Final Year Project

(Thesis Title)

Carbon Capture and Storage Using Two Stage Aqueous Mineral Carbonation

B.Sc. Chemical Engineering

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Under the direction of their thesis advisor, has been presented and accepted, in partial fulfillment of the requirements of the degree of Bachelor of Science in Chemical Engineering.

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Dedication

“This work is dedicated

To our beloved parents and

Our kind teachers”

CONTENTS

ACKNOWLEDGEMENTS

We would like to thanks **Allah Almighty**, because of His love and strength; that He has given us, to finish this project and report. We would like to express our special thanks of gratitude to our supervisor **Dr. Imran Rashid** because our project could not have been completed without their sincere efforts.

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ABSTRACT

Environmental pollution increases day by day. This is due to directly exhaust of flues gases from the chimneys of the industries. We can protect environment by capture and storage of Carbon (C) that is present in flue gases with the help of lizardite that present in earth's crust. By this, we can also capture Carbon (C) and reuse it. It will reduce the capital cost of industries.

LIST OF FIGURES

ABBREVIATIONS

CCS	Carbon capture and Storage
CSTR	Continuous Stirred Tank Reactor
EIA	Environmental Impact Assessment
GHGs	Green-House Gases
Cp	Heat Capacity

Chapter 1

INTRODUCTION

OVERVIEW

CO_2 is the most important greenhouse gas. Green house gasses are the one which absorbs and emit radiant energy within the thermal infrared range. So, their excessive amount in atmosphere is dangerous.

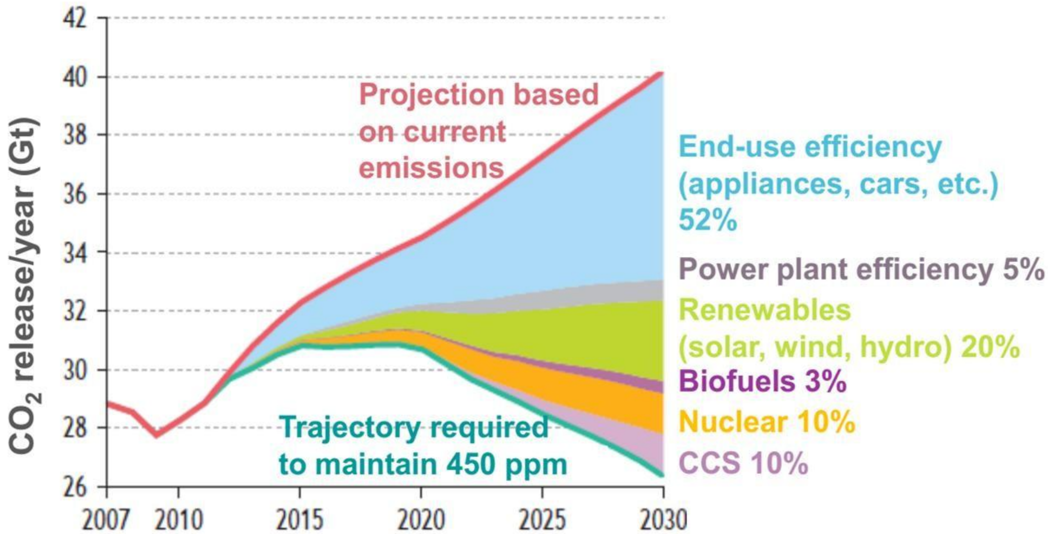
Carbon sequestration is the long-term removal, capture or sequestration of carbon dioxide from the atmosphere to slow or reverse atmospheric CO_2 pollution and to mitigate or reverse global warming.

CO_2 capture and Storage as sustainable development

According to the recent Panel on Climate Change, global greenhouse gas (GHG) emissions must be reduced by 50 to 80 percent to avoid dramatic consequences of global warming. By 2050, global population will rise from 7-9 billion people & the World enter demand is expected to increase by 50% over the next 20 years.

Due to global warming our climate is changing and increased in temperature has been observed. Results are in the form of Air pollution (smog), melting of glaciers, leading to reduced water and food resources. To avoid global warming, we choose this project as a solution. This project is sustainable as it captured the CO_2 from plant chimneys that causes global warming. Also, it stores carbon in the form magnesium carbonates that we can sell and make profit.

Figure1.1 International Energy Agency, 2009



<u>Main Sources of CO_2 Emission</u>

There are two main sources of CO_2 emission

- Industries
- Power station (coal based)

So, it can be captured from the air in the form of CO_2 or directly from the site (power station) to use in the mines to recover oil and gas.

CO2 Capture and storage by mineral carbonation

Mineral carbonation method is one such technique to capture atmospheric CO_2 and store it in a carbon sink. CO_2 can be mineralized in an engineered environment via the extraction of magnesium (Mg) or Calcium (Ca) from a suitable precursor material in an aqueous medium, followed by the reaction of these metals with dissolved CO_2 to form carbonate.

Carbonate can be used as raw material in the construction industry (e.g. aggregates, dykes, land expansion etc.) From storage point of view, less preferably, in chemical industry (e.g. fillers, fire retardants, etc.). Mineral carbonation, aims at chemically converting CO_2 into an environmentally stable product.

Mg, Fe and Ca are the most commonly used elements in mineral carbonation processes on account of the fact that not only they are abundantly found on the earth's crust, but are also able to be extracted from industrial waste. The products generated by mineral carbonation can be commercialized, thus reducing process costs.

Chapter 2

PROCESS DESCRIPTION

OVERVIEW

This section deals with the steps followed to capture and storage of carbon from flue gases that comes from industrial exhaust with the help of lizardite that is mineral, its process flow diagram and multiple routes that could have been taken.

Single stage carbonation

It is performed in stirred reactors at partial pressure of CO_2 up to 1bar, temperatures between 30^{o}C and 190^{o}C. The degree of carbonation of products is quantified using thermogravimetric analysis. Carbonation is confirmed by the formation of two Mg carbonates nesquehonite and hydromagnesite

Single stage carbonation limitations

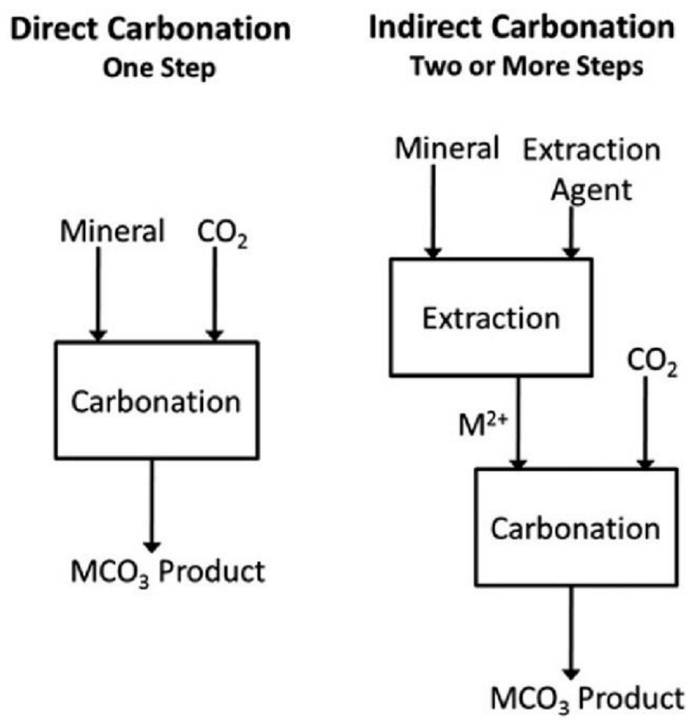
Low process efficiencies were observed for single-step batch experiments with partially dehydroxylated lizardite reacting in an aqueous medium under a gas flow of pure CO_2 and up to temperatures of 90C. The reaction progress was hindered by a passivating layer of re-precipitated silica or quartz. The extent of carbonation did not exceed more than 20% due to equilibrium limitations.

Two stage carbonation

Double-step carbonation experiments were carried out at an atmospheric pressure. Using one of the interconnected Teflon reactors as the precipitator. And the other one as the dissolution reactor. The CO_2 content of the feed gas (100%), and the slurry density (1wt%) in the dissolution reactor. The temperature in the precipitator (90C) were kept unchanged.

Double step carbonation is better than single stage carbonation

A double-step strategy proved successful in addressing the single stage problem by controlling the pH of the solution. This is achieved by continuously removing the Mg from the dissolution reactor and letting it precipitate at a higher T and a lower p CO_2 in a separate reactor. The extent of double stage carbonation is 50% much better than single stage carbonation. Thus, we choose double stage carbonation.



