University of Karachi

Department of Applied Chemistry and

Chemical Technology

Plant Designing Project File

Liquid Fuel from Plastic waste (Polyethylene and Polypropylene) by Catalytic Pyrolysis

Group # 1

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SECTION A

Teacher: Sir Bilal Kazmi and Sir Saqib Ali

Dedicated To

Our

Beloved Parents,

Respected Teachers,

&

All Those Who Devoted Their Yesterday for Our Bright Today

Acknowledgement

All praises to ALMIGHTY ALLAH, who provided us with the strength to accomplish the final year project. All respects are for His HOLY PROPHET (PBUH), whose teachings are true source of knowledge and guidance for whole mankind. Before anybody else we thank our Parents who have always been a source of moral support and driving force behind whatever we do. We are grateful to the Head of Department Prof. Dr. Ashraf Kamal and our faculty members for providing facilities and guidance. We are indebted to our project supervisors Engr. Saqib Ali and Mr. Bilal Kazmi for their worthy discussions, encouragement, inspiring guidance, remarkable suggestions, keen interest, constructive criticism & friendly discussions which enabled us to complete this report. They spared a lot of precious time in advising and helping us in writing this report. Without their painstaking tuition, kind patronization, sincere coaching and continuous consultation, we would not have been able to complete this arduous task successfully

Abstract

Liquid Fuel, the target product of the present work, is a fuel refinery product representing the most elementary configuration of the Hydrocarbons. In this ages Fuels are used everywhere like in Transport, electricity generation and producing heat energy.

The aim of the present work is to reach 91% conversion of Plastic waste in to liquid fuel using **USY Zeolite**

Catalyst. Detailed calculations were performed in this report for all equipment in the plant including all expenses of the plant erection, taking into account the required process conditions to achieve a production capacity of **1.6 ton/day** of Liquid Fuel (**Diesel, Gasoline and Kerosene**).

Contents

Chapter#1
Introduction

(Prepared by Altamash)

Introduction

Plastic waste is generated and the rate of consumption of plastic in world is increasing. These plastics are may be non-biodegradable that makes them cause of pollution too. There is no doubt that plastic has replaced metals and are involved in many portable things such as bottles for water and other electronic devices but at same time some plastics aren't recoverable i.e. thermosets. But some plastics can be used again and again i.e. Thermoplastics which are Polypropylene and Polyethylene, raw materials used in this process.

These plastic products can be either reuse and sometimes might become source of fuels which we are going to do explain in this file. In 2015 almost 29% of accounted maniple plastic waste from land fill and 31% were accounted from seas and majority plastic obtained from that waste was polyolefin which means polyethylene and polypropylene. These plastics are not biodegradable and might contribute to health and environmental problems by releasing toxic emission harmful for human and wild life.

We can't reuse these plastics because it's recycling required additives for good quality of product which is not then guaranteed but after that still those impurities cannot be separated so quality of reused plastic is reduced. So to get rid of such plastic products economy just dumped these plastic waste in sea and after that this becomes the main cause of sea toxicity and other pollution even the plastic waste of PVC might release chloride ion which then increase acidity in water which is harmful for water life because it disturbs alkalinity of sea water

But Plastic waste of Polypropylene and Polyethylene can have polluted sea water, it can be reused but as we mentioned before it required a lot of additives and after that product good quality is not guaranteed.

In this report we are going to use this maniple waste containing polypropylene and polyethylene for producing liquid fuel through Pyrolysis.

Introduction of process

In this process of Pyrolysis we are using catalytic degradation to recycle the maniple waste of plastic to produce fuel from it, we could use method of thermal plastic but thermal degradation produces much char as comparison with catalytic degradation so that's the main point to use catalytic degradation methane instead of thermal degradation, the another reason to choose catalytic degradation is thermal pyrolysis or degradation requires much higher temperature ranges due to which we need much amount of energy to burn plastic and in thermal pyrolysis there is also high production of CO_2 gas that's why we are not employing this method.

The catalytic pyrolysis or degradation involved the degradation of plastic maniple waste at temperature ranges from 30 degrees centigrade to 500 centigrade which doesn't only yield liquid fuels but also gaseous fuels which are then condense and collected in storage. Liquid fuels obtained by this production are Kerosene, Diesel and Gasoline while the gaseous products obtained are hydrogen, methane, ethane and propane. In this combination of hydrogen and methane gas can be used as fuel with amazing quality while combination of ethane and propane can be used as LPG later which means that this process is not only suitable to produce liquid fuel but also gaseous fuel. On other side in thermal pyrolysis these gases are already burned and requires a separate distillation column which might be very costly so that's a reason to employee catalytic degradation.

In this process we are employing a fix bed reactor made up of packaging of catalyst USY Zeolite. The catalyst amount is 10:1 ratio of plastic waste we used 1 ton of plastic waste so we need 0.1 ton of catalyst. This process requires condenser or shell and tube heat exchanger which condensed the vapor phase of gasoline, Kerosene and Diesel but ethane and propane will be condensed in pressure vessels but we can't condense hydrogen and methane gas because it requires more and more energy so we will use mixture of hydrogen and methane as gaseous fuel.

Moreover, we are using some storage tanks here and some pressure and temperature sensors to keep desire conditions maintained.

Properties of Raw Material

Raw material used here is washed and dried polyethylene and polypropylene with certain composition of atoms.

Plastic	Carbon	Hydrogen	Sulfur	Nitrogen	Oxygen
Polyethylene	86.23%	14.43%	0%	0%	0%
Polypropylene	86.44%	14.46%	0%	0%	0%

These plastic wastes were gathered at municipal waste which is then further washed with water and then dried at temperature above 100 degrees centigrade. Polyethylene we are using in this process is of high grade because low grade polyethylene will yield less liquid fraction than gases.

After drying these plastic waste is either crushed or cut into 6mm pieces to enhance surface area during the process of pyrolysis on bed.

Further we are not using PVC in it due to accumulation of chlorine might form hydrogen chloride in reactor due to which reactor might corrode but in case of PVC reactor requires further modification and combination of catalyst of USY Zeolite and Zinc Oxide but catalyst is recovered easily, but still pyrolysis of PVC produces much amount of char that might poison another catalyst which is USY Zeolite so we might use polypropylene and polyethylene in a single batch reactor.

Make sure that plastic doesn't have impurities of sulfur and oxygen because it might not only corrode reactor walls but also presence of oxygen effects on yield in negative impact i.e. Rapid combustion of gases in reactor and formation of water molecules which reduces calorific value of fuel and causes increase in acid number of fuel.

We didn't use LDPE here because it will yield gaseous fraction.

Thermal Properties:

Plastic No.	Plastic	Thermal Properties			Strength		Density	Float?
		Tm	Tg	Td	Tensile	Compressive		
		°C	°C	°C	Psi	Psi	g/cc	
1	PET (polyethyleneterephthalate	245 265	73 80	21 38	7000 10500	11000 15000	1.29 1.40	Completely sinks
2	HDPE (high density polyethylene)	130 137		79 91	3200 4500	2700 3600	0.952 0.965	Floats
3	V/PVC (polyvinyl chloride)		75 105	57 82	5900 7500	8000 13000	1.30 1.58	Completely sinks
4	LDPE (low density polyethylene)	98 115	-25	40 44	1200 4550		0.917 0.932	floats
5	PP (polypropylene)	168 175	-20	107 121	4500 6000	5500 8000	0.900 0.910	floats
6	PS (polystyrene) Styron		74 105	68 96	5200 7500	12000 13000	1.04 1.05	Completely sinks

Properties of Catalyst

Textural and acid properties of catalyst USY Zeolite are as follows:

SiO_2/Al_2O_3 (mol/mol)	15
Na_2O (wt %)	0.05
Micro pore Volume (cm^3/g)	0.1
Crystal Size (micro m)	0.7 to 1
Total Acidity (m mol NH_3/g)	0.1

Here question arises that why did we used USY Zeolite so here is table below which shows to which extent USY Zeolite catalyst is better than other in catalytic pyrolysis.

Catalyst name	Effect on Yield	Cause
ZSM-5	Higher gaseous products	Over Cracking
Y Zeolite	Higher gaseous products	High degree of cracking
MCM-41	Higher gaseous products and Char produced	Over Cracking
HZSM-5	Much higher gaseous products and High char content	Due to less acidity and small pore size activity
USY Zeolite	Higher liquid product yield and less char 1%	Low Degree of cracking, High Porosity, high acidity and rapid diffusion of cracked molecule from catalyst.

On the basis of that we used USY Zeolite, it produces 1% of char when used in ratio of 10:1 plastic and can be regenerated easily by heated to 500 degrees centigrade or by dissolving in aqua regia with ratio 2:3 of HCl and HNO_3.

USY Zeolite is only preferable for batch process because in continuous process char is removed but continuous process of this hasn't developed yet.

USY Zeolite has much better porosity and acid content enough to reduce over cracking and yield liquid fuel also it gives rapid diffusion of cracked molecule from pores.

Composition of USY Zeolite we are using is Sodium Oxide - 17%, Aluminum Oxide - 28%, Silicon dioxide – 33% and water – 22%.

Handling of waste material and Catalyst

Here are using stainless steel for storage and drying of raw material but make sure that plastic material has no other impurity while proportioning because presence of any other impurity might affect the yield so we are washing all impurities out and drying the raw material to reduce oxygen contents in it. Moreover, a vacuum of 1 atmospheric pressure is also applied here to remove oxygen from reactor, however zeolite catalyst has oxygen in composition but that won't affect the product at temperature less than 600 degrees centigrade so we are regenerating catalyst at 500 degrees centigrade to reduce its poisonous but at 14^{th} regeneration catalyst will reduce its activity so it's necessary to dissolve it in aqua-regia to recover acidity and porosity.

Temperature in drying shouldn't be greater than 100 degrees centigrade because at 130 degrees centigrade plastic started to melt and at 150 degrees centigrade light gases are collected over the reactor and condensed in pressure vessel.

Properties of liquid product obtained

Catalytic Pyrolysis of Polyethylene yields more gaseous fraction then Polyethylene.

Plastic	Liquid Yield %	Gaseous Yield %
Polyethylene	75	24
Polypropylene	80	19

While the 1% remains here is char.

Products obtained from Polypropylene catalytic degradation is in C_1 to C_{15} carbon range in which C_5 to C_7 fraction is maximum by 39 weight percent. While Product obtained from Polyethylene contained product from carbon range C_1 to C_{27} in which C_5 to C_7 fraction is maximum by 34 weight percent. The gaseous products obtained were dominated by C_3 and C_4. C_3 and C_4 fractions were present by weight percent 26 weight percent of Polypropylene and 23 weight percent of Polyethylene.

Compounds in carbon ranges from C_8 to C_{11} are usually aromatics.

These aromatics are present of 8.7 weight percent of Polypropylene and 5.7 weight percent for polyethylene.

More over the C6 to C7 ranges compounds were not identified in chromatography.

Overall analysis:

Plastic used	Carbon Ranges	Maximum fractions (C_5 to C_7)	Not identified compounds	Aromatics Produced (C_8 to C_{11})	Liquid Yield	Gaseous yield	Gaseous fractions (C_3 to C_4)
HDPE	C_1 to C_{27}	34 weight percent	C6 to C7	5.7 weight percent	75%	24%	23 weight percent
PP	C_1 to C_{15}	39 weight percent	C6 to C7	8.7 weight percent	80%	19%	26 weight percent

From all these process we will obtained product into three phases gasoline, diesel and kerosene,

Gasoline phase will have obtained at 160 degrees centigrade and will comprise 50% of liquid fuel but it will have really low octane number so it requires 25% OF Ethanol addition or MTBE (Methyl Tertio-Butyl ether) addition which increases its octane number to 96 to 98%.

Further, it contains aromatics formed during process which means that without addition of 25% OF Ethanol addition or MTBE (Methyl Tertio-Butyl ether) fuel will pollute environment so we add such additives and this causes to increase high octane number.

On other side Diesel phase which is obtained at 220 degrees centigrade has really low cetane number due to which 7% addition of biodiesel is necessary.

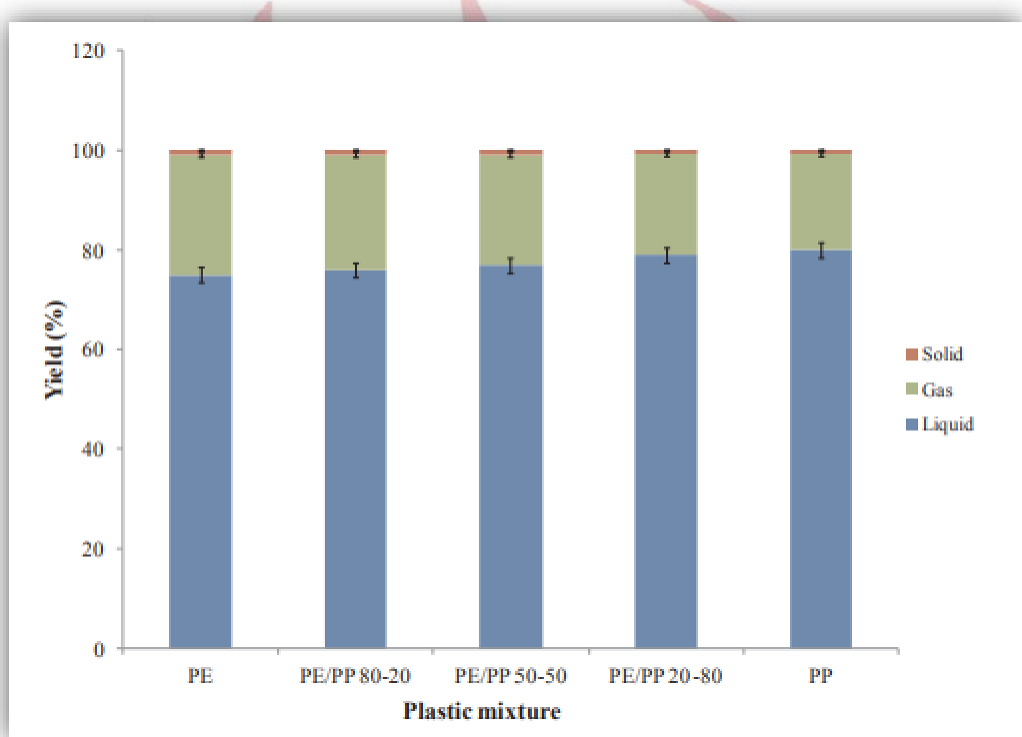
Kerosene phase obtained at 190 degrees centigrade.

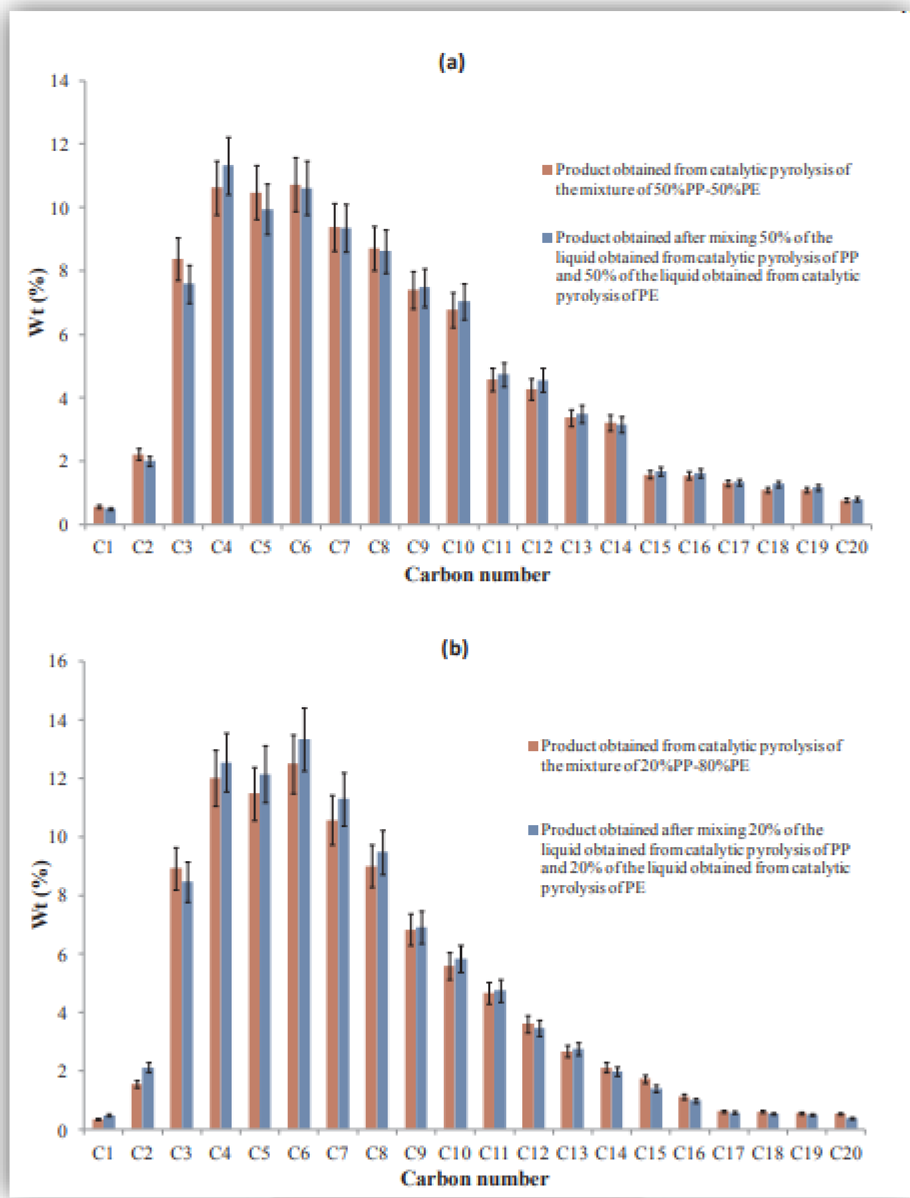
Aromatics here are produced due to hydrogen transfer and oligomerization of aliphatic chains. This is due to rearrangement of the formed carbocation to generate a branched carbocation.

Carbocation should undergo several reactions such as:

- Scission
- Isomerization and
- Cyclisation

These reactions are promoted by acidity of USY Zeolite and shape of it where molecules are easily trapped.




(a)
Product obtained from catalytic pyrolysis of the mixture of 50%PP-50%PE
Product obtained after mixing 50% of the liquid obtained from catalytic pyrolysis of PP and 50% of the liquid obtained from catalytic pyrolysis of PE
Wt (%)
14
12
10
8
6
4
2
0
C1 C2 C3 C4 C5 C6 C7 C8 C9 C10 C11 C12 C13 C14 C15 C16 C17 C18 C19 C20
Carbon number
(b)
Product obtained from catalytic pyrolysis of the mixture of 20%PP-80%PE
Product obtained after mixing 20% of the liquid obtained from catalytic pyrolysis of PP and 20% of the liquid obtained from catalytic pyrolysis of PE
Wt (%)
16
14
12
10
8
6
4
2
0
C1 C2 C3 C4 C5 C6 C7 C8 C9 C10 C11 C12 C13 C14 C15 C16 C17 C18 C19 C20
Carbon number

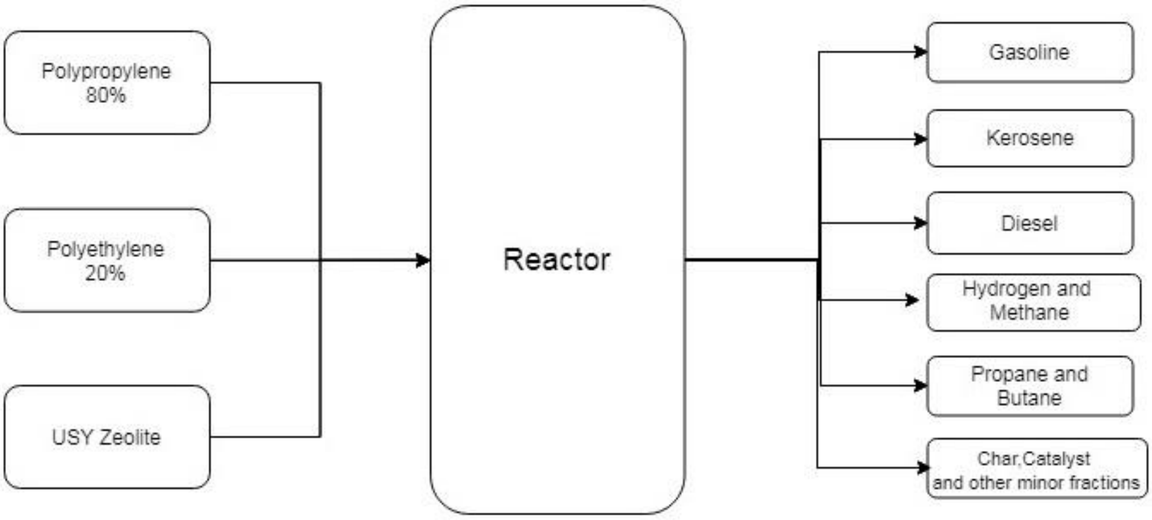
Parameters of the Process

Parameters	Results
Temperature	1. Conversion increases with temperature resulting in decrease of aliphatic content. 2. Gaseous products (C2-C4) and liquid products (C5-C9) increased and decreased with temperature respectively 3. Effect of the catalysts on the yields and structure of products 26 becomes less significant with increasing temperature.
Pressure	The inverse relation of pressure to temperature in the pyrolysis of polyethylene
Residence time	1. Generally, conversion increases with residence time. 2. The catalyst activity of HZSM-5 and an FCC catalyst decreased with increasing cracking time in the pyrolysis of HDPE waste. 3. Effect of residence time on product yield is more pronounced at lower than higher temperatures
Catalyst loading	Conversion increases with catalyst loading.

