the manhole and the flange that connects to the pressure safety valve, the dimension is shown in Table 11.11. The dimension of each flange used on the packed bed reactor, R-101 according to its position list in Table 11.11 below. The mechanical drawing shown at Appendix E.

Table 11.11 Dimension of each flange on Packed Bed Reactor, R-101

Flange	Nom.	d ₁	D	b	h ₁	d ₄	f	Bolt	Bolt	d ₂	k	d ₃	h ₂	r
										Size	No.			
S17	200	219.1	320	20	55	258	3	M16	8	18	280	236	15	10
S18	200	219.1	320	20	55	258	3	M16	8	18	280	236	15	10
S19	350	355.6	490	22	62	415	4	M20	12	22	445	385	15	12
S24	200	219.1	320	20	55	258	3	M16	8	18	280	236	15	10
CW	200	219.1	320	20	55	258	3	M16	8	18	280	236	15	10
PSV	100	114.3	210	16	45	148	3	M16	4	18	170	130	10	8

Manhole	1000	1016	1175	26	70	1080	5	M27	28	30	1120	1045	16	16
---------	------	------	------	----	----	------	---	-----	----	----	------	------	----	----

11.2 PHASE SEPARATOR, PS-101

Designed by: Nurzulaikha binti Zulkarnain (A173895)

11.2.1 Introduction

Two-phase separator is used to separate vapor and liquid phase. Phase separator (PS-101) is used to separate vapor phase and liquid phase of mixture of hydrogen gas, nitrogen gas, and ammonia liquid. Stream 22 is a stream coming out from catalytic packed bed reactor (R-101) that contains a mixture of excess hydrogen and nitrogen gas, and ammonia liquid. The operating temperature and pressure inside PS-101 is 40°C and 140 bar.

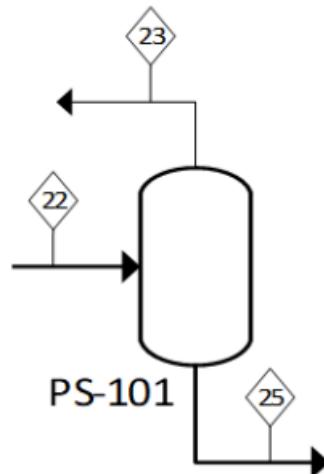


Figure 11.3 Schematic diagram of Phase Separator, PS-101

The mass flowrate of all components in each stream is shown in Table 11.12.

Table 11.12 Mass flow rates in each stream

Component	Stream 22	Stream 23	Stream 25
Hydrogen (kg/h)	263.99	264.78	7.98
Nitrogen (kg/h)	1231.96	1232.66	3.99
Ammonia (kg/h)	1993.71	0.00	1981.75

From the previous calculation in detailed design part of PS-101, the dimension of sizing is as Figure 11.4.

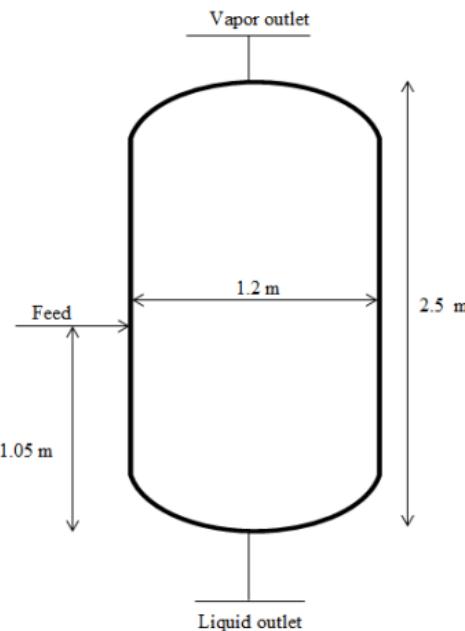


Figure 11.4 Dimension of Phase Separator, PS-101

11.2.2 Material Selection

Since the operating condition in PS-101 is 40°C and 140 bar, hence ductile and elastic material is required as the material must be ductile enough to be easily fabricated, and elastic enough to be able to expand and constrict when temperature and pressure changes. The basic material of construction for the pressure vessel that are used in producing ammonia is one or another variant of the 300 series stainless steels. It is essentially eliminates the possibility of iron and other metal contaminations which may either degrade the product or catalyze undesirable oxidation and other side reactions. Stainless steel type-316L has been chosen for fabrication of this equipment due to its availability and high resistances to corrosion. The value of maximum allowable stress, S for this material is 16700 psi (Dong 2012).

11.2.3 Design Specification

The operating pressure in this phase separator, PS-101 is 140 bar. Since the vessel operate in above atmospheric pressure, internal pressure vessel design will be used. It is a vertical column with cylindrical shell.

The most common type of head used for the pressure vessel is torispherical head, therefore torispherical head has been selected for both top and bottom of the vessel. The schematic diagram of torispherical head is shown in Figure 11.5. The internal dish depth, IDD can be determined using the equation below

$$IDD = L - \sqrt{(L - r)^2 - \left(\frac{ID}{2} - r\right)^2}$$

Where,

L = inner crown radius, m

r = inner knuckle radius, m

ID = inner diameter, m

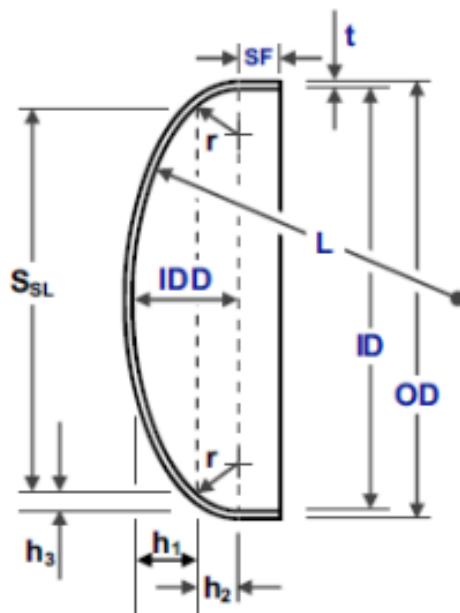


Figure 11.5 Schematic diagram of torispherical head

Taking crown radius same as inner diameter which is 1.2 m and knuckle radius 6% of crown radius,

$$IDD = 1.2 - \sqrt{(1.2 - 0.072)^2 - \left(\frac{1.2}{2} - 0.072\right)^2}$$

$$IDD = 0.2032 \text{ m} = 0.66 \text{ ft}$$

Hence, the height for both top and bottom head is 0.66 ft. Since the total height of the pressure vessel is 2.5 m (8.2 ft), the height of cylindrical shell is 6.88 ft. The diagram with the height for each part is shown in Figure 11.6.

Besides that, it is categorized as small or medium sized vessel, so the most suitable support to be used is bracket support. It is more economical compared to skirt support and it is able to hold the vessel. This phase separator is just an empty tank and short, so it does not need a critical cleaning. So, one manhole is enough to access the whole vessel and does not need a closure that can be opened at the top.

In addition, since corrosion is considered at the operating temperature, 4 mm of corrosion allowance is added. Finally, for safety factor, double-welded is chosen for the butt joints with full degree of radiographic.

11.2.4 Determination of Wall Thickness

Wall thickness is determined based on the minimum thickness of all part of the vessel.

Firstly, design pressure, P_D for each part of the vessel is calculated using the equation $P_D = P_o + 0.433h$ where h is the height of each part from top shell in ft unit and P_o is the operating gage pressure. The operating pressure is 1400 kPa, hence P_o is 1298.68 kPa (160.4 psi). Figure 11.6 show the height of each part of the vessel.

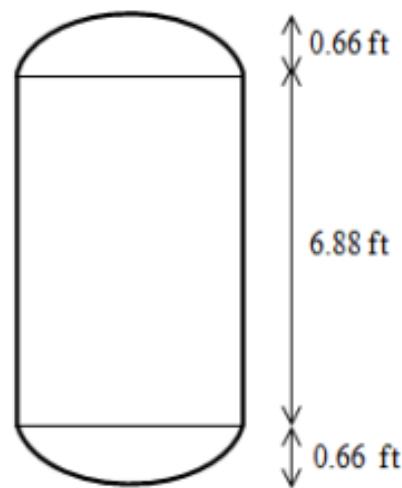


Figure 11.6 Height of each part in ft

$$\text{Cylindrical shell} : P_D = 160.4 + 0.433(6.88) = 163.64 \text{ psi}$$

$$\text{Torispherical top head} : P_D = 160.4 + 0.433(0.66) = 160.68 \text{ psi}$$

$$\text{Torispherical bottom head} : P_D = 160.4 + 0.433(8.20) = 163.94 \text{ psi}$$

This design pressure will be used in calculation to find wall thickness for each part. As mentioned before, the value of S is 16700 psi and for the double-welded joint with full degree of radiographic, the joint efficiency, E is 1.0 (ASME UW-12).

The design pressure does not exceed $0.385SE$, hence the pressure vessel PS-101 is considered as a thin wall pressure vessel. According to ASME UG-27(a), the thickness of shell under internal pressure for thin wall vessel shall be not less than that computed by the following formula.

a. Wall thickness of cylindrical shell

According to ASME UG-27(c)(1), the wall thickness of cylindrical shell under circumferential stress is determined using equation below.

$$t = \frac{P_D R}{SE - 0.6P}$$

where R is the inside radius of shell

$$t = \frac{163.64(23.62)}{(16700)(1) - 0.6(163.64)} = 0.21 \text{ in}$$

According to ASME UG-27(c)(2), the wall thickness of cylindrical shell under longitudinal stress is determined using equation below.

$$t = \frac{P_D R}{2SE + 0.4P}$$

where R is the inside radius of shell

Hence,

$$t = \frac{163.64(23.62)}{2(16700)(1) + 0.4(163.64)} = 0.103 \text{ in}$$

b. Wall thickness of torispherical top head

For the case in which the knuckle radius is 6% of the inside crown radius ($r = 6\% L$) and the inside crown radius equals the diameter ($L = D_i$), the minimum wall thickness of torispherical head is determine using following equation by ASME UG-32(e).

$$t = \frac{0.885P_DL}{SE - 0.1P_D}$$

where $L = D_i = 1.2 \text{ m} = 47.24 \text{ in}$

Hence,

$$t = \frac{0.885(160.68)(47.24)}{16700(1) - 0.1(160.68)} = 0.36 \text{ in}$$

c. Wall thickness of torispherical bottom head

Same as top head, to determine the minimum wall thickness of torispherical head, following equation by ASME UG-32(e) is used.

$$t = \frac{0.885P_DL}{SE - 0.1P_D}$$

where $L = D_i = 1.2 \text{ m} = 47.24 \text{ in}$

Hence,

$$t = \frac{0.885(163.94)(47.24)}{16700(1) - 0.1(163.94)} = 0.37 \text{ in}$$

From the calculation, the minimum wall thickness for each part is summarized as in Table 11.13.

Table 11.13 Minimum wall thickness of each part

Vessel part	Wall thickness (in)	Wall thickness (mm)
Cylindrical shell		
• Circumferential stress	0.21	5.33
• Longitudinal stress	0.103	0.26
Torispherical top head	0.36	9.14
Torispherical bottom head	0.37	9.40

The minimum thickness for vessel is determined using the largest thickness among all the part. From the table above the largest thickness is 0.37 in (9.4 mm).

Considering the corrosion allowance, CA = 4 mm,

$$t_{min} = t_{calc} + CA = 9.4 + 4 = 13.4 \text{ mm}$$

The closest nominal thickness with value is 15 mm (0.39 in). Hence, the actual minimum thickness is,

$$t_{min} = t_{nominal} - CA = 15 - 4 = 11 \text{ mm (0.43 in)}$$

11.2.5 Maximum Allowable Working Pressure (MAWP_{vessel}) of Phase Separator, PS-101

To calculate MAWP_{vessel}, MAWP for each part need to be calculated first. Corrosion allowance is excluded from the thickness to calculate MAWP part.

For cylindrical shell with circumferential stress, MAWP part is determined using equation from ASME UG-27(c)(1).

$$P = \frac{SEt}{R + 0.6t}$$

$$P = \frac{16700(1)(0.43)}{23.62 + 0.6(0.43)}$$

$$P = 334.95 \text{ psi}$$

For cylindrical shell with longitudinal stress, MAWP part is determined using equation from ASME UG-27(c)(2).

$$P = \frac{2SEt}{R - 0.4t}$$

$$P = \frac{2(16700)(1)(0.43)}{23.62 - 0.4(0.43)}$$

$$P = 682.2 \text{ psi}$$

For torispherical top and bottom head, MAWP part is determined using equation from ASME UG-32(e).

$$P = \frac{SEt}{0.885L + 0.1t}$$

$$P = \frac{16700(1)(0.43)}{0.885(47.24) + 0.1(0.43)}$$

$$P = 191.5 \text{ psi}$$

MAWP_{vessel} is the lowest MAWP part after subtracting static head.

MAWP_{shell} with circumferential stress – static head = 334.95 – 0.433(6.88) = 331.69 psi

MAWP_{shell} with longitudinal stress – static head = 682.2 – 0.433(6.88) = 678.94 psi

MAWP_{tophead} – static head = 191.5 – 0.433(0.66) = 190.71 psi

MAWP_{bottomhead} – static head = 191.5 – 0.433(8.2) = 187.95 psi

Hence, MAWP_{vessel} = 187.95 psi = 1.30 N/mm²

11.2.6 Combined Loading of Phase Separator, PS-101

Other than pressure, pressure vessel also is subjected to other loads, and it should be designed to withstand the worst combination of loading without failure.

a. Analysis of stresses

i. Longitudinal and circumferential stress

$$P = \text{MAWP}_{\text{vessel}} = 1.30 \text{ N/mm}^2 ; t = t_{\text{nominal}} = 15 \text{ mm} ; D_i = 1.2 \text{ m}$$

For longitudinal stress,

$$\sigma_L = \frac{PD_i}{4t} = \frac{1.3(1.2 \times 10^{-3})}{4(15)} = 26 \text{ Nmm}^{-2}$$

For circumferential stress,

$$\sigma_h = \frac{PD_i}{2t} = \frac{1.3(1.2 \times 10^{-3})}{2(15)} = 52 \text{ Nmm}^{-2}$$

ii. **Direct stress**

Formula for direct stress given by Towler & Sinnott (2013) is

$$\sigma_w = \frac{W_v}{\pi(D_i + t)t}$$

Where,

W_v = total weight of shell

Therefore, for a steel vessel,

$$W_v = 240C_v D_m(H_v + 0.8D_m)t$$

Assume that only a few internal fittings for vessel, $C_v = 1.08$,

$$\begin{aligned} D_m &= D_i + t = 1.2 + (15 \times 10^{-3}) = 1.215 \text{ m}, \\ H_v &= \frac{1}{3}H_{torispherical} + H_{cylindrical} + \frac{1}{3}H_{torispherical} \\ &= \frac{1}{3}(0.2) + 2.1 + \frac{1}{3}(0.2) = 2.23 \text{ m} \end{aligned}$$

So, the weight of the vessel,

$$W_v = 240(1.08)(1.215)(2.23 + 0.8(1.215))(15) = 15126 \text{ N}$$

Therefore, direct stress is

$$\sigma_w = \frac{W_v}{\pi(D_i + t)t} = \frac{15126}{\pi(1.215 \times 10^3 + 15)15} = 0.26 \text{ Nmm}^{-2}$$

σ_w is compressive stress and therefore the value is -0.26 Nmm^{-2}

iii. Bending stress

Formula for bending stress is given by Towler & Sinnott (2013) is

$$\sigma_b = \pm \frac{M}{I_v} \left(\frac{D_i}{2} + t \right)$$

Where,

M = total bending moment

I = second moment of area of the vessel about the plane of bending

Therefore, in order to calculate the bending stress, we need to determine both M and I first. For preliminary design, equivalent to wind pressure, $P_w = 1280 \text{ Nm}^{-2}$

The load per unit length,

$$W = P_w D_{eff}$$

Where,

$$D_{eff} = D_o = D_i + 2t = 1.2 + 2(15 \times 10^{-3}) = 1.23 \text{ m}$$

Hence wind load,

$$W = (1280)(1.23) = 1574.4 \text{ Nm}^{-1}$$

The total binding moment,

$$M = \frac{wH_v^2}{2} = \frac{(1574.4)(2.23^2)}{2} = 3914.67 \text{ Nm}$$

The second moment of area of the vessel about the plane of bending:

$$I_v = \frac{\pi}{64} (D_o^4 - D_i^4) = \frac{\pi}{64} ((1200 + 2(15))^4 - 1200^4) = 1.06 \times 10^{10} \text{ mm}^4$$

Therefore, the bending stress is,

$$\sigma_b = \pm \frac{M}{I_v} \left(\frac{D_i}{2} + t \right) = \pm \frac{3914.67 \times 10^3}{1.06 \times 10^{10}} \left(\frac{1200}{2} + 15 \right) = 0.23 \text{ Nmm}^{-2}$$

iv. Total Longitudinal Stresses for Upwind and Downwind

For upwind,

$$\sigma_z = \sigma_L - \sigma_w + \sigma_b = 26 - 0.26 + 0.23 = 25.97 \text{ Nmm}^{-2}$$

For downwind,

$$\sigma_z = \sigma_L - \sigma_w - \sigma_b = 26 - 0.26 - 0.23 = 25.51 \text{ Nmm}^{-2}$$

v. Principal stresses

For principal stresses,

$$\sigma_1 = \frac{1}{2} \left[\sigma_h + \sigma_z + \sqrt{(\sigma_h - \sigma_z)^2 + 4\tau^2} \right]$$

$$\sigma_2 = \frac{1}{2} \left[\sigma_h + \sigma_z - \sqrt{(\sigma_h - \sigma_z)^2 + 4\tau^2} \right]$$

Since the torsional shear stress is negligible,

$$\sigma_1 = \frac{1}{2} \left[52 + 25.97 + \sqrt{(52 - 25.97)^2 + 0} \right] = 52 \text{ Nmm}^{-2}$$

$$\sigma_2 = \frac{1}{2} \left[52 + 25.97 - \sqrt{(52 - 25.97)^2 + 0} \right] = 25.97 \text{ Nmm}^{-2}$$

If the torsional shear stress neglected, $\tau = 0$, σ_1 is equal to σ_h , and σ_2 is equal to σ_z . Since σ_3 is negligible for thin-walled vessel, and $\tau = 0$, therefore, to determine the maximum stress intensity, $\Delta\sigma$, only $\sigma_1 - \sigma_2$ will be considered.

vi. Maximum stress intensity

$$(\Delta\sigma)_{max} = \sigma_1 - \sigma_2 = \sigma_h - \sigma_z = 52 - 25.97 = 26.03 \text{ Nmm}^{-2}$$

$$S = 16700 \text{ psi} = 115.14 \text{ Nmm}^{-2}$$

Compare the $(\Delta\sigma)_{max}$, with the maximum allowable stress, S for stainless steel based on the ASME code, Subpart 1, Stress Tables 1A. If $(\Delta\sigma)_{max} < S_{design}$, the material construction that we used is acceptable and an elastic stability can be checked.

$$\therefore (\Delta\sigma)_{max} < S_{design} \text{ (acceptable)}$$

b. Elastic stability

If this elastic stability criterion is satisfied too, then the design is safe. For a curved plate subjected to an axial compressive load, the critical buckling stress is given as

$$\sigma_c = \frac{E}{\sqrt{3(1 - \nu^2)}} \left(\frac{t}{R_p} \right)$$

For steel at ambient temperature, $E = 200000 \text{ N/mm}^2$ (Towler & Sinnott 2013). By applying a suitable safety factor, the above equation can be used to predict the maximum allowable compressive stress to avoid failure by buckling. By taking Poisson's ratio as 3.0,

$$\sigma_c = 0.6E \left(\frac{t}{D_o} \right)$$

Hence,

$$\sigma_c = 0.6(200000) \left(\frac{15}{1230} \right) = 1463.41 \text{ N/mm}^2$$

$$\left(\sum \sigma_{compressive} \right) = \sigma_b + \sigma_w$$

$$\left(\sum \sigma_{compressive} \right) = 0.23 + 0.26$$

$$\left(\sum \sigma_{compressive} \right) = 0.49 \text{ N/mm}^2$$

Since, $(\sum \sigma_{compressive}) < \sigma_c$, the buckling process does not occur, and the design is safe.

11.2.7 Vessel support

Phase separator PS-101 is considered as medium sized vertical vessel. For small and medium sized vertical vessels, the most suitable and economical support is bracket support. For the bracket design, there are two typical designs which are single-gusset plate and double-gusset plate. Since the load from vessel is not too high, single-gusset plate is more suitable to be used.

The maximum design load per bracket is given by following formula (Towler & Sinnott 2013),

$$F_{bs} = 60L_c t_c$$

Where,

L_c = the characteristics dimension of bracket, mm

t_c = thickness of plate, mm

The values of L_c and t_c are assumed as 120 mm and 15 mm respectively.

Hence, the maximum design load per bracket,

$$F_{bs} = 60(120)(15) = 108\,000 \text{ N}$$

The value of total weight of vessel, $W = 8530 \text{ N}$

Since $F_{bs} > W$, the design thickness and characteristic length is acceptable.

The summarized dimension of the bracket is shown in Figure 11.7.

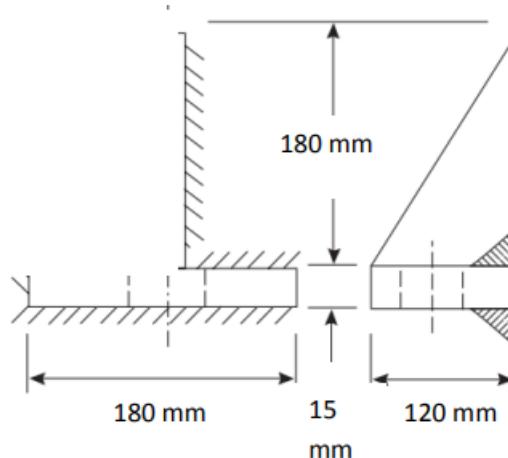


Figure 11.7 Dimension of the designed bracket

For vessels which located on the ground and the dimensions is limited as given in Table 11.14, they usually supported on uniformly spaced legs. The proposed maximum number of legs for a vessel is four to allow good access under the vessel, unless a larger number of legs cannot be avoided (Henry H. & Bednar 1986).

Table 11.14 Conditions for bracket and leg supports

Condition	Value
Maximum diameter	6 ft
Maximum H/D	5
Maximum L/D	2
Number of legs	3 for $D < 3'6"$ 4 for $D > 3'6"$ 6 or 8 if required

Source: Pressure Vessel Design Handbook 1986

For phase separator, PS-101

$$\begin{aligned}
 \text{Diameter} &= 1.216 \text{ m} = 4 \text{ ft} \\
 \text{H/D} &= 2.3\text{m}/1.2\text{m} = 2 \\
 \text{L/D} &= 0.7\text{m}/1.2\text{m} = 0.06
 \end{aligned}$$

All the conditions is satisfied and the suitable number of legs is 4

There a few possible types of legs such as cold-formed beam or a round pipe. For this design, a round pipe is selected since it has equal strength in all directions and has a high bending rigidity. The selected pipe is carbon steel pipe because of its high strength. The pipe size is selected by comparing the size of bracket plate with the outside diameter of the pipe to make sure the pipe cross section area is enough to hold the bracket plate. The nominal specification for the selected carbon steel pipe is as in Table 11.15.

Table 11.15 Dimension of carbon steel pipe legs

Unit	Nominal size (in)	Outside diameter (in)	Scheduled number	Wall thickness (in)	Inside diameter (in)
in	4	4.5	80XS	0.337	3.826
mm	101.6	114.3	80XS	85.6	97.2

Source: Engineering Toolbox

The height of the height selected is 1m. the height is not too high that will cause high bending moment and not too short so that allow to access under the vessel. Since the legs in cylindrical form, the anchor bolt also is designed in circular form. The bolt size is referred to the available standard for saddle support. Even though the total weight of the vessel is not too high compared to the maximum weight of vessel using saddle support, but safety factor should be considered due to the bending moment. Hence, the selected bolt size is,

Bolt diameter = 24 mm

Bolt holes = 30 mm

11.2.8 Bolted flanged joints

In this design, flanged joints are used for connecting pipes to vessel and for manhole covers. There are a few available types of flanged joints.

For the pipe connection, the selected type is the lap-joint flanges. Lap-joint flange is selected because it is suitable to be used for pipework and economical. It is economical especially when used the expensive alloy pipe, such as stainless steel, as the flange can be made from inexpensive carbon steel. Usually, a short lapped nozzle is welded to the pipe, but with some schedules of pipe the lap can be formed on the pipe itself, and this will give a cheap method of pipe assembly. The lap-joint flange diagram is shown in the Figure 11.8.

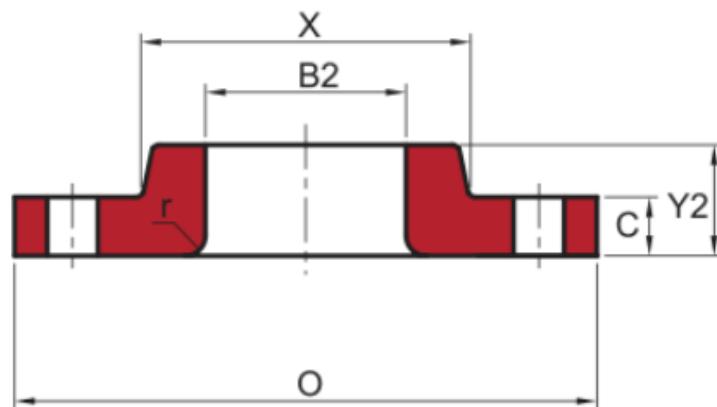


Figure 11.8 Lap-joint flange

Table 11.16 D_{optimum} of pipe connection for each stream

Stream	Mass flowrate (kg/h)	Mass flowrate (kg/s)	Density (kg/m ³)	D_{optimum} (mm)
22	3489.66	0.9694	1000	99.65
23	1495.95	0.4155	1000	28.09
25	1993.71	0.5538	1000	94.70

The most suitable standard flange design is selected by comparing D_{optimum} with the available standard nominal pipe size. Table 11.17 shows the selected flange for each stream.

Table 11.17 Dimension in mm of flanges at each stream

Stream	Nominal pipe size	Flange					Drilling		
		O	C	X	Y2	B2	Number of bolts	d	k
22	100	228.5	23.9	134.9	33.3	116.8	8	19.1	190.5
23	32	117.5	15.7	58.7	20.6	43.7	4	15.8	88.9

25	100	228.5	23.9	134.9	33.3	116.8	8	19.1	190.5
----	-----	-------	------	-------	------	-------	---	------	-------

Meanwhile, for the manhole, the selected type is the blind flange with slip-on flange. Blind flange is used as the manhole cover. Based on the shapes of all the flange, slip on is the most suitable flange that can be paired to the blind flange. Slip-on flanges have poor resistance to shock and vibration loads, but it is more economical to be used for the manhole. Figure 11.9 illustrate both blind and slip-on flange. The largest size is selected so that the opening is large enough for the people to pass through. The selected size with the specification is represented in Table 11.18.

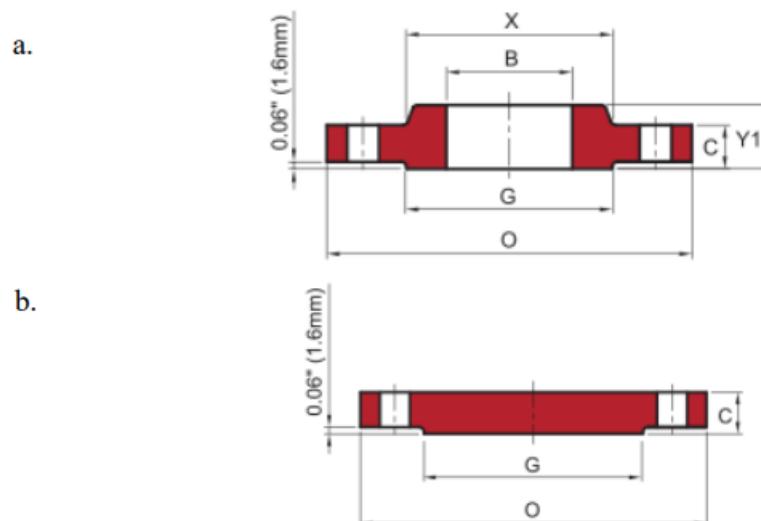


Figure 11.9 (a) Slip-on flange (b) Blind flange

Table 11.18 Dimension in mm of slip-on and blind flanges

Nominal pipe size	Flange					Drilling		
	O	C	X	B	Y1	Number of bolts	d	k
Slip-on flange								
600	914.5	69.9	701.5	616.0	106.4	24	41.1	812.8
Blind flange								
600	914.5	69.9	-	-	-	24	41.1	812.8

11.2.9 Summary of Mechanical Design of Phase Separator, PS-101

Table 11.19 shows the summary results for mechanical design of phase separator, PS-101. The mechanical drawing shown at Appendix E.

Table 11.19 Summary results for the design of PS-101

Properties	Value
Minimum wall thickness, t_{min} (mm)	6.84
Design thickness, t_D (mm)	8.0
Maximum allowable working pressure, MAWP _{vessel} (psi)	222.19
Maximum stress intensity, $(\Delta\sigma)_{max}$ (N/mm ²)	58.06
Design stress, S (N/mm ²)	137.9
Critical buckling stress, σ_c (N/mm ²)	1269.73
$\sum\sigma_{compressive}$ (N/mm ²)	0.79
Bracket plate thickness, t_c (mm)	15
Characteristics length, L_C (mm)	100
Number of legs, N	4

11.3 PLUG FLOW REACTOR, R-101

Designed by: Azrul Zulhilmi bin Ahmad Rosli (A173752)

11.3.1 Introduction

The operating temperature and operating pressure for R-102 are 180°C and 140 bar. There will be ammonia, water, ammonium carbamate, urea, and carbon dioxide in this reactor. Thus, material with high resistance to corrosion is being used for the construction of the reactor. The material that is suitable to be used is stainless steel SA-240 grade 405. This is because this material offers good results against a wide range of atmospheric pressure and corrosion substances. Figure 11.10 show schematic diagram of plug flow reactor.

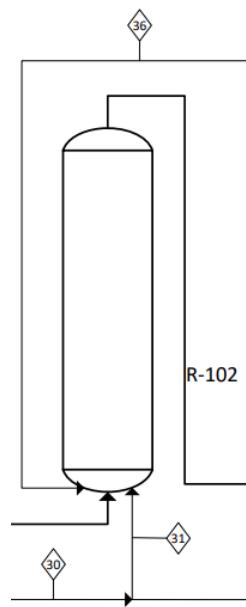


Figure 11.10 Schematic diagram of Plug Flow Reactor, R-102

11.3.2 Design Specification

For the R-102, the mechanical design calculation follows ASME internal pressure procedure. The shape of the reactor was chosen to be cylindrical shape because cylindrical shape is the common shape of the reactor that had been used for other production plant.

Hemispherical, torispherical and hemispherical heads are normally used as end closures for vessel. Torispherical and hemispherical heads are used where less pressure is required normally in the range of 15 bars but hemispherical head is the strongest head used for vessel having large pressure. The material of construction of head will be the same as reactor (carbon steel) to avoid from thermal expansion and dilation between the head and reactor. In the ASME BPV Code Sec. VIII D.1 the equation specified to calculate thickness of the hemispherical head is , $t = \frac{PD}{4SE - 0.4P}$, Where P is the design pressure, S is maximum allowable design stress, D is the diameter and E is the joint efficiency. Table 11.20 below shows the operating conditions and design parameters for R-102.

Table 11.20 Operating condition and design parameters of Plug Flow Reactors,
R-102

Condition	Value
Operating Pressure, P_0	140 bar
Temperature, T	180 °C
Joint Efficiency, E	1
Corrosion Allowance, CA	2mm
Height, H	2.75 m
Diameter, D	0.57 m
Material	Stainless Steel SA-240 grade 405

11.3.3 Detailed Design of R-102

For hemispherical height from ASME BPV Code Sec. VIII D.1 UG-32(F),

Condition:

$$P < 0.665SE$$

$$140 \text{ bar} < 0.665(14632)(1)$$

$$140 \text{ bar} < 9730.28 \text{ psi} = 670.86 \text{ bar}$$

$$h_h = \frac{D_i}{2} = \frac{0.57}{2} = 0.285 \text{ m}$$

For cylindrical shell height,

$$h_c = H - 2h_h = 2.75 - 2(0.285) = 2.18 \text{ m}$$

Table 11.21 shows the dimensions of R-102 in different unit.

Table 11.21 Dimensions of Plug Flow Reactors, R-102

Dimension	Value (m)	Value (in)	Value (ft)
Vessel Height, H	2.75	108.27	9.02
Vessel Inside Diameter, D_i	0.57	22.44	1.87
Shell Height, H_s	2.18	85.82	7.15
Top Head Height, h_o	0.285	11.22	0.935
Bottom Head Height, h_o	0.285	11.22	0.935

11.3.4 Design Pressure

Due to the availability of standard wall thickness materials, many components will have a MAWP higher than the required design pressure. Table 11.22 shows new design pressure for Plug Flow Reactor, R-102. Calculation at Appendix D.

$$P_D = P_O + 0.433h$$

Table 11.22 New design pressure for Plug Flow Reactors, R-102

Part	P _D (psi)	P _F (psi)
Hemispherical Top Head	2030.935	2234.028
Cylindrical Shell	2034.841	2238.325
Hemispherical Bottom Head	2035.245	2238.770

11.3.5 Minimum Wall Thickness

The wall thickness calculation is using the formulas that are written in ASME Code in section UG-32(d) for hemispherical shape and UG-27(c) for cylindrical shape. The value of maximum allowable stress, S is achieved from ASME Code Subpart 1 of Section II, Part D is 14632 psi.

a. Top hemispherical head

$$\begin{aligned} \text{Thickness, } t &= \frac{PL}{2SE - 0.2P} = \frac{2234.028(11.22)}{2(14632)(1) - 0.2(2234.028)} = 0.869 \text{ in} \\ &= 22.09 \text{ mm} \end{aligned}$$

b. Cylindrical shell

For circumference

$$\begin{aligned} \text{Thickness, } t &= \frac{PR}{SE - 0.6P} = \frac{2234.028(22.44/2)}{(14632)(1) - 0.6(2234.028)} = 0.945 \text{ in} \\ &= 24.00 \text{ mm} \end{aligned}$$

For longitudinal

$$\begin{aligned}Thickness, t &= \frac{PR}{2SE + 0.4P} = \frac{2234.028(22.44/2)}{2(14632)(1) + 0.4(2234.028)} = 0.831 \text{ in} \\&= 21.107 \text{ mm}\end{aligned}$$

c. **Bottom hemispherical shape**

$$\begin{aligned}Thickness, t &= \frac{PL}{2SE - 0.2P} = \frac{2234.028(11.22)}{2(14632)(1) - 0.2(2234.028)} = 0.869 \text{ in} \\&= 22.094 \text{ mm}\end{aligned}$$

The thickness that will be taken is the maximum thickness which is 0.94 inch equivalent to 24 mm. The closest nominal thickness, $t_{nominal}$, is 1.050 in or 26.67 mm. After considering CA of 2 mm:

$$\begin{aligned}Minimum thickness, t_{min} &= t_{nominal} - CA = 26.67 - 2 = 24.67 \text{ mm} \\&= 0.971 \text{ in}\end{aligned}$$

11.3.6 Summary of Maximum Allowable Working Pressure, MAWP

Table 2.3 and table 2.4 show the summary for the calculation of internal and MAWP of R-102 and primary stress. The calculation is shown in Appendix D.

Table 2.3 Internal Pressure and MAWP_{vessel} for each part of the R-102

Part of R-102	MAWP _{part} (psi)	Static Head, PH (psi)	MAWP _{vessel} (psi)
Top Hemispherical Head	2489.47	0.405	2489.07
Circumferential	1203.77	4.31	1199.464
Longitudinal	2407.55	4.31	2403.239
Bottom Hemispherical Head	2489.47	4.715	2484.755

Thus, the MAWP_{vessel} is choose from the smallest value which is 1203.77 psi (82.99 bar).

11.3.7 Design of Heating Jacket

R-102 has a heating jacket built in for heating functions, which include preventing heat loss and preserving the system's temperature. The ASME code specifies the Type 1 jacket, which is totally contained within the cylindrical shell. The jacket's chosen closure is typed (b-1) in accordance with ASME code specifies the Type 1 jacket. Dimple jackets are the type of jackets utilised for this reactor because they can endure both high temperatures and high pressures. Stainless steel grade 340 was used in the building of the jacket packed bed reactor. Figures 1.3 and 1.4, respectively, display type 1 jacketed vessels and a type (b-1) jacket closure.

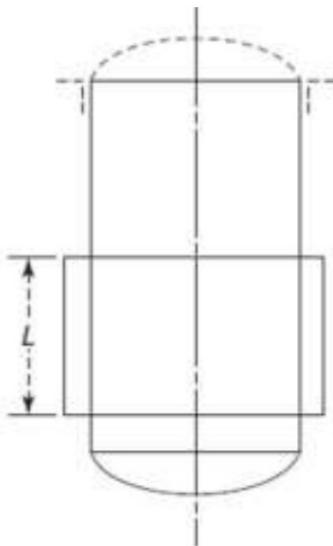


Figure 11.11 Type 1 jacket

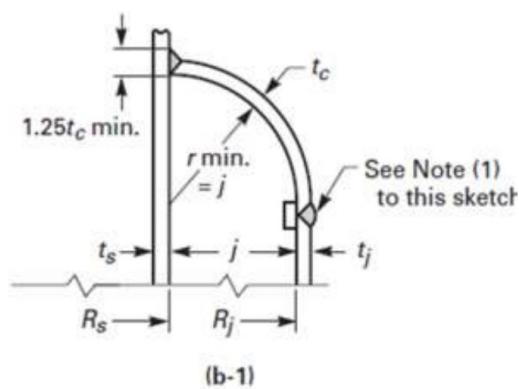


Figure 11.12 Type (b-1) jacket closure

Heating jacketed was used around the reactor in order to maintain the reactor isothermal conditions. From the energy balance, the amount of heat needs to release in order to maintain the reactor isothermal conditions is given by, $Q = 12083.96 \text{ kJ/h} = 334.22 \text{ W/m}^2\text{K}$. It was assumed that Therminol was feed at 210°C and removed at 180 °C. Table 11.23 thermodynamics properties of Therminol 66.

Table 11.23 Properties of Therminol 66

Parameter	Value
Heat capacity, Cp (kJ/kg.K)	2.12
T(K)	485.75
Tref (K)	453.15
Density, ρ (kg/m ³)	899

Source: Eastman 2019

Heat gained by heating medium is given by,

$$Q = mCpdT$$

The amount of Therminol 66 needed can be calculate as

$$m = \frac{Q}{CpdT}$$

$$m = \frac{12083.96}{(2.12 \times (485.75 - 453.15))}$$

$$m = 189.99 \text{ kg/h}$$

That is the amount of Therminol 66 needed to maintain the reactor isothermal conditions assuming that there no phase change occurs inside the reactor.

In order to fulfil the design operating conditions (140 bar and 453 K), half pipe heating jacket can be used as it can withstand high pressure. Standard sizes of the half pipe jacket are 2 3/8, 3 1/2 and 4 1/2-in.o.d. Thickness can be used as 3/16-in. for 2 3/8-in.od. and 1/4 in for both 3 1/2 and 4 1/2 in.od (McKetta, 1992, pp. 423-424) however heating jacket diameter and thickness can be slightly varied in order to accommodate

the higher pressure and temperature conditions and will be shown in the below calculations. Half pipe heating jacket is normally fabricated by 304stainless steel to avoid problem like differential thermal expansion.

The dimension of the jacket calculated shows as below:

There are few assumptions to be make in the calculation:

Jacket space, $j = 2 \frac{3}{8}\text{in} = 60.325 \text{ mm}$

Internal design pressure, $P = 1 \text{ bar} = 2030.528 \text{ psi}$

Maximum allowable stress, $S = 14632 \text{ psi}$

Height of jacket = 1.6 m

The baffle forms a continuous spiral channel, section 50.8 mm \times 200 mm

$$\text{Number of spiral} = \frac{\text{Height of jacket}}{\text{Pitch}} = \frac{1.6}{200 \times 10^{-3}} = 8$$

$$\text{Length of channel} = 8 \times \pi \times 1.345 = 33.80 \text{ m}$$

$$\text{Cross sectional area of channel} = (60.325 \times 200) \times 10^{-6} = 12065 \times 10^{-6}$$

$$\text{Hydraulic mena diameter} = d_C = \frac{4 \times \text{cross-sectional area}}{\text{wetted perimeter}} = \frac{4 \times 12065}{2(75+200)} = 87.75 \text{ mm}$$

Pressure drop is calculated to determine whether the design of cooling jacket is feasible or not.

$$\text{Velocity of heating agent through channel}, u_C = \frac{\text{mass flow}}{\text{density} \times \text{area}} = \frac{189.99}{899 \times 0.0121} = 17.465$$

Piping sizing is the process of selecting the appropriate diameter of pipes for a given flow rate and pressure drop, while considering factors such as fluid properties, pipe material, and other design considerations. Proper piping sizing is critical to ensure safe and efficient fluid transport in industrial processes.

The sizing of pipes is typically determined by calculating the Reynolds number, which is a dimensionless quantity that describes the flow regime in the pipe. The Reynolds number is calculated as

$$\text{Reynolds number, } \text{Re} = \frac{d_e u_c \rho}{\mu} = \frac{(87.75 \times 10^{-3})(17.465)(899)}{0.0012065} = 1141952.608$$

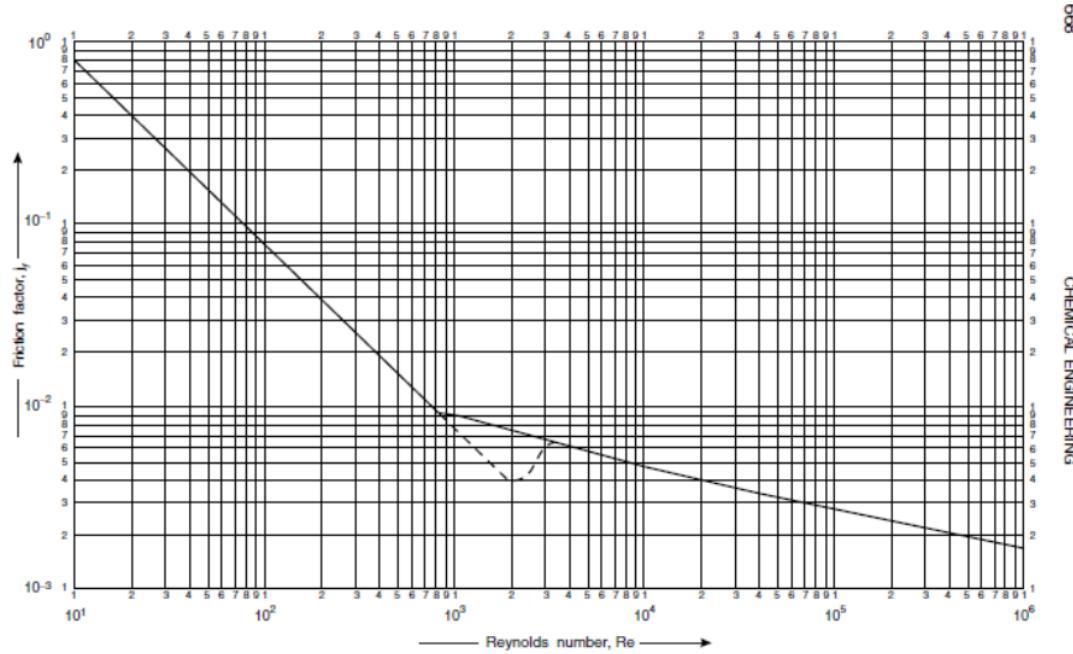


Figure 11.13 Diagram of tube side friction factors

Source: RK Sinnott 2019

From ASME code booklet, friction factor, $j_f = 2.8 \times 10^{-3}$

$$\begin{aligned} \text{Pressure drop, } \Delta P &= 8j_f \left(\frac{L}{D_e} \right) \rho \frac{u_c^2}{2} = 8(2.8 \times 10^{-3}) \left(\frac{33.80}{87.75 \times 10^{-3}} \right) (899) \frac{(17.465)^2}{2} \\ &= 1189.30 \text{ Pa.s} \end{aligned}$$

The cooling jacket design is acceptable since pressure drop calculated is small.

To find the minimum thickness of closure member, t_{rc} . It should be at least equal or not less than minimum thickness of jacket, to nominal thickness of outer jacket wall, t_j can be calculated based on the formula below.

$$t_{rc} = 0.707j \sqrt{\frac{P}{S}}$$

$$t_j = 2t_{rc}$$

Where,

t_c = nominal thickness of closure member (in)

t_j = nominal thickness of outer jacket wall

t_{rc} = requires minimum thickness of closure member as determined herein (in)

S = maximum allowable stress value (psi)

j = jacket space (in)

P = internal design pressure (psi)

The dimension of the jacket calculated shows as below:

There are few assumptions to be make in the calculation:

Jacket space, $j = 2 \frac{3}{8} \text{ in} = 60.325 \text{ mm}$

$$t_{rc} = 0.707j \sqrt{\frac{P}{S}}$$

$$t_{rc} = 0.707(2\frac{3}{8}) \sqrt{\frac{2030.528}{14632}}$$

$$t_{rc} = 0.198 \text{ in} = 5.02 \text{ mm}$$

$$t_j = 2t_{rc}$$

$$t_j = 2(5.02) = 11.04 \text{ mm}$$

11.3.8 Sieve Plates

The principal factor to consider when comparing the performance of sieve and valve plates and bubble plate are cost, operating range, efficiency and pressure drop. Sieve

plates rely on the flow of vapours through the holes to hold the liquid on the plate and cannot operate at very low pressure (Richardson, 2009) therefore sieve plates are used in this reactor because reactor operating conditions are high. The overall height of the column will depend on the plate spacing. Close spacing are used for small reactor diameter reactor. A larger spacing will be needed between certain plates to accommodate feed and side stream arrangement and for men ways. For this reactor

Plate spacing = 0.2 m, Length of the reactor = 2.85m, Total number of plates or stages required = 15

11.3.9 Combined Loading Analysis

Combined loading is happening when two or more types of loads contribute to the stress. There are the sources of combined loading which are internal and external pressure, weight loads, wind loads, earthquake, and eccentric loads. These type of stress will be under primary stresses and summarized into principal stresses at the end of calculations.

a. Primary Stresses

The sources of primary stresses (RK Sinnott 2019):

- i. Longitudinal and circumferential stresses
- ii. Direct stress
- iii. Bending stresses
- iv. Torsional shear stresses

10% of safety factors is taken account in design pressure:

$$P_D = 1.1(1203.77) = 1324.15 \text{ psi} = 15.401 \text{ N/mm}^2$$

i. **Longitudinal stresses, σ_L**

$$\sigma_L = \frac{PD_i}{4t} = \frac{15.401(570)}{4(26.67)} = 82.288 \text{ N/mm}^2$$

ii. **Circumferential stresses, σ_h**

$$\sigma_h = \frac{PD_i}{2t} = \frac{15.401(570)}{2(26.67)} = 164.578 \text{ N/mm}^2$$

iii. **Direct stress, σ_W :**

$$\sigma_W = \frac{W}{\pi(D_i + \tau)t}; W = W_V + W_I$$

$$W_V = 240C_V D_m (H_V + 0.8D_m)t$$

Where,

$$C_V = 1.15$$

$$t = 0.026 \text{ m}$$

$$D_m = (D_i + t) = 0.57 + 0.026 = 0.596 \text{ m}$$

$$H_V = h_c + \frac{2}{3}h_h = 2.75 + \frac{2}{3}(0.285) = 2.94 \text{ m}$$

Thus,

$$W_V = 240(1.15)(0.596)(2.94 + 0.8(0.596))(26.67) = 14989.87 \text{ N}$$

Hence,

$$\sigma_W = \frac{14989.87}{\pi(570 + 26.67)26.67} = 0.2998 \text{ N/mm}^2$$

iv. **Bending stress, σ_B**

$$\sigma_B = \pm \frac{M}{I_V} \left(\frac{D_i}{2} + t \right)$$

Where,

$$M = \frac{Wx^2}{2}$$

$$W = P_w D_{eff}$$

$$D_{eff} = D_i + 2t = 0.57 + (2)0.026 = 0.622 \text{ m}$$

$$W = 1280(0.622) = 796.16 \text{ N/m}$$

$$x = H_V = 2940 \text{ mm}$$

$$M = \frac{796.16 (2.94)^2}{2} = 3440.84 \text{ Nm} = 3.440 \times 10^6 \text{ Nmm}$$

$$I_V = \frac{\pi}{64} (D_o^4 - D_i^4) = \frac{\pi}{64} (622^4 - 570^4) = 2.166 \times 10^9 \text{ m}$$

Thus,

$$\sigma_B = \pm \frac{3.440 \times 10^6}{2.166 \times 10^9} \left(\frac{570}{2} + 52 \right) = \pm 0.0495 \text{ N/mm}^2$$

Torsional shear stress, τ , is the result from torque caused by loads offset from the vessel axis. These loads normally be small and can be neglected in preliminary design. The torsional shear stresses can be neglected in preliminary vessel design because these loads will normally be small. $\tau = 0$. Table 11.24 shows the summary of combined stress.

Table 11.24 Summary of Combined Stress

Primary Stress	Stress Value, N/mm ²
Longitudinal Stresses, σ_L	82.288
Circumferential Stresses, σ_h	164.578
Direct Stresses, σ_w	0.2998
Bending Stresss, σ_B	0.0495
Trosional Shear Stresses, τ	0 (neglected)

b. Principal Stresses

$$\sigma_1 = \frac{1}{2} \left[\sigma_h + \sigma_z + \sqrt{(\sigma_h - \sigma_z)^2 + 4\tau^2} \right]$$

$$\sigma_2 = \frac{1}{2} \left[\sigma_h + \sigma_z - \sqrt{(\sigma_h - \sigma_z)^2 + 4\tau^2} \right]$$

$$\sigma_3 = 0$$

Total longitudinal stresses for upwind, σ_z :

$$\sigma_z = \sigma_L + \sigma_w + \sigma_B = 82.288 + 0.2998 + 0.0495 = 82.637 \text{ N/mm}^2$$

Total longitudinal stresses for downwind, σ_z :

$$\sigma_z = \sigma_L + \sigma_w - \sigma_B = 82.288 + 0.2998 - 0.0495 = 82.538 \text{ N/mm}^2$$

Principal stress,

For upwind:

$$\sigma_1 = \frac{1}{2} \left[164.578 + 82.637 + \sqrt{(164.578 - 82.637)^2 + 4(0)^2} \right] = 164.56 \text{ N/mm}^2$$

$$\sigma_2 = \frac{1}{2} \left[164.578 + 82.637 - \sqrt{(164.578 - 82.637)^2 + 4(0)^2} \right] = 82.655 \text{ N/mm}^2$$

For downwind:

$$\sigma_1 = \frac{1}{2} \left[164.578 + 82.538 + \sqrt{(164.578 - 82.538)^2 + 4(0)^2} \right] = 164.57 \text{ N/mm}^2$$

$$\sigma_2 = \frac{1}{2} \left[100.107 + 82.538 - \sqrt{(164.578 - 82.538)^2 + 4(0)^2} \right] = 82.853 \text{ N/mm}^2$$

c. Maximum Allowable Stress Intensity, ($\Delta\sigma_{max}$)

$$(\Delta\sigma)_{max,upwind} = \sigma_H + \sigma_{z,upwind} = 164.56 - 82.655 = 81.905 \text{ N/mm}^2$$

$$(\Delta\sigma)_{max,downwind} = \sigma_H + \sigma_{z,upwind} = 164.57 - 82.853 = 81.717 \text{ N/mm}^2$$

Hence, maximum allowable stress intensity = 81.717 N/mm². According to ASME Code, the maximum allowable stress, S at 180°C is 14632 psi equivalent to 100.884 N/mm². Since, $(\Delta\sigma_{max}) < S$, the design is safe to use.

d. Elastic Stability

$$\text{Critical buckling stress, } \sigma_c = \frac{E}{\sqrt{3(1-\nu^2)}} \left(\frac{t}{R_p} \right)$$

Instead, assume the equation,

$$\sigma_c = 2 \times 10^4 \left(\frac{t}{D_o} \right)$$

$$\sigma_c = 2 \times 10^4 \left(\frac{26.67}{570} \right)$$

$$\sigma_c = 935.789 \text{ N/mm}^2$$

$$(\Sigma \sigma) \text{ compressive} = \sigma_W + \sigma_B = 0.2998 + 0.0495 = 0.3493 \text{ N/mm}^2$$

Since $(\Sigma \sigma) \text{ compressive} < \sigma_c$, thus the design is safe.

From the analysis of combined loading, the material chosen has fulfilled both requirements of maximum stress intensity and elastic stability.

11.3.10 Weight of the Plates

$$\text{Plate area} = \pi r^2 = \pi \frac{d^2}{4} \text{ Where } d \text{ is reactor diameter which is } 0.57 \text{ m}$$

$$\text{Plate area} = 0.255 \text{ m}^2, \text{ Weight of the plate including liquid on it, } 1.2 \times 0.255 = 0.306 \text{ kN}$$

$$\text{Total numbers of plates are 15 so total weights, } 15 \times 0.306 = 4.593 \text{ kN}$$

11.3.11 Insulation Weight

Mineral wool insulation is used because of it can be applied very easily and have good thermal conductivities range from 0.07 W/mK to 0.21 W/mK (L.Fiala, 2006) depending on the operating conditions., Insulation thickness= 38.1 mm (Perry, 1997), Density of material = 130kg/m³. Allow to double the density for attachment fittings and sealing (Sinnott & Towler, 2009)

$$\begin{aligned} &\text{Approximately volume of the insulator} \\ &= \pi \times \text{reactor diameter} \times \text{reactor height} \\ &\quad \times \text{insulation thickness} \end{aligned}$$

$$\text{Volume} = \pi \times 0.57 \times 2.75 \times 0.0381 = 0.188 \text{ m}^3,$$

$$\text{Density} = \text{mass/volume}, Z$$

$$\text{weight} = 0.188 \times 2 \times 130 \times 9.81 = 478.547 \text{ N}$$

11.3.12 Total weight

Table 11.25 shows summary of total weight of Plug Flow Reactor, R-102

Table 11.25 Summary of total weight of vessel

Parameter	Value (N)
-----------	-----------

Weight of vessel	14989.87
Weight of plate	4593
Weight of insulation	478.547
Total weight	20061.417

11.3.13 Vessel Support

The method used to support a vessel is determined by its scale, shape, and weight. The type of vessel support chosen has also been affected by the design temperature, design strain, vessel location, arrangement, internal and external fittings, and connection. Saddle supports for horizontal vessels, skirt supports for tall and vertical columns, and brackets or lugs for all types of vessels are the three types of vessel support used in pressure vessel design. The supports must be able to support the vessel's weight and contents, as well as any additional loads such as wind loads. The design of the support must be checked to ensure that resulting stress concentrations are below maximum allowable design stress. (Sinnott & Towler 2013). For this design of vessel supports, straight skirt support was chosen since it is recommended for vertical vessels.

a. Skirt Thickness

The skirt thickness must be sufficient to withstand the dead-weight loads and bending moments imposed on it by the vessel and it will not be under the vessel pressure.

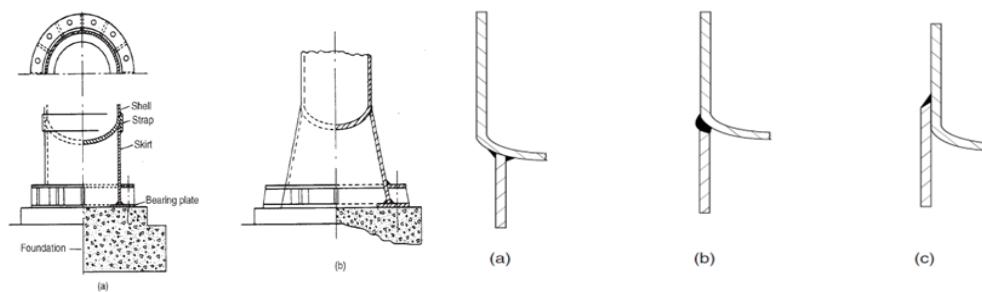


Figure 11.14 Type of skirt

Source: Sinnott & Towler 2013

The resultant stresses in the skirt are:

$$\sigma_s \text{ (tensile)} = \sigma_{bs} - \sigma_{ws}$$

$$\sigma_s \text{ (compressive)} = \sigma_{bs} + \sigma_{ws}$$

with bending stress in the skirt, $\sigma_{bs} = \frac{4M_s}{\pi(D_s + t_{sk})t_{sk}D_s}$

and dead weight stress in the skirt, $\sigma_{ws} = \frac{W}{\pi(D_s + t_{sk})t_{sk}}$

Assume, skirt support height, h_{sk} with ratio 4:1 to height of vessel= 0.688m

Assume, skirt thickness, $t_{sk} = 26$ mm

$$x = H + h_{sk} = 2.75 + 0.26 = 3.01 \text{ m}$$

$$Ds = Di = 0.57 \text{ m}$$

$$W = 796.16 \text{ N/m}$$

Bending moment at the base of skirt:

$$M_s = \frac{\text{windloading} * x^2}{2} = \frac{796.16 (3.01)^2}{2} = 3606.64 \text{ Nm}$$

For bending stress in the skirt, σ

$$\sigma_{bs} = \frac{4(3606.64 \times 10^3)}{\pi(570 + 26)(26)(570)} = 0.519 \text{ N/mm}^2$$

$$\text{Approximate weight} = \left(\frac{\pi}{4} \times D \times Le \right) \times 1000 \times g$$

$$= \left(\frac{\pi}{4} \times 0.570 \times 3.01 \right) \times 1000 \times 9.81$$

$$= 13242.34 \text{ N}$$

Total weight, $W_T = W_v + \text{approximate weight} = 20061.42 + 13242.34 = 33303.76 \text{ N}$

For the dead weight stress on the skirt, σ_{ws} when vessel is full of reactant,

$$\sigma_{ws(\text{test})} = \frac{W_T}{\pi(D_s + t_{sk})t_{sk}} = \frac{33303.76}{\pi(570+26)26} = 0.684 \text{ N/mm}^2$$

$$\sigma_{ws(\text{operating})} = \frac{W_v}{\pi(D_s + t_{sk})t_{sk}} = \frac{20061.42}{\pi(570+26)26} = 0.412 \text{ N/mm}^2$$

Therefore, resultant stresses:

$$\sigma_s(\text{tensile}) = \sigma_{bs} - \sigma_{ws(\text{operate})} = 0.519 - 0.412 = 0.197 \text{ N/mm}^2$$

$$\sigma_s(\text{compressive}) = \sigma_{bs} + \sigma_{ws(\text{test})} = 0.519 + 0.684 = 1.203 \text{ N/mm}^2$$

The skirt thickness should be such that under the worst combination of wind and dead-weight loading the following design criteria are not exceeded.

$$\sigma_s(\text{tensile}) < S_s E \sin \theta_s$$

$$\sigma_s(\text{compressive}) < 0.125 E_Y \left(\frac{t_{sk}}{D_s} \right) \sin \theta_s$$

Where,

S_s = maximum allowable design stress for the skirt material

E = welded-joint efficiency, if applicable.