Raw material selection

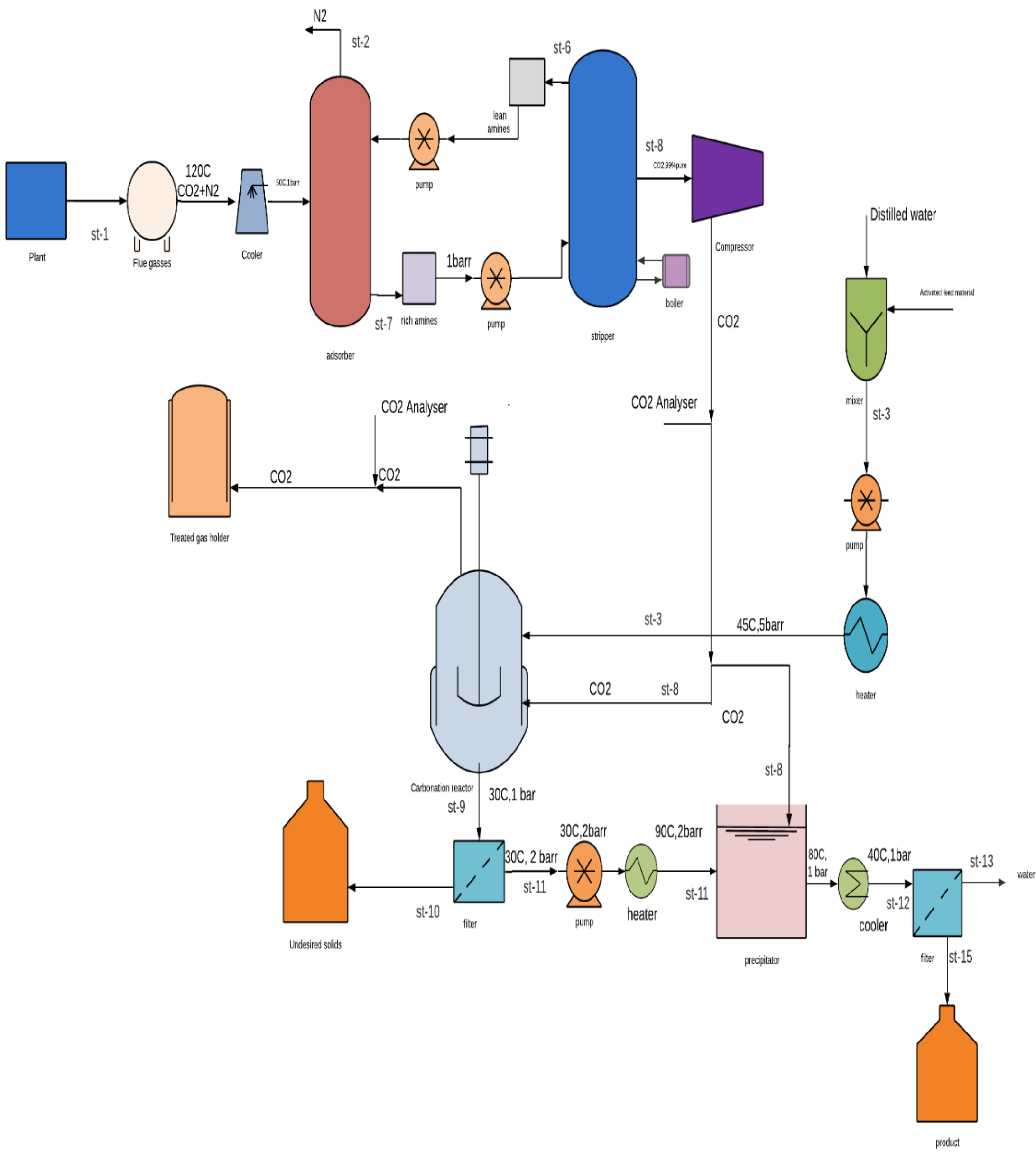
We select Lizardite as raw material

- Formula: $Mg_3(Si_2O_5)(OH)_4$
- Color: green, brown, light yellow to white
- Lustre: Resinous, Waxy, Greasy
- Hardness:2½
- Specific Gravity:2.55
- Crystal System: Trigonal
- Member of: Serpentine Subgroup

Process description

- Flue gases (CO_2+N_2) are coming from the plant that has temp. of 120C. These gases send to cooler where temp. reduces to 50C at atmospheric pressure.
- Then these flue gases send to adsorber where the N_2 is extracted and it converts rich amines into lean amines. The rich amines are made in the stripper where lean amines stream is attached and stripper makes amines rich that transfer to adsorber where N2 is extracted. This process is continuous for extraction of N_2 and streams b/w adsorber and stripper are transferred with the help of pumps.
- After stripper stream (99%pure,CO_2) is send to compressor. From where it is send to the carbonation reactor and precipitator. CO_2 analyzer is installed that analyze CO_2.
- We prepare slurry in mixer by adding activated feed material (Lizardite) and distilled water. It is send to the heater with the help of pump where its temp. rises. So that it can send to the carbonation reaction.
- In carbonation reactor, slurry is added at 45C with 5 bar pressure and CO_2 from compressor is added. From reactor CO2 is send to treated gas holder by analyzing with the help of CO_2 analyzer.
- From Carbonation reactor , product is send to the filter where undesired solids are removed from the product. From filter product is send to precipitator with the help of pump. After reaction in reactor product temp. is 90C and pressure is 2 bar.
- In precipitator , product is added and CO2 that is 99% pure from compressor is added. Temp. reduced to 40C and stream is send to filter. From filter circulated water and product is separated. Our product is Nesquehonite.

Process flow diagram



Chapter 3

MATERIAL & ENERGY BALANCE

OVERVIEW

This section deals with the material and energy balance on each equipment to produce desired quantity of ammonia. **Capacity selection**

- 1kg of CO_2 required 2 kg of lizardite
- 1 ton = 1000kg
- 1 ton CO_2 captured per day = 1000kg / day
- CO_2 capture per hour = 1000/24 = 41.67kg/h
- So, plant is designed to capture and store 41.67kg of CO_2
- 1kg CO_2 require = 2kg of lizardite
- 41.67kg/h CO_2 require = 83.34kg/h lizardite

Material Balance

Raw materials required

- We need 2% conc. Slurry for the reaction
- 2% lizardite (solids)
- 98% sol (water)

MATERIAL BALANCE

OVERALL MATERIAL BALANCE

Material in

COMP	ST-1 FLUE GAS		ST-3	
	Mol%	Kg/h	Mol%	Kg/h
N_2	68.08	218.20	-	-
O_2	5	16.0255	-	-
H_2O	12	38.46	98	4083.33
CO_2	13.5	43.36	-	-
Ar	2	6.4102	-	
LIZARDITE	-	-	2	83.33

Material out

Comp	ST-2		ST-4		ST-5	
	Mol%	Kg/h	Mol%	Kg/h	Mol%	Kg/h
N_2	93.16	217.69	-	-	-	-
O_2	3.3	7.71	-	-	-	-
H_2O	0.5	1.168	100	4120.71	1	1.33
CO2	1.84	4.299	-	-	-	-
Ar	1.2	2.8	-	-	-	-
Nesqhionite	-	-	-	-	99	131.43

CAPACITY SELECTION

1 kg of CO_2 requires 2 kg of Lizardite. So, 1 ton/day= 1000/24 kg/hr = 41.667kg/hr.

So, from the above statement it is clear that 41.667kg/hr of CO_2 will require 83.33kg/hr of Lizardite.

So, total inlet flowrate of **ST-3** = 83.33/0.02= 4166.7 kg/ hr of feed. From the above statement we know that 0.13*ST-1 = 41.667 kg/hr of CO_2

ST-1 = 320.51 kg/hr.

N_2 Balance

$$0.68*320.51 = 0.9316* ST\text{-}2$$

$$ST\text{-}2 = 233.68 \text{ kg/hr}$$

H_2O Balance

$$0.12*320.51 + 0.98*4166.5 = 0.005*233.68 + ST\text{-}3$$

$$ST\text{-}4 = 4120.41 \text{ kg/hr}$$

$$ST\text{-}1 + ST\text{-}3 = ST\text{-}4 + ST\text{-}2 + ST\text{-}5$$

$$ST\text{-}5 = 132.76 \text{ kg/hr}$$

EUIPMENT MATERIAL BALANCE

MATERIAL ON ABSORBER

Material in

COMP	ST- 1		ST-6	
	Mol%	Kg/h	Mol%	Kg/h
N_2	68.08	218.20	-	-
O_2	5	16.0255	-	-
H_2O	12	38.46	64.64	67.206
CO2	13.5	43.36	8.77	9.11
Ar	2	6.4102	-	-
MEA	-	-	26.6	27.65

Temp=8°C

Pressure=1.01325 bar

Material out

COMP	ST-2		ST-7	
	Mol%	Kg/hr	Mol%	Kg/hr
N_2	79.39	185.86	-	-
O_2	6.63	6.63	-	-
H_2O	1	1	54.58	103.94
CO_2	15.74	36.86	22.57	42.98
Ar	0.956	2.2386	-	-
MEA	-	-	22.58	43.001

ST-1 + ST-6 = ST-2 + ST-7

$$320.51 - 233.68 = ST\text{-}7 - ST\text{-}6$$

H_2O Balance

$$0.12*320.15 + 0.6464* ST\text{-}6 = 0.005*233.68 + 0.5485*(86.47+ ST\text{-}6)$$

$$ST\text{-}6 = 103.97 \text{ kg/hr}$$

$$ST\text{-}7 = 190.44 \text{ kg/hr}$$

MATERIAL BALANCE ACROSS STRIPPER:

Material in:

COMP	ST-7	
	Mol%	Kg/hr
H_2O	54.58	103.94
CO_2	22.57	42.98
MEA	22.58	43.001

Material out:

COMP	ST-6		ST-8	
	Mol%	Kg/hr	Mol%	Kg/hr
H_2O	64.64	67.206	1	0.8657
CO_2	8.77	9.11	99	85.7043
MEA	26.6	27.65	-	-

MATERIAL BALANCE ACROSS REACTOR:

Material in

COMP	ST-3		ST-8	
	Mol%	Kg/hr	Mol%	Kg/hr
H_2O	98	4083.366	1	0.8657
CO_2	-	-	99	85.7043
LIZARDITE	2	83.334	-	-

Material out:

COMP	ST-9	
	Mol%	Kg/hr
LIZARDITE	1	42.5327
CO_3^{-2}	0.057	2.24
Mg^{+2}	0.26	11.058
SiO_2	0.43	18.28
H_2O	98.253	4178.98

ST-7 = ST-6 + ST-8

ST-8 = 86.57 kg/hr

ST-3 + ST-8 = ST-9

ST-9 = 4253.27 kg/hr Molar

mass of Lizardite = 277.11 g/mole

No. of moles = 83334/277.11 = 300.72 mole/hr

Fa = Fa0(1-Xa)