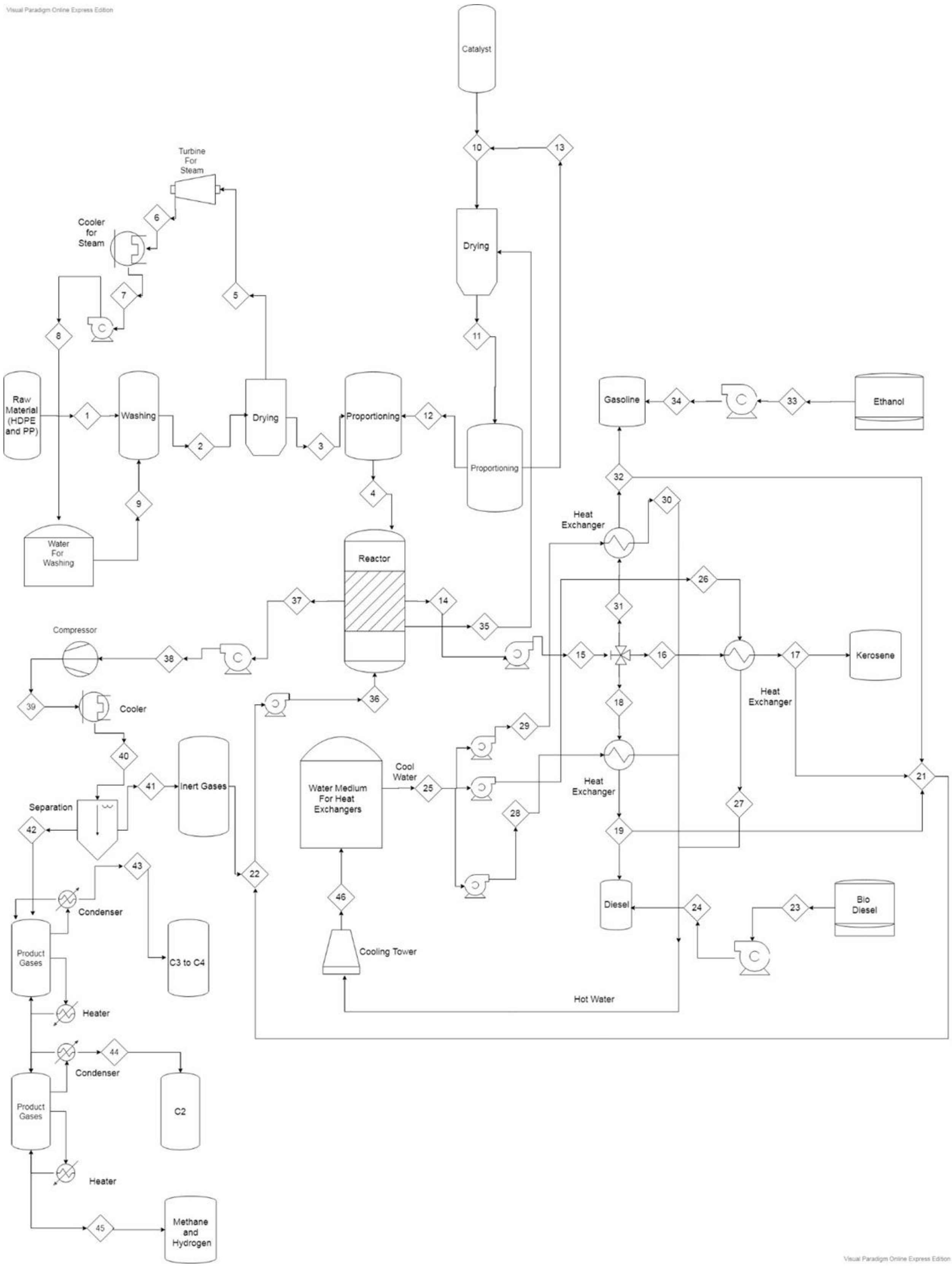
Chapter # 2
Diagram

(Prepared by Altamash)

1. Material Flow Diagram

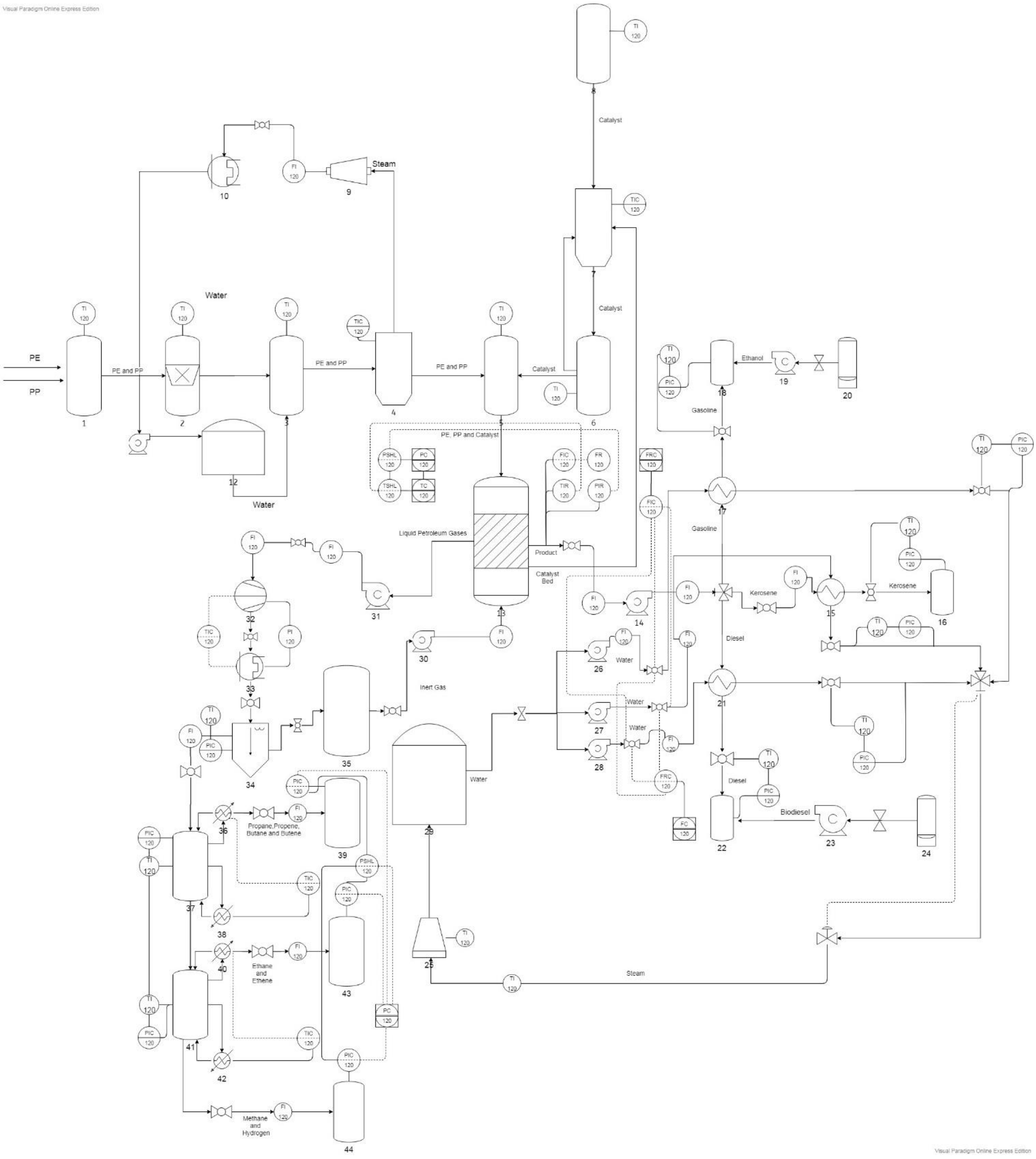


2. Process Flow Diagram



Prepared by Altamash Asif Ghori
Department of Applied Chemistry and Chemical Technology.

3. Piping and Instrumentation Diagram



1. Storage tank
2. Crushing and Grinding
3. Washing
4. Drying
5. Material Proportioning
6. Catalyst Proportioning
7. Catalyst Drying
8. Catalyst Storage
9. Turbine
10. Compressors
11. Pump
12. Water Storage Tank
13. Reactor
14. Pump
15. Heat Exchanger
16. Vessel
17. Heat exchanger
18. Vessel
19. Pump
20. Storage tank
21. Heat exchanger
22. Vessel
23. Pumps
24. Storage Tank
25. Cooling Tower
26. Pump
27. Pump
28. Pump
29. Water Storage Tank
30. Pump
31. Pump
32. Condenser
33. Compressor
34. Separator
35. Vessel
36. Cooler
37. Vessel
38. Heater
39. Cooler
40. Vessel
41. Heater
42. Heater 43. Vessel 44. Vessel

Chapter # 3
Mass Balance

(Prepared by Altamash)

Raw material used = 1 ton

80% PP and 20% HDPE

Which means that 800 kg is PP and 200 kg is HDPE

Reaction for Polyethylene:

$406(C_2H_4)_n \longrightarrow$

$4H_2+CH_4+C_2H_4+C_2H_6+C_3H_8+C_3H_6+C_4H_{10}+C_4H_8+C_5H_{10}+C_5H_{12}+C_6H_{12}+C_6H_{14}+C_7H_{14}+C_7H_{16}+C_8H_{16}+$

$C_8H_{18}+C_8H_{10}+C_9H_{18}+C_9H_{20}+C_9H_{12}+C_{10}H_{20}+C_{10}H_{22}+C_{10}H_{14}+C_{11}H_{22}+C_{11}H_{24}+C_{11}H_{16}+C_{12}H_{24}+C_{12}H_{26}+$

$C_{13}H_{26}+C_{13}H_{28}+C_{14}H_{28}+C_{14}H_{30}+C_{15}H_{30}+C_{15}H_{32}+C_{16}H_{32}+C_{16}H_{34}+C_{17}H_{34}+C_{17}H_{36}+C_{18}H_{36}+C_{18}H_{38}+$

$C_{19}H_{38}+C_{19}H_{40}+C_{20}H_{40}+C_{20}H_{42}+C_{21}H_{42}+C_{21}H_{44}+C_{22}H_{44}+C_{22}H_{46}+C_{23}H_{46}+C_{23}H_{48}+C_{24}H_{48}+C_{24}H_{50}+$

$C_{25}H_{50}+C_{25}H_{52}+C_{26}H_{52}+C_{26}H_{54}+C_{27}H_{56}+C_{27}H_{54}+19C$

<u>Fraction produces by 1 mole of HDPE:</u>

Fraction	Yield(g)	Fraction	Yield(g)	Fraction	Yield(g)	Fraction	Yield(g)
$4H_2$	7.04e-4	C_9H_{12}	0.01055	$C_{18}H_{36}$	0.0221	19C	0.0200
CH_4	1.41e-3	$C_{10}H_{20}$	0.0123	$C_{18}H_{38}$	0.0223		
C_2H_4	2.46e-3	$C_{10}H_{22}$	0.0125	$C_{19}H_{38}$	0.0233		
C_2H_6	2.64e-3	$C_{10}H_{14}$	0.0118	$C_{19}H_{40}$	0.0235		
C_3H_8	3.87e-3	$C_{11}H_{22}$	0.0135	$C_{20}H_{40}$	0.0246		
C_3H_6	3.70e-3	$C_{11}H_{24}$	0.0137	$C_{20}H_{42}$	0.0248		
C_4H_{10}	5.10e-3	$C_{11}H_{16}$	0.0130	$C_{21}H_{42}$	0.0258		
C_4H_8	4.92e-3	$C_{12}H_{24}$	0.0147	$C_{21}H_{44}$	0.0260		
C_5H_{10}	6.16e-3	$C_{12}H_{26}$	0.0150	$C_{22}H_{44}$	0.0270		
C_5H_{12}	6.33e-3	$C_{13}H_{26}$	0.0160	$C_{22}H_{46}$	0.0272		
C_6H_{12}	7.40e-3	$C_{13}H_{28}$	0.0161	$C_{23}H_{46}$	0.0283		
C_6H_{14}	7.56e-3	$C_{14}H_{28}$	0.0172	$C_{23}H_{48}$	0.0285		
C_7H_{14}	8.62e-3	$C_{14}H_{30}$	0.0174	$C_{24}H_{48}$	0.0295		
C_7H_{16}	8.80e-3	$C_{15}H_{30}$	0.0184	$C_{24}H_{50}$	0.0297		
C_8H_{16}	9.85e-3	$C_{15}H_{32}$	0.0186	$C_{25}H_{50}$	0.0307		
C_8H_{18}	0.0100	$C_{16}H_{34}$	0.0198	$C_{25}H_{52}$	0.0309		
C_8H_{10}	9.32e-3	$C_{16}H_{32}$	0.0197	$C_{26}H_{54}$	0.0322		
C_9H_{18}	0.0110	$C_{17}H_{34}$	0.0209	$C_{27}H_{56}$	0.0334		
C_9H_{20}	0.01125	$C_{17}H_{36}$	0.0211	$C_{27}H_{54}$	0.0332		

Molecular Mass of HDPE: 11368 g/mole

For HDPE:

- Theoretical Yield of Gasoline (C_4 –C_{12}):
  From reaction we weight of fractions from C_4 –C_{12} = 0.2236 g
- Theoretical of Diesel (C_{12} –C_{20}):
  From reaction we weight of fractions from C_{12} –C_{20} = 0.3555 g
- Theoretical Yield of Kerosene (C_{10} –C_{12}):
  From reaction we weight of fractions from C_{10} –C_{12} = 0.1065 g

Reaction for Polypropylene:

$94(C_3H_6)_n \longrightarrow$

$2H_2+CH_4+C_2H_4+C_2H_6+C_3H_8+C_3H_6+C_4H_{10}+C_4H_8+C_5H_{10}+C_5H_{12}+C_6H_{12}+C_6H_{14}+C_7H_{14}+C_7H_{16}+C_8H_{16}+$

$C_8H_{18}+C_8H_{10}+C_9H_{18}+C_9H_{20}+C_9H_{12}+C_{10}H_{20}+C_{10}H_{22}+C_{10}H_{14}+C_{11}H_{22}+C_{11}H_{24}+C_{11}H_{16}+C_{12}H_{24}+C_{12}H_{26}+$

$C_{13}H_{26}+C_{13}H_{28}+C_{14}H_{28}+C_{14}H_{30}+C_{15}H_{30}+C_{15}H_{32}+5C$

Fraction produces by 1 mole of PP:

Fraction	Yield(g)	Fraction	Yield(g)
$2H_2$	1.013e-3	C_9H_{12}	0.0304
CH_4	4.052e-3	$C_{10}H_{20}$	0.0354
C_2H_4	7.092e-3	$C_{10}H_{22}$	0.0360
C_2H_6	7.60e-3	$C_{10}H_{14}$	0.0340
C_3H_8	0.0111	$C_{11}H_{22}$	0.0390
C_3H_6	0.0106	$C_{11}H_{24}$	0.0395
C_4H_{10}	0.0147	$C_{11}H_{16}$	0.0374
C_4H_8	0.0142	$C_{12}H_{24}$	0.0425
C_5H_{10}	0.0177	$C_{12}H_{26}$	0.0430
C_5H_{12}	0.0182	$C_{13}H_{26}$	0.0461
C_6H_{12}	0.0213	$C_{13}H_{28}$	0.0466
C_6H_{14}	0.0218	$C_{14}H_{28}$	0.0496
C_7H_{14}	0.0248	$C_{14}H_{30}$	0.0502
C_7H_{16}	0.0253	$C_{15}H_{30}$	0.0532
C_8H_{16}	0.0283	$C_{15}H_{32}$	0.0537
C_8H_{18}	0.0288	5C	0.0152
C_8H_{10}	0.0268		
C_9H_{18}	0.0319		
C_9H_{20}	0.0324		

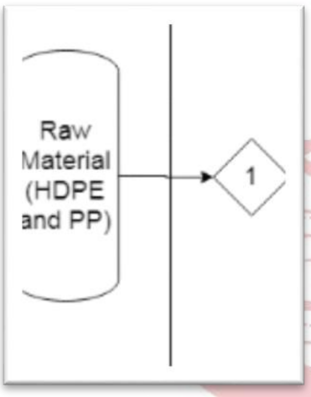
Molecular Mass of PP: 3948 g/mole

For PP:

- Theoretical Yield of Gasoline (C_4 –C_{12}):
  From reaction we weight of fractions from C_4 –C_{12} = 0.6434 g
- Theoretical Yield of Diesel (C_{12} –C_{20}):
  From reaction we weight of fractions from C_{12} –C_{20} = 0.3849 g
- Theoretical Yield of Kerosene (C_{10} –C_{12}):
  From reaction we weight of fractions from C_{10} –C_{12} = 0.3068 g

Mass Balance Practically:

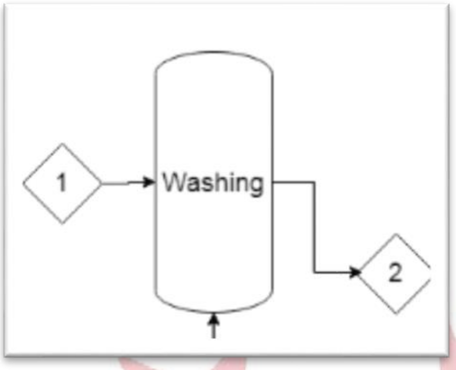
1. Storage:



Material	PP	HDPE	Total
Inlet (Kg)	800	200	1000
Outlet (Kg)	800	200	1000

No calculation for this part.

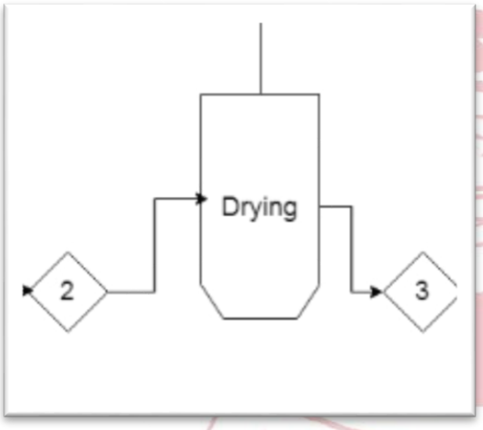
2. Washing Tank:



Material	PP	HDPE	Water	Total
Inlet (Kg)	800	200	1000	2000
Outlet (Kg)	800	200	1000	2000

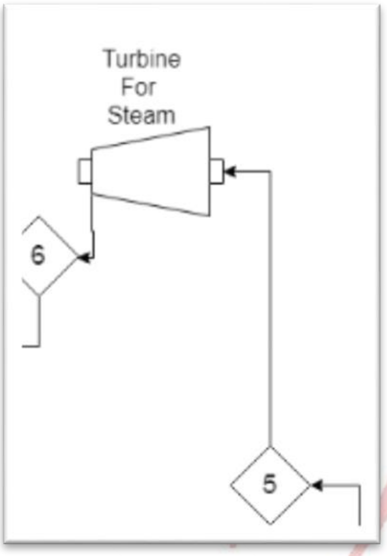
No calculation for this part.

3. Drying:



Material	PP	HDPE	Water	Total
Inlet (Kg/min)	800	200	1000	2000
Outlet (Kg/min)	800	200	1000	2000

4. Turbine:

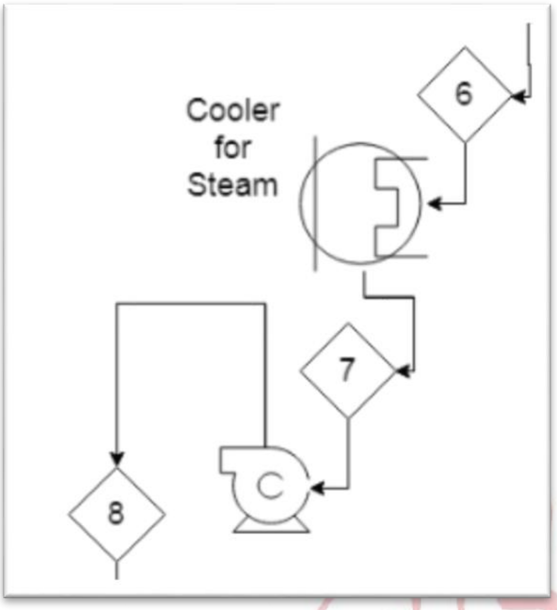


Material	PP	HDPE	Steam	Total
Inlet (Kg/min)	0	0	990	990
Outlet (Kg/min)	0	0	985	985

n.A + n.B = n.C + n.D
n = variation in weight (guess)
A (for Plastic) and B (for water) for inlet and C and D for outlet.
(0). A + (99%) x (1000kg) = (0). C + (98.5%)x (1000kg)
990kg = 985kg

990 kg water for inlet which will further loss to 0.5% in drying process while 1% water will still be in raw material.

5. Cooler:



Material	PP	HDPE	Water	Steam	Total
Inlet (Kg/min)	0	0	0	985	985
Outlet (Kg/min)	0	0	980	0	980

n.A + n.B = n.C + n.D

n = variation in weight (guess)

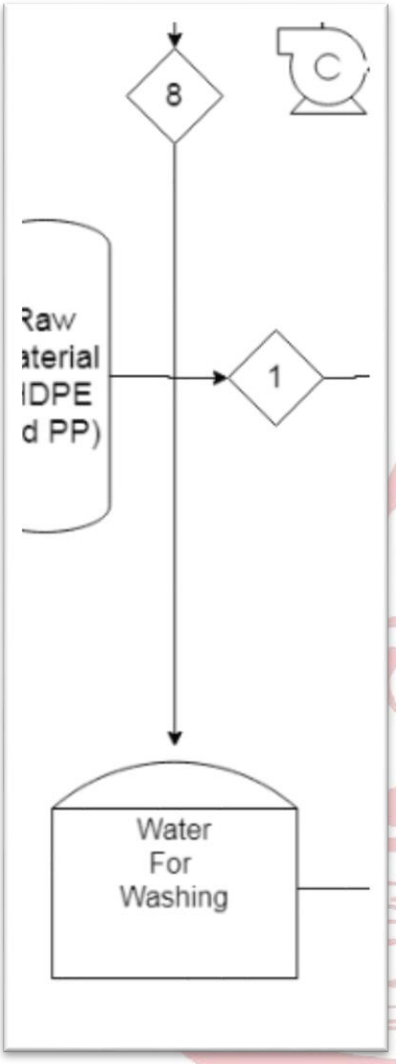
A (for Plastic) and B (for water) for inlet and C and D for outlet.