θ_s = base angle of a conical skirt, normally 80° and 90°

Assume Young's modulus, $E = 200000 \text{ N/mm}^2$ at ambient T

$$S_s E \sin \theta_s = 90 \times 1.0 \times \sin 90^\circ = 90 \text{ N/mm}^2$$

$$0.125E\left(\frac{tsk}{D_s}\right)\sin \theta_s = 0.125 \times 200000 \times (26/570) \sin 90^\circ = 1140.35 \text{ N/mm}^2$$

So,

$$\sigma_s \text{ (tensile)} < S_s E \sin \theta_s$$

$$0.197 \text{ N/mm}^2 < 90 \text{ N/mm}^2$$

So,

$$\sigma_s \text{ (compressive)} < 0.125E\left(\frac{tsk}{D_s}\right)\sin \theta_s$$

$$1.203 \text{ N/mm}^2 < 1140.35 \text{ N/mm}^2$$

Since both criteria are satisfied, the assumed value of skirt thickness, $tsk = 0.026$ m is acceptable. With corrosion allowance of 2 mm, the design skirt thickness, $tsk = 0.024$ m. The skirt will be welded flush with the vessel since this arrangement is usually preferred (Sinnott & Towler 2013). Table 11.26 shows skirt design for Plug Flow Reactor, R-102.

Table 11.26 Skirt design for Plug Flow Reactor, R-102

Parameter	Value
Bending Stress, σ_{bs}	0.519 N/mm ²
Dead Weight Stress, $\sigma_{ws} \text{ (test)}$	0.684 N/mm ²
Dead Weight Stress, $\sigma_{ws} \text{ (operating)}$	0.412 N/mm ²
$\sigma_s \text{ (tensile)}$	0.197 N/mm ²
$\sigma_s \text{ (compressive)}$	1.203 N/mm ²
Skirt thickness	26 mm

11.3.14 Base Ring and Anchors Bolts Design

The loads carried by the skirt will be transmitted to the foundation slab by the skirt base ring. The pressure vessel can overturn due to the moment generated by the wind and other lateral loads (Sinnott & Towler 2013). For R-102, the skirt support is designed

with a double plate with gusset as the base ring to make the vessel more stable and stronger.

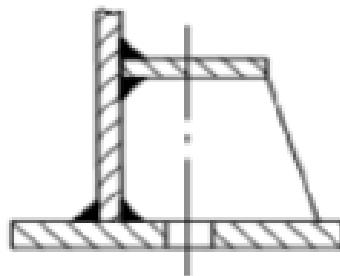


Figure 11.15 Double Plate with Gusset

Source: Sinnott & Towler 2013

The anchor bolts are assumed to share the overturning load equally, and the bolt area required is given by (Sinnott & Towler 2013):

$$\text{Bolt area, } A_b = \frac{1}{N_b f_b} \left(\frac{4M_s}{D_b} - W \right)$$

where,

A_b = area of one bolt at the root of the thread (mm^2)

N_b = no. of bolts

f_b = maximum allowable bolt stress (N/mm^2) = 125 N/mm^2 = 18,000 psi

M_s = bending moment at the base (Nm)

W = weight of the vessel (N)

D_b = bolt circle diameter (m)

Assumptions:

- Approximation pitch circle diameter, $D_b = 0.0125 \text{ m}$ (assumed)
- Bending moment at the base, $M_s = 3606.64 \text{ Nm}$

- Take number of bolt, $N_b = 8$
- For ATSM A325 high stress bolt, maximum allowable bolt stress, $f_b = 125 \text{ N/mm}^2$

Total weight = 33303.76 N

$$A_b = \frac{1}{8(125)} \left(\frac{4(3606.64)}{0.0125} - 33303.76 \right) = 1120.82 \text{ mm}^2$$

Thus, M48 bolts (BS 4190:1967) root area = 1470 mm² was used (M45 bolts (BS 4190:1967))

The base ring must be sufficiently wide to distribute the load to the foundation. The total compressive load on the base ring is determined by,

$$F_b = \left[\frac{4M_s}{\pi D_s^2} + \frac{W}{\pi D_s} \right]$$

where,

F_b = the compressive load on the base ring (N/m),

D_s = skirt diameter (m).

Assume $D_s = D_i$

$$\begin{aligned} F_b &= \left[\frac{4M_s}{\pi D_s^2} + \frac{W}{\pi D_s} \right] \\ &= \left[\frac{4(3606.64)}{\pi(0.57)^2} + \frac{33303.76}{\pi(0.57)} \right] \\ &= 32732.04 \text{ N/m} \end{aligned}$$

The minimum width of the base ring,

$$L_b = \frac{F_b}{f_c} \times \frac{1}{10^3}$$

where,

L_b = base ring width (mm)

f_c = the maximum allowable bearing pressure on the concrete foundation, ranging from 3.5–7.0 N/mm²

Taking maximum allowable bearing pressure as, $f_c = 3.5$ N/mm²

$$L_b = \frac{32732.04}{3.5} \times \frac{1}{10^3} = 16.37 \text{ mm}$$

This is the minimum width required; actual width will depend on the chair design.

Skirt thickness, $t_{sk} = 26$ mm

Assume L_r to be 150 mm

$$\text{Actual width required} = L_r + t_{sk} + 50$$

$$= 150 + 26 + 50$$

$$= 226 \text{ mm}$$

The required thickness for the base ring,

$$t_b = L_r \sqrt{\frac{3f'_c}{f_r}}$$

where,

L_r = the distance from the edge of the skirt to the outer edge of the ring (mm)

t_b = base ring thickness (mm)

f_c' = actual bearing pressure (N/mm²)

f_r = allowable design stress in the ring material = 140 N/mm²

Allowable stress in the ring material, f_r = 140 N/mm² (assumed)

$$f_c' = \frac{F_b}{140 \times 10^3}$$

$$= \frac{32732.04}{140 \times 10^3}$$

$$= 0.2338 \text{ N/mm}^2$$

$$\text{Base ring thickness, } t_b = L_r \sqrt{\frac{3f_c'}{f_r}}$$

$$= 226 \sqrt{\frac{3(0.2338)}{140}} = 16 \text{ mm}$$

Table 11.27 show summary of base ring and anchor bolt design

Table 11.27 Summary of base ring and anchor bolt design

Parameter	Value
Pitch Circle Diameter, D_b	12.5 mm
Number of bolt, N_b	8
Area of one bolt, A_b	1120.82 mm ²
Minimum width of base ring, L_b	16.37 mm
Actual width required	266 mm
Required base ring thickness, t_b	16 mm

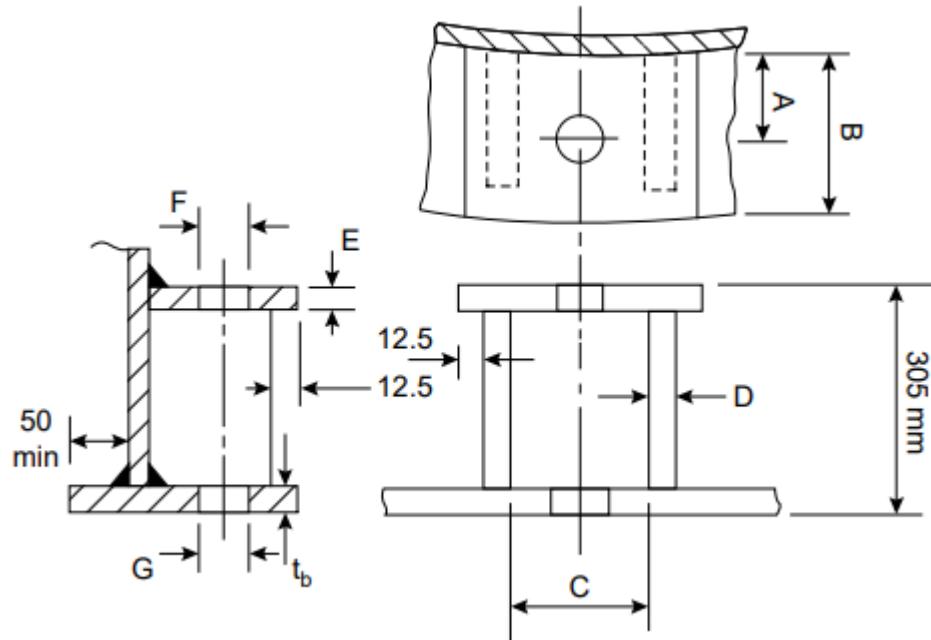


Figure 11.16 Base ring and Anchor bolt

Source: Sinnott & Towler 2013

Table 11.28 Anchor bolt chair design

Bolt size	Root area	Dimensions mm						
		A	B	C	D	E	F	G
M48	1470	67	127	89	19	38	54	60

Source: Sinnott & Towler 2013

11.3.15 Design of Flanged Joints

Flanged joints are used to attach pipes and instruments to the vessel, as well as manhole covers and removable vessel heads when access is required. It's often used in the body of a vessel when a part of the body has to be divided for transport or repair. There are many types of flange such as welding-neck flanges, slip-on flanges, lap-joint flanges, screwed flanges and blank flanges. Welding-neck flanges were chosen as the flange joint type to be used because they are listed for connections and nozzles on process vessels and process equipment, rather than other flanges that are more suitable for pipework.

Welding-neck flange have a long-tapered hub between the flange ring and the welded joint. The flange and branch are separated by a gradual transfer of the segment, which decreases discontinuity stresses and increases the flange assembly's power.

Welding-neck flanges are designed for use in extreme environments where the flange would be exposed to temperature, shear, and vibration loads. Thus it will be the most suitable flange joint to be used in R-102. Figure shows the diagram for welding-neck flange.

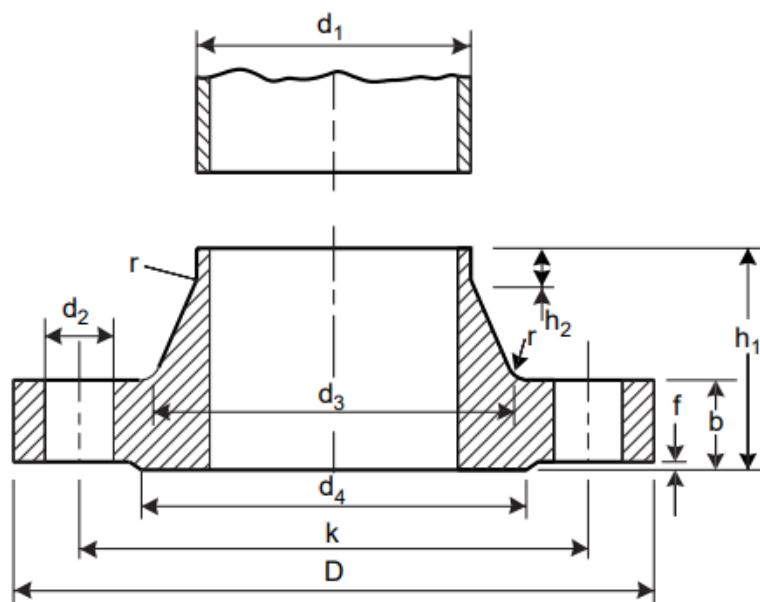


Figure 11.17 Steel welding neck flanges

Source: RK Sinnott 2019

Table 11.29 Welding neck flanges

Connection	Nominal Pipe Size	d_1	Flange				Raised face		Drilling			Neck		
			D	b	h_1	d_4	f	Number of bolts	d_2	k	d_3	h_2	r	
Stream 26	32	42.4	120	14	35	70	2	4	14	90	55	6	6	
Stream 31	32	42.4	120	14	35	70	2	4	14	90	55	6	6	
Steam 33	50	60.3	140	14	38	90	3	8	14	120	74	8	6	
Stream 36	40	48.3	130	14	38	80	3	4	14	100	62	7	6	
Heating Agent in	20	26.9	90	14	32	50	2	4	11	65	38	6	4	
Heating Agent out	20	26.9	90	14	32	50	2	4	11	65	38	6	4	
Manhole	400	406.4	540	22	65	465	4	16	22	495	438	15	12	

Source: RK Sinnott 2019

Based on Figure 11.17, Table 11.29 shows the standard flange dimension for welding-neck flanges based on ASME B16.5 Annex F (Sinnott & Towler 2013) according to the stream. The pipe nominal size was adjusted to suit with the available flange. Flange class of 150 is used since the operating temperature is below 300 °C.

11.3.16 Summary of Mechanical Design of Plug Flow Reactor, R-102

The conditions for the design of condenser have been summarized and tabulated as followed in Table 11.30 below. The mechanical drawing shown at Appendix E.

Table 11.30 Summary of mechanical design of Plug Flow Reactor, R-102

Parameter	Value
Operating temperature, °C	180
Operating pressure, bar	140 bar
Material of construction	Stainless Steel SA-240 grade 405
Vessel internal diameter, m	0.57 m
Vessel external diameter, m	0.59 m
Total vessel height, m	2.75 m
Hemispherical head/bottom height, m	0.285 m
Vessel wall thickness, m	0.025 m
Number of tray, N	15
MAWP _{vessel}	1203.77 psi
Type of heating agent	Therminol 66
Flowrate of heating agent, kg/h	189.99
($\Sigma \sigma$) compressive, N/mm ²	0.3493
Critical bulking stress, σ_c (N/mm ²)	935.79
Type of vessel support	Straight Skirt support
Skirt height, m	0.406 m
Skirt support thickness, mm	0.026 m
Skirt height, m	0.688
Base ring type	Double plate with gusset
Width of base ring, L _b (mm)	16.37 mm
Base ring thickness, t _b (mm)	16 mm
Bolt type	M48 with root area 1470 mm ²
Number of bolt, N _b	8
Type of Flanges Joint	Welding-neck flange
Flanges class	150

11.4 COOLER, CL-106

Design by: Nur Iffa binti Rizuan (A173952)

11.4.1 Introduction

Shell and tube heat exchanger is used as the type of cooler, CL-106. This is because it has low purchase and maintenance cost. It also can be constructed from a wide range of materials and easy to clean and maintain. The function of CL-106 is to lower the temperature of ammonia and carbon dioxide in gas form from 55.3°C to 28°C. The ammonia and carbon dioxide are placed in the tube side as both gases are corrosive compared to cooling water and to reduce the cost. The cooling agent used is cooling water and it is placed in the shell side. Since carbon dioxide and ammonia are corrosive gasses, the material chosen for CL-106 is 316 stainless steel as it has excellent corrosion resistance and good toughness. The type of head that has been chosen for CL-106 is torispherical head. This is because it has lower cost compared to ellipsoidal shape. Since the operating condition of CL-105 is not above 15 bar, so ellipsoidal and hemispherical head are not suitable shape for the head of CL-106. Table 11.31 below shows the conditions of CL-106.

Table 11.31 Condition of CL-106

Parameter	Value
Operating pressure (kPa)	200
Temperature for process fluid (ammonia and carbon dioxide) (From 55.8°C to 28°C
Temperature for cooling agent (cooling water)	From 16°C to 25°C
Corrosion allowance, CA (mm)	2
Joint efficiency, E	1
Length (m)	4.38
Shell diameter (mm)	400
Inner radius of cylindrical shell	0.16

11.4.2 Design Pressure

The vessel is designed using internal pressure as the operating pressure of cooler, CL-106 which is 2 bar is higher than the atmospheric pressure. The design pressure is calculated as below:

$$P_D = P_O + 0.433h$$

Where, P_D = design pressure (psi)

P_O = operating pressure (psi)

a. **Top head (torispherical)**

$$h = 0.333\text{m} = 1.09\text{ft}$$

$$P_D = 29 + 0.433(1.09)$$

$$P_D = 29.47 \text{ psi}$$

b. **Shell (cylindrical)**

$$h = 3.66 \text{ m} = 12.01\text{ft}$$

$$P_D = 29 + 0.433(12.01)$$

$$P_D = 34.2 \text{ psi}$$

c. **Bottom head (Torispherical)**

$$h = 0.33 + 3.66 = 3.99 \text{ m} = 13.1\text{ft}$$

$$P_D = 29 + 0.433(13.1)$$

$$P_D = 34.67 \text{ psi}$$

11.4.3 Minimum Wall Thickness

a. Top head (torispherical)

$$t_{th} = \frac{0.885 PL}{SE - 0.1P}$$

$$= \frac{0.855 \times 29.47 \times 13.08}{20000 \times 1 - 0.1 \times 29.47}$$

$$t_{th} = 0.0171 \text{ inch} = 0.4343 \text{ mm}$$

b. Shell (cylindrical)

i. Circumferential stress

$$t_{sc} = \frac{PR}{SE - 0.6P}$$

$$= \frac{34.2 \times 7.874}{20000 \times 1 - 0.6 \times 34.2}$$

$$t_{sc} = 0.0135 \text{ inch} = 0.3429 \text{ mm}$$

ii. Longitudinal stress

$$t_{tl} = \frac{PR}{2SE + 0.4P}$$

$$= \frac{34.2 \times 7.874}{2 \times 20000 \times 1 + 0.4 \times 34.2}$$

$$t_{tl} = 0.0067 \text{ inch} = 0.1702 \text{ mm}$$

c. Bottom head (torispherical)

$$t_b = \frac{0.885 PL}{SE - 0.1P}$$

$$= \frac{0.885 \times 34.67 \times 157.2}{20000 \times 1 - 0.1 \times 34.67}$$

$$t_b = 0.24 \text{ inch} = 6.1 \text{ mm}$$

All the calculated thickness will be added with the corrosion allowance, CA which is 2 mm or 0.08 inch.

$$t_{th} = 0.4343 + 2 = 2.4343 \text{ mm}$$

$$t_{sc} = 0.3429 + 2 = 2.3429 \text{ mm}$$

$$t_{sl} = 0.1702 + 2 = 2.1702 \text{ mm}$$

$$t_b = 6.1 \text{ mm} + 2 = 8.1 \text{ mm}$$

The overall thickness is determined by taking the highest value calculated as minimum thickness. Therefore, $t_b = 8.1 \text{ mm}$ is chosen.

$$t_{overall} = 8.1 \text{ mm} = 0.32 \text{ inch}$$

Based on the market, $t_{nominal} = 10 \text{ mm}$ (Hilton n.d.)

$$t_{min} = t_{nominal} - CA$$

$$t_{min} = 10 - 2 = 8 \text{ mm} = 0.31 \text{ inch}$$

11.4.4 Allowable Working Pressure, MAWP_{vessel}

a. Internal pressure, P

i. Top head (Torispherical)

$$P = \frac{SE t_{min}}{0.885L + 0.1t_{min}}$$

$$P = \frac{20000 \times 1 \times 0.31}{0.885 \times 13.08 + 0.1 \times 0.31} = 1727.7 \text{ psi}$$

ii. Shell (cylindrical)

Circumferential

$$P = \frac{SEt_{min}}{0.885L + 0.1t_{min}}$$

$$P = \frac{20000 \times 1 \times 0.31}{0.885 \times 144.10 + 0.1 \times 0.31} = 48.60 \text{ psi}$$

Longitudinal

$$P = \frac{22SEt_{min}}{L - 0.4t_{min}}$$

$$P = \frac{2 \times 20000 \times 1 \times 0.31}{7.874 - 0.4 \times 0.31} = 1600 \text{ psi}$$

iii. Bottom head (Torispherical)

$$P = \frac{SEt_{min}}{0.885L + 0.1t_{min}}$$

$$P = \frac{20000 \times 1 \times 0.31}{0.885 \times 44.10 + 0.1 \times 0.31} = 48.60 \text{ psi}$$

$$\text{MAWP} = \text{internal pressure} - 0.433h$$

$$\text{MAWP}_{\text{top head}} = 1727.7 - 0.433(1.09) = 1727.2 \text{ psi}$$

$$\text{MAWP}_{\text{shell}} = 48.6 - 0.433(12.01) = 43.4 \text{ psi}$$

$$\text{MAWP}_{\text{bottom head}} = 48.6 - 0.433(13.1) = 42.93 \text{ psi}$$

The smallest value of MAWP is chose as MAWP_{vessel}, thus MAWP_{vessel} is 42.93 psi.

11.4.5 Combined Loading Analysis

Other than pressure, pressure vessel is subjected to other loads such as major and subsidiary loads. Because of that, it has to design and built to withstand the worst combination of loading without failure.

a. Longitudinal and Circumferential Stresses

The longitudinal and circumferential stress due to pressure internal of the vessel or the external of the vessel.

i. Longitudinal stress

P is MAWP_{vessel} in N/mm² ; D_i = internal diameter of shell which is 400 mm ; t = t_{min} = 8mm

$$\sigma_L = \frac{PD_i}{4t} = \frac{0.296 \times 400}{4 \times 8} = 3.7 \frac{N}{mm^2}$$

ii. Circumferential stress

$$\sigma_h = \frac{PD_i}{2t} = \frac{0.296 \times 400}{2 \times 8} = 7.4 \frac{N}{mm^2}$$

b. Direct stresses

The weight of the vessel, content and any attachment of the vessel will be direct stress.

The stress will be tensile for point above the plane of the vessel supports, and compressive for points below the supports.

W = total weight which is supported by the vessel wall ; D_i = internal diameter of shell which is 400 mm ; t = t_{min} = 8mm

$$\sigma_w = \frac{W}{\pi(D_i + t)t}$$

Where,

$$W = W_v + W_t$$

$$Weight\ of\ the\ shell, W_v = C_w \pi \rho_m D_m g (H_v + 0.8D_m) t \times 10^{-3}$$

C_w = a factor to account for the weight of nozzles, manways, internal supports which is 1.15

H_v = height of the top head + height of shell + height of bottom head

g = gravitational acceleration, 9.81 m/s²

$t = t_{min}$

ρ_m = density of vessel material in kg/m³

D_m = mean diameter of vessel = $D_i + t \times 10^{-3} = 0.4 + 0.008 \times 10^{-3} = 0.4\text{m}$

$$W_s = 1.15\pi \times 999.07 \times 0.4 \times 9.81(4.32 + 0.8 \times 0.4)0.008 \times 10^{-3} = 526\text{ N}$$

$$\text{Weight of tube, } W_t = \frac{[\pi \rho_m (d_o^2 - d_i^2)LNg]}{4}$$

$$W_t = 3756\text{N}$$

$$W = 526 + 3756 = 4282\text{ N}$$

$$\text{Direct stress, } \sigma_w = \frac{4282}{\pi(400+8)8} = 0.418\text{ N/mm}^2$$

c. Bending stress

Since the position of cooler, CL-106 is horizontal and not too high, thus the wind load and bending stress is considered negligible.

d. Torsional stress

Does not involve any torque in CL-106. The loads will normally be very small and can be neglected.

e. Principal stresses

$$\sigma_1 = \sigma_h \text{ (circumferential stress)}$$

$$\sigma_2 = \sigma_z \text{ (Longitudinal stress)}$$

$$\sigma_3 = 0.5P$$

$$\sigma_z = \sigma_L + \sigma_w + \sigma_b = 3.7 + 0.418 + 0 = 4.118 \text{ N/mm}^2$$

$$\text{Hence, } \sigma_1 - \sigma_2 = \sigma_h - \sigma_z = \Delta\sigma_{max} = 7.4 - 4.118 = 3.282 \text{ N/mm}^2$$

Based on ASME Code, maximum allowable stress of 316 stainless steel is 137 N/mm² which is higher than maximum allowable stress intensity, $\Delta\sigma_{max}$ that has been calculated which is 3.282 N/mm². Thus, the designed cooler, CL-106 is accepted and safe to operate.

f. Analysis of elastic stability

The vessel may fail by the elastic instability or known as buckling if the resultant axial stress, σ_z due to the combined loading is compressive. The critical buckling stress, σ_c for a curved plate subjected to an axial compressive load can be calculated as below:

$$\sigma_c = \frac{E}{\sqrt{3(1-\nu^2)}} \left(\frac{t}{R_p}\right)$$

Where,

E = modulus of elasticity

V = Poisson's ratio

R_p = radius of curvature = $D_o / 2 = (0.008+0.4+0.008)/2 = 0.208 \text{ m} = 208 \text{ mm}$

E for stainless steel is 20000 N/mm² while V is 0.29.

$$\sigma_c = \frac{20000}{\sqrt{3(1-0.29^2)}} \left(\frac{8}{208}\right) = 4640.58 \text{ N/mm}^2$$

Maximum allowable compressive stress, $\sigma_{compressive} = 2 \times 10^4 \left(\frac{t}{D_o} \right)$

$$\sigma_{compressive} = 2 \times 10^4 \left(\frac{8}{8+400+8} \right) = 384.62 \text{ N/mm}^2$$

Since $\sigma_{compressive} < \sigma_c$ so the design is acceptable and CL-106 can operate safely.

11.4.6 Design of Vessel Supports

A vessel support method depends on the size, shape and weight of the vessel. Horizontal vessels are usually use saddle support as shown in Figure 11.18 and Figure 11.19. The designed saddles must withstand the load imposed by the weight of the vessel and contents. The condition of contact angle is not less than 120° and not greater than 150° . The dimension of typical “standard” saddle designs for this plant as shown in Figure 11.18 and Figure 11.19.

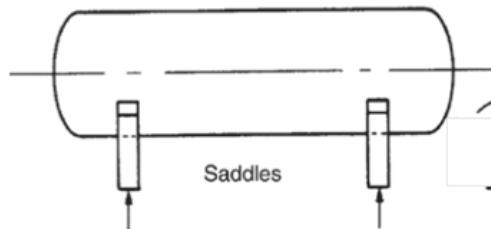


Figure 11.18 Schematic diagram of saddle support

Source: Towler & Sinnott 2013

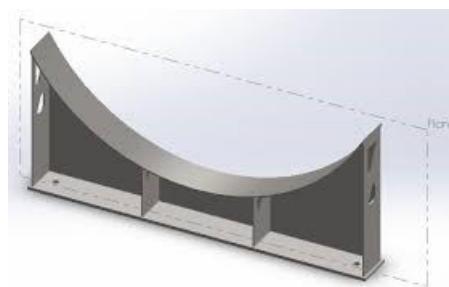


Figure 11.19 Diagram of saddle support

Source: Davis RL & Keith HD 2017

a. Longitudinal bending stress at the saddle-without stiffeners

$$M_{L2} = \frac{M_1}{k_1 r^2 t_s}$$

$$M_1 = 6Q \left[\frac{8AH + 6A^2 - 3R^2 + 3H^2}{3L + 4H} \right] = 13453.13 \text{ lb/ft}^2$$

$$M_{L2} = 1528.77 \text{ lb/ft}^2 = 10.11 \text{ psi}$$

b. Longitudinal bending at midspan

$$M_{L1} = \frac{M_2}{\pi r^2 t_s}$$

$$M_2 = 3Q \left[\frac{3L^2 + 6R^2 - 6H^2 - 12AL - 16AH}{3L + 4H} \right] = 1455.296 \text{ lb/ft}^2$$

$$M_{L1} = 24.13 \text{ lb/ft}^2 = 0.1676 \text{ psi}$$

c. Longitudinal bending stress

$$\sigma_{b1} = \frac{4M_{L1}}{\pi D^2 t} = 0.4 \frac{lb}{ft^2} = 0.003 \text{ psi}$$

d. Resultant axial stress due to bending and pressure

$$\sigma_{b1} = \frac{4M_{L1}}{\pi D^2 t} + \frac{PD}{4T} = 545.21 \text{ psi}$$

e. Magnitude of the longitudinal bending stress at the support

$$\sigma_{b2} = \frac{4M_{L2}}{C_h \pi D^2 t} = 253.19 \frac{lb}{ft^2} = 1.758 \text{ psi}$$

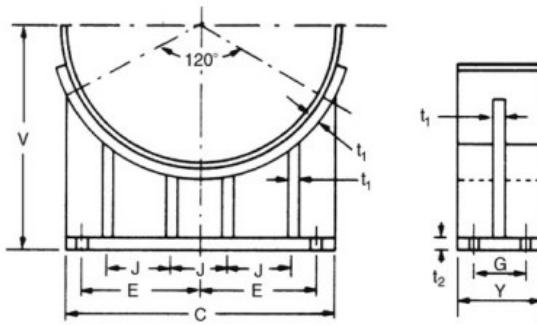


Figure 11.20 Dimension of saddle

Source: Towler & Sinnott 2013

Table 11.32 Dimensions value of the saddle

Parameters	Dimension
Vessel diameter	0.416 m
V	0.672
Y	0.15
C	0.838
E	0.336
J	0.2572
G	0.095
t ₂	9.8
Bolt D	20
Bolt holes	25

11.4.7 Design of Flanged Joints

There are many usage of flanged joints. One of it is to connect pipes and instruments to vessels, for manhole covers and for removable heads when ease of access is required. It also used to connect pipes to other equipments such as pumps and valve. The type of flanged joint used for cooler, CL-106 is welding-neck flanges as shown in Figure 11.21 and the dimension is in Figure 11.22 and Table 11.34. It is designed to be joined to the pipe by butt welding. The advantages of long tapered hub is for usage involving high pressure or elevated temperatures. It also has good distribution of stress since the joint has smooth transition between the flange and pipe (Towler & Sinnott 2013). Not just that, welding neck flanges easy to install and has low erosion rates.



Figure 11.21 Diagram of welding-neck flanges

Source: Projectmaterials 2017

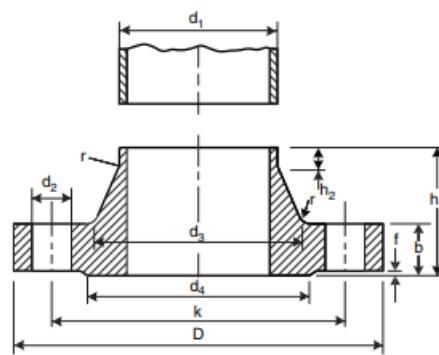


Figure 11.22 Dimension of welding-neck flanges

Source: Sinnott 2005

Table 11.33 Dimensions value of welding-neck flanges

	Dimensions (mm)										
	d ₁	D	b	h ₁	d ₄	f	d ₂	k	d ₃	h ₂	r
Tube side inlet	114.3	210	16	45	148	3	18	170	130	10	8
Tube side outlet	139.7	240	18	48	178	3	18	200	155	10	8
Shell side	26.9	90	14	32	50	2	11	65	38	6	4

11.4.8 Summary of Mechanical Design of Cooler, CL-106

The table below shows the value for the mechanical design of cooler, CL-106: The mechanical drawing shown at Appendix E.

Table 11.34 Summary of mechanical design CL-106

Design condition	Unit	Value

Operating pressure	psi	29
Design pressure	psi	34.67
Material of construction	-	stainless-steel Type 316
Shell diameter	m	0.4
Vessel height	m	4.38
Corrosion allowance, CA	mm	2
Joint efficiency, E	-	1
Overall minimum thickness of vessel, toverall	mm	8
MAWP of vessel	psi	42.93
Longitudinal stress, σ_L	N/mm ²	3.7
Circumferential stress, σ_h	N/mm ²	7.4
Direct stress, σ_w	N/mm ²	0.418
Bending stress, σ_b	N/mm ²	0
Torsional shear stress, τ	N/mm ²	0
Stress analysis	N/mm ²	$(\Delta\sigma_{max}) < S$ $3.282 < 137$
Elastic stability	N/mm ²	$(\sum\sigma)$ compressive $< \sigma_c$ $(384.62 < 4640.58)$
Type of vessel support	-	Saddle support
Type of flanged joint	-	Welding-neck flanges

11.5 CONDENSER, CD-101

Designed by Suriya Vathi A/P Subramanian (A174271)

11.5.1 Design Specification

The mechanical design of a condenser involves designing and specifying the components and systems necessary for efficient heat transfer and condensation of a vapor into a liquid state. A condenser is a device commonly used in various industries to remove heat from a hot vapor or gas, causing it to condense and form a liquid. The mechanical design for condenser, CD-101 is done based on American Society of Mechanical Engineers (ASME). The material chosen for designing condenser is austenitic stainless-steel chosen is type 316 because type 316 stainless steel has good resistance to high temperatures, making it suitable for condensers that operate at elevated temperatures. It retains its mechanical strength and corrosion resistance at

temperatures up to approximately 870°C (1600°F). Type 316 stainless steel exhibits compatibility with various cooling media commonly used in condensers, such as water and certain refrigerants. It resists corrosion from these media and maintains its integrity over extended periods.

Cylindrical shell is chosen for the construction since provides inherent structural strength and stability. The cylindrical shape is inherently resistant to external pressures, making it suitable for containing high-pressure fluids or gases that may be present in the condenser. The cylindrical geometry helps distribute the internal pressure evenly, reducing stress concentrations. Other than that, The cylindrical shape lends itself well to pressure vessel design principles, which are often applicable to condensers. The cylindrical shell allows for efficient stress distribution, making it easier to meet pressure vessel design codes and standards

Torispherical head are chosen for top head since it is good for low pressure and cheapest. The torispherical shape also can promote efficient heat transfer within the condenser. The curved geometry allows for improved fluid flow and circulation, optimizing heat transfer between the vapor or gas being condensed and the cooling medium. The condenser is designed with corrosion allowance of 2 mm and joint efficiency of 1. Specification for condenser is shown in the Table 11.35 below.

Table 11.35 Specification of condenser, CD-101

Condition	Value
Operating pressure, P_o (bar)	1
Operating temperature, T (°C)	140
Joint efficiency, E	1
Corrosion allowance, CA	2
Length (m)	2.44
Shell diameter, D_s (mm)	260.12
Inner radius of cylindrical shell, R (mm)	130.06

11.5.2 Design Pressure

The design pressure for each part of the vessel is designed using the equation below:

$$P_D = P_o + 0.433h$$

Where,

h = height of each part from the top shell (ft)

P_o = operating pressure

P_D = design pressure

Hence,

$$P_{D,\text{Top}} = 14.504 + 0.433(1.07) = 15.16 \text{ psi}$$

$$P_{D,\text{Shell}} = 14.504 + 0.433(1.07) = 17.97 \text{ psi}$$

A safety factor about 5% is added to design pressure for safety purpose. Hence,

$$P_j = 1.05PD$$

$$P_{j,\text{Top}} = 1.05(14.97) = 15.92 \text{ psi}$$

$$P_{j,\text{Bottom}} = 1.05(14.97) = 18.87 \text{ psi}$$

11.5.3 Minimum Wall Thickness

The wall thickness formulas for each part of the vessel are from ASME Code.

The maximum allowable stress value, S is from ASME Code 2013.

For top torispherical head:

$$\text{Thickness, } t = \frac{0.885PL}{SE - 0.1P} = \frac{(0.885)(15.9154)(8.005)}{(23931.2)(1) - 0.1(15.9154)} = 0.00471 \text{ inches}$$

For cylindrical shell:

i. Circumferential stress

$$\text{Thickness, } t = \frac{PR}{SE - 0.6P} = \frac{(18.8729)(0.427)}{(23931.2)(1) - 0.6(18.8729)} = 0.000337 \text{ in}$$

ii. Longitudinal stress

$$\text{Thickness, } t = \frac{PR}{2SE - 0.4P} = \frac{(18.8729)(0.427)}{(2)(23931.2)(1) - 0.4(18.8729)} = 0.000168 \text{ in}$$

By taking the highest t ,

$$T_{\text{overall}} = 0.00471 \text{ in}$$

$$= 0.120 \text{ mm}$$

Since, the corrosion allowance is 2 mm,

The closest t_{nominal} of stainless steel type 316 is 6 mm.

$$t_{\min} = t_{\text{nominal}} - CA$$

$$= 6 - 2 = 4 \text{ mm (0.157 in)}$$

11.5.4 Maximum Allowable Working Pressure (MAWP)

The Maximum Allowable Working Pressure (MAWP) refers to the maximum pressure at which a pressure vessel, such as a condenser or any other equipment, can operate safely under normal operating conditions. The maximum allowable working pressure (MAWP) for a pressure vessel is determined by calculating every part using internal pressure procedure

For top torispherical head;

$$\begin{aligned} MAWP_{\text{torispherical}} &= \frac{SET}{0.885L + 0.1t} \\ &= \frac{(23931.2)(1)(0.157)}{0.885(96.06) + 0.1(0.157)} = 44.32 \text{ psi} \end{aligned}$$

Pressure at top = $MAWP_{\text{torispherical}} - P_H$

Where,

$$P_H = \text{static head} = 0.433h$$

Hence,

Pressure at top = $1495.46 - 0.433(1.07) = 43.67 \text{ psi}$

For cylindrical shell:

iii. Circumferential stress

$$MAWP_{\text{Circumferential}} = \frac{SEt}{R + 0.6t}$$

$$= \frac{(23931.2)(1)(0.157)}{(5.124)+0.6(0.157)} = 722.181 \text{ psi}$$

Pressure at top = $MAWP_{\text{Circumferential}} - P_H$

$$= 722.181 - 0.433 \left(\frac{1.07}{4} + 1.07 \right) = 719.36 \text{ psi}$$

iv. Longitudinal stress

$$\begin{aligned} MAWP_{\text{Longitudinal}} &= \frac{2SEt}{R - 0.4t} \\ &= \frac{(2)(23931.2)(1)(0.157)}{(5.124)-0.4(0.157)} = 1453.13 \text{ psi} \end{aligned}$$

Pressure at top = $MAWP_{\text{Longitudinal}} - P_H$

$$= 1453.13 - 0.433 \left(\frac{1.07}{4} + 1.07 \right) = 1450.32 \text{ psi}$$

The value of $MAWP_{\text{part}}$ and pressure at top is obtained and shown as Table 11.36.

Table 11.36 MAWP_{part} and pressure at top of condenser, CD-101

Part of vessel	MAWP _{part} (psi)	Pressure at top (psi)
Torispherical head	44.323	43.673
Cylindrical shell		
Circumferential stress	722.181	719.364
Longitudinal stress	1453.132	1450.316

The smallest value of pressure at top will be taken as the $MAWP_{\text{vessel}}$ as it shows the maximum allowable pressure at the weakest point on the vessel. $MAWP_{\text{vessel}} =$

1453.132 psi which is higher than the operating pressure. Hence, The design is acceptable.

11.5.5 Combined Loading

Combined loading refers to the simultaneous application of multiple types of loads on a component or structure. It occurs when a structure or component is subjected to different types of loads, such as axial (tensile or compressive), bending, shear, torsion, or a combination of these loads. The effects of combined loading need to be considered to accurately assess the strength and integrity of the component or structure.

a. Primary Stresses

i. Longitudinal and Circumferential Stress

Design pressure take as 10% above operating P as safety factors.

$$P = 1.10(\text{MAWP}_{\text{vessel}}) = 1.10(1453.132)$$

$$= 1598.45 \text{ psi}$$

$$= 11.02 \text{ N/mm}^2$$

$$\begin{aligned} \text{Longitudinal stress, } \sigma_L &= \frac{PD_i}{4t} \\ &= \frac{2.528(260.117)}{4(4)} = 41.095 \text{ N/mm}^2 \end{aligned}$$

$$\begin{aligned} \text{Circumferential stress, } \sigma_H &= \frac{PD_i}{2t} \\ &= \frac{2.528(260.117)}{2(4)} = 82.190 \text{ N/mm}^2 \end{aligned}$$

ii. Direct Stress

$$\text{Direct stress, } \sigma_W = \frac{W}{\pi(D_i+t)t} \text{ where } W = W_v + W_I$$

Where,

$$W_v = 240C_v D_m (H_v + 0.8D_m)t$$

Where,

W_v = total weight of the shell, excluding internal fittings, such as plates, N

C_v = a factor to account for the weight of nozzles, manways, internal supports, which can be taken as 1.08 (for vessel with only few internal fittings)

H_v = height, or length, between tangent lines (the length of the cylindrical section, m)

t = wall thickness, mm

D_m = mean diameter of vessel = $(D_i + (t \times 10^{-3}))$, m

Hence,

Calculation for W_v is shown below. H_v can be calculated using the formula below:

$$H_v = h_c + \frac{2}{3}h_t$$

Where,

h_c = cylindrical height

h_t = torispherical head height

Thus,

$$H_v = 6.505 + \frac{2}{3}(1.5) = 7.505 \text{ m} = 7.505 \text{ m}$$

$$D_m = D_i + t = 0.252 + (18 \times 10^{-3}) = 0.256 \text{ m}$$

So,

$$W_v = 240(1.20)(0.256)(2.287 + 0.8(0.256))(0.004) = 0.735 \text{ N}$$

Hence,

$$\sigma_w = \frac{0.735}{\pi(252.117+4)^4} = 0.000228 \text{ N/mm}^2$$

iv. Torsional Shear

Torsional shear stresses, τ results from torque caused by loads offset from the vessel axis. These loads will normally be small and can be neglected in preliminary vessel designs.

b. Principal Stresses, σ_1 and σ_2

$$\sigma_1 = \frac{1}{2} [\sigma_h + \sigma_z + \sqrt{(\sigma_h - \sigma_z)^2 + 4\tau^2}]$$

$$\sigma_2 = \frac{1}{2} [\sigma_h + \sigma_z - \sqrt{(\sigma_h - \sigma_z)^2 + 4\tau^2}]$$

$$\sigma_2 = 0.5p$$

Since torsional shear stress can be neglected and σ_3 will be negligible for thin wall vessels.

Total longitudinal stresses for upwind, σ_z :

$$\sigma_z(\text{upwind}) = \sigma_L + \sigma_w + \sigma_b$$

$$\sigma_z(\text{upwind}) = 41.094 + 0.000228 + 0 = 41.095 \text{ N/mm}^2$$

$$\sigma_z(\text{downwind}) = \sigma_L + \sigma_w - \sigma_b$$

$$\sigma_z(\text{downwind}) = 41.094 + 0.000228 - 0 = 41.094 \text{ N/mm}^2$$

Table 11.37 Summary of primary stress in the condenser, CD-101

Primary stress	Value (N/mm ²)
Longitudinal stress, σ_L	41.095
Circumferential stress, σ_h	82.190
Direct stress, σ_w	0.000228
Bending stress, σ_b	0
Torsional shear stress, τ	0
Total longitudinal stress, σ_z (upwind)	41.095
Total longitudinal stress, σ_z (downwind)	41.094

The condenser, CD-101 is in horizontal position and not considered tall, thus, no wind load is assumed, bending stress, $\sigma_b = 0$.

Principal stress for upwind:

$$\sigma_1 = \frac{1}{2} [\sigma_h + \sigma_z + \sqrt{(\sigma_h - \sigma_z)^2 + 4\tau^2}]$$

$$\sigma_1 = \frac{1}{2} [(82.190) + (41.095) + \sqrt{(82.190 - 41.095)^2 + 4(0)^2}] = 82.090 \text{ N/mm}^2$$

$$\sigma_2 = \frac{1}{2} [\sigma_h + \sigma_z - \sqrt{(\sigma_h - \sigma_z)^2 + 4\tau^2}]$$

$$\sigma_1 = \frac{1}{2} [(82.190) + (41.095) - \sqrt{(82.190 - 41.095)^2 + 4(0)^2}] = 41.095 \text{ N/mm}^2$$

Principal stress for downwind:

$$\sigma_1 = \frac{1}{2} [\sigma_h + \sigma_z + \sqrt{(\sigma_h - \sigma_z)^2 + 4\tau^2}]$$

$$\sigma_1 = \frac{1}{2} [(82.190) + (41.094) + \sqrt{(82.190 - 41.094)^2 + 4(0)^2}] = 82.190 \text{ N/mm}^2$$

$$\sigma_2 = \frac{1}{2} [\sigma_h + \sigma_z - \sqrt{(\sigma_h - \sigma_z)^2 + 4\tau^2}]$$

$$\sigma_1 = \frac{1}{2} [(82.190) + (41.094) - \sqrt{(82.190 - 41.094)^2 + 4(0)^2}] = 41.095 \text{ N/mm}^2$$

c. Maximum Allowable Stress Intensity ($\Delta\sigma_{\max}$)

By assume $\sigma_3 = 0$,

For upwind condition:

$$\sigma_1 - \sigma_3 = 82.190 - 0 = 82.190 \text{ N/mm}^2$$

For downwind condition:

$$\sigma_2 - \sigma_3 = 41.095 - 0 = 41.095 \text{ N/mm}^2$$

Hence, the maximum allowable stress intensity ($\Delta\sigma_{\max}$) = 41.095 N/mm².

According to the ASME Code, maximum allowable stress, S at 343.15 K is 165 N/mm².

Since ($\Delta\sigma_{\max}$) = 41.095 N/mm² < S = 165 N/mm², the designed condenser, C-102 is safe to operate.

d. Elastic Stability

When the total force results in compressive axial stress σ_z , the vessel may break owing to elastic instability (buckling). Local buckling usually occurs at a lower stress than that necessary to buckle the whole vessel. The critical buckling stress, σ_c , for a curved plate exposed to an axial compressive load may be stated as follows:

$$\text{Critical buckling stress, } \sigma_c = \frac{E}{\sqrt{3(1 - V_2)}} \left(\frac{t}{R_p} \right)$$

For steel at ambient temperature, $E = 200000 \text{ N/mm}^2$, the poisson's ratio is 0.339 and taking safety factor of 12.

Where,

$$D_{\text{eff}} = D_0 = D_i + 2t$$

$$D_0 = 0.252 + 2(4 \times 10^{-3}) = 0.268 \text{ m}$$

Hence,

$$\text{Radius of curvature, } R_p = \frac{D_0}{2} = \frac{0.268}{2} = 0.134 \text{ m}$$

$$\sigma_c = \frac{20000}{\sqrt{3(1 - 0.339)}} \left(\frac{4}{0.134} \right) = 423958.973 \text{ N/mm}^2$$

The maximum compressive stress, $(\Sigma \sigma_{\text{compressive}}) = \sigma_b + \sigma_w = 0.000228 \text{ N/mm}^2$, is substantially below the critical buckling stress, σ_c . As a result (compressive) σ_c . Because both criteria are valid, the design is safe and may be adopted. Based on the combined loading study, the material we picked met both the requirements of maximum stress intensity and elastic stability.

$(\Sigma \sigma)_{\text{max}} < S$ and $(\Sigma \sigma)_{\text{compressive}} < \sigma_c$, therefore, the design is safe.

1.2.6 Vessel Support Analysis

It refers to analysis and design of the support structure or supports for a vessel or tank. It involves determining the appropriate supports, connections, and reinforcements needed to ensure the stability and integrity of the vessel. The analysis typically includes considerations such as the weight and load distribution of the vessel, the material and construction of the vessel, the operating conditions, and any external forces or environmental factors that could impact the stability of the vessel. The goal of Vessel Support Analysis in mechanical drawing is to ensure that the support structure is designed to adequately support the weight of the vessel and withstand any anticipated loads or stresses. It involves calculations, simulations, and sometimes physical testing to verify the structural integrity and safety of the support system.

a. Design of Saddle Support

Saddle are made of bricks or concrete, alternatively they are made of steel plate. It must be built to sustain the weight of the vessel and its cargo. The contact angle should not be less than 120° and should not be more than 150° . Wear plates are frequently bonded to the shell wall to strengthen the wall above the saddle contact region.

Table 11.38 Dimension of saddle design of condenser, CD-101

Vessel diameter (m)	Maximum weight (kN)	Dimension (m)			Dimension (mm)		
		V	C	E	t ₁	Bolt diam.	Bolt holes
0.30	12.5	0.33	0.325	0.165	5	20	25

11.5.6 Flanged Joint

A flanged joint is a type of connection or joint between two components, typically pipes or fittings, that involves the use of flanges. A flange is a flat, circular disc or rim with evenly spaced bolt holes around its circumference. The flanges are aligned and bolted together to create a strong and leak-proof connection. It is also used on the vessel body to split the vessel into portions for transportation and repair. By transmitting stress to the next pipe, it can alleviate high-stress concentrations at the flange's base. The condenser, CD-101, is designed with a welding neck flange. A long-tapered hub connects the flange ring with the welded junction on a welding neck flange. This flange

is appropriate for harsh service situations in which the flange is anticipated to be subjected to temperature, shear, and vibration loads (Sinnot 2005).

Table 11.39 Dimension welding neck flange for each connection in condenser, CD-101

Connections	Nominal size (in)	Dimensions(mm)					
		A	B	O	X	Y	tf
Cooling water inlet, T1	1/2	21.3	15.8	90	30	46	11.2
Cooling water outlet, T2	½	21.3	15.8	90	30	46	11.2
Stream 49	2	60.3	52.5	150	78	62	17.5
Stream 51	2	60.3	52.5	150	78	62	17.5

11.5.7 Summary of Mechanical Design of Condenser, CD-101

The conditions for the design of condenser have been summarized and tabulated as followed in Table 11.40 below. The mechanical drawing shown at Appendix E.

Table 11.40 Summary of mechanical design for condenser, CD-101

Design condition	Unit	Value
Operating pressure	psi	14.504
Operating temperature	°C	140
Design pressure	Psi	17.97
Material of construction	-	Austenitic stainless-steel Type 316
Shell diameter	m	0.260
Vessel height	m	1.98
Corrosion allowance, CA	mm	2
Joint efficiency, E	-	1
Overall minimum thickness of vessel, toverall	mm	0.12
MAWP of vessel	psi	719.36
Longitudinal stress, σ_L	N/mm ²	41.09
Circumferential stress, σ_h	N/mm ²	82.19
Direct stress, σ_w	N/mm ²	0.000228
Bending stress, σ_b	N/mm ²	0
Torsional shear stress, τ	N/mm ²	0
Stress analysis	N/mm ²	$(\Delta\sigma_{max}) < S$

		41.095 < 164.99
Elastic stability	N/mm ²	($\sum\sigma$) compressive < σ_c (0.000228 < 1423958.973)
Type of vessel support	-	Saddle support
Type of flanged joint	-	Welded flanged joint

REFERENCE

- Agitators: Parts, Types, Flow Patterns, and Configurations. (n.d.)
- Aicher, T. (2015). Renewable Hydrogen Technologies. Production, Purification, Storage, Applications, and Safety. Edited by Luis M. Gandía, Gurutze Arzamendi, and Pedro M. Diéguez . *Energy Technology*, 3(1), 90–91.
- Alfian, M., & Purwanto, W. W. (2019). Multi - objective optimization of green urea production. *Energy Science & Engineering*, 7(2), 292-304.
- Al-Jilil, S.A. 2009. COD and BOD reduction of domestic wastewater using activated sludge, sand filters and activated Carbon in Saudi Arabia. *Biotechnology* 8(4): 473–477.
- Alluri, Siva. (2017, April 18). Evaporator Design formulas and important design considerations with online calculator. Sugar Industry Technologies. <https://www.sugarprocesses.com/evaporator-design-online-calculator/> [5 May 2023]
- American Chemical Society. 2021. Urea - American Chemical Society. American Chemical Society. <https://www.acs.org/content/acs/en/molecule-of-the-week/archive/u/urea.html> [2 November 2022].
- Anon. (n.d.). Coagulation, flocculation and clarification.
- Anon. 2021, April 4. Wastewater Clarifier Performance.
- Anon. 2022. The global urea market is projected to grow from \$129.52 billion in 2022 to \$150.61 billion by 2029, at a CAGR of 2.2% in the forecast period, 2022-2029. Fortune Business Insights. <https://www.fortunebusinessinsights.com/urea-market-106850> [30 October 2022].
- Arie Gumilar. 2009, January 30. Mass Balance.
- Baboo, P. 2018. The Analysis and Prevention of Safety Hazards in NFL Complex. *International Journal of Engineering Research and Technology* 7(10).
- Bessarabov, D., & Millet, P. (2018). The PEM Water Electrolysis Plant. *PEM Water Electrolysis*, 1–31.
- Britannica. 2021. urea | Definition, Formula, Production, Uses, & Facts | Britannica. <https://www.britannica.com/science/urea> [6 November 2022].
- Chehade, G., & Dincer, I. (2021). Progress in green ammonia production as potential carbon-free fuel. *Fuel*, 299, 120845.
- Chen, Y., Lyu, Y., Yang, X., Zhang, X., Pan, H., Wu, J., Lei, Y., Zhang, Y., Wang, G., Xu, M., & Luo, H. (2022). Performance comparison of urea production using

- one set of integrated indicators considering energy use, economic cost and emissions' impacts: A case from China. *Energy*, 254, 124489.
- Cinti, G., Frattini, D., Jannelli, E., Desideri, U., & Bidini, G. 2017. Coupling Solid Oxide Electrolyser (SOE) and ammonia production plant. *Applied Energy*, 192, 466–476.
- Company, T.C. 2022. Urea - The Chemical Company
- Dang Saebea, Y. Patcharavorachot, Hacker, V., S. Assabumrungrat, A. Arpornwichanop, & Suthida Authayanun. (2017). Analysis of Unbalanced Pressure PEM Electrolyzer for High Pressure Hydrogen Production. *Chemical Engineering*
- Davis Rl & Keith Hd. 1971. Finite- element analysis of pressure vessels. ASME Pap 71-WA/PT-10 2(2): 7–13.
- Deepa & Ravishankar. 2013. Reducing Hot and Cold Utility Requirements for Finishing Column Section Using Pinch Analysis Techniques. International Journal of Engineering Research and Applications (IJERA) 3: 1587–1592.
- Department of Environment. 2009. Environmental Quality (Industrial Effluent) Regulations 2009.
- Department of Environment. 2014. Environmental Quality (Clean Air) Regulations 2014
- Department of Environment. 2014. Environmental Quality (Scheduled Waste) Regulations 205
- Department of Environment. 2014. Solid Waste and Public Cleansing Management (Scheme for Commercial, Industrial and Institutional Solid Waste) Regulations 2018.
- Dong, Z. 2012. Comparison of 316 and 316L stainless steel alloys. Экономика Региона 304(Kolisch 1996): 49–56.
- Edrisi, A., Mansoori, Z., & Dabir, B. (2016). Urea synthesis using chemical looping process – Techno-economic evaluation of a novel plant configuration for a green production. *International Journal of Greenhouse Gas Control*, 44, 42–51.
- Electrodeionization (EDI), Water Purification Technology, *ELGA LabWater*. (2021). Elgalabwater.com. <https://www.elgalabwater.com/electrodeionization-edi> [5 May 2023]
- Electrodeionization Plants. (2023). https://www.lennotech.com/edi_plants.htm [5 May 2023]
- Fernando, C., & Purwanto, W. W. (2021). Techno-economic analysis of a small-scale power-to-green urea plant. *IOP Conference Series: Earth and Environmental Science*, 716(1), 012010.

- Hart, J. 2021. Hazardous Materials Identification. <https://www.nfpa.org/News-and-Research/Publications-and-media/Blogs-Landing-Page/NFPA-Today/Blog-Posts/2021/11/05/Hazardous-Materials-Identification> [1 January 2023].
- Haslego, C. 2010. Design considerations for shell tube heat exchanger. <http://www.cheresources.com/content/articles/heat-transfer/design-considerations-for-shell-and-tube-heat-exchangers> [10 May 2023].
- Henry H. & Bednar, P. E. 1986. Pressure vessel design handbook.pdf, hlm. second.
- Hilton, P. (n.d.). Shell and Tube heat exchanger. <https://www.p-a-hilton.co.uk/products/heat-transfer/shell-and-tube-heat-exchanger> [26 May 2023].
- Kenton, W. 2022. Sensitivity analysis definition
- Kenton, W. 2022. Sensitivity analysis definition. <https://www.investopedia.com/terms/s/sensitivityanalysis.asp> [28 January 2023]
- Li, J. & Zhang, Y. 2021. Morphology and Crystallinity of Urea-Formaldehyde Resin Adhesives with Different Molar Ratios. *Polymers* 13(5): 1–17. doi:10.3390/POLYM13050673
- Malaysia - Inflation rate 2027 | Statista. 2021. Statista; Statista. <https://www.statista.com/statistics/319033/inflation-rate-in-malaysia>
- Maloney, J.O. 2007. PERRY Chemical Engineering Handbook. Perrys' Chemical Engineers' Handbook 21.
- Manisha, K. 2009. Difference Between Urea and Uric Acid | Difference Between. <http://www.differencebetween.net/miscellaneous/difference-between-urea-and-uric-acid/> [6 November 2022].
- Mccabe, W., Smith, J. C., & Harriott, P. (2019). Unit Operations of Chemical Engineering. <https://www.semanticscholar.org/paper/Unit-Operations-of-Chemical-Engineering-Mccabe-Smith>
- Minton, P. E. (1988). Handbook of Evaporation Technology. William Andrew. <https://www.elsevier.com/books/handbook-of-evaporation-technology/minton/978-0-8155-1097-0>
- Mukherjee, R. 2015. TEMA designations for shell-and-tube heat exchangers .
- National Center for Biotechnology Information. 2021. urea | NH₂CONH₂ - PubChem. PubChem Compound Summary for CID 1176, Urea. <https://pubchem.ncbi.nlm.nih.gov/compound/Urea#section=Odor> [2 November 2022].

- Nayak-Luke, R. M., & Bañares-Alcántara, R. (2020). Techno-economic viability of islanded green ammonia as a carbon-free energy vector and as a substitute for conventional production. *Energy & Environmental Science*, 13(9), 2957–2966.
- Nguyenvan, Thienduc & Samsudin, Mohamad Fakhrul Ridhwan & Sufian, Suriati. (2018). The Reaction Mechanism of Ammonia Production via Magnetic Induction Method: A Density Functional Theory (DFT) Study. 1. 24-30.
- Nilai Industrial 10 acre Flat Land Neaby Town Rm80psf, Nilai, Negeri Sembilan, Industry Properties for sale, by Gary Khoo, RM 34,848,000, 35734097. (n.d.). <https://www.propertyguru.com.my/commercial-property/nilai-industrial-10-acre-flat-land-neaby-town-rm80psf-for-sale-by-gary-khoo-35734097#map> [6 November 2022].
- Ojha, D. K., Kale, M. J., McCormick, A. V., Reese, M., Malmali, M., Dauenhauer, P., & Cussler, E. L. (2019). Integrated Ammonia Synthesis and Separation. *ACS Sustainable Chemistry & Engineering*, 7(23), 18785–18792.
- Pasir Gudang Tanjung Langsat Industrial Land, Pasir Gudang Industrial Land for sale | iProperty.com.my. (2022). Iproperty.com.my. <https://www.iproperty.com.my/property/pasir-gudang/sale-103299259/> [1 January 2023].
- Peters, M. & Timmerhaus, K. 1991. *Plant design and economics for chemical engineers*. 4th Ed.
- Price. (2022). Oxygen | Price | per kg | USD | PharmaCompass.com. PharmaCompass.com. <https://www.pharmacompas.com/price/oxygen> [1 January 2023].
- Process Engineer's Tools. (2023). *Compressor temperature elevation calculation - Process Engineer's Tools*. Powderprocess.net. https://www.powderprocess.net/Tools_html/Compressors/Tools_Compressor_T.html [1 January 2023].
- Projectmaterials. 2017. weld neck flange dimension. <https://blog.projectmaterials.com/flanges/weld-neck-flange-dimensions-asme-ansi/> [26 May 2023].
- Puncak Alam Industrial Park Land for Sale. (2022). EdgeProp.my. https://www.edgeprop.my/listing/sale/1531953/selangor/bandar_puncak_alam/industrial/industrialland/puncak-alam-industrial-park-land-for-sale [1 January 2023].
- Qureshi, S., Mumtaz, M., Chong, F. K., Mukhtar, A., Saqib, S., Ullah, S., Mubashir, M., Khoo, K. S., & Show, P. L. (2022). A review on sensing and catalytic activity of nano-catalyst for synthesis of one-step ammonia and urea: Challenges and perspectives. *Chemosphere*, 291, 132806.
- Qureshi, S., Mumtaz, M., Chong, F. K., Mukhtar, A., Saqib, S., Ullah, S., Mubashir, M., Khoo, K. S., & Show, P. L. (2022). A review on sensing and catalytic

- activity of nano-catalyst for synthesis of one-step ammonia and urea: Challenges and perspectives. *Chemosphere*, 291, 132806.
- Ratnayaka, D.D., Brandt, M.J. & Johnson, K.M. 2009. Storage, Clarification and Chemical Treatment. *Water Supply* 267–314
- Ratti, C. & Mujumdar, A.S. 2014. Infrared drying. *Handbook of Industrial Drying*, Fourth Edition 405–420.
- Road, I. 2005. The engineered mist eliminator. *Chemical Engineering Progress* 101(6).
- Saebea, Dang et al. “Analysis of Unbalanced Pressure Pem Electrolyzer for High Pressure Hydrogen Production.” *Chemical engineering transactions* 57 (2017): 1615-1620.
- Sardar Q. Hassan & Dennis L. Timberlake. 2012. *Journal of the Air & Waste Management Association*.
- Seader, D. & Henley, E. J. 1999. Separation process principles. *Choice Reviews Online* 36(09): 36-5112-36–5112. doi:10.5860/choice.36-5112
- Sindisiwe mvundla. (2019). Module #3 Design Of Evaporator: Introduction, Types Of Evaporators, Methods Of Feeding Of Evaporators, General Design Consideration Of Evaporator. [5 May 2023]
- Singh, R. 2021. Urea Market is estimated to expand at a moderate CAGR of 2.3% over the forecast period of 2021-2031: PMR. <https://www.prnewswire.com/news-releases/urea-market-is-estimated-to-expand-at-a-moderate-cagr-of-2-3-over-the-forecast-period-of-2021-2031-pmr-301332393.html> [30 October 2022].
- Sinnott, R. & Towler, G. 2019. *Chemical Engineering Design*: Six Edition. *Chemical Engineering Design* 6: 1359.
- Sinnott, R.K. 2005. *Chemical Engineering Design*. 4th Ed. Butterworth-Heinemann, Elsevier.
- Sinnott, RK. 2005. *Chemical engineering*. Fourth Edition.
- Smart, K. (2021). Review of Recent Progress in Green Ammonia Synthesis. *Johnson Matthey Technology Review*.
- Society, R. (2020). Green ammonia | Royal Society. [Royalsociety.org](https://royalsociety.org/topics-policy/projects/low-carbon-energy-programme/green-ammonia/). <https://royalsociety.org/topics-policy/projects/low-carbon-energy-programme/green-ammonia/> [1 January 2023].
- Therital. 2018. Physical and Chemical Properties of Water.