Where Xa at 45 C, 5 bar, 600 Pa in one hour is 0.5

Fa = 300.725(1-0.5) = 150.36 moles/hr

HCO_3^{-2} Balance

$$Fb = Fb0 - Fa0*Xa*b/a$$

$Mg_3Si_2O_5(OH)_4 + 6H^+ \longrightarrow 3Mg^{+2} + 2SiO_2$ 5H_2O

$$Fb0 = CO2 \text{ in feed/MW of } CO2 = 4144/44 = 941.818 \text{ mol/hr}$$

$$Fb = 941.818 - (300.725) *(0.5) *6$$

$$Fb = 39.643$$

Mg^{+2} Balance

$$Fc = Fc0 - Fa0*Xb*c/a$$

$$Fc = (300.725) *(0.5) *(3) = 451.0875 \text{ moles/hr}$$

O_2 Balance

$$Fd = Fd0 - Fa0*Xa*d/a$$

$$Fd = (300.725) * (0.5) * (2)$$

Fd = 300.725 moles/hr **Product stream**

- Lizardite = 150.36 * 277.11 = 42.52 kg/hr
- CO_3^{-2} = 39.643 * 60.009 = 2.42 kg/hr
- Mg^{+2} = 451.087 * 24.305 = 11.15 kg/hr
- SiO_2 = 300.725 * 60 = 18.283 kg/hr
- H_2O (out) = 4178.96 kg/hr Total = 4253.23 kg/hr

Composition of the product stream

- Lizardite = 42.52/4253.23 = 0.01
- CO_3^{-2} = 2.42/4253.23 = 0.00051
- Mg^{+2} = 11.15/4253.23 = 0.0026

- SiO_2 = 18.283/4253.23 = 0.0043
- H_2O = 4178.96/4253.23 = 0.9825

MATERIAL BALANCE ACROSS FILTER 1:

Material in

COMP	ST-9	
	Mol%	Kg/hr
LIZARDITE	1	42.5327
CO_3^{-2}	0.057	2.24
Mg^{+2}	0.26	11.058
SiO_2	0.43	18.28
H_2O	98.253	4178.98

Material out

COMP	ST-10		ST-11	
	Mol%	Kg/hr	Mol%	Kg/hr
SiO_2	0.5	10.6352	-	-
LIZARDITE	2	42.54	-	-
H_2O	97.5	2073.864	99.51	2116.23
Mg^{+2}	-	-	0.09	1.91
CO_3^{-2}	-	-	0.4	8.5

ST-9 = ST-10 + ST-11

0.97* ST-10 + 0.99* ST-11 = 4178.83

0.975*(4253.27 - ST-11) + 0.99* ST-11 = 4178.83

ST-11 = 2126.66 kg/hr

ST-10 = 2127.04 kg/hr

MATERIAL BALANCE ACROSS PRECIPITAOR

$Mg^{+2} + CO_3^{-2} \longrightarrow MgCO_3$

(MAGNESITE)

$MgCO_3 \longrightarrow MgCO_3.3H_2O$

Material in

COMP	ST-11		ST-8	
	Mol%	Kg/hr	Mol%	Kg/hr
CO2	-	-	99	85.7043
H_2O	99.51	2116.23	1	0.8657
Mg^{+2}	0.09	1.91	-	-
CO_3^{-2}	0.4	8.5	-	-

Material out

COMP	ST-12	
	Mol%	Kg/hr
$MgCO_3.3H_2O$	0.43	9.51
H_2O	99.56	2203.47

ST-11 + ST-8 = ST-12

ST-12 = 2213.21 kg/hr

Molecular mass of Mg^{+2} = 24.305 g/mol

$$\text{No. of moles} = 11058/24.305 = 454.96$$

Mg^{+2} Balance

$$Fa0 = 454.96$$

$$Fa = Fa_0(1-Xa) = 454.96(1-0.5) = 227.48 \text{ moles/hr}$$

CO_3^{-2} Balance

$$Fb = Fb_0(1-Xa)*b/a$$

$$Fb = 40.39 + (227.48)(0.5)$$

$$Fb = 154.13 \text{ moles/hr}$$

$MgCO_3$ Balance

$$Fc = Fc_0 - Fa_0(Xa)$$

$$Fc = (227.48)(0.5)$$

$$Fc = 113.74 \text{ moles/hr}$$

Product stream

$$MgCO_3 = 84.313 * 113.74 = 9589.76/1000 = 9.58 \text{ kg/hr}$$

$$9.58/2213.21 = 0.0043$$

$$1 - 0.0043 = 0.9956$$

MATERIAL BALANCE ACROSS FILTER 2

$$ST\text{-}12 = ST\text{-}15 + ST\text{-}13$$

$$ST\text{-}13 = 2080.09 \text{ kg/hr}$$

ST-15 = 133.12 kg/hr

Material in:

COMP	**ST-12**	
	Mol%	Kg/hr
$MgCO_3.3H_2O$	0.43	9.51
H_2O	99.56	2203.47

Material out:

COMP	**ST-13**		**ST-15**	
	Mol%	Kg/hr	Mol%	Kg/hr
$MgCO_3.3H_2O$	0.2	4.16	99	131.788
H_2O	99.56	2070.93	1	1.33

OVERALL ENERGY BALANCE

Overall Energy Balance

Energy balance accounts for energy being transferred to or from the each equipment and is done here by taking into account the law of conservation of energy that is defined as below.

Law of conservation of energy

It states that:

[Rate of energy going into the system] - [Rate of energy going out of the system] + [Rate of energy generation within the system] - [Rate of energy consumption within the system] = [Rate of energy accumulation in the system]

Now the energy balance of each equipment is given bellow

STREAM NO	ΔT	MASS FLOW	AVERAGE C_P	AVERAGE DENSITY	$m*c_p*\Delta T$	$m*\Delta P/þ$	Q
	(k)	Kg/h	Kj/kg.k	Kg/m^3	KW	KW	KW
1	393	320.51	1.39	0	48.63	-	48.63
2	323	233.94	1.0347	0	21.71	0.13	21.71
3	298	4166.7	4.068	0	1403.09	-	1403.09
4	313	4120.71	4.0737	0	1459.49	-	1459.49
5	313	132.56	1.5	0	17.28	-	17.28

Stream in: 81.28-0.77-.013 = 80.49 KW

Stream out: -8.79-27.36-13.85 = -50.03 KW

EQUIPMENT ENERGY BALANCE

ENERGY BALANCE ACROSS DIRECT CONTACT COOLER

STREAM	TEMPERATURE	AVERAGE CP	FLOW RATE	Q
	°C	Kj/kg.k	Kg/h	KW
FLUE GAS INTO DCC-1	50	1.49	7872.94	81.46
FLUE GAS FROM DCC-1	30	1.49	7872.94	16.29

ENERGY BALANCE ACROSS HEAT EXCHANGER (BEFORE ABSORBER)

STREAM	TEMPERATURE	AVERAGE CP	FLOW RATE	Q
	°C	Kj/kg.k	Kg/h	KW
FLUE GAS INTO CHILLER-1	30	1.49	7872.94	16.29
FLUE GAS FROM CHILLER-1	8	1.49	7872.94	-55.39

ABSORBER ENERGY BALANCE

COMPONENTS	HEAT OF FORMATION
CO_2	-393.5
H_2O	-285.8
NH_3	-46.2
NH_4HCO_3	-853.385
$(NH_4)_2CO_3$	-940.772
$NH_4CO_2NH_2$	151.8

STREAM	TEMPERATURE	AVERAGE CP	FLOW RATE	Q
	°C	Kj/kg.k	Kg/h	KW
FLUE GAS INTO ABSORBER	8	1.49	7872.94	81.46
FLUE GAS FROM TOP OF THE ABSORBER	9	1.55	6416.37	-16.29
LEAN SOLUTION INTO ABSORBER	8	3.09	3732.334	-54.46
RICH SOLUTION DISCHARGE FROM THE ABSORBER	50	3.28	5191.16	118.24

ENERGY BALANCE ACROSS STRIPPER

STREAM	TEMPERATURE	AVERAGE CP	FLOW RATE	Q
	°C	Kj/kg.k	Kg/h	KW
RICH SOLUTION FROM STRIPPER	120	3.025	136.098	44.94
LEAN SOLUTION FROM ABSORBER	70	2.694	222.668	57.15
COMPRESSOD CO2	120	0.939	86.57	8.87

INTERMEDIATE HEAT EXCHANGER ENERGY BALANCE:

STREAM	TEMPERATURE	AVERAGE CP	FLOW RATE	Q
	°C	Kj/kg.k	Kg/h	KW
LEAN SOLUTION FORM STRIPPER BEFORE HE-1	110	3.09	3732.334	272.30
LEAN SOLUTION INTO ABSORBER AFTER HE-1	70	3.09	3732.334	144.161
RICH SOLUTION FROM ABSORBER BEFORE HE-1	50	3.28	5191.16	118.24
RICH SOLUTION INTO STRIPPER AFTER HE-1	90	3.28	5191.16	307.43

Chapter 4

EQUIPMENT DESIGN

OVERVIEW

Equipment design is an extremely essential part of plant design. We designed three equipment reactor, heat exchanger and pump. The equipment design may be a vital step within the plant design. A correct equipment design gives the highest quality product. The planning of equipment in manufacturing industry assumes a dominant role within the industrial competitiveness.

An equipment should be designed in such how that it gives maximum efficiency with minimum cost. In our project we've designed the three major equipment from the three major processes, i.e. Reactor, heat exchanger and pump. Moreover, we've also discussed about the selection criteria of selecting the precise equipment.

REACTOR DESIGN

A reactor is a vessel in which chemical reactions takes place to convert the reactants into desired product.

Types of Reactors

- Batch Reactor
- CSTR (continuous stirred tank reactor)
- PFR (plug flow reactor)
- Semi batch reactor
- Catalytic reactor

CSTR (continuous stirred tank reactor)

When we are dealing with high quantity of reactants and higher amount of product is required CSTR id used. The quality of the products can be compromised. The process is continuous and more than one reactor can be attached in series for different kind of reactants and products. This is the most common reactor in the process industry and high amount of product can be obtained with this type of reactor.