(0).A + (100%) x (985kg) = (0).C + (99.5%)x(985kg)

985kg = 980 kg

0.5 % water will loss here.

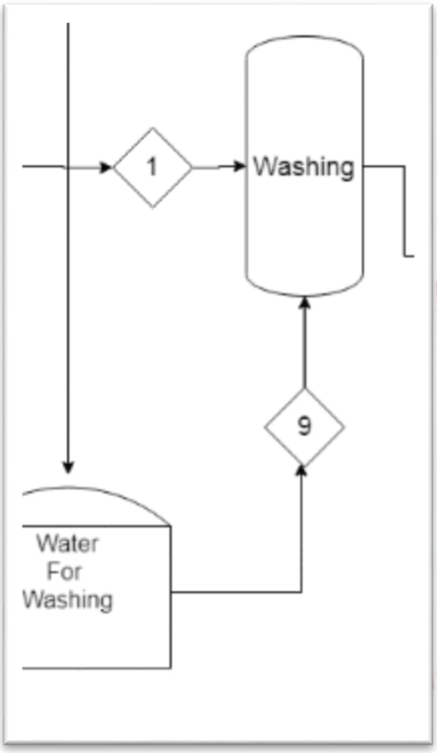
6. Storage Tank for washing Water:



Material	Water	Total
Inlet (Kg/min)	980	980
Outlet (Kg/min)	980	980

From initial step almost 2% water is lost during washing of raw material.

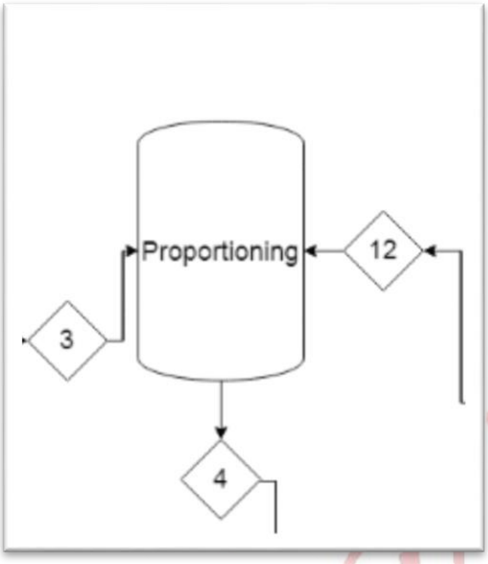
7. From Storage tank to washing tank:



Material	Water	Total
Inlet (Kg/min)	1000	1000
Outlet (Kg/min)	1000	1000

No calculation required here because 1000 kg water is required here.

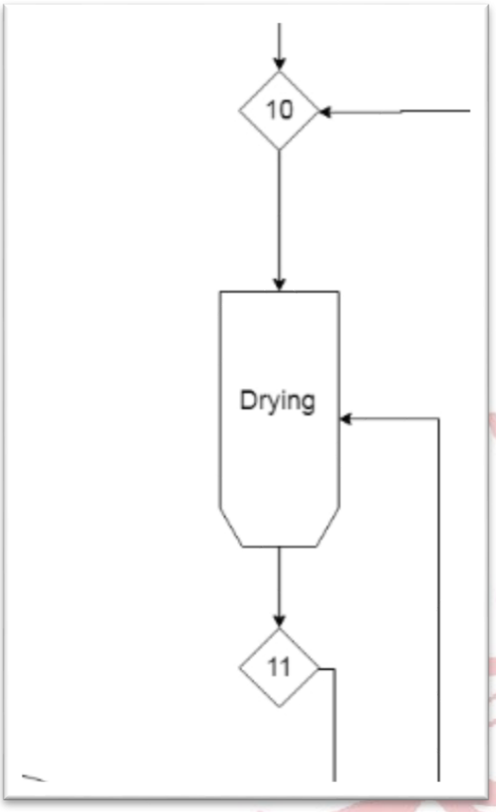
8. Plastic from drying to proportioning:



Material	PP	HDPE	Total
Inlet (Kg)	800	200	1000
Outlet (Kg)	800	200	1000

This raw material still contains during proportioning still contains 1% water which is 100 kg.

9. Catalyst from Storage Tank to Drying:



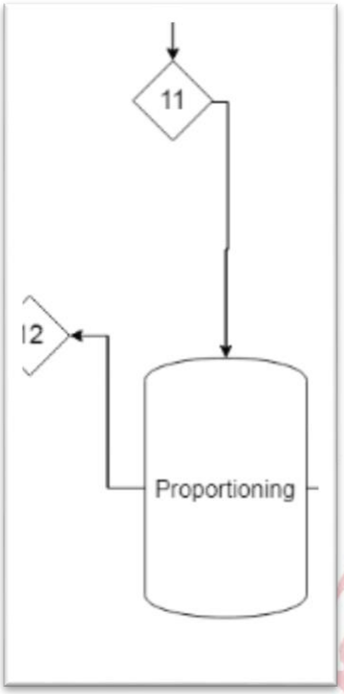
Material	USY Zeolite	Moisture	Total
Inlet (Kg)	105	0	105
Outlet (Kg)	100 (approx.)	4.89	105 (approx.)

n.A + n.B = n.C + n.D

n = variation in weight (guess)
A (for USY Zeolite) and B (for moisture) for inlet and C and D for outlet.
(100%) x (105kg) + (0). B = (0).C + (95.2%)x(105kg)

105kg = 100 kg (approx.)
0.5 % water will loss here.

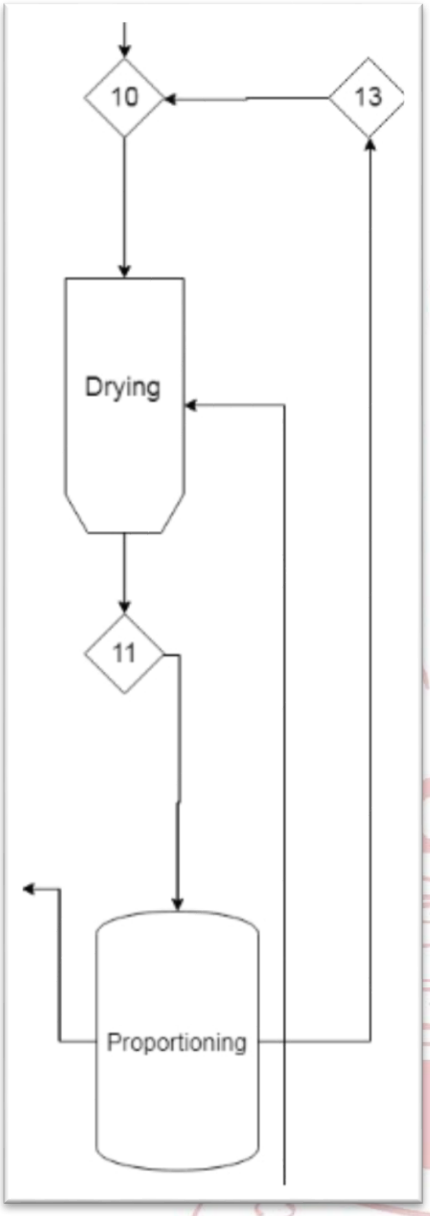
10. From Drying to Proportioning:



Material	USY Zeolite 1	USY Zeolite 2	Total
Inlet (Kg)	100 approx.	-	100±2
Outlet (Kg)	100±2	100	100

No calculation required here as it is proportioning process for zeolite catalyst

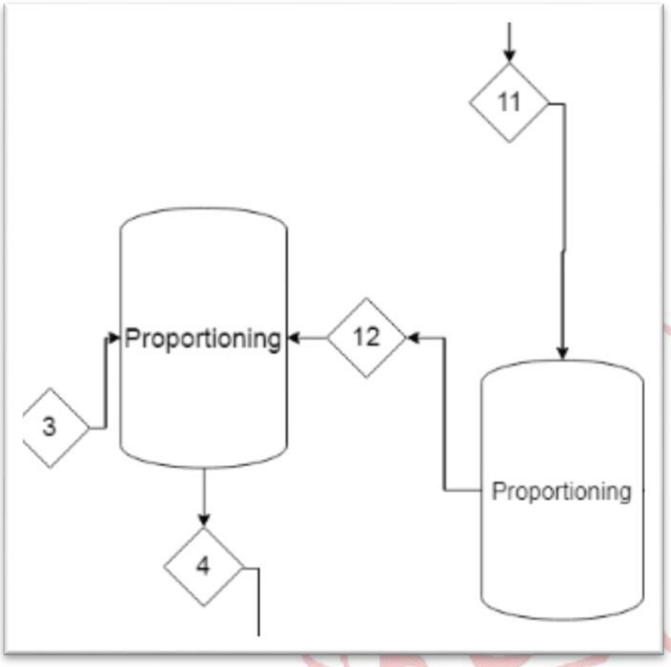
11. From Proportioning of Catalyst to Muffle Furnace of Catalyst:



Material	USY Zeolite 1	USY Zeolite 2	Total
Inlet (Kg)	+2	-	+2
Outlet (Kg)	-	+2	+2

Excess amount is stored here to make up with upcoming batch of catalyst

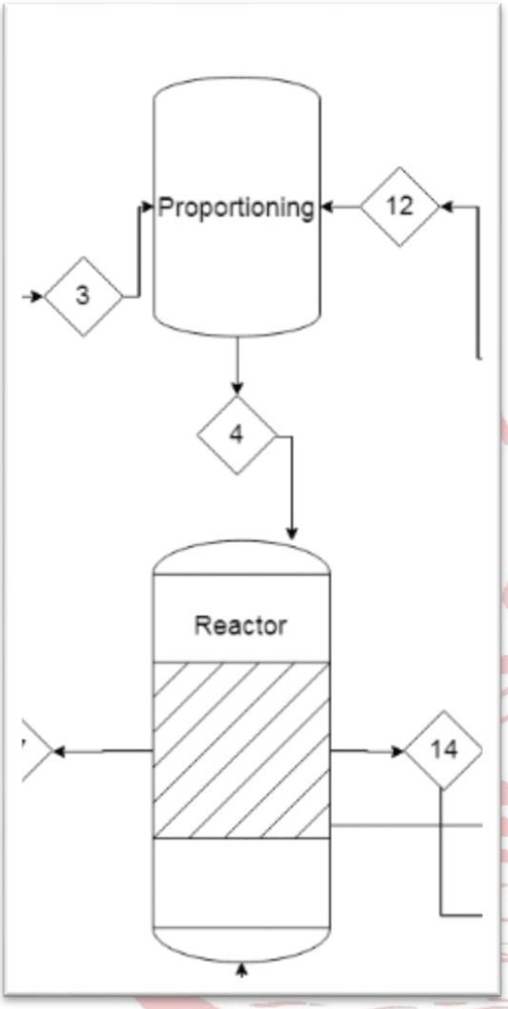
12. Both Catalyst and Waste mixed in Proportioning tank:



Material	PP	HDPE	USY Zeolite	Total
Inlet (Kg/min)	800	200	100	1100
Outlet (Kg/min)	800	200	100	1100

No calculation required here as material is just introducing into reactor after it, so no loss here. But still material contains 1% water from washing prior to any other process.

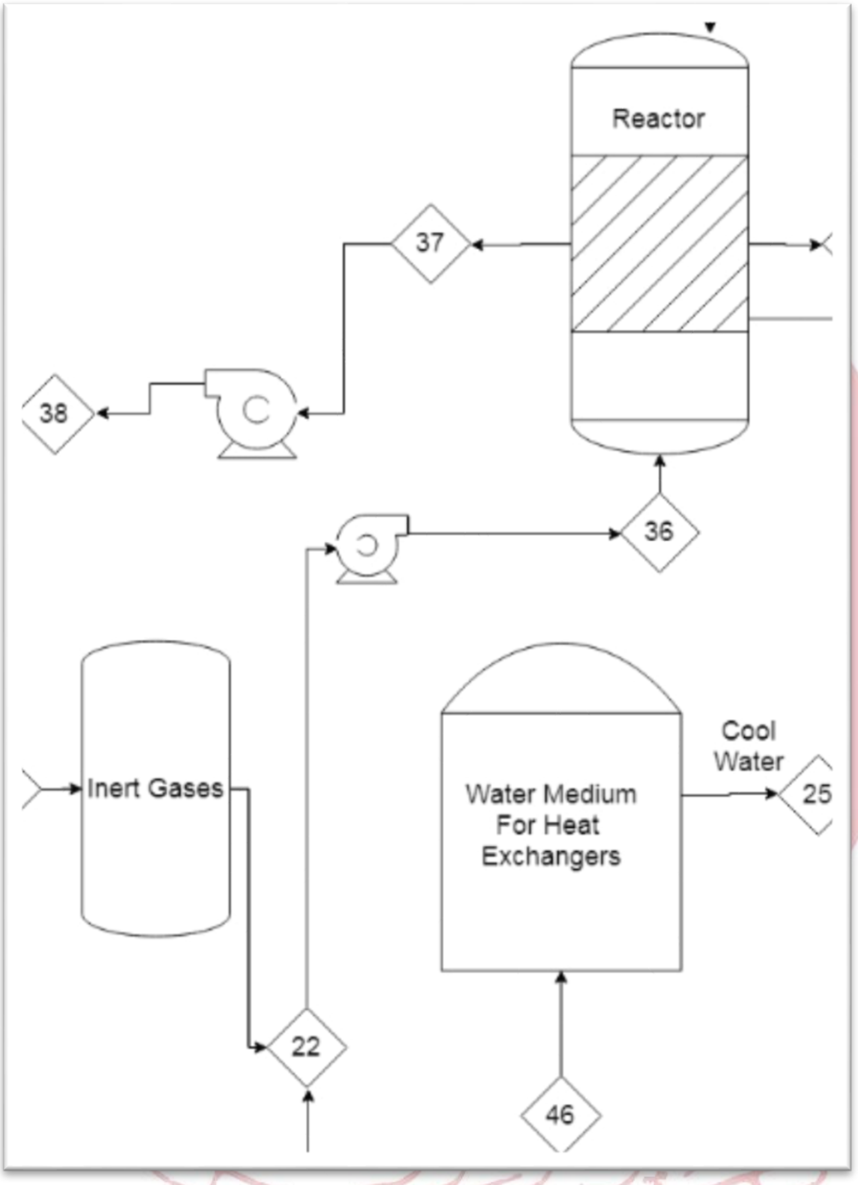
13. From Proportioning Tank to Reactor:



Material	PP	HDPE	USY Zeolite	Total
Inlet (Kg/min)	800	200	100	1100
Outlet (Kg/min)	800	200	100	1100

No loss here as the material is introducing into reactor.

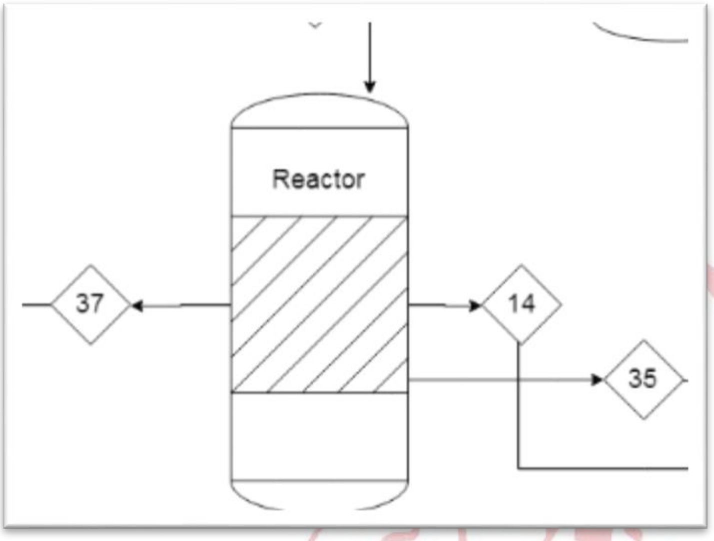
14. Inert Gas from Vessel to Reactor:



Material	Inert Gases	Total
Inlet (Kg)	807.88	807.88
Outlet (Kg)	807.88	807.88

Inert is provide until pressure 1 atmospheric pressure is attained in reactor.

15. From Reactor to other Routes:



Material	PP	HDPE	USY Zeolite	Gasoline	Kerosene	Diesel	H_2	CH_4	C_2H_6	C_2H_4	C_3H_8	C_3H_6	C_4H_{10}	C_4H_8	Char	Total
Inlet (Kg)	800	200	100	0	0	0	0	0	0	0	0	0	0	0	0	1100
Outlet (Kg)	0	0	100	390	250	160	6.4234	10.91	20.46	19.21	29.37	27.112	38.409	38.1835	10	1100

Mass Balance equation for reactor is:

Inlet = Outlet + Generation + Accumulation + Consumption

Inlet	Weight (Kg)
HDPE	200
PP	800
USY Zeolite	100
Total	1100

Outlet	Weight (Kg)
Gasoline	390
Kerosene	250
Diesel	160
Total	800

Generation	Weight (Kg)
H_2	6.4234
CH_4	10.91
C_2H_6	20.46
C_2H_4	19.21
C_3H_8	29.37
C_3H_6	27.112
C_4H_{10}	38.409
C_4H_8	38.1835
Total	190.07

Accumulation	Weight (Kg)
Char	10
Other heavy fractions	Minor
USY Zeolite	100
Total	110

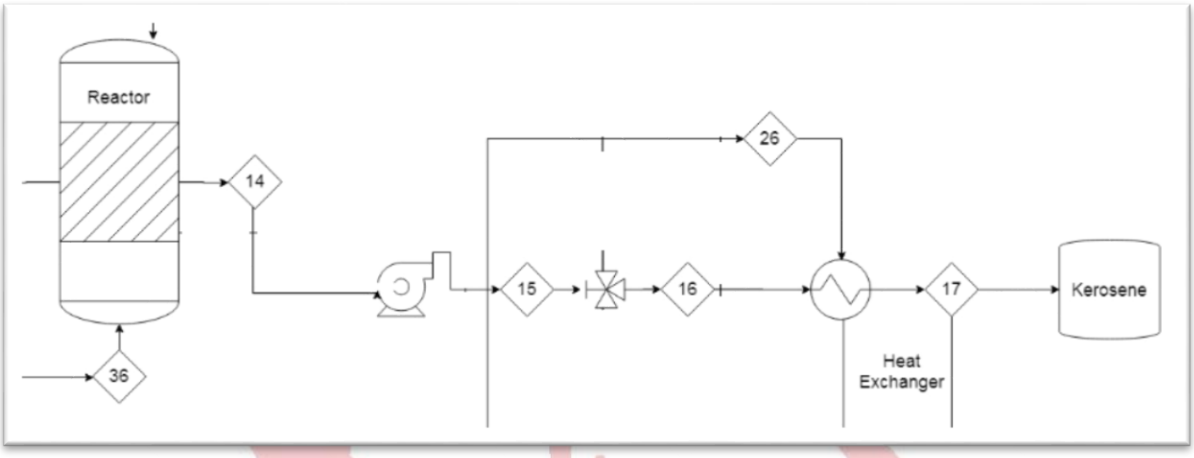
There is no consumption of any material here except plastic waste which we have taken it as Inlet.

Now putting values for mass balance equation:

(1100 kg) = (800 kg) + (190 kg) + (110 kg) + (0 kg)

1100 kg = 1100 kg

16. Kerosene from Reactor to Heat exchanger:



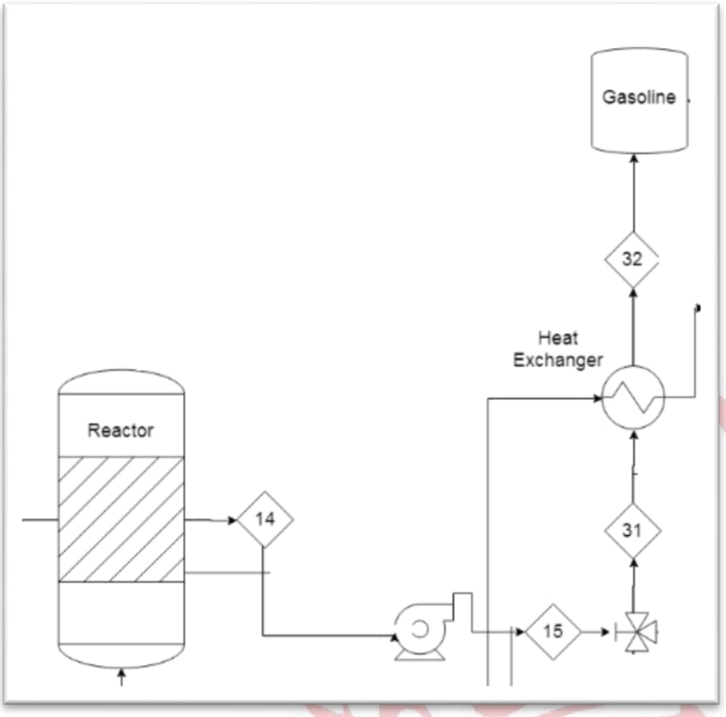
Material	Kerosene	Water	Total
Inlet (Kg/hr.)	253.5	106	359.5
Outlet (Kg/hr.)	250	105.160	355.16

n.A + n.B = n.C + n.D

n = variation in weight (guess)
A (for Kerosene) and B (for Water) for inlet and C and D for outlet.
(100%) x (253.5kg) + (100%) x (106) = (253.5Kg) x (98.5%) + (99.20%) x (106kg)

359.5 kg = 354.84 kg
1.378 % material will loss here, in which 0.79% is water and 0.58% is Kerosene.