- Towler, G. & Sinnott, R. 2013. Chemical Engineering Design Principles, Practice and Economics of Plant and Process Design, Second Edition. Chemical Engineer. Vol. 76.
- Towler, G. & Sinnott, R. 2019. Chemical Engineering Design Principles. Journal of Chemical Information and Modeling. Vol. 53.
- Towler, G. & Sinnott, R.A.Y. 2013. Chemical Engineering Design, Principles, Practice and Economics of Plant and Process Design. *Elsevier*
- Towler, G.P. & Sinnott, R.K. 2013. Chemical engineering design : principles, practice, and economics of plant and process design 1303.
- Towler, Gavin Sinnott, R.K. 2013. 7. Capital Cost Estimating - Knovel (1975).
- Unified Alloys. 2021. Stainless Steel Pipe Chart - Unified Alloys. <https://www.unifiedalloys.com/p/stainless-steel-pipe-data> [31 January 2023].
- Urea Market Size, Growth | Industry Analysis & Forecast, 2035. (2015). Chemanalyst.com. <https://www.chemanalyst.com/industry-report/urea-market-666>
- Utami Ledyana, Apriliana Dwijayanti & Karl Kolmetz. 2020. DEMISTER PAD SELECTION, SIZING AND TROUBLESHOOTING, Kolmetz Handbook of Process Equipment Design. Researchgate (November).
- Vania, R. 2009. The Panipat tragedy: what went wrong? Down to Earth. Retrieved from <https://www.downtoearth.org.in/news/the-panipat-tragedy-what-went-wrong-30201> [5 November 2022].
- Vlaanderen. 2020. Activated carbon adsorption | EMIS. <https://emis.vito.be/en/bat/tools-overview/sheets/activated-carbon-adsorption> [12 January 2023].
- Wang, W., Li, A., Zhu, Y., Yao, X., Liu, Y. & Chen, Z. 2009. The explosion reason analysis of urea reactor of Pingyin. Engineering Failure Analysis 16(3): 972–986.
- Wenliang, M., Wang, D., Zhou, H., Yong, Y., Li, H., Liao, Z., Yang, S., Hong, X., & Li, G. (2022). Carbon Dioxide from Oxy-Fuel Coal-Fired Power Plant Integrated Green Ammonia for Urea Synthesis: Process Modeling, System Analysis, and Techno-Economic Evaluation. *SSRN Electronic Journal*.
- Wiremesh. 2019. Demister pads of monel and stainless steel knitted mesh. <https://www.wiremesh.net/wiremesh/stainless-steel-monel-mesh-demister-pad.htm> [24 May 2023].
- Yahya, N. (2018). Green Urea. *SpringerLink*.

Zhang, H., Wang, L., Van herle, J., Maréchal, F., & Desideri, U. (2021). Techno-economic comparison of 100% renewable urea production processes. *Applied Energy*, 284, 116401.

APPENDIX A

MASS AND ENERGY BALANCE, AND SIMULATION

a. Mass Balance on Storage Tank, ST-102

$$F_{6H_2O} = 3148.17 \text{ kg/h}$$

$$F_{12H_2O} = 57.07 \text{ kg/h}$$

$$F_{13H_2O} = 47.098$$

$$F_{7H_2O} = 3253.22 \text{ kg/h}$$

So,

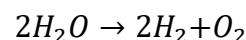
$$\text{Inlet stream 6} + \text{Outlet stream 12} + \text{Inlet stream 13} = \text{Outlet stream 7}$$

$$3253.22 \text{ kg/h} = 3253.22 \text{ kg/h} \text{ (Balanced)}$$

b. Mass Balance on Electrolyser, E-101

Assume that the conversion of water to produce hydrogen and oxygen is 96%

The chemical equation involve in this reaction is:



$$F_{9H_2O} = 3253.22 \text{ kg/h}$$

$$F_{10H_2O} = 57.07 \text{ kg/h}$$

$$F_{10O} = 2796.34 \text{ kg/h}$$

$$F_{11H_2O} = 47.98 \text{ kg/h}$$

$$F_{11H_2O} = 351.83 \text{ kg/h}$$

So,

$$\text{Inlet stream 8} = \text{Outlet stream 10} + \text{Inlet stream 11}$$

$$3253.22 \text{ kg/h} = 3253.22 \text{ kg/h} \text{ (Balanced)}$$

c. Mass Balance on Demister, D-101

$$F_{6H_2O} F_{10H_2O} = 57.07 \text{ kg/h}$$

$$F_{10O} = 2796.34 \text{ kg/h}$$

$$F_{12H_2O} = 57.07 \text{ kg/h}$$

$$F_{14O} = 2796.35 \text{ kg/h}$$

So,

$$\text{Inlet stream 6} + \text{Outlet stream 12} + \text{Inlet stream 13} = \text{Outlet stream 7}$$

$$3253.22 \text{ kg/h} = 3253.22 \text{ kg/h} \text{ (Balanced)}$$

d. Mass Balance on Demister, D-102

$$F_{11H_2O} = 47.98 \text{ kg/h}$$

$$F_{11O} = 351.83 \text{ kg/h}$$

$$F_{13H_2O} = 47.98 \text{ kg/h}$$

$$F_{16O} = 351.83 \text{ kg/h}$$

So,

$$\text{Inlet stream 10} = \text{Outlet stream 12} + \text{Inlet stream 14}$$

$$399.81 \text{ kg/h} = 399.81 \text{ kg/h} \text{ (Balanced)}$$

e. Mass Balance on Catalytic Packed Bed Reactor, R-101



Conversion of HDPE = 25%

i. Hydrogen

Inlet flowrate of H₂, F_{H2} = 351.83 kg/h = 175.915 kmol/h

$$X_{H2} = -\frac{\alpha r}{N_{H2}}$$

$$0.25 = -(-3r)/175.915$$

$$r = 14.64 \text{ kmol/h}$$

$$N_{in} = N_{out} - \alpha r$$

$$175.915 = N_{19H2} - (-3)(14.64)$$

$$F_{19H2} = 131.995 \text{ kmol/h} \times 2 \text{ g/mol} = 263.99 \text{ kg/h}$$

ii. Nitrogen

$$58.638 = N_{19N2} - (-1)(14.64)$$

$$F_{19N2} = 43.998 \text{ kmol/h} \times 28 \text{ g/mol} = 1231.96 \text{ kg/h}$$

iii. Ammonia

$$0 = N_{19A} - (2)(14.64)$$

$$F_{19A} = 29.28 \text{ kmol/h} \times 17 \text{ g/mol} = 497.76 \text{ kg/h}$$

So,

$$\text{Inlet stream 18} + \text{Inlet stream 17} + \text{Inlet stream 24} = \text{Outlet stream 19}$$

$$3489.66 \text{ kg/h} = 3489.66 \text{ kg/h (Balanced)}$$

f. Mass Balance on Phase Separator, PS-101

Assume that the efficiency of the phase separator (PS-101) is 100%.

$$\text{Inlet stream 22} = 3489.66 \text{ kg/h}$$

$$F_{23H2} = 263.99 \text{ kg/h}$$

$$F_{23N2} = 1231.96 \text{ kg/h}$$

$$F_{25A} = 1993.71 \text{ kg/h}$$

So,

$$\text{Inlet stream 22} = \text{Outlet stream 23} + \text{Inlet stream 25}$$

$$3489.66 \text{ kg/h} = 3489.66 \text{ kg/h (Balanced)}$$

g. Mass Balance on Plug Flow Reactor, R-102



Given urea: 50 metric ton/day = 2083.33 kg/h = 34.68 kmol/h

Conversion: 77%

i. Urea

$$N_{in} = N_{out} - \alpha r$$

$$0 = 34.68 - r_2$$

$$r_2 = 34.68 \text{ kmol/h}$$

$$\frac{r_2}{r_1} = \frac{34.68}{r_1} = 0.77$$

$$r_1 = 45.04 \text{ kmol/hr}$$

ii. Water

$$N_{in} = N_{out} - \alpha r$$

$$N_{in} = N_{out} - r_2$$

$$0 = N_{out} - 34.68$$

$$N_{out} = 34.68 \text{ kmol/h}$$

$$F_{out} = 624.93 \text{ kg/h}$$

iii. Ammonium carbamate

$$N_{in} = N_{out} - \alpha r$$

$$N_{in} = N_{out} - (r_1 - r_2)$$

$$0 = N_{out} - (45.04 - 34.68)$$

$$N_{out} = 10.36 \text{ kmol/h}$$

$$F_{out} = 808.82 \text{ kg/h}$$

iv. Carbon dioxide

$$N_{in} = N_{out} - \alpha r$$

$$N_{in} = N_{out} - r_1$$

$$(68 + 8.3 + 11.4) = N_{out} - 45.04$$

$$N_{out} = 42.66 \text{ kmol/h}$$

$$F_{out} = 1877 \text{ kg/h}$$

v. Ammonia

$$N_{in} = N_{out} - \alpha r$$

$$N_{in} = N_{out} - 2r_1$$

$$(117.07 + 16.58) = N_{out} - (2 \times 45.04)$$

$$N_{out} = 43.57 \text{ kmol/h}$$

$$F_{out} = 742 \text{ kg/h}$$

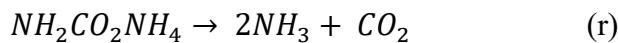
So,

$$\text{Inlet stream 26} + \text{Inlet stream 31} + \text{Inlet stream 36} = \text{Outlet stream 33}$$

$$1993.71 + 2994 + 1147.2 = 6135.75$$

$$6134.91 \text{ kg/h} = 6135.75 \text{ kg/h (Balanced)}$$

h. Mass Balance on Stripper, ST-101



Conversion: 80%

$$\text{Inlet flowrate of ammonium carbamate, } F_{AC33} = 808.82 \text{ kg/h} = 10.36 \text{ kmol/h}$$

$$X_{AC33} = -\frac{\alpha r}{N_{i,AC33}}$$

$$0.80 = -\frac{-r}{10.36}$$

$$r = 8.29 \text{ kmol/h}$$

i. Ammonia

$$N_{in} = N_{out} - \alpha r$$

$$N_{in} = N_{out} - 2r$$

$$0 = N_{out} - (2 \times 8.29)$$

$$N_{out} = 16.58 \text{ kmol/h}$$

$$F_{out} = 282.36 \text{ kg/h}$$

ii. Carbon dioxide

$$N_{in} = N_{out} - \alpha r$$

$$N_{in} = N_{out} - r$$

$$0 = N_{out} - 8.29$$

$$N_{out} = 8.29 \text{ kmol/h}$$

$$F_{out} = 364.84 \text{ kg/h}$$

iii. Ammonium carbamate

$$N_{in} = N_{out} - \alpha r$$

$$N_{in} = N_{out} - (-r)$$

$$10.36 = N_{out} - (-8.29)$$

$$N_{out} = 2.07 \text{ kmol/h}$$

$$F_{out} = 161.61 \text{ kg/h}$$

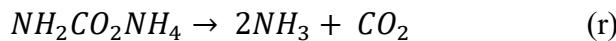
So,

$$\text{Inlet stream 32} + \text{Inlet stream 34} = \text{Outlet stream 35} + \text{Outlet stream 37}$$

$$123 + 6135.75 = 1147.2 + 5111.42$$

$$6258.75 \text{ kg/h} = 6258.62 \text{ kg/h (Balanced)}$$

i. Mass Balance on Decomposer, DP-101



Conversion: 100%

Inlet flowrate of ammonium carbamate, $F_{AC39} = 161.61 \text{ kg/h} = 2.07 \text{ kmol/h}$

$$X_{AC33} = -\frac{\alpha r}{N_{i,AC33}}$$

$$1.0 = -\frac{-r}{2.07}$$

$$r = 2.07 \text{ kmol/h}$$

i. Ammonia

$$N_{in} = N_{out} - \alpha r$$

$$N_{in} = N_{out} - 2r$$

$$0 = N_{out} - (2 \times 2.07)$$

$$N_{out} = 47.71 \text{ kmol/h}$$

$$F_{out} = 812.50 \text{ kg/h}$$

ii. Carbon dioxide

$$N_{in} = N_{out} - \alpha r$$

$$N_{in} = N_{out} - r$$

$$0 = N_{out} - 2.07$$

$$N_{out} = 36.15 \text{ kmol/h}$$

$$F_{out} = 1591.10 \text{ kg/h}$$

iii. Ammonium carbamate

$$N_{in} = N_{out} - \alpha r$$

$$N_{in} = N_{out} - (-r)$$

$$2.07 = N_{out} - (2.07)$$

$$N_{out} = 0 \text{ kmol/h}$$

$$F_{out} = 0 \text{ kg/h}$$

So,

$$\text{Inlet stream 39} = \text{Outlet stream 40} + \text{Outlet stream 42}$$

$$5111.87 = 2242.8 + 2869.07$$

$$5111.87 \text{ kg/h} = 5111.87 \text{ kg/h} \text{ (Balanced)}$$

j. Mass Balance on Evaporator, EV-101

$$\text{Efficiency} = 97.3 \%$$

$$\text{Inlet stream 42} = 2869.07 \text{ kg/h}$$

$$F_{43H_2O} = 436.27 \text{ kg/h}$$

$$F_{43NH_3} = 81.25 \text{ kg/h}$$

$$F_{43CO_2} = 79.56 \text{ kg/h}$$

So,

$$\text{Inlet stream 42} = \text{Outlet stream 43} + \text{Inlet stream 44}$$

$$2869.07 = 597.08 + 2271.99$$

$2869.07 \text{ kg/h} = 2869.07 \text{ kg/h}$ (Balanced)

k. Mass Balance on Granulator, G-101

Efficiency = 99.5 %

Inlet stream 45 = 2271.99 kg/h

$F_{43\text{H}_2\text{O}} = 12.35 \text{ kg/h}$

$F_{43\text{UREA}} = 2083.33 \text{ kg/h}$

So,

Inlet stream 45 = Outlet stream 46 + Inlet stream 48

$2271.99 = 176.31 + 2095.68$

$2271.99 \text{ kg/h} = 2271.99 \text{ kg/h}$ (Balanced)

l. Mass Balance on Condenser, CD-101

Efficiency = 100 %

Inlet stream 47 = 612.58 kg/h

$F_{43\text{H}_2\text{O}} = 612.58 \text{ kg/h}$

$F_{43\text{CO}_2} = 79.56 \text{ kg/h}$

$F_{43\text{NH}_3} = 81.25 \text{ kg/h}$

So,

Inlet stream 47 = Outlet stream 49

$612.58 \text{ kg/h} = 612.58 \text{ kg/h}$ (Balanced)

m. Simulation

i. Electrolysis, E-101

/E-101 (Conversion Reactor)

Solved

Name: E-101 Description:

Simultaneous Reactions:

Summary **Reactions** **Settings** **Equilibrium Results** **Notes**

Main Data		Configuration	
Name	Value	Name	Value
OutQ [W]	-1.388E+7	Split Phases	<input type="checkbox"/>
Delta P [kPa]	0.00	Rxn0_Conversion [Fraction]	0.9679

Material

PortName	In	Out
Energy [W]	-1.519E+6	7.593E+5
H [kJ/kmol]	-30283.6	10200.4
S [kJ/kmol-K]	83.629	153.303
MW	18.02	12.14
Mass Density [kg/m3]	971.8659	6.1910
Cp [kJ/kmol-K]	76.677	29.673
Thermal Conductivity [W/mK]	0.6677	0.1188
Viscosity [Pa-s]	3.5472E-4	1.9666E-5
Molar Volume [m3/kmol]	0.019	1.961
Z Factor	0.0113	1.0002
Mole Fraction [Fraction]		
Mass Fraction [Fraction]		
Std Liq Vol Fraction [Fraction]		

/17 (Material Stream)

Solved

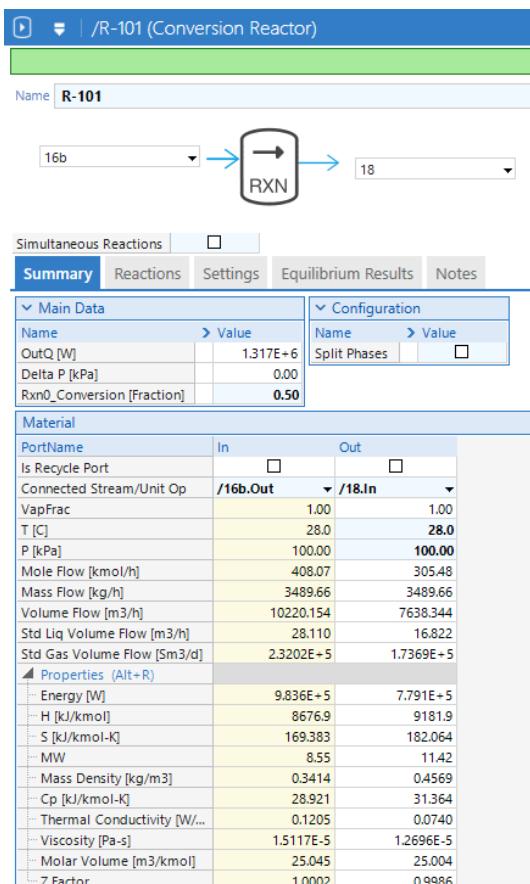
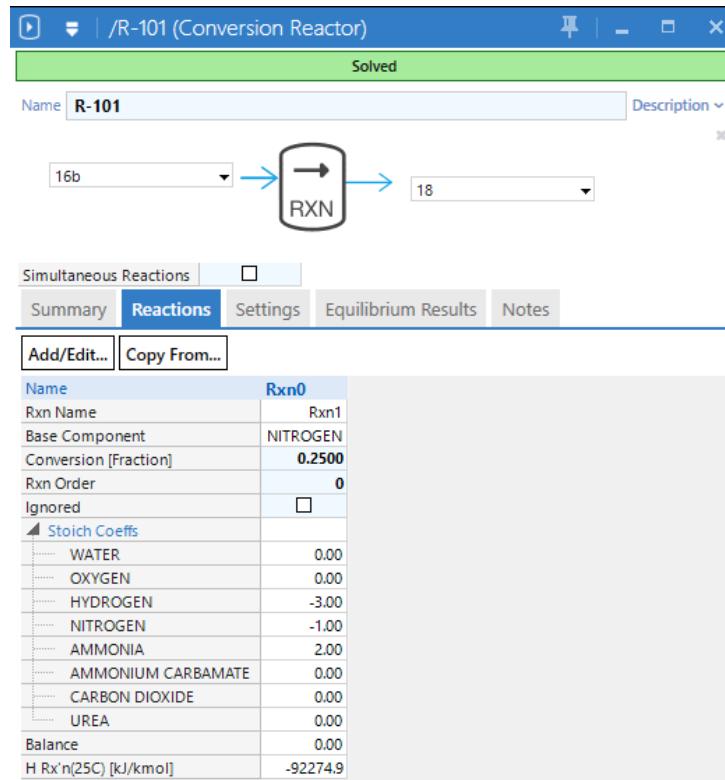
Name: 17 Description: Is Recycle:

Summary **Equilibrium Results** **More Properties** **Line Sizing** **Settings** **Notes**

Material

Connected to [In Out]	/M2.in0
VapFrac	1.00
T [C]	28.0
P [kPa]	100.00
Mole Flow [kmol/h]	58.61
Mass Flow [kg/h]	1641.88
Volume Flow [m3/h]	1467.014
Std Liq Volume Flow [m3/h]	5.154
Std Gas Volume Flow [Sm3/d]	3.3324E+4
Properties	
Mole	[Fraction] [kmol/h]
Mass	[Fraction] [kg/h]
Std Liq Volume	[Fraction] [m3/h]

ii. Catalytic Packed Bed Reactor, R-101



iii. Plug Flow Reactor, R-102

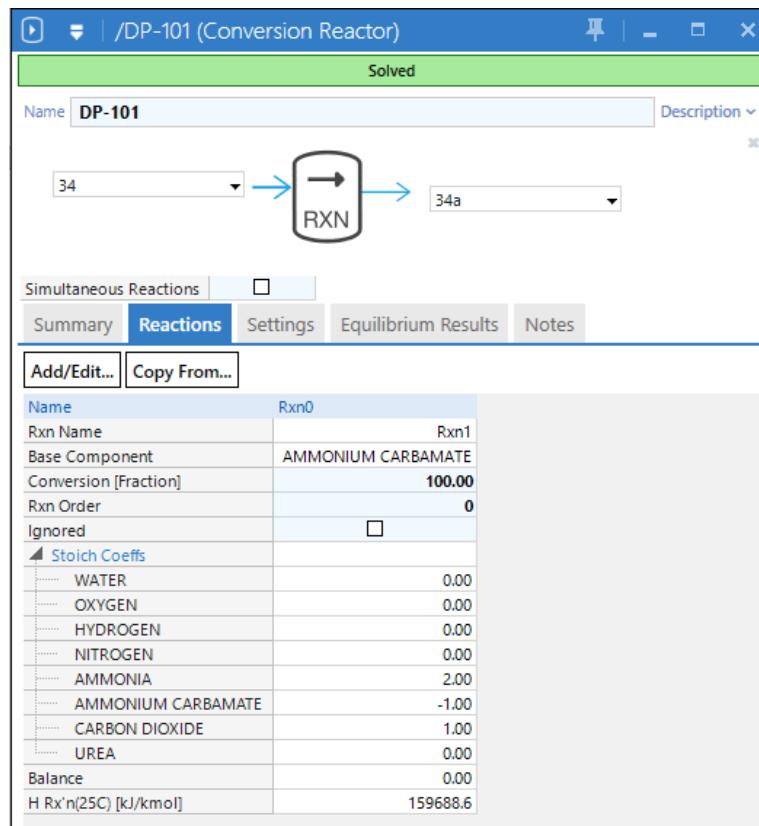
Open /R-102 (Conversion Reactor) | Solved

Name: R-102 Description:

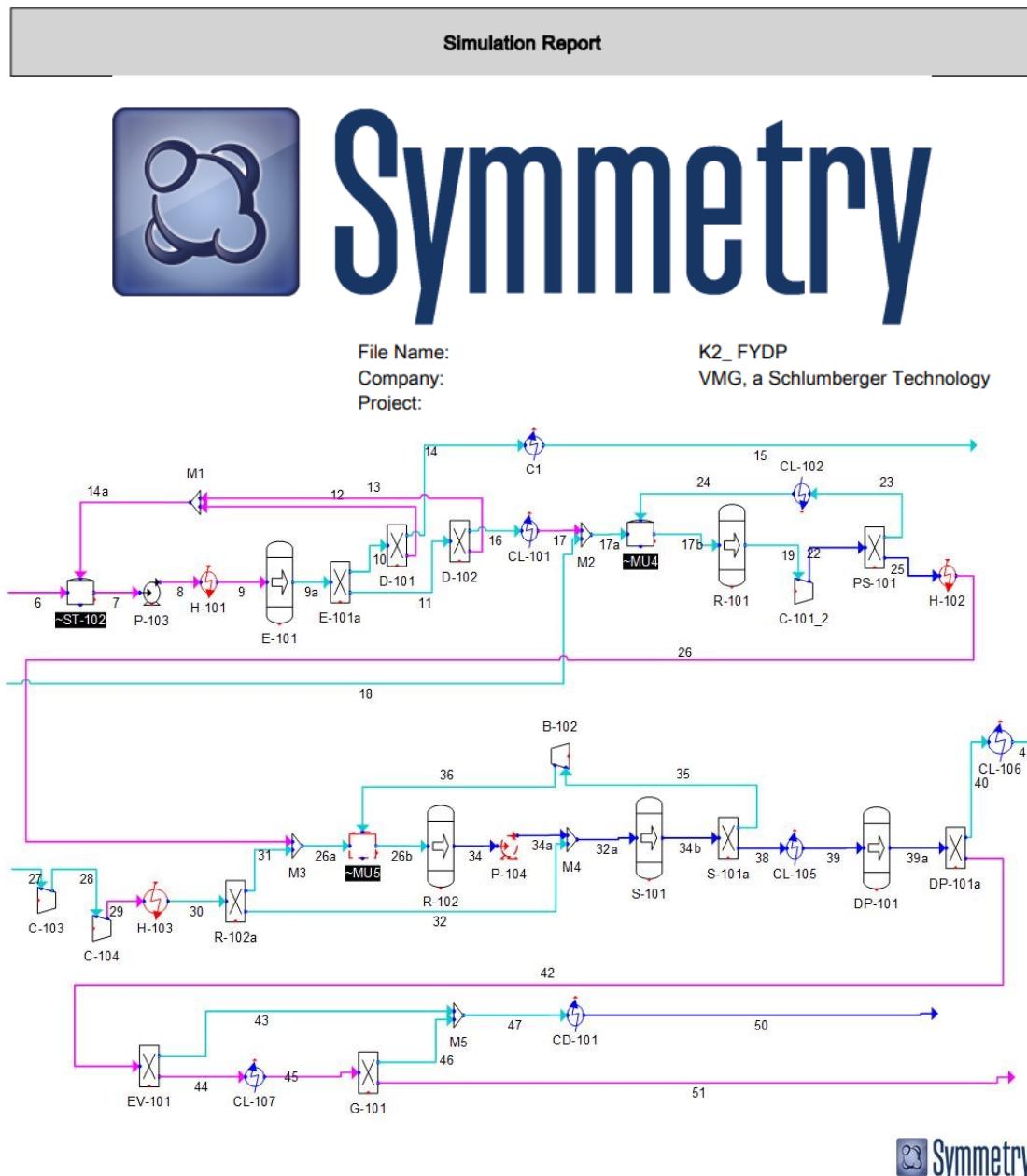
23b → RXN → 29

Reactions

Name	Rxn0	Rxn1
Rxn Name	Rxn1_1	Rxn2
Base Component	AMMONIA	AMMONIUM CARBAMATE
Conversion [Fraction]	0.7700	0.7700
Rxn Order	0	0
Ignored	<input type="checkbox"/>	<input type="checkbox"/>
Stoich Coeffs		
WATER	0.00	1.00
OXYGEN	0.00	0.00
HYDROGEN	0.00	0.00
NITROGEN	0.00	0.00
AMMONIA	-2.00	0.00
AMMONIUM CARBAMATE	1.00	-1.00
CARBON DIOXIDE	-1.00	0.00
UREA	0.00	1.00
Balance	0.00	0.00
H Rx'n[25C] [kJ/kmol]	-79844.3	69767.1

iv. Decomposer, DP-101

v. Overall Simulation Data



Material Stream				
	6	7	8	9
In.VapFrac	0.00	0.00	0.00	0.00
In.T [C]	25.0	25.0	25.0	80.0
In.P [kPa]	150.00	100.00	1500.00	1500.00
In.Mole Flow [kmol/h]	174.75	180.58	180.58	180.58
In.Mass Flow [kg/h]	3148.17	3253.22	3253.22	3253.22
In.Volume Flow [m ³ /h]	3.160	3.265	3.265	3.347
In.Mole Fraction [Fraction]				
WATER	1.00	1.00	1.00	1.00
OXYGEN	0.00	0.00	0.00	0.00
HYDROGEN	0.00	0.00	0.00	0.00
NITROGEN	0.00	0.00	0.00	0.00
AMMONIA	0.00	0.00	0.00	0.00
AMMONIUM CARBAMATE	0.00	0.00	0.00	0.00
CARBON DIOXIDE	0.00	0.00	0.00	0.00
UREA	0.00	0.00	0.00	0.00
	10	11	12	13
In.VapFrac	1.00	1.00	0.00	0.00
In.T [C]	80.0	80.0	80.0	80.0
In.P [kPa]	200.00	1000.00	100.00	1000.00
In.Mole Flow [kmol/h]	90.52	177.45	3.13	2.67
In.Mass Flow [kg/h]	2852.84	400.38	56.39	48.04
In.Volume Flow [m ³ /h]	1327.441	522.915	0.058	0.049
In.Mole Fraction [Fraction]				
WATER	0.0346	0.0150	1.00	1.00
OXYGEN	0.9654	0.00	0.00	0.00
HYDROGEN	0.00	0.9850	0.00	0.00
NITROGEN	0.00	0.00	0.00	0.00
AMMONIA	0.00	0.00	0.00	0.00
AMMONIUM CARBAMATE	0.00	0.00	0.00	0.00
CARBON DIOXIDE	0.00	0.00	0.00	0.00
UREA	0.00	0.00	0.00	0.00
	14	15	16	17
In.VapFrac	1.00	1.00	1.00	0.00
In.T [C]	80.0	28.0	80.0	28.0
In.P [kPa]	100.00	100.00	100.00	100.00
In.Mole Flow [kmol/h]	87.39	87.39	174.78	174.78
In.Mass Flow [kg/h]	2796.45	2796.45	352.34	352.34
In.Volume Flow [m ³ /h]	2565.068	2186.345	5134.293	4378.351
In.Mole Fraction [Fraction]				
WATER	0.00	0.00	0.00	0.00
OXYGEN	1.00	1.00	0.00	0.00
HYDROGEN	0.00	0.00	1.00	1.00
NITROGEN	0.00	0.00	0.00	0.00
AMMONIA	0.00	0.00	0.00	0.00

	14	15	16	17
AMMONIUM CARBAMATE	0.00	0.00	0.00	0.00
CARBON DIOXIDE	0.00	0.00	0.00	0.00
UREA	0.00	0.00	0.00	0.00
	18	19	22	23
In.VapFrac	1.00	1.00	0.8105	1.00
In.T [C]	28.0	28.0	40.0	40.0
In.P [kPa]	100.00	100.00	14000.00	13500.00
In.Mole Flow [kmol/h]	58.61	305.48	305.48	174.93
In.Mass Flow [kg/h]	1641.88	3489.66	3489.66	1495.95
In.Volume Flow [m3/h]	1467.014	7638.344	47.027	41.637
In.Mole Fraction [Fraction]				
WATER	0.00	0.00	0.00	0.00
OXYGEN	0.00	0.00	0.00	0.00
HYDROGEN	0.00	0.4963	0.4963	0.7486
NITROGEN	1.00	0.1679	0.1679	0.2514
AMMONIA	0.00	0.3358	0.3358	0.00
AMMONIUM CARBAMATE	0.00	0.00	0.00	0.00
CARBON DIOXIDE	0.00	0.00	0.00	0.00
UREA	0.00	0.00	0.00	0.00
	24	25	26	27
In.VapFrac	1.00	0.3562	0.00	1.00
In.T [C]	28.0	80.0	180.0	25.0
In.P [kPa]	100.00	13500.00	14000.00	100.00
In.Mole Flow [kmol/h]	174.93	102.59	102.59	70.83
In.Mass Flow [kg/h]	1495.95	1747.13	1747.13	3117.00
In.Volume Flow [m3/h]	4381.517	8.918	18.137	1745.952
In.Mole Fraction [Fraction]				
WATER	0.00	0.00	0.00	0.00
OXYGEN	0.00	0.00	0.00	0.00
HYDROGEN	0.7486	0.00	0.00	0.00
NITROGEN	0.2514	0.00	0.00	0.00
AMMONIA	0.00	1.00	1.00	0.00
AMMONIUM CARBAMATE	0.00	0.00	0.00	0.00
CARBON DIOXIDE	0.00	0.00	0.00	1.00
UREA	0.00	0.00	0.00	0.00
	28	29	30	31
In.VapFrac	1.00	0.00	1.00	1.00
In.T [C]	50.0	40.0	180.0	180.0
In.P [kPa]	4600.00	13500.00	14000.00	14000.00
In.Mole Flow [kmol/h]	70.83	70.83	70.83	68.03
In.Mass Flow [kg/h]	3117.00	3117.00	3117.00	2994.00
In.Volume Flow [m3/h]	32.234	4.137	16.301	15.658
In.Mole Fraction [Fraction]				
WATER	0.00	0.00	0.00	0.00
OXYGEN	0.00	0.00	0.00	0.00
HYDROGEN	0.00	0.00	0.00	0.00

	28	29	30	31
NITROGEN	0.00	0.00	0.00	0.00
AMMONIA	0.00	0.00	0.00	0.00
AMMONIUM CARBAMATE	0.00	0.00	0.00	0.00
CARBON DIOXIDE	1.00	1.00	1.00	1.00
UREA	0.00	0.00	0.00	0.00
	32	34	35	36
In.VapFrac	1.00	0.3321	1.00	1.00
In.T [C]	180.0	180.0	177.0	180.0
In.P [kPa]	14000.00	13500.00	13500.00	14000.00
In.Mole Flow [kmol/h]	2.79	146.91	31.75	31.75
In.Mass Flow [kg/h]	123.00	5746.45	1005.32	1005.32
In.Volume Flow [m3/h]	0.643	12.797	6.842	6.650
In.Mole Fraction [Fraction]				
WATER	0.00	0.2363	0.00	0.00
OXYGEN	0.00	0.00	0.00	0.00
HYDROGEN	0.00	0.00	0.00	0.00
NITROGEN	0.00	0.00	0.00	0.00
AMMONIA	0.00	0.1834	0.4576	0.4576
AMMONIUM CARBAMATE	0.00	0.0706	0.00	0.00
CARBON DIOXIDE	1.00	0.2734	0.5424	0.5424
UREA	0.00	0.2363	0.00	0.00
	38	39	40	41
In.VapFrac	0.7000	0.3979	1.00	1.00
In.T [C]	108.7	135.0	135.0	28.0
In.P [kPa]	135.00	3500.00	100.00	2235.41
In.Mole Flow [kmol/h]	134.55	134.55	64.14	64.14
In.Mass Flow [kg/h]	4864.13	4864.13	2017.66	2017.66
In.Volume Flow [m3/h]	2199.547	49.428	2170.640	59.743
In.Mole Fraction [Fraction]				
WATER	0.2580	0.2580	0.00	0.00
OXYGEN	0.00	0.00	0.00	0.00
HYDROGEN	0.00	0.00	0.00	0.00
NITROGEN	0.00	0.00	0.00	0.00
AMMONIA	0.2155	0.2155	0.4652	0.4652
AMMONIUM CARBAMATE	0.0154	0.0154	0.00	0.00
CARBON DIOXIDE	0.2529	0.2529	0.5348	0.5348
UREA	0.2580	0.2580	0.00	0.00
	42	43	44	45
In.VapFrac	0.00	1.00	0.00	0.00
In.T [C]	135.0	115.0	135.0	100.0
In.P [kPa]	2873.48	100.00	37.83	10.72
In.Mole Flow [kmol/h]	74.56	38.90	35.66	35.66
In.Mass Flow [kg/h]	2846.47	744.50	2101.97	2101.97
In.Volume Flow [m3/h]	2.746	1246.087	1.629	1.568
In.Mole Fraction [Fraction]				
WATER	0.4657	0.8684	0.0263	0.0263

	42	43	44	45
OXYGEN	0.00	0.00	0.00	0.00
HYDROGEN	0.00	0.00	0.00	0.00
NITROGEN	0.00	0.00	0.00	0.00
AMMONIA	0.0445	0.0852	0.00	0.00
AMMONIUM CARBAMATE	0.00	0.00	0.00	0.00
CARBON DIOXIDE	0.0242	0.0464	0.00	0.00
UREA	0.4657	0.00	0.9737	0.9737

	46	47	50	51
In.VapFrac	1.00	1.00	0.0566	0.00
In.T [C]	135.0	115.2	30.0	135.0
In.P [kPa]	200.00	100.00	100.00	200.00
In.Mole Flow [kmol/h]	0.37	39.28	39.28	35.28
In.Mass Flow [kg/h]	6.76	751.25	751.25	2095.22
In.Volume Flow [m ³ /h]	6.273	1258.657	56.385	1.616
In.Mole Fraction [Fraction]				
WATER	1.00	0.8696	0.8696	0.0159
OXYGEN	0.00	0.00	0.00	0.00
HYDROGEN	0.00	0.00	0.00	0.00
NITROGEN	0.00	0.00	0.00	0.00
AMMONIA	0.00	0.0844	0.0844	0.00
AMMONIUM CARBAMATE	0.00	0.00	0.00	0.00
CARBON DIOXIDE	0.00	0.0460	0.0460	0.00
UREA	0.00	0.00	0.00	0.9841

APPENDIX B

PROCESS FLOW DIAGRAM AND PIPING, INSTRUMENTATION DIAGRAM AND PLAN LAYOUT

At here shows:

- Process Flow Diagram before Heat Integration
- Process Flow Diagram after Heat Integration
- Piping and Instrumentation Diagram before HAZOP
- Piping and Instrumentation Diagram after HAZOP
- Process Flow Diagram of Wastewater Treatment Plant.
- Plant Layout of the plant.

ST-101 Storage Tank	B-101 Blower	AF-101 Activated Carbon Filter	EV-101 Evaporator	C-101 Compressor	CL-107 Cooler	H-102 Heater	
P-101 Pump	H-103 Heater	ED-101 Electrodeionization modules	D-101 Demister	E-101 PEM Electrolyser	G-101 Granulator	P-105 Pump	
P-102 Pump	CL-105 Cooler	ST-102 Storage Tank	D-102 Demister	PS-101 Phase Separator	TC-101Conveyer	CD-101 Condenser	
R-102 Plug Flow Reactor	S-101 Stripper	P-104 Centrifugal Pump	CL-106 Cooler	R-101 Packed Bed Reactor	CL-103 Cooler	CL-102 Cooler	
C-103 Compressor	P-103 Pump	CV-101 Control Valve	DP-101 Decomposer	CL-101 Cooler	C-102 Compressor	CL-104 Cooler	
H-103 Heater	H-101 Heater	C-104 Compressor	B-102 Blower	CV-102 Control Valve			



Urea Synthesis Using Green Ammonia Technology

Coordinators:

1. Ir. Dr. Nor Yuliana Yuhana
 2. PM Dr. Mohd Shahbudin
Mastar@Masdar
 3. Dr. Muhammad Zulhaziman
Mat Salleh
 4. Dr. Nur Tantiyani Ali
Othman

Supervisors:

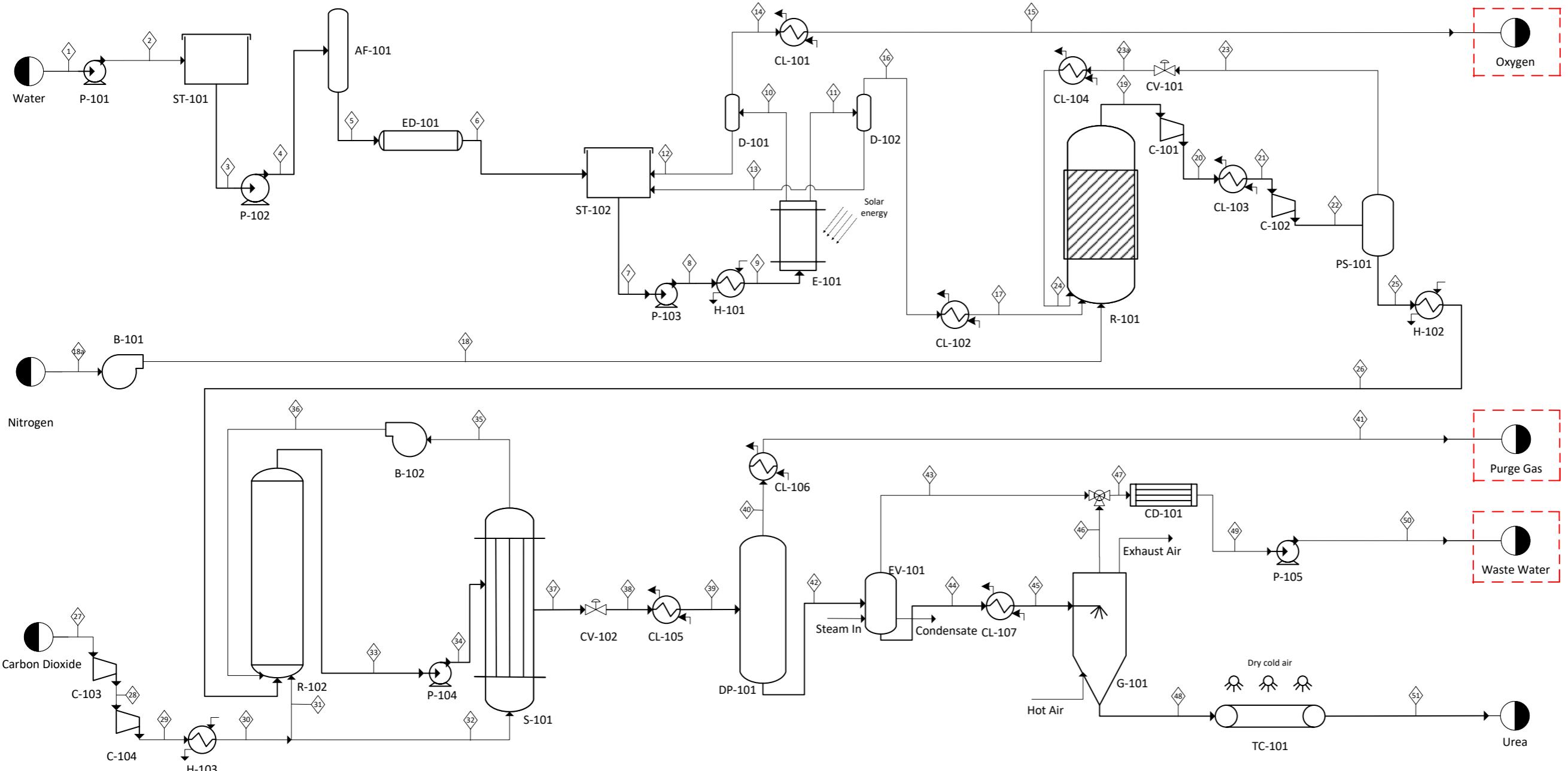
1. PM Noorhisham Tan Kofli
 2. Dr. Peer Mohamed
 3. Mr. Tan Chung Chuan
(Exxonmobil)

Group: K2

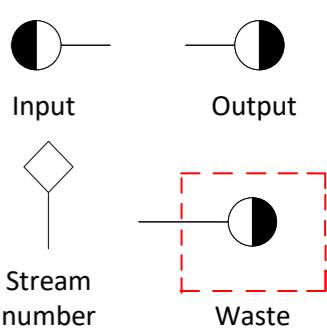
Group Members:

1. Azrul Zulhilmi bin Ahmad
Rosli
(A173752)
2. Nurzulaikha binti Zulkarnian
(A173895)
3. Nur Iffa binti Rizuan
(A173952)
4. Aerry Ting Wei Huan
(A174141)

5. Suriya Vathi A/P
Subramanian
(A174271)



Date: 5th June 2023



ST-101 Storage Tank	B-101 Blower	AF-101 Activated Carbon Filter	EV-101 Evaporator	C-101 Compressor	CL-107 Cooler	P-105 Pump	
P-101 Pump	H-101 Heater	ED-101 Electrodeionization modules	D-101 Demister	E-101 PEM Electrolyser	G-101 Granulator	CD-101 Condenser	
P-102 Pump	CL-105 Cooler	ST-102 Storage Tank	D-102 Demister	PS-101 Phase Separator	TC-101Conveyer	CL-102 Cooler	
R-102 Plug Flow Reactor	S-101 Stripper	P-104 Centrifugal Pump	CL-106 Cooler	R-101 Packed Bed Reactor	CL-103 Cooler	CL-104 Cooler	
C-103 Compressor	P-103 Pump	CV-102 Control Valve	DP-101 Decomposer	CL-101 Cooler	C-102 Compressor	C-104 Compressor	
		B-102 Blower	HE-101 Heat exchanger	HE-102 Heat exchanger	CV-101 Control valve		



Urea Synthesis Using Green Ammonia Technology

Coordinators:

1. Ir. Dr. Nor Yuliana Yuhana
 2. PM Dr. Mohd Shahbudin
Mastar@Masdar
 3. Dr. Muhammad Zulhaziman
Mat Salleh
 4. Dr. Nur Tantiyani Ali
Othman

Supervisors:

1. PM Noorhisham Tan Kofli
 2. Dr. Peer Mohamed
 3. Mr. Tan Chung Chuan
Exxonmobil)

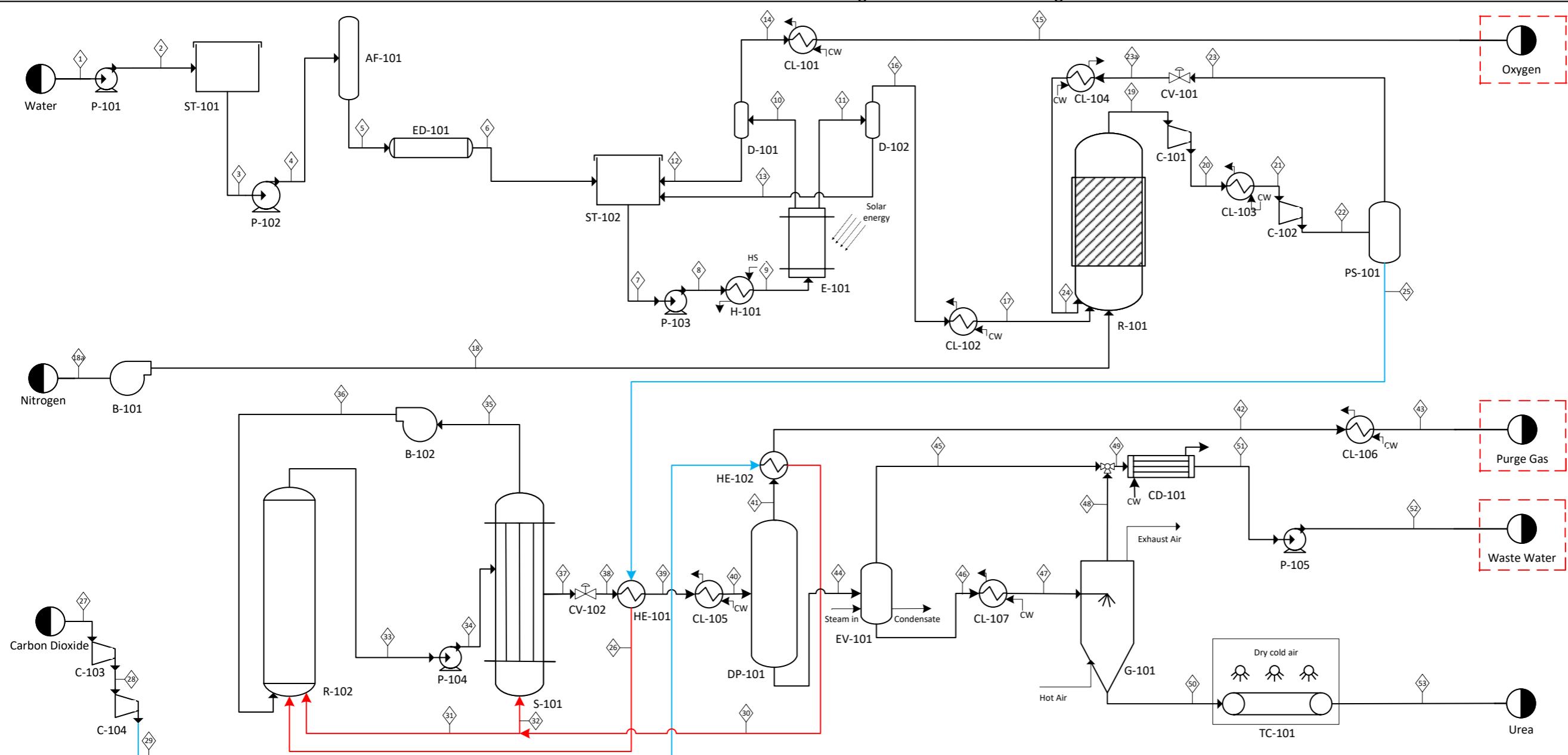
Group: K2

Group Members:

1. Azrul Zulhilmi bin Ahmad
Rolsi
(A173752)
2. Nurzulaikha binti Zulkarnia
(A173895)
3. Nur Iffa binti Rizuan
(A173952)

4. Aerry Ting Wei Huan
(A174141)

5. Suriya Vathi A/P
Subramanian
(A174271)



Date: 5th June 2023

ST-101 Storage Tank	B-101 Blower	AF-101 Activated Carbon Filter	EV-101 Evaporator	C-101 Compressor	CL-107 Cooler	P-105 Pump	
P-101 Pump	H-101 Heater	ED-101 Electrodeionization modules	D-101 Demister	E-101 PEM Electrolyser	G-101 Granulator	CD-101 Condenser	
P-102 Pump	CL-105 Cooler	ST-102 Storage Tank	D-102 Demister	PS-101 Phase Separator	TC-101Conveyer	CL-102 Cooler	
R-102 Plug Flow Reactor	S-101 Stripper	P-104 Centrifugal Pump	CL-106 Cooler	R-101 Packed Bed Reactor	CL-103 Cooler	CL-104 Cooler	
C-103 Compressor	P-103 Pump	CV-102 Control Valve	DP-101 Decomposer	CL-101 Cooler	C-102 Compressor	C-104 Compressor	
		B-102 Blower	HE-101 Heat exchanger	HE-102 Heat exchanger	CV-101 Control valve		

Coordinators:

1. Ir. Dr. Nor Yuliana Yuhana
2. PM Dr. Mohd Shahbudin Mastar@Masdar
3. Dr. Muhammad Zulhaziman Mat Salleh
4. Dr. Nur Tantiyani Ali Othman

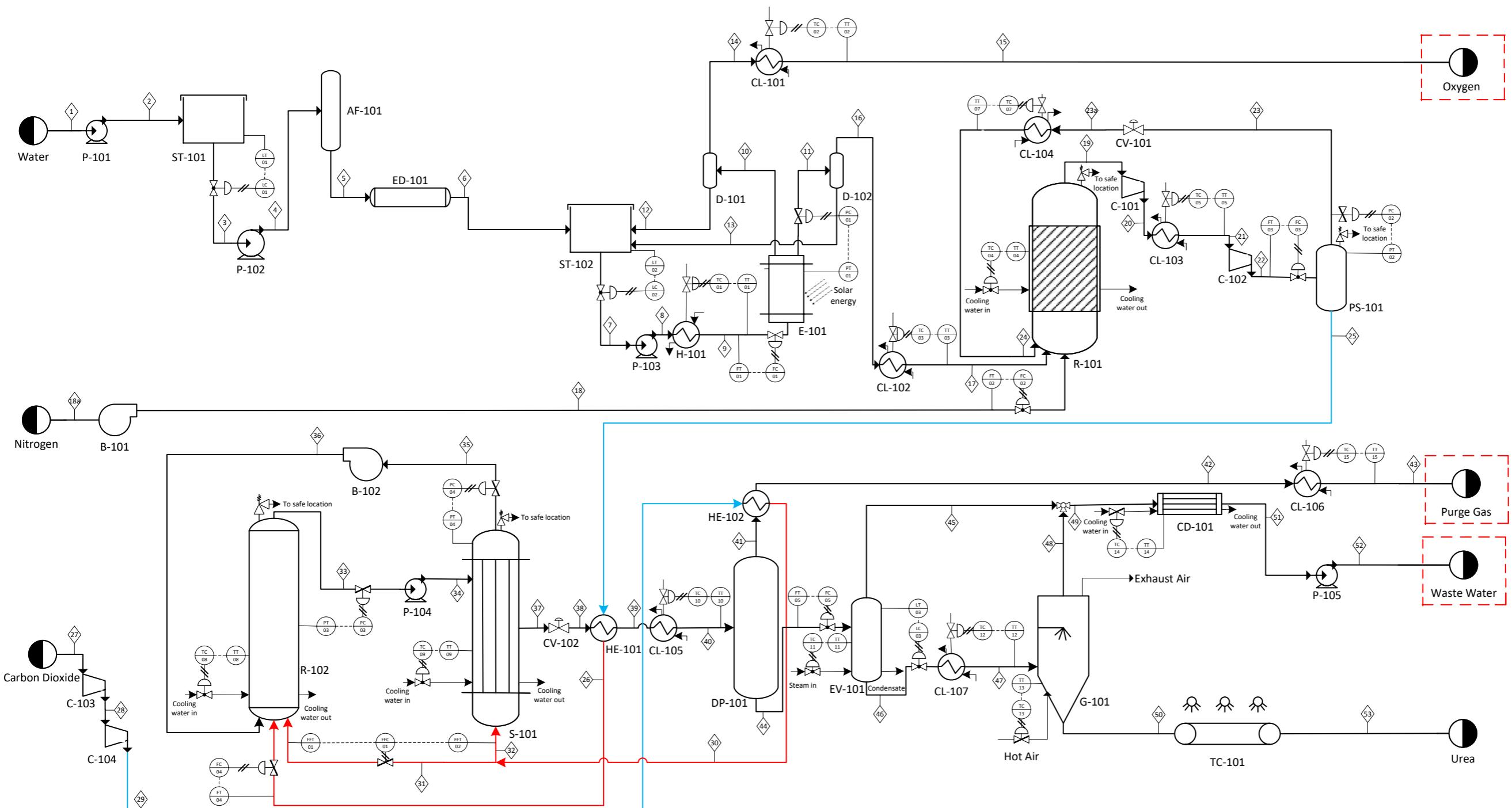
Supervisors:

1. PM Noorhisham Tan Kofli
2. Dr. Peer Mohamed
3. Mr. Tan Chung Chuan (Exxonmobil)

Group: K2

Group Members:

1. Azrul Zulhilmi bin Ahmad Rolsi (A173752)
2. Nurzulaikha binti Zulkarnian (A173895)
3. Nur Iffa binti Rizuan (A173952)
4. Aerry Ting Wei Huan (A174141)
5. Suriya Vathi A/P Subramanian (A174271)



Input Output Electrical signal
 Stream number Pneumatic signal Cold stream
 Hot stream

ST-101 Storage Tank	B-101 Blower	AF-101 Activated Carbon Filter	EV-101 Evaporator	C-101 Compressor	CL-107 Cooler	P-105 Pump	
P-101 Pump	H-101 Heater	ED-101 Electrodeionization modules	D-101 Demister	E-101 PEM Electrolyser	G-101 Granulator	CD-101 Condenser	
P-102 Pump	CL-105 Cooler	ST-102 Storage Tank	D-102 Demister	PS-101 Phase Separator	TC-101Conveyer	CL-102 Cooler	
R-102 Plug Flow Reactor	S-101 Stripper	P-104 Centrifugal Pump	CL-106 Cooler	R-101 Packed Bed Reactor	CL-103 Cooler	CL-104 Cooler	
C-103 Compressor	P-103 Pump	CV-102 Control Valve	DP-101 Decomposer	CL-101 Cooler	C-102 Compressor	C-104 Compressor	
		B-102 Blower	HE-101 Heat exchanger	HE-102 Heat exchanger	CV-101 Control valve		

Piping and Instrumentation Diagram
(P&ID) After HAZOP- Urea Synthesis
Using Green Ammonia Technology

Coordinators:

1. Ir. Dr. Nor Yuliana Yuhana
2. PM Dr. Mohd Shahbudin Mastar@Masdar
3. Dr. Muhammad Zulhaziman Mat Salleh
4. Dr. Nur Tantiyani Ali Othman

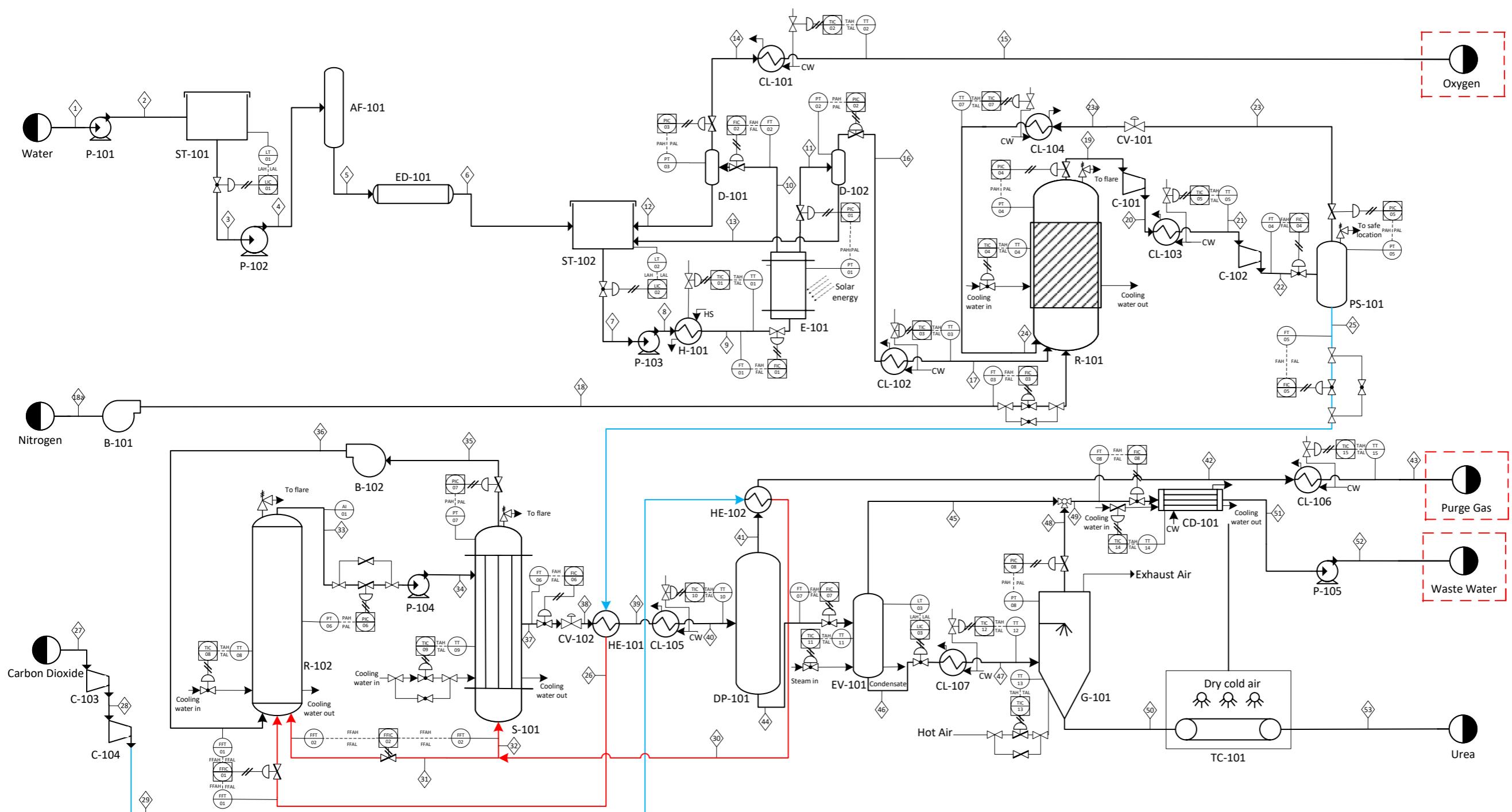
Supervisors:

1. PM Noorhisham Tan Kofli
2. Dr. Peer Mohamed
3. Mr. Tan Chung Chuan (Exxonmobil)

Group: K2

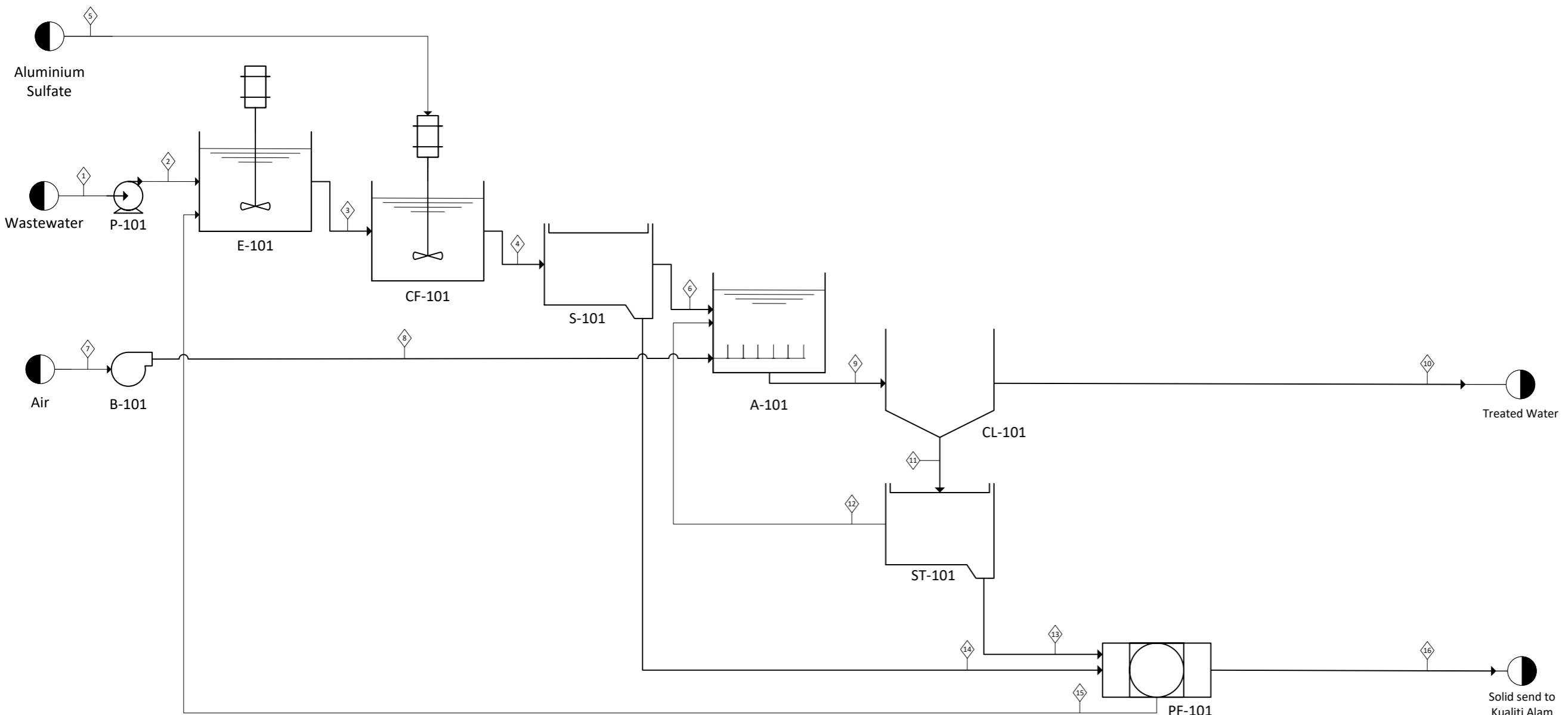
Group Members:

1. Azrul Zulhilmi bin Ahmad Rolsi (A173752)
2. Nurzulaikha binti Zulkarnian (A173895)
3. Nur Iffa binti Rizuan (A173952)
4. Aerry Ting Wei Huan (A174141)
5. Suriya Vathi A/P Subramanian (A174271)



Input Output Electrical signal
 Stream number Pneumatic signal Cold stream
 Hot stream

P-101 Pump	E-101 Equalization Tank	CF-101 Coagulation and Flocculation Tank	A-101 Aeration Tank	CL-101 Clarifier
B-101 Blower	S-101 Sedimentation Tank	ST-101 Sludge Thickening	PF-101 Press Filter	



Wastewater Treatment Plant

Coordinators:

1. Ir. Dr. Nor Yuliana Yuhana
2. PM Dr. Mohd Shahbudin Mastar@Masdar
3. Dr. Muhammad Zulhaziman Mat Salleh
4. Dr. Nur Tantiyani Ali Othman

Supervisors:

1. PM Noorhisham Tan Kofli
2. Dr. Peer Mohamed
3. Mr. Tan Chung Chuan (Exxonmobil)

Group: K2

Group Members:

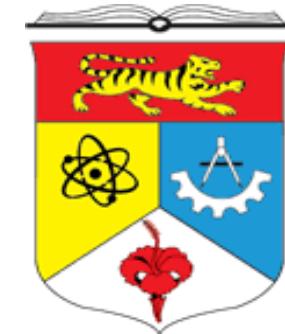
1. Azrul Zulhilmi bin Ahmad Rolsi (A173752)
2. Nurzulaikha binti Zulkarnian (A173895)
3. Nur Iffa binti Rizuan (A173952)
4. Aerry Ting Wei Huan (A174141)
5. Suriya Vathi A/P Subramanian (A174271)



Stream number

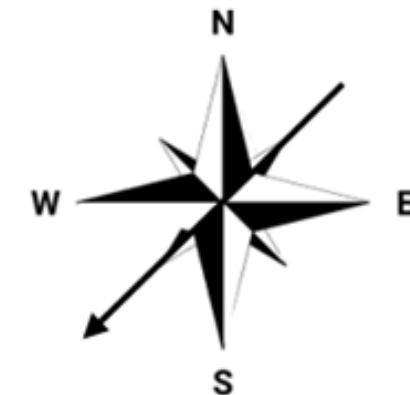
Date: 13th January 2023

Stream	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
BOD (mg/L)	1056	1056	739.2	591.36	0	414	0	0	20.7	12.42	12.42	0	11.18	0	10.06	10.06
COD (mg/L)	3520	3520	2464	1971.1	0	1379.84	0	0	68.99	41.394	41.39	0	37.25	0	33.53	33.53
SS (mg/L)	180	180	180	180	0	63	0	0	18.9	3.78	3.74	0	3.02	117	2.57	2.57
Flowrate (kg/h)	773.39	773.39	798.52	808.52	10	777.51	20.03	20.03	812.65	709.96	102.69	15.11	87.58	31.03	25.13	93.48



DESCRIPTION
PLANT LAYOUT

WIND DIRECTION

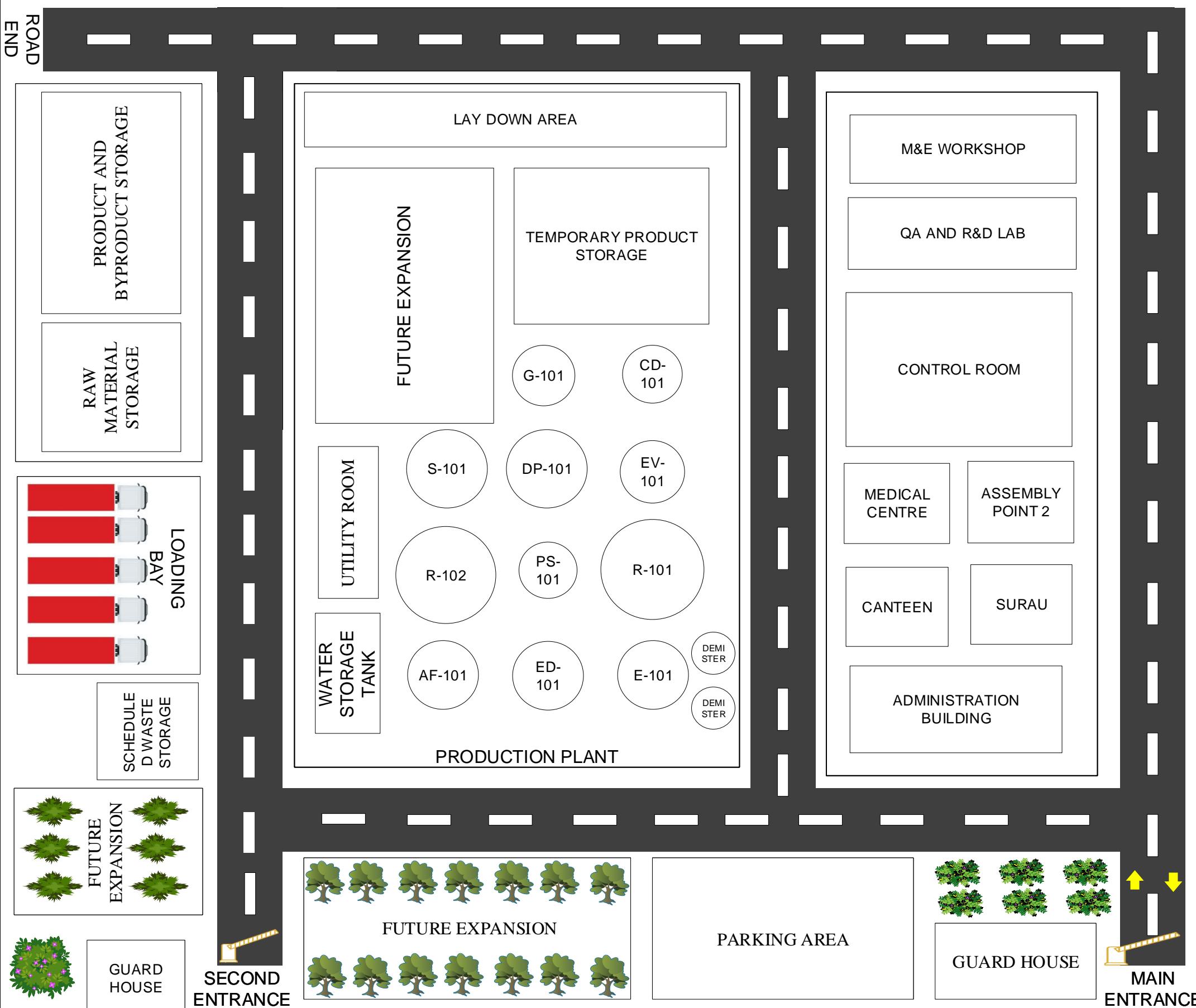
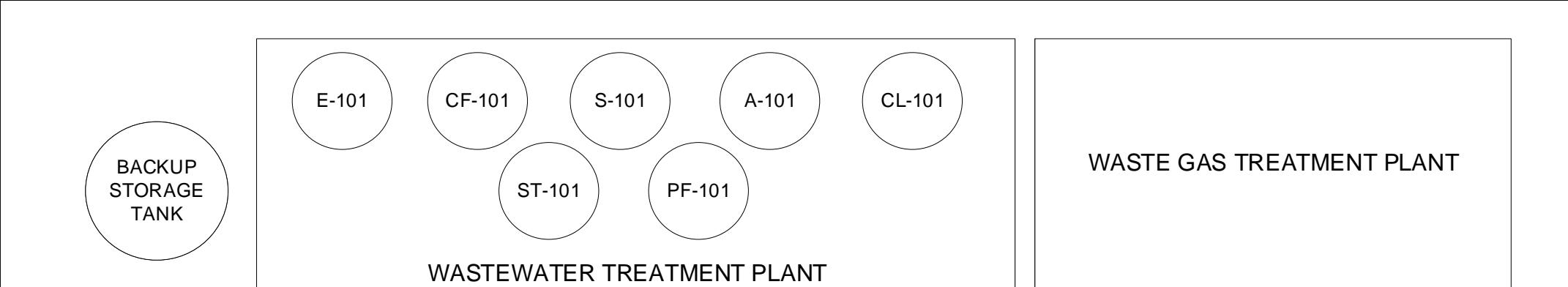


SUPERVISORS:

1. PM NOORHISYAM TAN KOFLI
2. DR. PEER MOHAMED
3. MR.TAN CHUNG CHUAN

GROUP MEMBERS

1. AZRUL ZULHILMI BIN AHMAD ROLSI (A173752)
2. NURZULAIKAH BINTI ZULKARNIAN (A173895)
3. NUR IFFA BINTI RIZUAN (A173952)
4. AERRY TING WEI HUAN (A174141)
5. SURIYA VATHI A/P SUBRAMANIAN (A174271)



APPENDIX C

INDUSTRIAL SAFETY

Hazard and Operability Study (HAZOP)

The HAZOP studies are conducted on the major equipment in the plant which includes electrolyser (E-101), catalytic packed bed reactor (R-101), phase separator (PS-101), plug flow reactor (R-102), and stripper (S-101).

a. **Electrolyser, E-101**

Electrolyser is used in order to get hydrogen gas from the water. The hydrogen gas produced will be used as one of the reactant in the ammonia synthesis. The oxygen gas from the electrolysis is a by product and will be sell. The operating condition for the electrolyser is 80°C and 15 bar.

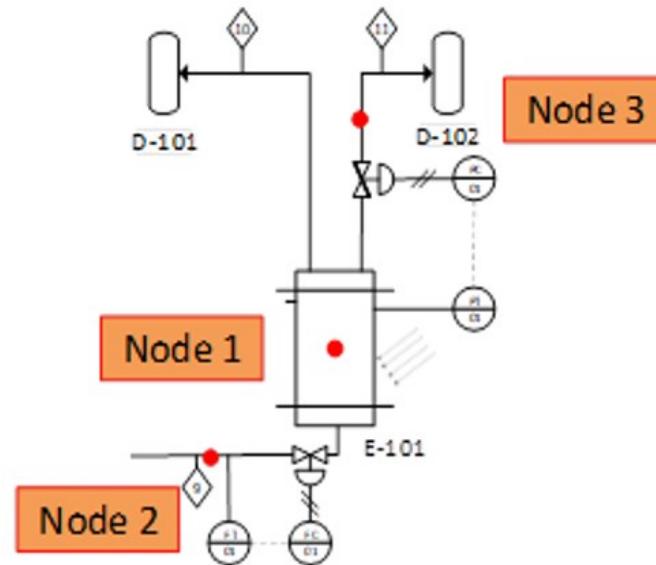


Figure 1 HAZOP study on electrolyser, E-101

Table 1 HAZOP study on E-101 at node 1

HAZARD AND OPERABILITY STUDY REPORT						
PROJECT TITLE: HAZOP of an electrolyser						
Project Number: Electrolyser		Date: 05 January 2023				
Drawing Number: E-101		Chairman: Nur Iffa binti Rizuan,				
Node: Node No 1		Study Team: Azrul Zulhilmi bin Ahmad Rosli, Nurzulaikha binti Zulkarnian, Aerry Ting Wei Huan, Suriya Vathi A/P Subramanian				
Item: Electrolyser						
Parameter	GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED

Pressure	HIGH	High pressure inside the electrolyser	<ul style="list-style-type: none"> Relief valve failed to close Outlet pipeline blockage 	<ul style="list-style-type: none"> Explosion of electrolyser occurred. The pipeline of the electrolyser rupture. 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Installed high pressure alarm.
	LOW	Low pressure inside the electrolyser	<ul style="list-style-type: none"> Relief valve failed open 	<ul style="list-style-type: none"> Oxygen and hydrogen gas cannot be obtained as it does not reach optimum pressure. 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Install low pressure alarm.
Temperature	HIGH	High temperature inside the electrolyser	<ul style="list-style-type: none"> Faulty of temperature controller (TC) at heat exchanger, H-101 	<ul style="list-style-type: none"> Product does not meet specification. 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Installed high temperature alarm
	LOW	Low temperature inside the electrolyser	<ul style="list-style-type: none"> Faulty of temperature controller (TC) at heat exchanger, H-101 	<ul style="list-style-type: none"> Product does not meet specification. 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Install low temperature alarm.

Table 2 HAZOP study on E-101 at node 2

HAZARD AND OPERABILITY STUDY REPORT					
PROJECT TITLE: HAZOP of an electrolyser					
Project Number: Electrolyser		Date: 05 January 2023			
Drawing Number: E-101		Chairman: Nur Iffa binti Rizuan,			
Node: Node No 2		Study Team: Azrul Zulhilmi bin Ahmad Rosli, Nurzulaikha binti Zulkarnian, Aerry Ting Wei Huan, Suriya Vathi A/P Subramanian			
Item: Inlet electrolyser at stream 9		Parameter: Flowrate			
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED

MORE	High flowrate into electrolyser	<ul style="list-style-type: none"> Valve at stream 9 failed open 	<ul style="list-style-type: none"> Electrolyser overflow 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Installed high level alarm
LESS	Low flow rate into electrolyser	<ul style="list-style-type: none"> Valve at stream 9 partially blocked Valve leaked Pipe leak 	<ul style="list-style-type: none"> Less hydrogen and oxygen gas will be formed 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Installed low level alarm.
NO	No flow inside the electrolyser	<ul style="list-style-type: none"> Blockage at pipeline Rupture at pipeline Rupture at storage ST-102 	<ul style="list-style-type: none"> No production of hydrogen and oxygen gas 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance Installed flow indicator

Table 3 HAZOP study on E-101 at node 3

HAZARD AND OPERABILITY STUDY REPORT					
PROJECT TITLE: HAZOP of an electrolyser					
Project Number: Electrolyser		Date: 05 January 2023			
Drawing Number: E-101		Chairman: Nur Iffa binti Rizuan,			
Node: Node No 3		Study Team: Azrul Zulhilmi bin Ahmad Rosli, Nurzulaikha binti Zulkarnian, Aerry Ting Wei Huan, Suriya Vathi A/P Subramanian			
Item: Outlet electrolyser at stream 11		Parameter: Flowrate			
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED
MORE	High flowrate out from the electrolyser	<ul style="list-style-type: none"> High pressure of the electrolyser 	<ul style="list-style-type: none"> High flowrate of hydrogen to the catalytic packed bed reactor, R-101 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Installed high level alarm
LESS	Low flow rate out from the electrolyser	<ul style="list-style-type: none"> Pipe leak 	<ul style="list-style-type: none"> Less flowrate of hydrogen to the R-101 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Install low level alarm.
NO	No flow out from the electrolyser	<ul style="list-style-type: none"> Blockage at pipeline 	<ul style="list-style-type: none"> No flowrate of hydrogen to the R-101 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance

		<ul style="list-style-type: none"> • Rupture at pipeline • Rupture at electrolyser 		<ul style="list-style-type: none"> • Installation flow indicator
--	--	--	--	---

b. Catalytic Packed Bed Reactor, R-101

Catalytic packed bed reactor (R-101) is designed to undergo the reaction between nitrogen and hydrogen gas to produce ammonia gas. The unreacted nitrogen and hydrogen gas will be recycled back to R-101 after it has undergone phase separation at PS-101. The operating condition at R-101 is 28 °C and 1 bar and the catalyst used is nanocatalyst manganese zinc ferrate.

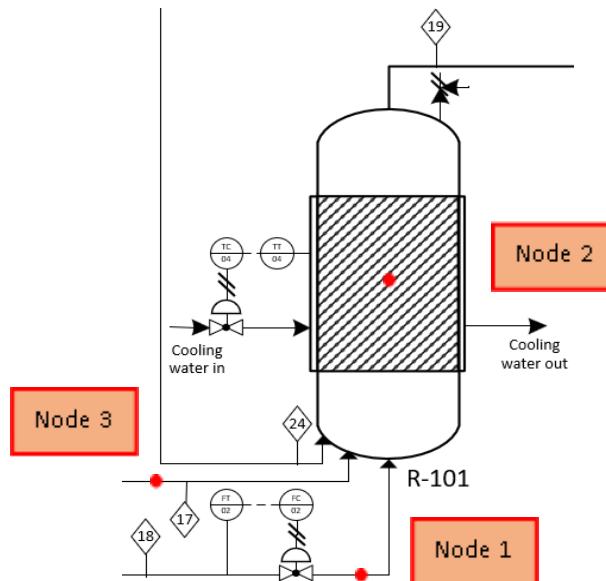


Figure 2 HAZOP study on Catalytic Packed Reactor, R-101

Table 4 HAZOP study on R-101 at node 1

HAZARD AND OPERABILITY STUDY REPORT					
PROJECT TITLE: HAZOP of a catalytic packed bed reactor					
Project Number: Catalytic Packed Bed Reactor		Date: 05 January 2023			
Drawing Number: R-101		Chairman: Nurzulaikha binti Zulkarnain			
Node: Node No 1		Study Team: Azrul Zulhilmi bin Ahmad Rosli, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Suriya Vathi A/P Subramanian			
Item: Inlet R-101 at stream 18		Parameter: Flowrate			
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED
MORE	High flowrate into catalytic packed bed reactor	<ul style="list-style-type: none"> Valve at stream 18 failed opened 	<ul style="list-style-type: none"> Catalytic packed bed reactor overflow 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Installed high level alarm
LESS	Low flow rate into catalytic packed bed reactor	<ul style="list-style-type: none"> Valve at stream 18 partially blocked Valve leaked Pipe leakage 	<ul style="list-style-type: none"> R-101 takes longer time to fill up and reaction process become longer Production rate of desired product become slower 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Installed low level alarm.
NO	No flow inside the catalytic packed bed reactor	<ul style="list-style-type: none"> Valve failed closed Blockage at pipeline Rupture at pipeline 	<ul style="list-style-type: none"> Reaction process cannot occur and no production of ammonia 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance Installed flow indicator

Table 5 HAZOP study on R-101 at node 2

HAZARD AND OPERABILITY STUDY REPORT		
PROJECT TITLE: HAZOP of a catalytic packed bed reactor		
Project Number: Catalytic Packed Bed Reactor		Date: 05 January 2023
Drawing Number: R-101		Chairman: Nurzulaikha binti Zulkarnain
Node: Node No 2		Study Team: Azrul Zulhilmi bin Ahmad Rosli, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Suriya Vathi A/P Subramanian

Item: Catalytic Packed Bed Reactor				Parameter: Temperature, Pressure		
Parameter	GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED
Pressure	MORE	High pressure inside R-101	<ul style="list-style-type: none"> Relief valve failed closed Outlet pipeline blockage 	<ul style="list-style-type: none"> Explosion and rupture of R-101 occurred. 	Pressure relief valve	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Install high pressure alarm. Install pressure indicator
	LESS	Low pressure inside R-101	<ul style="list-style-type: none"> Relief valve failed opened 	<ul style="list-style-type: none"> Ammonia cannot be obtained as it does not reach optimum pressure. Low reaction efficiency 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Install low pressure alarm.
Temperature	MORE	High temperature inside R-101	<ul style="list-style-type: none"> Valve of cooling water in failed closed Low cooling water flowrate into R-101 	<ul style="list-style-type: none"> Overheating in the R-101 causing overpressure and may lead to explosion 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Installed high temperature alarm
	LESS	Low temperature inside R-101	<ul style="list-style-type: none"> Valve of cooling water in failed opened High cooling water flowrate into R-101 	<ul style="list-style-type: none"> Product does not meet specification. 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Install low temperature alarm.

Table 6 HAZOP study on R-101 at node 3

HAZARD AND OPERABILITY STUDY REPORT	
PROJECT TITLE: HAZOP of a catalytic packed bed reactor	
Project Number: Catalytic Packed Bed Reactor	Date: 05 January 2023
Drawing Number: R-101	Chairman: Nurzulaikha binti Zulkarnain

Node: Node No 3			Study Team: Azrul Zulhilmi bin Ahmad Rosli, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Suriya Vathi A/P Subramanian		
Item: Inlet R-101 at stream 17			Parameter: Flowrate		
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED
MORE	High flowrate of hydrogen into catalytic packed bed reactor	<ul style="list-style-type: none"> No suitable valve and controller 	<ul style="list-style-type: none"> Catalytic packed bed reactor overflow 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Installed high level alarm Install flowrate indicator
LESS	Low flow rate of hydrogen into catalytic packed bed reactor	<ul style="list-style-type: none"> Pipe leakage Pipe partially blocked 	<ul style="list-style-type: none"> R-101 takes longer time to fill up and reaction process become longer Production rate of desired product become slower 	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance. Installed low level alarm. Install flowrate indicator
NO	No flowrate of hydrogen into the catalytic packed bed reactor	<ul style="list-style-type: none"> Blockage at pipeline Rupture at pipeline 	Reaction process cannot occur and no production of ammonia	None	<ul style="list-style-type: none"> Scheduled inspection and maintenance Installed flowrate indicator

c. **Phase Separator, PS-101**

Phase separator (PS-101) is designed to undergo liquid-gas separation process whereby the separated gas will be recycled back to catalytic packed bed reactor (R-101) and liquid product will be channelled to next unit operation. There are 4 study node on PS-101 which are inlet stream 1, outlet stream 3 and 2, and inside the phase separator. Figure show the HAZOP study nodes on reactor PS-101.

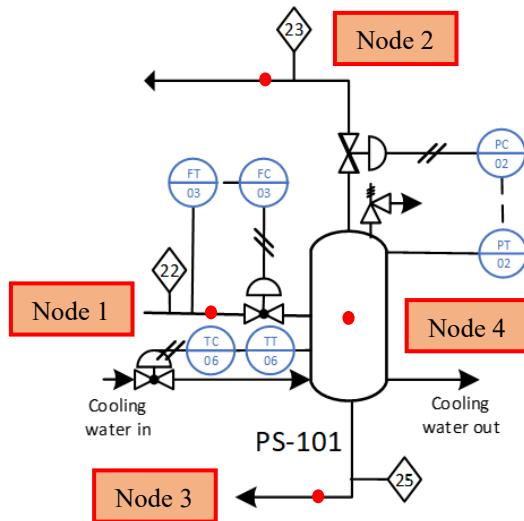


Figure 3 HAZOP study on Phase Separator, PS-101

Table 7 HAZOP study on PS-101 at Node 1

HAZARD AND OPERABILITY STUDY REPORT					
Project Title: HAZOP of a phase separator					
Project Number: Phase Separator		Date: 05 January 2023			
Drawing Number: PS-101		Chairman: Aerry Ting Wei Huan			
Node: Node No. 1		Study Team: Azrul Zulhilmi bin Ahmad Rosli, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Suriya Vathi A/P Subramanian			
Item: Inlet stream 22		Parameter: Flow			
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED

NO	<ul style="list-style-type: none"> ▪ No flow rate feed into PS-101 	<ul style="list-style-type: none"> ▪ Valve failed closed ▪ Pipe blocked ▪ Rupture of pipe 	<ul style="list-style-type: none"> ▪ Separation process cannot carry out due to no component inside PS-101 	<ul style="list-style-type: none"> ▪ Low level alarm 	<ul style="list-style-type: none"> ▪ Scheduled inspection and maintenance ▪ Install level indicator
LESS	<ul style="list-style-type: none"> ▪ Low flow rate feed into PS-101 	<ul style="list-style-type: none"> ▪ Valve partially blocked ▪ Valve leaked ▪ Pipe leakage 	<ul style="list-style-type: none"> ▪ PS-101 takes longer time to fill up and the separation process become longer ▪ Production rate of desired product become slower 	<ul style="list-style-type: none"> ▪ None 	<ul style="list-style-type: none"> ▪ Scheduled inspection and maintenance
MORE	<ul style="list-style-type: none"> ▪ High flow rate feed into PS-101 	<ul style="list-style-type: none"> ▪ Valve failed opened 	<ul style="list-style-type: none"> ▪ Phase separator overflow ▪ Pressure could build up in PS-101 and could cause leakage or explosion 	<ul style="list-style-type: none"> ▪ High level alarm ▪ Level controller 	<ul style="list-style-type: none"> ▪ Scheduled inspection and maintenance ▪ Install level indicator

Table 8 HAZOP study on PS-101 at Node 2

HAZARD AND OPERABILITY STUDY REPORT					
Project Title: HAZOP of a phase separator					
Project Number: Phase Separator		Date: 05 January 2023			
Drawing Number: PS-101		Chairman: Aerry Ting Wei Huan			
Node: Node No. 2		Study Team: Azrul Zulhilmi bin Ahmad Rosli, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Suriya Vathi A/P Subramanian			
Item: Outlet stream 23		Parameter: Flow			
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED
NO	<ul style="list-style-type: none"> ▪ No product flow from the top outlet 	<ul style="list-style-type: none"> ▪ Valve failed closed ▪ Outlet pipe blocked ▪ Rupture of pipe 	<ul style="list-style-type: none"> ▪ High pressure builds up in S-102 ▪ Phase separator rupture ▪ Leakage of gas product to surrounding 	<ul style="list-style-type: none"> ▪ High level alarm 	<ul style="list-style-type: none"> ▪ Scheduled inspection and maintenance ▪ Installation of bypass stream
LESS	<ul style="list-style-type: none"> ▪ Low flow rate of the top outlet product 	<ul style="list-style-type: none"> ▪ Valve partially blocked ▪ Valve leaked 	<ul style="list-style-type: none"> ▪ Leaking of gas product to surrounding ▪ Less product is discharged 	<ul style="list-style-type: none"> ▪ None 	<ul style="list-style-type: none"> ▪ Scheduled inspection and maintenance ▪ Installation of bypass stream

		▪ Outlet pipe leakage			
MORE	▪ High flow rate of the top outlet product	▪ Valve failed opened	▪ Excess product is discharged ▪ Pressure in PS-101 decreases	▪ Low level alarm	▪ Scheduled inspection and maintenance ▪ Installation of bypass stream

Table 9 HAZOP study on PS-101 at Node 3

HAZARD AND OPERABILITY STUDY REPORT					
Project Title: HAZOP of a phase separator					
Project Number: Phase Separator		Date: 05 January 2023			
Drawing Number: PS-101		Chairman: Aerry Ting Wei Huan			
Node: Node No. 3		Study Team: Azrul Zulhilmi bin Ahmad Rosli, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Suriya Vathi A/P Subramanian			
Item: Outlet stream 25		Parameter: Flow			
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED
NO	▪ No product flow from the bottom outlet	▪ Outlet pipe blocked ▪ Rupture of pipe	▪ High pressure builds up in S-102 ▪ Phase separator rupture ▪ Leakage of liquid product to surrounding ▪ Level of phase separator increase, causing overflow in phase separator	▪ High level alarm	▪ Scheduled inspection and maintenance ▪ Installation of bypass stream
LESS	▪ Low flow rate of the bottom outlet product	▪ Outlet pipe partially blocked ▪ Outlet pipe leakage	▪ Leaking of liquid product to surrounding ▪ Less product is discharged	▪ None	▪ Scheduled inspection and maintenance ▪ Installation of bypass stream

Table 10 HAZOP study on PS-101 at Node 4

HAZARD AND OPERABILITY STUDY REPORT					
--	--	--	--	--	--

Project Title: HAZOP of a phase separator						
Project Number: Phase Separator		Date: 05 January 2023				
Drawing Number: PS-101		Chairman: Aerry Ting Wei Huan				
Node: Node No. 4		Study Team: Azrul Zulhilmi bin Ahmad Rosli, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Suriya Vathi A/P Subramanian				
Item: Phase separator		Parameter: Temperature, Pressure				
PARAMETER	GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED
Temperature	LESS	▪ Low temperature inside PS-101	▪ Valve of cooling water stream failed opened ▪ High cooling water flow rate into PS-101	▪ Product quality does not meet requirement	▪ Temperature controller	▪ Scheduled inspection and maintenance ▪ Installation of temperature indicator ▪ Installation of low temperature alarm
	MORE	▪ High temperature inside PS-101	▪ Valve of cooling water stream failed closed ▪ Low cooling water flow rate into PS-101	▪ Overheating in the phase separator, causing overpressure ▪ May lead to explosion	▪ Temperature controller	▪ Scheduled inspection and maintenance ▪ Installation of temperature indicator ▪ Installation of high temperature alarm
Pressure	LESS	▪ Low pressure inside PS-101	▪ Top outlet valve failed opened ▪ Valve partially blocked	▪ Low separation efficiency ▪ Production rate of desired product become slower ▪ Backflow of gas product back to PS-101	▪ Pressure controller	▪ Scheduled inspection and maintenance ▪ Installation of pressure indicator ▪ Installation of low pressure alarm
	MORE	▪ High pressure inside PS-101	▪ Top outlet valve failed closed	▪ High pressure builds up in PS-101 and could cause leakage or explosion	▪ Pressure controller	▪ Scheduled inspection and maintenance

				<ul style="list-style-type: none">▪ Phase separator rupture	<ul style="list-style-type: none">▪ Pressure relief valve	<ul style="list-style-type: none">▪ Installation of pressure indicator▪ Installation of high pressure alarm
--	--	--	--	---	---	--

d. Plug Flow Reactor, R-102

Ammonia from phase separator (PS-101) and carbon dioxide will enter the plug flow reactor and it will be compress and heating up to 180°C and 140 bar. There are 2 study node on R-102 which are inlet stream 26 and inside the reactor. Figure show the HAZOP study nodes on reactor R-102.

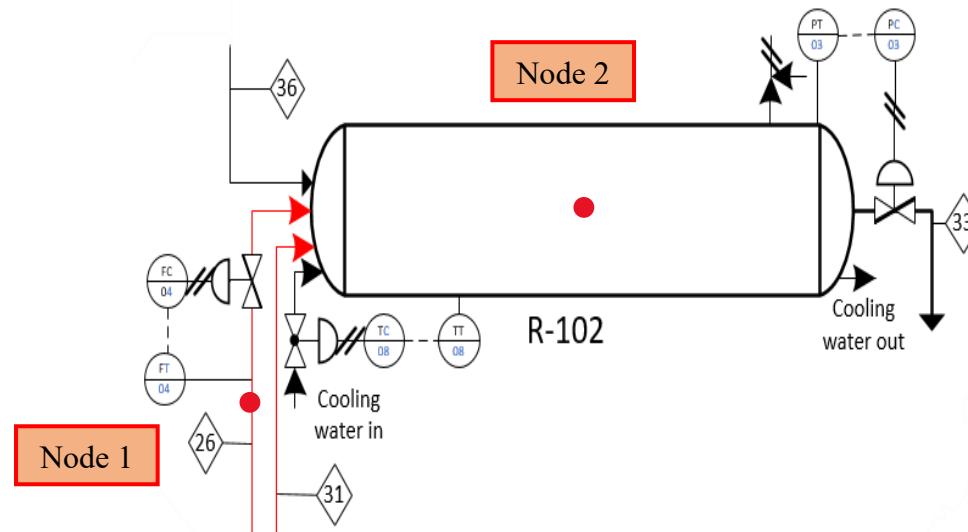


Figure 4 HAZOP study on Plug Flow Reactor, R-102

Table 11 HAZOP study on R-102 at node 1

HAZARD AND OPERABILITY STUDY REPORT					
Project Title: HAZOP of a urea reactor					
Project Number: Urea Reactor		Date: 05 January 2023			
Drawing Number: R-102		Chairman: Suriya Vathi A/P Subramanian			
Node: Node No. 1		Study Team: Azrul Zulhilmi bin Ahmad Rosli, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Aerry Ting Wei Huan			
Item: Inlet stream 26		Parameter: Flow			
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED
NO	No flow of ammonia gas into the reactor	<ul style="list-style-type: none"> • Complete blockage of inlet pipeline 	<ul style="list-style-type: none"> • No feed in the R-102 	<ul style="list-style-type: none"> • Flow controller 	<ul style="list-style-type: none"> • Scheduled inspection and maintenance on every pipe

		<ul style="list-style-type: none"> Inlet pipeline rupture Not enough ammonia supply 	<ul style="list-style-type: none"> No reaction will take place, product will not form Process plant cannot proceed 		<ul style="list-style-type: none"> Install flow controller Install low flow alarm
LESS	Less flow of ammonia gas into the reactor	<ul style="list-style-type: none"> Inlet pipeline leak Clogged in inlet pipeline Pipe partially blocked 	<ul style="list-style-type: none"> Insufficient feed into the reactor Efficiency of reaction occur is low Reaction fails to form product Less production will occur 	<ul style="list-style-type: none"> Flow controller 	<ul style="list-style-type: none"> Scheduled inspection and maintenance on every pipe Install flow controller Install low flow alarm
MORE	High feed flow rate of ammonia gas into the reactor	Flowrate input too high	<ul style="list-style-type: none"> Pressure in reactor could build up and could cause explosion Ammonia may leak into the plant Overflow and spillage of containment 	<ul style="list-style-type: none"> Pressure Relief Valve Flow controller 	<ul style="list-style-type: none"> Schedule inspection and maintenance regularly Install high flow alarm

Table 12 HAZOP study on R-102 at node 2

HAZARD AND OPERABILITY STUDY REPORT					
Project Title: HAZOP of a urea reactor					
Project Number: Urea Reactor		Date: 05 January 2023			
Drawing Number: R-102		Chairman: Suriya Vathi A/P Subramanian			
Node: Node No. 2		Study Team: Azrul Zulhilmi bin Ahmad Rosli, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Aerry Ting Wei Huan			
Item: Plug Flow Reactor (PFR)		Parameter: Temperature			
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED

LOW	Low temperature in the reactor , R-102	<ul style="list-style-type: none"> Temperature valve leaked Temperature valve failed opened 	<ul style="list-style-type: none"> Temperature inside the column drop Reaction rate is low due to insufficient operating condition. 	Temperature controller Temperature transmitter	<ul style="list-style-type: none"> Scheduled inspection and maintenance Installation of temperature sensor and low temperature alarm
HIGH	High temperature inside reactor, R-102	<ul style="list-style-type: none"> Temperature valve failed opened 	<ul style="list-style-type: none"> Reactor could overheat Reactor pressure may increase Reactant or product may decompose to unwanted chemicals 	Temperature controller Temperature transmitter	<ul style="list-style-type: none"> Regular inspection and maintenance of the reactor heating jacket Installation of temperature sensor and high temperature alarm Installation of emergency shutdown system

Table 13 HAZOP study on R-102 at node 3

HAZARD AND OPERABILITY STUDY REPORT								
Project Title: HAZOP of a urea reactor								
Project Number: Urea Reactor		Date: 05 January 2023						
Drawing Number: R-102		Chairman: Suriya Vathi A/P Subramanian						
Node: Node No. 2		Study Team: Azrul Zulhilmi bin Ahmad Rosli, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Aerry Ting Wei Huan						
Item: Plug Flow Reactor (PFR)		Parameter: Pressure						
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED			
LOW	Low pressure inside reactor	<ul style="list-style-type: none"> Pipe leak around reactor Fouling of pipeline of reactant Compressors fail to operate 	<ul style="list-style-type: none"> Product produced have low quality or purity Reactor damaged by external pressure Pressure controller and transmitter will be triggered 	Pressure controller Pressure transmitter	<ul style="list-style-type: none"> Install low pressure alarm Regular inspection and maintenance Install bypass pipelines 			

HIGH	High pressure inside reactor	<ul style="list-style-type: none"> • Pressure valve failed closed. • Overheating of reactor • Pressure transmitter failed 	<ul style="list-style-type: none"> • Reactor become highly pressurized and may rupture or explode 	Pressure relief valve Pressure controller	<ul style="list-style-type: none"> • Install high pressure alarm to alert operator so that emergency shutdown system can be activated. • Scheduled inspection and maintenance
------	------------------------------	--	--	--	---

e. **Stripper, S-101**

Ammonium carbamate, ammonia, carbon dioxide, and urea from plug flow reactor, R-102 will enter the stripper and it will be decompose and heating up to 180°C and 140 bar. There are 6 study node on S-101 which are inlet stream 34 and 32, outlet stream 35 and 37, and inside the stripper.HAZOP study on Stripper, S-101 show the HAZOP study nodes on reactor S-101.

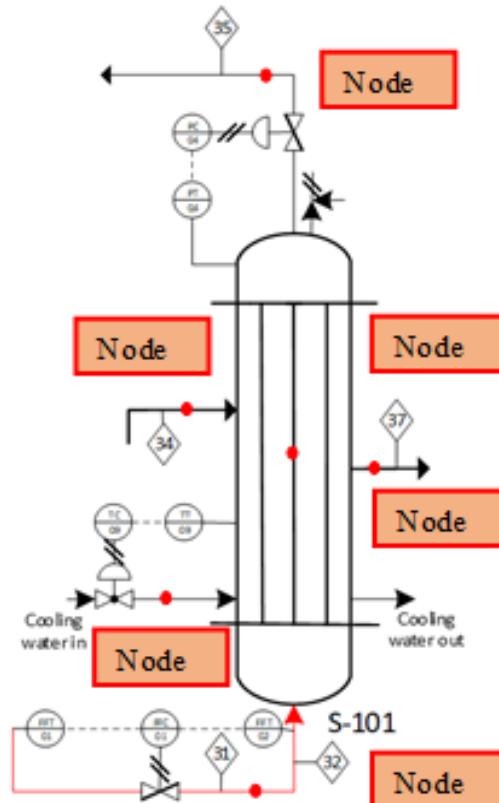


Figure 5 HAZOP study on Stripper, S-101

Table 14 HAZOP study on S-101 at node 1

HAZARD AND OPERABILITY STUDY REPORT	
PROJECT TITLE: HAZOP of a stripper	
Project Number: Stripper	Date: 05 January 2023
Drawing Number: S-101	Chairman: Azrul Zulhilmi bin Ahmad Rosli

Node: Node No 1				Study Team: Aerry Ting Wei Huan, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Suriya Vathi A/P Subramanian		
Item: In Stripper						
Parameter	GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED
Pressure	HIGH	High pressure inside in stripper	<ul style="list-style-type: none"> Valve (top) failed to close Pipe blockage 	Rupture of stripper and explosion occur due to high pressure exist inside the stripper Lead to injury and death	Pressure controller	<ul style="list-style-type: none"> Scheduled maintenance and inspection Install by-pass valve Install pressure indicator Install high pressure alarm
	LOW	Low pressure inside in stripper	<ul style="list-style-type: none"> Valve (top) failed to open Pipe ruptured or leakage 	<ul style="list-style-type: none"> Low efficiency of separation process Leakage of hazardous gaseous 	Pressure controller	<ul style="list-style-type: none"> Scheduled maintenance and inspection Install by-pass valve Install pressure indicator Install low pressure alarm
Temperature	HIGH	High temperature inside the stripper	<ul style="list-style-type: none"> Valve (cw) failed to close 	<ul style="list-style-type: none"> Less cooling water flows through stripper The temperature of stripper is high due to cooling down process slowly Overheating occurs in stripper and cause a fire or explosion Lead to injury and death 	Temperature controller	<ul style="list-style-type: none"> Scheduled maintenance and inspection Install by-pass valve Install temperature indicator Install high temperature alarm

	LOW	Low temperature inside the stripper	<ul style="list-style-type: none"> • Valve (cw) failed to open 	<ul style="list-style-type: none"> • High cooling water flows through stripper • The temperature of stripper is low due to cooling down process quickly • Optimum reaction temperature cannot be achieved • Low efficiency of separation process 	Temperature controller	<ul style="list-style-type: none"> • Scheduled maintenance and inspection • Install by-pass valve • Install temperature indicator • Install low temperature alarm
Flow	HIGH	High flow enters stripper	<ul style="list-style-type: none"> • Valve failed to open 	<ul style="list-style-type: none"> • Overflow of stripper occur • Overflow cause a fire to occur 	• Flow controller	<ul style="list-style-type: none"> • Scheduled maintenance and inspection • Install by-pass valve • Install flow indicator • Install high flow alarm
	LOW	Low flow enters stripper	<ul style="list-style-type: none"> • Valve partially close • Inlet pipe partially blocked 	<ul style="list-style-type: none"> • Take longer time to fill up the stripper • Leakage of piping cause a fire to occur 	• Flow controller	<ul style="list-style-type: none"> • Scheduled maintenance and inspection • Install by-pass valve • Install flow indicator • Install low flow alarm
	NO	No flow enters stripper	<ul style="list-style-type: none"> • Valve failed to close 	<ul style="list-style-type: none"> • No feed enters stripper • Process reaction in stripper unable to occur • No desired products produced • Overall process plant unable to proceed 	• Flow controller	<ul style="list-style-type: none"> • Scheduled maintenance and inspection • Install by-pass valve • Install flow indicator

						<ul style="list-style-type: none"> • Install low flow alarm
--	--	--	--	--	--	--

Table 15 HAZOP study on S-101 at node 2

HAZARD AND OPERABILITY STUDY REPORT					
PROJECT TITLE: HAZOP of a stripper					
Project Number: Stripper		Date: 05 January 2023			
Drawing Number: S-101		Chairman: Azrul Zulhilmi bin Ahmad Rosli			
Node: Node No 2		Study Team: Aerry Ting Wei Huan, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Suriya Vathi A/P Subramanian			
Item: Inlet pipe of cooling water supply		Parameter: Flow			
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED
MORE	High flow enters stripper	<ul style="list-style-type: none"> • Valve (cw) failed open 	<ul style="list-style-type: none"> • More cooling water enters stripper • The temperature of stripper is low due to cooling down process quickly • Low efficiency of separation 	Temperature controller	<ul style="list-style-type: none"> • Scheduled inspection and maintenance.
LESS	Low flow enters stripper	<ul style="list-style-type: none"> • Valve (cw) partially blocked or close • Valve leaked • Pipe leak • Rupture at pipeline 	<ul style="list-style-type: none"> • Less cooling water enters stripper • The temperature of stripper is high due to cooling down process slowly • Explosion or fire occur due to overheat • Lead to injury and death 	Temperature controller	<ul style="list-style-type: none"> • Scheduled inspection and maintenance.
NO	No flow enters stripper	<ul style="list-style-type: none"> • Blockage at pipeline • Rupture at reactor, R-102 	<ul style="list-style-type: none"> • No cooling water enters stripper • Cooling process unable to carry out • Explosion or fire occur due to overheat • Lead to injury and death 	Temperature controller	<ul style="list-style-type: none"> • Scheduled inspection and maintenance

Table 16 HAZOP study on S-101 at node 3

HAZARD AND OPERABILITY STUDY REPORT					
PROJECT TITLE: HAZOP of a stripper					
Project Number: Stripper		Date: 05 January 2023			
Drawing Number: S-101		Chairman: Azrul Zulhilmi bin Ahmad Rosli			
Node: Node No 3		Study Team: Aerry Ting Wei Huan, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Suriya Vathi A/P Subramanian			
Item: Inlet stream 34		Parameter: Flow			
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED
MORE	High flow enter stripper	<ul style="list-style-type: none"> Valve failed to open. 	<ul style="list-style-type: none"> Overflow of stripper occur Overflow cause a fire to occur Lead to injury and death 	None	<ul style="list-style-type: none"> Scheduled maintenance and inspection Install by-pass valve Install flow indicator Install high flow alarm
LESS	Low flow enter stripper	<ul style="list-style-type: none"> Pipe leak Rupture at pipeline Pipe partially blocked. 	<ul style="list-style-type: none"> Take longer time to fill up the stripper Leakage of piping cause a fire to occur 	None	<ul style="list-style-type: none"> Scheduled maintenance and inspection Install by-pass valve Install flow indicator Install low flow alarm
NO	No flow enter stripper	<ul style="list-style-type: none"> Blockage at pipeline Valve failed to close 	<ul style="list-style-type: none"> No feed enters stripper Process reaction in stripper unable to occur No desired products produced Overall process plant unable to proceed 	None	<ul style="list-style-type: none"> Scheduled maintenance and inspection Install by-pass valve Install flow indicator Install low flow alarm

Table 17 HAZOP study on S-101 at node 4

HAZARD AND OPERABILITY STUDY REPORT	
PROJECT TITLE: HAZOP of a stripper	
Project Number: Stripper	Date: 05 January 2023
Drawing Number: S-101	Chairman: Azrul Zulhilmi bin Ahmad Rosli

Node: Node No 4			Study Team: Aerry Ting Wei Huan, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Suriya Vathi A/P Subramanian			
Item: Inlet stream 32			Parameter: Flow			
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED	
MORE	High flow enter stripper	<ul style="list-style-type: none"> Valve failed to open. 	<ul style="list-style-type: none"> Overflow of stripper occur Overflow cause a fire to occur Lead to injury and death 	None	<ul style="list-style-type: none"> Scheduled maintenance and inspection Install flow indicator Install flow alarm 	
LESS	Low flow enter stripper	<ul style="list-style-type: none"> Pipe leak Rupture at pipeline Pipe partially blocked. 	<ul style="list-style-type: none"> Take longer time to fill up the stripper Leakage of piping cause a fire to occur 	None	<ul style="list-style-type: none"> Scheduled maintenance and inspection Install flow indicator Install flow alarm 	
NO	No flow enter stripper	<ul style="list-style-type: none"> Blockage at pipeline 	<ul style="list-style-type: none"> No feed enters stripper Process reaction in stripper unable to occur No desired products produced Overall process plant unable to proceed 	None	<ul style="list-style-type: none"> Scheduled maintenance and inspection Install flow indicator Install flow alarm 	

Table 18 HAZOP study on S-101 at node 5

HAZARD AND OPERABILITY STUDY REPORT					
PROJECT TITLE: HAZOP of a stripper					
Project Number: Stripper		Date: 05 January 2023			
Drawing Number: S-101		Chairman: Azrul Zulhilmi bin Ahmad Rosli			
Node: Node No 5		Study Team: Aerry Ting Wei Huan, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Suriya Vathi A/P Subramanian			
Item: Outlet stream 37		Parameter: Flow			
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED

MORE	High flow out stripper	<ul style="list-style-type: none"> Valve failed to open. 	<ul style="list-style-type: none"> More product flow out from stripper Overpressures exist in next unit operation due to high flow of gaseous 	Pressure controller	<ul style="list-style-type: none"> Scheduled maintenance and inspection Install flow indicator Install flow alarm
LESS	Low flow out stripper	<ul style="list-style-type: none"> Pipe leak Rupture at pipeline Outlet pipe partially blocked. 	<ul style="list-style-type: none"> Less product flow out from stripper Overpressure occurs in stripper Overpressure cause an explosion to occur Lead to injury and death 	Pressure controller	<ul style="list-style-type: none"> Scheduled maintenance and inspection Install flow indicator Install flow alarm
NO	No flow out stripper	<ul style="list-style-type: none"> Blockage at pipeline Valve failed to close 	<ul style="list-style-type: none"> No product flow out from stripper Overpressure occurs in stripper Overpressure cause an explosion to occur Lead to injury and death 	Pressure controller	<ul style="list-style-type: none"> Scheduled maintenance and inspection Install flow indicator Install flow alarm

Table 19 HAZOP study on S-101 at node 6

HAZARD AND OPERABILITY STUDY REPORT					
PROJECT TITLE: HAZOP of a stripper					
Project Number: Stripper		Date: 05 January 2023			
Drawing Number: S-101		Chairman: Azrul Zulhilmi bin Ahmad Rosli			
Node: Node No 6		Study Team: Aerry Ting Wei Huan, Nurzulaikha binti Zulkarnian, Nur Iffa binti Rizuan, Suriya Vathi A/P Subramanian			
Item: Outlet stream 35		Parameter: Flow			
GUIDE WORDS	DEVIATIONS	CAUSES	CONSEQUENCES	SAFEGUARDS	ACTION REQUIRED
MORE	High flow out stripper	<ul style="list-style-type: none"> Valve failed to open. 	<ul style="list-style-type: none"> More product flow out from stripper Overpressures exist in next unit operation due to high flow of gaseous 	Pressure controller	<ul style="list-style-type: none"> Scheduled maintenance and inspection
LESS	Low flow out stripper	<ul style="list-style-type: none"> Pipe leak Rupture at pipeline 	<ul style="list-style-type: none"> Less product flow out from stripper Overpressure occurs in stripper 	Pressure controller	<ul style="list-style-type: none"> Scheduled maintenance and inspection

		<ul style="list-style-type: none"> Outlet pipe partially blocked. 	<ul style="list-style-type: none"> Overpressure cause an explosion to occur Lead to injury and death 		
NO	No flow out stripper	<ul style="list-style-type: none"> Blockage at pipeline Valve failed to close 	<ul style="list-style-type: none"> No product flow out from stripper Overpressure occurs in stripper Overpressure cause an explosion to occur Lead to injury and death 	Pressure controller	<ul style="list-style-type: none"> Scheduled maintenance and inspection

Hazard Identification, Risk Analysis And Risk Control (Hirarc) On Major Unit Operation (Hirarc)

The HIRARC studies are conducted on the major equipment in the plant which includes electrolyser (E-101), catalytic packed bed reactor (R-101), phase separator (PS-101), plug flow reactor (R-102), and stripper (S-101).

f. Electrolyser, E-101

Table 20 HIRARC assessment of Electrolyser, E-101

bHIRARC FORM								
Company		GreenREA Sdn. Bhd.			Conducted by		Nur Iffa binti Rizuan	
Process/Location		Electrolyser (E-101)						
Approved by		-			Review date		-	
Date		4 January 2023			Risk Analysis			
No.	Work Activity	Hazard	Which Can Causes/Effects	Existing Risk Control	Likelihood	Severity	Risk	Recommended Control Measure
1.	Electrolysis of water	Overpressure in electrolyser	<ul style="list-style-type: none"> Rupture of electrolyser and if there is ignition source it can cause fire and explosion 	<ul style="list-style-type: none"> Installation of pressure controller 	3	5	15 (High)	<ul style="list-style-type: none"> Perform scheduled inspection and maintenance

			<ul style="list-style-type: none"> Major property damage 	<ul style="list-style-type: none"> Emergency Response Plan (ERP) 				<ul style="list-style-type: none"> Install high pressure alarm
		Overheating of electrolyser	<ul style="list-style-type: none"> Rupture of electrolyser Lead to overpressure 	<ul style="list-style-type: none"> Emergency Response Plan (ERP) 	3	5	15 (High)	<ul style="list-style-type: none"> Perform scheduled inspection and maintenance Install high temperature alarm
3.	Pumping out from the electrolyser	Rupture or leakage of hydrogen pipeline	<ul style="list-style-type: none"> Occurrence of fire 	<ul style="list-style-type: none"> Emergency Response Plan (ERP) Wear personal protective equipment (PPE) 	3	4	12 (Medium)	<ul style="list-style-type: none"> Perform scheduled inspection and maintenance Install leakage detector Ensure no ignition source nearby
4.	Pumping out from the electrolyser	Rupture or leakage of oxygen pipeline	<ul style="list-style-type: none"> Occurrence of fire whence there is ignition 	<ul style="list-style-type: none"> Emergency Response Plan (ERP) Wear personal protective equipment (PPE) 	3	4	12 (Medium)	<ul style="list-style-type: none"> Perform scheduled inspection and maintenance Install leakage detector Ensure no ignition source nearby
5.	Pumping into the electrolyser from storage	Valve malfunction	<ul style="list-style-type: none"> Occurrence of backflow Overpressure inside the electrolyser 	<ul style="list-style-type: none"> Installation of flow controller Emergency Response Plan (ERP) 	2	2	4 (Low)	<ul style="list-style-type: none"> Perform scheduled inspection and maintenance

g. **Catalytic Packed Bed Reactor, R-101**

Table 21 HIRARC assessment of Catalytic Packed Bed Reactor, R-101

HIRARC FORM

Company	GreenREA Sdn. Bhd.			Conducted by		Nurzulaikha binti Zulkarnain		
Process/Location	Catalytic Packed Bed Reactor (R-101)							
Approved by	-			Review date		-		
Date	5 January 2023							
Hazard Identification			Risk Analysis			Risk Control		
No.	Work Activity	Hazard	Which Can Causes/Effects	Existing Risk Control	Likelihood	Severity	Risk	Recommended Control Measure
1	Flow of reactant into R-101	<ul style="list-style-type: none"> • Pipe leakage at inlet stream • Valve malfunction 	<ul style="list-style-type: none"> • Occurrence of fire • Worker's exposure to the chemicals • Irrecoverable property damage • Can cause fatality 	<ul style="list-style-type: none"> • Flow controller • Followed Emergency response plan (ERP) • Personal Protective Equipment (PPE) 	2	4	8 (Medium)	<ul style="list-style-type: none"> • Perform schedule inspection on the pipe and floor • Install control gas leakage system
2	Usage of high pressure in R-101	Wall of R-101 vessel rupture	<ul style="list-style-type: none"> • R-101 become overpressurized and may rupture or explode • Major property damage 	<ul style="list-style-type: none"> • Pressure relief valve • Followed Emergency response plan (ERP) • Personal Protective Equipment (PPE) 	3	5	15 (High)	<ul style="list-style-type: none"> • Perform schedule inspection on pressure relief valve and the condition of R-101 • Install a high-pressure alarm to alert change of high pressure
3	Usage of high temperature in R-101	Overheating of reactor	<ul style="list-style-type: none"> • Numerous fatalities • Irrecoverable property damage and productivity. 	<ul style="list-style-type: none"> • Temperature controller • Temperature transmitter • Followed Emergency 	3	5	15 (High)	<ul style="list-style-type: none"> • Perform schedule inspection on temperature controller • Install a high temperature alarm

			<ul style="list-style-type: none"> Occurrence of fire and explosion that can lead to total system loss 	<ul style="list-style-type: none"> response plan (ERP) Personal Protective Equipment (PPE) 				and emergency shut down system
4	Maintenance and inspection of R-101	Inhalation of toxic gas	<ul style="list-style-type: none"> May cause difficulty breathing, dizziness, vomiting, even leads to death 	<ul style="list-style-type: none"> Personal protective equipment (PPE) 	3	3	9 (Medium)	<ul style="list-style-type: none"> Training of workers regularly
5	Flow of product at outlet stream R-101	Pipe leakage	<ul style="list-style-type: none"> Flammable substances such as hydrogen may cause thermal burns Toxic gas and pungent odour of ammonia gas will affect to workers 	<ul style="list-style-type: none"> Followed Emergency response plan (ERP) Personal Protective Equipment (PPE) 	2	4	8 (Medium)	<ul style="list-style-type: none"> Scheduled inspection and maintenance Need to ensure no ignition source nearby Install a leakage detector system

h. Phase Separator, PS-101

Table 22 HIRARC assessment of Phase Separator (PS-101)