Important aspects of CSTR

- The flow rate should be equal to the mass flow rate out, at steady state,
- For all the calculations performed with CSTR assume perfect mixing.
- The reaction proceeds with the reaction rate which is associated with the final output concentration.
- To operate several CSTR's in series or in parallel economically beneficial.

PFR (plug flow reactor)

In the CSTR the reactants input and the product output is the same and continuous but the problem is that different molecules of the reactants have different residence time and the composition of the reactants is same throughout the reactor this means that the concentration of the reactants at inlet and outlet is the same with different residence time of the molecules which reduce the rate of the reaction and which affects the product directly. To overcome this problem a PFR is used which is also called ideal reactor and in this reactor the concentration is not same and no back mixing is done in this reactor which increases the product quality. Another advantage of thus reactor is that the residence time can be increased by increasing the length of the reactor.

Selection Reason

CSTR is chosen based on the following reasons:

- We are reacting two different phases of the components and their mixing is necessary to initiate the reaction
- Their reaction is endo thermic and we have to deal with high energy and mass transfer
- Our Reactants have two different phases i.e Gas and liquid(slurry).
- Dealing with high quantity **Design**

1. Volume is calculated with the help of:
   - Rate of reaction
   - Residence time
2. Then power consumed is calculated
   - Mechanical design step
   - Thickness of shell
   - Impeller design
   - Diameter of impeller
   - Material of construction
   - Insulation of selection

Procedure

- Collect all the kinetics and thermodynamics data on the desired reaction
- Collect physical data required for the design
- Identify the pre dominant rate controlling mechanism
- Choose a suitable reactor type
- Make an initial selection of the reactor condition to give desired conversion and yield
- Size the reactor
- Select the suitable material of construction

Table 1: Physical properties of streams in reactor

Stream	M	FA0	Density	Molar wt.	Vo
	Kg/hr	Kmol/hr	Kg/m^3	Kg/kgmol	m^3/hr
Lizardite	83.334	0.3007	$2.57*10^3$	277.11	32425.68
Water	4083.36	226.85	997	18	4.095
CO_2	85.7043	1.947	1.98	44	43.285
Total	4252.4043	-			32473.06

Given Data

X=0.50 -

r_A=0.1666

$$V= \frac{Fa}{-ra} * X$$

$$V= 0\frac{3007*0.5}{0.1666}.$$

V= 0.9024m^3

$$\text{Space time } (\lambda)= \frac{Volume}{Volumetric\ Flowrate} = \frac{V}{V0}$$

Volumetric Flowrate = total mass flow rate / density of the mixture

Density of the mixture = $2.57*10^{-3}$*0.02 + 997*0.98

Density of the mixture = 977.06005kg/m^3

Volumetric Flowrate = V_0 = $\frac{4166.694}{977.06005}$ V_0

= 4.264 m^3/hr

$$\text{Space time} = \frac{0.9024}{4.264}$$

Space time = 0.2116 hr or 12.697min

By giving 20% allowance

V = 1.2 * 0.9024

$V = 1.08288m^3$

(Reference: unit operation of chemical engineering by McCabe & smith: Ed:6th)

H= 1.5*D

$$V = \frac{3.141 * D2 * 1.5D}{4}$$

$$1.08288 = \frac{3.141 * D2 * 1.5D}{4}$$

D = 0.9723m

So,

H = 1.5 * 0.9723

H = 1.4585m **Vessel**

A dished bottom requires less power than a flat one.

Selection criteria of an impeller

The impeller selected for the agitation is pitched blade turbine 45° because:

- The measured viscosity of mixture is 0.3049cP which is in the range of the impeller.
- Efficient turbulence flow impeller for blending immiscible liquids.
- Combine axial and radial flow are achieved.
- Especially effective for heat exchange with vessel walls and internal coils.
- It can be operated at different speeds
- The cost is low as compared to other

Design of Impeller

Da/Dt = 1/3	Da = 0.3241m
H/Dt = 1	H = 0.9723m
J/Dt = 1/12	J = 0.081025m
E/Dt = 1/3	E = 0.3241m
W/Da = 1/5	W = 0.06482m
L/Da = ¼	L = 0.081025m

Da = diameter of impeller

Dt = tank diameter

H = depth of liquid in tank

J = width of baffles

E = height of impeller above vessel floor

L = length of impeller blade

(Reference: unit operation of chemical engineering by McCabe & smith: Ed:6th) **Baffles**

Four radial baffles at equal spacing are used

Impeller Reynold number

$$Re = \frac{Da^2 * Nr * \rho}{\mu}$$

Da = 0.3241m

$$Nr = 1500rpm = 25rph$$

$$Re = \frac{(0.321)2*25*977.06005}{0.0003049}$$

$$Re = 8415150$$

Power requirement

$$P = KT*Nr3 *Da* \rho$$

$$K_{T} = 1.63$$

$$P = 1.63 * (25)^3 * (0.3241)^5 * 977.06$$

$$P = 88986.478W$$

$$P = 88.986KW$$

Power number

$$N_p = \frac{\rho}{Ne3* De5* \rho}$$

$$N_p = \frac{977.06}{(25)3*(0.3241)5*977.06}$$

$$N_p = 2.67$$

Material of construction

Mechanical design for reactor

diameter of shell = Di = 0.9723 m

working of operating pressure = 3 bar

design pressure = 3.6 bar working

operating temperature = 45 ^oC design

Temperature = 1.2 * 45 = 54 ^oC

Material selection

Carbon steel type 310

Its composition is

Cr = 24-26%   Ni = 19-22%   C = 0.25%

- High strength and resistant to scaling at high temperature
- This alloy shows increased resistance to high temperature corrosion
- Jacketed high temperature, high pressure reactor, exothermic reaction

involved

For blades

carbon steel type 410 its

composition is

Cr = 11.50-13.50%   C = 0.15%

- Lowest cost general purpose stainless steel
- Wide use where corrosion is not severe
- Bubble tower parts for pump, rods and valves, machine parts and turbine

blades

For baffles

carbon steel type 405 its composition is

Cr = 11.50-14.50%   Al = 0.1-0.3%   C = 0.08%

- Version of type 410 with limited hardenability but improved weldability.
- Good weld ability and cladding properties.
- Tower lining, baffles and heat exchangers.

Baffle spacing

Baffle spacing is calculated from following formula

Baffle spacing = 3.14*Di/4

Baffle spacing = 3.14 *0.9723/4

Baffle spacing = 0.2430 m

Width of baffle = Di/12

Width of baffle = 0.9723/12

Width of baffle = 0.0810 m

Distance from bottom = Di/2

Distance from bottom = 0.9723/2

Distance from bottom = 0.4861

Minimum particle wall thickness

The minimum wall thickness is calculated to make sure that the vessel will withstand its own wait and the pressure inside it. As a general guide the wall thickness of any vessel should not be less than the vessel given below; the values include a corrosion allowance of 2 mm.

Vessel Diameter (m)	Minimum thickness (mm)
1	5
1 to 2	7
2 to 2.5	9
2.5 to 3	10
3 to 3.5	12

Table 2: minimum wall thickness against vessel diameter

PUMP DESIGN

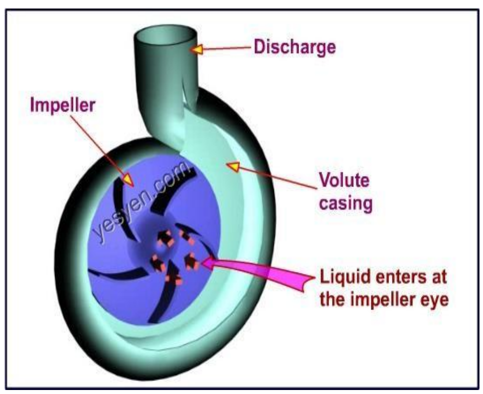
Pump

A pump is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action, typically converted from electrical energy into hydraulic energy

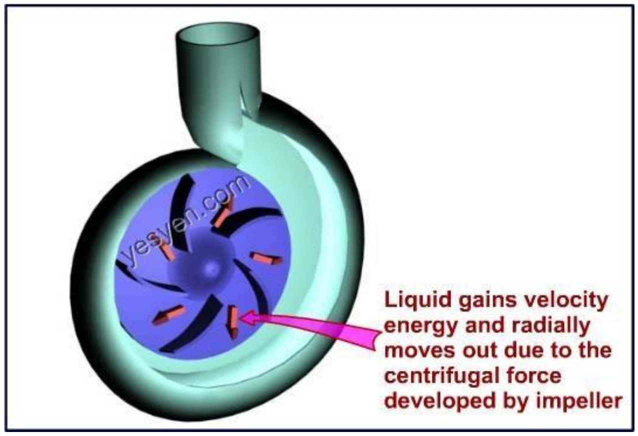
Working principle of pump

A Pump is generally used to induce flow or raise the pressure of a liquid. Centrifugal pumps are a category of Dynamic pumps. The **working principle** of **centrifugal pumps** involves imparting energy to the liquid by means of a centrifugal force developed by the rotation of an impeller that has several blades or vanes. The basic **centrifugal pump theory** of working comprises of the following working stages.