17. Gasoline from Reactor to Heat exchanger:



Material	Gasoline	Water	Total
Inlet (Kg/hr.)	395	227	622
Outlet (Kg/hr.)	390	224.256	614.256

n.A + n.B = n.C + n.D

n = variation in weight (guess)

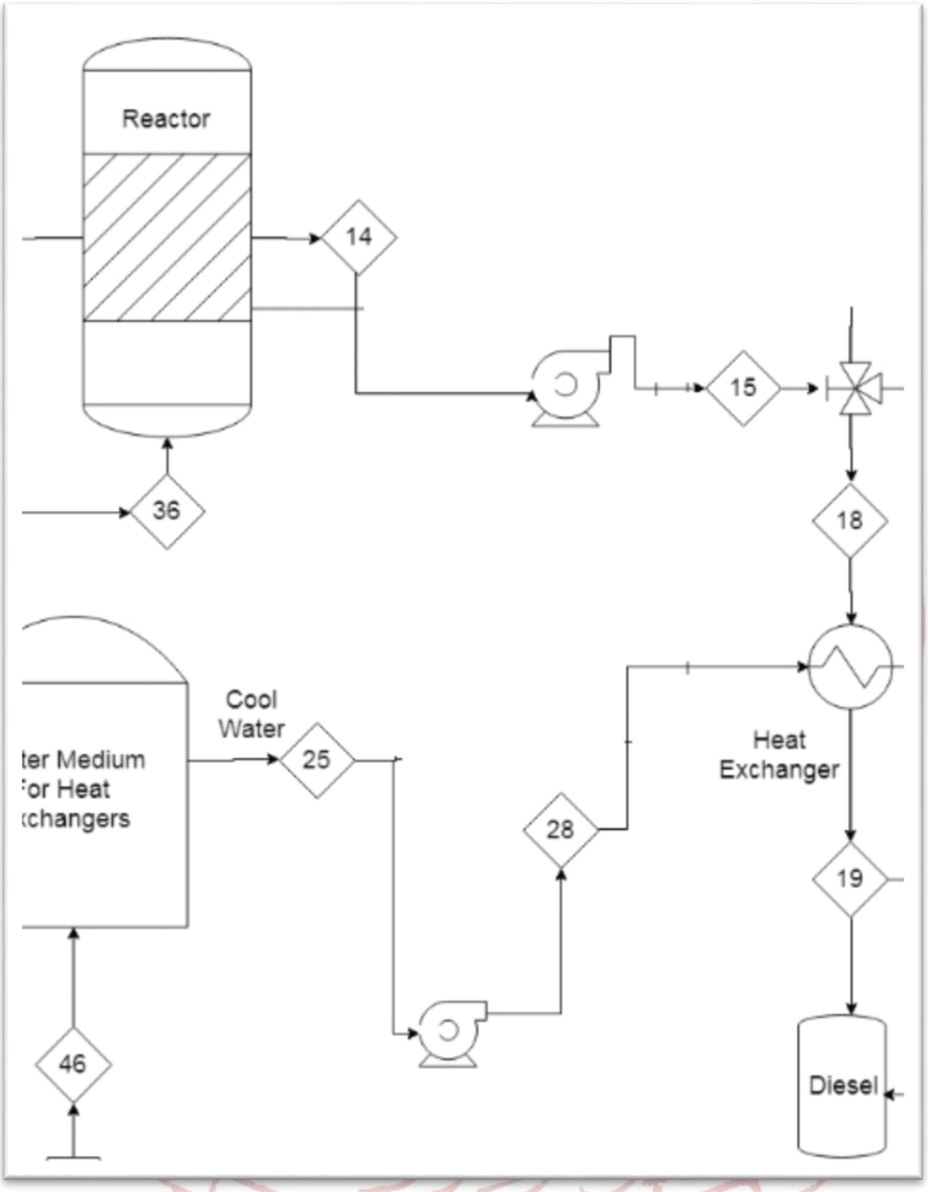
A (for Gasoline) and B (for Water) for inlet and C and D for outlet.

(100%) x (395kg) + (100%) x (227) = (395Kg) x (98.73%) + (98.79%) x (227kg)

622 kg = 614.256 kg

1.24 % material will loss here, in which 1.207% is water and 1.26% is Gasoline.

18. Diesel from Reactor to Heat exchanger:



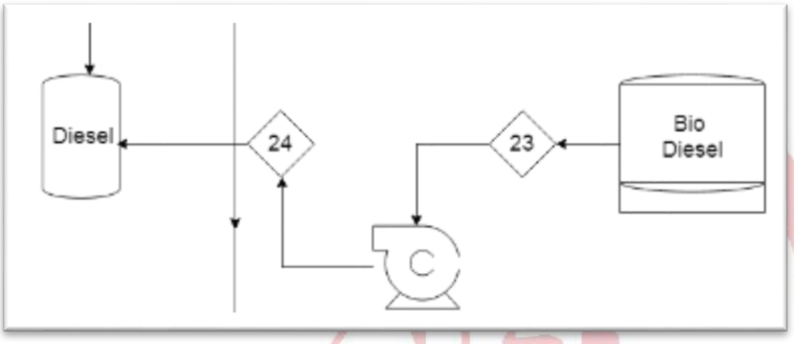
Material	Diesel	Water	Total
Inlet (Kg/hr.)	165	50	215
Outlet (Kg/hr.)	160	47.99	207.99

n.A + n.B = n.C + n.D

n = variation in weight (guess)
A (for Diesel) and B (for Water) for inlet and C and D for outlet.
(100%) x (165kg) + (100%) x (50) = (165Kg) x (96.96%) + (95.98%) x (50kg)

215 kg = 207.99 kg
3.26 % material will loss here, in which 4.02% is water and 3.03% is Diesel.

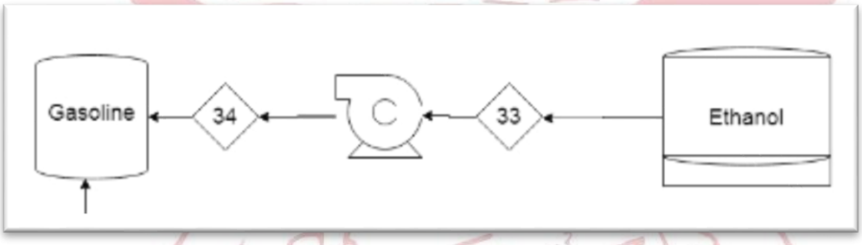
19. 7% Biodiesel is added in Diesel Tank:



Material	Diesel	Biodiesel	Total
Inlet (Kg)	160	11.2	171.2
Outlet (Kg)	160	11.2	171.2

Loss here will not evaluate because Biodiesel is added as an additive.

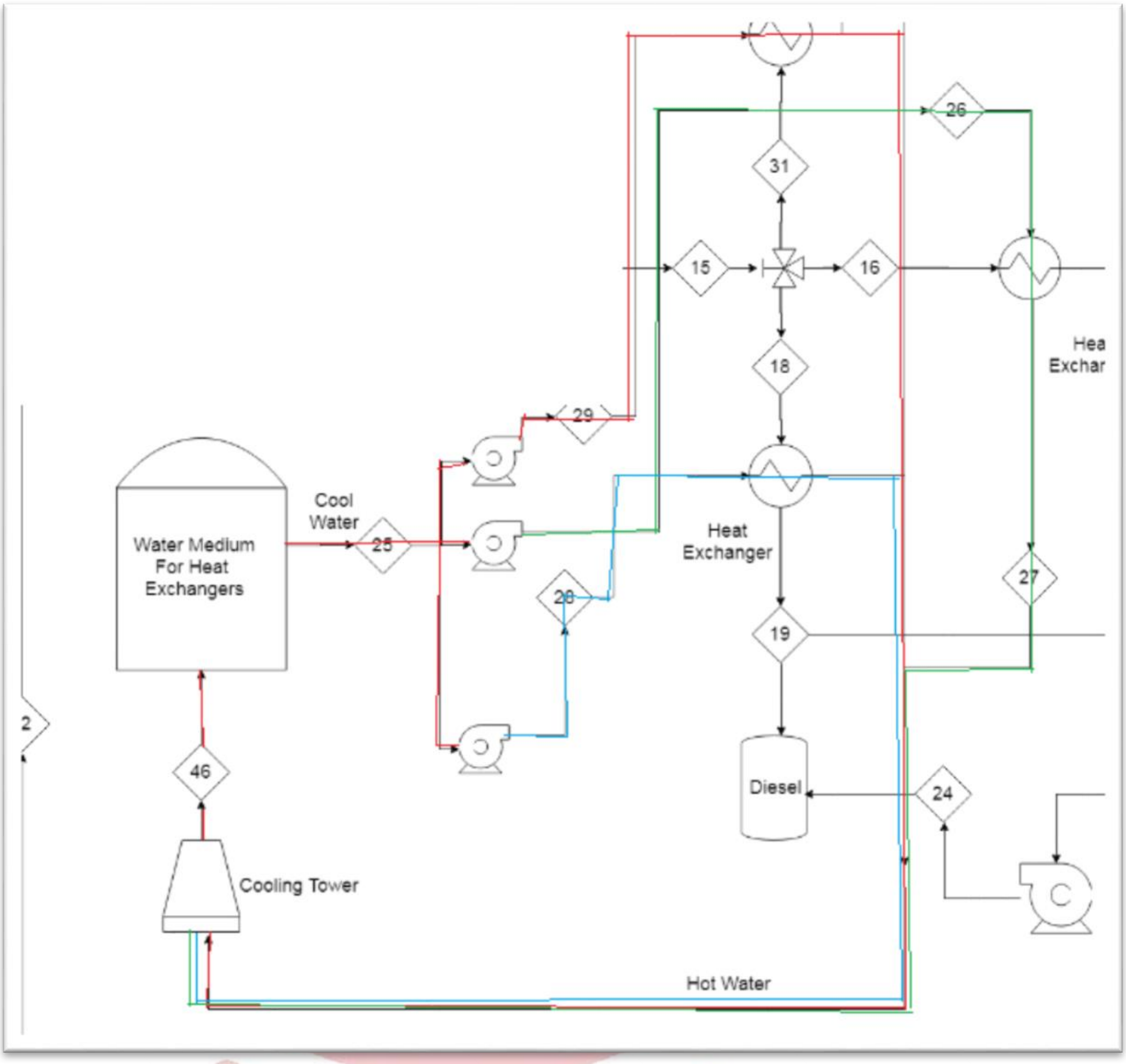
20. 25% Ethanol is added in Gasoline Tank:



Material	Gasoline	Ethanol	Total
Inlet (Kg)	390	97.5	487.5
Outlet (Kg)	390	97.5	487.5

Loss here will not evaluate because Ethanol is added as an additive.

21. Amount of Water used for Heat exchangers moving to Cooling tower and Storage:



Material	Stream 1	Stream 2	Stream 3	Total
Inlet (Kg)	108	226	51	385
Outlet (Kg)	105.160	224.256	47.99	377.406

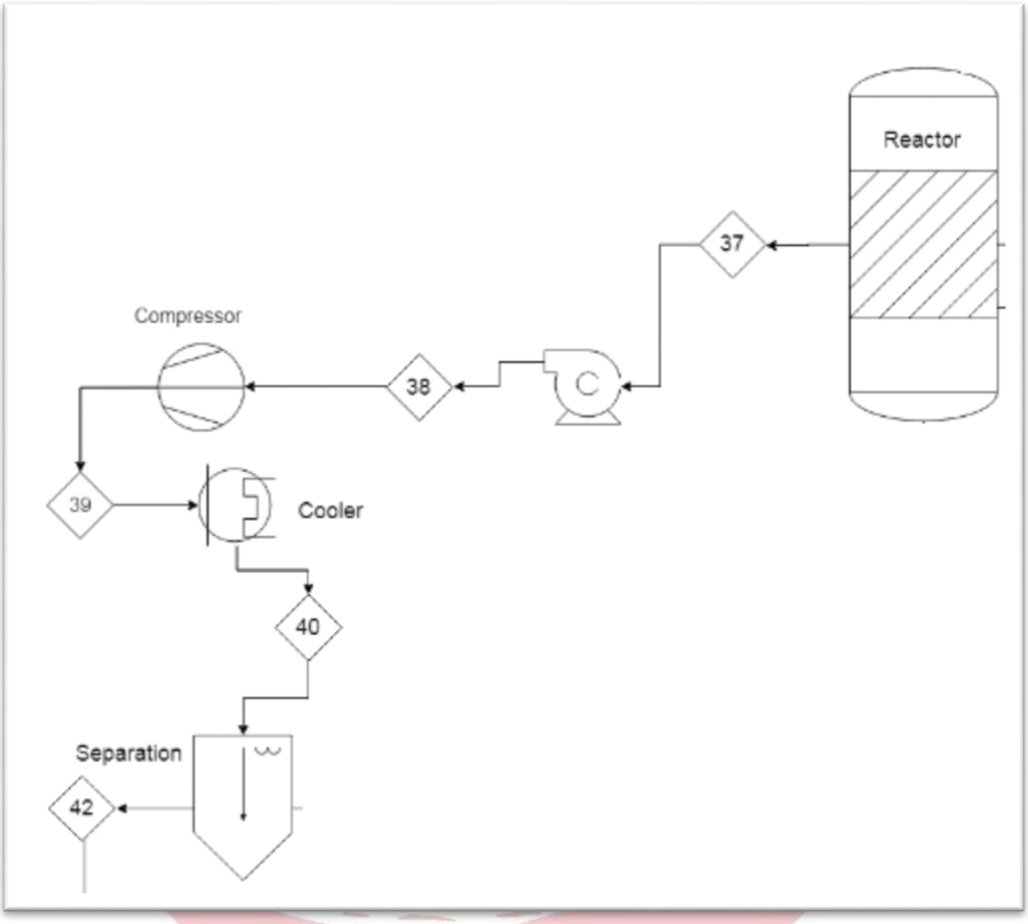
n.A + n.B + n.C = n.D + n.E + n.F

n = variation in weight (guess)
A (for stream 1), B (for stream 2) and C (for stream 3) for inlet and D, E and F for outlet.
(100%) x (108kg) + (100%) x (226kg) + (100%) x (51 kg) = (108Kg) x (97.37%) + (99.22%) x (226kg) + (94.1%) x (51)

385 kg = 377.406 kg

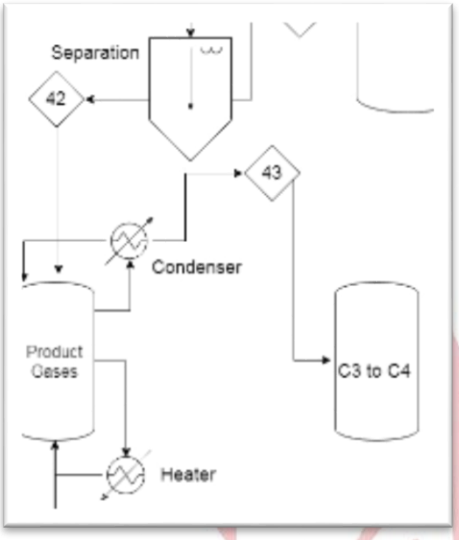
2 % material will loss here, in which 2.6%, 0.77% and 2% for respective streams.

22. Treatment of Gases (Compression):



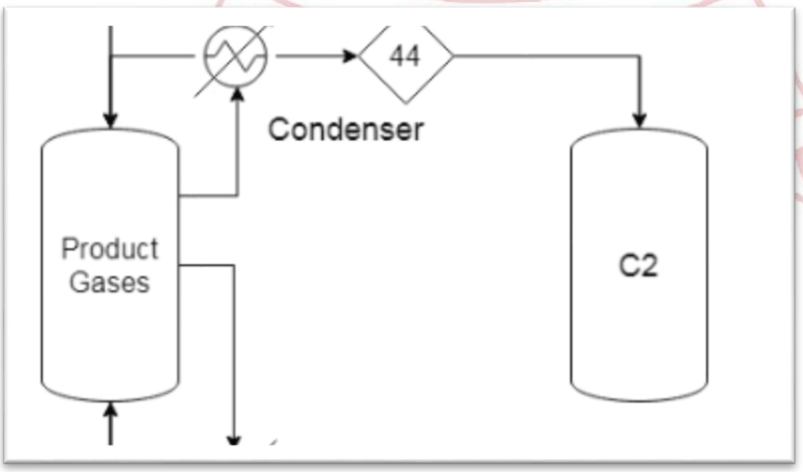
Gases	Inlet (Kg)	Outlet (Kg)	Loss %
H_2	7	6.4234	8.23
CH_4	11	10.91	0.80
C_2H_6	21	20.46	2.57
C_2H_4	21	19.21	8.52
C_3H_8	31	29.37	5.26
C_3H_6	31	27.112	12.54
C_4H_{10}	40	38.409	3.97
C_4H_8	40	38.1835	4.54
Total	202	190.07	6

23. From Product Vessel to C_3 and C_4 Vessel:



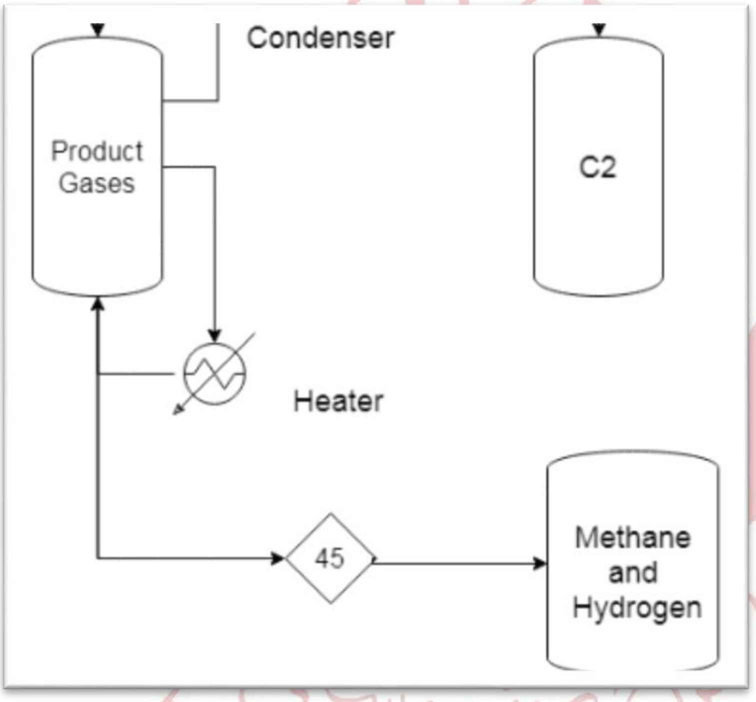
Gases	Inlet (Kg)	Outlet (Kg)	Loss %
H_2	7	0	0
CH_4	11	0	0
C_2H_6	21	0	0
C_2H_4	21	0	0
C_3H_8	31	29.37	5.26
C_3H_6	31	27.112	12.54
C_4H_{10}	40	38.409	3.97
C_4H_8	40	38.1835	4.54
Total	202	133.0745	34.12

24. From Product Vessel to C_2 Vessel:



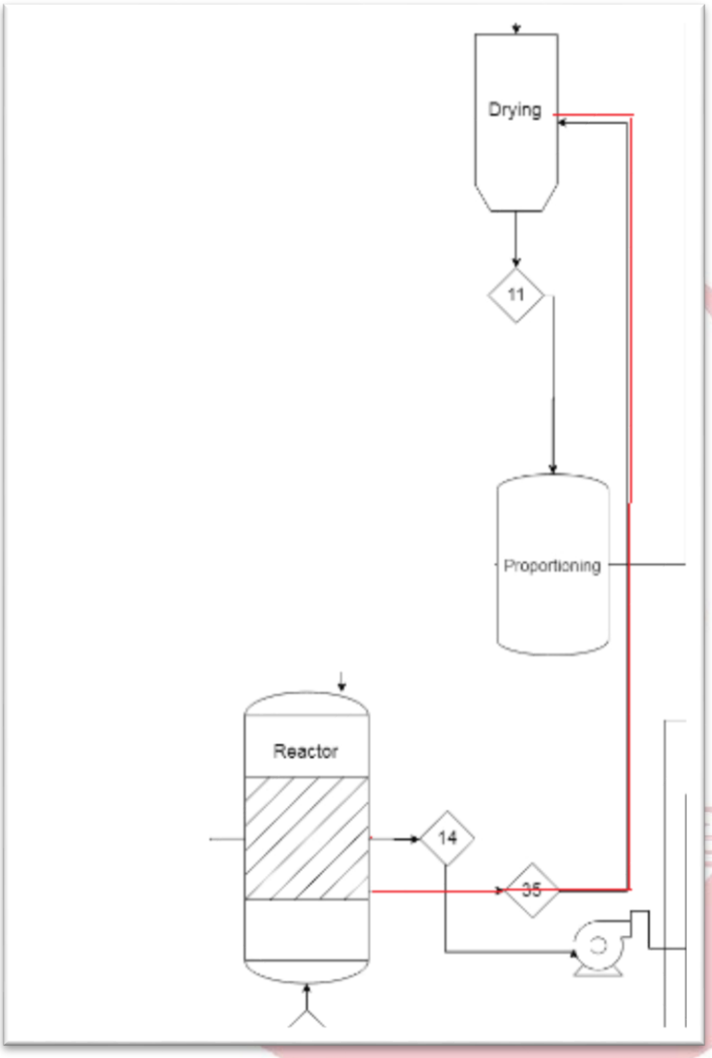
Gases	Inlet (Kg)	Outlet (Kg)	Loss%
H_2	7	0	0
CH_4	11	0	0
C_2H_6	21	20.46	2.57
C_2H_4	21	19.21	8.52
C_3H_8	0	0	0
C_3H_6	0	0	0
C_4H_{10}	0	0	0
C_4H_8	0	0	0
Total	60	39.67	11.09

25. From Product Vessel to Hydrogen and Methane Vessel:



Gases	Inlet (Kg)	Outlet (Kg)	Loss %
H_2	7	6.4234	8.23
CH_4	11	10.91	0.81
C_2H_6	0	0	0
C_2H_4	0	0	0
C_3H_8	0	0	0
C_3H_6	0	0	0
C_4H_{10}	0	0	0
C_4H_8	0	0	0
Total	18	17.334	9.04

26. Regeneration of Catalyst by sending it to muffle Furnace:



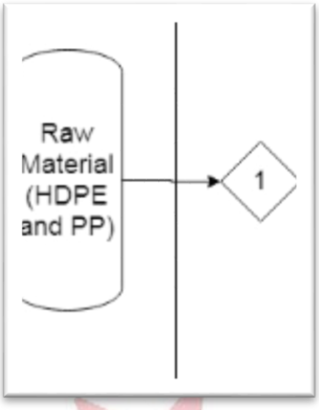
Material	USY Zeolite	Total
Inlet (Kg)	110	110
Outlet (Kg)	101	101

This 10 kg excess is of water trapped inside catalyst from plastic.