HIRARC FORM			
Company	GreenREA Sdn. Bhd.		
Process/Location	Phase Separator (PS-101)	Conducted by	Aerry Ting Wei Huan
Approved by	-		
Date	4 January 2023	Review date	-

Hazard Identification				Risk Analysis				Risk Control
No.	Work Activity	Hazard	Which Can Causes/Effects	Existing Risk Control	Likelihood	Severity	Risk	Recommended Control Measure
1	Separation process inside the phase separator	High operating temperature (overheating)	Overheating may cause overpressure and may lead to explosion of the phase separator	<ul style="list-style-type: none"> ▪ Installation of temperature controller and high temperature alarm ▪ High temperature alarm triggered ▪ Automatic shutdown system ▪ Followed Emergency Response Plan (ERP) 	3	5	15 (High)	<ul style="list-style-type: none"> ▪ Scheduled inspection and maintenance ▪ Install temperature indicator
2		High operating pressure (overpressure)	Overpressure may cause rupture and lead to explosion. Released huge amount of toxic and flammable substances into environment which brings health hazard to the workers	<ul style="list-style-type: none"> ▪ Installation of pressure controller and pressure relief valve ▪ Followed Emergency Response Plan (ERP) 	3	5	15 (High)	<ul style="list-style-type: none"> ▪ Scheduled inspection and maintenance ▪ Install pressure indicator and high pressure alarm
3		Pipe leakage	Flammable substances such as hydrogen may cause thermal burns	<ul style="list-style-type: none"> ▪ Personal protective equipment (PPE) ▪ Followed Emergency Response Plan (ERP) 	3	2	6 (Medium)	<ul style="list-style-type: none"> ▪ Schedule inspection and maintenance ▪ Need to ensure no ignition nearby ▪ Install a leakage detector
4		Valve malfunction	Overpressure and explosion may occur inside the phase separator and leads to serious injury to the operator	<ul style="list-style-type: none"> ▪ Installation of pressure controller and pressure relief valve 	3	5	15 (High)	<ul style="list-style-type: none"> ▪ Scheduled inspection and maintenance

				▪ Followed Emergency Response Plan (ERP)				▪ Install pressure indicator and high pressure alarm
5	Pumping of product from the phase separator	Pipe leakage	Flammable substances such as hydrogen may cause thermal burns	▪ Personal protective equipment (PPE) ▪ Followed Emergency Response Plan (ERP)	3	2	6 (Medium)	▪ Schedule inspection and maintenance ▪ Need to ensure no ignition nearby ▪ Install a leakage detector
6		Valve malfunction	Overpressure and explosion may occur inside the phase separator and leads to serious injury to the operator	▪ Installation of pressure controller and pressure relief valve ▪ Followed Emergency Response Plan (ERP)	3	5	15 (High)	▪ Scheduled inspection and maintenance ▪ Install pressure indicator and high pressure alarm
7	Maintenance and inspection	Inhalation of toxic gas	May cause difficulty breathing, dizziness, vomiting even leads to death	▪ Personal protective equipment (PPE)	2	3	6 (Medium)	▪ Supervision and training for the operators or workers

i. **Plug Flow Reactor, R-102**

Table 23 HIRARC assessment of Plug Flow Reactor, R-102

HIRARC FORM									
Company	GreenREA Sdn. Bhd.			Conducted by	Suriya Vathi A/P Subramanian				
Process/Location	Plug Flow Reactor, R-102								
Approved by	-								
Date	4 January 2023			Review date	-				
Hazard Identification			Risk Analysis			Risk Control			

No.	Work Activity	Hazard	Which Can Causes/Effects	Existing Risk Control	Likelihood	Severity	Risk	Recommended Control Measure
1	Flow of reactant into the reactor	Pipe leaking in the inlet	<ul style="list-style-type: none"> • Occurrence of fire • Worker's exposure to the chemicals • Irrecoverable property damage • Can cause fatality 	<ul style="list-style-type: none"> • Flow controller 	2	4	8 (Medium)	<ul style="list-style-type: none"> • Perform schedule inspection on the pipe and floor • Install control liquid leakage system • Evacuated Emergency Response • Plan (ERP)
2	Usage of high pressure in tank	Wall of tank vessel rupture	<ul style="list-style-type: none"> • Reactor become highly pressurized and may rupture or explode • Approximately one single fatality • Major property damage 	<ul style="list-style-type: none"> • Pressure controller • Pressure relief valve 	2	4	8 (Medium)	<ul style="list-style-type: none"> • Perform schedule inspection on pressure controller and the condition of tank vessel • Install a high-pressure alarm to alert change of high pressure
3	Operating condition of ammonia and carbon dioxide	Overheating of reactor	<ul style="list-style-type: none"> • Numerous fatalities • Irrecoverable property damage and productivity also • Occurrence of fire that can lead to total system loss 	<ul style="list-style-type: none"> • Temperature control • Temperature transmitter 	3	5	15	<ul style="list-style-type: none"> • Perform schedule inspection on temperature controller • Install a high temperature alarm and emergency shut down system
4	Maintenance of reactor	Falling from top of reactor	<ul style="list-style-type: none"> • Disabling but not permanently injured 	None	3	3	9 (Medium)	<ul style="list-style-type: none"> • Workers should use personal protective equipment by using safety rope and wear

								helmet and safety boot
5	Flow of in and out of the reactor	Valve malfunction may cause backflow	• Damage of valve	None	3	3	9 (Medium)	• Scheduled inspection and maintenance

j. Stripper, S-101

Table 24 HIRARC assessment of Stripper, S-101

HIRARC FORM								
Company		GreenREA Sdn. Bhd.			Conducted by		Azrul Zulhilmi bin Ahmad Rosli	
Process/Location		Stripper, S-101						
Approved by		-			Review date		-	
Date		4 January 2023						
Hazard Identification				Risk Analysis				Risk Control
No.	Work Activity	Hazard	Which Can Causes/Effects	Existing Risk Control	Likelihood	Severity	Risk	Recommended Control Measure
1	Flow of reactant into the stripper	Pipe leaking in the inlet	<ul style="list-style-type: none"> Occurrence of fire Worker's exposure to the chemicals Irrecoverable property damage Can cause fatality 	<ul style="list-style-type: none"> Flow controller Wearing PPE – protective helmets, goggles, safety boots. Install gas leakage indicator Alarm system 	4	3	12 (Medium)	<ul style="list-style-type: none"> Perform schedule inspection on the pipe and floor Install control liquid leakage system Evacuated Emergency Response Plan (ERP)
2	Usage of high pressure in stripper	Wall of stripper rupture	<ul style="list-style-type: none"> Stripper become highly pressurized and may rupture or explode 	<ul style="list-style-type: none"> Pressure controller Pressure relief valve 	2	5	10 (Medium)	<ul style="list-style-type: none"> Perform schedule inspection on pressure controller

			<ul style="list-style-type: none"> • Approximately one single fatality • Major property damage 	<ul style="list-style-type: none"> • High pressure alarm • Increase thickness of reactor to withstand the high temperature 				<ul style="list-style-type: none"> • and the condition of tank vessel • Install a high-pressure alarm to alert change of high pressure
3	Usage of high temperature in stripper	Valve malfunction may cause backflow	<ul style="list-style-type: none"> • Overpressure inside the stripper • Rupture 	<ul style="list-style-type: none"> • Temperature Controller • High temperature alarm • Increase thickness of reactor to withstand the high temperature • Automatic shutdown system 	2	4	8 (Medium)	<ul style="list-style-type: none"> • Scheduled inspection and maintenance

APPENDIX D

DETAILS DESIGN AND MECHANICAL DESIGN

Detailed Design

a. Activated Carbon Filter, AF-101

Designed by: Aerry Ting Wei Huan (A174141)

Table A.D 1 Properties of water

Properties	Water (Stream 4)
Flowrate (kg/hr)	3148.17
Density (kg/m ³)	997
Viscosity (kg/m s)	0.001

$$\text{Volumetric flowrate, } V = \frac{\text{Total flowrate filtrate}}{\text{Average density}}$$

$$= \frac{3148.17 \frac{\text{kg}}{\text{hr}}}{997 \frac{\text{kg}}{\text{m}^3}}$$

$$= 3.158 \frac{\text{m}^3}{\text{hr}}$$

$$\text{Area of filtration, } A_f = \frac{\mu_0 \alpha \rho_c}{2t \Delta P}$$

$$= \sqrt{\frac{(0.001)(1 \times 10^9)(500)(3.158)^2}{2(3600)(300000)}}$$

$$= 1.519 \text{ m}^2$$

$$\text{Height, } H = \frac{\text{Volumetric flowrate}}{\text{Area} \times \text{Filter bed loading rate}}$$

$$= \frac{3.158}{1.519 \times 0.55}$$

$$= 3.78 \text{ m}$$

$$\text{Area} = \pi r^2$$

$$1.519 = \pi r^2$$

$$r^2 = 0.4835$$

$$r = 0.6953$$

$$D = 2r$$

$$= 2(0.6953) = 1.391 \text{ m}$$

$$V = \pi r^2 h$$

$$V = \pi(0.6953)^2(3.78)$$

$$= 5.741 \text{ m}^3$$

$$\text{Amount of activated carbon} = 0.3 \times H \times A \times \rho_c$$

$$= 0.3(3.78)(1.519)(500)$$

$$= 861.27 \text{ kg}$$

b. Heat Exchanger (HE-101 & HE-102)

Designed by: Aerry Ting Wei Huan (A174141)

Estimation of Physical Properties at Inlet Stream 38

i. Estimation on Heat Capacity of Mixture

$$C_p(\text{Mixture}) = n_a C_{pa} + n_b C_{pb} + n_c C_{pc} \dots$$

Where n is mol fractions of the components a, b, c.(Sinnott 2005b). The heat capacities of each component are obtained from Perry Handbooks. Table A.D 2 shows the calculation of heat capacity of mixture.

Table A.D 2 Calculation of heat capacity of mixture

Component	Molar flowrate (kmol/h)	Mol fraction	Cp (Jmol/K)	x(Cp) (Jmol/K)	MW (g/mol)	x(Cp) (kJ/kgK)
Ammonia	43.57	0.292	37.00	10.812	17.03	0.635
Carbon dioxide	34.08	0.229	37.35	8.539	44.01	0.194
Ammonium carbamate	2.07	0.014	90.00	1.250	78.07	0.016
Water	34.68	0.233	75.60	17.586	18.02	0.976
Urea	34.69	0.233	90.00	20.940	60.06	0.349
Total	149.09	1	-	-	-	-

$$C_p(\text{Mixture}) = n_a C_{pa} + n_b C_{pb} + n_c C_{pc} \dots$$

$$= 2.169 \text{ kJ/kgK}$$

ii. Estimation on Density of Mixture

The density of each component is obtained from Perry Handbook.

Table A.D 3 Calculation of density of mixture.

	Molar flowrate (kmol/h)	Mass flowrate (kg/h)	Mass fraction, x	Density (kg/m3)
Ammonia	43.57	742.00	0.145	0.86
Carbon dioxide	34.08	1500.00	0.293	1.87
Ammonium carbamate	2.07	161.61	0.032	750
Water	34.68	624.93	0.122	997
Urea	34.69	2083.33	0.408	1126
Total	149.09	5111.87	1	-

For density of mixture, the formula used for calculation are shown below:

$$\rho_t = \frac{1}{\frac{x_a}{\rho_a} + \frac{x_b}{\rho_b} + \dots}$$

Where ρ_t is the total density of mixture,

x_a, x_b are mass fractions of the components a and b,

ρ_a, ρ_b are densities of components a and b

$$\begin{aligned}\rho_t &= \frac{1}{\frac{0.145}{0.86} + \frac{0.293}{1.87} + \frac{0.032}{750} + \frac{0.122}{997} + \frac{0.408}{1126}} \\ &= 3.065 \text{ kg/m}^3\end{aligned}$$

iii. Estimation on Viscosity of Mixture

Assume the viscosity of mixture is affected only by water, hydorxymethylfurral and furfural due to their high mass fraction in that mixture and the viscosity of other components can be neglected.

For heat-transfer calculations, Kern (1950) gives a rough rule of thumb for organic liquid mixtures:

$$\frac{1}{\mu_m} = \frac{x_1}{\mu_1} + \frac{x_2}{\mu_2} + \dots$$

Where μ_m is the viscosity of mixture,

x_1, x_2 are mass fractions of the components 1 and 2,

μ_1, μ_2 are viscosities of components 1 and 2

(Sinnott 2005b).

Table A.D 4 Calculation of viscosity of mixture

Component	Molar flowrate (kmol/h)	Mass flowrate (kg/h)	Mass fraction, x	Viscosity (Ns/m ²)
Ammonia	43.57	742.00	0.145	0.0006

Carbon dioxide	34.08	1500.00	0.293	0
Ammonium carbamate	2.07	161.61	0.032	1.56
Water	34.68	624.93	0.122	0.0085
Urea	34.69	2083.33	0.408	1.571
Total	149.09	5111.87	1	-

$$\frac{1}{\mu_m} = \frac{x_1}{\mu_1} + \frac{x_2}{\mu_2} + \dots$$

$$\mu_m = \frac{1}{\frac{x_1}{\mu_1} + \frac{x_2}{\mu_2}}$$

$$\mu_m = \frac{1}{\frac{0.145}{0.0006} + \frac{0.032}{1.56} + \frac{0.032}{0.0085} + \frac{0.408}{1.571}}$$

$$\mu_m = 0.068 \text{ Ns/m}^2$$

iv. Estimation of Thermal Conductivity of Mixture

For the thermal conductivity, the Weber equation (Weber 1880) can be used to make a rough estimate of the thermal conductivity of organic liquids, for use in heat-transfer calculations.

$$k = 3.56 \times 10^{-5} C_p \left(\frac{\rho^4}{M} \right)^{\frac{1}{3}}$$

Where k = thermal conductivity, W/m°K

M = molecular mass,

C_p = specific heat capacity, kJ/kg °K

ρ = density, kg/ m³

In general, the thermal conductivities of liquid mixtures, and gas mixtures, are not simple functions of composition and the thermal conductivity of the components. Bretsznajder (1971) discusses the methods that are available for estimating the thermal conductivities of mixtures from a knowledge of the thermal conductivity of the

components. If the components are all non-polar a simple weighted average is usually sufficiently accurate for design purposes.

$$k_m = k_1 w_1 + k_2 w_2 + k_3 w_3 \dots$$

Where k_m is thermal conductivity of mixture,

k_1, k_2 and k_3 are thermal conductivity off components,

w_1, w_2 and w_3 are component mass fraction

(Sinnott 2005b)

At Stream 38:

Table A.D 5 Calculation of thermal conductivity of mixture

Component	Mass flowrate (kg/h)	Mass fraction, x	Density (kg/m ³)	MW (g/mol)	Cp (Jmol/°K)	Cp (kJ/kg°K)	k (W/m°K)
Ammonia	742.00	0.145	0.86	17.03	37.00	2.173	0.144
Carbon dioxide	1500.00	0.293	1.87	44.01	37.35	0.849	0.017
Ammonium carbamate	161.61	0.032	750	78.07	90.00	1.153	0.230
Water	624.93	0.122	997	18.02	75.60	4.195	0.598
Urea	2083.33	0.408	1126	60.06	90.00	1.498	0.25
0.Total	5111.87	1.0000					-

$$k_m = 0.145(0.144) + 0.293(0.017) + 0.032(0.230) + 0.122(0.598) \\ + 0.408(0.25)$$

$$= 0.208 \text{ W/m}^\circ\text{K}$$

v. Heat Duty, Q

Table A.D 6 below shows the physical properties for cooling water and product mixture at heat exchanger (HE-101).

Table A.D 6 Physical properties for cooling water and product mixture at HE-101

Physical properties	Cooling Water	Product mixture
---------------------	---------------	-----------------

Inlet temperature, Tin (°C)	40	180
Outlet temperature, Tout (°C)	150	140.02
Heat capacity, Cp (kJ/kg.K)	4.187	2.169
Viscosity, μ (Ns/m ²)	0.001	0.068
Density, ρ (kg/m ³)	997	3.065
Thermal conductivity, k (W/mK)	0.598	0.208

In the heat exchanger HE-101, the fluid movement across the shell and tube heat exchanger is counter current flow. This is due to counter current flow has high efficiency in term of heat transfer compared to co-current flow. Figure 10.1 below show the temperature profile for counter current flow in HE-101.

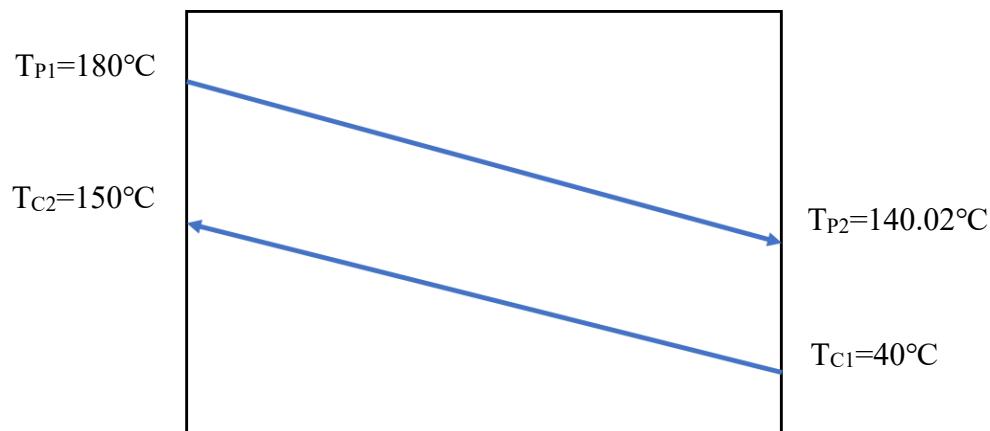


Figure A.D 1 Temperature profile for counter current flow in HE-101

$$\text{Heat load, } Q \text{ of mixture} = \dot{m} C_p \Delta T$$

$$Q = \frac{5111.87 \text{ kg}}{3600 \text{ s}} \left(\frac{0.007947 \text{ kJ}}{\text{kg°C}} \right) (180^\circ\text{C} - 140.02^\circ\text{C}) = 4.511 \text{ kW}$$

$$\text{Heat load, } Q \text{ of cooling water} = \text{Heat load of mixture}$$

$$4.511 \text{ kW} = m_s (0.04817)(150 - 40)$$

$$\dot{m}_c = 0.851 \text{ kg/s}$$

For counter current flow:

Log mean temperature difference

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln \frac{(T_1 - t_2)}{(T_2 - t_1)}} = \frac{(180 - 150) - (140.02 - 40)}{\ln \frac{(180 - 150)}{(140.02 - 40)}} = 124.55^\circ\text{C}$$

Use one shell pass, two tube pass,

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{180 - 140.02}{150 - 40} = 0.36$$

$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{150 - 40}{180 - 40} = 0.79$$

From the equation 12.8 from Coulson and Richardson, at $R = 0.33$ and $S = 0.79$,

$$Ft = 0.94$$

$$\Delta T_{lm} = Ft \Delta T_{lm} = 0.94 (124.55) = 117.08^\circ\text{C}$$

Provisional area, A

From table 12.1 of typical overall coefficient, $U = 300 \text{ W/m}^2\text{C}$

$$A = \frac{4.511 \times 10^3}{300(117.08)} = 4.817 \text{ m}^2$$

Table A.D 7 below shows the summary calculation of heat duty for cooling water and product mixture at HE-101.

Table A.D 7 Heat duty for steam and mixture at HE-101

Parameter	Cooling water	Product mixture
Inlet temperature, $T_{in} (\text{ }^\circ\text{C})$	40	180
Outlet temperature, $T_{out} (\text{ }^\circ\text{C})$	150	140.02
Heat load, Q (kW)	4.511	
Mass flow rate, $\dot{m}_s (\text{kg/h})$	3065.03	5111.87
Log mean temperature difference, $\Delta T_{lm} (\text{ }^\circ\text{C})$	124.55	
R	0.36	
S	0.79	
Ft (From Figure 12.19)	0.94	
True Temperature different, ΔT_m ($\text{ }^\circ\text{C}$)	117.08	
Provisional area, A (m^2)	4.82	

Typical overall coefficient, U (W/m ² °C)	300
---	-----

It is a counter-current flow due to the temperature of hottest cold fluid is greater than coldest hot fluid. Using one shell pass, two tube pass to evaluate temperature correction factor, R and S. Based on Table A.D 7, the overall coefficient, U is 300 W/m²°C.

vi. Design Parameter

Choose 20 mm outer diameter, 16 mm inner diameter, 1.83 m long tubes, carbon steel.

$$L = 1.83 \text{ m}$$

$$\text{Area of one tube, } A_t = \pi D_o L = \pi(20 \times 10^{-3})(1.83) = 0.115 \text{ m}^2$$

$$\text{Number of tubes, } N_t = \frac{A}{A_t} = \frac{4.817}{0.115} = 41.89 \approx 42 \text{ tubes (even number)}$$

As the shell-side fluid is relatively clean use 1.25 triangular pitch. From table 19.4, constants value for two tube passes are: $K_1 = 0.249$ and $n_1 = 2.07$.

$$\text{Bundle diameter, } D_b = (20) \left(\frac{42}{0.249} \right)^{\frac{1}{2.07}} = 204.23 \text{ mm}$$

Split ring floating head is chosen due to tube bundle can be removed and replaced for inspection and cleaning. It allows differential thermal expansion between shell and tube.

From figure 12.10 of shell-bundle clearance, bundle diametrical clearance is $C = 71 \text{ mm}$

$$\text{Shell diameter, } D_s = D_b + C = 204.23 + 71 = 275.23 \text{ mm}$$

Table A.D 8 shows the summary calculation for design parameter of HE-101.

Table A.D 8 Design Parameter for HE-101

Design parameter	Value
------------------	-------

Outer diameter, OD, (mm)	20
Inner diameter, ID, (mm)	16
Length of tube, L (m)	1.83
Material	Carbon steel
Provisional Area, A (m^2)	4.817
Area of one tube, $A_t = \pi D_o L$ (m^2)	0.115
Number of tubes, $N_t = \frac{A}{A_t}$	41.89
Number of tubes, N_t (round off)	42 (even number)
K_1 (From Table 19.4)	0.249
n_1 (From Table 19.4)	2.207
Bundle diameter, D_b , (mm)	204.23
Shell Clearance, C, (mm) (Figure 12.10)	71
Shell diameter, $D_s = D_b + C$, (mm)	275.23

vii. Tube Side Coefficient

$$\text{Mean cooling water temperature, } t = \frac{T_1+T_2}{2} = \frac{40+150}{2} = 95 \text{ } ^\circ\text{C}$$

$$\text{Tube cross-sectional area} = \pi \frac{D_t^2}{4} = \pi \frac{16^2}{4} = 201.06 \text{ mm}^2$$

Tubes per pass = 4 tubes per passes

$$\text{Total flow area} = 4 (201.06 \times 10^{-6}) = 8.04 \times 10^{-4} \text{ m}$$

$$\text{Cooling water mass flow rate, } \dot{m}_s = 0.851 \text{ kg/s}$$

$$\text{Water mass velocity} = \frac{0.851}{8 \times 10^{-4}} = 201.64 \text{ kg/sm}^2$$

$$\text{Water linear velocity, } u_t = \frac{201.64}{997} = 0.202 \text{ m/s}$$

$$\text{Coefficient for cooling water, } h_i = 4200(1.35 + 0.02t) \frac{u_t^{0.8}}{d_i^{0.2}}$$

$$= 4200(1.35 + 0.02(95)) \frac{0.202^{0.8}}{16^{0.2}}$$

$$= 2182.83 \text{ W/m}^2 \text{ } ^\circ\text{C}$$

The coefficient can be calculated by using formula below:

$$h_i = j_h Re Pr^{0.33} \left(\frac{\mu}{\mu_w} \right)^{0.14} \left(\frac{k_f}{d} \right)$$

Thermal conductivity of cooling water, $k_f = 0.598$

$$\text{Reynold number, } Re = \frac{\rho u_t d_i}{\mu} = \frac{(997)(0.202)(16 \times 10^{-3})}{0.001} = 3219.852$$

$$\text{Prandtl number, } Pr = \frac{c_p \mu}{k_f} = \frac{(4.187 \times 10^3)(0.001)}{0.598} = 7.016$$

$$\frac{L}{d_i} = \frac{1.83 \times 10^3}{16} = 114.375$$

From Figure 10.8, heat transfer factor, $j_h = 0.004$

$$h_i = (0.004)(3219.852)(7.016)^{0.33} \left(\frac{0.598}{16 \times 10^{-3}} \right) = 915.55 \text{ W/m}^2\text{C}$$

From the calculation, lower figure value of coefficient value is chosen which is 915.55 W/m²C.

Table A.D 9 shows the tube side coefficient of HE-101.

Table A.D 9 Tube side coefficient of HE-101

Tube side coefficient	Value
Mean cooling water temperature, t (°C)	95
Tube cross-sectional area (mm ²)	201.06
Fluid thermal conductivity, k_f (W/m ² °C)	0.598
Tubes per pass	4
Total flow area, (m ²)	0.004
Coefficient for cooling water, h_i	2182.83
Density of component in tube, ρ (kg/m ³)	997
Reynold number in tube, Re	3219.85
Prandtl number in tube	7.016
Tube friction factor from Figure 12.23, j_h	0.004
Tube side coefficient, h_i (W/m ² °C)	915.55

viii. Shell Side Coefficient

Choose 30% baffle spacing, $l_B = D_s(0.30) = (275.23)(0.30) = 82.57$ mm

Tube pitch, $p_t = 1.25(20) = 25 \text{ mm}$

$$\text{Cross-flow area, } A_s = \frac{(p_t - d_o)D_s l_B}{p_t} = \frac{(25 - 20)(275.23)(82.57)}{25} \times 10^{-6} = 0.0045 \text{ m}^2$$

$$\text{Mass velocity, } G_s = \left(\frac{1.420}{0.0045}\right) = 312.42 \text{ kg/m}^2\text{s}$$

$$\begin{aligned} \text{Equivalent diameter, } d_e &= \frac{1.10}{d_o} (p_t^2 - 0.917d_o^2) = \frac{1.10}{20} (25^2 - 0.917(20)^2) = 36.63 \\ &\text{mm} \end{aligned}$$

$$\text{Mean shell side temperature} = \frac{t_1 + t_2}{2} = \frac{180 + 140.02}{2} = 160.01^\circ\text{C}$$

$$R_e = \frac{G_s d_e}{\mu} = \frac{312.42(36.63 \times 10^{-3})}{0.0045} = 2517.926$$

$$P_r = \frac{c_p \mu}{k_f} = \frac{0.068(0.208)}{0.007947} = 1.786$$

Choose 25 per cent baffle cut where the baffle cut of 20-25% provides good heat transfer with reasonable pressure drop, from Figure 10.10 of shell-side heat-transfer factors, segmental baffles get $j_h = 0.012$.

Shell-side heat transfer coefficient,

$$h_s = \frac{j_h R_e k_f Pr^{1/3} \left(\frac{\mu}{\mu_w}\right)^{0.14}}{d_e} = \frac{0.012(2517.926)(0.208)(1.786)^{1/3}}{36.63 \times 10^{-3}} = 102.13 \text{ W/m}^2\text{C}$$

ix. Overall Coefficient

From Table 10.12 of fouling coefficient, steam condensate = 3000 W/m²°C while product mixture = 5000 W/m²°C and the thermal conductivity of material is 45 W/m²°C.

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{1}{h_{od}} + \frac{d_o \ln\left(\frac{d_o}{d_i}\right)}{2k_w} + \frac{d_o}{d_i} \times \frac{1}{h_{id}} + \frac{d_o}{d_i} \times \frac{1}{h_i}$$

$$\frac{1}{U_o} = \frac{1}{102.13} + \frac{1}{5000} + \frac{20 \ln\left(\frac{20}{16}\right)}{2(45)} + \frac{20}{16} \times \frac{1}{3000} + \frac{20}{16} \times \frac{1}{915.55}$$

$$U_o = 143.46 \text{ W/m}^2\text{C}$$

x. **10.1.7 Pressure Drop**

xi. **Tube side**

From figure 12.24 of tube side friction factor, at $R_e = 3219.852$ get $j_f = 0.0055$

$$\Delta P_t = N_p \left[8j_f \left(\frac{L'}{d_i} \right) \left(\frac{\mu}{\mu_w} \right)^{-m} + 2.5 \right] \frac{\rho(u_t)^2}{2}$$

$\Delta P_t = 6.451 \text{ kPa (0.936 psi)}$ acceptable range

xii. **Shell side**

$$\text{Linear velocity, } U_s = \frac{G_s}{\rho} = \frac{312.42}{3.065} = 101.92 \text{ m/s}$$

From Figure 12.30 of shell-side friction factors, segmental baffles, at $R_e = 2517.926$ get $j_f = 0.06$.

$$\Delta P_s = 8j_f \left(\frac{D_s}{d_e} \right) \left(\frac{L'}{l_B} \right) \frac{\rho(u_s)^2}{2} \left(\frac{\mu}{\mu_w} \right)^{-0.14}$$

$\Delta P_s = 76.32 \text{ kPa (11.07 psi)}$ acceptable range

c. **Evaporator (EV-101)**

Designed by: Azrul Zulhilmi bin Ahmad Rosli (A173752)

i. Tube Details

Tube OD of $\frac{3}{4}$ and 1 inch are very common to design an evaporator. The most efficient condition for heat transfer is to have the maximum number of tubes in the shell to increase turbulence. The tube thickness should be enough to withstand the internal pressure along with the adequate corrosion allowance. The tube thickness is expressed in terms of BWG (Birmingham Wire Gauge) and true outside diameter (OD). The tube length of 6, 8, 12, 16, 20 and 24 ft are preferably used. Longer tube reduces shell diameter at the expense of higher shell pressure drop. Finned tubes are also used when fluid with low heat transfer coefficient flows in the shell side. Transport process and separation process principle book, size for tube evaporator have been chosen:

Table A.D 10 Size for tubes in evaporator

Parameter	Value
Nominal diameter	3/4 in.
Schedule	40
Brass tube	1.8288 m
Outer diameter, do	26.67 mm
Inner diameter	20.93 mm

Source: Geankoplis 2003

Table A.D 11 Evaporator shell parameters

Parameter	Value
Type	Low carbon steel (IS-2062)
Tube material	Brass
Permissible stress for low carbon steel	980 kg/cm ²
Modulus elasticity for low carbon steel	19×10^5 kg/cm ²
Modulus of elasticity for brass	19.5×10^5 kg/cm ²

Source: Geankoplis 2003

Assumption:

- Consider a standard vertical short tube evaporator (calandria type) for this service
- Natural circulation evaporator
- Evaporator drum operated at 2 bar pressure.
- Amount of water to be evaporated: 436.27 kg/hr
- Specific heat of feed is constant for all temperature and concentrations.

- Overall heat transfer coefficient remains constant through the operation of the evaporator.
- The evaporator is operated at a steady state.
- Steam at 4 bar pressure and evaporator drum is 2 bar

Design pressure (P) = 5% more than the maximum working pressure

$$= 1.05 \times 2.0 \text{ bar} = 2.1 \text{ bar} = 2.063 \text{ kgf/cm}^2$$

Mean diameter, D_m = Tube OD – Tube Thickness = $26.67 - 2.87 = 23.8 \text{ mm} = 0.0238$

Effective of the tube (L) = Tube length – 2(Tube plate thickness) – 2 (Tube expansion allowance)(assume: 5mm)

$$= 1.8288 - 2(0.011) - 2(0.01)$$

$$= 1.7968 \text{ m}$$

The number of tubes (N) = Heating surface / π (Mean diameter) (Effective length)

$$= 23.82\text{m}^2 / \pi (0.0238\text{m}) (1.7968\text{m})$$

$$= 177$$

Tube pitch (Pt) = $1.25 \times d_o$ (recommended)= $1.25 \times 26.67 = 33.34 \text{ mm}$

Surface area of each tube, $a = \pi(\text{tube pitch})(L) = \pi (33.34 \times 10^{-3})(1.7968) = 0.92 \text{ m}^2$

ii. Area Occupied for Tubes in Tube Plate

The tube thickness is given by, $t_t = \frac{Pd_i}{2fJ-P}$

The permissible stress of brass (f) = 538 kg/cm^2 ; Welding or joint efficiency, $J = 1$ is used for seamless tube

$$\text{Therefore, } t_t = \frac{(2.063)(20.93)}{2(538)(1)-2.063} = 0.40 \text{ mm}$$

The specified thickness is 5.74 mm. Therefore, the selected tube is suitable for this service.

iii. Calandria Sheet Thickness

$$\begin{aligned}\text{Thickness is given by: } t_t &= \frac{PD_o}{2fJ+P} \\ &= \frac{(2.063)(590)}{2(980)(1)+2.063} \text{ mm} \\ &= 0.63 \text{ mm}\end{aligned}$$

Normally, the corrosion allowance of 3 mm is used for carbon steel.

It may be taken as $t_s = 10$ mm

iv. Tube Sheet Thickness

Tube plate area required for tubes only (A_T) = $(0.866 \times \text{Tube Pitch}^2 \times \text{No. of Tubes} / \text{proportional factor } (\beta)) \times \% \text{ extra}$

Where,

proportional factor (β) = Generally β value taken for multiple pass 0.6 to 0.8 and for single pass 8 to 1.0. (assume 8)

% extra = Take extra diameter in percentage on area occupied for tubes in tube plate for stay roads arrangement, free withdrawal of condensate and noxious gases removal purpose. while providing the multiple down design than this percentage may go higher side. Its value lies in the range 10 to 20% on area occupied for tubes. (assume 10%)

Tube plate area required for tubes only (A_T) = $(0.866 \times P^2 \times N / \beta) \times \% \text{ extra}$

$$A_T = (0.866)(0.03334)^2 \left(\frac{177}{8}\right)(0.1)$$

$$A_T = (0.866)(0.03334)^2 \left(\frac{177}{8}\right)(0.1)$$

$$= (0.866 * 0.033342 * 174 / 8) 10\% = 0.00639 \text{ m}^2$$

Tube plate diameter required for tubes only = $\sqrt{A_T \left(\frac{4}{\pi}\right)} = \sqrt{0.00639 \left(\frac{4}{\pi}\right)} = 0.0902 \text{ m} = 90.2 \text{ mm}$

Then,

Diameter consider less than 25% of the tube plate dia

According to E. Hugot, the diameter of the centre well varies from $\frac{1}{4}$ to $\frac{1}{8}$ of the interior diameter of the vessel.

Diameter of the single downtake = Tube plate diameter for tubes (% of downtake on tube plate)

From the above generally downtake diameter take 20% on tube plate.

$$= 90.2 * 0.2 = 18.04 \text{ mm}$$

$$\text{Area of the downtake} = \pi r^2 = \pi(0.00902) = 0.02834 \text{ m}^2$$

Diameter of the central downtake in multiple down takes design =

$$\sqrt{(area of single downtake - total area of peripheral downtake) \times \frac{4}{\pi}}$$

$$= \sqrt{(0.02834 - 0.00639) \times \frac{4}{\pi}}$$

$$= 0.167 \text{ m}$$

Final Diameter of the tube plate,

$$= \sqrt{(area of the tube plare for tube + downtake area) \times \frac{4}{\pi}}$$

$$= \sqrt{(0.02834 + 0.00693) \times \frac{4}{\pi}}$$

$$= 0.212 \text{ m (tube sheet/plate diameter)}$$

v. Evaporator Drum Diameter Determination

The following equation helps to estimate the drum diameter. The diameter of the drum may be same as that of the calandria.

$$R_d = \frac{V}{A} \times \frac{1}{(0.0172 \times \sqrt{\frac{\rho_l - \rho_v}{\rho_v}})}$$

where,

V=volumetric flow rate of vapor [m³/s]

A=cross sectional area of drum

Assume density of 73% of urea is: 1150 kg/m³

Density of water vapor (ρ_v) = PM/RT at saturated vapor temperature

$$= \frac{(4)(18)}{(8.134 \times 10^{-5})(448.15)}$$

$$= 0.966 \text{ kg/m}^3$$

Volumetric flow rate of water vapor (V): mass flowrate / (density x 3600)

$$= \frac{436.27}{(0.966)(3600)} = 0.125 \text{ m}^3/\text{s}$$

For drums having wire mesh as entrainment separator device, R_d may be taken as 1.3.

$$A = \frac{V}{R_d \times (0.0172 \times \sqrt{\frac{\rho_l - \rho_v}{\rho_v}})}$$

$$A = \frac{0.125}{0.212 \times (0.0172 \times \sqrt{\frac{1150 - 0.966}{0.966}})}$$

$$= 0.994 \text{ m}^2$$

$$\text{The drum diameter} = \sqrt{\frac{4(0.994)}{3.14}} = 1.13 \text{ m}$$

Drum height is usually taken as 2 to 5 times of tube sheet diameter

Thus, the drum height = $5 \times 0.212 = 1.06 \text{ m}$

The tube length is in between the border line of short tube (4 to 10 ft) and long tube (12 ft).

vi. Drum Thickness

Drum is operating at 2 bar pressure

Design pressure = 2.063 bar

$$= 2.104 \text{ kgf/cm}^2$$

$$\begin{aligned} \text{Drum thickness: } t_d &= \frac{PD_o}{2fJ+P} \\ &= \frac{(2.1453)(590)}{2(980)(1) + 2.1453} \end{aligned}$$

$$= 0.645 \text{ mm}$$

Therefore the same thickness of 10 mm for both the drum and calandria sheet may be used including the tolerance for corrosion.

Mechanical Design

a. Packed Bed Reactor, R-101

Designed by: Aerry Ting Wei Huan (A174141)

i. Design Specification

Volume of reactor based on Section 3.4 = 61.17 m^3

Height of ellipsoidal head to diameter ratio of 2:1

Height of reactor to internal diameter ratio of 3:1

$$V = \frac{\pi D_i^2}{4} h$$

$$61.17 = \frac{\pi D_i^2}{4} (3D_i)$$

$$81.56 = \pi D_i^3$$

$$D_i = 2.961 \text{ m}$$

Overall height of bioreactor = (3)(2.961)

$$= 8.88 \text{ m}$$

$$\text{Ellipsoidal 2:1 top head height} = \frac{D}{4} [\text{UG-32(d)}]$$

$$= (2.961)(1/4)$$

$$= 0.740 \text{ m}$$

Ellipsoidal 2:1 bottom head height = 0.740 m

Cylindrical shell height = 8.88 m - 0.74 m - 0.74 m

$$= 7.399 \text{ m}$$

ii. Design Pressure

Ellipsoidal 2:1 top head

$$P_D = 14.50 + (0.433)(2.429)$$

$$= 15.556 \text{ psi}$$

$$P_J = (1.10)(15.556)$$

$$= 17.111 \text{ psi}$$

Cylindrical shell

$$P_D = 14.50 + (0.433)(2.429+24.278)$$

$$= 26.068 \text{ psi}$$

$$P_J = (1.10)(26.068)$$

$$= 28.675 \text{ psi}$$

Ellipsoidal 2:1 bottom head

$$\begin{aligned} P_D &= 14.50 + (0.433)(2.429+24.278+2.429) \\ &= 27.120 \text{ psi} \end{aligned}$$

$$\begin{aligned} P_J &= (1.10)(27.120) \\ &= 29.832 \text{ psi} \end{aligned}$$

iii. Minimum Wall Thickness

Ellipsoidal 2:1 top head [UG-32(d)]

$$\begin{aligned} t &= \frac{PD}{2SE - 0.2P} \\ &= \frac{(17.111)(29.144)}{(2)(26600)(1.0) - (0.2)(17.111)} \\ &= 0.0094 \text{ in} \end{aligned}$$

Cylindrical shell

Circumferential stress part [UG-27(c)(1)]

$$\begin{aligned} t &= \frac{PR}{SE - 0.6P} \\ &= \frac{(28.675)(58.288)}{(26600)(1.0) - (0.6)(28.675)} \\ &= 0.0629 \text{ in} \end{aligned}$$

Longitudinal stress part [UG-27(c)(2)]

$$\begin{aligned} t &= \frac{PR}{2SE + 0.4P} \\ &= \frac{(28.675)(58.288)}{(2)(26600)(1.0) + (0.4)(28.675)} \\ &= 0.0314 \text{ in} \end{aligned}$$

Ellipsoidal 2:1 bottom head [UG-32(d)]

$$\begin{aligned} t &= \frac{PD}{2SE - 0.2P} \\ &= \frac{(29.832)(29.144)}{(2)(26600)(1.0) - (0.2)(29.832)} \\ &= 0.0163 \text{ in} \end{aligned}$$

iv. Maximum Allowable Working Pressure (MAWP)

Ellipsoidal 2:1 top head [UG-32(d)]

$$\begin{aligned}
 P &= \frac{2SEt}{D + 0.2t} \\
 &= \frac{(2)(26600)(1.0)(0.109)}{116.576 + (0.2)(0.109)} \\
 &= 49.852 \text{ psi}
 \end{aligned}$$

$$P_{\text{top}} = 49.852 - (0.433)(2.429)$$

$$= 48.800 \text{ psi}$$

Cylindrical shell

Circumferential stress part [UG-27(c)(1)]

$$\begin{aligned}
 P &= \frac{SEt}{R + 0.6t} \\
 &= \frac{(26600)(1.0)(0.109)}{58.288 + (0.6)(0.109)} \\
 &= 49.805 \text{ psi}
 \end{aligned}$$

$$P_{\text{top}} = 49.805 - (0.433)(2.429 + 24.278)$$

$$= 38.241 \text{ psi}$$

Longitudinal stress part [UG-27(c)(2)]

$$\begin{aligned}
 P &= \frac{2SEt}{R - 0.4t} \\
 &= \frac{(2)(26600)(1.0)(0.109)}{58.288 - (0.4)(0.109)} \\
 &= 99.798 \text{ psi}
 \end{aligned}$$

$$P_{\text{top}} = 99.798 - (0.433)(2.429 + 24.278)$$

$$= 88.234 \text{ psi}$$

Ellipsoidal 2:1 bottom head [UG-32(d)]

$$P = \frac{2SEt}{D + 0.2t}$$

$$= \frac{(2)(26600)(1.0)(0.109)}{116.576 + (0.2)(0.109)} \\ = 49.852 \text{ psi}$$

$$P_{\text{top}} = 49.852 - (0.433)(2.429 + 24.278 + 2.429) \\ = 37.236 \text{ psi}$$

b. Plug Flow Reactor, R-102

Designed by: Azrul Zulhilmi bin Ahmad Rosli (A173752)

i. Pressure Design

The operating pressure of R-102 is greater than atmospheric pressure. Thus, the design of the R-102 is using internal pressure. The design pressure for each part of the reactor can be calculated using equation :

$$P_D = P_O + 0.433h$$

Top hemispherical head,

$$P_D = P_O + 0.433h = 2030.53 + 0.433(0.935) = 2030.935 \text{ psi}$$

Cylindrical shell,

$$P_D = P_O + 0.433h = 2030.53 + 0.433(0.935 + 9.02) = 2034.841 \text{ psi}$$

Bottom hemispherical head,

$$P_D = P_O + 0.433h = 2030.53 + 0.433(0.935 + 9.02 + 0.935) = 2035.245 \text{ psi}$$

Use safety factor value 10% to design pressure for safety reason. The new design pressure is shown on table A.D 12 below.

Table A.D 12 New Design Pressure for R-102

Part	P _D (psi)	P _F (psi)
Hemispherical Top Head	2030.935	2234.028
Cylindrical Shell	2034.841	2238.325
Hemispherical Bottom Head	2035.245	2238.770

ii. Maximum Allowable Working Pressure, MAWP

Maximum allowable working pressure, MAWP is being calculated using internal pressure. The formula that being use is taken from ASME Code UG-32(f) for hemispherical head and UG-27(c) for cylindrical shell. Using t_{min} that have been calculated, MAWP_{vessel} is calculated.

Hemispherical top head,

$$\text{Internal Pressure} = \frac{2SET}{D+0.2t} = \frac{2(14632)(1)(0.971)}{11.22+0.2(0.971)} = 2489.47 \text{ psi}$$

$$\text{Static head, } P_H = 0.433(0.935) = 0.405 \text{ psi}$$

$$\text{MAWP}_{\text{vessel}} = \text{Internal Pressure} - P_H = 2489.07 \text{ psi}$$

Cylindrical shell,

For circumferential stress:

$$\text{Internal Pressure} = \frac{SET}{R+0.6t} = \frac{(14632)(1)(0.971)}{(22.44/2)+0.6(0.971)} = 1203.77 \text{ psi}$$

$$\text{Static head, } P_H = 0.433(0.935 + 9.02) = 4.31 \text{ psi}$$

$$\text{MAWP}_{\text{vessel}} = \text{Internal Pressure} - P_H = 1199.464 \text{ psi}$$

For longitudinal stress:

$$\text{Internal Pressure} = \frac{2SET}{R-0.4t} = \frac{2(14632)(1)(0.971)}{(22.44/2)-0.4(0.971)} = 2407.549 \text{ psi}$$

$$\text{Static head, } P_H = 0.433(0.935 + 9.02) = 4.31 \text{ psi}$$

$$\text{MAWP}_{\text{vessel}} = \text{Internal Pressure} - P_H = 2403.239 \text{ psi}$$

Hemispherical bottom head,

$$\text{Internal Pressure} = \frac{2SET}{D+0.2t} = \frac{2(14632)(1)(0.971)}{22.44+0.2(0.971)} = 2489.47 \text{ psi}$$

$$\text{Static head, } P_H = 0.433(0.935 + 9.02 + 0.935) = 4.715 \text{ psi}$$

$$\text{MAWP}_{\text{vessel}} = \text{Internal Pressure} - P_H = 2484.755 \text{ psi}$$

The summary of the internal pressure and MAWP_{vessel} is shown in table A.D 13 below.

Table A.D 13 Internal Pressure and MAWP_{vessel} for R-102

Part	MAWP _{part} (psi)	Static Head, P _H (psi)	MAWP _{vessel} (psi)
Top Hemispherical Head	2489.47	0.405	2489.07
Circumferential	1203.77	4.31	1199.464
Longitudinal	2407.55	4.31	2403.239
Bottom Hemispherical Head	2489.47	4.715	2484.755

Thus, the MAWP_{vessel} is choose from the smallest value which is 1203.77 psi (82.99 bar).

APPENDIX E**MECHANICAL DRAWING**

At here shows:

- Mechanical drawing of Packed Bed Reactor, R-101
- Mechanical drawing of Phase Separator, PS-101
- Mechanical drawing of Plug Flow Reactor, R-102
- Mechanical drawing of Cooler, CL-106
- Mechanical drawing of Condenser, CD-101

FACULTY OF ENGINEERING AND BUILT ENVIRONMENT
DEPARTMENT OF CHEMICAL AND PROCESS ENGINEERING

KKKR4852 PROJEK REKA BENTUK LOJI PROSES II

SUPERVISORS

PROF. MADY NOORHISHAM TAN KOFLI
DR. PEER MOHAMED
TAN CHUNG CHUAN (EXXONMOBIL)

PROJECT TITLE
UREA SYNTHESIS USING GREEN AMMONIA TECHNOLOGY

DRAWING TITLE
MECHANICAL DRAWING OF PACKED BED REACTOR (R-101)

GROUP MEMBERS K2

AZRUL ZULHILMI BIN AHMAD ROSLI	A173752
--------------------------------	---------

NURZULAIKHA BINTI ZULKARNAIN	A173895
------------------------------	---------

NUR IFFA BINTI RIZUAN	A173952
-----------------------	---------

AERRY TING WEI HUAN	A174141
---------------------	---------

SURIYA VATHI A/P SUBRAMANIAN	A174271
------------------------------	---------

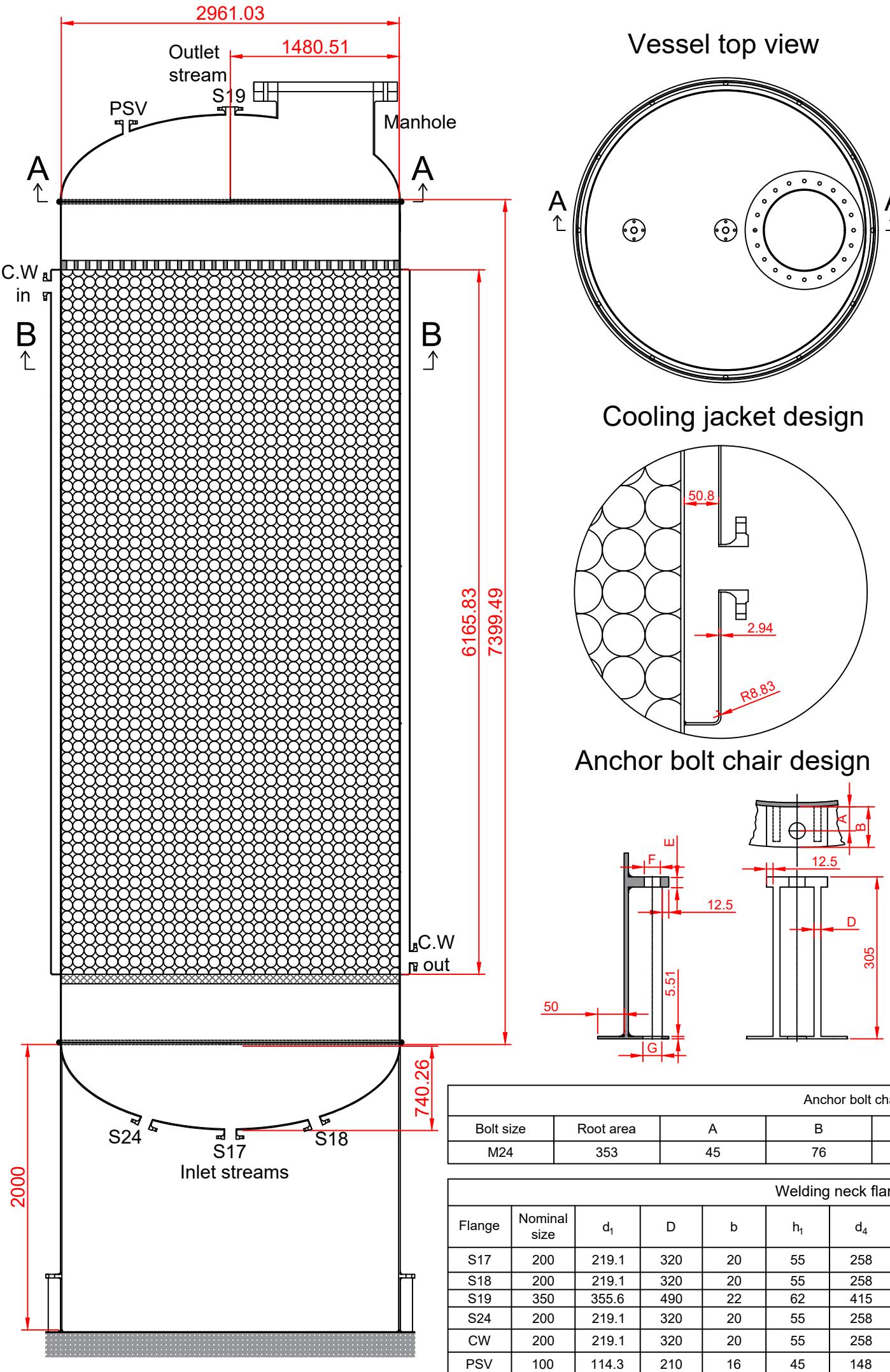
DATE
31st MAY 2023

DRAWING NOT ACCORDING TO SCALE
UNIT DIMENSION IN MM

DRAWN BY
AERRY TING WEI HUAN A174141

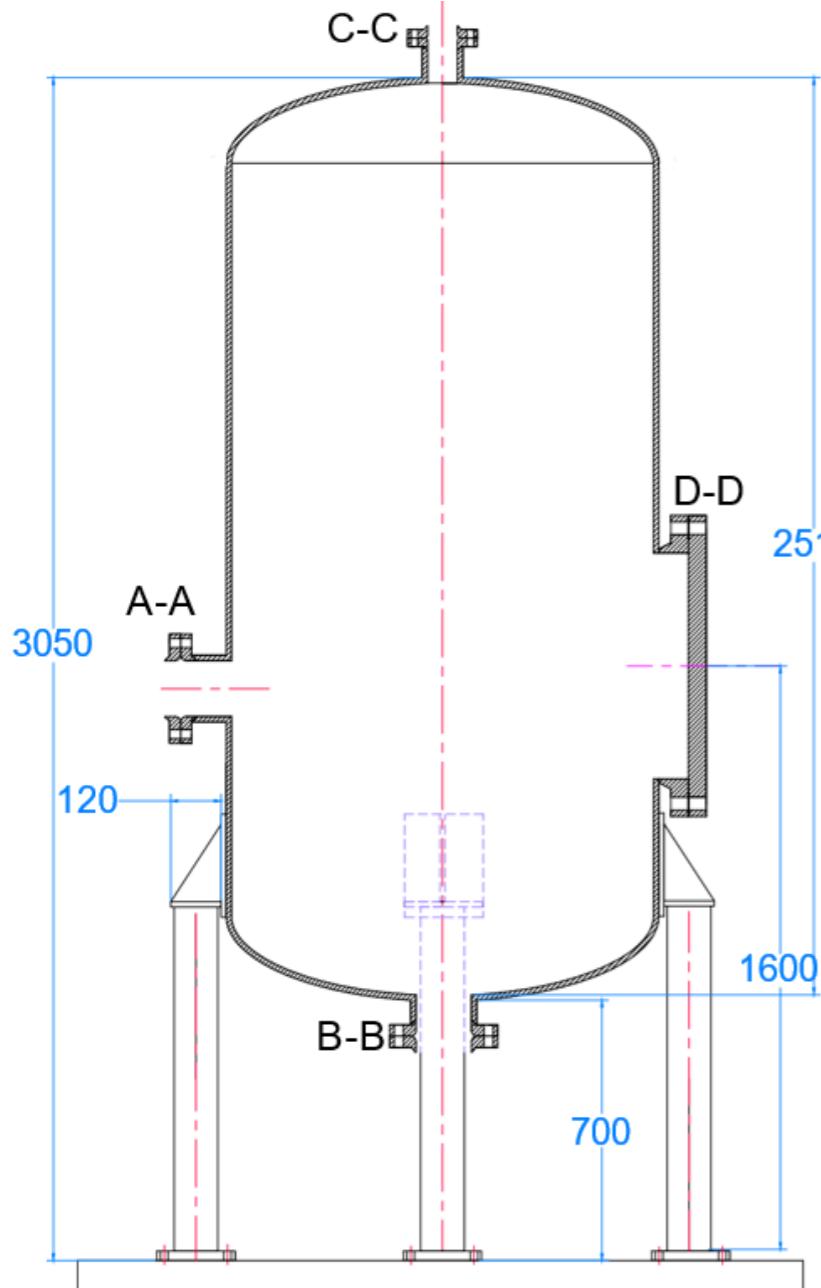
DESIGN SPECIFICATION

OPERATING TEMPERATURE	: 28°C
DESIGN TEMPERATURE	: 100°C
OPERATING PRESSURE	: 100 kPa
DESIGN PRESSURE	: 186.99 kPa
MAWP VESSEL	: 256.73 kPa
DESIGN THICKNESS	: 2.78 mm
CORROSION ALLOWANCE	: 2 mm
DESIGN STRESS	: 183400.54 kPa
INSIDE DIAMETER	: 2961.03 mm
HEIGHT	: 8880 mm
SHELL	: CYLINDRICAL
TOP HEAD	: ELLIPSOIDAL 2:1
BOTTOM HEAD	: ELLIPSOIDAL 2:1
MATERIAL USED	: STAINLESS STEEL SA-240
JOINT EFFICIENCY	: 1.0
BASED ON ASME CODE 2010	

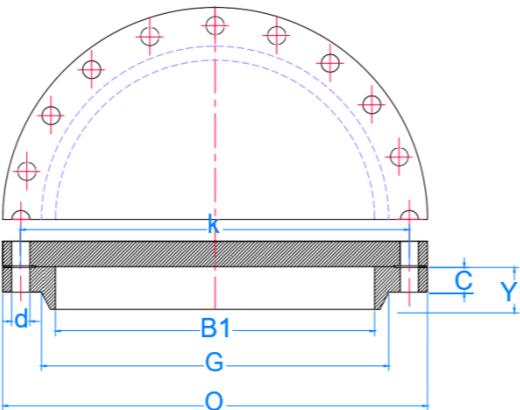


PHASE SEPARATOR PS-101

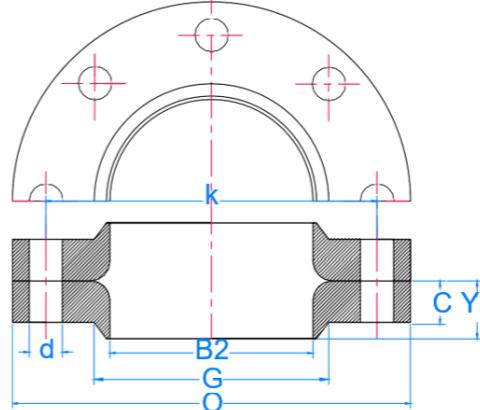
CROSS SECTIONAL
VIEW OF PHASE
SEPARATOR



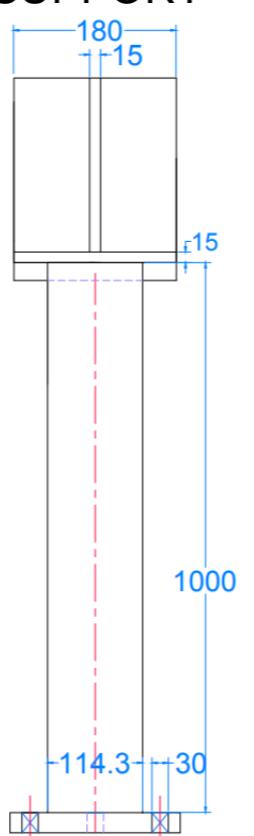
CROSS SECTIONAL
VIEW OF MANHOLE



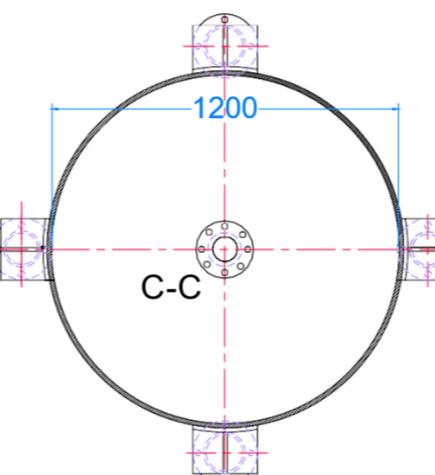
CROSS SECTIONAL
VIEW OF FLANGES



FRONT VIEW
OF BRACKET
SUPPORT



TOP VIEW
OF VESSEL



FLANGES SPECIFICATION

Connection	Nominal pipe size	Flange						Drilling		
		0	C	X	Y2	B2	Number of bolts	d	k	
A-A	100	228.5	23.9	134.9	33.3	116.8	8.0	19.1	190.5	
B-B	100	228.5	23.9	134.9	33.3	116.8	8.0	19.1	190.5	
C-C	32	117.5	15.7	58.7	20.6	43.7	4.0	15.8	88.9	