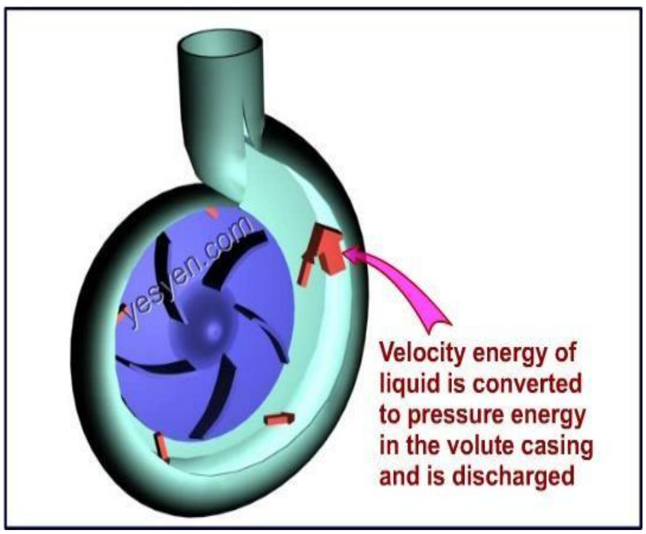
- Liquid enters the pump casing at the impeller eye.(fig 4.1a)



- Velocity energy is imparted to the liquid by means of the centrifugal force produced by rotation of the impeller and the liquid is radially pushed out towards the impeller periphery.(fig 4.1b)



- The velocity energy of liquid is converted to pressure energy by directing it to an expanding volute design casing in a volute type centrifugal pump or diffusers in a turbine pump.(fig 4.1 c)

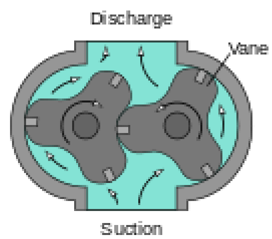


Types of pump

Positive-displacement pumps

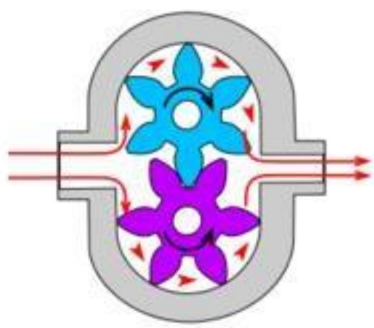
A positive-displacement pump makes a fluid move by trapping a fixed amount and forcing (displacing) that trapped volume into the discharge pipe.

Some positive-displacement pumps use an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pump as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is constant through each cycle of operation (fig 4.2)



Gear pump

This is the simplest form of rotary positive-displacement pumps. It consists of two meshed gears that rotate in a closely fitted casing. The tooth spaces trap fluid and force it around the outer periphery. The fluid does not travel back on the meshed part, because the teeth mesh closely in the center. Gear pumps see wide use in car engine oil pumps and in various hydraulic power packs.(fig 4.3)



Screw pump

A screw pump is a more complicated type of rotary pump that uses two or three screws with opposing thread — e.g., one screw turns clockwise and the other counter clockwise. The screws are mounted on parallel shafts that have gears that mesh so the shafts turn together and everything stays in place. The screws turn on the shafts and drive fluid through the pump. As with other forms of rotary pumps, the clearance between moving parts and the pump's casing is minimal.(fig4.4)

Radial-flow pumps

Such a pump is also referred to as a centrifugal pump. The fluid enters along the axis or center, is accelerated by the impeller and exits at right angles to the shaft (radially); an example is the centrifugal fan, which is commonly used to implement a vacuum cleaner. Another type of radial-flow pump is a vortex pump. The liquid in them moves in tangential direction around the working wheel. The conversion from the mechanical energy of motor into the potential energy of flow comes by means of multiple whirls, which are excited by the impeller in the working channel of the pump. Generally, a radial-flow pump operates at higher pressures and lower flow rates than an axial- or a mixed-flow pump.

Axial-flow pumps

These are also referred to as All fluid pumps. The fluid is pushed outward or inward to move fluid axially. They operate at much lower pressures and higher flow rates than radialflow (centrifugal) pumps. Axial-flow pumps cannot be run up to speed without special precaution. If at a low flow rate, the total head rise and high torque associated with this pipe would mean that the starting torque would have to become a function of acceleration for the whole mass of liquid in the pipe system. If there is a large amount of fluid in the system, accelerate the pump slowly.

Mixed-flow pumps function as a compromise between radial and axial-flow pumps. The fluid experiences both radial acceleration and lift and exits the impeller somewhere between 0 and 90 degrees from the axial direction. As a consequence mixed-flow pumps operate at higher pressures than axial-flow pumps while delivering higher discharges than radial-flow pumps. The exit angle of the flow dictates the pressure head-discharge characteristic in relation to radial and mixed-flow.

Centrifugal pumps

These are used to transport fluids by the conversion of rotational kinetic energy to the hydrodynamic energy of the fluid flow. The rotational energy typically comes from an engine or electric motor. They are a sub-class of dynamic axisymmetric work-absorbing turbomachinery. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from which it exits.

Common uses include water, sewage, agriculture, petroleum and petrochemical pumping. Centrifugal pumps are often chosen for their high flow rate capabilities, abrasive solution compatibility, mixing potential, as well as their relatively simple engineering. A centrifugal fan is commonly used to implement an air handling unit or vacuum cleaner. The reverse function of the centrifugal pump is a water turbine converting potential energy of water pressure into mechanical rotational energy.(fig 4.5)

Why I choose centrifugal pump

- It can pump hazardous liquids
- There are very less frictional losses
- There is almost no noise
- Centrifugal pump has high efficiency than other
- Centrifugal pump have minimum wear with respect to others
- Centrifugal pump use magnetic coupling which breakup on high load eliminating the risk of damaging the motor

General steps to design the centrifugal pump

Following steps generally used to design the centrifugal pump

Step 1: Determine required flow rate

The flow rate refers to the volume of fluid passing through a pump's per unit time. This parameter is determined by the process and the number of pumps to be installed.

Step 2: Determine static head

The static head refers to the difference in the elevation of highest point where you want to deliver the water and the elevation of the water source. As the name suggests, static head is constant i.e. it does not vary with the system discharge.

Step 3: Determine friction head

To calculate the loss of head due to friction, you will need to consider all the elements present in the pipe system connected to the pump: pipe, fittings, heat exchangers, valves...

with the resistance characteristics of these elements and the fluid characteristics the friction head is calculated.

Step 4: Determine total head

You get the total head by adding the static head and friction head.

Step 5: Choose centrifugal pump

Centrifugal pump manufacturers have pumps for specific purposes. Pump curves are available as flow rate against pump head to help you choose an impeller. Use your calculated values from step 1 and step 4 to find a suitable pump through the pump curves. Choose the most efficient option between the possible pumps and check also that the NPSH required by the pump is less that the NPSH available in the installation to ensure that the liquid will not cause failure or cavitation in pump. Other aspects as size of impeller or position of duty point in the curve shall be considered.

Design Step 1

Flow rate = Area(velocity)

Area= 3.14/4 $(0.152)^2$

The diameter of pipe is 6 inches. That we used in our project

Area = $0.181 m^2$

Velocity = 2-3m/s

Flow rate = $0.181 m^2 * 2.5 m/s = 0.0453 m^3/s = 163 m^3/h$

Step2 Static head or vertical head

This we take from the replacement or positioning of equipment directly. In our case we take 65ft.

H_v = 65ft

Step 3

Friction head

$H_f = f *L + f*L_e$

L=length of pipe=140ft f=friction

factor from moody chart

f=0.027

Le=elbow equivalent length

Le=8.5ft

$H_f = f *L + f*L_e$

Hf =0.027*140+0.027*8.5*2 = 4.28ft

We multiply with 2 for two joints

TDH=total dynamic head=static head+ friction head

TDH= 65ft + 4.28ft = 69.28ft

We design pump by using this data, this is taken from our project

Static delivery head = h_d = 19.8m

Static suction head = h_s = 2.5m

Length of suction pipe = L_s = 5m

Length of delivery pipe = L_d = 35m

Discharge or flow rate = $163 m^3/h$

We design impeller, shaft, bearing and casing (layout)

Given data

$Hs = 2.5m$, $Ls = 5m$

$H_d = 19.8m$, $Ld = 35m$

$Q_{act} = 0.0453 m^3/s$

Volumetric efficiency = Q_{act}/Q_{the}

$0.95 = 0.0453/Q_{the}$

$Q_{the} = 0.0477 m^3/s$

Step 1 Design of pipe diameter

$Q_{the} = As\ Vs$

Vs is between 1-3m/s

$0.0477 = 3.14/4(ds)^2\ (2)\ ds=$

$0.174m = 174mm$

$Q_{the} = A_d V_d$

$0.0477 = 3.14/4(d_d)^2(3)\ d_d$

$= 0.142m = 142m$

step 2 Calculation of manometric head

$$Hm = h_s + h_d + h_{fs} + h_{fd} + (V_d^2/2g)$$

Friction loss in suction pipe

$$H_{fs} = 4fL_sV_s^2/d_s(2g) = 4\ (0.027)\ (5)\ (2)^2/0.174\ (2)\ (9.8) = 0.63m$$

Friction loss in delivery pipe

$$H_{fd} = 4fL_dV_d^2/d_d\,(2g) = 4\,(0.027)\,(35)\,(3)^2/0.142\,(2)(9.8) = 12.2m$$

$$V_d^2/2g = (3)^2/2(9.8) = 0.4591m$$

$$H_m = h_s + h_d + h_{fs} + h_{fd} + (V_d^2/2g)$$

$$H_m = 2.5+19.8+0.63+12.2+0.459$$

$$H_m = 35.59m$$

Step 3 Selection of motor

Power

P = water power / overall efficiency

= [density(g)] $_w$ (Q_{act}) (H_m)/ (mechanical +volumetric +manometric efficiency)

= 1000(9.8) (0.0453) (35.59) / (0.95*0.95*0.80) = 21853.7W =21.8kW

We use standard value of power that is 11kW

Overall efficiency includes mechanical and volumetric and manometric efficiency

Speed (N)

$$N_{min} = 10H_m^{3/4}/(Q_{act})^{1/2} = 10(35.59)^{3/4}/(0.0453)^{1/2} = 684rpm$$

We select standard speed that is

$$N=1440rpm$$

3)Type of centrifugal pump

$$N_s=N\,(Q_{act})^{1/2}/(H_m)^{3/4} = 1440(0.0453)^{1/2}/(35.59)^{3/4} = 21$$

The N values lie between 10-30. Thus, we used low speed radius flow type centrifugal pump