Chapter # 4 Energy Balance

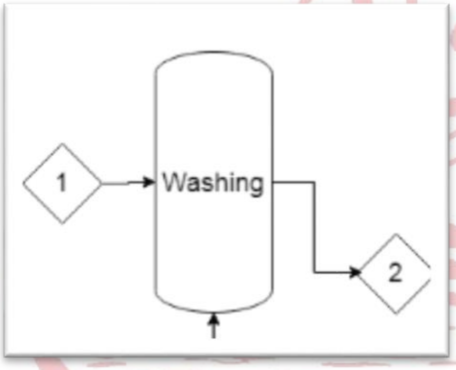
(Prepared by Altamash)

1. Raw Material Storage Tank:



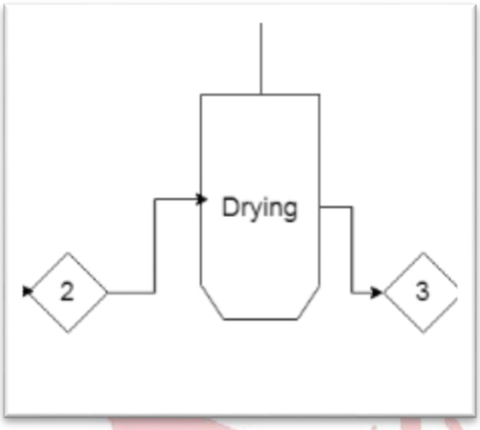
No heat required here.

2. Washing of Raw material:



No heat required here.

3. Drying of Raw Material:

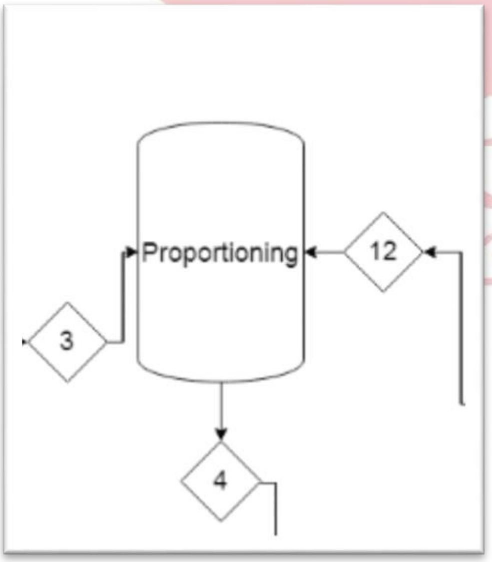


Q=m.Cp ΔT

Material	Mass (kg)	Cp (kJ/kg.k)	T_1 (K)	T_2 (K)	ΔT (K)	Q (kJ)
PP	800	1.8	293	373	80	115200
HDPE	200	1.9	293	373	80	30400
Water	1000	4.19	293	373	80	335200

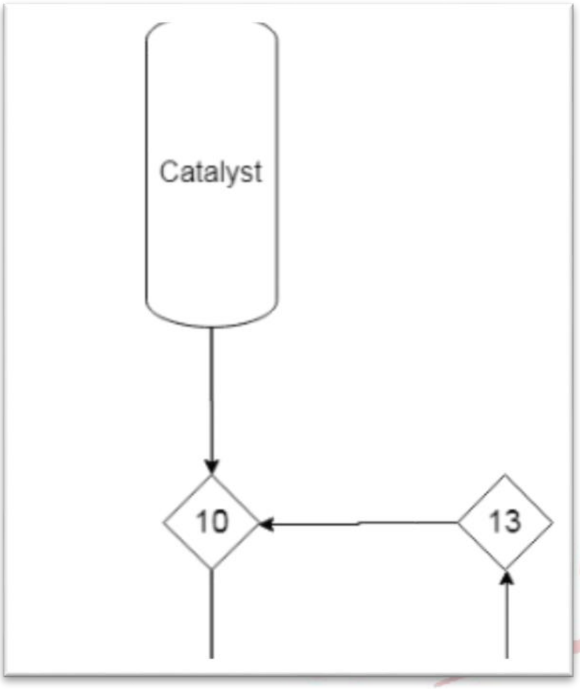
Q_{in} = 335200 Kj
Q_{out} = 115200+30400 = 145600 Kj
Q_{loss} = 189600 Kj

4. Proportioning of Raw Material:



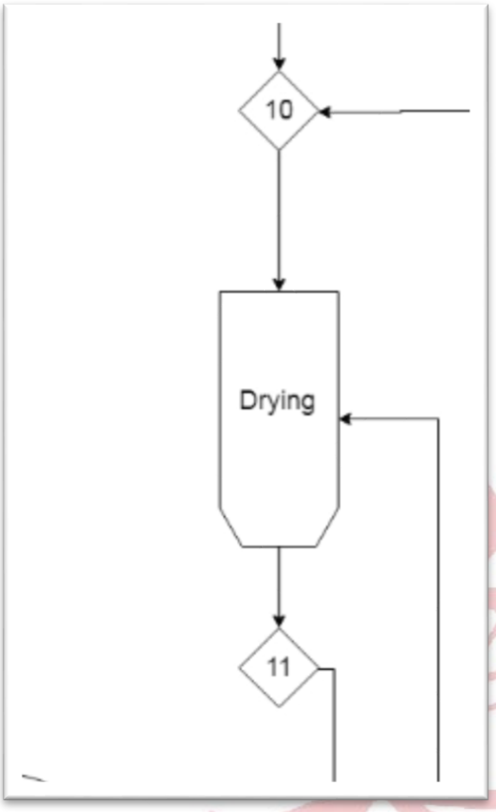
No Heat Required here.

5. Storage of Catalyst:



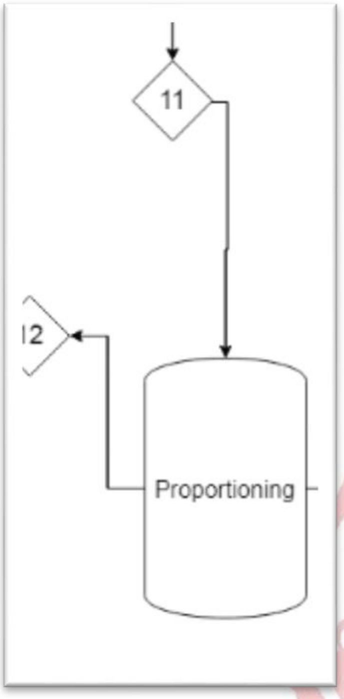
No heat required here.

6. Catalyst Drying:



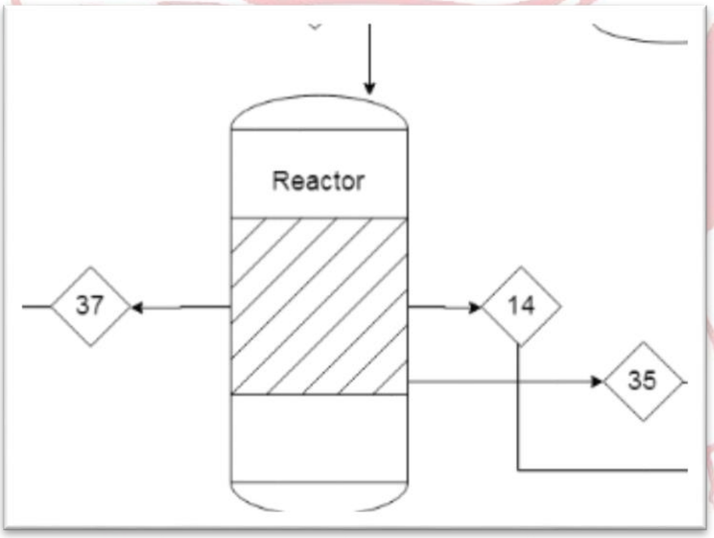
Material	Mass (kg)	Cp (kJ/kg.k)	T_1 (K)	T_2 (K)	ΔT (K)	Q (kJ)
USY Zeolite	100	1.082	293	773	480	51936

7. Catalyst Proportioning:



No heat required here.

8. Reactor:



For this we will use equation:

$Q_{in} - Q_{out} + Q_{generation} - Q_{consumption} = Q_{accumulation}$

Q_{in} = Heat required to melt plastic at 130 degrees Centigrade

Q_{out} = Heat of product formed at given temperatures

$Q_{generation}$ = Heat produced in reaction

$Q_{consumption}$ = Heat absorbed in reaction

$Q_{accumulation}$ = Heat accumulated in reactor (For continuous process)

Heat of reactants:

Material	Mass (kg)	Cp (kJ/kg.k)	T_1 (K)	T_2 (K)	ΔT (K)	Q (kJ)
PP	800	1.8	293	403	110	158400
HDPE	200	1.9	293	403	110	41800
USY Zeolite	100	1.082	293	773	480	51936

Q_{in} = 158400 + 41800 + 51936 = 252136 Kj

Heat of product:

Material	Mass (kg)	Cp (kJ/kg.k)	T_1 (K)	T_2 (K)	ΔT (K)	Q (kJ)
Kerosene	250	2.01	403	463	60	30150
Gasoline	390	2.22	403	433	30	25974
Diesel	160	1.750	403	493	90	25200
Gases	190	1.68	403	423	20	6384

Q_{out} = 30150 +25974+25200+6384 = 87708 Kj

Heat Generated by vapors:

Q= m λ

Material	Mass (kg)	λ (Kj/kg)	Q (kJ)
Kerosene	250	251	62750
Gasoline	390	350	136500
Diesel	160	298	47680
Gases	190	426.2	80978

$Q_{generation}$ = 62750+136500+47680+80978 = 327908 Kj

Heat accumulated in reactor:
Since process is batch so there is no heat accumulation here.

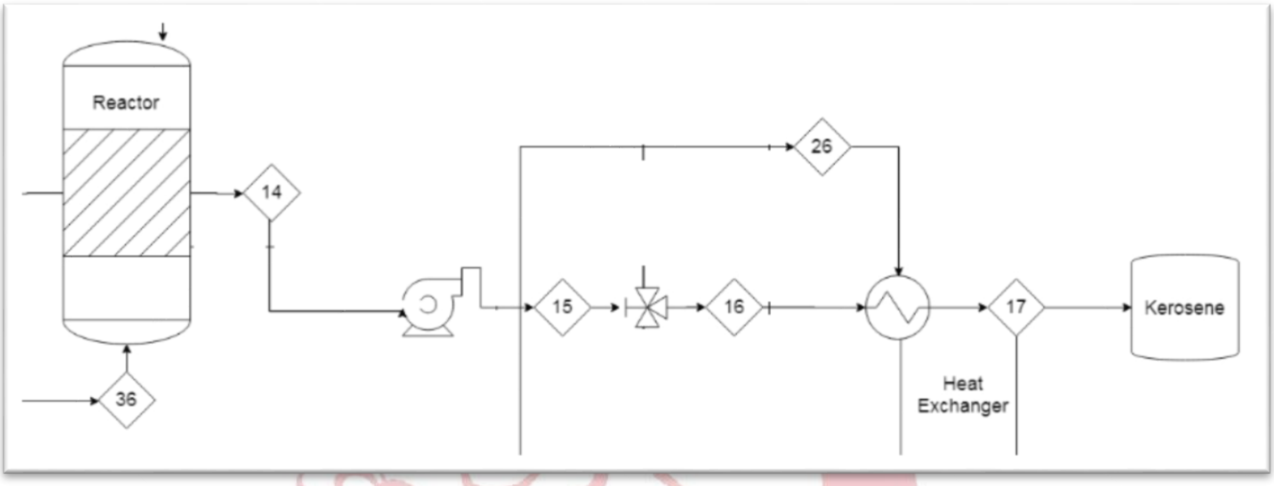
Heat consumption:
It can be find out by putting values in energy equation.

$Q_{in} – Q_{out} + Q_{generation} – Q_{consumption} = Q_{accumulation}$
$(252136) – (87708) + (327908) – Q_{consumption} = 0$
$Q_{consumption}$ = 492336 Kj

$Q_{consumption}$ is the energy loss by reactor.

9. Heat balance for exchangers:

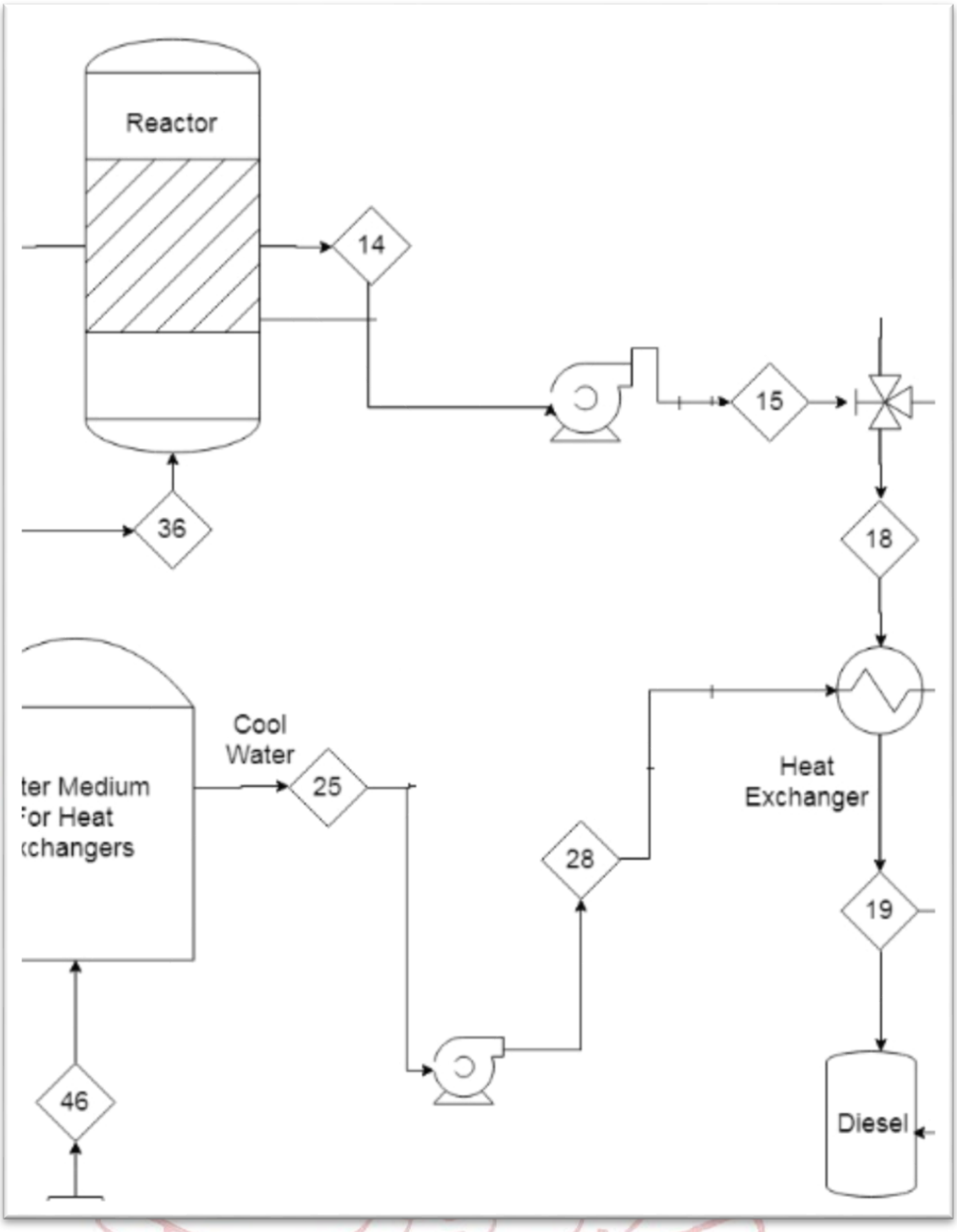
Exchanger for Kerosene:



Material	Mass (kg)	Cp (kJ/kg.k)	T_1 (K)	T_2 (K)	ΔT (K)	Q (kJ)
Kerosene	220	1.84	463	323	140	56672
Water	105.16	4.1868	293.15	422.01	128.86	56642

Q_{loss} = 56672-56642 = 30 Kj

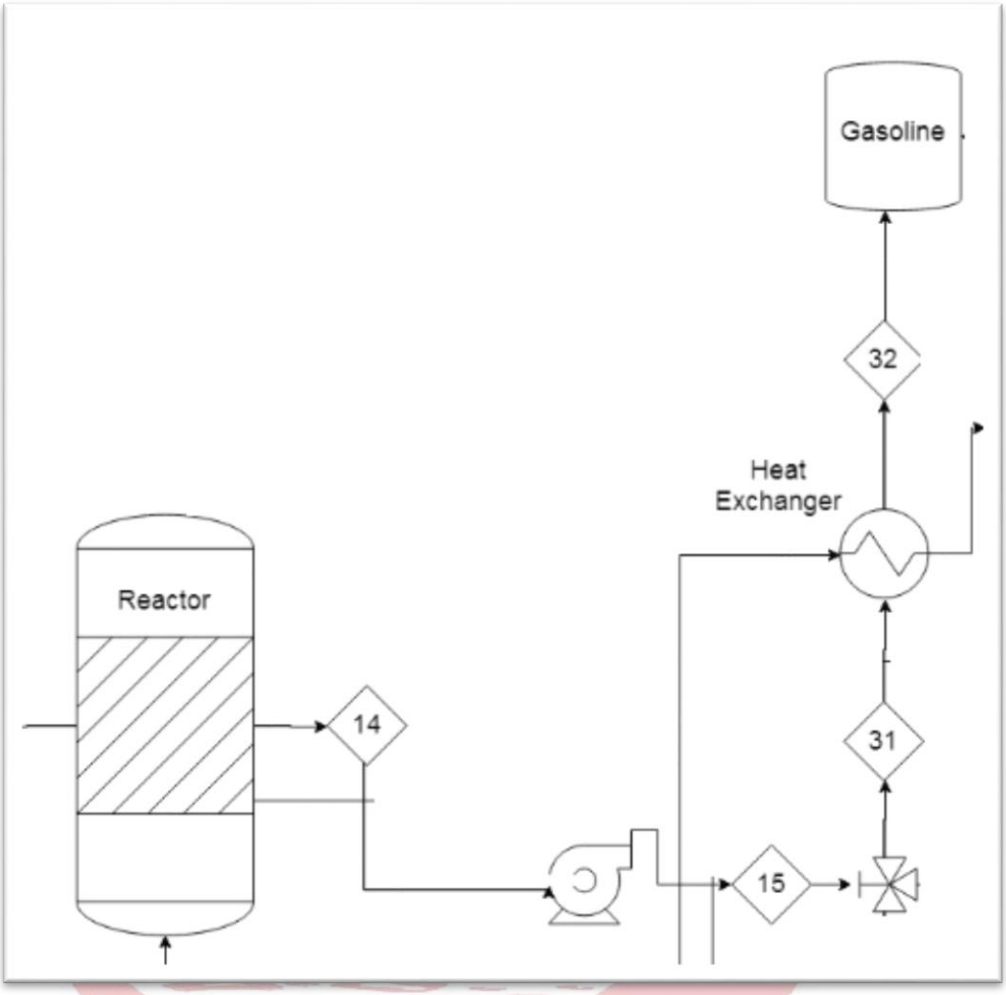
Exchanger for Diesel:



Material	Mass (kg)	Cp (kJ/kg.k)	T_1 (K)	T_2 (K)	ΔT (K)	Q (kJ)
Diesel	140	1.86	493	343.15	149.85	39020.94
Water	48.1	4.22	293.15	485.928	192.778	39130.464