Connection	Nominal pipe size	Flange						Drilling		
		0	G	C	Y1	B1	X	Number of bolts	d	k
D-D	600	813.0	692.2	47.8	82.6	616.0	663.4	20.0	35.1	749.3

Connection	Nominal pipe size	Flange						Drilling		
		0	G	C	Y1	B1	X	Number of bolts	d	k
D-D	600	813.0	692.2	47.8	-	-	-	20.0	35.1	749.3

* All sizes in mm



Faculty of Engineering and
Built Environment
Department of Chemical and
Process Engineering

Project Title: Urea Synthesis from Green
Ammonia Technology

Drawing Title:
Mechanical Drawing of Phase Separator
PS-101

Prepared By:
Group K2

Group Members:
Azrul Zulhilmi bin Ahmad Rosli (A172752)
Nurzulaikha binti Zulkarnain (A173895)
Nur Iffa binti Rizuan (A173952)
Aerry Ting Wei Huan (A174141)
Suriya Vathi A/P Subramanian (A174271)

Supervisors:
Prof. Madya Noorhisham Tan Kofli
Dr. Peer Mohamed
Mr. Tan Chung Chuan (ExxonMobil)

Drawn By:
Nurzulaikha binti Zulkarnain (A173895)

Matric No.:
A173895

Date:
05 June 2023

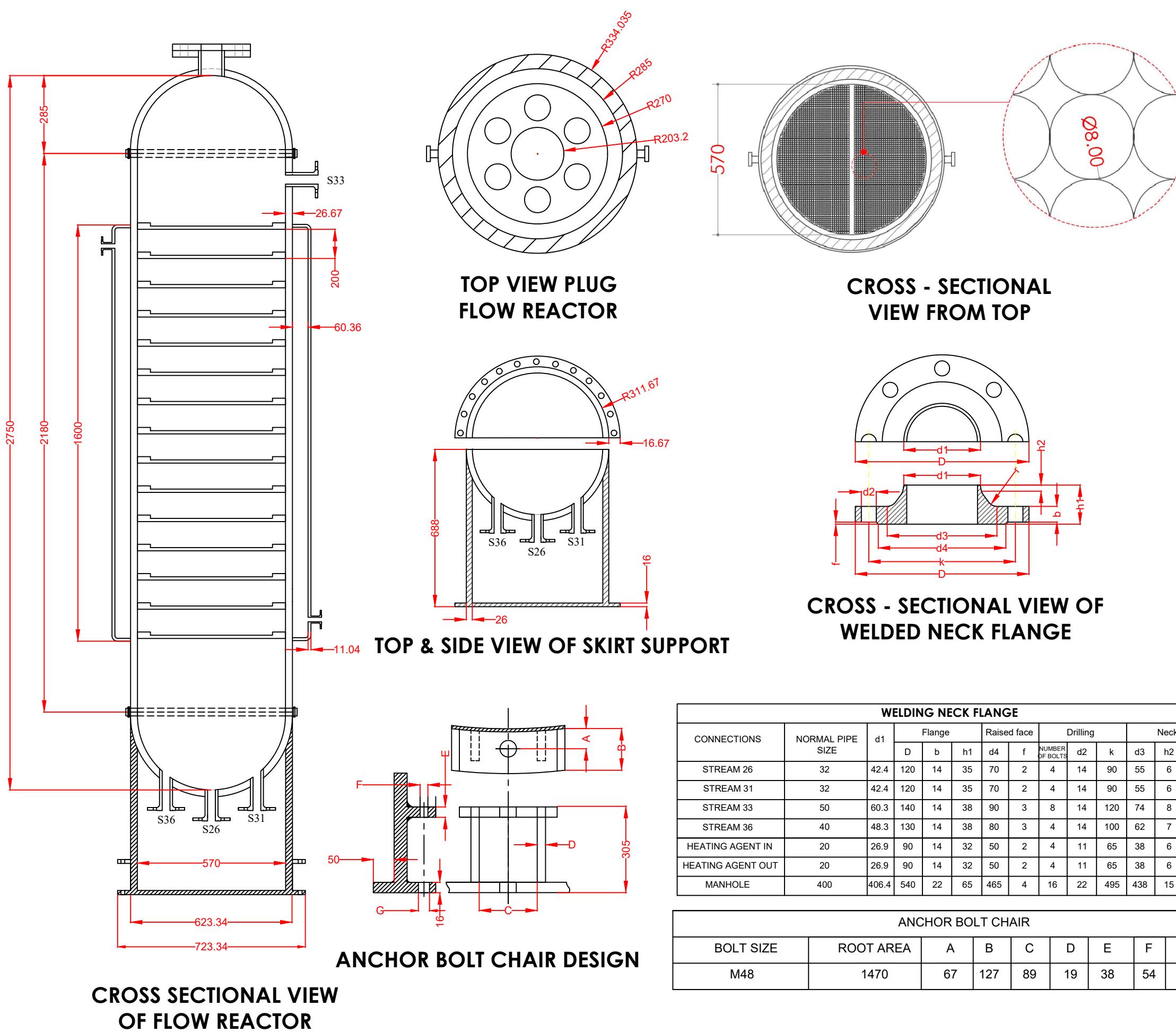
Scale:
Drawing is not according to scale

Dimension:
All dimensions in mm

Drawing No.:

Design Specification:

Internal diameter	:	1.2 m
Outer Diameter	:	1.216 m
Height	:	2.5 m
Design temperature	:	40 °C
Design pressure	:	140 bar
MAWP vessel	:	1.55 N/mm²
Wall thickness	:	8 mm
Top/bottom head	:	Torospherical
Shell	:	Cylindrical
Type of support	:	Bracket
Material	:	Stainless steel type-316



**FAKULTI KEJURUTERAAN DAN
ALAM BINA
JABATAN KEJURUTERAAN KIMIA
DAN PROSES**

**PRODUCTION OF UREA USING GREEN
AMMONIA TECHNOLOGY**

**DRAWING TITLE:
MECHANICAL DESIGN FOR PLUG FLOW
REACTOR (R-102)**

**DESIGN BY:
AZRUL ZULHILMI BIN AHMAD ROSLI
(A173752)**

SUPERVISORS:
 1) PM NOORHISHAM TAN KOFLI
 2) DR. PEER MOHAMED
 3) MR. TAN CHUNG CHUAN (EXXONMOBIL)

GROUP K1:
 1) AZRUL ZULHILMI BIN AHMAD ROSLI
(A173752)
 2) NURZULAIKHA BINTI ZULKARNIAN
(A173895)
 3) NUR IFFA BINTI RIZUAN
(A173952)
 4) AERRY TING WEI HUAN
(A174141)
 5) SURIYA VATHI A/P SUBRAMANIAN
(A174271)

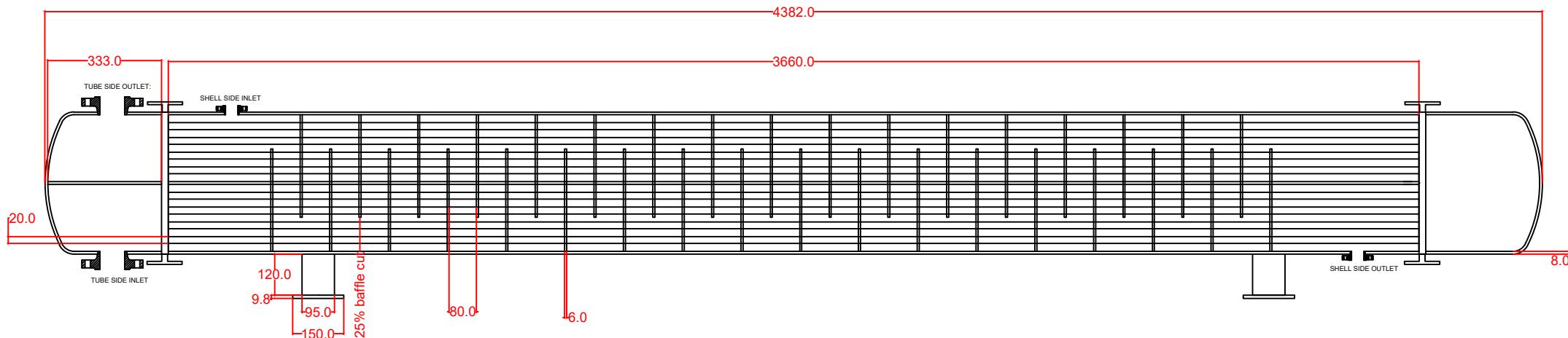
SUBMISSION DATE : 9 MAY 2023

DESIGN SPECIFICATION:

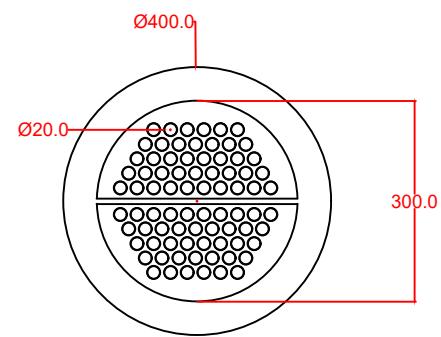
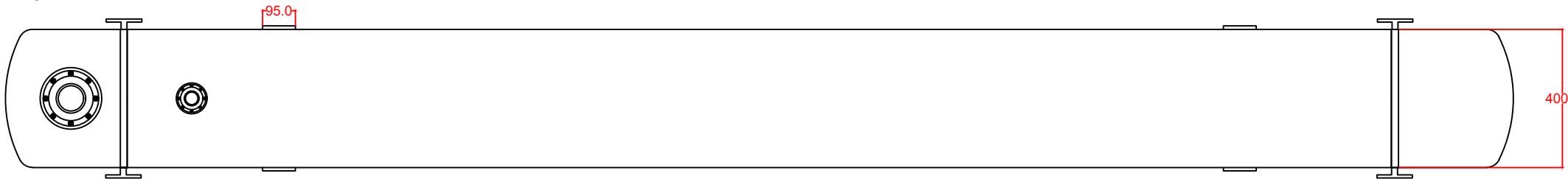
OPERATING TEMPERATURE	: 180 °C
OPERATING PRESSURE	: 140 bar
MAWPvessel	: 82.99 bar
DESIGN THICKNESS	: 24.67 mm
DESIGN STRESS	: 1008.84 bar
CORROSION ALLOWANCE	: 2 mm
JOINT EFFICIENCY	: 1.0
HEIGHT OF VESSEL	: 2.75 m
INSIDE DIAMETER	: 0.57 m
MATERIAL	: SS SA-240 GRADE-405
TOP HEAD	: HEMISPERICAL
BOTTOM HEAD SHELL	: CYLINDRICAL

**UNIT MEASUREMENT IN MM
DRAWING NOT TO SCALE**

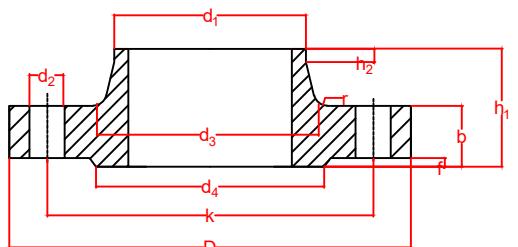
CROSS SECTIONAL VIEW:



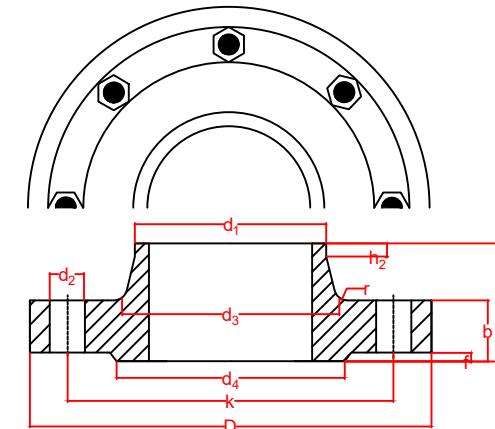
UPPER VIEW:



CROSS SECTIONAL VIEW OF TUBE BUNDLE



SIDE VIEW OF FLANGE



WELDING-NECK FLANGES

Dimensions(mm)

	d_1	D	b	h_1	d_4	f	d_2	k	d_3	h_2	r
Tube Side Inlet	114	210	16	45	148	3	18	170	130	10	8
Tube Side Outlet	139	240	18	48	178	3	18	200	155	10	8
Shell Side	269	90	14	32	50	2	11	65	38	6	4

FAKULTI KEJURUTERAAN DAN
ALAM BINA
JABATAN KEJURUTERAAN KIMIA
DAN PROSES

PRODUCTION OF UREA FROM GREEN
AMMONIA

MECHANICAL DESIGN FOR
COOLER (CL-106)

SUPERVISORS:

- 1) PROF. MADYA NOORHISHAM TAN KOFLI
- 2) DR. PEER MOHAMED
- 3) TAN CHUNG CHUAN (EXXON MOBIL)

GROUP K2:

- 1) AZRUL ZULHILMI BIN AHMAD ROSLI (A173752)
- 2) AERRY TING WE HUAN (A174141)
- 3) SURIYA VATHI A/P SUBRAMANIAN (A174271)
- 4) NURZULAIKHA BINTI ZULKARNAIN (A173895)
- 5) NUR IFFA BINTI RIZUAN (A173952)

DRAWN BY:

NUR IFFA BINTI RIZUAN (A173952)

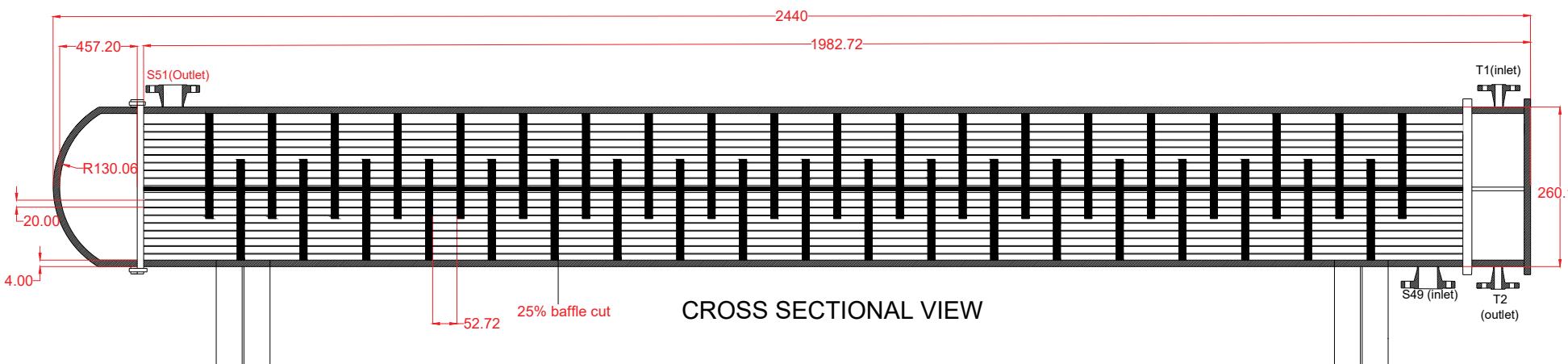
SUBMISSION DATE : 5 JUNE 2023

DESIGN SPECIFICATION:
OPERATING PRESSURE : 200.00 kPa
DESIGN PRESSURE : 239.04 kPa
MAWP VESSEL : 295.99 kPa
TEMPERATURE OF TUBE :
55.3 °C to 28°C
TEMPERATURE OF SHELL :
16 °C to 25°C
MATERIAL : 316 STAINLESS STEEL
NUMBER OF TUBE : 80
VESSEL'S HEIGHT : 4382 mm
THICKNESS : 8 mm
CORROSION ALLOWANCE, CA : 2 mm
INNER DIAMETER : 400 mm
TOP HEAD : TORISpherical
BOTTOM HEAD : TORISpherical
SHELL : CYLINDRICAL

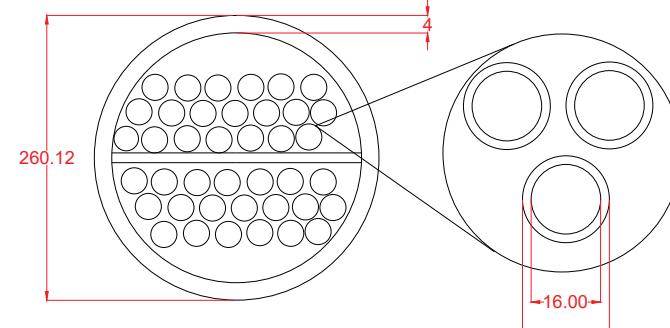
UNIT MEASUREMENT IN MM



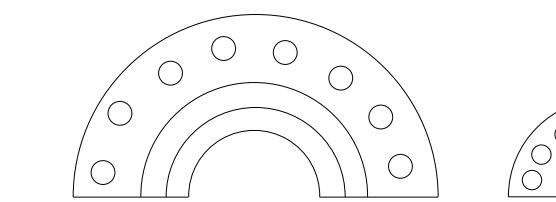
TOP VIEW



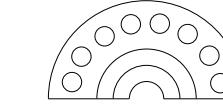
CROSS SECTIONAL VIEW



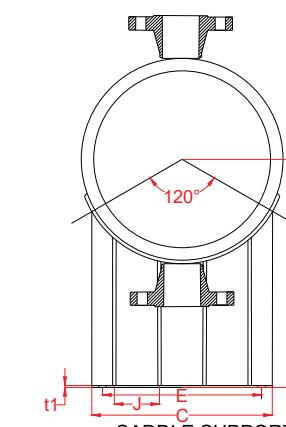
CROSS SECTIONAL VIEW OF TUBE BUNDLE



CROSS SECTIONAL VIEW OF WELDING NECK FLANGE OF SHELL



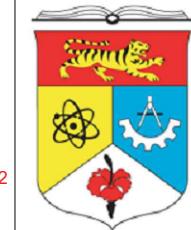
CROSS SECTIONAL VIEW OF WELDING NECK FLANGE OF TUBE



SADDLE SUPPORT

WELDING NECK FLANGE						
CONNECTIONS	NORMAL SIZE (INCH)	DIMENSIONS (mm)				
		A	B	D	X	Y
T1	1/2	21.3	15.8	90	30	46
T2	1/2	21.3	15.8	90	30	46
STREAM 49	2	60.3	52.5	150	78	62
STREAM 51	2	60.3	52.5	150	78	62
						17.5

VESSEL DIAMETER (m)	MAXIMUM WEIGHT (kN)	DIMENSIONS (mm)				
		V	C	E	J	t1
0.30	12.5	0.33	0.33	0.17	0.14	5
						20



UNIVERSITI
KEBANGSAAN
MALAYSIA
*The National University
of Malaysia*

FACULTY OF ENGINEERING AND BUILT ENVIRONMENT

CHEMICAL ENGINEERING PROGRAMME

KKKR4852 PROJEK REKA BENTUK LOJI PROSES II

SUPERVISORS
PM NOORHISYAM TAN KOFLI
DR.PEER MOHAMED
MR. TAN CHUNG CHUAN

UREA SYNTHESIS USING GREEN AMMONIA
TECHNOLOGY

MECHANICAL DESIGN OF CONDENSER (CD-101)

GROUP K2

GROUP MEMBERS
SURIYA VATHI A/P SUBRAMANIAN A174271
AZRUL ZULHILMI BIN AHMAD ROSLI A173752
NURZULAIKHA BINTI ZULKARNIAN A173892
AERRY TING WEI HUAN A174141
NUR IFFA BINTI RIZUAN A173952

DRAWN BY
SURIYA VATHI A/P SUBRAMANIAN A174271

DATE
6th MAY 2023

DRAWING NOT ACCORDING TO SCALE
UNIT DIMENSION IN MILLIMETER (MM)

DESIGN SPECIFICATIONS

DESIGN TEMPERATURE : 140°C
DESIGN PRESSURE : 1.24 Bar
MAWP VESSEL : 49.80 Bar
DESIGN STRESS : 1650 Bar
DESIGN THICKNESS : 4.00 MM
DIAMETER OF SHELL : 260.12 MM
LENGTH OF TUBE : 2440 MM
SHELL : CYLINDRICAL
TOP HEAD : TORISPHERICAL
CORROSION ALLOWANCE : 2 MM
JOINT EFFICIENCY : 1
MATERIAL USED : AUSTENITIC
STAINLESS STEEL TYPE 316
TYPE OF VESSEL SUPPORT : SADDLE SUPPORT
BASED ON ASME CODE
TYPE OF FLANGED JOINT : WELDING NECK FLANGED JOINT

APPENDIX F**MATERIAL SAFETY DATA SHEET (MSDS)**

At here shows:

- MSDS of Hydrogen, H₂
- MSDS of Oxygen, O₂
- MSDS of Nitrogen, N₂
- MSDS of Ammonia, NH₃
- MSDS of Carbon Dioxide, CO₂
- MSDS of Urea, N₂H₂CONH₂
- MSDS of Ammonium Carbamate, NH₂CO₂NH₄

SAFETY DATA SHEET

Airgas[®]
an Air Liquide company

Hydrogen

Section 1. Identification

GHS product identifier	:	Hydrogen
Chemical name	:	hydrogen
Other means of identification	:	Dihydrogen; o-Hydrogen; p-Hydrogen; Molecular hydrogen; H ₂ ; UN 1049
Product type	:	Gas.
Product use	:	Synthetic/Analytical chemistry.
Synonym	:	Dihydrogen; o-Hydrogen; p-Hydrogen; Molecular hydrogen; H ₂ ; UN 1049
SDS #	:	001026
Supplier's details	:	Airgas USA, LLC and its affiliates 259 North Radnor-Chester Road Suite 100 Radnor, PA 19087-5283 1-610-687-5253
24-hour telephone	:	1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status	:	This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).
Classification of the substance or mixture	:	FLAMMABLE GASES - Category 1 GASES UNDER PRESSURE - Compressed gas
GHS label elements	:	
Hazard pictograms	:	 
Signal word	:	Danger
Hazard statements	:	Extremely flammable gas. Contains gas under pressure; may explode if heated. May displace oxygen and cause rapid suffocation. Burns with invisible flame. May form explosive mixtures with air.
Precautionary statements	:	
General	:	Read and follow all Safety Data Sheets (SDS'S) before use. Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction. Approach suspected leak area with caution.
Prevention	:	Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.
Response	:	Leaking gas fire: Do not extinguish, unless leak can be stopped safely. In case of leakage, eliminate all ignition sources.
Storage	:	Protect from sunlight. Store in a well-ventilated place.
Disposal	:	Not applicable.
Hazards not otherwise classified	:	In addition to any other important health or physical hazards, this product may displace oxygen and cause rapid suffocation.

Section 3. Composition/information on ingredients

Substance/mixture	: Substance
Chemical name	: hydrogen
Other means of identification	: Dihydrogen; o-Hydrogen; p-Hydrogen; Molecular hydrogen; H ₂ ; UN 1049
Product code	: 001026

CAS number/other identifiers

CAS number	: 1333-74-0
-------------------	-------------

Ingredient name	%	CAS number
hydrogen	100	1333-74-0

Any concentration shown as a range is to protect confidentiality or is due to batch variation.

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Occupational exposure limits, if available, are listed in Section 8.

Section 4. First aid measures

Description of necessary first aid measures

Eye contact	: Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention if irritation occurs.
Inhalation	: Remove victim to fresh air and keep at rest in a position comfortable for breathing. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.
Skin contact	: Flush contaminated skin with plenty of water. Remove contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, soak contaminated clothing thoroughly with water before removing it. Get medical attention if symptoms occur. Wash clothing before reuse. Clean shoes thoroughly before reuse.
Ingestion	: As this product is a gas, refer to the inhalation section.

Most important symptoms/effects, acute and delayed

Potential acute health effects

Eye contact	: Contact with rapidly expanding gas may cause burns or frostbite.
Inhalation	: No known significant effects or critical hazards.
Skin contact	: Contact with rapidly expanding gas may cause burns or frostbite.
Frostbite	: Try to warm up the frozen tissues and seek medical attention.
Ingestion	: As this product is a gas, refer to the inhalation section.

Over-exposure signs/symptoms

Eye contact	: No specific data.
Inhalation	: No specific data.
Skin contact	: No specific data.
Ingestion	: No specific data.

Indication of immediate medical attention and special treatment needed, if necessary

Notes to physician	: Treat symptomatically. Contact poison treatment specialist immediately if large quantities have been ingested or inhaled.
Specific treatments	: No specific treatment.

Section 4. First aid measures

- Protection of first-aiders** : No action shall be taken involving any personal risk or without suitable training. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

See toxicological information (Section 11)

Section 5. Fire-fighting measures

Extinguishing media

- Suitable extinguishing media** : Use an extinguishing agent suitable for the surrounding fire.
- Unsuitable extinguishing media** : None known.
- Specific hazards arising from the chemical** : Contains gas under pressure. Extremely flammable gas. In a fire or if heated, a pressure increase will occur and the container may burst, with the risk of a subsequent explosion.
- Hazardous thermal decomposition products** : No specific data.
- Special protective actions for fire-fighters** : Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training. Contact supplier immediately for specialist advice. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool. If involved in fire, shut off flow immediately if it can be done without risk. If this is impossible, withdraw from area and allow fire to burn. Fight fire from protected location or maximum possible distance. Eliminate all ignition sources if safe to do so.
- Special protective equipment for fire-fighters** : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions, protective equipment and emergency procedures

- For non-emergency personnel** : Accidental releases pose a serious fire or explosion hazard. No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Shut off all ignition sources. No flares, smoking or flames in hazard area. Avoid breathing gas. Provide adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Put on appropriate personal protective equipment.
- For emergency responders** : If specialized clothing is required to deal with the spillage, take note of any information in Section 8 on suitable and unsuitable materials. See also the information in "For non-emergency personnel".
- Environmental precautions** : Ensure emergency procedures to deal with accidental gas releases are in place to avoid contamination of the environment. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods and materials for containment and cleaning up

- Small spill** : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment.
- Large spill** : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment. Note: see Section 1 for emergency contact information and Section 13 for waste disposal.

Section 7. Handling and storage

Precautions for safe handling

- Protective measures** : Put on appropriate personal protective equipment (see Section 8). Contains gas under pressure. Avoid breathing gas. Use only with adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Do not enter storage areas and confined spaces unless adequately ventilated. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.
- Use only non-sparking tools. Avoid contact with eyes, skin and clothing. Empty containers retain product residue and can be hazardous. Store and use away from heat, sparks, open flame or any other ignition source. Use explosion-proof electrical (ventilating, lighting and material handling) equipment.
- Advice on general occupational hygiene** : Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. See also Section 8 for additional information on hygiene measures.
- Conditions for safe storage, including any incompatibilities** : Store in accordance with local regulations. Store in a segregated and approved area. Store away from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see Section 10). Eliminate all ignition sources. Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F). Keep container tightly closed and sealed until ready for use. See Section 10 for incompatible materials before handling or use.

Section 8. Exposure controls/personal protection

Control parameters

Occupational exposure limits

Ingredient name	Exposure limits
hydrogen	California PEL for Chemical Contaminants (Table AC-1) (United States). Oxygen Depletion [Asphyxiant]. ACGIH TLV (United States, 3/2019). Oxygen Depletion [Asphyxiant]. Explosive potential.

- Appropriate engineering controls** : Use only with adequate ventilation. Use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits. The engineering controls also need to keep gas, vapor or dust concentrations below any lower explosive limits. Use explosion-proof ventilation equipment.

- Environmental exposure controls** : Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to the process equipment will be necessary to reduce emissions to acceptable levels.

Individual protection measures

- Hygiene measures** : Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Section 8. Exposure controls/personal protection

- Eye/face protection** : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, gases or dusts. If contact is possible, the following protection should be worn, unless the assessment indicates a higher degree of protection: safety glasses with side-shields.
- Skin protection**
- Hand protection** : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Considering the parameters specified by the glove manufacturer, check during use that the gloves are still retaining their protective properties. It should be noted that the time to breakthrough for any glove material may be different for different glove manufacturers. In the case of mixtures, consisting of several substances, the protection time of the gloves cannot be accurately estimated.
- Body protection** : Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product. When there is a risk of ignition from static electricity, wear anti-static protective clothing. For the greatest protection from static discharges, clothing should include anti-static overalls, boots and gloves.
- Other skin protection** : Appropriate footwear and any additional skin protection measures should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
- Respiratory protection** : Based on the hazard and potential for exposure, select a respirator that meets the appropriate standard or certification. Respirators must be used according to a respiratory protection program to ensure proper fitting, training, and other important aspects of use. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

Section 9. Physical and chemical properties

Appearance

- Physical state** : Gas
- Color** : Colorless.
- Odor** : Odorless.
- Odor threshold** : Not available.
- pH** : Not available.
- Melting point** : -259.15°C (-434.5°F)
- Boiling point** : -253°C (-423.4°F)
- Critical temperature** : -240.15°C (-400.3°F)
- Flash point** : Not available.
- Evaporation rate** : Not available.
- Flammability (solid, gas)** : Extremely flammable in the presence of the following materials or conditions: oxidizing materials.
- Lower and upper explosive (flammable) limits** : Lower: 4%
Upper: 76%
- Vapor pressure** : Not available.
- Vapor density** : 0.07 (Air = 1) Liquid Density@BP: 4.43 lb/ft³ (70.96 kg/m³)
- Specific Volume (ft³/lb)** : 12.0482
- Gas Density (lb/ft³)** : 0.083
- Relative density** : Not applicable.
- Solubility** : Not available.
- Solubility in water** : Not available.
- Partition coefficient: n-octanol/water** : Not available.
- Auto-ignition temperature** : 500 to 571°C (932 to 1059.8°F)
- Decomposition temperature** : Not available.

Section 9. Physical and chemical properties

Viscosity	: Not applicable.
Flow time (ISO 2431)	: Not available.
Molecular weight	: 2.02 g/mole
Aerosol product	
Heat of combustion	: -116486080 J/kg

Section 10. Stability and reactivity

Reactivity	: No specific test data related to reactivity available for this product or its ingredients.
Chemical stability	: The product is stable.
Possibility of hazardous reactions	: Under normal conditions of storage and use, hazardous reactions will not occur.
Conditions to avoid	: Avoid all possible sources of ignition (spark or flame). Do not pressurize, cut, weld, braze, solder, drill, grind or expose containers to heat or sources of ignition.
Incompatible materials	: Oxidizers
Hazardous decomposition products	: Under normal conditions of storage and use, hazardous decomposition products should not be produced.
Hazardous polymerization	: Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 11. Toxicological information

Information on toxicological effects

Acute toxicity

Not available.

Irritation/Corrosion

Not available.

Sensitization

Not available.

Mutagenicity

Not available.

Carcinogenicity

Not available.

Reproductive toxicity

Not available.

Teratogenicity

Not available.

Specific target organ toxicity (single exposure)

Not available.

Specific target organ toxicity (repeated exposure)

Not available.

Aspiration hazard

Not available.

Section 11. Toxicological information

Information on the likely routes of exposure : Not available.

Potential acute health effects

- Eye contact** : Contact with rapidly expanding gas may cause burns or frostbite.
- Inhalation** : No known significant effects or critical hazards.
- Skin contact** : Contact with rapidly expanding gas may cause burns or frostbite.
- Ingestion** : As this product is a gas, refer to the inhalation section.

Symptoms related to the physical, chemical and toxicological characteristics

- Eye contact** : No specific data.
- Inhalation** : No specific data.
- Skin contact** : No specific data.
- Ingestion** : No specific data.

Delayed and immediate effects and also chronic effects from short and long term exposure

Short term exposure

- Potential immediate effects** : Not available.
- Potential delayed effects** : Not available.

Long term exposure

- Potential immediate effects** : Not available.
- Potential delayed effects** : Not available.

Potential chronic health effects

Not available.

- General** : No known significant effects or critical hazards.
- Carcinogenicity** : No known significant effects or critical hazards.
- Mutagenicity** : No known significant effects or critical hazards.
- Teratogenicity** : No known significant effects or critical hazards.
- Developmental effects** : No known significant effects or critical hazards.
- Fertility effects** : No known significant effects or critical hazards.

Numerical measures of toxicity

Acute toxicity estimates

Not available.

Section 12. Ecological information

Toxicity

Not available.

Persistence and degradability

Not available.

Bioaccumulative potential

Not available.

Section 12. Ecological information

Mobility in soil

Soil/water partition coefficient (K_{oc}) : Not available.

Other adverse effects : No known significant effects or critical hazards.

Section 13. Disposal considerations

Disposal methods

: The generation of waste should be avoided or minimized wherever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Waste should not be disposed of untreated to the sewer unless fully compliant with the requirements of all authorities with jurisdiction. Empty Airgas-owned pressure vessels should be returned to Airgas. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Empty containers or liners may retain some product residues. Do not puncture or incinerate container.

Section 14. Transport information

	DOT	TDG	Mexico	IMDG	IATA
UN number	UN1049	UN1049	UN1049	UN1049	UN1049
UN proper shipping name	HYDROGEN, COMPRESSED	HYDROGEN, COMPRESSED	HYDROGEN COMPRESSED	HYDROGEN, COMPRESSED	HYDROGEN, COMPRESSED
Transport hazard class(es)	2.1 	2.1 	2.1 	2.1 	2.1 
Packing group	-	-	-	-	-
Environmental hazards	No.	No.	No.	No.	No.

"Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product."

Additional information

DOT Classification

: **Limited quantity** Yes.
Quantity limitation Passenger aircraft/rail: Forbidden. Cargo aircraft: 150 kg.

TDG Classification

: Product classified as per the following sections of the Transportation of Dangerous Goods Regulations: 2.13-2.17 (Class 2).

Explosive Limit and Limited Quantity Index 0.125

ERAP Index 3000

Passenger Carrying Vessel Index Forbidden

Passenger Carrying Road or Rail Index Forbidden

IATA

: **Quantity limitation** Passenger and Cargo Aircraft: Forbidden. Cargo Aircraft Only: 150 kg.

Special precautions for user

: **Transport within user's premises:** always transport in closed containers that are upright and secure. Ensure that persons transporting the product know what to do in the event of an accident or spillage.

Section 14. Transport information

Transport in bulk according to IMO instruments : Not available.

Section 15. Regulatory information

U.S. Federal regulations : TSCA 8(a) CDR Exempt/Partial exemption: This material is listed or exempted.
Clean Air Act (CAA) 112 regulated flammable substances: hydrogen

Clean Air Act Section 112 : Not listed

(b) Hazardous Air Pollutants (HAPs)

Clean Air Act Section 602 : Not listed
Class I Substances

Clean Air Act Section 602 : Not listed
Class II Substances

DEA List I Chemicals (Precursor Chemicals) : Not listed

DEA List II Chemicals (Essential Chemicals) : Not listed

SARA 302/304

Composition/information on ingredients

No products were found.

SARA 304 RQ : Not applicable.

SARA 311/312

Classification : Refer to Section 2: Hazards Identification of this SDS for classification of substance.

State regulations

Massachusetts : This material is listed.

New York : This material is not listed.

New Jersey : This material is listed.

Pennsylvania : This material is listed.

California Prop. 65

This product does not require a Safe Harbor warning under California Prop. 65.

International regulations

Chemical Weapon Convention List Schedules I, II & III Chemicals

Not listed.

Montreal Protocol

Not listed.

Stockholm Convention on Persistent Organic Pollutants

Not listed.

Rotterdam Convention on Prior Informed Consent (PIC)

Not listed.

UNECE Aarhus Protocol on POPs and Heavy Metals

Not listed.

Inventory list

Australia : This material is listed or exempted.

Canada : This material is listed or exempted.

China : This material is listed or exempted.

Europe : This material is listed or exempted.

Section 15. Regulatory information

Japan	: Japan inventory (ENCS): Not determined. Japan inventory (ISHL): Not determined.
New Zealand	: This material is listed or exempted.
Philippines	: This material is listed or exempted.
Republic of Korea	: This material is listed or exempted.
Taiwan	: This material is listed or exempted.
Thailand	: Not determined.
Turkey	: Not determined.
United States	: This material is active or exempted.
Viet Nam	: This material is listed or exempted.

Section 16. Other information

Hazardous Material Information System (U.S.A.)

Health	/	1
Flammability		4
Physical hazards		3

Caution: HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks. Although HMIS® ratings and the associated label are not required on SDSs or products leaving a facility under 29 CFR 1910.1200, the preparer may choose to provide them. HMIS® ratings are to be used with a fully implemented HMIS® program. HMIS® is a registered trademark and service mark of the American Coatings Association, Inc.

The customer is responsible for determining the PPE code for this material. For more information on HMIS® Personal Protective Equipment (PPE) codes, consult the HMIS® Implementation Manual.

National Fire Protection Association (U.S.A.)



Reprinted with permission from NFPA 704-2001, Identification of the Hazards of Materials for Emergency Response Copyright ©1997, National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association, on the referenced subject which is represented only by the standard in its entirety.

Copyright ©2001, National Fire Protection Association, Quincy, MA 02269. This warning system is intended to be interpreted and applied only by properly trained individuals to identify fire, health and reactivity hazards of chemicals. The user is referred to certain limited number of chemicals with recommended classifications in NFPA 49 and NFPA 325, which would be used as a guideline only. Whether the chemicals are classified by NFPA or not, anyone using the 704 systems to classify chemicals does so at their own risk.

Procedure used to derive the classification

Classification	Justification
FLAMMABLE GASES - Category 1 GASES UNDER PRESSURE - Compressed gas	Expert judgment According to package

History

Date of printing	: 11/15/2020
Date of issue/Date of revision	: 11/15/2020
Date of previous issue	: 9/27/2018
Version	: 1.01

Section 16. Other information

Key to abbreviations

: ATE = Acute Toxicity Estimate
BCF = Bioconcentration Factor
GHS = Globally Harmonized System of Classification and Labelling of Chemicals
IATA = International Air Transport Association
IBC = Intermediate Bulk Container
IMDG = International Maritime Dangerous Goods
LogPow = logarithm of the octanol/water partition coefficient
MARPOL = International Convention for the Prevention of Pollution From Ships, 1973
as modified by the Protocol of 1978. ("Marpol" = marine pollution)
UN = United Nations

References

: Not available.

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.

Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.



OXYGEN COMPRESSED

A-Gas (UK) Ltd

Chemwatch: 1072

Version No: 8.1

Safety data sheet according to REACH Regulation (EC) No 1907/2006, as amended by UK REACH Regulations SI 2019/758

Chemwatch Hazard Alert Code: 2

Issue Date: 20/06/2022

Print Date: 30/12/2022

L.REACH.GB.EN

SECTION 1 Identification of the substance / mixture and of the company / undertaking

1.1. Product Identifier

Product name	OXYGEN COMPRESSED
Synonyms	O2; industrial grade compressed oxygen; food grade compressed oxygen; medical oxygen EP grade; medical dry breathing oxygen; aviators dry breathing oxygen; Gas code 020,024, 025, 027, 224, 226; NZIG Medical Oxygen Code 180; Medical oxygen, compressed;; oxygen, compressed; high purity compressed; medical oxygen; cylinder oxygen
Proper shipping name	OXYGEN, COMPRESSED
Chemical formula	O O2
Other means of identification	Not Available
CAS number	7782-44-7.
EC number	231-956-9
Index number	008-001-00-8

1.2. Relevant identified uses of the substance or mixture and uses advised against

Relevant identified uses	Oxygen is used in the manufacture of steel, glass, ethylene oxide, methanol, acrolein, titanium dioxide, vinyl acetate and synthesis gas. In combination with fuel gas such as acetylene, hydrogen or liquefied petroleum gas, it is used in welding, cutting, hardening, scarffing, flame cleaning and heating. Oxygen can be considered for use in any chemical reaction where air is used to give faster reaction time and higher yields. A typical use would be in the treatment of bulk refuse and effluent. In anaesthesia, oxygen functions as a carrier gas for the delivery of anaesthetic agents to the tissues in the body. In respiratory therapy, oxygen is administered to increase its content and thus decrease the amount of other gases circulating in the blood. Oxygen is also widely used in high altitude and underwater breathing, and in hyperbaric chambers. Other medical applications are in anaesthesia and respiratory therapy.
Uses advised against	Not Applicable

1.3. Details of the manufacturer or supplier of the safety data sheet

Registered company name	A-Gas (UK) Ltd
Address	Banyard Road, Portbury West Bristol BS20 7XH United Kingdom
Telephone	+44 (0) 1275 376600
Fax	[+44] (0) 1275 376601
Website	www.agas.com
Email	info.uk@agas.com

1.4. Emergency telephone number

Association / Organisation	A-Gas (UK) Ltd	CHEMWATCH EMERGENCY RESPONSE
Emergency telephone numbers	+44 (0) 1275 376600	+44 20 3901 3542
Other emergency telephone numbers	Not Available	+44 808 164 9592

Once connected and if the message is not in your preferred language then please dial 01

SECTION 2 Hazards identification

2.1. Classification of the substance or mixture

Classified according to GB-CLP	H270 - Oxidizing Gases Category 1, H280 - Gases Under Pressure (Compressed Gas)
--------------------------------	---

OXYGEN COMPRESSED

**Regulation, UK SI 2019/720
and UK SI 2020/1567 [1]**

Legend: 1. Classified by Chemwatch; 2. Classification drawn from GB-CLP Regulation, UK SI 2019/720 and UK SI 2020/1567

2.2. Label elements

Hazard pictogram(s)



Signal word

Danger

Hazard statement(s)

H270 May cause or intensify fire; oxidiser.

H280 Contains gas under pressure; may explode if heated.

Supplementary statement(s)

EUH044 Risk of explosion if heated under confinement.

Precautionary statement(s) General

P101 If medical advice is needed, have product container or label at hand.

P102 Keep out of reach of children.

P103 Read carefully and follow all instructions.

Precautionary statement(s) Prevention

P220 Keep away from clothing and other combustible materials.

P244 Keep valves and fittings free from oil and grease.

Precautionary statement(s) Response

P370+P376 In case of fire: Stop leak if safe to do so.

Precautionary statement(s) Storage

P410+P403 Protect from sunlight. Store in a well-ventilated place.

Precautionary statement(s) Disposal

Not Applicable

2.3. Other hazards

hydrogen Listed in the Europe Regulation (EC) No 1907/2006 - Annex XVII (Restrictions may apply)

SECTION 3 Composition / information on ingredients**3.1. Substances**

1.CAS No 2.EC No 3.Index No 4.REACH No	%[weight]	Name	Classified according to GB-CLP Regulation, UK SI 2019/720 and UK SI 2020/1567	SCL / M-Factor	Nanoform Particle Characteristics
1.7782-44-7. 2.231-956-9 3.008-001-00-8 4.Not Available	>=99.5	<u>oxygen</u>	Oxidizing Gases Category 1, Gases Under Pressure (Compressed Gas); H270, H280, EUH044 [1]	Not Available	Not Available
1.7440-37-1 2.231-147-0 3.Not Available 4.Not Available	<=0.5	<u>argon</u>	Gases Under Pressure (Compressed Gas); H280, EUH044 [1]	Not Available	Not Available

Continued...

OXYGEN COMPRESSED

1.CAS No 2.EC No 3.Index No 4.REACH No	%[weight]	Name	Classified according to GB-CLP Regulation, UK SI 2019/720 and UK SI 2020/1567	SCL / M-Factor	Nanoform Particle Characteristics
1.7727-37-9. 2.231-783-9 3.Not Available 4.Not Available	< 500ppm [^]	<u>nitrogen</u>	Gases Under Pressure (Compressed Gas); H280, EUH044 ^[1]	Not Available	Not Available
1.1333-74-0 2.215-605-7 3.001-001-00-9 4.Not Available	< 500ppm [^]	<u>hydrogen</u>	Flammable Gases Category 1, Gases Under Pressure; H220, H280 ^[2]	Not Available	Not Available
Not Available	< 1ppm [^]	hydrocarbon as methane	Not Applicable	Not Applicable	Not Available

Legend: 1. Classified by Chemwatch; 2. Classification drawn from GB-CLP Regulation, UK SI 2019/720 and UK SI 2020/1567; 3. Classification drawn from C&L; * EU IOELVs available; [e] Substance identified as having endocrine disrupting properties

3.2.Mixtures

See 'Information on ingredients' in section 3.1

SECTION 4 First aid measures

4.1. Description of first aid measures

Eye Contact	<ul style="list-style-type: none"> ▶ If product comes in contact with eyes remove the patient from gas source or contaminated area. ▶ Take the patient to the nearest eye wash, shower or other source of clean water. ▶ Open the eyelid(s) wide to allow the material to evaporate. ▶ Gently rinse the affected eye(s) with clean, cool water for at least 15 minutes. Have the patient lie or sit down and tilt the head back. Hold the eyelid(s) open and pour water slowly over the eyeball(s) at the inner corners, letting the water run out of the outer corners. ▶ The patient may be in great pain and wish to keep the eyes closed. It is important that the material is rinsed from the eyes to prevent further damage. ▶ Ensure that the patient looks up, and side to side as the eye is rinsed in order to better reach all parts of the eye(s) ▶ Transport to hospital or doctor. ▶ Even when no pain persists and vision is good, a doctor should examine the eye as delayed damage may occur. ▶ If the patient cannot tolerate light, protect the eyes with a clean, loosely tied bandage. ▶ Ensure verbal communication and physical contact with the patient. <p>DO NOT allow the patient to rub the eyes DO NOT allow the patient to tightly shut the eyes DO NOT introduce oil or ointment into the eye(s) without medical advice DO NOT use hot or tepid water.</p>
Skin Contact	<p>If skin contact occurs:</p> <ul style="list-style-type: none"> ▶ Immediately remove all contaminated clothing, including footwear. ▶ Flush skin and hair with running water (and soap if available). ▶ Seek medical attention in event of irritation.
Inhalation	<ul style="list-style-type: none"> ▶ Following exposure to gas, remove the patient from the gas source or contaminated area. ▶ NOTE: Personal Protective Equipment (PPE), including positive pressure self-contained breathing apparatus may be required to assure the safety of the rescuer. ▶ Prostheses such as false teeth, which may block the airway, should be removed, where possible, prior to initiating first aid procedures. ▶ If the patient is not breathing spontaneously, administer rescue breathing. ▶ If the patient does not have a pulse, administer CPR. ▶ If medical oxygen and appropriately trained personnel are available, administer 100% oxygen. ▶ Summon an emergency ambulance. If an ambulance is not available, contact a physician, hospital, or Poison Control Centre for further instruction. ▶ Keep the patient warm, comfortable and at rest while awaiting medical care. ▶ MONITOR THE BREATHING AND PULSE, CONTINUOUSLY. ▶ Administer rescue breathing (preferably with a demand-valve resuscitator, bag-valve mask-device, or pocket mask as trained) or CPR if necessary.
Ingestion	<ul style="list-style-type: none"> ▶ Not considered a normal route of entry.

4.2 Most important symptoms and effects, both acute and delayed

See Section 11

4.3. Indication of any immediate medical attention and special treatment needed

Treat symptomatically.

Continued...

OXYGEN COMPRESSED**SECTION 5 Firefighting measures****5.1. Extinguishing media**

FOR SMALL FIRE:

- ▶ USE FLOODING QUANTITIES OF WATER.
- ▶ **DO NOT** use dry chemical, CO₂, foam or halogenated-type extinguishers.

FOR LARGE FIRE

- ▶ Flood fire area with water from a protected position

5.2. Special hazards arising from the substrate or mixture

Fire Incompatibility	▶ Avoid storage with reducing agents.
-----------------------------	---------------------------------------

5.3. Advice for firefighters

	<p>GENERAL</p> <p>Fire Fighting</p> <ul style="list-style-type: none"> ▶ Alert Fire Brigade and tell them location and nature of hazard. ▶ Wear breathing apparatus and protective gloves. ▶ Fight fire from a safe distance, with adequate cover. ▶ Use water delivered as a fine spray to control fire and cool adjacent area. <p>Fire/Explosion Hazard</p> <p>Contains low boiling substance: Closed containers may rupture due to pressure buildup under fire conditions.</p> <ul style="list-style-type: none"> ▶ The material may provide sufficient oxygen to make the fire fierce and self sustaining. ▶ Smothering action may not be effective for established fire. ▶ Intense heat may cause spontaneous decomposition (detonation). ▶ Due to possibility of reignition, extinguished residues must be thoroughly cooled before approaching.
--	---

SECTION 6 Accidental release measures**6.1. Personal precautions, protective equipment and emergency procedures**

See section 8

6.2. Environmental precautions

See section 12

6.3. Methods and material for containment and cleaning up

Minor Spills	<ul style="list-style-type: none"> ▶ Avoid breathing vapour and any contact with liquid or gas. Protective equipment including respirator should be used. ▶ DO NOT enter confined spaces where gas may have accumulated. ▶ Increase ventilation.
Major Spills	<p>Evacuate area. Eliminate all sources of ignition, NO smoking, No naked lights.</p> <ul style="list-style-type: none"> ▶ Clear area of all unprotected personnel and move upwind. ▶ Alert Emergency Authority and advise them of the location and nature of hazard. ▶ Wear breathing apparatus and protective gloves. ▶ Prevent by any means available, spillage from entering drains and water-courses. ▶ Remove leaking cylinders to a safe place. ▶ Fit vent pipes. Release pressure under safe, controlled conditions ▶ Burn issuing gas at vent pipes. ▶ DO NOT exert excessive pressure on valve; DO NOT attempt to operate damaged valve.

6.4. Reference to other sections

Personal Protective Equipment advice is contained in Section 8 of the SDS.

SECTION 7 Handling and storage**7.1. Precautions for safe handling**

Safe handling	<p>Concentrated (i.e. compressed,pure) oxygen turns most materials, including metals, into a fuel. Never use oil or grease on oxygen cylinder valves or regulators. It readily causes an explosion.</p> <ul style="list-style-type: none"> · Consider use in closed pressurised systems, fitted with temperature, pressure and safety relief valves which are vented for safe dispersal. Use only properly specified equipment which is suitable for this product, its supply pressure and temperature · The tubing network design connecting gas cylinders to the delivery system should include appropriate pressure indicators and vacuum or suction lines. · Fully-welded types of pressure gauges, where the bourdon tube sensing element is welded to the gauge body, are recommended. · Before connecting gas cylinders, ensure manifold is mechanically secure and does not contain another gas. ▶ DO NOT transfer gas from one cylinder to another.
----------------------	---

Continued...

OXYGEN COMPRESSED

Fire and explosion protection	See section 5
Other information	<ul style="list-style-type: none"> ► Cylinders should be stored in a purpose-built compound with good ventilation, preferably in the open. ► Such compounds should be sited and built in accordance with statutory requirements. ► The storage compound should be kept clear and access restricted to authorised personnel only. ► Cylinders stored in the open should be protected against rust and extremes of weather.

7.2. Conditions for safe storage, including any incompatibilities

Suitable container	<ul style="list-style-type: none"> ► Cylinder: ► Ensure the use of equipment rated for cylinder pressure. ► Ensure the use of compatible materials of construction. ► Valve protection cap to be in place until cylinder is secured, connected. ► Cylinder must be properly secured either in use or in storage.
Storage incompatibility	<p>Oxygen:</p> <ul style="list-style-type: none"> ► is a powerful oxidiser ► is non-flammable but may initiate fire or explosions, or enhance the combustibility or oxidation rate of materials that were non-combustible in air ► at high concentrations (above 24%) will promote or support and accelerate the combustion of combustible and flammable materials; noncombustible materials such as steel and other metals will burn in pure oxygen. ► reacts exothermically with many materials ► reacts explosively with phosphine, hydrazine, hydrogen sulfide, ethers, alcohols and hydrocarbons ► reacts violently with reducing agents and all easily oxidisable materials; contact may cause fire/ explosion <p>NOTE: the heat of water will vigorously vapourise liquid oxygen. The low temperature may cause brittleness on contact with some materials Keep away from clothing, lubricants, greases, elastic polymers and rubbers.</p> <p>The slightest increase in atmospheric oxygen will amplify the flammability and burning rate of any material including the human body.</p> <ul style="list-style-type: none"> ► Inorganic reducing agents react with oxidizing agents to generate heat and products that may be flammable, combustible, or otherwise reactive. Their reactions with oxidizing agents may be violent. ► Incidents involving interaction of active oxidants and reducing agents, either by design or accident, are usually very energetic and examples of so-called redox reactions. ► Avoid any contamination of this material as it is very reactive and any contamination is potentially hazardous ► Compressed gases may contain a large amount of kinetic energy over and above that potentially available from the energy of reaction produced by the gas in chemical reaction with other substances ► Avoid storage with reducing agents.



X — Must not be stored together

0 — May be stored together with specific preventions

+ — May be stored together

Note: Depending on other risk factors, compatibility assessment based on the table above may not be relevant to storage situations, particularly where large volumes of dangerous goods are stored and handled. Reference should be made to the Safety Data Sheets for each substance or article and risks assessed accordingly.

7.3. Specific end use(s)

See section 1.2

SECTION 8 Exposure controls / personal protection**8.1. Control parameters**

Ingredient	DNELs Exposure Pattern Worker	PNECs Compartment
Not Available	Not Available	Not Available

* Values for General Population

Occupational Exposure Limits (OEL)**INGREDIENT DATA**

Source	Ingredient	Material name	TWA	STEL	Peak	Notes
Not Available						

Not Applicable

Continued...

OXYGEN COMPRESSED**Emergency Limits**

Ingredient	TEEL-1	TEEL-2	TEEL-3
argon	65,000 ppm	2.30E+05 ppm	4.00E+05 ppm
nitrogen	7.96E+05 ppm	8.32E+05 ppm	8.69E+05 ppm
hydrogen	65000*** ppm	230000*** ppm	400000*** ppm

Ingredient	Original IDLH	Revised IDLH
oxygen	Not Available	Not Available
argon	Not Available	Not Available
nitrogen	Not Available	Not Available
hydrogen	Not Available	Not Available

MATERIAL DATAppO₂ 148 mm Hg NA D NA -

Sensory irritants are chemicals that produce temporary and undesirable side-effects on the eyes, nose or throat. Historically occupational exposure standards for these irritants have been based on observation of workers' responses to various airborne concentrations. Present day expectations require that nearly every individual should be protected against even minor sensory irritation and exposure standards are established using uncertainty factors or safety factors of 5 to 10 or more. On occasion animal no-observable-effect-levels (NOEL) are used to determine these limits where human results are unavailable.

For oxygen:

No exposure standards available.

NOTE: Detector tubes for oxygen, measuring in excess of 5 vol%, are commercially available

Established occupational exposure limits frequently do not take into consideration reproductive end points that are clearly below the thresholds for other toxic effects.

Occupational reproductive guidelines (ORGs) have been suggested as an additional standard. These have been established after a literature search for reproductive no-observed-adverse effect-level (NOAEL) and the lowest-observed-adverse-effect-level (LOAEL). In addition the US EPA's procedures for risk assessment for hazard identification and dose-response assessment as applied by NIOSH were used in the creation of such limits.

These exposure guidelines have been derived from a screening level of risk assessment and should not be construed as unequivocally safe limits. ORGS represent an 8-hour time-weighted average unless specified otherwise.

CR = Cancer Risk/10000; UF = Uncertainty factor:

TLV believed to be adequate to protect reproductive health:

LOD: Limit of detection

Toxic endpoints have also been identified as:

D = Developmental; R = Reproductive; TC = Transplacental carcinogen

Jankovic J., Drake F.: A Screening Method for Occupational Reproductive

American Industrial Hygiene Association Journal 57: 641-649 (1996)

8.2. Exposure controls

8.2.1. Appropriate engineering controls	Engineering controls are used to remove a hazard or place a barrier between the worker and the hazard. Well-designed engineering controls can be highly effective in protecting workers and will typically be independent of worker interactions to provide this high level of protection. The basic types of engineering controls are: Process controls which involve changing the way a job activity or process is done to reduce the risk. Enclosure and/or isolation of emission source which keeps a selected hazard "physically" away from the worker and ventilation that strategically "adds" and "removes" air in the work environment.
8.2.2. Personal protection	   
Eye and face protection	<ul style="list-style-type: none"> ▶ Safety glasses with side shields. ▶ Chemical goggles. ▶ Contact lenses may pose a special hazard; soft contact lenses may absorb and concentrate irritants. A written policy document, describing the wearing of lenses or restrictions on use, should be created for each workplace or task.
Skin protection	See Hand protection below
Hands/feet protection	<ul style="list-style-type: none"> ▶ When handling sealed and suitably insulated cylinders wear cloth or leather gloves.
Body protection	See Other protection below
Other protection	<ul style="list-style-type: none"> ▶ Overalls. ▶ PVC Apron. ▶ PVC protective suit may be required if exposure severe. ▶ Eyewash unit. ▶ Some plastic personal protective equipment (PPE) (e.g. gloves, aprons, overshoes) are not recommended as they may produce static electricity. ▶ For large scale or continuous use wear tight-weave non-static clothing (no metallic fasteners, cuffs or pockets). ▶ Non sparking safety or conductive footwear should be considered. Conductive footwear describes a boot or shoe with a sole made from a conductive compound chemically bound to the bottom components, for permanent control to electrically ground the foot and shall

Continued...

OXYGEN COMPRESSED

dissipate static electricity from the body to reduce the possibility of ignition of volatile compounds.

Respiratory protection

Full face respirator with supplied air.

- Positive pressure, full face, air-supplied breathing apparatus should be used for work in enclosed spaces if a leak is suspected or the primary containment is to be opened (e.g. for a cylinder change)
- Air-supplied breathing apparatus is required where release of gas from primary containment is either suspected or demonstrated.

8.2.3. Environmental exposure controls

See section 12

SECTION 9 Physical and chemical properties**9.1. Information on basic physical and chemical properties**

Appearance	Colourless, odourless, tasteless, neutral gas that supports combustion; slightly soluble in water (0.032 cm ³ /cm ³). Normal air contains 21% oxygen. Permanent gas, critical temperature -118.6 deg. C., critical pressure 5043 kPa. Available in black cylinders fitted with AS2473 Type 10 valve outlet.		
Physical state	Compressed Gas	Relative density (Water = 1)	Not Applicable
Odour	Not Available	Partition coefficient n-octanol / water	Not Available
Odour threshold	Not Available	Auto-ignition temperature (°C)	Not Applicable
pH (as supplied)	Not Applicable	Decomposition temperature (°C)	Not Applicable
Melting point / freezing point (°C)	Not Applicable	Viscosity (cSt)	Not Applicable
Initial boiling point and boiling range (°C)	-183	Molecular weight (g/mol)	32.00
Flash point (°C)	Not Applicable	Taste	Not Available
Evaporation rate	Not Available	Explosive properties	Not Available
Flammability	Not Applicable	Oxidising properties	Not Available
Upper Explosive Limit (%)	Not Applicable	Surface Tension (dyn/cm or mN/m)	Not Available
Lower Explosive Limit (%)	Not Applicable	Volatile Component (%vol)	100
Vapour pressure (kPa)	Not Available	Gas group	Not Available
Solubility in water	Partly miscible	pH as a solution (1%)	Not Applicable
Vapour density (Air = 1)	1.105	VOC g/L	Not Applicable
Nanoform Solubility	Not Available	Nanoform Particle Characteristics	Not Available
Particle Size	Not Available		

9.2. Other information

Not Available

SECTION 10 Stability and reactivity

10.1. Reactivity	See section 7.2
10.2. Chemical stability	Extremely high temperatures and pressures. Stable when kept isolated as a compressed gas in cylinders equipped with safety devices to release O ₂ at excessive temperatures and pressures. <ul style="list-style-type: none"> ▸ Unstable in the presence of incompatible materials. ▸ Product is considered stable. ▸ Hazardous polymerisation will not occur.
10.3. Possibility of hazardous reactions	See section 7.2
10.4. Conditions to avoid	See section 7.2
10.5. Incompatible materials	See section 7.2

Continued...