And if

30-50 medium speed radius flow type centrifugal pump is used

50-80 high speed radius flow type centrifugal pump is used

80-160 mixed flow type centrifugal pump is used

160-450 axial flow type centrifugal pump is used

Step 4 1) Impeller design

$$D_2=K_u\,(60/\,(3.14)\,(N)).\,(2gH_m)^{1/2}$$

$$= 0.95(60/\,(3.14)\,(1440))\,(2*9.8*35.59)^{1/2}=0.333m=333mm$$

$$D_1=0.5D_2=0.166m=166mm$$

2)velocity of impeller

$$U_1=3.14D_1N/60=3.14\,(0.166)\,(1440)/60=12.5m/s$$

$$U_2=3.24D_2N/60=3.14\,(0.333)\,(1440)/60=25m/s$$

3) velocity of liquid

$$V_{f1} = sigh(2gH_m)_{1/2}$$

$$=0.15\,(26.41)\,=3.96m/s=V_{f2}$$

4)Inlet vane angle

$$B_1=\tan^{-1}[V_{f1}/u_1]\,=17.57^o$$

$$B_2=20.25^o$$

We select B_2 between 17.5^o to27.5^o

5)Impeller width

Q_{act}=A.V

Q_{act}=3.14(D_1) b_1. V_{f1}

b_1=Q_{act}/(3.14(D_1) V_{f1}) =0.0453/ (3.14(0.166) (3.96)) =0.02194m=21.94mm b_2=Q

$_{act}$/(3.14(D_2) V_{f2}) =0.0453/ (3.14(0.333) (3.96)) =0.01094m=10.94mm

6)No. of vanes

Z=13(D_2+D_1/(D_2-D_1)) sin(B_1+B_2/2)

=13(0.166+0.333/ (0.333-0.1666)) sin (17.57-20.25/2) =38.84sin (18.91)
=12.6=approximation=13

7)Thickness

t = 7mm

that we select between (4mm to 10mm)

8)Vane spacing

S_1=3.14D_1/Z

=3.14(0.166)/13=40.1mm

S_2=3.14D_2/Z

=3.14(0.333)/13=80.4mm

Step 5 Design impeller shaft

Torque/(d_s/2) =T/J

Material of selection

C=0.45

Sigma out= 380N/mm^2

F_{os}= 4

Sigma t = 95N/mm^2

Torque=47.5N/mm^2

Torque/(d_s/2) =T/ ((3.14/ 32) (d_s)4)

By arranging this we get d_s= [T/ {(3.14)

(torque)}]1/2………. (1)

➲ P=2(3.14) NT/ (60(100))

T=11(60) (1000)/ (2(3.14) (1440)) =72.98Nm=72000Nmm

By putting values in eq. 1, we get d_s

=19.76mm

Step 6 Casing of centrifugal pump

1) diameter of casing(D_3)

$$D_3=1.07D_2$$

$$=1.07\ (0.333)\ =0.356m=356mm$$

2)Width(b_3)

$$b_3=1.75b_2$$

$$=1.75\ (10.94)\ =\ 19.145mm$$

3)Thickness(t)

Material selection (P.S.G

1.4)

GCI .20

Sigma out = 220N/mm^2

F_{os} =4

Sigma t= 55N/mm^2

$$t_c = [PoD3/\ (2\ (3.14)\ (t))] +1\ldots\ldots.\ (2)$$

$$P=density(g)(H_m)$$

$$=1000\ (9.8)\ (35.59) = 348782N/m^2 = 0.23487N/mm^2$$

Putting values in eq. 2, we get t

$_c$ = 2.129mm

For manufacturing consideration, we take

$t_c = 6mm$

Heat exchanger Design

Heat exchanger layout

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between or extra fluids, between a strong floor and a fluid, or between strong particulates and a fluid, at distinct temperatures and in thermal contact. In warmness exchangers, there are generally no outside heat and paintings interactions. Standard packages involve heating or cooling of fluid circulate of problem and evaporation or condensation of single- or multithing fluid streams.

In different programs, the objective may be to get better or reject warmness or sterilize, pasteurize, fractionate, distil, concentrate, crystallize, or manipulate a technique fluid. In some warmth exchangers, the fluids changing heat are in direct touch. A warmth exchanger is a warmth switch device this is used for the transfer of internal thermal strength among or more fluids available at exceptional temperatures. In most of the exchangers, the fluids are separated utilizing a heat switch floor and ideally do not blend. However, there are instances in which the two fluids are in direct contact with each other.

Applications of Heat Exchangers

Exchangers discover extensive utility in the chemical method industries, such as.

- petroleum refining and petrochemical processing.
- inside the food enterprise, as an example, for pasteurization of milk and canning of processed foods
- inside the era of steam for production of power and energy
- in nuclear reaction structures
- in plane and space motors
- chemical technique enterprise
- refrigeration
- cryogenic applications

- electricity technology systems
- warmth restoration systems

Warmness exchangers are the workhorses of the whole subject of heating, ventilating, airconditioning, and refrigeration.

Special kinds of heat exchanger

There are many specific kinds of heat exchangers some of which can be written under,

- double pipe
- shell and tube
- scrapped surface
- gasket and welded plate
- spiral plate and tube
- compact exchangers
- plate and body
- plate-fin and tube fin

Selection criteria for heat exchangers

Selection Criteria for Heat Exchangers

The choice of heat exchangers depends upon the following factors:

- space
- efficiency
- availability
- ease of creation
- running strain
- cloth compatibility
- fabric of production
- operational protection
- thermal and repair possibilities
- environmental health and safety considerations

- operating temperature
- flow price
- waft preparations
- supposed application
- fouling inclinations
- types and stages of fluids
- fabrication technique
- overall economic system

Primarily based on these parameters the shell and tube warmth exchanger are selected.

Shell and Tube Heat

A shell and tube warmth exchanger are a category of the warmth exchanger. It is the most commonplace form of warmth exchanger in oil refineries and different huge chemical strategies. As its call implies, this type of warmness exchanger includes a shell (a big vessel) with a package of tubes interior it. Idea and alertness fluids, of different beginning temperatures, glide through the heat exchanger.

One flows via the tubes (the tube facet) and the alternative flows outside the tubes however within the shell (the shell facet). Warmness is transferred from one fluid to the alternative thru the tube partitions, both from the tube aspect to the shell aspect or vice versa. The fluids may be either liquids or gases on both the shell and the tube aspect.

To transfer warmth effectively, a big warmness transfer location ought to be used, so there are numerous tubes. In this manner, waste warmth may be positioned to use. This is a firstrate manner to preserve power. Heat exchangers with the most effective one segment (liquid or gas) on every side may be referred to as one-segment or unmarried-segment warmth exchangers. Two-segment heat exchangers may be used to warm a liquid to boil it into gasoline (vapour), sometimes called boilers, or cool vapour to condense it into a liquid (referred to as condensers), with the segment change typically happening on the shell facet.

Boilers in steam engine locomotives are usually massive, typically cylindrically fashioned shell-and-tube warmth exchangers.

In massive strength plants with steam-pushed mills, shell-and-tube condensers are used to condense the exhaust steam exiting the turbine into condensate water which can be recycled lower back to become steam, likely into a shell-and-tube type boiler.

Shell and tube warmness exchangers based totally on their production capabilities are the widest spread and maximum commonly used warmness exchangers. Some of the fundamental motives for this are

- it presents a big ratio of heat switch place to extent and weight
- its production in numerous sizes is easy
- it is far notably compact
- it covers a very good variety of working conditions
- it can be without difficulty wiped clean
- its protection is easy

Layout steps for shell and tube warmth exchanger

Design Steps for Shell and Tube Heat Exchanger

The design steps for the shell and tube warmness exchanger are as follows

- calculation of the inlet and outlet temperatures of the streams
- observe heat balance at the technique streams to discover any unknown temperatures of the streams
- then calculate the lmtd in order that the temperature variations within the method may be taken to be uniform
- calculate the general heat transfer coefficient u
- expect a price of the heat switch vicinity to be had based at the data supplied in literature for the kind of fluids you are using. Then calculate values of all the variables and constants at the tube facet calculate values of all the variables and constants at the shell aspect.
- calculate the fee of the heat transfer coefficient for the tube facet
- calculate the fee of the heat transfer coefficient for the shell facet
- calculate the fee of the general heat transfer coefficient

- examine the calculated price of the overall heat transfer coefficient with the assumed value.
- if the price is the same or within a number 10 % of the assumed fee then proceed or repeat the procedure with a brand-new assumed value
- calculate the values of the pressure drops on the shell and tube facet
- if all of the values calculated are inside the given range in the literature, then the theoretical design is accurate.