Q_{loss} =39130.464 -39020.94 = 109.5 Kj

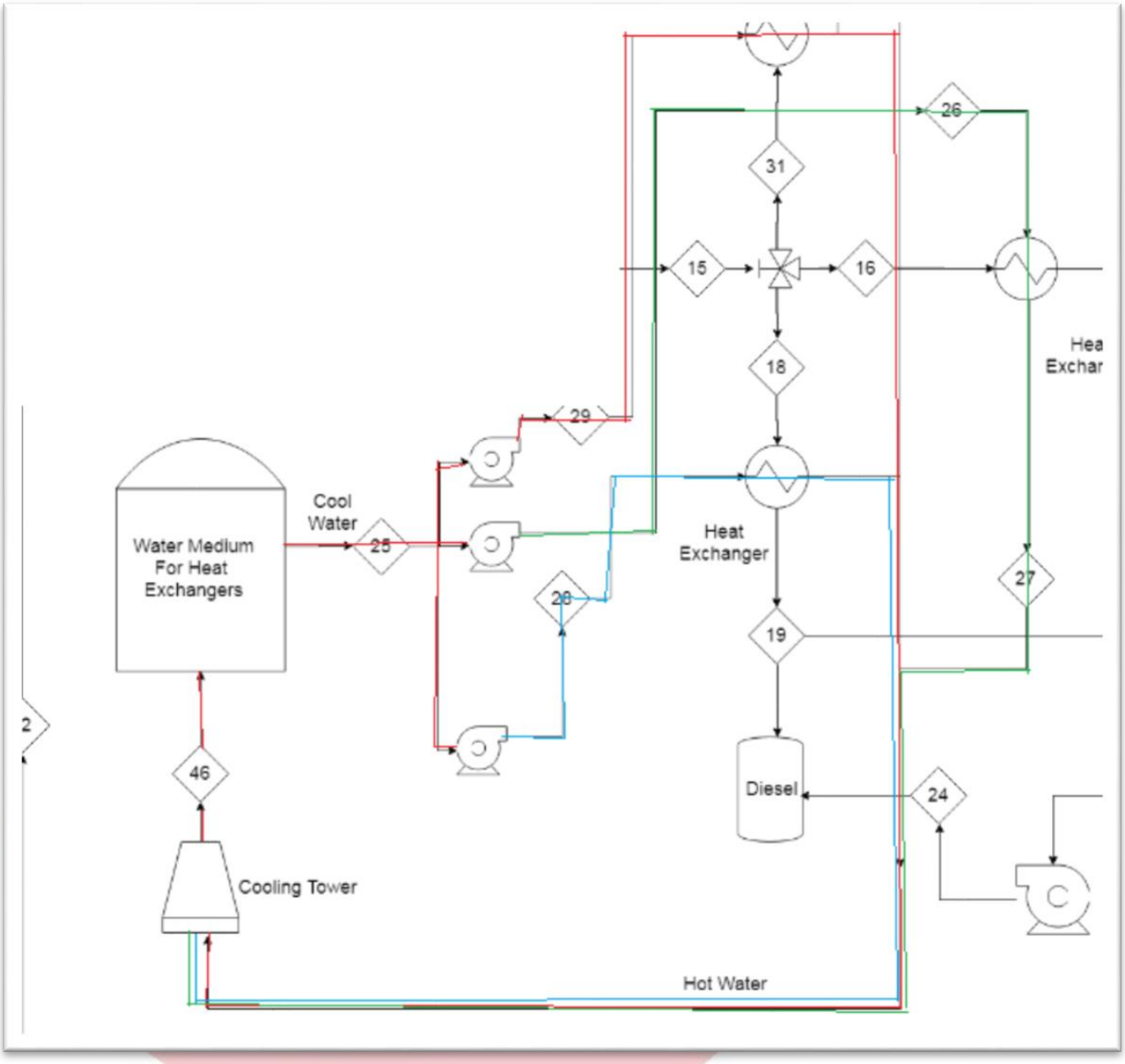
Exchanger for Gasoline:



Material	Mass (kg)	Cp (kJ/kg.k)	T_1 (K)	T_2 (K)	ΔT (K)	Q (kJ)
Gasoline	390.089	1.94	433.15	308.15	125	94575
Water	224.256	4.18	293.15	394.261	101.11	95203

Q_{loss} = 95203 - 94575 = 628 Kj

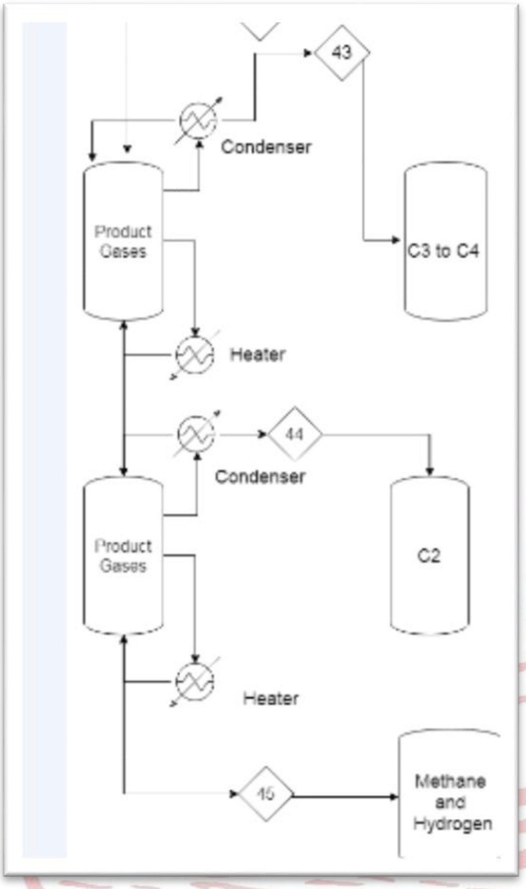
10. Heat absorbed by cold water discharged from Heat exchangers:



Stream	Mass (kg)	Cp (kJ/kg.k)	ΔT (K)	Q (kJ)
1	105.16	4.1868	128.86	56642
2	48.1	4.22	192.778	39130.464
3	224.256	4.18	101.11	95203

Q = 56642 +39130.464+95203 = 190975.464 Kj heat required to absorbed by cooling tower.

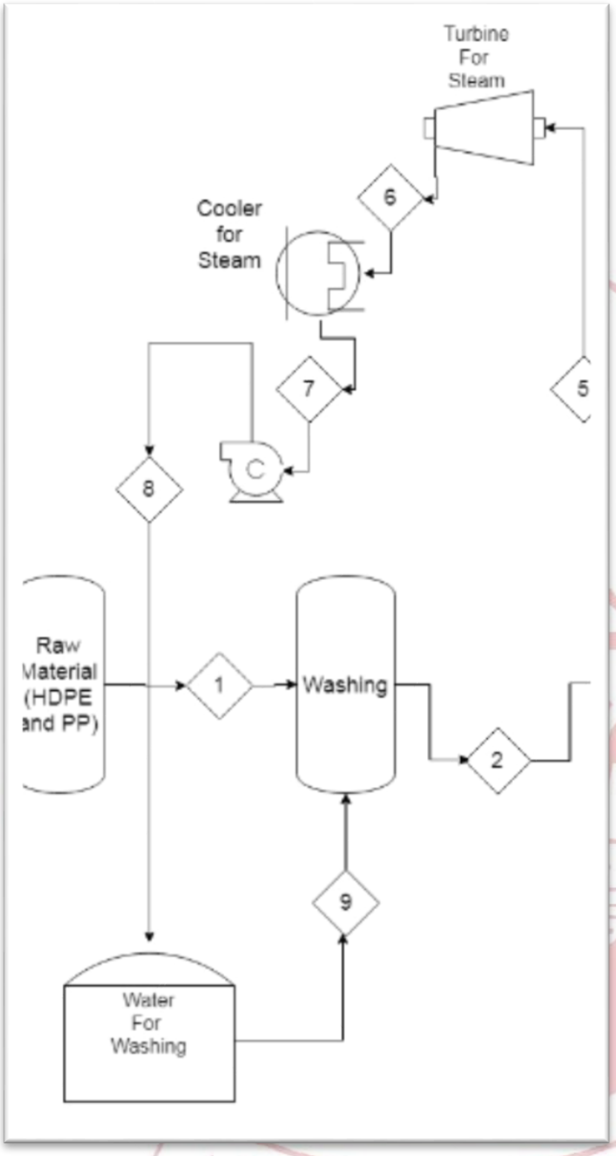
11. For condensation of LPG:



Material	Mass (kg)	Cp (kJ/kg.k)	ΔT (K)	Q (kJ)
LPG	190	1.68	258	82353.6

There will be 82353.6 Kj of heat absorbed from LPG.

12. Condensation of steam:



Material	Mass (kg)	Cp (kJ/kg.k)	ΔT (K)	Q (kJ)
Water	1000	4.19	80	335200

Chapter # 5 Design of Equipment

(Prepared by Altamash and Muhammad Kaamil Arif)

1. Design of Reactor:

Radius of fixed reactor can be find out by formula:
Also
$V_r = V_c/ (1- \text{Voidage})$
Here Voidage is 0.82 and Volume of Catalyst is 0.1163 m^3
So,
$V_r = 0.1163/ (1- 0.82)$
$V_r = 0.646\ m^3$
Now for Length and Diameter of Reaction
L= 3D
So Formula $V_r = (\pi/4) *D^2L$
Becomes
$V_r = (\pi/4) *D^2.3D$
We know that volume of reactor is 0.646 m^3
So,
$0.646\ m^3 = (\pi/4) *D^2.3D$
$0.646\ m^3 = (\pi/4) *3D^3$
$0.646\ m^3 = (\pi/4) *3D^3$
$0.646\ m^3 = 2.355D^3$
$D^3 = 0.27413\ m^3$
$D = (0.27413\ m^3)^{1/3}$
D = 0.65 m
And Length is L = 3D so,
L = 3*0.65
L = 1.95 m

2. Design of Pumps:

For this we required power of pumps and for this we used Formula,

$g.\Delta z + \Delta P/\rho - \Delta P_f/\rho - W = 0$

Where,
g is acceleration due to gravity
Δz is difference in elevation $(Z_1 – Z_2)$
ΔP is difference in system pressures $(P_1 – P_2)$
ΔP_f is pressure drop due to friction, including miscellaneous losses, and equipment losses.
ρ is liquid density
W is work done by Pump

$\Delta P_f = 8flv^2\ \gamma /2d$
Here,

f = friction factor
l = length of pipe
v = velocity of fluid
d = is inner diameter of pipe
γ = specific weight

Power = (W*M)/n
W = power required by pump
M = mass flow rate
N = efficiency

- Calculation for Gasoline pump:

First for pressure drop due to friction, including miscellaneous losses, and equipment losses
$\Delta P_f = 8flv^2\ \rho/2d$
$\Delta P_f = 8\ (64/N_{Re})\ (1.94m)\ (0.04m/s^2)^2\ (800\ Kg/m^3)\ /2(0.0068326m)$
$N_{Re} = 64/965.5 = 0.066$
$\Delta P_f = 8\ (0.066)\ (1.94m)\ (0.04m/s^2)^2\ (800\ Kg/m^3)\ /2(0.0068326m)$
$\Delta P_f = 95.94\ N/m^2$

$g.\Delta z + \Delta P/\rho - \Delta P_f/\rho - W = 0$
$(9.8\ m/s^2).(1.90m-1m) + (60000\ N/m^2/800\ Kg/m^3) – (95.94\ N/m^2\ /800\ Kg/m^3) – W = 0$
8.82 + 75 – 0.119 = W
W = 83.7 J/kg

Power = (W*M)/n
Power = (83.701 j/kg*390 kg/hr)/0.7
Power = 46633 Watt or 46.33 KW or 62.13 hp.

- Calculation for Diesel pump:

First for pressure drop due to friction, including miscellaneous losses, and equipment losses
$\Delta P_f = 8flv^2\ \rho/2d$
$\Delta P_f = 8\ (64/N_{Re})\ (1.94m)\ (0.02m/s^2)^2\ (850\ Kg/m^3)\ /2(0.0068326m)$
$N_{Re} = 64/135.07 = 0.47$
$\Delta P_f = 8\ (0.47)\ (1.94m)\ (0.02m/s^2)^2\ (850\ Kg/m^3)\ /2(0.0068326m)$
$\Delta P_f = 181.48\ N/m^2$

$g.\Delta z + \Delta P/\rho - \Delta P_f/\rho - W = 0$
$(9.8\ m/s^2).(1.90m-1m) + (56000\ N/m^2/850\ Kg/m^3) – (181.48\ N/m^2\ /850\ Kg/m^3) – W = 0$
8.82 + 65.88 – 0.21 = W
W = 74.5 J/kg

Power = (W*M)/n
Power = (74.5 j/kg*140 kg/hr)/0.7

Power = 14900 Watt or 14.7 KW or 20 hp.

- <u>Calculation for Kerosene pump:</u>

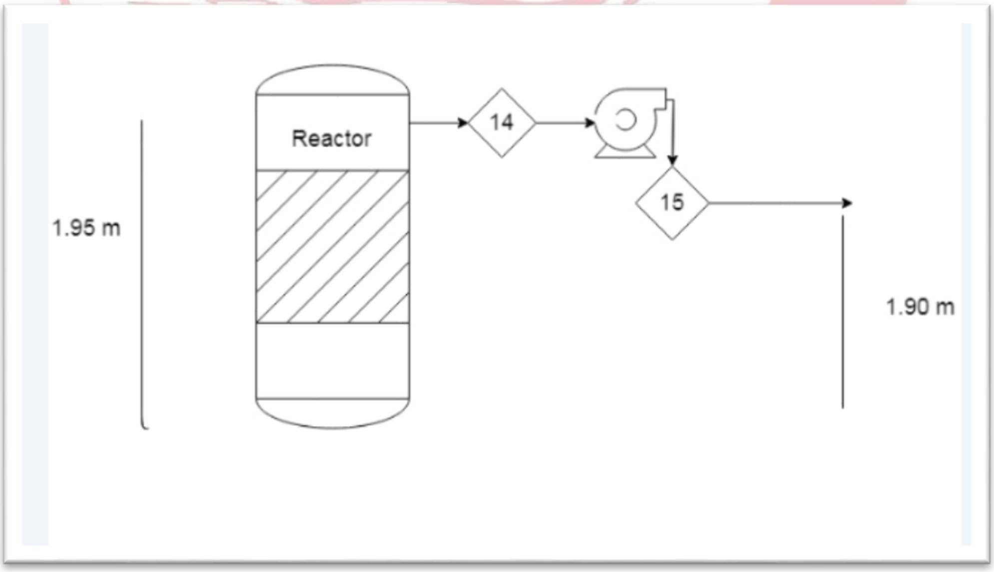
First for pressure drop due to friction, including miscellaneous losses, and equipment losses
$\Delta P_f = 8flv^2 \rho /2d$
$\Delta P_f = 8 (64/N_{Re}) (1.94m) (0.03m/s^2)^2 (810 Kg/m^3) /2(0.0068326m)$
$N_{Re} = 64/550 = 0.116$
$\Delta P_f = 8 (0.116) (1.94m) (0.03m/s^2)^2 (810 Kg/m^3) /2(0.0068326m)$
$\Delta P_f = 96.042 N/m^2$

$g.\Delta z + \Delta P/\rho - \Delta P_f/\rho - W = 0$
$(9.8 m/s^2).(1.90m-1m) + (56000 N/m^2/810 Kg/m^3) – (96.042 N/m^2 /810 Kg/m^3) – W = 0$
$8.82 + 69.2 – 0.11 = W$
$W = 77.9 J/kg$

Power = (W*M)/n
Power = (77.9 j/kg* 220kg/hr)/0.7

Power = 24482.85 Watt or 24.48 KW or 32.82 hp

Maximum power required here is 61.687 hp.



3. Design of Heat Exchanger:

- Heat Exchanger for Gasoline:

LMTD:

LMTD=Δt= $(\Delta t_1 - \Delta t_2)/\ln(\Delta t_1/\Delta t_2)$
LMTD=Δt= [(320-250)-(95-68)]/ln[(320-250)/(95-68)]
LMTD=Δt= 45.13

Calorific Temperature:

$\Delta t_c/\Delta t_h$ = (95-68)/(320-250) = 0.38
K_c = 0.14
F_c = 0.38
(From Appendix A5)

T_c = 95 F + 0.38 (32 F—95 F) = 180.5 F
t_c = 68 F + 0.38 (250 F – 68 F) = 137.16 F

Heat and Mass Balance:

Here hot stream is Gasoline and cold stream is water:
WC ΔT for Gasoline and wc Δt for water
We know that WC ΔT= wc Δt = Q

$WC_p \Delta T = wc_p \Delta t$

W is mass flow rate of Hot stream and w is mass flow rate of cold stream
C_p specific heat coefficient at constant temperature for hot stream and c_p is specific heat coefficient at constant temperature for cold stream
ΔT is temperature change for hot stream and Δt is temperature change for cold stream

Value of C_p and c_p can be find out at 180.5 F and 137.16 F
(From Appendix A8)

(860 lb/hr)(0.465 Btu/lb.F)(320 F – 95 F) = w(1Btu/lb.F)(250F-68F)
w= 494.4 lb/hr is mass flow rate of water required

Number of Tubes:

For number of tubes we required are of heat exchange
$Q = U_D A \Delta t$

Q is Heat exchanged
U_D is Dirt Coefficient
A is Area required
Δt is Log mean temperature

From
WC ΔT= wc Δt = Q = 90000 Btu/lb.
U_D is assumed 88 Btu/hr.ft^2.F (From Appendix A1)

A is to find out in ft^2
And Δt is 45.13

90000 Btu/lb = (88 Btu/hr.ft^2.F).A.(45.13)
A = 22.66 ft^2

Number of Tubes required = Area / Length of tube x Surface per lin ft (outside)
Number of Tubes required = 22.66 ft^2 / 4 ft x 0.3271 ft
Number of Tubes required = 11.54 which means 12 tubes are required

Shell diameter is 10 in
Tube outer diameter is 11/4 and 19/16 sq. Pinch
2 passes, BWG is 14 and 8 in Baffles.
(From Appendix A3)

For Clean Coefficient,
$1/U_c = (1/U_D) - R_d$
Suppose R_d is 0.002 (From Appendix A1)
So Uc we get is 106.8 Btu/hr.ft^2.F

s.no	Shell Side (Gasoline)	Tube Side (Water)
1	Flow area: $a_t = (ID \times C'' \times B)/(144 \times P_r)$ a_t = (10in x 0.3125 x 8in)/ (144 x 1.5625) a_t = 0.11 ft^2	Flow area: $a_t = (N_t \times a_t')/(144 \times n)$ a_t = (12 x 0.923 in^2)/ (144 x 2) a_t = 0.04 ft^2 From a_t' = 0.923 in^2 (From Appendix A3) Tube inner dia is 1.08 in

		Weight per lin ft is 1.13 lb steel Wall thickness is 0.083 in Surface per lin ft (inside) = 0.2839 ft
2	Mass Velocity: $G_a = W/a_t$ $G_a = (860 lb/hr)/ 0.11 ft^2$ $G_a = 7818.18 lb/hr.ft^2$	Mass Velocity: $G_a = W/a_t$ $G_a = (494.4 lb/hr)/ 0.04 ft^2$ $G_a = 12360 lb/hr.ft^2$
3	Reynold's number: $R_e = (D_e. Ga)/\mu$ Where μ is find out at 180.5 F (From Appendix A6) D_e can be find out from (From Appendix A9) $R_e = [(1.23 in/12).(7818.6 lb/hr.ft^2)]/(0.83 lb/hr.ft)$ $R_e = 965.5$	Reynold's number: $Re=(D_e.G_a)/\mu$ Where μ is find out at 137.16 F (From Appendix A6) $R_e = [(1.08 in/12).(12360 lb/hr.ft^2)]/(1.23 lb/hr.ft)$ $R_e = 904.4$
	Pressure drop	
4	$R_e = 965.5$ $f = 0.0035 ft^2/in^2$ (From Appendix A4) number of crosses = 12 L/B number of crosses = 12 x4/8 number of crosses = 6 $\Delta P = (f \times Ga^2 \times D_e \times \text{No of crosses})/(5.22e10 \times D \times s \times \Phi)$ S can be find out by (From Appendix A7) Putting values in formulae we get $\Delta P = (0.0035^2 \times 7818.6^2 \times 0.833 \times 6)/ (5.22e10 \times 0.1025 \times 0.78 \times 1)$ $\Delta P = 2.56e\text{-}4$ Psia or $1.77 N/m^2$	$R_e = 904.4$ $f = 0.0038 ft^2/in^2$ (From Appendix A4) $\Delta P = (f \times Ga^2 \times L \times \text{No of passes})/(5.22e10 \times D \times s \times \Phi)$ S can be find out by (From Appendix A7) Putting values in formulae we get $\Delta P_1 = (0.0038 \times 12360^2 \times 4 \times 2)/(5.22e10 \times 0.09 \times 1 \times 1)$ $\Delta P_1 = 9.88e\text{-}4$ Psia $\Delta P_2 = (4n/s) \times (v^2/2g)$ $\Delta P_2 = (4x2/1) \times (0.055 lb/hr^2/2x32.2 ft/hr^2)$ $\Delta P_2 = 3.74e\text{-}4$ Psia $\Delta P = \Delta P_1 + \Delta P_2$

		ΔP = 9.88e-4 Psia + 3.74e-4 Psia ΔP = 1.362e-3 Psia or 10.15 N/m^2

Heat Exchanger Specification:

Inner diameter of Shell = 10 in
Inner Diameter of Tube = 1.08 in^2
Weight per lin ft is 1.13 lb steel
Outer Diameter of Tube = Tube outer diameter is 11/4 and 19/16 sq. Pinch
Area of Shell = 0.11 ft^2
Area of Tube = 0.04 ft^2
Number of Tubes = 12
Number of Passes = 2
BWG = 14
Baffles Distance = 8 in
Wall Thickness of Tubes = 0.083 in
Weight per Length of tube = 1.13 lb steel
Length of Pipe = 4 ft
Surface per lin ft (inside) = 0.2839 ft
Surface per lin ft (outside) = 0.3271 ft
Dirt Coefficient = 88 Btu/hr.ft^2.F
Clean Coefficient = 106.8 Btu/hr.ft^2.F
Dirt factor = 0.002
Allowable Pressure = 67.2 Psia

- Heat Exchanger for Kerosene:

LMTD:

LMTD=Δt= $(\Delta t_1 - \Delta t_2)/\ln(\Delta t_1/\Delta t_2)$
LMTD=Δt= [(374-300)-(122-68)]/ln[(374-300)/(122-68)]
LMTD=Δt= 48.82