OXYGEN COMPRESSED**10.6. Hazardous decomposition products**

See section 5.3

SECTION 11 Toxicological information**11.1. Information on toxicological effects**

Inhaled	In oxygen-enriched atmospheres both the respiratory and central nervous systems may be affected. No health effects have been observed in humans exposed to concentrations of up to 80 vol% oxygen for a few hours or up to 50 vol% for 24 hours. At pressures above one atmosphere, hyperoxia may appear after 2-6 hours. Symptoms of hyperoxia include cramps, nausea, dizziness, hypothermia, amblyopia (loss of vision), bradycardia, fainting spells and convulsions capable of causing death.
Ingestion	Overexposure is unlikely in this form. Not normally a hazard due to physical form of product. Considered an unlikely route of entry in commercial/industrial environments
Skin Contact	Skin contact is not thought to have harmful health effects (as classified under EC Directives); the material may still produce health damage following entry through wounds, lesions or abrasions. Limited evidence exists, or practical experience predicts, that the material either produces inflammation of the skin in a substantial number of individuals following direct contact, and/or produces significant inflammation when applied to the healthy intact skin of animals, for up to four hours, such inflammation being present twenty-four hours or more after the end of the exposure period. Skin irritation may also be present after prolonged or repeated exposure; this may result in a form of contact dermatitis (nonallergic). The dermatitis is often characterised by skin redness (erythema) and swelling (oedema) which may progress to blistering (vesiculation), scaling and thickening of the epidermis. At the microscopic level there may be intercellular oedema of the spongy layer of the skin (spongiosis) and intracellular oedema of the epidermis. Open cuts, abraded or irritated skin should not be exposed to this material Entry into the blood-stream through, for example, cuts, abrasions, puncture wounds or lesions, may produce systemic injury with harmful effects. Examine the skin prior to the use of the material and ensure that any external damage is suitably protected.
Eye	Although the material is not thought to be an irritant (as classified by EC Directives), direct contact with the eye may produce transient discomfort characterised by tearing or conjunctival redness (as with windburn). Direct contact with the eye may not cause irritation because of the extreme volatility of the gas; however concentrated atmospheres may produce irritation after brief exposures..
Chronic	Limited evidence suggests that repeated or long-term occupational exposure may produce cumulative health effects involving organs or biochemical systems. There is some evidence that human exposure to the material may result in developmental toxicity. This evidence is based on animal studies where effects have been observed in the absence of marked maternal toxicity, or at around the same dose levels as other toxic effects but which are not secondary non-specific consequences of the other toxic effects. Principal route of occupational exposure to the gas is by inhalation. A variety of central nervous system effects can occur following prolonged exposure to oxygen at partial pressures in excess of 200 kPa: these include dizziness, impaired coordination, visual and hearing disturbances, and seizures. Prolonged exposure at/ or normal elevated pressure may cause severe thickening and scarring of tissue.

oxygen	TOXICITY Not Available	IRRIGATION Not Available
argon	TOXICITY Not Available	IRRIGATION Not Available
nitrogen	TOXICITY Not Available	IRRIGATION Not Available
hydrogen	TOXICITY Inhalation(Rat) LC50: >7500 ppm4h ^[2]	IRRIGATION Not Available
Legend:	1. Value obtained from Europe ECHA Registered Substances - Acute toxicity 2. Value obtained from manufacturer's SDS. Unless otherwise specified data extracted from RTECS - Register of Toxic Effect of chemical Substances	

OXYGEN	Inhalation (human) TCLO: 100pph (100%)/14hNil reported		
ARGON	No known carcinogenic, mutagenic or specific reproductive effects. [BOC]		
OXYGEN & ARGON & NITROGEN & HYDROGEN	No significant acute toxicological data identified in literature search.		
Acute Toxicity	X	Carcinogenicity	X
Skin Irritation/Corrosion	X	Reproductivity	X

Continued...

OXYGEN COMPRESSED

Serious Eye Damage/Irritation	X	STOT - Single Exposure	X
Respiratory or Skin sensitisation	X	STOT - Repeated Exposure	X
Mutagenicity	X	Aspiration Hazard	X

Legend: **X** – Data either not available or does not fill the criteria for classification
✓ – Data available to make classification

11.2 Information on other hazards**11.2.1. Endocrine Disruption Properties**

Not Available

11.2.2. Other Information

See Section 11.1

SECTION 12 Ecological information**12.1. Toxicity**

	Endpoint	Test Duration (hr)	Species	Value	Source
				Not Available	Not Available
	Endpoint	Test Duration (hr)	Species	Value	Source
				Not Available	Not Available
	Endpoint	Test Duration (hr)	Species	Value	Source
				Not Available	Not Available
	Endpoint	Test Duration (hr)	Species	Value	Source
				Not Available	Not Available
Legend:		Extracted from 1. IUCLID Toxicity Data 2. Europe ECHA Registered Substances - Ecotoxicological Information - Aquatic Toxicity 4. US EPA, Ecotox database - Aquatic Toxicity Data 5. ECETOC Aquatic Hazard Assessment Data 6. NITE (Japan) - Bioconcentration Data 7. METI (Japan) - Bioconcentration Data 8. Vendor Data			

DO NOT discharge into sewer or waterways.

12.2. Persistence and degradability

Ingredient	Persistence: Water/Soil	Persistence: Air
	No Data available for all ingredients	No Data available for all ingredients

12.3. Bioaccumulative potential

Ingredient	Bioaccumulation
	No Data available for all ingredients

12.4. Mobility in soil

Ingredient	Mobility
	No Data available for all ingredients

12.5. Results of PBT and vPvB assessment

	P	B	T
Relevant available data	Not Available	Not Available	Not Available
PBT	X	X	X
vPvB	X	X	X

Continued...

OXYGEN COMPRESSED

PBT Criteria fulfilled?	No
vPvB	No

12.6. Endocrine Disruption Properties

Not Available

12.7. Other adverse effects

Not Available

SECTION 13 Disposal considerations**13.1. Waste treatment methods**

Product / Packaging disposal	Place leaking oxygen cylinder(s) in a remote place away from combustibles and allow the gas to slowly bleed off to the atmosphere. To increase the rate of controlled evaporation of spilled or leaking oxygen (when desired), spray the spill with large amounts of water. (This may generate a fog and reduce visibility). <ul style="list-style-type: none"> ▶ Evaporate residue at an approved site. ▶ Return empty containers to supplier. If containers are marked non-returnable establish means of disposal with manufacturer prior to purchase. ▶ Ensure damaged or non-returnable cylinders are gas-free before disposal.
Waste treatment options	Not Available
Sewage disposal options	Not Available

SECTION 14 Transport information**Labels Required**

		
Marine Pollutant	NO	
HAZCHEM	2S	

Land transport (ADR-RID)

14.1. UN number	1072													
14.2. UN proper shipping name	OXYGEN, COMPRESSED													
14.3. Transport hazard class(es)	Class Subrisk	2.2 5.1												
14.4. Packing group	Not Applicable													
14.5. Environmental hazard	Not Applicable													
14.6. Special precautions for user	<table border="1"> <tr> <td>Hazard identification (Kemler)</td> <td>25</td> </tr> <tr> <td>Classification code</td> <td>10</td> </tr> <tr> <td>Hazard Label</td> <td>2.2 +5.1</td> </tr> <tr> <td>Special provisions</td> <td>355 655 662</td> </tr> <tr> <td>Limited quantity</td> <td>0</td> </tr> <tr> <td>Tunnel Restriction Code</td> <td>3 (E)</td> </tr> </table>		Hazard identification (Kemler)	25	Classification code	10	Hazard Label	2.2 +5.1	Special provisions	355 655 662	Limited quantity	0	Tunnel Restriction Code	3 (E)
Hazard identification (Kemler)	25													
Classification code	10													
Hazard Label	2.2 +5.1													
Special provisions	355 655 662													
Limited quantity	0													
Tunnel Restriction Code	3 (E)													

Air transport (ICAO-IATA / DGR)

14.1. UN number	1072	
14.2. UN proper shipping name	Oxygen, compressed	
14.3. Transport hazard class(es)	ICAO/IATA Class	2.2

Continued...

OXYGEN COMPRESSED

	ICAO / IATA Subrisk	5.1														
	ERG Code	2X														
14.4. Packing group	Not Applicable															
14.5. Environmental hazard	Not Applicable															
14.6. Special precautions for user	<table border="1"> <tr> <td>Special provisions</td> <td>A175 A302</td> </tr> <tr> <td>Cargo Only Packing Instructions</td> <td>200</td> </tr> <tr> <td>Cargo Only Maximum Qty / Pack</td> <td>150 kg</td> </tr> <tr> <td>Passenger and Cargo Packing Instructions</td> <td>200</td> </tr> <tr> <td>Passenger and Cargo Maximum Qty / Pack</td> <td>75 kg</td> </tr> <tr> <td>Passenger and Cargo Limited Quantity Packing Instructions</td> <td>Forbidden</td> </tr> <tr> <td>Passenger and Cargo Limited Maximum Qty / Pack</td> <td>Forbidden</td> </tr> </table>		Special provisions	A175 A302	Cargo Only Packing Instructions	200	Cargo Only Maximum Qty / Pack	150 kg	Passenger and Cargo Packing Instructions	200	Passenger and Cargo Maximum Qty / Pack	75 kg	Passenger and Cargo Limited Quantity Packing Instructions	Forbidden	Passenger and Cargo Limited Maximum Qty / Pack	Forbidden
Special provisions	A175 A302															
Cargo Only Packing Instructions	200															
Cargo Only Maximum Qty / Pack	150 kg															
Passenger and Cargo Packing Instructions	200															
Passenger and Cargo Maximum Qty / Pack	75 kg															
Passenger and Cargo Limited Quantity Packing Instructions	Forbidden															
Passenger and Cargo Limited Maximum Qty / Pack	Forbidden															

Sea transport (IMDG-Code / GGVSee)

14.1. UN number	1072							
14.2. UN proper shipping name	OXYGEN, COMPRESSED							
14.3. Transport hazard class(es)	IMDG Class	2.2						
	IMDG Subrisk	5.1						
14.4. Packing group	Not Applicable							
14.5. Environmental hazard	Not Applicable							
14.6. Special precautions for user	<table border="1"> <tr> <td>EMS Number</td> <td>F-C, S-W</td> </tr> <tr> <td>Special provisions</td> <td>355</td> </tr> <tr> <td>Limited Quantities</td> <td>0</td> </tr> </table>		EMS Number	F-C, S-W	Special provisions	355	Limited Quantities	0
EMS Number	F-C, S-W							
Special provisions	355							
Limited Quantities	0							

Inland waterways transport (ADN)

14.1. UN number	1072											
14.2. UN proper shipping name	OXYGEN, COMPRESSED											
14.3. Transport hazard class(es)	2.2	5.1										
14.4. Packing group	Not Applicable											
14.5. Environmental hazard	Not Applicable											
14.6. Special precautions for user	<table border="1"> <tr> <td>Classification code</td> <td>10</td> </tr> <tr> <td>Special provisions</td> <td>355; 655; 662</td> </tr> <tr> <td>Limited quantity</td> <td>0</td> </tr> <tr> <td>Equipment required</td> <td>PP</td> </tr> <tr> <td>Fire cones number</td> <td>0</td> </tr> </table>		Classification code	10	Special provisions	355; 655; 662	Limited quantity	0	Equipment required	PP	Fire cones number	0
Classification code	10											
Special provisions	355; 655; 662											
Limited quantity	0											
Equipment required	PP											
Fire cones number	0											

14.7. Transport in bulk according to Annex II of MARPOL and the IBC code

Not Applicable

14.8. Transport in bulk in accordance with MARPOL Annex V and the IMSBC Code

Product name	Group
oxygen	Not Available
argon	Not Available
nitrogen	Not Available
hydrogen	Not Available

14.9. Transport in bulk in accordance with the ICG Code

Product name	Ship Type

Continued...

OXYGEN COMPRESSED

Product name	Ship Type
oxygen	Not Available
argon	Not Available
nitrogen	Not Available
hydrogen	Not Available

SECTION 15 Regulatory information**15.1. Safety, health and environmental regulations / legislation specific for the substance or mixture**

oxygen is found on the following regulatory lists

Great Britain GB mandatory classification and labelling list (GB MCL)

argon is found on the following regulatory lists

FEI Equine Prohibited Substances List - Banned Substances

FEI Equine Prohibited Substances List (EPSL)

nitrogen is found on the following regulatory lists

Great Britain GB Biocidal Active Substances

hydrogen is found on the following regulatory lists

Great Britain GB mandatory classification and labelling list (GB MCL)

This safety data sheet is in compliance with the following EU legislation and its adaptations - as far as applicable - : Directives 98/24/EC, - 92/85/EEC, - 94/33/EC, - 2008/98/EC, - 2010/75/EU; Commission Regulation (EU) 2020/878; Regulation (EC) No 1272/2008 as updated through ATPs.

15.2. Chemical safety assessment

For further information please look at the Chemical Safety Assessment and Exposure Scenarios prepared by your Supply Chain if available.

ECHA SUMMARY

Ingredient	CAS number	Index No	ECHA Dossier
oxygen	7782-44-7.	008-001-00-8	Not Available

Harmonisation (C&L Inventory)	Hazard Class and Category Code(s)	Pictograms Signal Word Code(s)	Hazard Statement Code(s)
1	Ox. Gas 1	GHS03; GHS04; Dgr	H270
2	Ox. Gas 1; Comp.; Ref. Liq.	GHS03; GHS04; Dgr	H270; H280; H281

Harmonisation Code 1 = The most prevalent classification. Harmonisation Code 2 = The most severe classification.

Ingredient	CAS number	Index No	ECHA Dossier
argon	7440-37-1	Not Available	Not Available

Harmonisation (C&L Inventory)	Hazard Class and Category Code(s)	Pictograms Signal Word Code(s)	Hazard Statement Code(s)
1	Comp.	GHS04; Wng	H280
2	Comp.; Ref. Liq.	GHS04; Dgr	H280; H281

Harmonisation Code 1 = The most prevalent classification. Harmonisation Code 2 = The most severe classification.

Ingredient	CAS number	Index No	ECHA Dossier
nitrogen	7727-37-9.	Not Available	Not Available

Harmonisation (C&L Inventory)	Hazard Class and Category Code(s)	Pictograms Signal Word Code(s)	Hazard Statement Code(s)
1	Comp.	GHS04; Wng	H280
2	Comp.; Ref. Liq.; Skin Irrit. 2; Eye Irrit. 2; Acute Tox. 4; STOT SE 3; Muta. 1B; Carc. 1A; Skin Sens. 1; Aquatic Acute 1; Aquatic Chronic 1	GHS04; GHS08; Dgr; GHS09	H280; H281; H315; H319; H332; H335; H340; H350; H317; H410

Harmonisation Code 1 = The most prevalent classification. Harmonisation Code 2 = The most severe classification.

Ingredient	CAS number	Index No	ECHA Dossier
hydrogen	1333-74-0	001-001-00-9	Not Available

Harmonisation (C&L Inventory)	Hazard Class and Category Code(s)	Pictograms Signal Word Code(s)	Hazard Statement Code(s)

Continued...

OXYGEN COMPRESSED

Harmonisation (C&L Inventory)	Hazard Class and Category Code(s)	Pictograms Signal Word Code(s)	Hazard Statement Code(s)
1	Flam. Gas 1; Comp.	GHS02; GHS04; Dgr	H220; H280
2	Flam. Gas 1; Comp.; Ref. Liq.; Ox. Gas 1; Resp. Sens. 1; Muta. 1B; Carc. 1A	GHS02; GHS04; Dgr; GHS03; GHS08	H220; H280; H281; H270; H334; H340; H350

Harmonisation Code 1 = The most prevalent classification. Harmonisation Code 2 = The most severe classification.

National Inventory Status

National Inventory	Status
Australia - AIIC / Australia Non-Industrial Use	Yes
Canada - DSL	Yes
Canada - NDSL	No (oxygen; argon; nitrogen; hydrogen)
China - IECSC	Yes
Europe - EINEC / ELINCS / NLP	Yes
Japan - ENCS	No (oxygen; argon; nitrogen; hydrogen)
Korea - KECL	Yes
New Zealand - NZIoC	Yes
Philippines - PICCS	Yes
USA - TSCA	Yes
Taiwan - TCSI	Yes
Mexico - INSQ	Yes
Vietnam - NCI	Yes
Russia - FBEPH	Yes
Legend:	<i>Yes = All CAS declared ingredients are on the inventory No = One or more of the CAS listed ingredients are not on the inventory. These ingredients may be exempt or will require registration.</i>

SECTION 16 Other information

Revision Date	20/06/2022
Initial Date	04/05/2005

Full text Risk and Hazard codes

H220	Extremely flammable gas.
H281	Contains refrigerated gas; may cause cryogenic burns or injury.
H315	Causes skin irritation.
H317	May cause an allergic skin reaction.
H319	Causes serious eye irritation.
H332	Harmful if inhaled.
H334	May cause allergy or asthma symptoms or breathing difficulties if inhaled.
H335	May cause respiratory irritation.
H340	May cause genetic defects.
H350	May cause cancer.
H410	Very toxic to aquatic life with long lasting effects.

SDS Version Summary

Version	Date of Update	Sections Updated
7.1	12/12/2017	Acute Health (inhaled), Advice to Doctor, Fire Fighter (fire/explosion hazard), Physical Properties, Storage (storage incompatibility), Supplier Information, Synonyms, Toxicity and Irritation (Other)
8.1	20/06/2022	Expiration. Review and Update

Other information

Classification of the preparation and its individual components has drawn on official and authoritative sources as well as independent review by the Chemwatch Classification

Continued...

OXYGEN COMPRESSED

committee using available literature references.

The SDS is a Hazard Communication tool and should be used to assist in the Risk Assessment. Many factors determine whether the reported Hazards are Risks in the workplace or other settings. Risks may be determined by reference to Exposures Scenarios. Scale of use, frequency of use and current or available engineering controls must be considered.

For detailed advice on Personal Protective Equipment, refer to the following EU CEN Standards:

EN 166 Personal eye-protection

EN 340 Protective clothing

EN 374 Protective gloves against chemicals and micro-organisms

EN 13832 Footwear protecting against chemicals

EN 133 Respiratory protective devices

Definitions and abbreviations

PC—TWA: Permissible Concentration-Time Weighted Average

PC—STEL: Permissible Concentration-Short Term Exposure Limit

IARC: International Agency for Research on Cancer

ACGIH: American Conference of Governmental Industrial Hygienists

STEL: Short Term Exposure Limit

TEEL: Temporary Emergency Exposure Limit,

IDLH: Immediately Dangerous to Life or Health Concentrations

ES: Exposure Standard

OSF: Odour Safety Factor

NOAEL :No Observed Adverse Effect Level

LOAEL: Lowest Observed Adverse Effect Level

TLV: Threshold Limit Value

LOD: Limit Of Detection

OTV: Odour Threshold Value

BCF: BioConcentration Factors

BEI: Biological Exposure Index

AIC: Australian Inventory of Industrial Chemicals

DSL: Domestic Substances List

NDSL: Non-Domestic Substances List

IECSC: Inventory of Existing Chemical Substance in China

EINECS: European INventory of Existing Commercial chemical Substances

ELINCS: European List of Notified Chemical Substances

NLP: No-Longer Polymers

ENCS: Existing and New Chemical Substances Inventory

KECI: Korea Existing Chemicals Inventory

NZIoC: New Zealand Inventory of Chemicals

PICCS: Philippine Inventory of Chemicals and Chemical Substances

TSCA: Toxic Substances Control Act

TCSI: Taiwan Chemical Substance Inventory

INSQ: Inventario Nacional de Sustancias Químicas

NCI: National Chemical Inventory

FBEPH: Russian Register of Potentially Hazardous Chemical and Biological Substances

This document is copyright.

Apart from any fair dealing for the purposes of private study, research, review or criticism, as permitted under the Copyright Act, no part may be reproduced by any process without written permission from CHEMWATCH.

TEL (+61 3) 9572 4700.



Nitrogen, compressed

Safety Data Sheet P-4631

This SDS conforms to U.S. Code of Federal Regulations 29 CFR 1910.1200, Hazard Communication.

Issue date: 01/01/1980 Revision date: 11/10/2022 Supersedes: 02/03/2022 Version: 2.3

SECTION: 1. Product and company identification

1.1. Product identifier

Product form	: Substance
Trade name	: Nitrogen, Medipure Nitrogen, Extendapak Nitrogen
Chemical name	: Nitrogen
CAS-No.	: 7727-37-9
Formula	: N2
Other means of identification	: Dinitrogen, Refrigerant R728, Nitrogen, Medipure Nitrogen, Extendapak Nitrogen, Nitrogen - Diving Grade

1.2. Relevant identified uses of the substance or mixture and uses advised against

Use of the substance/mixture	: Industrial use Medical applications. Food applications. Diving Gas (Underwater Breathing)
------------------------------	--

1.3. Details of the supplier of the safety data sheet

Linde Inc.
10 Riverview Drive
Danbury, CT 06810-6268, USA
www.lindeus.com

Linde Inc. 1-844-44LINDE (1-844-445-4633)

1.4. Emergency telephone number

Emergency number	: Onsite Emergency: 1-800-645-4633
------------------	------------------------------------

CHEMTREC, 24 hr/day 7 days/week
— Within USA: 1-800-424-9300, Outside USA: 001-703-527-3887
(collect calls accepted, Contract 17729)

SECTION 2: Hazard identification

2.1. Classification of the substance or mixture

GHS-US classification

Simple asphyxiant SIAS
Press. Gas (Comp.) H280

2.2. Label elements

GHS US labelling

Hazard pictograms (GHS US) :



GHS04

Signal word (GHS US)	: Warning
Hazard statements (GHS US)	: H280 - CONTAINS GAS UNDER PRESSURE; MAY EXPLODE IF HEATED OSHA-H01 - MAY DISPLACE OXYGEN AND CAUSE RAPID SUFFOCATION
Precautionary statements (GHS US)	: P202 - Do not handle until all safety precautions have been read and understood. P271+P403 - Use and store only outdoors or in a well-ventilated place. CGA-PG05 - Use a back flow preventive device in the piping. CGA-PG10 - Use only with equipment rated for cylinder pressure. CGA-PG12 - Do not open valve until connected to equipment prepared for use. CGA-PG06 - Close valve after each use and when empty. CGA-PG02 - Protect from sunlight when ambient temperature exceeds 52°C (125°F).



Nitrogen, compressed

Safety Data Sheet P-4631

This SDS conforms to U.S. Code of Federal Regulations 29 CFR 1910.1200, Hazard Communication.

Issue date: 01/01/1980 Revision date: 11/10/2022 Supersedes: 02/03/2022 Version: 2.3

P304, P340, P313 - IF INHALED: Remove person to fresh air and keep comfortable for breathing. Get medical advice/attention.

2.3. Other hazards

No additional information available

2.4. Unknown acute toxicity (GHS US)

Not applicable

SECTION 3: Composition/information on ingredients

3.1. Substances

Name : Nitrogen, compressed
CAS-No. : 7727-37-9

Name	Product identifier	%
Nitrogen	(CAS-No.) 7727-37-9	99.5 – 100

3.2. Mixtures

Not applicable

SECTION 4: First aid measures

4.1. Description of first aid measures

- First-aid measures after inhalation : Remove to fresh air and keep at rest in a position comfortable for breathing. If not breathing, give artificial respiration. If breathing is difficult, trained personnel should give oxygen. Call a physician.
- First-aid measures after skin contact : Adverse effects not expected from this product.
- First-aid measures after eye contact : Adverse effects not expected from this product. In case of eye irritation: Rinse immediately with plenty of water. Consult an ophthalmologist if irritation persists.
- First-aid measures after ingestion : Ingestion is not considered a potential route of exposure.

4.2. Most important symptoms and effects, both acute and delayed

No additional information available

4.3. Indication of any immediate medical attention and special treatment needed

None.

SECTION 5: Firefighting measures

5.1. Extinguishing media

Suitable extinguishing media : Use extinguishing media appropriate for surrounding fire.

5.2. Special hazards arising from the substance or mixture

Reactivity : Under certain conditions, nitrogen can react violently with lithium, neodymium, titanium (above 1472°F/800°C), or magnesium to form nitrides. At high temperature, it can also combine with oxygen and hydrogen.

5.3. Advice for firefighters

- Firefighting instructions : Evacuate all personnel from the danger area. Use self-contained breathing apparatus (SCBA) and protective clothing. Immediately cool containers with water from maximum distance. Stop flow of gas if safe to do so, while continuing cooling water spray. Remove ignition sources if safe to do so. Remove containers from area of fire if safe to do so. On-site fire brigades must comply with OSHA 29 CFR 1910.156 and applicable standards under 29 CFR 1910 Subpart L—Fire Protection.
- Protection during firefighting : Compressed gas: asphyxiant. Suffocation hazard by lack of oxygen.
- Special protective equipment for fire fighters : Standard protective clothing and equipment (Self Contained Breathing Apparatus) for fire fighters.



Nitrogen, compressed

Safety Data Sheet P-4631

This SDS conforms to U.S. Code of Federal Regulations 29 CFR 1910.1200, Hazard Communication.

Issue date: 01/01/1980 Revision date: 11/10/2022 Supersedes: 02/03/2022 Version: 2.3

Specific methods

- : Use fire control measures appropriate for the surrounding fire. Exposure to fire and heat radiation may cause gas containers to rupture. Cool endangered containers with water spray jet from a protected position. Prevent water used in emergency cases from entering sewers and drainage systems.
 - Stop flow of product if safe to do so.
 - Use water spray or fog to knock down fire fumes if possible.

SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures

- General measures
- : Evacuate area. Ensure adequate air ventilation. Wear self-contained breathing apparatus when entering area unless atmosphere is proven to be safe. Stop leak if safe to do so.

6.1.1. For non-emergency personnel

No additional information available

6.1.2. For emergency responders

No additional information available

6.2. Environmental precautions

No additional information available

6.3. Methods and material for containment and cleaning up

No additional information available

6.4. Reference to other sections

See also sections 8 and 13.

SECTION 7: Handling and storage

7.1. Precautions for safe handling

Precautions for safe handling

- : Wear leather safety gloves and safety shoes when handling cylinders. Protect containers from physical damage; do not drag, roll, slide or drop. While moving cylinder, always keep in place removable valve cover. Never attempt to lift a cylinder by its cap; the cap is intended solely to protect the valve. When moving cylinders, even for short distances, use a cart (trolley, hand truck, etc.) designed to transport cylinders. Never insert an object (e.g. wrench, screwdriver, pry bar) into cap openings; doing so may damage the valve and cause a leak. Use an adjustable strap wrench to remove over-tight or rusted caps. Slowly open the valve. If the valve is hard to open, discontinue use and contact your supplier. Close the container valve after each use; keep closed even when empty. Never apply flame or localized heat directly to any part of the container. High temperatures may damage the container and could cause the pressure relief device to fail prematurely, venting the container contents. For other precautions in using this product, see section 16.

Safe use of the product

- : **The suitability of this product as a component in underwater breathing gas mixtures** is to be determined by or under the supervision of personnel experienced in the use of underwater breathing gas mixtures and familiar with the physiological effects, methods employed, frequency and duration of use, hazards, side effects, and precautions to be taken.

7.2. Conditions for safe storage, including any incompatibilities

Storage conditions

- : Store in a cool, well-ventilated place. Store and use with adequate ventilation. Store only where temperature will not exceed 125°F (52°C). Firmly secure containers upright to keep them from falling or being knocked over. Install valve protection cap firmly in place by hand. Store full and empty containers separately. Use a first-in, first-out inventory system to prevent storing full containers for long periods.

OTHER PRECAUTIONS FOR HANDLING, STORAGE, AND USE: When handling product under pressure, use piping and equipment adequately designed to withstand the pressures to be encountered. Never work on a pressurized system. Use a back flow preventive device in the piping. Gases can cause rapid suffocation because of oxygen deficiency; store and use with adequate ventilation. If a leak occurs, close the container valve and blow down the system in a safe and environmentally correct manner in compliance with all international, federal/national, state/provincial, and local laws; then repair the leak. Never place a container where it may become part of an electrical circuit.



Nitrogen, compressed

Safety Data Sheet P-4631

This SDS conforms to U.S. Code of Federal Regulations 29 CFR 1910.1200, Hazard Communication.

Issue date: 01/01/1980 Revision date: 11/10/2022 Supersedes: 02/03/2022 Version: 2.3

7.3. Specific end use(s)

None.

SECTION 8: Exposure controls/personal protection

8.1. Control parameters

Nitrogen, compressed (7727-37-9)	
ACGIH	Not established
USA OSHA	Not established

Nitrogen (7727-37-9)	
ACGIH	Not established
USA OSHA	Not established

8.2. Exposure controls

Appropriate engineering controls

: Use a local exhaust system with sufficient flow velocity to maintain an adequate supply of air in the worker's breathing zone. Mechanical (general): General exhaust ventilation may be acceptable if it can maintain an adequate supply of air.

Eye protection

: Wear safety glasses with side shields.

Skin and body protection

: Wear metatarsal shoes and work gloves for cylinder handling, and protective clothing where needed. Wear appropriate chemical gloves during cylinder changeout or wherever contact with product is possible.

Respiratory protection

: When workplace conditions warrant respirator use, follow a respiratory protection program that meets or exceeds the requirements of the appropriate Health and Safety Regulations. Use an air-supplied or air-purifying cartridge if the action level is exceeded. Ensure that the respirator has the appropriate protection factor for the exposure level. If cartridge type respirators are used, the cartridge must be appropriate for the chemical exposure. For emergencies or instances with unknown exposure levels, use a self-contained breathing apparatus (SCBA).

SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

Physical state	: Gas
Appearance	: Colourless gas.
Molecular mass	: 28 g/mol
Colour	: Colourless.
Odour	: No odour warning properties.
Odour threshold	: No data available
pH	: Not applicable.
Relative evaporation rate (butylacetate=1)	: No data available
Relative evaporation rate (ether=1)	: Not applicable.
Melting point	: -210 °C
Freezing point	: No data available
Boiling point	: -195.8 °C
Flash point	: No data available
Critical temperature	: -149.9 °C
Auto-ignition temperature	: Not applicable.
Decomposition temperature	: No data available
Flammability (solid, gas)	: No data available
Vapour pressure	: Not applicable.
Critical pressure	: 3390 kPa
Relative vapour density at 20 °C	: No data available
Relative density	: No data available
Density	: 1.16 kg/m³



Nitrogen, compressed

Safety Data Sheet P-4631

This SDS conforms to U.S. Code of Federal Regulations 29 CFR 1910.1200, Hazard Communication.

Issue date: 01/01/1980 Revision date: 11/10/2022 Supersedes: 02/03/2022 Version: 2.3

Relative gas density	: 0.97
Solubility	: Water: 20 mg/l
Partition coefficient n-octanol/water (Log Pow)	: Not applicable.
Partition coefficient n-octanol/water (Log Kow)	: Not applicable.
Viscosity, kinematic	: Not applicable.
Viscosity, dynamic	: Not applicable.
Explosive properties	: Not applicable.
Oxidizing properties	: None.
Explosive limits	: No data available

9.2. Other information

Gas group	: Compressed gas
Additional information	: None.

SECTION 10: Stability and reactivity

10.1. Reactivity

Under certain conditions, nitrogen can react violently with lithium, neodymium, titanium (above 1472°F/800°C), or magnesium to form nitrides. At high temperature, it can also combine with oxygen and hydrogen.

10.2. Chemical stability

Stable under normal conditions.

10.3. Possibility of hazardous reactions

May occur.

10.4. Conditions to avoid

None under recommended storage and handling conditions (see section 7).

10.5. Incompatible materials

None.

10.6. Hazardous decomposition products

None.

SECTION 11: Toxicological information

11.1. Information on toxicological effects

Acute toxicity (oral)	: Not classified
Acute toxicity (dermal)	: Not classified
Acute toxicity (inhalation)	: Not classified

Skin corrosion/irritation	: Not classified pH: Not applicable.
Serious eye damage/irritation	: Not classified pH: Not applicable.
Respiratory or skin sensitisation	: Not classified
Germ cell mutagenicity	: Not classified
Carcinogenicity	: Not classified
Reproductive toxicity	: Not classified
STOT-single exposure	: Not classified



Nitrogen, compressed

Safety Data Sheet P-4631

This SDS conforms to U.S. Code of Federal Regulations 29 CFR 1910.1200, Hazard Communication.

Issue date: 01/01/1980 Revision date: 11/10/2022 Supersedes: 02/03/2022 Version: 2.3

STOT-repeated exposure : Not classified

Aspiration hazard : Not classified

SECTION 12: Ecological information

12.1. Toxicity

Ecology - general : No ecological damage caused by this product.

12.2. Persistence and degradability

Nitrogen, compressed (7727-37-9)

Persistence and degradability	No ecological damage caused by this product.
-------------------------------	--

Nitrogen (7727-37-9)

Persistence and degradability	No ecological damage caused by this product.
-------------------------------	--

12.3. Bioaccumulative potential

Nitrogen, compressed (7727-37-9)

Partition coefficient n-octanol/water (Log Pow)	Not applicable.
---	-----------------

Partition coefficient n-octanol/water (Log Kow)	Not applicable.
---	-----------------

Bioaccumulative potential	No ecological damage caused by this product.
---------------------------	--

Nitrogen (7727-37-9)

Partition coefficient n-octanol/water (Log Pow)	Not applicable for inorganic products.
---	--

Partition coefficient n-octanol/water (Log Kow)	Not applicable.
---	-----------------

Bioaccumulative potential	No ecological damage caused by this product.
---------------------------	--

12.4. Mobility in soil

Nitrogen, compressed (7727-37-9)

Mobility in soil	No data available.
------------------	--------------------

Ecology - soil	No ecological damage caused by this product.
----------------	--

Nitrogen (7727-37-9)

Mobility in soil	No data available.
------------------	--------------------

Ecology - soil	No ecological damage caused by this product.
----------------	--

12.5. Other adverse effects

Effect on the ozone layer : None.

Effect on global warming : None.

SECTION 13: Disposal considerations

13.1. Waste treatment methods

Product/Packaging disposal recommendations : Dispose of contents/container in accordance with local/regional/national/international regulations. Contact supplier for any special requirements.

SECTION 14: Transport information

In accordance with DOT

Transport document description (DOT) : UN1066 Nitrogen, compressed, 2.2

UN-No.(DOT) : UN1066

Proper Shipping Name (DOT) : Nitrogen, compressed

Class (DOT) : 2.2 - Class 2.2 - Non-flammable compressed gas 49 CFR 173.115

Hazard labels (DOT) : 2.2 - Non-flammable gas





Nitrogen, compressed

Safety Data Sheet P-4631

This SDS conforms to U.S. Code of Federal Regulations 29 CFR 1910.1200, Hazard Communication.

Issue date: 01/01/1980 Revision date: 11/10/2022 Supersedes: 02/03/2022 Version: 2.3

Additional information

- Emergency Response Guide (ERG) Number : 121
- Other information : No supplementary information available.
- Special transport precautions : Avoid transport on vehicles where the load space is not separated from the driver's compartment. Ensure vehicle driver is aware of the potential hazards of the load and knows what to do in the event of an accident or an emergency. Before transporting product containers:
- Ensure there is adequate ventilation. - Ensure that containers are firmly secured. - Ensure valve is closed and not leaking. - Ensure valve outlet cap nut or plug (where provided) is correctly fitted. - Ensure valve protection device (where provided) is correctly fitted.

Transport by sea

- UN-No. (IMDG) : 1066
- Proper Shipping Name (IMDG) : NITROGEN, COMPRESSED
- Class (IMDG) : 2 - Gases
- Division (IMDG) : 2.2 - Non-flammable, non-toxic gases
- MFAG-No : 121

Air transport

- UN-No. (IATA) : 1066
- Proper Shipping Name (IATA) : Nitrogen, compressed
- Class (IATA) : 2.2 - Gases : Non-flammable, non-toxic
- Civil Aeronautics Law : Gases under pressure/Gases nonflammable nontoxic under pressure(Hazardous materials notice Appended Table 1 Article 194 of the Enforcement Regulations)

SECTION 15: Regulatory information

15.1. US Federal regulations

Nitrogen, compressed (7727-37-9)

Listed on the United States TSCA (Toxic Substances Control Act) inventory

All components of this product are listed, or excluded from listing, on the United States Environmental Protection Agency Toxic Substances Control Act (TSCA) inventory.

15.2. International regulations

CANADA

Nitrogen, compressed (7727-37-9)

Listed on the Canadian DSL (Domestic Substances List)

Nitrogen (7727-37-9)

Listed on the Canadian DSL (Domestic Substances List)

EU-Regulations

Nitrogen, compressed (7727-37-9)

Listed on the EEC inventory EINECS (European Inventory of Existing Commercial Chemical Substances)



Nitrogen, compressed

Safety Data Sheet P-4631

This SDS conforms to U.S. Code of Federal Regulations 29 CFR 1910.1200, Hazard Communication.

Issue date: 01/01/1980 Revision date: 11/10/2022 Supersedes: 02/03/2022 Version: 2.3

15.2.2. National regulations

Nitrogen, compressed (7727-37-9)

Listed introduction on Australian Industrial Chemicals Introduction Scheme (AICIS Inventory)

Listed on IECSC (Inventory of Existing Chemical Substances Produced or Imported in China)

Listed on KECL/KECI (Korean Existing Chemicals Inventory)

Listed on NZIoC (New Zealand Inventory of Chemicals)

Listed on PICCS (Philippines Inventory of Chemicals and Chemical Substances)

Listed on INSQ (Mexican National Inventory of Chemical Substances)

Listed on the TCSI (Taiwan Chemical Substance Inventory)

15.3. US State regulations

Nitrogen, compressed(7727-37-9)

U.S. - California - Proposition 65 - Carcinogens List	No
U.S. - California - Proposition 65 - Developmental Toxicity	No
U.S. - California - Proposition 65 - Reproductive Toxicity - Female	No
U.S. - California - Proposition 65 - Reproductive Toxicity - Male	No
State or local regulations	U.S. - Massachusetts - Right To Know List U.S. - New Jersey - Right to Know Hazardous Substance List U.S. - Pennsylvania - RTK (Right to Know) List

California Proposition 65 - This product does not contain any substances known to the state of California to cause cancer, developmental and/or reproductive harm

Nitrogen (7727-37-9)

U.S. - California - Proposition 65 - Carcinogens List	U.S. - California - Proposition 65 - Developmental Toxicity	U.S. - California - Proposition 65 - Reproductive Toxicity - Female	U.S. - California - Proposition 65 - Reproductive Toxicity - Male	No significant risk level (NSRL)
No	No	No	No	

Nitrogen (7727-37-9)

U.S. - Massachusetts - Right To Know List

U.S. - New Jersey - Right to Know Hazardous Substance List

U.S. - Pennsylvania - RTK (Right to Know) List



Nitrogen, compressed

Safety Data Sheet P-4631

This SDS conforms to U.S. Code of Federal Regulations 29 CFR 1910.1200, Hazard Communication.

Issue date: 01/01/1980 Revision date: 11/10/2022 Supersedes: 02/03/2022 Version: 2.3

SECTION 16: Other information

Other information

- : When you mix two or more chemicals, you can create additional, unexpected hazards. Obtain and evaluate the safety information for each component before you produce the mixture. Consult an industrial hygienist or other trained person when you evaluate the end product. Before using any plastics, confirm their compatibility with this product.

Linde asks users of this product to study this SDS and become aware of the product hazards and safety information. To promote safe use of this product, a user should (1) notify employees, agents, and contractors of the information in this SDS and of any other known product hazards and safety information, (2) furnish this information to each purchaser of the product, and (3) ask each purchaser to notify its employees and customers of the product hazards and safety information.

The opinions expressed herein are those of qualified experts within Linde Inc. We believe that the information contained herein is current as of the date of this Safety Data Sheet. Since the use of this information and the conditions of use are not within the control of Linde Inc, it is the user's obligation to determine the conditions of safe use of the product.

Linde SDSs are furnished on sale or delivery by Linde or the independent distributors and suppliers who package and sell our products. To obtain current SDSs for these products, contact your sales representative, local distributor, or supplier, or download from www.lindeus.com. If you have questions regarding Linde SDSs, would like the document number and date of the latest SDS, or would like the names of the Linde suppliers in your area, phone or write the Linde Call Center (Phone: 1-844-44-Linde (1-844-445-4633); Address: Linde Call Center, Linde Inc, P.O. Box 44, Tonawanda, NY 14151-0044).

Linde and the Linde wordmark are trademarks or registered trademarks of Linde Inc. or its affiliates. The information contained herein is offered for use by technically qualified personnel at their discretion and risk without warranty of any kind.

Copyright © 2022, Linde Inc.

Revision date

- : 11/10/2022

NFPA health hazard

- : 0 - Materials that, under emergency conditions, would offer no hazard beyond that of ordinary combustible materials.

NFPA fire hazard

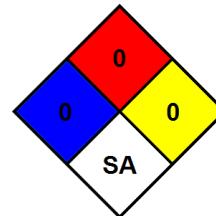
- : 0 - Materials that will not burn under typical fire conditions, including intrinsically noncombustible materials such as concrete, stone, and sand.

NFPA instability

- : 0 - Material that in themselves are normally stable, even under fire conditions.

NFPA specific hazard

- : SA - Materials that are simple asphyxiants.



SDS US (GHS HazCom 2012) - Linde 2022

This information is based on our current knowledge and is intended to describe the product for the purposes of health, safety and environmental requirements only. It should not therefore be construed as guaranteeing any specific property of the product.



Safety Data Sheet

1. Product Identifier and Company Identification

Product name	: Anhydrous Ammonia	
HBCC SDS number	: CA10000	
Synonym	: Ammonia; NH ₃	
Product use and Restrictions	: Refer to label or call	
Manufacturer	: Corporate Headquarters	Corporate Safety & Compliance
Contact Address	Hill Brothers Chemical Company 3000 E Birch St, Suite 108 Brea, California 92821 714-998-8800 800-821-7234	Hill Brothers Chemical Company 7121 West Bell Road, Suite 250 Glendale, Arizona 85308 623-535-9955 - Office 623-535-9944 - Fax
Emergency telephone Number (Chemtrec)	: 800-424-9300	
Website	: https://hillbrothers.com	

2. Hazard Identification

Classification	: Flammable Gases – Category 2 Gases Under Pressure – Compressed Gas Acute Toxicity: Inhalation – Category 3 Skin Corrosion/Irritation – Category 1B Serious Eye Damage/Eye Irritation – Category 1 Aquatic Toxicity (Chronic) – Category 1
Signal Word	: DANGER
Pictogram(s)	:
Hazard Statements	: H221 Flammable Gas. H280 Contains gas under pressure; may explode if heated. H331 Toxic if inhaled. H314 Causes severe skin burns and eye damage. H410 Very toxic to aquatic life with long lasting effects.

Precautionary Statements

Response

- : P304 + P340 + P311: IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing. Immediately call a POISON CENTER or doctor.
- : P301 + P330 + P331+P310: IF SWALLOWED: Rinse mouth. Immediately call a POISON CENTER or physician. Do NOT induce vomiting.
- : P303 + P361 + P353 + P363+P310: IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water or shower. Wash contaminated clothing before reuse. Immediately call a POISON CENTER or doctor.
- : P305 + P351 + P338 + P310: IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a POISON CENTER or doctor.

Prevention

- : P280: Wear protective gloves, protective clothing, eye protection and face protection.
- : P210: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. – No Smoking.
- : P271: Use only outdoors or in a well-ventilated area.
- : P273: Avoid release to the environment.
- : P260: Do NOT breathe gas or vapors.
- : P264: Wash hands thoroughly after handling.
- : P391: Collect spillage.
- : P377: Leaking gas fire: Do not extinguish, unless can leak be stopped safely.
- : P381: In case of leakage, eliminate all ignition sources.

Storage

- : P405: Store locked up.
- : P410: Protect from sunlight.
- : P403+ P233: Store in a well-ventilated place. Keep container tightly closed.

Disposal

- : P501: Dispose of contents and container in accordance with all local, regional, national and international regulations.

3. Composition/Information on Ingredients

CAS Number	Ingredient Name	Weight %
7664-41-7	Anhydrous Ammonia (NH ₃)	99.8 – 99.999% wt.
7732-18-5	Water	0.2% -.001% wt.

4. First Aid Measures

Ingestion

- : If this gas is swallowed in liquid form, keep victim warm and OBTAIN IMMEDIATE MEDICAL ATTENTION. If signs of respiratory obstruction develop, immediately transport to medical facility. Do not induce vomiting. Never give fluids or induce vomiting if patient is unconscious or having convulsions.

Inhalation	: Remove victim to fresh air. Give oxygen if breathing is difficult. If breathing has stopped, start artificial respiration. OBTAIN IMMEDIATE MEDICAL ATTENTION.
Skin	: Apply water immediately to exposed areas of skin and continue for at least 30 minutes. Remove contaminated clothing, shoes, and constrictive clothing while continuing to apply water, being careful not to tear the skin. If skin surface is damaged, apply a clean dressing. If skin surface is not damaged, cleanse the affected area(s) thoroughly with mild soap and water. Do not apply salves or ointments to affected areas. OBTAIN IMMEDIATE MEDICAL ATTENTION.
Eyes	: Remove victim to fresh air. Immediately flush with plenty of water for at least 30 minutes with the eyelids held apart. OBTAIN IMMEDIATE MEDICAL ATTENTION.
Medical Conditions	: Ammonia is a respiratory irritant. Persons with impaired pulmonary function may be at an increased risk from exposure. Also pre-existing skin disorders may be aggravated by exposure.
Effects of Overexposure	: N/A
<u>Summary of Acute Health Hazards</u>	: N/A
Ingestion	: This material is a gas under normal atmospheric conditions and ingestion is unlikely. Ingestion of liquid ammonia may result in severe irritation or ulceration of the mouth, throat and digestive tract which may be displayed by nausea, vomiting, diarrhea and, in severe cases, collapse, shock and death.
Inhalation	: Irritation to the mucous membranes of the nose, throat and lungs is noticeable at 100 ppm. Concentrations above 400 ppm will cause throat irritation and may destroy mucous surfaces upon prolonged contact. High concentrations can cause pulmonary edema. Breathing air containing concentrations greater than 5,000 ppm may cause sudden death from spasm or inflammation of the larynx.
Skin	: Liquid Ammonia produces severe skin burns on contact. Ammonia gas may cause skin irritation, especially if skin is moist. The liquid can cause skin damage resulting from combined freezing and corrosive action on the skin. Atmospheric concentrations above 30,000 ppm will burn and blister skin after a few seconds of exposure.
Eyes	: Exposure to high gas concentrations may cause temporary blindness and severe eye damage. Direct contact of the eyes with liquid ammonia will produce serious eye burns.
Note to Physicians	: N/A
<u>Summary of Chronic Health</u>	: N/A

5. Fire Fighting Measures

- Extinguishing**
- : Use Water Spray or Water Fog, Carbon Dioxide, Polar or Alcohol Foam, Dry Chemical. Halon may decompose into toxic materials. Carbon dioxide can displace oxygen. Use caution when applying halon or carbon dioxide in confined spaces.
- Special Exposure Hazards**
- : Gas may ignite at vapor concentrations between 16% and 25% in air. However, ammonia-air mixtures are difficult to ignite and burn with little vigor. In the absence of oxygen enrichment, the risk of initiating an accidental fire or explosion is low. Do not allow ammonia vapors to accumulate in confined areas where ignition may occur. Intense heating particularly in contact with hot metallic surfaces may cause decomposition of ammonia generating hydrogen, a flammable gas.
- Special Protective Equipment for Firefighters**
- : Stop flow of gas. Use water fog to keep fire-exposed containers cool and to protect personnel effecting the shut-off. Wear self-contained breathing apparatus (SCBA) and encapsulating chemical protective clothing. Approach fire upwind and evacuate area downwind. Emergency responders in the danger area should wear bunker gear and self-contained breathing apparatus for fires beyond the incipient stage (29CFR 1910.156). In addition, wear other appropriate protective equipment as conditions warrant (See Section VIII). Isolate damage area, keep unauthorized personnel out. Stop spill/release if it can be done with minimal risk. If this cannot be done, allow fire to burn. Move undamaged containers from danger area if it can be done with minimal risk. Stay away from ends of container. Water spray may be useful in minimizing or dispersing vapors. Cool equipment exposed to fire with water, if it can be done with minimal risk.
- Fire Fighting Procedures**
- : Dry Chemical or carbon dioxide are recommended extinguishing media. Stop flow of gas before extinguishing fire. Use water spray to keep fire exposed containers cool. Extinguish fire using agent suitable for surrounding fire.
Combustible. Wear goggles, self-contained breathing apparatus, and rubber over clothing (including gloves). Stop flow of gas, or liquid if possible. Let fire burn.
If material involved in fire: Cool all affected containers with flooding quantities of water. Apply water from as far distance as possible. Use water spray to knock-down vapors. Solid streams of water may spread fire. Do not use water on material itself. Do not apply water to point of leak in tank car or container.

NFPA Rating

- : Health - 3
- Flammability - 1
- Instability - 0



0=Insignificant 1=Slight 2=Moderate 3=High 4=Extreme

Uniform Fire Code Rating

- : According to the (UFC) Uniform Fire Code Standard 79-3 (2000), the degree of Hazard is 3-3-0 in a confined space.

Additional Description Requirement

- : Inhalation Hazard

6. Accidental Release Measures

Personal Precautions

- : Note that although ammonia gas is lighter than air, sudden release may generate an aerosol of liquefied ammonia which may cling to the ground for long distances. May ignite in the presence of open flames and sparks. Narrow lower to upper combustion range (16-25%) makes ignition difficult. Keep all sources of ignition away from spill/release. Do not apply water onto leaking tank. Stop the flow of gas or liquid. Use water to protect personnel effecting the shut-off. Approach from upwind. Evacuate the area immediately. Eliminate all open flames in vicinity of indoor spills or released vapor. Water fog can be used to cleanse atmosphere of ammonia vapor. Downwind areas can be protected by water fog nozzles positioned downwind.

Emergency Procedures

- : Do not enter a visible cloud of ammonia. Isolate and evacuate the leak or spill area immediately for at least 150 feet in all directions. For larger spills, isolate at least 300 feet in all directions and then evacuate area downwind at least 0.4 miles in width and at least 0.8 miles in length. Keep area isolated until gas has dispersed.

Methods of Containment And Clean-Up

- : Dike liquid spills to contain liquid.

7. Handling and Storage

Safe Handling

- : Contents are under pressure. The use of explosion-proof equipment is recommended and may be required (see appropriate fire codes). Do not enter confined spaces such as tanks or pits without following proper entry procedures such as ASTM D-4276. Protect against physical damage.

- Storage** : Outside shaded area or detached storage is preferred. Inside storage should be in a cool, dry, well ventilated, noncombustible location, away from all possible sources of ignition.
- Work/Hygienic Practices** : Avoid contact with skin and avoid breathing vapors. Do not eat, drink, or smoke in work area. Wash hands before eating, drinking, or using restroom. Do NOT place food, coffee or other drinks in the area where dusting or splashing of solutions is possible.
- Ventilation** : Local exhaust is essential. Spark-proof fans desirable with mechanical ventilation. Ducts should be located at ceiling level and lead upwards to the outside. Eyewash and safety shower should be available in work area.

8. Exposure Controls/Personal Protection

- Occupational Exposure Limits** : CAL-OSHA: 25 ppm, 18 mg/m³ Oregon-OSHA: 25 ppm, 18 mg/m³; STEL: 35 ppm, 27 mg/m³
- | Chemical Name: Anhydrous Ammonia | | | | |
|---|-------------|------------------------------|------------------------------|------------------------------|
| Exposure Limits (TWAs) in Air | | | | |
| CAS Number | IDLH | ACGIH TLV | OSHA PEL | STEL |
| 7664-41-7 | 300 ppm | 25 ppm, 18 mg/m ³ | 50 ppm, 35 mg/m ³ | 35 ppm, 27 mg/m ³ |
- Protective Equipment** : Rubber or synthetic chemical gloves and boots should be worn as well as cotton clothing and underwear. Rubber or synthetic chemical coats or aprons should be available, an encapsulating chemical protective clothing garment is desirable for heavy exposures. The use of long sleeved clothing closed at the neck is advised. Change if clothing becomes contaminated.
- Eye Protection** : Chemical splash goggles should be worn when handling Anhydrous Ammonia to protect from liquids or mists. A face shield can be worn over chemical splash goggles as additional protection. Do not wear contact lenses when handling Anhydrous Ammonia. A full-face air-purifying respirator (APR) or supplied-air respirator (SAR) should be worn to protect from chemical vapors.
- Respiratory Protection** : Unless ventilation is adequate to keep concentration below permissible exposure limit (PEL), wear NIOSH approved ammonia chemical cartridge or canister full facepiece chin-style respirators with an air-purification factor (APF=50). In emergency or planned entry into unknown concentrations, use self-contained breathing apparatus (SCBA) or any supplied-air full facepiece chin-style respirators.

9. Physical and Chemical Properties

Appearance: Compressed Liquid Gas, clear, colorless	Odor: Sharp, penetrating
Odor Threshold: 5 ppm	pH: 11.6 for 1% NH ₃ solution
Melting Point/Freezing Point: -107.9°F; -78°F	Initial Boiling Point/Range: -28°F; -33.4°C
Flash Point: N/A	Evaporation Rate (BuAc=1): N/A
Flammability: 16 – 25% in air	Lower/Upper Explosive Limit: 25% by Volume/16% by Volume
Vapor Pressure (mmHg): 110 PSIG at 68°F (20°C)	Vapor Density (Air=1): 0.0549 lb./ft ³ at -28°F at 1 atm
Relative Density: 42.57 lbs./cu.ft @ -28°F and 1 atm	Solubility in Water: 33.10%
Partition Coefficient: N/A	Autoignition Temperature: 650°C; 1204°F
Decomposition Temperature: N/A	Viscosity: N/A
% Volatiles: 100%	Specific Gravity (Water=1): 0.6189 of liquid at -28°F and 1 atm
Molecular Weight: 17.032	VOC: N/A

10. Stability and Reactivity

- Reactivity** : Reacts violently and explosively with oxidizing gases such as chlorine, bromine, and other halogens. Reacts explosively with hypochlorites such as bleach. Reacts vigorously with acids. Highly reactive with reducing agents. Hazardous polymerization will not occur.
- Chemical Stability** : Stable
- Possibility of Hazardous Reactions or Polymerizations** : Avoid contact with oxidizing gases, chlorine, bromine, mineral hypochlorite, iodine, halogens, calcium, and strong acids. Avoid contact with copper, silver, zinc, and alloys of same. Mercury, silver oxide can form explosive compounds.
- Conditions to Avoid** : Avoid all possible sources of ignition. Heat will increase pressure in the storage tank.
- Incompatible Materials** : Avoid contact with strong acids, use of metals containing copper or zinc.
- Hazardous Decomposition Products** : Combustion will generate oxides of nitrogen. Intense heating of the gas, particularly in contact with hot metallic surfaces, may cause decomposition of ammonia to hydrogen and nitrogen.

11. Toxicological Information

- Acute and Chronic Effects** : Can cause irritation and burns of the skin and mucous membranes, and headache, salivation, nausea, and vomiting. Difficult or labored breathing and cough with bloody mucous discharge. Can cause bronchitis, laryngitis,

hemoptysis, and pulmonary edema or pneumonitis. Death may result. Can cause ulceration of the conjunctiva and cornea, and corneal and lenticular opacities. Damage to the eyes may be permanent.

Routes of Exposure

- Ingestion** : Yes
- Inhalation** : Yes
- Skin** : Yes
- Eyes** : Yes

Symptoms related to Physical, Chemical & Toxicological Characteristics

: Can cause burning of the eyes, conjunctivitis, skin irritation, swelling of the eyelids and lips, dry red mouth and tongue, burning in the throat, and coughing, and in more severe cases of exposure, difficulty in breathing, signs and symptoms of lung congestion, and, ultimately, death from respiratory failure due to pulmonary edema may occur.

Numerical Measures of Toxicity

:

Oral LD50	350 mg/kg	Rat	ATSDR 1991
	96 mg/kg	Mouse	EPA 1989
Inhalation LC50	19,770 ppm	F Rat	EPA 1989
	14,140 ppm	M Rat	EPA 1989
	17,401 ppm	Rat	ATSDR 1991

Chronic Toxicity

: N/A

Carcinogenicity

:

Product Name: Anhydrous Ammonia					
ACGIH	IARC	EPA	NIOSH	NTP	OSHA
No	No	No	No	No	No

TARGET ORGANS

: N/A

12. Ecological Information

Ecotoxicity

: Even at extremely low concentrations aquatic life will be harmed by liquid ammonia.

Persistence and Degradability

: N/A

Bioaccumulative Potential

:

Product/Ingredient	Log Pow	BCF	Potential
-	-	-	-

Mobility in Soil

: When anhydrous ammonia is applied in the soil, ammonia reacts with organic matter, and it dissolves in water. Anhydrous Ammonia reacts with water to form ammonium. The initial reactions with water, organic matter and clays limit the mobility of ammonia.

13. Disposal Considerations

Disposal of Container

: Because of the toxicity of ammonia to aquatic organisms, NEVER dispose of or allow any ammonia or ammonia contaminated water to flow into any surface water bodies. Surface water bodies include drainage ditches, storm water and sanitary sewers, wetlands, ponds, lakes and streams. Diking will contain the liquid and allow it to stabilize. Keep unprotected personnel away from area until it is free of ammonia. Do not apply water directly to ammonia liquid as this will cause boiling and splattering. Soil contaminated with ammonia or aqua ammonia may need to be excavated and properly disposed of according to local and state regulations. Consult Federal, State, or Local Authorities for additional proper disposal procedures.

14. Transport Information

UN#

Proper Shipping Name

Hazard Class/Division

Packing Group

Marine Pollutant

Special Provisions

Emergency Response Guidebook

Placard Advisory

: UN1005

: Anhydrous Ammonia

: 2.2 [Domestic]; 2.3, (8) [International]

: N/A

: Yes

: 13, T50

: 2012 ERG, Guide 125, pages 188-189

:



15. Regulatory Information

SARA 302 Extremely Hazardous Substances (EHS)

: This product contains the following Extremely Hazardous Substance(s) (EHS) under Section 302 of EPCRA, subject to the reporting requirements of Sections 311 and 312 (Tier I/Tier II reporting) at quantities greater than or equal to 500 pounds or in excess of the substance's EHS Threshold Planning Quantity (TPQ), whichever is lower. A Safety Data Sheet (SDS) must be provided to the SERC, LEPC, and local fire department.
Ammonia, CAS #7664-41-7 Sec. 302 EHS TPQ = 500 lbs. (226.8 kg.)

SARA 304 Extremely Hazardous Substances (EHS) Release Notification

: EPCRA Section 304 requires a facility to notify the SERC and LEPC in the event of a release an EHS at or exceeding the substance's RQ under Section 302 of EPCRA, or its CERCLA RQ, if applicable, whichever is lower. This product contains the following Extremely Hazardous Substance(s) (EHS) subject to the reporting requirements of Section 304.
Ammonia, CAS #7664-41-7 Sec. 304 RQ = 100 lbs. (45.4 kg.)