Design of Heat exchanger

Hot fluid		Cold fluid	Difference
248 F	Higher temperature	113 F	$\Delta t2 = 167$
122 F	Lower temperature	77 F	$\Delta t1 = 77$
			$\Delta t2 - \Delta t1 = 122$ F

$$LMTD = (\Delta t2-\Delta t1)/[2.3\log(\Delta t2/\Delta t1)]$$

$$= (122)/ [2.3\log (167/77)]$$

$$=114 \text{ F}$$

At temperature range in shell side of gas is 248 F

Kc =0.971 **Fig 17**

$$\Delta t1/\Delta t2 = 77/167$$

$$=0.46$$

So, Fc = 0.33

Tc = 122 + 0.33*158 = 163.5F tc

= 77 + 0.33*68 = 88.88 F

R = 70/20 = 3.5

S = 20/95 = 0.21

Ft = 0.74 using fig (18)

Take 1 shell pass two or more tube passes

Δt = 114* 0.74 = 84 F

Cp of mixture = 0.97 Btu/lb F

Cp of water = 1Btu/lb F

Mass of flue gases = ms = 9186.001 lb/hr

Mass of water = mw = 31235.093 lb/hr

For flue gases Q = mcpΔt =19545.39*0.97(248-122)

=1122712.92 Btu/hr

For water Q = mcpΔt = 5588985.6Btu/hr

Ud for mixture of is 50-125 so we take Ud = 87

A = Q ÷ (Ud*Δt) = 1124653.54 / (87*84.36) = 153.23 ft2

1 in OD, 16 BWG tubes, 8'0'' long

a'' = 0.2618 ft2/lin ft **Using Table 10**

Number of tubes = 153 ÷ (8*0.2618) = 88

Assume the two tube passes

1 in OD tube on 1 ¼ in square Pitch **Table 9**

ID = 17 ¼ in. for 88 tubes

Corrected Ud = A = 88 * 8’’ *0.2618 = 184 ft^2

Ud = Q /(A*Δt) = 1124653.54/ (184*84.36) = 72

Hot fluid in shall side (flue gases)	**Cold fluid in tube side (flue gas)**
1) **Flow area**	**Flow area**
Minimum baffle space provided greater ho **B = ID/5 = 17.25/5 = 3.45in as = (ID * C’B)/144*Pr = (17.25 * 0.25 *3.45)/144*1** **= 0.103 ft2**	at’’ = 0.594ft2 **Table 9** at = Nt * at” /144*n = (88 * 0.594)/ (144* 2) =0.18ft2
2) **Mass velocity**	**Mass velocity**
Gs = W/as = 31209.18/0.103 **= 303001 lb/hrft2**	Gs = W/as = 9177.75/0.18 = 50987.5 lb/hrft2
3) **At Tc = 163.5 F**	**At tc = 88.88 F**

Viscosity = u = 9.2 cP **= 9.2*2.42 = 22.26 lb/ft hr** **De = 0.99/12 = 0.0825ft**	Viscosity = u = 0.6 cP = 0.6 * 2.42 = 1.452 lb/ft hr D = 0.87/12 = 0.0725sft

Re = D*G/u = (0.0825*303001) ÷ 22.26 **= 1122.98**	Re = D*G/u = (0.0725*50987.5) ÷ 1.452 = 2545.86
4) **Jh = 19**	**Jh = 7**
5) **At u =22.26** **K(c*u/K)1/3 = 0.069**	**At u = 1.452** **K(c*u/K)1/3 = 0.065**
6) **ho = (Jh*K)/De(c*u/K)1/3*ø ho/ø** **= 19*5.2*0.069 /0.0825** **= 82.62**	**hi = (Jh*K)/D(c*u/K)1/3*ø** hi/ø = 7*2.057*0.065/0.0725 = 12.9
ho = ho/ø = 82.62/1 = 82.62	hio/ø = hi/ø * ID/OD = 12.9* 0.87/1 = 11.22 hio = hio/ø = 11.22/1 = 11.22

7) **Pressure drops**	**Pressure drop**
At Re = 1122.98 **Fr = 0.003,** **At tc = 163.5 F** **S = 1.033** **Number of crosses = N + 1 = 12*L/B** **= 12 * 8 / 3.452 = 27.82** **Ds = 17.25/12 = 1.43ft**	At Re = 2545.86 Fr = 0.00029 At tc = 88.88 F S = 0.98 ΔP = [Fr*G2*L*n]/ [5.22 *exp10 *D*S*ø]
ΔP = [Fr*G2*Ds*(N+1)]/ [5.22 *exp10 *De*S*ø] **ΔP = [0.003*(303001)^2*1.43*28.82]/[5.22*exp10*0.0825*1.033*1]** **= 2.55 Psi**	ΔP = [0.00029*(50987.5)^2*8*2]/[5.22*exp10*0.0725*0.98*1] = 0.0035 Psi

8) **Overall coefficient**

Uc = (hio * ho) / (hio + ho)

= (11.22 * 82.62) / (11.22 + 82.62)

= 9.8

9) **Dirt factor**

Rd = (Uc-Ud)/Uc*Ud

$$= (72-9.8)/(72*9.8)$$

$$= 0.089$$

Shell side	Tube side
ID = 17.25 in	Number of tubes = 88
Baffle space = 3.45 in	length of tubes = 8’0”
Passes = 1	OD, BWG, Pitch = 1 in, 16 BWG, 1 ¼ in square pitch
Area = 153.23 ft2	Passes = 2

Chapter 5

INSTRUMENTATION AND CONTROL

OVERVIEW

Instrumentation and control play a very important role in an industry or in any process. Today everything is up-to-date and computers are controlling everything, and this is for the ease of human beings.

Process is controlled in a very systematic way and a little disturbance can be recognized by instrumentation and control. Higher quality products are obtained when we use automatic control system and it also helps in attaining high profit high purity and, we can save a lot of time and labor also.

NEED OF INSTRUMENTATION AND CONTROL Incentives of process control

Basically, process control has three main incentives:

- Putting down the effect of external disturbances
- The solidity of a chemical process is secured.
- The optimization of a chemical process.

Three main incentives of process control. Process control is the main thing in any process plant because without control, once disturbance comes into the system, the whole plant will be shut down and production will be stop.

PROCESS CONTROL OBJECTIVES

Safe plant operation

The operating limits of process variables should be safe.

Production Rate

To obtain specific production rate to meet supply and demand balance of desired quality in order to earn maximum profit.

Product quality

Quality standards of the product composition should be specified.

Cost

Operating cost is low so that to earn maximum profit.

CONTROL SCHEMES OF CSTR

Objectives

In CSTR following things should be controlled:

- Temperature inside the reactor
- Flow of streams
- Pressure inside the reactor
- Product quality
- Maintain level

Control Scheme Temperature Control

Temperature control inside CSTR is very important and we measure the reactor temperature and then the low of cooling water inside the jacket is manipulated.

Colling jacket has certain advantages:

- The risk of leakage is minimized
- Temperature control efficiently

Pressure Measurement

Pressure control inside the reactor is very important as below or above the particular pressure we can not achieve our desired product. A pressure control loop is installed to maintain the pressure inside the reactor, if pressure increases or decreases controller take actions on two valve son the same time.

Level Measurement

Level control inside the reactor is very important as below or above the particular level we can not achieve our desired product. A level sensor is installed to maintain the level inside the reactor, if level increases or decreases sensor take actions and level is controlled

CSTR CONTROL CONFIGURATION

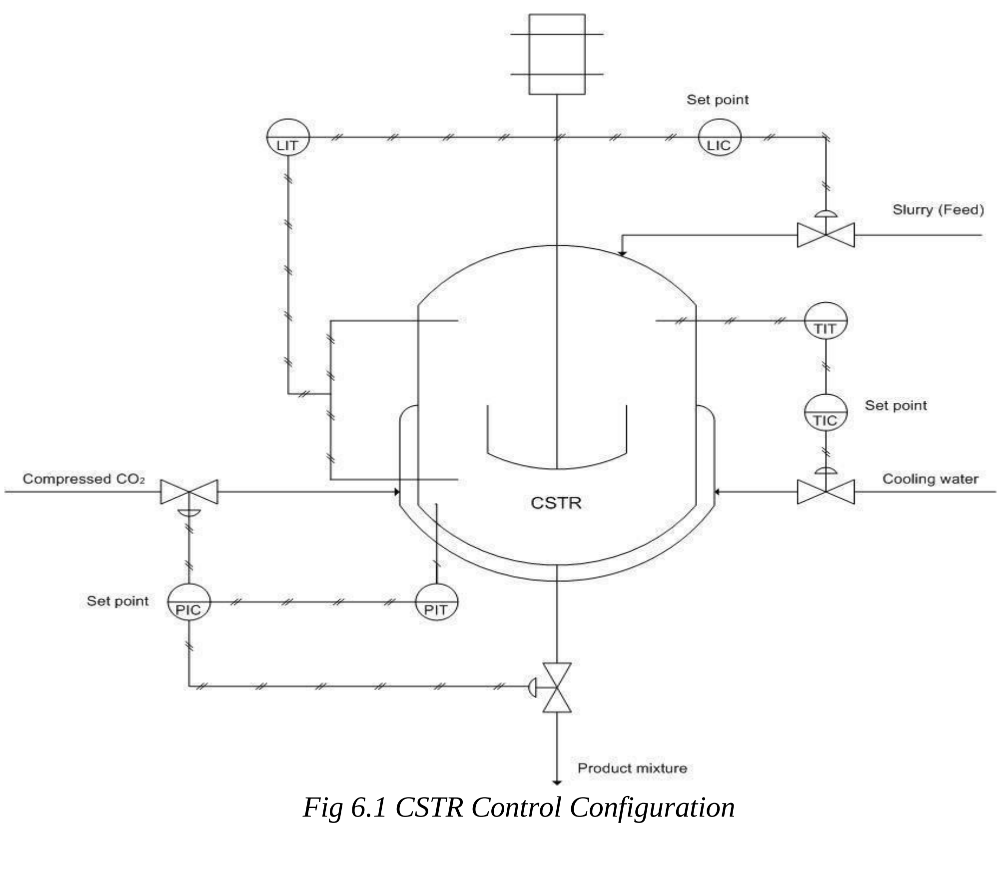


Fig 6.1 CSTR Control Configuration

Chapter 7

SOCIO-ECONOMIC CONSIDERATION

OVERVIEW

This section deals not only on estimated capital and operational cost of the plant but also signifies the positive impact of the project on the society.

COST ESTIMATION

Cost estimations evaluate

Capital funding is needed for any commercial procedure to put in. Inside the possible file, a distinctive stage of price estimation is present to check the proper price requirement. The willpower of the vital funding is an important part of a plant layout assignment. Assessment of this investment is referred to as price estimation.

Capital funding

Before an industrial plant can place into operation, a massive amount of cash has to be supplied to purchase and deploy the important machinery and system. Land and service facilities must be obtained and the plant needs to be erected entirely with all piping, controls, and carrier. Similarly, it's miles important to have money available for the installation and working of a plant. The entire quantity required for the setup and working of the plant is known as general capital funding.