Calorific Temperature:

$\Delta t_c/\Delta t_h$ = (122-68)/(374-300) = 1.37
K_c = 0.3
F_c = 0.52
(From Appendix A5)

T_c = 122 F + 0.52 (374 F—122 F) = 253.04 F
t_c = 68 F + 0.52 (300 F – 68 F) = 188.64 F

Heat and Mass Balance:

Here hot stream is Kerosene and cold stream is water:
WC ΔT for Kerosene and wc Δt for water
We know that WC ΔT= wc Δt = Q

WC_p ΔT= wc_p Δt

W is mass flow rate of Hot stream and w is mass flow rate of cold stream
C_p specific heat coefficient at constant temperature for hot stream and c_p is specific heat coefficient at constant temperature for cold stream
ΔT is temperature change for hot stream and Δt is temperature change for cold stream

Value of C_p and c_p can be find out at 253.04 F and 188.64 F
(From Appendix A8)

(485.1 lb/hr)(0.448 Btu/lb.F)(374 F – 122 F) = w(1Btu/lb.F)(300F-68F)
w= 231.84 lb/hr is mass flow rate of water required

Number of Tubes:

For number of tubes we required are of heat exchange
Q = U_D A Δt

Q is Heat exchanged
U_D is Dirt Coefficient
A is Area required
Δt is Log mean temperature

From
WC ΔT= wc Δt = Q = 53787.88 Btu/lb.
U_D is assumed 40 Btu/hr.ft^2.F (From Appendix A1)

A is to find out in ft^2
And Δt is 49

54000 Btu/lb = (40 Btu/hr.ft^2.F).A.(49)
A = 27.55 ft^2

Number of Tubes required = Area / Length of tube x Surface per lin ft (outside)
Number of Tubes required = 27.55 ft^2 / 6 ft x 0.3925 ft
Number of Tubes required = 11.69 which means 12 tubes are required

Shell diameter is 12 in
Tube outer diameter is 11/2 and 17/8 sq. Pinch
4 passes, BWG is 12 and 6 in Baffles.
(From Appendix A3)

For Clean Coefficient,
$1/U_c = (1/U_D) - R_d$
Suppose R_d is 0.003(From Appendix A1)

So Uc we get is 45.5 Btu/hr.ft^2.F

s.no	Shell Side (Kerosene)	Tube Side (Water)
1	Flow area: a_t = (ID x C'' x B)/ (144 x P_r) a_t = (12in x 0.375 x 6 in)/ (144 x 0.875) a_t = 0.1 ft^2	Flow area: a_t = (N_t x a_t')/ (144 x n) a_t = (12 x 1.29 in^2)/ (144 x 4) a_t = 0.027 ft^2 From a_t' = 1.29 in^2 (From Appendix A3) Tube inner dia is 1.28 in Weight per lin ft is 1.77 lb steel Wall thickness is 0.109 in Surface per lin ft (inside) = 0.3356 ft
2	Mass Velocity: G_a = W/ a_t G_a = (485.1lb/hr)/ 0.1 ft^2 G_a = 4851 lb/hr.ft^2	Mass Velocity: G_a = W/ a_t G_a = (231.84lb/hr)/ 0.027 ft^2 G_a = 8586.667 lb/hr.ft^2
3	Reynold's number: R_e= (D_e. Ga)/μ Where μ is find out at 253.04 F (From Appendix A6) D_e can be find out from (From Appendix A9)	Reynold's number: Re=(D_e.G_a)/ μ Where μ is find out at 188.64 F (From Appendix A6) R_e= [(1.28 in/12). (8586.667 lb/hr.ft^2)]/(0.8lb/hr.ft) R_e= 1144.88

	R_e= [(1.48 in/12).(4851 lb/hr.ft^2)]/(1.085lb/hr.ft) R_e= 550	
	Pressure drop	
4	R_e= 550 f= 0.004 ft^2/in^2 (From Appendix A4) number of crosses = 12 L/B number of crosses = 12 x6/6 number of crosses = 12 ΔP= (f x Ga^2 x D_e x No of crosses)/ (5.22e10 x D x s x Φ) S can be find out by (From Appendix A7) Putting values in formulae we get ΔP= (0.004^2 x 4851^2 x 1 x 12)/ (5.22e10 x 0.123 x 0.7 x 1) ΔP= 2.51e-4 Psia or 1.73 N/m^2	R_e= 1144.88 f= 0.0033 ft^2/in^2 (From Appendix A4) ΔP= (f x Ga^2 x L x No of passes)/ (5.22e10 x D x s x Φ) S can be find out by (From Appendix A7) Putting values in formulae we get ΔP_1= (0.0033 x 8586.667^2 x 6 x 4)/ (5.22e10 x 0.10667 x 1 x 1) ΔP_1 = 1.048e-3 Psia ΔP_2 = (4n/s) x(v^2/2g) V = Ga/3600ρ = 0.04 fps ΔP_2 = (4x4/1) x (0.04 fps)^2/(2x32.2ft/hr^2) ΔP_2 = 3.975e-4 Psia ΔP = ΔP_1 + ΔP_2 ΔP = 1.048e-3 Psia + 3.975e-4 Psia ΔP = 1.44e-3 Psia or 1 N/m^2

<u>Heat Exchanger Specification:</u>

Inner diameter of Shell = 12 in

Inner Diameter of Tube = 1.28 in

Weight per lin ft is 1.77 lb steel

Outer Diameter of Tube = Tube outer diameter is 11/2 and 17/8 sq. Pinch

Area of Shell = 0.1 ft^2

Area of Tube = 0.027 ft^2

Number of Tubes = 12

Number of Passes = 4

BWG = 12
Baffles Distance = 6 in
Wall Thickness of Tubes = 0.109 in
Weight per Length of tube = 1.77 lb steel
Length of Pipe = 6 ft
Surface per lin ft (inside) = 0.3356 ft
Surface per lin ft (outside) = 0.3925 ft
Clean Coefficient = 45.5 Btu/hr.ft^2.F
Dirt Factor = 0.003
Dirt Coefficient = 40 Btu/hr.ft^2.F
Allowable Pressure is 55.86 Psia

- Heat Exchanger for Diesel:

LMTD:

$LMTD=\Delta t= (\Delta t_1 - \Delta t_2)/\ln(\Delta t_1/ \Delta t_2)$
$LMTD=\Delta t= [(428-415)-(158-68)]/\ln[(428-415)/(158-68)]$
$LMTD=\Delta t= 39.8$

Calorific Temperature:

$\Delta t_c/\Delta t_h = (158-68)/(428-415) = 6.9$
$K_c = 0.88$
$F_c = 0.425$
(From Appendix A5)

T_c = 158 F + 0.425 (428 F—158 F) = 272.75 F
t_c = 68 F + 0.425 (415 F – 68 F) = 215.475 F

Heat and Mass Balance:

Here hot stream is Diesel and cold stream is water:
WC ΔT for Diesel and wc Δt for water
We know that WC ΔT= wc Δt = Q

$WC_p \Delta T= wc_p \Delta t$

W is mass flow rate of Hot stream and w is mass flow rate of cold stream
C_p specific heat coefficient at constant temperature for hot stream and c_p is specific heat coefficient at constant temperature for cold stream

ΔT is temperature change for hot stream and Δt is temperature change for cold stream

Value of C_p and c_p can be find out at 272.75 F and 215.475 F (From Appendix A8)

(308.71 lb/hr)(0.445 Btu/lb.F)(428 F – 158 F) = w(1.01 Btu/lb.F)(415F-68F)

w= 105.8 or 106 lb/hr is mass flow rate of water required

<u>Number of Tubes:</u>

For number of tubes we required are of heat exchange

$Q = U_D A \Delta t$

Q is Heat exchanged

U_D is Dirt Coefficient

A is Area required

Δt is Log mean temperature

From

WC ΔT= wc Δt = Q = 37100 Btu/lb.

U_D is assumed 75 Btu/hr.ft^2.F(From Appendix A1)

A is to find out in ft^2

And Δt is 39.8

37100 Btu/lb = (75 Btu/hr.ft^2.F).A.(39.8)

A = 12.48 0r 13 ft^2

Number of Tubes required = Area / Length of tube x Surface per lin ft (outside)

Number of Tubes required = 13 ft^2 / 3 ft x 0.3925 ft

Number of Tubes required = 11.69 which means 12 tubes are required

Shell diameter is 12 in

Tube outer diameter is 1 1/2 and 1 7/8 sq. Pinch

4 passes, BWG is 11 and 3 in Baffles.

(From Appendix A3)

For Clean Coefficient,

$1/U_c = (1/U_D) - R_d$

Suppose R_d is 0.003(From Appendix A1)

So Uc we get is 96.77 Btu/hr.ft^2.F

s.no	Shell Side (Diesel)	Tube Side (Water)
1	Flow area: a_t = (ID x C'' x B)/ (144 x P_r) a_t = (12in x 0.375 x 3 in)/ (144 x 0.875) a_t = 0.05 ft^2	Flow area: a_t = (N_t x a_t')/ (144 x n) a_t = (12 x 1.29 in^2)/ (144 x 4) a_t = 0.026 ft^2 From a_t' = 1.25 in^2 (From Appendix A3) Tube inner dia is 1.26 in Weight per lin ft is 1.98 lb steel Wall thickness is 0.120 in Surface per lin ft (inside) = 0.3299 ft
2	Mass Velocity: G_a = W/ a_t G_a = (308.711lb/hr)/ 0.05 ft^2 G_a = 6147.2 lb/hr.ft^2	Mass Velocity: G_a = W/ a_t G_a = (105.8lb/hr)/ 0.026 ft^2 G_a = 4069.61 lb/hr.ft^2
3	Reynold's number: R_e= (D_e. Ga)/µ Where µ is find out at 272.75 F (From Appendix A6) D_e can be find out from (From Appendix A9) R_e= [(1.08 in/12).(6174.2 lb/hr.ft^2)]/(4.114 lb/hr.ft) R_e= 135.07	Reynold's number: Re=(D_e.G_a)/ µ Where µ is find out at 215.475 F (From Appendix A6) R_e= [(1.26 in/12).(4069.61lb/hr.ft^2)]/(0.605 lb/hr.ft) R_e= 706.29
	Pressure drop	
4	R_e= 135.07 f= 0.0055 ft^2/in^2 (From Appendix A4) number of crosses = 12 L/B number of crosses = 12 x3/3 number of crosses = 12 ΔP= (f x Ga^2 x D_e x No of crosses)/ (5.22e10 x D x s x Φ) S can be find out by	R_e= 706.29 f= 0.004 ft^2/in^2 (From Appendix A4) ΔP= (f x Ga^2 x L x No of passes)/ (5.22e10 x D x s x Φ) S can be find out by (From Appendix A7) Putting values in formulae we get

	(From Appendix A7) Putting values in formulae we get ΔP= $(0.0055^2 \times 2885.14^2 \times 1 \times 12)/(5.22e10 \times 0.09 \times 0.89 \times 1)$ ΔP= 1.314e-4 Psia or 2.16 N/m^2	$\Delta P_1 = (0.004 \times 4069.61^2 \times 3 \times 4)/(5.22e10 \times 0.105 \times 1 \times 1)$ ΔP_1 = 1.450e-4 Psia $\Delta P_2 = (4n/s) \times (v^2/2g)$ V = Ga/3600ρ = 0.018 fps $\Delta P_2 = (4 \times 4/1) \times (0.018\ fps)^2/(2 \times 32.2 ft/hr^2)$ ΔP_2 = 8.05e-5 Psia $\Delta P = \Delta P_1 + \Delta P_2$ ΔP = 1.450e-3 Psia + 8.05e-4 Psia ΔP = 2.25e-4 Psia or 1.55 N/m^2

Heat Exchanger Specification:

Inner diameter of Shell = 12 in
Inner Diameter of Tube = 1.26 in
Weight per lin ft is 1.98 lb steel
Outer Diameter of Tube = Tube outer diameter is 11/2 and 17/8 sq. Pinch
Area of Shell = 0.05 ft^2
Area of Tube = 0.0260 ft^2
Number of Tubes = 12
Number of Passes = 4
BWG = 11
Baffles Distance = 3 in
Wall Thickness of Tubes = 0.120 in
Weight per Length of tube = 1.98 lb steel
Length of Pipe = 3 ft
Surface per lin ft (inside) = 0.3299 ft
Surface per lin ft (outside) = 0.3925 ft
Clean Coefficient = 96.77 Btu/hr.ft^2.F
Dirt Factor = 0.003
Dirt Coefficient = 75 Btu/hr.ft^2.F
Allowable Pressure is 40 Psia

Chapter # 6 Cost Estimation

(Prepared by Muhammad Kaamil Arif and Altamash)

1. Cost of Reactor:

   Equation we are using here is,

   $C_e = a + b.S^n$

   According to 2010:

a	b	S	n	C_e
61500	32500	0.65 m^3	0.8	84525.76 $

   Now,

   Cost of Equipment in Year 2021 = Cost of equipment in year 2010 x (Cost Index of Year 2021/Cost Index of Year 2010)

   Cost of Equipment in Year 2021 = 84525.76 x (717.8/740.0)

   Cost of Equipment in Year 2021 = 81989.99 $ or 82000$

2. Cost of Heat Exchangers:

   From Graph in Appendix

   Cost of heat exchanger in 2010 is 13000$

   So,

   Cost of Equipment in Year 2021 = Cost of equipment in year 2010 x (Cost Index of Year 2021/Cost Index of Year 2010)

   Cost of Equipment in Year 2021 = 13000 x (405.95/418.5)

   Cost of Equipment in Year 2021 = 12610 $

3. Cost of storage tanks:

   Equation we are using here is,

   $C_e = a + b.S^n$

   According to 2010:

a	b	S	n	C_e
1700	2900	50 m^3	0.55	26636.27 $

   Now,

Cost of Equipment in Year 2021 = Cost of equipment in year 2010 x (Cost Index of Year 2021/Cost Index of Year 2010)

Cost of Equipment in Year 2021 = 26636.27 x (630.306/649.8)

Cost of Equipment in Year 2021 = 25837.1824$

4. Cost of Dryer:

Equation we are using here is,
$C_e = S^n .C$

According to 2010:

C	S	n	C_e
11500 $	5	0.45	23726.5 $

Now,
Cost of Equipment in Year 2021 = Cost of equipment in year 2010 x (Cost Index of Year 2021/Cost Index of Year 2010)

Cost of Equipment in Year 2021 =23726.5 x (541.745/558.5)

Cost of Equipment in Year 2021 = 23014.7 $

5. Cost of vessel 1 and 2:

Equation we are using here is,
$C_e = a + b.S^n$

- According to 2010:

a	b	S	n	C_e
-10000	600	120	0.6	608.64 $

Now,
Cost of Equipment in Year 2021 = Cost of equipment in year 2010 x (Cost Index of Year 2021/Cost Index of Year 2010)

Cost of Equipment in Year 2021 = 608.64 x (630.306/649.8)

Cost of Equipment in Year 2021 = 590.38$

- According to 2010:

a	b	S	n	C_e

-10000	600	300	0.6	8383.3 $

Now,
Cost of Equipment in Year 2021 = Cost of equipment in year 2010 x (Cost Index of Year 2021/Cost Index of Year 2010)

Cost of Equipment in Year 2021 = 8383.3 x (630.306/649.8)

Cost of Equipment in Year 2021 = 8131.822 $

6. Cost of pumps:
   $Cp = 705.48 \times Wp^{0.71} (1 + 0.2/ \text{Efficiency})$
   $Cp = 705.48 \times 62.65^{0.71} (1 + 0.2/ 0.7)$
   Cp = 20838.74713 $
   Cost of Equipment in Year 2021 = Cost of equipment in year 2010 x (Cost Index of Year 2021/Cost Index of Year 2010)
   Cost of Equipment in Year 2021 = 20838.74713 x (1069.2/1037.24)
   Cost of Equipment in Year 2021 = 26564.3 $

   Similarly, for pump 2 at power 19.71302 hp at efficiency 70% we get cost 2413.6375 $

Cost of Equipment and Quantities:

S.no	Name of Equipment	Quantity	Cost ($)
1	Reactor	1	82000
2	Heat Exchangers	3	37830
3	Pump 1	1	26564.3
4	Pump 2	8	19309.1
5	Storage Tank	8	206697.5
6	Vessel 1	6	3542.28
7	Vessel 2	5	40660
8	Dryer	2	46029.4
9	Crusher	1	14872.9
10	Cooler	1	18744.40
11	Condenser	1	10402.55
12	Total	-	506652.408

Direct Cost:

S.no	Components	Cost $	Considering %	Range
1	Purchased Equipment	506652.408	100	-

2	Instrumentation	126663.103	25	6 to 30 %
3	Piping	227997.862	45	10 to 80 %
4	Electrical facilities	75997.8615	15	24 %
5	Building	126663.103	25	10 to 70 %
6	Service facilities	303991.446	60	40 to 80 %
7	Land/Property	60798.3	12	-
8	Total	1428760	-	-

Indirect Cost:

S.no	Component	% Equipment	Total Cost $
1	Construction	38	192527.9
2	Contingency	36	182394.86
3	Contractor Fees	22	111463.53
4	Design and Engineering	40	202660.964
5	Total	-	689047.254

Fixed Capital Investment (FCI) = Direct Cost + Indirect Cost
Fixed Capital Investment (FCI) = 1428760 $ + 689047.254 $
Fixed Capital Investment (FCI) = 2117807.254 $

Working Capital Investment (WCI) = 20% of FCI
Working Capital Investment (WCI) = 423561.4508 $

Total Capital Investment (WCI) = WCI + FCI
Total Capital Investment (WCI) = 423561.4508 $ + 2117807.254 $
Total Capital Investment (WCI) = 2541368.7 $
Total production cost:

S.no	Raw Material	Mass Consumed/ batch in Kg	Cost per kg, $	Cost per year, $
1	HDPE	200	0.367	24222
2	PP	800	0.267	70488
3	USY Zeolite	100	13.34	440220
4	Biodiesel	12	13.5	53460
5	Ethanol	98	4.04	130653.6
6	-	-	-	719043.6

Variable Cost:

S.no	Components	% Consideration	Cost, $
1	Raw Material	100	719043.6
2	Miscellaneous Material	12% of maintenance	25413.7
3	Utilities	16 % of FCI	338849.16
4	Total	-	1683306.46

Fixed Cost:

S.no	Components	% Consideration	Cost, $
1	Maintenance	10% of FCI	211780.7254
2	Royalties	2% of FCI	42356.145
3	Local Taxes	3% of FCI	63534.21762
4	Capital Changes	25% of FCI	529451.8135
5	Insurance	2% of FCI	42356.145
6	Total	-	889479.04

General Expenses:

S.no	Components	% Consideration	Cost, $
1	Financing	12% of FCI	304964.244
2	Administration Cost	10% of FCI	254136.87
3	Total	-	559101.114

Total Product Cost = Variable Cost + Fixed Cost + General Expenses
Total Product Cost = 1683306.46 $ + 889479.04 $ + 559101.114 $
Total Product Cost = 3131886.614 $

Our Profit = TPC/ Product per year
Our Profit = 3131886.614 $/ (330 days x 990 kg)
Our Profit = 9.5864 $

Selling Prices:

S.no	Products	Quantity in m^3	Cost, $
1	Gasoline	0.4875	332.475
2	Diesel	0.188	132.728
3	Kerosene	0.308	147.224
4	Total	-	312.427

Profit = Selling price – Profit per year

Profit = 312.427 \$ - 9.5864 \$
Profit = 302.8406 \$

% Analysis = (302.8406 \$/312.427 \$) x 100
% Analysis = 96.93%

Gross Scale = TPC x Sell Price
Gross Scale =3131886.614 \$ x 9.5864 \$
Gross Scale = 30023517.84 \$

Gross Profit = Scale of gross – TMC
Gross Profit = 30023517.84 \$ – 2572785.5 \$
Gross Profit = 27450732.34 \$

Payout Period = Investment / Net cash flow
Payout Period = 3131886.614 \$ / 719043.6 \$
Payout Period = 4.35 years

Break Even analysis:

Variable Cost = 1683306.46 \$
Fixed Cost = 889479.04 \$
Variable Cost unit = 1683306.46 \$/330 days x990 kg
Variable Cost unit = 5.15 \$
Selling cost= 312.427 \$ x 330 days x 990 kg
Selling cost/unit = (10206990.9 \$/330 days) x 990 kg
Selling cost/unit = 312.427 \$

Breakeven point = Fixed cost / (Selling cost/unit - Variable Cost unit)
Breakeven point = 889479.04 \$/ (312.427 \$ - \$5.15 \$)
Breakeven point = 2894 \$

2894 \$ must be sold in order to get profit.

Depreciation:
D = (V- Vs)/ N
D = [2217807.254\$ -(2217807.254\$x5%)]/20 years
D = 100595.8446 \$

Gross Earning:
Capacity = 330000 ton/year
Selling price = 312.427 \$
Total income = 27.4 million dollars.

Chapter # 7 Market Analysis

(Prepared by Muhammad Azim Khan and Afnan)

Petroleum products are used across the entire economy in every country. Gasoline and Diesel are the primary fuels used in road transport. Kerosene is derived from petroleum and is used to fuel rocket engines, lighting fuel, and in industries such as chemicals and agriculture. It is also widely used as jet fuel to power aircrafts.

Our target of our project is to produce liquid fuels and study its sources, and application etc.

GASOLINE:

Gasoline is made when crude oil is broken into various petroleum products through a process of fractional distillation. The finished product is then distributed to gas stations through pipelines. Gasoline industry has grown robustly in the five years, though this growth is mostly regarded to recovered losses since the recession. In the upcoming years, petroleum prices are expected to increase as the global economy gains demand for fuel worldwide.