SARA 311/312 Hazards

SARA 311/312 Hazards				
Acute	Chronic	Flammability	Pressure	Reactivity
Yes	No	Yes	Yes	No

SARA 313 Reportable Chemicals

- : This product contains the following chemical(s) subject to annual emissions, transfers, and/or waste management reporting under the Community-Right-to-Know provisions of EPCRA Section 313, also known as the Toxic Release Inventory (TRI) Report or Form R: Ammonia, CAS #7664-41-7

CERCLA Hazardous Substances

- : This product contains the following CERCLA hazardous substance(s) subject to the National Response Center (NRC) reporting requirements if released to the environment in quantities greater than or equal to the substance's CERCLA Reportable Quantity (RQ).
Ammonia, CAS #7664-41-7 CERCLA RQ = 100 lbs. (45.4 kg.)

Clean Air Act (CAA) Section 112(r) Air Pollutants

- : This product contains the following air pollutant(s) under the U.S. Clean Air Act (CAA), Section 112(r) [40 CFR 61], which, if accidentally released to the atmosphere in quantities at or above the CAA 112(r) Threshold Quantity (TQ), is reportable.
Ammonia, CAS #7664-41-7 CAA 112(r) TQ = 10,000 lbs. (4436 kg.)

California Prop 65 Chemicals

- : This product does not contain any chemicals known to the state of California to cause cancer, birth defects or other reproductive harm.

Hazard Label Warning

- : This product requires the following hazard label warning:
Domestic: Non-Flammable Gas (Class 2.2)
International: Poisonous Gas Inhalation (Class 2.3); Corrosive (Class 8)

ACRONYMS:

CAS # – Chemical Abstract Services Registry Number

CFR – Code of Federal Regulations

CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act

EPCRA – Emergency Planning and Community Right-to-Know Act

LEPC – Local Emergency Planning Committee

SERC – State Emergency Response Commission



Maximum use level for Anhydrous Ammonia under NSF/ANSI Standard 60

Maximum Use

5 mg/l

16. Other Information

Revision date	:	03/31/2021
Supersedes	:	05/14/2015
First Issue	:	12/01/1985
Chemical Family/Type	:	Hydride, (Alkaline Gas), Inorganic Base
Section(s) changed since last revision	:	MSDS to First Issue SDS Conversion

IMPORTANT! Read this SDS before use or disposal of this product. Pass along the information to employees and any other persons who could be exposed to the product to be sure that they are aware of the information before use or other exposure. This SDS has been prepared in accordance with the Globally Harmonized System of Chemical and Labeling of Chemicals (GHS) Fifth Edition and the OSHA Hazard Communication Standard [29 CFR 1910.1200]. The SDS information is based on sources believed to be reliable. Available data, safety standards, and government regulations are subject to change and the conditions of handling and use, or misuse are beyond our control; **Hill Brothers Chemical Company** makes no warranty, either expressed or implied, with respect to the completeness or continuing accuracy of the information contained herein and disclaims all liability for reliance thereon. Additional information may be necessary or helpful for specific conditions and circumstances of use. It is the user's responsibility to determine the suitability of this product and to evaluate risks and exercise appropriate precautions for protection of employees and others prior to use.



SAFETY DATA SHEET

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013 Version: 2.2 SDS No.: 000010021714
Last revised date: 22.07.2021 1/15

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1 Product identifier

Product name:	Carbon dioxide
Trade name:	Gasart 370 BIOGON® C, E290, Gasart 374 Kohlendioxid, Gasart 375 Kohlendioxid med., Gasart 410 VERISEQ® GAC Pharma, Gasart 471 Kältemittel R 744, Gasart 471 Kohlendioxid 4.5, Gasart 472 Kohlendioxid 4.8, Gasart 473 Kohlendioxid 2.0, Kohlendioxid 3.0, Kohlendioxid 5.3
Other Name:	R744
Additional identification	
Chemical name:	Carbon dioxide
Chemical formula:	CO ₂
INDEX No.	-
CAS-No.	124-38-9
EC No.	204-696-9
REACH Registration No.	Listed in Annex IV/V of Regulation (EC) No 1907/2006 (REACH), exempted from registration.

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses:	Industrial and professional. Perform risk assessment prior to use. Aerosol propellant. Balance gas for mixtures. Beverage applications. Biocidal uses. Blanketing gas. Blast cleaning. Calibration gas. Carrier gas. Chemical synthesis. Combustion, melting and cutting processes. Cooling applications. Fire suppressant gas. Food freezing. Food packaging gas. Freezing, Cooling and heat transfer. Inerting gas. Inflation systems. Laboratory use. Laser gas. Plant growth promoter. Pressure head gas, operational assist gas in pressure systems. Process gas. Purge gas. Refrigerant. Solvent for extraction. Special effects (entertainment). Test gas. Consumer use. Propellant gas. Shielding gas in gas welding. It is the responsibility of the end user to ensure that the product as supplied is suitable for its intended use.
Uses advised against	Industrial or technical grade is unsuitable for medical and/or food applications or inhalation.

1.3 Details of the supplier of the safety data sheet

Supplier

Linde Gas GmbH
Carl-von-Linde-Platz 1
A-4651 Stadl-Paura

Telephone: +43 50 4273



SAFETY DATA SHEET

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013
Last revised date: 22.07.2021

Version: 2.2

SDS No.: 000010021714
2/15

E-mail: office@at.linde-gas.com

1.4 Emergency telephone number: Emergency number UMC0: +49 89 220 61012 (German), +44 1865 407333 (English)

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

Classification according to Regulation (EC) No 1272/2008 as amended.

Physical Hazards

Gases under pressure	Liquefied gas	H280: Contains gas under pressure; may explode if heated.
----------------------	---------------	---

2.2 Label Elements



Signal Word: Warning

Hazard Statement(s): H280: Contains gas under pressure; may explode if heated.

Precautionary Statements

General None.

Prevention: None.

Response: None.

Storage: P403: Store in a well-ventilated place.

Disposal: None.

Supplemental information

EIGA-As: Asphyxiant in high concentrations.

2.3 Other hazards

Contact with evaporating liquid may cause frostbite or freezing of skin.



SAFETY DATA SHEET

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013 Version: 2.2 SDS No.: 000010021714
 Last revised date: 22.07.2021 3/15

SECTION 3: Composition/information on ingredients

3.1 Substances

Chemical name	Carbon dioxide
INDEX No.:	-
CAS-No.:	124-38-9
EC No.:	204-696-9
REACH Registration No.:	Listed in Annex IV/V of Regulation (EC) No 1907/2006 (REACH), exempted from registration.
Purity:	100% The purity of the substance in this section is used for classification only, and does not represent the actual purity of the substance as supplied, for which other documentation should be consulted.
Trade name:	Gasart 370 BIOGON® C, E290, Gasart 374 Kohlendioxid, Gasart 375 Kohlendioxid med., Gasart 410 VERISEQ® GAC Pharma, Gasart 471 Kältemittel R 744, Gasart 471 Kohlendioxid 4.5, Gasart 472 Kohlendioxid 4.8, Gasart 473 Kohlendioxid 2.0, Kohlendioxid 3.0, Kohlendioxid 5.3

Chemical name	Chemical formula	Concentration	CAS-No.	REACH Registration No.	M-Factor:	Notes
Carbon dioxide	CO ₂	100%	124-38-9	Listed in Annex IV/V of Regulation (EC) No 1907/2006 (REACH), exempted from registration.	-	#

The concentrations of the components in the SDS header, product name on page one and in section 3.2 are in mol due to regulatory requirements. All concentrations are nominal.

This substance has workplace exposure limit(s).

PBT: persistent, bioaccumulative and toxic substance.

vPvB: very persistent and very bioaccumulative substance.



SAFETY DATA SHEET

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013 Version: 2.2 SDS No.: 000010021714
Last revised date: 22.07.2021 4/15

SECTION 4: First aid measures

General: In high concentrations may cause asphyxiation. Symptoms may include loss of mobility/consciousness. Victim may not be aware of asphyxiation. Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped.

4.1 Description of first aid measures

Inhalation: In high concentrations may cause asphyxiation. Symptoms may include loss of mobility/consciousness. Victim may not be aware of asphyxiation. Remove victim to uncontaminated area wearing self contained breathing apparatus. Keep victim warm and rested. Call a doctor. Apply artificial respiration if breathing stopped. Low concentrations of CO₂ cause increased respiration and headache.

Eye contact: Rinse the eye with water immediately. Remove contact lenses, if present and easy to do. Continue rinsing. Flush thoroughly with water for at least 15 minutes. Get immediate medical assistance. If medical assistance is not immediately available, flush an additional 15 minutes.

Skin Contact: Contact with evaporating liquid may cause frostbite or freezing of skin.

Ingestion: Ingestion is not considered a potential route of exposure.

4.2 Most important symptoms and effects, both acute and delayed: Respiratory arrest. Contact with liquefied gas can cause damage (frostbite) due to rapid evaporative cooling.

4.3 Indication of any immediate medical attention and special treatment needed

Hazards: Respiratory arrest. Contact with liquefied gas can cause damage (frostbite) due to rapid evaporative cooling.

Treatment: Thaw frosted parts with lukewarm water. Do not rub affected area. Get immediate medical advice/attention.

SECTION 5: Firefighting measures

General Fire Hazards: Heat may cause the containers to explode.

5.1 Extinguishing media

Suitable extinguishing media: Material will not burn. In case of fire in the surroundings: use appropriate extinguishing agent.



SAFETY DATA SHEET

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013
Last revised date: 22.07.2021

Version: 2.2

SDS No.: 000010021714
5/15

Unsuitable extinguishing media: None.

5.2 Special hazards arising from the substance or mixture: None.

Hazardous Combustion Products: None.

5.3 Advice for firefighters

Special fire fighting procedures: In case of fire: Stop leak if safe to do so. Continue water spray from protected position until container stays cool. Use extinguishants to contain the fire. Isolate the source of the fire or let it burn out.

Special protective equipment for fire-fighters: Firefighters must use standard protective equipment including flame retardant coat, helmet with face shield, gloves, rubber boots, and in enclosed spaces, SCBA. Guideline: EN 469 Protective clothing for firefighters. Performance requirements for protective clothing for firefighting. EN 15090 Footwear for firefighters. EN 659 Protective gloves for firefighters. EN 443 Helmets for fire fighting in buildings and other structures. EN 137 Respiratory protective devices - Self-contained open-circuit compressed air breathing apparatus with full face mask - Requirements, testing, marking.

SECTION 6: Accidental release measures

- | | |
|---|--|
| 6.1 Personal precautions, protective equipment and emergency procedures: | Evacuate area. Provide adequate ventilation. Prevent from entering sewers, basements and workpits, or any place where its accumulation can be dangerous. Wear self-contained breathing apparatus when entering area unless atmosphere is proved to be safe. EN 137 Respiratory protective devices - Self-contained open-circuit compressed air breathing apparatus with full face mask - Requirements, testing, marking. |
| 6.2 Environmental Precautions: | Prevent further leakage or spillage if safe to do so. |
| 6.3 Methods and material for containment and cleaning up: | Provide adequate ventilation. |
| 6.4 Reference to other sections: | Refer to sections 8 and 13. |



SAFETY DATA SHEET

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013 Version: 2.2 SDS No.: 000010021714
Last revised date: 22.07.2021 6/15

SECTION 7: Handling and storage:

- 7.1 Precautions for safe handling:** Only experienced and properly instructed persons should handle gases under pressure. Use only properly specified equipment which is suitable for this product, its supply pressure and temperature. Refer to supplier's handling instructions. The substance must be handled in accordance with good industrial hygiene and safety procedures. Protect containers from physical damage; do not drag, roll, slide or drop. Do not remove or deface labels provided by the supplier for the identification of the container contents. When moving containers, even for short distances, use appropriate equipment eg. trolley, hand truck, fork truck etc. Secure cylinders in an upright position at all times, close all valves when not in use. Provide adequate ventilation. Suck back of water into the container must be prevented. Do not allow backfeed into the container. Avoid suckback of water, acid and alkalis. Keep container below 50°C in a well ventilated place. Observe all regulations and local requirements regarding storage of containers. When using do not eat, drink or smoke. Store in accordance with local/regional/national/international regulations. Never use direct flame or electrical heating devices to raise the pressure of a container. Leave valve protection caps in place until the container has been secured against either a wall or bench or placed in a container stand and is ready for use. Damaged valves should be reported immediately to the supplier. Close container valve after each use and when empty, even if still connected to equipment. Never attempt to repair or modify container valves or safety relief devices. Replace valve outlet caps or plugs and container caps where supplied as soon as container is disconnected from equipment. Keep container valve outlets clean and free from contaminates particularly oil and water. If user experiences any difficulty operating container valve discontinue use and contact supplier. Never attempt to transfer gases from one container to another. Container valve guards or caps should be in place. Depressurisation of liquid CO₂ below approximately 5 bar can create solid CO₂ which may block protective devices, pipework and create dry-ice within containers. Containers, which contain or have contained flammable or explosive substances, must not be inerted with liquid carbon dioxide.
- 7.2 Conditions for safe storage, including any incompatibilities:** Containers should not be stored in conditions likely to encourage corrosion. Stored containers should be periodically checked for general conditions and leakage. Container valve guards or caps should be in place. Store containers in location free from fire risk and away from sources of heat and ignition. Keep away from combustible material.
- 7.3 Specific end use(s):** None.



SAFETY DATA SHEET

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013 Version: 2.2 SDS No.: 000010021714
 Last revised date: 22.07.2021 7/15

SECTION 8: Exposure controls/personal protection**8.1 Control Parameters****Occupational Exposure Limits**

Chemical name	Type	Exposure Limit Values		Source
Carbon dioxide	MAK CEIL	10.000 ppm	18.000 mg/m ³	Austria. MAK List, OEL Ordinance (GwV), BGBl. II, no. 184/2001, as amended (09 2018)
	MAK	5.000 ppm	9.000 mg/m ³	Austria. MAK List, OEL Ordinance (GwV), BGBl. II, no. 184/2001, as amended (09 2018)
	TWA	5.000 ppm	9.000 mg/m ³	EU. Indicative Exposure Limit Values in Directives 91/322/EEC, 2000/39/EC, 2006/15/EC, 2009/161/EU, 2017/164/EU, as amended (12 2009)

8.2 Exposure controls**Appropriate engineering controls:**

Consider a work permit system e.g. for maintenance activities. Ensure adequate air ventilation. Oxygen detectors should be used when asphyxiating gases may be released. Provide adequate ventilation, including appropriate local extraction, to ensure that the defined occupational exposure limit is not exceeded. Systems under pressure should be regularly checked for leakages. Preferably use permanent leak tight connections (eg. welded pipes). Do not eat, drink or smoke when using the product. CO₂ detectors should be used when CO₂ may be released.

Individual protection measures, such as personal protective equipment**General information:**

A risk assessment should be conducted and documented in each work area to assess the risks related to the use of the product and to select the PPE that matches the relevant risk. The following recommendations should be considered. Keep self contained breathing apparatus readily available for emergency use. Personal protective equipment for the body should be selected based on the task being performed and the risks involved.

Eye/face protection:

Safety eyewear, goggles or face-shield to EN166 should be used to avoid exposure to liquid splashes. Wear eye protection to EN 166 when using gases. Guideline: EN 166 Personal Eye Protection.

Skin protection**Hand Protection:**

Guideline: EN 388 Protective gloves against mechanical risks.

Additional Information: Wear working gloves while handling containers



SAFETY DATA SHEET

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013 Version: 2.2 SDS No.: 000010021714
 Last revised date: 22.07.2021 8/15

Body protection: No special precautions.

Other: Wear safety shoes while handling containers
 Guideline: ISO 20345 Personal protective equipment - Safety footwear.

Respiratory Protection: When allowed by a risk assessment Respiratory Protective Equipment (RPE) may be used. The selection of the Respiratory Protective Device (RPD) must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected RPD. Self-contained breathing apparatus (SCBA) or positive pressure airline with mask are to be used in oxygen-deficient atmospheres
 Guideline: EN 137 Respiratory protective devices - Self-contained open-circuit compressed air breathing apparatus with full face mask - Requirements, testing, marking.

Thermal hazards: No precautionary measures are necessary.

Hygiene measures: Specific risk management measures are not required beyond good industrial hygiene and safety procedures. Do not eat, drink or smoke when using the product.

Environmental exposure controls: For waste disposal, see section 13 of the SDS.

SECTION 9: Physical and chemical properties

9.1 Information on basic physical and chemical properties

Appearance

Physical state:	Gas
Form:	Liquefied gas
Color:	Colorless
Odor:	Odorless
Odor Threshold:	Odor threshold is subjective and is inadequate to warn of over exposure.
pH:	3,2 - 3,7 The pH of saturated CO ₂ solutions varies from 3.7 at 101 kPa (1 atm) to 3.2 at 2370 kPa (23.4 atm)
Melting Point:	-56,6 °C
Boiling Point:	-78,5 °C
Sublimation Point:	-78,5 °C
Critical Temp. (°C):	31,0 °C
Flash Point:	Not applicable to gases and gas mixtures.
Evaporation Rate:	Not applicable to gases and gas mixtures.



SAFETY DATA SHEET

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013
Last revised date: 22.07.2021

Version: 2.2

SDS No.: 000010021714
9/15

Flammability (solid, gas):	This product is not flammable.
Flammability Limit - Upper (%):	Not applicable.
Flammability Limit - Lower (%):	Not applicable.
Vapor pressure:	45,1 bar (10 °C)
Vapor density (air=1):	1,522 (21 °C)
Relative density:	1,512 (-56,6 °C)
Solubility(ies)	
Solubility in Water:	2,900 mg/l (25 °C)
Partition coefficient (n-octanol/water):	0,83
Autoignition Temperature:	Not applicable.
Decomposition Temperature:	Not known.
Viscosity	
Kinematic viscosity:	No data available.
Dynamic viscosity:	0,07 mPa.s (20 °C)
Explosive properties:	Not applicable.
Oxidizing properties:	Not applicable.

9.2 Other information:
Molecular weight: Gas/vapour heavier than air. May accumulate in confined spaces, particularly at or below ground level.
44,01 g/mol (CO₂)

SECTION 10: Stability and reactivity

10.1 Reactivity:	No reactivity hazard other than the effects described in sub-section below.
10.2 Chemical Stability:	Stable under normal conditions.
10.3 Possibility of hazardous reactions:	None.
10.4 Conditions to avoid:	None.
10.5 Incompatible Materials:	No reaction with any common materials in dry or wet conditions.
10.6 Hazardous Decomposition Products:	Under normal conditions of storage and use, hazardous decomposition products should not be produced.



SAFETY DATA SHEET

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013
Last revised date: 22.07.2021

Version: 2.2

SDS No.: 000010021714
10/15

SECTION 11: Toxicological information

General information: In high concentrations may cause rapid circulatory deterioration even at normal levels of oxygen concentration. Symptoms are headache, nausea and vomiting, which may lead to unconsciousness and even death.

11.1 Information on toxicological effects

Acute toxicity - Oral Product Based on available data, the classification criteria are not met.

Acute toxicity - Dermal Product Based on available data, the classification criteria are not met.

Acute toxicity - Inhalation Product Based on available data, the classification criteria are not met.

Skin Corrosion/Irritation Product Based on available data, the classification criteria are not met.

Serious Eye Damage/Eye Irritation Product Based on available data, the classification criteria are not met.

Respiratory or Skin Sensitization Product Based on available data, the classification criteria are not met.

Germ Cell Mutagenicity Product Based on available data, the classification criteria are not met.

Carcinogenicity Product Based on available data, the classification criteria are not met.

Reproductive toxicity Product Based on available data, the classification criteria are not met.

Specific Target Organ Toxicity - Single Exposure Product Based on available data, the classification criteria are not met.

Specific Target Organ Toxicity - Repeated Exposure Product Based on available data, the classification criteria are not met.

**SAFETY DATA SHEET**

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013
Last revised date: 22.07.2021

Version: 2.2

SDS No.: 000010021714
11/15

Aspiration Hazard
Product Not applicable to gases and gas mixtures..

SECTION 12: Ecological information**12.1 Toxicity**

Acute toxicity
Product No ecological damage caused by this product.

12.2 Persistence and Degradability
Product Not applicable to gases and gas mixtures..

12.3 Bioaccumulative potential
Product The subject product is expected to biodegrade and is not expected to persist for long periods in an aquatic environment.

12.4 Mobility in soil
Product Because of its high volatility, the product is unlikely to cause ground or water pollution.

12.5 Results of PBT and vPvB assessment
Product Not classified as PBT or vPvB.

12.6 Other adverse effects: No ecological damage caused by this product.

SECTION 13: Disposal considerations**13.1 Waste treatment methods**

General information: Do not discharge into any place where its accumulation could be dangerous. Vent to atmosphere in a well ventilated place.

Disposal methods: Refer to the EIGA code of practice (Doc.30 "Disposal of Gases", downloadable at <http://www.eiga.org>) for more guidance on suitable disposal methods. Dispose of container via supplier only. Discharge, treatment, or disposal may be subject to national, state, or local laws.

European Waste Codes

Container: 16 05 05: Gases in pressure containers other than those mentioned in 16 05 04.

**SAFETY DATA SHEET**

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013
Last revised date: 22.07.2021

Version: 2.2

SDS No.: 000010021714
12/15**SECTION 14: Transport information****ADR**

14.1 UN Number:	UN 1013
14.2 UN Proper Shipping Name:	CARBON DIOXIDE
14.3 Transport Hazard Class(es)	
Class:	2
Label(s):	2.2
Hazard No. (ADR):	20
Tunnel restriction code:	(C/E)
14.4 Packing Group:	-
14.5 Environmental hazards:	Not applicable
14.6 Special precautions for user:	-

RID

14.1 UN Number:	UN 1013
14.2 UN Proper Shipping Name:	CARBON DIOXIDE
14.3 Transport Hazard Class(es)	
Class:	2
Label(s):	2.2
14.4 Packing Group:	-
14.5 Environmental hazards:	Not applicable
14.6 Special precautions for user:	-

IMDG

14.1 UN Number:	UN 1013
14.2 UN Proper Shipping Name:	CARBON DIOXIDE
14.3 Transport Hazard Class(es)	
Class:	2.2
Label(s):	2.2
EmS No.:	F-C, S-V
14.4 Packing Group:	-
14.5 Environmental hazards:	Not applicable
14.6 Special precautions for user:	-



SAFETY DATA SHEET

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013
 Last revised date: 22.07.2021

Version: 2.2

SDS No.: 000010021714
 13/15

IATA

14.1 UN Number:	UN 1013
14.2 Proper Shipping Name:	Carbon dioxide
14.3 Transport Hazard Class(es):	
Class:	2.2
Label(s):	2.2
14.4 Packing Group:	-
14.5 Environmental hazards:	Not applicable
14.6 Special precautions for user:	-
Other information	
Passenger and cargo aircraft:	Allowed.
Cargo aircraft only:	Allowed.

14.7 Transport in bulk according to Annex II of MARPOL and the IBC Code: Not applicable

Additional identification:

Avoid transport on vehicles where the load space is not separated from the driver's compartment. Ensure vehicle driver is aware of the potential hazards of the load and knows what to do in the event of an accident or an emergency. Before transporting product containers ensure that they are firmly secured. Ensure that the container valve is closed and not leaking. Container valve guards or caps should be in place. Ensure adequate air ventilation.

SECTION 15: Regulatory information

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture:

EU Regulations

EU. Directive 2012/18/EU (SEVESO III) on major accident hazards involving dangerous substances, as amended.:
 Not applicable

National Regulations

Council Directive 89/391/EEC on the introduction of measures to encourage improvements in the safety and health of workers at work Directive 89/686/EEC on personal protective equipment Only products that comply with the food regulations (EC) No. 1333/2008 and (EU) No. 231/2012 and are labelled as such may be used as food additives.

This Safety Data Sheet has been produced to comply with Regulation (EU) 2015/830.

15.2 Chemical safety assessment: Listed in Annex IV/V of Regulation (EC) No 1907/2006 (REACH), exempted from



SAFETY DATA SHEET

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013 Version: 2.2 SDS No.: 000010021714
Last revised date: 22.07.2021 14/15

registration. A CSA does not need to be carried out for this product.

SECTION 16: Other information

Revision Information:	Not relevant.
Key literature references and sources for data:	<p>Various sources of data have been used in the compilation of this SDS, they include but are not exclusive to:</p> <p>Agency for Toxic Substances and Diseases Registry (ATSDR) (http://www.atsdr.cdc.gov/).</p> <p>European Chemical Agency: Guidance on the Compilation of Safety Data Sheets.</p> <p>European Chemical Agency: Information on Registered Substances http://apps.echa.europa.eu/registered/registered-sub.aspx#search</p> <p>European Industrial Gases Association (EIGA) Doc. 169 "Classification and Labelling guide", as amended.</p> <p>International Programme on Chemical Safety (http://www.inchem.org/)</p> <p>ISO 10156:2010 Gases and gas mixtures - Determination of fire potential and oxidizing ability for the selection of cylinder valve outlets.</p> <p>Matheson Gas Data Book, 7th Edition.</p> <p>National Institute for Standards and Technology (NIST) Standard Reference Database Number 69.</p> <p>The ESIS (European chemical Substances 5 Information System) platform of the former European Chemicals Bureau (ECB) ESIS (http://ecb.jrc.ec.europa.eu/esis/).</p> <p>The European Chemical Industry Council (CEFIC) ERICards.</p> <p>United States of America's National Library of Medicine's toxicology data network TOXNET (http://toxnet.nlm.nih.gov/index.html)</p> <p>Threshold Limit Values (TLV) from the American Conference of Governmental Industrial Hygienists (ACGIH).</p> <p>Substance specific information from suppliers.</p> <p>Details given in this document are believed to be correct at the time of publication.</p>

Wording of the H-statements in section 2 and 3

H280	Contains gas under pressure; may explode if heated.
------	---

Training information:	Users of breathing apparatus must be trained. The hazard of asphyxiation is often overlooked and must be stressed during operator training. Ensure operators understand the hazards.
-----------------------	--

Classification according to Regulation (EC) No 1272/2008 as amended.

Press. Gas Liq. Gas, H280



SAFETY DATA SHEET

According to Regulation (EC) No. 1907/2006 (REACH) Article 31, Annex II as amended

Carbon dioxide

Issue Date: 16.01.2013 Version: 2.2 SDS No.: 000010021714
Last revised date: 22.07.2021 15/15

Other information:

Before using this product in any new process or experiment, a thorough material compatibility and safety study should be carried out. Ensure adequate air ventilation. Ensure all national/local regulations are observed. Whilst proper care has been taken in the preparation of this document, no liability for injury or damage resulting from its use can be accepted.

Last revised date:

22.07.2021

Disclaimer:

This information is provided without warranty. The information is believed to be correct. This information should be used to make an independent determination of the methods to safeguard workers and the environment.

Safety data sheet

acc. to Safe Work Australia - Code of Practice



Urea ≥99,5 %, p.a., for molecular biology, for biochemistry

article number: 3941

Version: GHS 4.0 en

Replaces version of: 2019-12-19

Version: (GHS 3)

date of compilation: 2016-07-12

Revision: 2021-12-14

SECTION 1: Identification of the substance/mixture and of the company/undertaking

1.1 Product identifier

Identification of the substance

Urea ≥99,5 %, p.a., for molecular biology, for biochemistry

Article number

3941

CAS number

57-13-6

1.2 Relevant identified uses of the substance or mixture and uses advised against

Relevant identified uses:

Laboratory chemical
Laboratory and analytical use

Uses advised against:

Do not use for products which come into contact with foodstuffs. Do not use for private purposes (household).

1.3 Details of the supplier of the safety data sheet

Carl Roth GmbH + Co KG

Schoemperlenstr. 3-5

D-76185 Karlsruhe

Germany

Telephone: +49 (0) 721 - 56 06 0

Telefax: +49 (0) 721 - 56 06 149

e-mail: sicherheit@carlroth.de

Website: www.carlroth.de

Competent person responsible for the safety data sheet: :Department Health, Safety and Environment

e-mail (competent person):

sicherheit@carlroth.de

1.4 Emergency telephone number

Name	Street	Postal code/city	Telephone	Website
NSW Poisons Information Centre Childrens Hospital	Hawkesbury Road	2145 Westmead, NSW	131126	

SECTION 2: Hazards identification

2.1 Classification of the substance or mixture

Classification acc. to GHS

This substance does not meet the criteria for classification.

2.2 Label elements

Labelling

not required

Safety data sheet

acc. to Safe Work Australia - Code of Practice



Urea ≥99,5 %, p.a., for molecular biology, for biochemistry

article number: 3941

2.3 Other hazards

Results of PBT and vPvB assessment

According to the results of its assessment, this substance is not a PBT or a vPvB.

SECTION 3: Composition/information on ingredients

3.1 Substances

Name of substance	Urea
Molecular formula	CH ₄ N ₂ O
Molar mass	60.06 g/mol
CAS No	57-13-6

SECTION 4: First aid measures

4.1 Description of first aid measures



General notes

Take off contaminated clothing.

Following inhalation

Provide fresh air. In all cases of doubt, or when symptoms persist, seek medical advice.

Following skin contact

Rinse skin with water/shower.

Following eye contact

Rinse cautiously with water for several minutes. In all cases of doubt, or when symptoms persist, seek medical advice.

Following ingestion

Rinse mouth. Call a doctor if you feel unwell.

4.2 Most important symptoms and effects, both acute and delayed

Nausea, Vomiting, Cough, Dyspnoea

4.3 Indication of any immediate medical attention and special treatment needed

none

SECTION 5: Firefighting measures

5.1 Extinguishing media



Suitable extinguishing media

co-ordinate firefighting measures to the fire surroundings
water, foam, alcohol resistant foam, dry extinguishing powder, ABC-powder

Safety data sheet

acc. to Safe Work Australia - Code of Practice



Urea ≥99,5 %, p.a., for molecular biology, for biochemistry

article number: 3941

Unsuitable extinguishing media

water jet

5.2 Special hazards arising from the substance or mixture

Non-combustible.

Hazardous combustion products

In case of fire may be liberated: Nitrogen oxides (NOx), Carbon monoxide (CO), Carbon dioxide (CO₂)

5.3 Advice for firefighters

In case of fire and/or explosion do not breathe fumes. Fight fire with normal precautions from a reasonable distance. Wear self-contained breathing apparatus.

SECTION 6: Accidental release measures

6.1 Personal precautions, protective equipment and emergency procedures



For non-emergency personnel

No special measures are necessary.

6.2 Environmental precautions

Keep away from drains, surface and ground water.

6.3 Methods and material for containment and cleaning up

Advice on how to contain a spill

Covering of drains. Take up mechanically.

Advice on how to clean up a spill

Take up mechanically.

Other information relating to spills and releases

Place in appropriate containers for disposal. Ventilate affected area.

6.4 Reference to other sections

Hazardous combustion products: see section 5. Personal protective equipment: see section 8. Incompatible materials: see section 10. Disposal considerations: see section 13.

SECTION 7: Handling and storage

7.1 Precautions for safe handling

Avoid: Aerosol or mist formation.

Advice on general occupational hygiene

Keep away from food, drink and animal feedingstuffs.

7.2 Conditions for safe storage, including any incompatibilities

Store in a dry place. Keep container tightly closed. Hygroscopic solid.

Incompatible substances or mixtures

Observe hints for combined storage.

Consideration of other advice:

Safety data sheet

acc. to Safe Work Australia - Code of Practice



Urea ≥99,5 %, p.a., for molecular biology, for biochemistry

article number: **3941**

Specific designs for storage rooms or vessels

Recommended storage temperature: 15 – 25 °C

7.3 Specific end use(s)

No information available.

SECTION 8: Exposure controls/personal protection

8.1 Control parameters

National limit values

Occupational exposure limit values (Workplace Exposure Limits)

This information is not available.

8.2 Exposure controls

Individual protection measures (personal protective equipment)

Eye/face protection



Use safety goggle with side protection.

Skin protection



• hand protection

Wear suitable gloves. Chemical protection gloves are suitable, which are tested according to EN 374.

• type of material

NBR (Nitrile rubber)

• material thickness

>0,11 mm

• breakthrough times of the glove material

>480 minutes (permeation: level 6)

• other protection measures

Take recovery periods for skin regeneration. Preventive skin protection (barrier creams/ointments) is recommended.

Respiratory protection



Respiratory protection necessary at: Dust formation. Particulate filter device (EN 143). P1 (filters at least 80 % of airborne particles, colour code: White).

Environmental exposure controls

Keep away from drains, surface and ground water.

Safety data sheet

acc. to Safe Work Australia - Code of Practice



Urea ≥99,5 %, p.a., for molecular biology, for biochemistry

article number: 3941

SECTION 9: Physical and chemical properties

9.1 Information on basic physical and chemical properties

Physical state	solid
Form	crystalline
Colour	white
Odour	faintly perceptible - like ammonia
Melting point/freezing point	134 °C (ECHA)
Boiling point or initial boiling point and boiling range	not determined
Flammability	non-combustible
Lower and upper explosion limit	not determined
Flash point	not applicable
Auto-ignition temperature	not determined
Decomposition temperature	>134 °C
pH (value)	9 (in aqueous solution: 100 g/l, 20 °C)
Kinematic viscosity	not relevant

Solubility(ies)

Water solubility	624 g/l at 20 °C (ECHA)
------------------	-------------------------

Partition coefficient

Partition coefficient n-octanol/water (log value):	<-1.73 (22 °C) (ECHA)
Soil organic carbon/water (log KOC)	-1.431 -- 1.193 (ECHA)

Vapour pressure	not determined
-----------------	----------------

Density and/or relative density

Density	1.33 g/cm³ at 20 °C
Relative vapour density	information on this property is not available
Bulk density	~750 kg/m³

Particle characteristics	No data available.
--------------------------	--------------------

Other safety parameters

Oxidising properties	none
----------------------	------

9.2 Other information

Information with regard to physical hazard classes:	hazard classes acc. to GHS (physical hazards): not relevant
---	---

Safety data sheet

acc. to Safe Work Australia - Code of Practice



Urea ≥99,5 %, p.a., for molecular biology, for biochemistry

article number: 3941

Other safety characteristics:

There is no additional information.

SECTION 10: Stability and reactivity

10.1 Reactivity

This material is not reactive under normal ambient conditions.

10.2 Chemical stability

The material is stable under normal ambient and anticipated storage and handling conditions of temperature and pressure.

10.3 Possibility of hazardous reactions

Violent reaction with: strong oxidiser, Alkalies, Chlorates, Perchlorates, Hydrogen peroxide

10.4 Conditions to avoid

Keep away from heat. Decomposition takes place from temperatures above: >134 °C.

10.5 Incompatible materials

There is no additional information.

10.6 Hazardous decomposition products

Hazardous combustion products: see section 5. Release of: Ammonia (NH₃).

As a result of heating

Ammonia (NH₃).

SECTION 11: Toxicological information

11.1 Information on toxicological effects

Classification acc. to GHS

This substance does not meet the criteria for classification.

Acute toxicity

Shall not be classified as acutely toxic.

Acute toxicity					
Exposure route	Endpoint	Value	Species	Method	Source
oral	LD50	8,471 mg/kg	rat		TOXNET

Skin corrosion/irritation

Shall not be classified as corrosive/irritant to skin.

Serious eye damage/eye irritation

Shall not be classified as seriously damaging to the eye or eye irritant.

Respiratory or skin sensitisation

Shall not be classified as a respiratory or skin sensitisier.

Germ cell mutagenicity

Shall not be classified as germ cell mutagenic.

Carcinogenicity

Shall not be classified as carcinogenic.

Safety data sheet

acc. to Safe Work Australia - Code of Practice



Urea ≥99,5 %, p.a., for molecular biology, for biochemistry

article number: 3941

Reproductive toxicity

Shall not be classified as a reproductive toxicant.

Specific target organ toxicity - single exposure

Shall not be classified as a specific target organ toxicant (single exposure).

Specific target organ toxicity - repeated exposure

Shall not be classified as a specific target organ toxicant (repeated exposure).

Aspiration hazard

Shall not be classified as presenting an aspiration hazard.

Symptoms related to the physical, chemical and toxicological characteristics

- If swallowed

vomiting, nausea

- If in eyes

Data are not available.

- If inhaled

If decomposition products are inhaled the following symptoms can occur: cough, Dyspnoea

- If on skin

Data are not available.

- Other information

none

11.2 Endocrine disrupting properties

Not listed.

SECTION 12: Ecological information

12.1 Toxicity

Aquatic toxicity (acute)				
Endpoint	Value	Species	Source	Exposure time
EC50	>10,000 mg/l	aquatic invertebrates	ECHA	24 h

Biodegradation

Data are not available.

12.2 Process of degradability

Theoretical Oxygen Demand with nitrification: 1.132 mg/mg

Theoretical Oxygen Demand: 0 mg/mg

Theoretical Carbon Dioxide: 0.7328 mg/mg

Process of degradability		
Process	Degradation rate	Time
biotic/abiotic	96 %	16 d

Safety data sheet

acc. to Safe Work Australia - Code of Practice



Urea ≥99,5 %, p.a., for molecular biology, for biochemistry

article number: 3941

12.3 Bioaccumulative potential

Does not significantly accumulate in organisms.

n-octanol/water (log KOW)	<-1.73 (22 °C) (ECHA)
---------------------------	-----------------------

12.4 Mobility in soil

The Organic Carbon normalised adsorption coefficient	-1.431 --1.193 (ECHA)
--	-----------------------

12.5 Results of PBT and vPvB assessment

Data are not available.

12.6 Endocrine disrupting properties

Not listed.

12.7 Other adverse effects

Data are not available.

SECTION 13: Disposal considerations

13.1 Waste treatment methods



Consult the appropriate local waste disposal expert about waste disposal.

Sewage disposal-relevant information

Do not empty into drains.

13.3 Remarks

Waste shall be separated into the categories that can be handled separately by the local or national waste management facilities. Please consider the relevant national or regional provisions.

SECTION 14: Transport information

14.1 UN number not subject to transport regulations

14.2 UN proper shipping name not assigned

14.3 Transport hazard class(es) not assigned

14.4 Packing group not assigned

14.5 Environmental hazards non-environmentally hazardous acc. to the dangerous goods regulations

14.6 Special precautions for user

There is no additional information.

14.7 Transport in bulk according to Annex II of MARPOL and the IBC Code

The cargo is not intended to be carried in bulk.

14.8 Information for each of the UN Model Regulations

Transport information National regulations Additional information (UN RTDG)

Not subject to transport regulations. UN RTDG

Safety data sheet

acc. to Safe Work Australia - Code of Practice



Urea ≥99,5 %, p.a., for molecular biology, for biochemistry

article number: 3941

International Maritime Dangerous Goods Code (IMDG) - Additional information

Not subject to IMDG.

International Civil Aviation Organization (ICAO-IATA/DGR) - Additional information

Not subject to ICAO-IATA.

SECTION 15: Regulatory information

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

There is no additional information.

National regulations(Australia)

Australian Inventory of Chemical Substances(AICS)

Substance is listed.

Other information

Directive 94/33/EC on the protection of young people at work. Observe employment restrictions under the Maternity Protection Directive (92/85/EEC) for expectant or nursing mothers.

National inventories

Country	Inventory	Status
AU	AICS	substance is listed
CA	DSL	substance is listed
CN	IECSC	substance is listed
EU	ECSI	substance is listed
EU	REACH Reg.	substance is listed
JP	CSCL-ENCS	substance is listed
KR	KECI	substance is listed
MX	INSQ	substance is listed
NZ	NZIoC	substance is listed
PH	PICCS	substance is listed
TR	CICR	substance is listed
TW	TCSI	substance is listed
US	TSCA	substance is listed

Legend

AICS	Australian Inventory of Chemical Substances
CICR	Chemical Inventory and Control Regulation
CSCL-ENCS	List of Existing and New Chemical Substances (CSCL-ENCS)
DSL	Domestic Substances List (DSL)
ECSI	EC Substance Inventory (EINECS, ELINCS, NLP)
IECSC	Inventory of Existing Chemical Substances Produced or Imported in China
INSQ	National Inventory of Chemical Substances
KECI	Korea Existing Chemicals Inventory
NZIoC	New Zealand Inventory of Chemicals
PICCS	Philippine Inventory of Chemicals and Chemical Substances (PICCS)
REACH Reg.	REACH registered substances
TCSI	Taiwan Chemical Substance Inventory
TSCA	Toxic Substance Control Act

15.2 Chemical Safety Assessment

No Chemical Safety Assessment has been carried out for this substance.

Safety data sheet

acc. to Safe Work Australia - Code of Practice



Urea ≥99,5 %, p.a., for molecular biology, for biochemistry

article number: 3941

SECTION 16: Other information

Indication of changes (revised safety data sheet)

Alignment to regulation: Globally Harmonized System of Classification and Labelling of Chemicals ("Purple book").

Restructuring: section 9, section 14

Section	Former entry (text/value)	Actual entry (text/value)	Safety-relevant
2.1	Classification acc. to GHS: This substance does not meet the criteria for classification in accordance with Regulation No 1272/2008/EC. This substance does not meet the criteria for classification.	Classification acc. to GHS: This substance does not meet the criteria for classification.	yes
2.2	Signal word: not required		yes
2.3	Other hazards: There is no additional information.	Other hazards	yes
2.3		Results of PBT and vPvB assessment: According to the results of its assessment, this substance is not a PBT or a vPvB.	yes

Abbreviations and acronyms

Abbr.	Descriptions of used abbreviations
CAS	Chemical Abstracts Service (service that maintains the most comprehensive list of chemical substances)
DGR	Dangerous Goods Regulations (see IATA/DGR)
EC50	Effective Concentration 50 %. The EC50 corresponds to the concentration of a tested substance causing 50 % changes in response (e.g. on growth) during a specified time interval
EINECS	European Inventory of Existing Commercial Chemical Substances
ELINCS	European List of Notified Chemical Substances
GHS	"Globally Harmonized System of Classification and Labelling of Chemicals" developed by the United Nations
IATA	International Air Transport Association
IATA/DGR	Dangerous Goods Regulations (DGR) for the air transport (IATA)
ICAO	International Civil Aviation Organization
IMDG	International Maritime Dangerous Goods Code
LD50	Lethal Dose 50 %: the LD50 corresponds to the dose of a tested substance causing 50 % lethality during a specified time interval
MARPOL	International Convention for the Prevention of Pollution from Ships (abbr. of "Marine Pollutant")
NLP	No-Longer Polymer
PBT	Persistent, Bioaccumulative and Toxic
UN RTDG	UN Recommendations on the Transport of Dangerous Good
vPvB	Very Persistent and very Bioaccumulative

Key literature references and sources for data

Safety data sheet

acc. to Safe Work Australia - Code of Practice



Urea ≥99,5 %, p.a., for molecular biology, for biochemistry

article number: 3941

Safe Work Australia's Code of Practice for Labelling of Workplace Hazardous Chemicals (under WHS Regulations).

UN Recommendations on the Transport of Dangerous Good. International Maritime Dangerous Goods Code (IMDG). Dangerous Goods Regulations (DGR) for the air transport (IATA).

Disclaimer

This information is based upon the present state of our knowledge. This SDS has been compiled and is solely intended for this product.

SAFETY DATA SHEET

according to Occupational Safety And Health
(Classification, Labelling And Safety Data Sheet Of
Hazardous Chemicals) Regulations 2013 (CLASS 2013)

Revision Date 10.10.2019

Version 2.1

SECTION 1. Identification of the substance/mixture and of the company/undertaking**1.1 Product identifier**

Catalogue No. 101134
Product name Ammonium carbamate for analysis EMSURE®

REACH Registration Number A registration number is not available for this substance as the substance or its use are exempted from registration according to Article 2 REACH Regulation (EC) No 1907/2006, the annual tonnage does not require a registration or the registration is envisaged for a later registration deadline.

CAS-No. 1111-78-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses Reagent for analysis
For additional information on uses please refer to the Merck Chemicals portal (www.merckgroup.com).

1.3 Details of the supplier of the safety data sheet

Company Merck KGaA * 64271 Darmstadt *Germany* Telefon:+49 6151 72-0
Responsible Department LS-QHC * e-mail: prodsafe@merckgroup.com
Regional representation Merck Sdn. Bhd. (Co. No: 178145), No. 4, Jalan U1/26, Section U1, Hicom Glenmarie Industrial Park, 40150 Shah Alam, Selangor. Tel: 03-74943688 Fax: 03-74910850

1.4 Emergency telephone Customer Call Centre: + 62 0800 140 1253 (Toll Free) number**SECTION 2. Hazards identification****2.1 Classification of the substance or mixture****Classification according to CLASS regulations 2013**

Acute toxicity, Category 4, Oral, H302
Skin irritation, Category 2, H315
Serious eye damage, Category 1, H318

For the full text of the H-Statements mentioned in this Section, see Section 16.

SAFETY DATA SHEET

according to Regulation (EC) No. 1907/2006

Catalogue No. 101134
Product name Ammonium carbamate for analysis EMSURE®

2.2 Label elements

Labelling according to CLASS regulations 2013

Hazard pictograms



Signal word

Danger

Hazard statements

H302 Harmful if swallowed.

H315 Causes skin irritation.

H318 Causes serious eye damage.

Precautionary statements

Prevention

P280 Wear eye protection.

Response

P302 + P352 IF ON SKIN: Wash with plenty of soap and water.

P305 + P351 + P338 IF IN EYES: Rinse cautiously with water for several minutes.

Remove contact lenses, if present and easy to do. Continue rinsing.

P313 Get medical advice/ attention.

Reduced labelling (≤ 125 ml)

Hazard pictograms



Signal word

Danger

Hazard statements

H318 Causes serious eye damage.

Precautionary statements

P280 Wear eye protection.

P305 + P351 + P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.

P313 Get medical advice/ attention.

CAS-No. 1111-78-0

2.3 Other hazards

None known.

SECTION 3. Composition/information on ingredients

3.1 Substance

SAFETY DATA SHEET

according to Regulation (EC) No. 1907/2006

Catalogue No.
Product name

101134
Ammonium carbamate for analysis EMSURE®

Formula H₂NCOONH₄ CH₆N₂O₂ (Hill)
EC-No. 214-185-2
Molar mass 78.07 g/mol

Hazardous components according to CLASS regulations 2013

Chemical name (Concentration)

CAS-No. Registration number
ammonium carbamate (<= 100 %)

1111-78-0 *)

Acute toxicity, Category 4, H302
Skin irritation, Category 2, H315
Serious eye damage, Category 1, H318

*) A registration number is not available for this substance as the substance or its use are exempted from registration according to Article 2 REACH Regulation (EC) No 1907/2006, the annual tonnage does not require a registration or the registration is envisaged for a later registration deadline.

For the full text of the H-Statements mentioned in this Section, see Section 16.

3.2 Mixture

Not applicable

SECTION 4. First aid measures

4.1 Description of first aid measures

After inhalation: fresh air.

In case of skin contact: Take off immediately all contaminated clothing. Rinse skin with water/ shower.

After eye contact: rinse out with plenty of water. Immediately call in ophthalmologist. Remove contact lenses.

After swallowing: immediately make victim drink water (two glasses at most). Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The following applies to ammonium salts in general: after swallowing: local irritation symptoms, nausea, vomiting, diarrhoea. Systemic effect: after the uptake of very large quantities: drop in blood pressure, collapse, CNS disorders, spasms, narcotic conditions, respiratory paralysis, haemolysis.

Irritation and corrosion

Risk of serious damage to eyes.

4.3 Indication of any immediate medical attention and special treatment needed

No information available.

SECTION 5. Firefighting measures

5.1 Extinguishing media

Suitable extinguishing media

SAFETY DATA SHEET

according to Regulation (EC) No. 1907/2006

Catalogue No.	101134
Product name	Ammonium carbamate for analysis EMSURE®

Use extinguishing measures that are appropriate to local circumstances and the surrounding environment.

Unsuitable extinguishing media

For this substance/mixture no limitations of extinguishing agents are given.

5.2 Special hazards arising from the substance or mixture

Not combustible.

Ambient fire may liberate hazardous vapours.

Fire may cause evolution of:

nitrogen oxides

5.3 Advice for firefighters

Special protective equipment for firefighters

Stay in danger area only with self-contained breathing apparatus. Prevent skin contact by keeping a safe distance or by wearing suitable protective clothing.

Further information

Suppress (knock down) gases/vapours/mists with a water spray jet. Prevent fire extinguishing water from contaminating surface water or the ground water system.

SECTION 6. Accidental release measures

6.1 Personal precautions, protective equipment and emergency procedures

Advice for non-emergency personnel: Avoid inhalation of dusts. Avoid substance contact. Ensure adequate ventilation. Evacuate the danger area, observe emergency procedures, consult an expert.

Advice for emergency responders:

Protective equipment see section 8.

6.2 Environmental precautions

Do not let product enter drains.

6.3 Methods and materials for containment and cleaning up

Cover drains. Collect, bind, and pump off spills. Observe possible material restrictions (see sections 7 and 10). Take up dry. Dispose of properly. Clean up affected area. Avoid generation of dusts.

6.4 Reference to other sections

Indications about waste treatment see section 13.

SECTION 7. Handling and storage

7.1 Precautions for safe handling

Advice on safe handling

Observe label precautions.

Hygiene measures

Immediately change contaminated clothing. Apply preventive skin protection. Wash hands and face after working with substance.

7.2 Conditions for safe storage, including any incompatibilities

Page 4 of 12

SAFETY DATA SHEET

according to Regulation (EC) No. 1907/2006

Catalogue No.	101134
Product name	Ammonium carbamate for analysis EMSURE®

Storage conditions

Tightly closed. Dry.

Recommended storage temperature see product label.

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated.

SECTION 8. Exposure controls/personal protection

8.1 Control parameters

Contains no substances with occupational exposure limit values.

8.2 Exposure controls

Engineering measures

Technical measures and appropriate working operations should be given priority over the use of personal protective equipment.

See section 7.1.

Individual protection measures

Protective clothing needs to be selected specifically for the workplace, depending on concentrations and quantities of the hazardous substances handled. The chemical resistance of the protective equipment should be enquired at the respective supplier.

Eye/face protection

Tightly fitting safety goggles

Hand protection

full contact:

Glove material:	Nitrile rubber
Glove thickness:	0.11 mm
Break through time:	480 min

splash contact:

Glove material:	Nitrile rubber
Glove thickness:	0.11 mm
Break through time:	480 min

The protective gloves to be used must comply with the specifications of EC Directive 89/686/EEC and the related standard EN374, for example KCL 741 Dermatril® L (full contact), KCL 741 Dermatril® L (splash contact).

The breakthrough times stated above were determined by KCL in laboratory tests acc. to EN374 with samples of the recommended glove types.

This recommendation applies only to the product stated in the safety data sheet, supplied by us and for the designated use. When dissolving in or mixing with other substances and under conditions deviating from those stated in EN374 please contact the supplier of CE-approved gloves (e.g. KCL GmbH, D-36124 Eichenzell, Internet: www.kcl.de).

Other protective equipment

protective clothing

SAFETY DATA SHEET

according to Regulation (EC) No. 1907/2006

Catalogue No. 101134
Product name Ammonium carbamate for analysis EMSURE®

Respiratory protection

required when dusts are generated.

Recommended Filter type: filter ABEK

The entrepreneur has to ensure that maintenance, cleaning and testing of respiratory protective devices are carried out according to the instructions of the producer.

These measures have to be properly documented.

Environmental exposure controls

Do not let product enter drains.

SECTION 9. Physical and chemical properties

9.1 Information on basic physical and chemical properties

Form	solid
Colour	colourless
Odour	ammoniacal
Odour Threshold	No information available.
pH	ca. 10 at 100 g/l 20 °C
Melting point	152 °C (closed capillary tube)
Boiling point/boiling range	Not applicable
Flash point	does not flash
Evaporation rate	No information available.
Flammability (solid, gas)	No information available.
Lower explosion limit	Not applicable
Upper explosion limit	Not applicable
Vapour pressure	82 hPa at 20 °C
Relative vapour density	No information available.
Density	1.6 g/cm ³ at 20 °C
Relative density	No information available.

SAFETY DATA SHEET

according to Regulation (EC) No. 1907/2006

Catalogue No.	101134
Product name	Ammonium carbamate for analysis EMSURE®
Water solubility	790 g/l at 20 °C
Partition coefficient: n-octanol/water	log Pow: -0.47 (25 °C) (experimental) (External MSDS) Bioaccumulation is not expected.
Auto-ignition temperature	No information available.
Decomposition temperature	> 35 °C
Viscosity, dynamic	No information available.
Explosive properties	Not classified as explosive.
Oxidizing properties	none

9.2 Other data

Ignition temperature	Not applicable
Bulk density	ca.750 kg/m ³

SECTION 10. Stability and reactivity

10.1 Reactivity

See section 10.3

10.2 Chemical stability

heat-sensitive

Sensitive to air.

The product is chemically stable under standard ambient conditions (room temperature).

10.3 Possibility of hazardous reactions

Caution! In contact with nitrites, nitrates, nitrous acid possible liberation of nitrosamines!

Exothermic reaction with:

nitrates, Bases, alkalines

10.4 Conditions to avoid

Heating (decomposition).

10.5 Incompatible materials

no information available

10.6 Hazardous decomposition products

in the event of fire: See section 5.

SAFETY DATA SHEET

according to Regulation (EC) No. 1907/2006

Catalogue No. 101134
Product name Ammonium carbamate for analysis EMSURE®

SECTION 11. Toxicological information

11.1 Information on toxicological effects

Acute oral toxicity

LD50 Rat: 681 - 1,470 mg/kg
OECD Test Guideline 401

Acute inhalation toxicity

Symptoms: Possible damages:, mucosal irritations

Acute dermal toxicity

This information is not available.

Skin irritation

In vitro study
Result: non-corrosive
OECD Test Guideline 431
In vitro study
Result: irritating
OECD Test Guideline 439
Causes skin irritation.

Eye irritation

In vitro study
Result: Causes serious eye damage.
Hen's egg-membrane test for irritation (HET-CAM)
In vitro study
Result: Causes serious eye damage.
OECD Test Guideline 437
Causes serious eye damage.

Sensitisation

This information is not available.

Germ cell mutagenicity

Genotoxicity in vitro
Mutagenicity (mammal cell test):
Result: negative
Method: OECD Test Guideline 476

Carcinogenicity

This information is not available.

Reproductive toxicity

This information is not available.

Teratogenicity

This information is not available.

Specific target organ toxicity - single exposure

This information is not available.

Specific target organ toxicity - repeated exposure

This information is not available.

Aspiration hazard

This information is not available.

SAFETY DATA SHEET

according to Regulation (EC) No. 1907/2006

Catalogue No.	101134
Product name	Ammonium carbamate for analysis EMSURE®

11.2 Further information

The following applies to ammonium salts in general: after swallowing: local irritation symptoms, nausea, vomiting, diarrhoea. Systemic effect: after the uptake of very large quantities: drop in blood pressure, collapse, CNS disorders, spasms, narcotic conditions, respiratory paralysis, haemolysis.

Under given conditions, contact with nitrites or nitric acid can lead to the formation of nitrosamines, which have shown themselves to be carcinogenic in animal experiments.

Other dangerous properties can not be excluded.

Handle in accordance with good industrial hygiene and safety practice.

SECTION 12. Ecological information

12.1 Toxicity

Toxicity to fish

LC50 Pimephales promelas (fathead minnow): 37 mg/l; 96 h
(External MSDS)

Toxicity to daphnia and other aquatic invertebrates

EC50 Daphnia magna (Water flea): 63.7 mg/l; 48 h
OECD Test Guideline 202

Toxicity to algae

IC50 Desmodesmus subspicatus (green algae): 129.1 mg/l; 72 h
(External MSDS)

Toxicity to bacteria

Respiration inhibition EC20 activated sludge: 1,000 mg/l; 30 min
OECD Test Guideline 209

12.2 Persistence and degradability

No information available.

12.3 Bioaccumulative potential

Partition coefficient: *n*-octanol/water
log Pow: -0.47 (25 °C)
(experimental)

(External MSDS) Bioaccumulation is not expected.

12.4 Mobility in soil

No information available.

12.5 Results of PBT and vPvB assessment

PBT/vPvB assessment not available as chemical safety assessment not required/not conducted.

12.6 Other adverse effects

Discharge into the environment must be avoided.

SAFETY DATA SHEET

according to Regulation (EC) No. 1907/2006

Catalogue No.	101134
Product name	Ammonium carbamate for analysis EMSURE®

SECTION 13. Disposal considerations

Waste treatment methods

Waste material must be disposed of in accordance with the national and local regulations. Leave chemicals in original containers. No mixing with other waste. Handle uncleaned containers like the product itself.

See www.retrologistik.com for processes regarding the return of chemicals and containers, or contact us there if you have further questions.

According to Quality Environment Regulation (Scheduled Waste) 2005, waste need to be sent to designated premise for recycle, treatment or disposal. Please contact Kualiti Alam for waste classification and correct disposal method.

SECTION 14. Transport information

Land transport (ADR/RID)

14.1 - 14.6 Not classified as dangerous in the meaning of transport regulations.

Inland waterway transport (ADN)

Not relevant

Air transport (IATA)

14.1 - 14.6 Not classified as dangerous in the meaning of transport regulations.

Sea transport (IMDG)

14.1 - 14.6 Not classified as dangerous in the meaning of transport regulations.

14.7 Transport in bulk according to Annex II of MARPOL 73/78 and the IBC Code

Not relevant

SECTION 15. Regulatory information

15.1 Safety, health and environmental regulations/legislation specific for the substance or mixture

All national and local regulations, including Occupational Safety and Health (Classification, Labelling and Safety Data Sheet of Hazardous Chemicals) Regulations 2013, if applicable to the use, should be observed.

National legislation

Storage class 10 - 13

15.2 Chemical safety assessment

For this product a chemical safety assessment was not carried out.

SAFETY DATA SHEET

according to Regulation (EC) No. 1907/2006

Catalogue No. 101134
Product name Ammonium carbamate for analysis EMSURE®

SECTION 16. Other information

Full text of H-Statements referred to under sections 2 and 3.

- H302 Harmful if swallowed.
H315 Causes skin irritation.
H318 Causes serious eye damage.

Training advice

Provide adequate information, instruction and training for operators.

Labelling

Hazard pictograms



Signal word

Danger

Hazard statements

- H302 Harmful if swallowed.
H315 Causes skin irritation.
H318 Causes serious eye damage.

Precautionary statements

Prevention

P280 Wear eye protection.

Response

P302 + P352 IF ON SKIN: Wash with plenty of soap and water.

P305 + P351 + P338 IF IN EYES: Rinse cautiously with water for several minutes.

Remove contact lenses, if present and easy to do. Continue rinsing.

P313 Get medical advice/ attention.

Key or legend to abbreviations and acronyms used in the safety data sheet

Used abbreviations and acronyms can be looked up at www.wikipedia.org.

Regional representation

Merck Sdn. Bhd. (Co. No: 178145), No. 4, Jalan U1/26, Section U1, Hicom Glenmarie Industrial Park, 40150 Shah Alam, Selangor. Tel: 03-74943688 Fax: 03-74910850

The information contained herein is based on the present state of our knowledge. It characterises the product with regard to the appropriate safety precautions. It does not represent a guarantee of any properties of the product.

The branding on the header and/or footer of this document may temporarily not visually

Page 11 of 12

The life science business of Merck operates as MilliporeSigma in the US and Canada



SAFETY DATA SHEET
according to Regulation (EC) No. 1907/2006

Catalogue No. 101134
Product name Ammonium carbamate for analysis EMSURE®

match the product purchased as we transition our branding. However, all of the information in the document regarding the product remains unchanged and matches the product ordered. For further information please contact mlsbranding@sial.com.