Total capital funding = fixed capital + working capital

FIXED CAPITAL INVESTMENT

The capital needed to deliver the essential production and plant centers is known as fixed capital investment. The constant capital is similarly subdivided into the subsequent.

- production fixed capital investment
- non-manufacturing fixed capital investment

The constant capital funding labeled into two subdivisions:

- direct cost
- oblique cost

DIRECT COST

The direct fee objects arc incurred within the production of the plant in addition to the price of equipment. Bought equipment cost

Bought gadget installation

- insulation price
- instrumentation and manage
- piping
- electrical installation
- building consisting of services
- yard development
- provider centers
- land

INDIRECT COST

Direct price may be anticipated through estimating the subsequent costs.

- engineering and supervision
- creation costs a
- contractor's charge

- start-up fees

Working capital

The capital required for the operation of the plant is referred to as operating capital. Operating capital consists of the subsequent things to be taken into consideration

- Raw materials and resources carried in inventory
- completed product in inventory and semi-completed products inside the manner of being synthetic
- bills receivable
- coins kept available for a monthly fee of running charges, which includes salaries, wages and raw cloth purchases
- bills payable
- taxes payable

CAPITAL VALUE ESTIMATES

An estimate of the capital funding for a procedure might also range, pre-design expected based totally on little records except for the size of the proposed challenge to an in depth estimate prepared from whole drawings and specifications. Between these two extremes of capital investment estimates, there can be severa other estimates which vary in accuracy depending on the degree of improvement of the assignment. These estimates are known as with the aid of a spread of names, however the following five categories represent the accuracy variety and designation typically used for layout purposes.

- observe estimate (factorial estimate)
- preliminary estimates (price range authorization estimate
- definitive estimate (assignment manage estimate)
- specific estimate (contractor’s estimate).

Table 7-1: Equipment Cost

QUANTITY	EQUIPMENT	PER UNIT COST	TOTAL EQUIPMENT COST
1	COMPRESSOR	25667	25667
4	PUMP	10500	42000
2	HEAT EXCHANEGR	50595	101190
1	ABSORBER	45000	45000
1	STRIPPER	50000	50000
1	REACTOR	96137	96137
TOTAL COST			**US$ 359994**

Direct Cost

Direct cost depends upon the different ranges of material cost. Following are the cost assumed for the plant of carbon dioxide capturing.[37]

$$installtion\ cost = \frac{30}{100} \times 359994\ US\$$$

Installation cost (30%E) = 107998 US$

$$instrumentation\ and\ control\ cost = \frac{13}{100} \times 359994\ US\$$$

Instrumentation and control cost (13%E) = 46799 US$

Piping cost (10% E) = 35999 US$

Electric cost (10%E) = 35999 US$

Building (including services) (21%E) = 75598 US$

Yard improvement (10%E) = 35999 US$

Land cost (6%E) = 21599 US$

TOTAL DIRECT COST = 359991 US$

INDIRECT COST

Engineering and Supervision Cost (20%E) = 71998 US$

Construction Expenses (30%E) = 107998 US$

Contractor fee (18%E) = 64798 US$

Contingency Cost (20%E) = 71998 US$

TOTAL INDIRECT COST= 316792.0 US$

TOTAL CAPITAL INVESTMENT

Fixed capital investment = direct cost + indirect cost

$$Fixed\ capital\ investment = 316792 + 359991.0$$

$$\boldsymbol{FCI} = \mathbf{676783}\ \boldsymbol{US}\$$$

Working Capital (13%F.C.I) = 87981 US$

$$Total\ capital\ investment = working\ capital\ cost + fixed\ capital\ investment$$

$$TCI = 87981 + 676783$$

$$\boldsymbol{TCI} = \mathbf{784764}\ \boldsymbol{US}\$$$

PER UNIT COST

CO2 cylinders are usually available in 5kg weight so by conversion of 1 ton into 5 kg:

$$total\ cylinders\ produced\ per\ day = (1*1000)/5 = 200\ cylinders$$

$$per\ unit\ cost = \mathbf{784764/200} = 3923\ US\$$$

It is clearly shown from the per unit cost that this process is not feasible for small plants and most plants avoid to capture CO2 from the flue gases. Normal price for the CO2 cylinder of 5 kg weight is starting from 50 US$ to 90 US$ based on the expiry date of cylinder.

Chapter 8

HAZOP STUDY

OVERVIEW

The HAZOP studies are time consuming and expensive. Just getting the P&ID's up to date on an older plant may be a major engineering effort. They are very cost effective when we use it in our daily life in business and property and they even save the fututre of the company that can face a major disaster. We also use it for uptodate of our P&ID's and it may be a major engineerimg effort.

OPERABILITY

Any operation in the process design envelop which can cause a shutdown and can possibly led to the violation of environmental, health and safety rules or can have negative impact on profitability.

WHEN HAZOP IS PERFORMED

The HAZOP study should prioritize to be first carry out as in the design phase, to have safety margin impact on the design. While to carry out a HAZOP we should have a complete design. To compromise this situation the HAZOP is performed as a final check when the detailed design is completed. A HAZOP study can also be performed on an existing facility to check for modifications that can be implemented to reduce risks and operational problems

HAZOP study can also be used more diversely, including:

- When design drawings are available than in initial conceptional stage
- After the final piping and instrumentation diagram (P&ID) availability
- To ensure recommendations are either implemented during construction and installation
- During the design commissioning
- While in operation to check that plant emergency and operating procedures are either regularly reviewed or updated.

HAZOP STUDY OF REACTOR, HEAT EXCHANGER, PRECIPITATOR, AND PUMP

HAZOP analysis on reactor

equipment	Guide words	Deviations	causes	consequences	actions
reactor	pressure				
	Low	Leakages in the pipe	Necessary conditions for reaction may be vanished	Exposure to surrounding can cause severe damage	Low pressure sensor be installed.
	high	Chocking in downstream valve	Damage to jacket due to high pressure	Reactor can explode	Relief valve should be installed.

reactor	temperature

	Low	Streams are entering at low temperature	Temperature is not feasible for reaction to occur	Rate of reaction will decrease	The feed should be provided at its required temp.
	high	Feed is entering at high temperature	Thermal shocking	Nozzles can be damaged	Reactor should be protected from damage

Hazop analysis on heat exchanger

Equipment	Guide words	Deviations	Causes	Consequences	Action
Heat exchanger	Flow				
	Less	Less flow of cooling fluid. Less cooling fluid.	1. Pipe blockage. 2. Leakage of pipe	Temperature of fluid remains constant. Fluid temperature too low	Installation of high Temperature Alarm. Flow meter installation.
	more	More cooling fluid flow.	1. Failure of cooling fluid valve. 2. Failure of inlet cooling fluid valve to close.	Temp. for process fluid decreases. Output for process fluid temperature is too low.	Installation of low temperature alarm. Temp. indicator before and after the process fluid line installation

Equipment	Guide words	Deviations	Causes	Consequences	Action
Heat exchanger	No	No cooling fluid flow.	Failure of inlet cooling fluid valve to open.	Process fluid temp. is not lowered to the requirement	Temp. indicator before and after the process fluid line installation
	Reverse	Reverse of process fluid flow.	Failure of working of process fluid inlet valve	Off set of product.	Check valve installation
	contamination	Process fluid contamination	Outlet temp. is too low. Process fluid contamination	Operator alert and proper maintenance. Operator alert and proper maintenance.	

Hazop analysis on precipitator

Equipment	Guide words	Deviations	Causes	Consequences	Action
precipitator	Temperature				
	Less	Expected precipitation does not occur	Damage het exchanger that adjusted before the precipitator	This leads to decrease in efficiency of precipitator	Determine the temp. limits of the precipitator accurately

	more	Expected precipitation does not occur	Damage het exchanger that adjusted before the precipitator	This leads to decrease in efficiency of precipitator	Determine the temp. limits of the precipitator accurately
	Pressure				
	more	No precipitators are formed	Valve is damaged that control the flow	Decrease in purity of products	We need to prepare damage

Equipment	Guide words	Deviations	Causes	Consequences	Action
precipitator	Leakage				
	Less	The amount of products decreased	Erosion/ corrosion	It leads to loss of products	Repair corrosion
	more	Precipitator tank dry	Larger amount of holes formed due to corrosion	No precipitation occur	Repair corrosion

Hazop analysis on pump

Equipment	Guide words	Deviations	Causes	Consequences	Action
pump	Temperature				
	More	Output valve of pump is closed	Deadhead pump	Pump damage	Valve be should open
	Pressure				
	less	Pump inlet valve closed	Deadhead pump	Pump damage	Valve should be open
	more	Pump outlet valve closed	Pump cavitates	Pump damage	Outlet valve should open. be

Equipment	Guide words	Deviations	Causes	Consequences	Action
pump	Flow				
	Less	Pump inlet valve closed	Pump cavitates	Pump damage	Overheated in pump should be eliminated.
	More	Pump outlet valve fails to open	Upset in pump	Pump damage	Possible problem in pump

Chapter 9

CONCLUSION AND ACHIEVED SUSTAINABLE DEVELOPMENT GOALS (SDG'S)

Our main objective for this project is to make CO2 free environment with very less cost. And at the end we are able to make a design which is very cost effective and environment friendly. As Pakistan is a large consumer of fossil fuels due to which emission of CO2 is also increasing so, by ex-situ lizardite carbonation we are able to capture CO2.

Moreover, we are able to make profit of 30,000 dollars per year by selling by-products (MgCO3 & SiO2). MgCO3 can be used in flooring, cosmetics. fire proofing, dusting powder, tooth pastes and, fire extinguishers. SiO2 is used in manufacturing of glass, food additives and many industrial purposes as raw material for different compounds.

So, they can be sold easily. If this design project is installed at commercial scale, it will (IN SHA ALLAH) make revolutionary changes in the industrial sector and will also be able to make the environment friendly for its inhabitants

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