Regional segmentation of the global gasoline trading market can be done by identifying the major consumers of gasoline. Asia Pacific is one of the leading markets in gasoline trading. Rapid industrialization in countries such as India, China and Indonesia has augmented the demand for gasoline. Number of gasoline run vehicles has tremendously increased in India and China, which is one of the major factors driving the demand for gasoline in Asia Pacific Market. North America and Europe have also shown substantial growth, owing to the increased industrialization and rising number of vehicles. Rise in oil production particularly in Canada and the U.S. is another factor that has contributed towards the growth of this region.

APPLICATIONS OF GASOLINE:

Gasoline was discovered nearly 160 years ago as a byproduct of refining crude oil to make kerosene for lighting. There was no use for gasoline at the time. In 1911, gasoline outsold kerosene for the first time. It is used to power many heat engines, most importantly it acts as a fuel for a large proportion of cars.

U.S. consumers use gasoline in

- Cars, sport utility vehicles, light trucks, and motorcycles
- Recreational vehicles and boats, Small aircraft

TOP 10 GASOLINE PRODUCING COUNTRIES PER DAY

S.no	Country	Production (Thousand Barrels per Day)
1	United States	8,926.00
2	China	2,098.00
3	Japan	920.00
4	Russian Federation	893.00
5	India	704.00
6	Canada	687.00
7	Germany	479.00
8	Brazil	462.00
9	United Kingdom	407.00
10	Mexico	404.00

Pakistan ranked 56th in gasoline production per day.

- Equipment and tools used in construction, farming, forestry, and landscaping Electricity generators for portable and emergency power supply

KEROSENE

Kerosene is a flammable liquid mixture of chemicals that are produced in the distillation of crude oil. To produce kerosene, crude oil is distilled in a distillation tower in a process similar to that used to produce diesel and gasoline. It is a medium weight distillate in the refining process, and can be produced by distilling crude oil (here it is known as straight run kerosene) or by hydrocarbon cracking heavier petroleum (here it is known as cracked kerosene).

APPLICATIONS OF KEROSENE

Kerosene is a major component of aviation fuel, making up more than 60% of the fuel. In addition, it can be used as an oil in central heating systems and can be used as a cleaning agent. Although the use of kerosene in many places has decreased over the years as a result of improved access to electricity and natural gas, it is still used extensively in the developing world for cooking, heating, and lightening.
Kerosene is often seen as a good alternative to solid fuels, biomass, and coal and thus kerosene lanterns are used in places where access to electricity is not available.

HIGH SPEED DIESEL(HSD):

A liquid fuel used in diesel engines such as generators, trucks, military vehicles and marine vessels. The key characteristic of this fuel is the fuel ignition as a result of compression of the fuel with air. Diesel has a higher energy density; i.e. more energy can be extracted from diesel as compared with the same volume of gasoline. Diesel is heavier and oilier compared with gasoline and has a boiling point higher than that of water. And diesel engines are attracting greater attention due to higher efficiency and cost effectiveness.

APPLICATIONS OF HIGH SPEED DIESEL

Diesel engines are commonly used as mechanical engines, power generators and in mobile drives. They find wide spread use in locomotives, construction equipment, automobiles, and countless industrial applications.

Industrial diesel engines and diesel-powered generators have construction, marine, mining, hospital, forestry, telecommunications, underground, and agricultural applications, just to name a few. Power generation for prime or standby backup power is the major application of today's diesel generators.

S.NO	Country	Production (Thousand Barrels per Day)
1	United States	4,550.00
2	China	3,465.00
3	India	1,870.00
4	Russian Federation	1,420.00
5	Germany	938.00
6	Japan	925.00
7	Korea	854.00
8	Brazil	830.00
9	Italy	738.00
10	Saudi Arabia	641.00

Pakistan ranked 47th in producing diesel per day.

Chapter # 8 Hazards and Precautions

(Prepared by Altamash)

Material of Selection:

These points are considered to select material of concentration in this plant piping system and equipment:

1. Mechanical Strength:

    - Tensile Strength: This should be high or proof stress is 0.1%.
    - Stiffness: Material of equipment must be stiff that it should avoid buckling and Bending.
    - Toughness: no fracture occurs or resist to fracture.
    - Hardness: It must be able to resist wear.
    - Fatigue resistance: This usually occurs in pumps and compressors i.e. Rotating equipment
    - Creep resistance: resistance towards gradual extension under high tensile strength

2. Effect of Temperature:
   Tensile strength and elastic modulus decreases with increasing temperature so it must be sure that the material should be able to withstand at above 500 degrees Celsius and should not brittle at below 10 degrees Celsius.
   For this we used Stainless Steel for piping material.

3. Corrosion Resistance:
   There are several types of Corrosion:

    - Pitting: To reduce this we need good surface finish, low cavitation in pump and uniform composition of used material and no slag formation if other catalyst is used.
    - Inter-granular corrosion: To avoid this we used alloys instead of pure metals or catastrophic failure may occur. Annealing of material is necessary to avoid wield decay which causes this type of corrosion.
    - Stress Cracking: This occurs when Corrosion rate and direction of stress is changed by certain metal combinations, temperature and stress.
    - Erosion-Corrosion: Always use plastic inserts at heat exchangers inlet to avoid this. This occurs when there is turbulence in flow or sold particles that not only removes corrosion product but also the protective film.
    - High temperature oxidation: Low alloy steel shouldn't be used because it oxidizes at temperature above 500 degrees Celsius. But beside using stainless steel we can use Chromium alloys because it resists oxidation.
    - Hydrogen Embrittlement: Loss of ductility when hydrogen is adsorbed.

Stainless steel with high chromium content or Duplex steel is the only material we can use for equipment designing and piping but now we see what are other possible materials we can use beside that.

1. Iron and Steel:
   - Advantages:
     I. Cheap
     II. Available in Wide range and sizes
     III. Good Tensile Strength and Ductility

   - Disadvantages:
     I. Poor resistance to corrosion
     II. Discoloration
     III. Chlorinated content, Caustic alkalis and sulfuric acid can't be handled
     IV. Stress Corrosion may occurred

2. Stainless Steel (Type 304,309,310 or Type 321):
   - Advantages:
     I. Excellent to use when temperature is required above 500 degrees Celsius with 12% high chromium content. i.e. Oxidation at temperature is avoided.
     II. Addition of Nickel can also resist all types of corrosion
   - Disadvantages:
     I. Expensive.

3. Nickel:
   - Advantages:
     I. Good Mechanical properties
     II. Can be used to resist action of caustic alkalis.
   - Disadvantages:
     I. Above 70 degrees Celsius cracking corrosion may have occurred.
     II. Expensive
4. Monel (with Nickel copper ratio 2:1):
   - Advantages:
     I. Easily worked
     II. can be stable at temperature above 500 degrees Celsius
     III. Prefer after stainless steel
   - Disadvantages:
     I. More Expensive than stainless steel
5. Inconel:
   - Advantages:

I. Corrosion against HCl and mineral acids.

- Disadvantages:
  I. Expensive
  II. Stress Corrosion

6. Copper and Copper alloys:
   - Advantages:
     I. Soft and easily workable
     II. Can be used for tubes
     III. Resistance at hot water
     IV. Resist to erosion corrosion
   - Disadvantages:
     I. Attacked by hot mineral acids, salts and ammonia and organic acids
     II. Low tensile strength
7. Aluminum and its alloy:
   - Advantages:
     I. High resistance to corrosion
     II. Good erosion corrosion resistance
   - Disadvantages:
     I. Low mechanical properties
     II. Thin oxide film is produced

Now we talk about hazards and precaution with respect to every equipment used here:

1. Storage:
   Plastic material should store at room temperature but not more than 80 degrees Celsius.

2. Crushing and Grinding:
   Particle sized should be of less than 6 mm or material will take time to melt.

3. Washing:
   Washing water temperature should be at room temperature or at 50 degrees Celsius to dissolve deposited impurities on plastic.

4. Drying:
   Drying should be so quick to avoid melting of HDPE for about 1 hour by steam drying or hot air method if possible and there should be no moisture left in plastic material or they will form oxides of nitrogen during process so we make sure that no oxides of nitrogen is formed.

5. Proportioning:
   Proportioning should be done with 80% PP and 20% HDPE but if percentage of PP drops to 80% then diesel formula will be less and if HDPE is used more than 20%

then petroleum gases will form which might cause difficulties in compression and condensation process.

6. Catalyst storage:
   Environment where Zeolite Catalyst is used must be moisture free because it might disrupt its activity.

7. Drying of Catalyst:
   Activity temperature of Zeolite is 500 degrees Celsius, we make sure that it must heated at this temperature and moisture free environment.

8. Proportioning:
   After this proportioning is done through any mechanical equipment but we make sure that catalyst temperature doesn't drop to 200 degrees Celsius.

9. Reactor:
   First of all, we need our reactor to be air free or oxygen free for this we need to create vacuum by any inert gas in case of nitrogen then there should be complete removal of Nitrogen from product because on combustion oxides of nitrogen will form which further spreads in atmosphere and causes acid rain or from nitric acid in water.
   That's why there should be complete removal of oxygen from reactor prior to process and nitrogen from product.
   Uniform bed of catalyst is formed for efficient process and Reactor should be packed. There must be a dumping valve in case of emergency and for sudden cooling there must be jacketed tubes which permits cooling of reactor.
   There should be thermocouples and pressure sensors to provide instant indication of temperatures and pressure or any presence of air inside, pressure should be 1 atmospheric pressure and must not be over loaded. Keep the labors to stay away from reactor in case of any failure happens.

10. Piping:
    Piping should be done properly. There must be no cracking, pitting and there should be proper fitting in case of sudden expansion and contraction. The reactor material must be stainless steel.

11. Shell and Tube heat exchanger:
    Water will be supplied into the tube instead of shell because designing shell may be cost money but tubes are easy to replace, so we make sure that we use different heat exchangers for every product. Flow of water must be in tube and according to calculated flow rate.

12. Compressors:

Same condition as Shell and Tube heat exchangers.

13. Vessels:
    Vessel used must be free tight and pressure should be approx. to desirable in case of to maintain condensed form of product.

14. Pumps:
    They should be centrifugal and must have high capacity as required.

15. Removal of Nitrogen:
    Removal of nitrogen from gases can be done by temperature difference between them and nitrogen through condensation and for liquid products there is passage of hydrogen produced through liquid fuel which produces ammonia and easy to escape out by the Al_2O_3 catalyst.

Influence of process temperature and process time:

Temperature is the main parameter for the conversion process: below 460 °C produces a huge content of highly viscous liquids, and beyond 600 °C produces a low fraction of liquids with a high content of aromatics. Thermo-gravimetric analysis on PP, PE, PET, PS, and polyvinyl chloride were carried out with a different temperature. It shows that 460 °C was the minimum optimized temperature for complete combustion. Some other studies resulted that maximum complete combustion was at 500 °C.

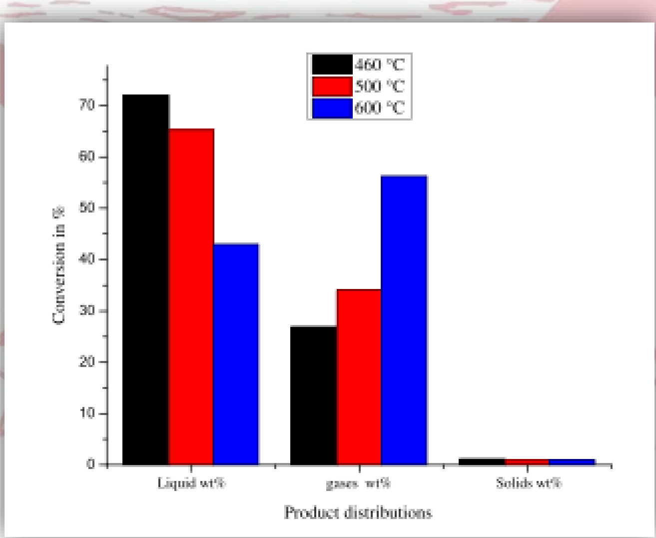


Figure shows the solid yield was very low and almost constant with all the temperature, but the liquid yields were higher at a lower temperature and decrease with increasing temperature till higher extent. The gas yield was opposite to the liquid yield, which is lower at 460 °C and higher at 600 °C.

Influence of Catalyst:

Two sorts of catalyst have been widely applied in plastics pyrolysis, namely:

1. molecular sieve catalyst or reformed molecular sieve catalyst, such as Y-zeolite and REY zeolite
2. metal oxide catalyst, such as silica–alumina, Al2O3, CuO, ZnO, Fe2O3, cerium oxide and Co–Mo oxide.

Species	Temperature range(°C)	Catalyst	Product
PE	120–140	O_2	Olefin oxide
	350–500	H_2, $ZnCl_2$	Gasoline with high RON
	350–450	$Al_2O_3 \cdot SiO_2$	Fuel oil
	400–650	Silica–alumina	Isobutene
PP	320–380	Y-molecular sieve	Gasoline and diesel oil
	200	Cu	Ethylene chloride
PVC	350	Phosphoric acid, sodium silicate	Aromatics
	400–500	$AlCl_3$, $ZrCl_4$, etc.	Gasoline and diesel oil
PS	400–450	Solid acid, solid base, transition metal oxide	Styrene monomers

Zeolite catalyst:

The decomposition of a polymer chain, being a hydrocarbon cracking reaction, is catalyzed by acidic catalysts. The main category of solid cracking catalysts, as well as the more widely used in industry, are zeolites, as they constitute the main ingredient of catalysts used in the FCC process in refineries. Zeolites are crystalline alumina silicates with a well-defined microporous structure with cages and channels of dimensions comparable to the size of common simple organic molecules. Zeolites have SiO4 and AlO4 tetrahedral as the primary structure units that link together through shared oxygen atoms in a three-dimensional structure. The AlO4 tetrahedral carry a negative charge that is counterbalanced by cations inside the zeolite pore structure, usually Na+, K+ or Ca++. When these cations are exchanged by protons, zeolite acid sites are formed. Zeolite acidity can be either of Bronsted type, proton donors, or Lewis type, electron pair acceptors. Each ¨ acidity type leads to different reaction mechanisms, as hydrocarbon reactions are catalyzed by proton addition over Bronsted sites rather than by hydride abstraction over Lewis ¨ sites. Another important characteristic of acidity is its strength that is usually measured by temperature-programmed desorption (TPD) of base components, usually NH3. The catalyst sample is saturated with the base molecule first, with the physisorbed amount removed afterwards, and then the sample temperature increases, usually with a linear temperature programmed. During the temperature programmed stage, the desorbed amount is monitored using a detector, such as a TCD (thermal conductivity detector). Obviously, the stronger the acid sites the higher is the temperature needed for the desorption of the base molecules from these sites. Stronger acid sites favor cracking reactions. There is a plethora of natural or synthetic zeolite structures, each one existing in a wide range of relative compositions of Si or Al atoms, characterized by the Si/Al ratio.

Chapter # 9
ECONOMIC ASPECTS

(Prepared by Altamash)

According to the Packaging Research Foundation (USA), costs of tertiary waste plastics recycling (fuel fractions or monomer production) cannot be recovered with an oil price of ~25–30 USD per barrel. Polyolefin are high-calorific solid fuels, similar to fuel oil and that 114 waste to-energy (WTO) facilities were working in 32 states in the USA. In any economically viable recycling process the costs of collecting, sorting and washing should be repaid by reclaiming products from the collected wastes. There is no doubt that waste plastics have to be utilized. Then the main problem is whether they should be combusted in WTO facilities or paralyzed or cracked in order to obtain monomers or gaseous, liquid and solid hydrocarbon fractions. It is evident that from an economic point of view prices of waste plastics cracking products (gasoline, light gas oil and heavy wax fractions) have to be correlated with the crude oil world price. It is necessary to add that waste-plastics-derived products are sulfur-free, composed mainly of gasoline and light gas oil fractions, suitable for fuel production. For instance, when the price of crude oil amounted $30 US per barrel, i.e. ~$0.197 US per kg, Polish refineries offered a price equivalent to $0.35 US per kg for the liquid product of waste plastics cracking. This is almost as high as the crude oil price. This is possible since in Poland the economy of the utilization plants is aided by tax relief and lowering in excise duty as well as by 'product payment', i.e. obligatory payments for plastics package reclamation by their producers. The results obtained by VEBA in a high-pressure hydrogenation plant indicated an almost four times higher price of fuels from waste plastics than current fuel market prices. At the beginning of 1990s on the basis of pilot-plant-scale hydrogenation process the UK researchers stated that this process is not economically viable and they foresaw that it would not be available commercially until after 2000. Economic efficiency of waste plastics processing depends on the methods of their selection and preparation for processing as well as the cost of thermal or catalytic treatment, i.e. the cost of investment and exploitation of the cracking plant. For instance, the main characteristic of fluid-bed reactors is the possibility of exploitation of large-scale units (at least 50 000 tons or more per year), low cost of exploitation, but accompanied by large investment and feed delivery costs. And on the other hand, smaller reactors can be built on a smaller scale, a few thousand tons per year output, lower investment costs and lower feed deliveries (processing of local wastes in limited area), but operated with larger exploitation costs. Finally, economic efficiency of waste plastics processing (tertiary recycling) can be influenced by state tax policy, e.g. by lowered income taxes and excise duty in the case of fuels produced from waste material. It will also be strongly influenced by continuous increasing of landfill costs and local legislation (local taxes lowered for waste plastics utilizing companies) as well as obligatory payments for package reclamation by their producers.

Chapter # 10

Conclusion

(Prepared by Altamash, Muhammad Kaamil Arif, Afnan and Muhammad Azim Khan)

In this work, catalytic cracking of HDPE and PP have been carried out in a batch reactor but also there is comparison between these two process of cracking i.e. Catalytic cracking and Thermal Cracking. Plus, we discussed that what are achievable requirements to get more liquid products during process and which is component of our raw material might give more liquid product i.e. PP and Production of HDPE gives less liquid product but many gas fractions but the main purpose of that was to utilize the HDPE and PP together in a waste. We didn't used PVC as raw material because utilization of chlorine produced might be not possible with such catalyst and the most hazardous problem is formation of hydrochloric acid during the process of cracking which might corrode reactor and other equipment.

We also discussed GC analysis and Distribution curves that how separation of both components take place while cracking, and we also find out that 460 degrees Celsius is the optimum temperature when the all plastic material will be degrade whereas heavy compounds will break into lightest fraction.

The efficiency of process depends upon the temperature employed and the activity of catalysts only, we also discussed the minimum pressure drop for the vapors introducing into heat exchangers.

Selection of material also considered for both pipes and equipment such as heat exchangers and storage tank and also we discussed hazards and economical aspects of this process.

Hydrogen produced in this process might be used in removal of nitrogen from liquid fuel otherwise if there is separation of liquid from nitrogen gas then hydrogen gas should be blend with methane in order to increase its calorific value. Aromatics produced in this process are also blended with liquid fuel might become cause of pollution so to fulfill their unsaturation we used ethanol and bio-diesel which turns them into cyclic compounds.

Appendix

1. <u>Appendix for Heat Exchanger Calculations:</u>

A1. Table for U_D and R_d assumption:

Hot fluid	Cold fluid	Overall U_D
Water	Water	250–500§
Methanol	Water	250–500§
Ammonia	Water	250–500§
Aqueous solutions	Water	250–500§
Light organics*	Water	75–150
Medium organics†	Water	50–125
Heavy organics‡	Water	5–75‖
Gases	Water	2–50¶
Water	Brine	100–200
Light organics	Brine	40–100
	Heaters	
Hot fluid	**Cold fluid**	**Overall U_D**
Steam	Water	200–700§
Steam	Methanol	200–700§
Steam	Ammonia	200–700§
Steam	Aqueous solutions:	
Steam	Less than 2.0 cp	200–700
Steam	More than 2.0 cp	100–500§
Steam	Light organics	100–200
Steam	Medium organics	50–100
Steam	Heavy organics	6–60
Steam	Gases	5–50¶
	Exchangers	
Hot fluid	**Cold fluid**	**Overall U_D**
Water	Water	250–500§
Aqueous solutions	Aqueous solutions	250–500§
Light organics	Light organics	40–75
Medium organics	Medium organics	20–60
Heavy organics	Heavy organics	10–40
Heavy organics	Light organics	30–60
Light organics	Heavy organics	10–40

A2. Table for number of Tubes:

For Square Pitches:

TUBE-SHEET LAYOUTS (TUBE COUNTS)
Square Pitch

¾ in. OD tubes on 1-in. square pitch

Shell ID, in.	1-P	2-P	4-P	6-P	8-P
8	32	26	20	20	
10	52	52	40	36	
12	81	76	68	68	60
13¼	97	90	82	76	70
15¼	137	124	116	108	108
17¼	177	166	158	150	142
19¼	224	220	204	192	188
21¼	277	270	246	240	234
23¼	341	324	308	302	292
25	413	394	370	356	346
27	481	460	432	420	408
29	553	526	480	468	456
31	657	640	600	580	560
33	749	718	688	676	648
35	845	824	780	766	748
37	934	914	886	866	838
39	1049	1024	982	968	948

1 in. OD tubes on 1¼-in. square pitch

Shell ID, in.	1-P	2-P	4-P	6-P	8-P
8	21	16	14		
10	32	32	26	24	
12	48	45	40	38	36
13¼	61	56	52	48	44
15¼	81	76	68	68	64
17¼	112	112	96	90	82
19¼	138	132	128	122	116
21¼	177	166	158	152	148
23¼	213	208	192	184	184
25	260	252	238	226	222
27	300	288	278	268	260
29	341	326	300	294	286
31	406	398	380	368	358
33	465	460	432	420	414
35	522	518	488	484	472
37	596	574	562	544	532
39	665	644	624	612	600

1¼ in. OD tubes on 1 9/16-in. square pitch

Shell ID, in.	1-P	2-P	4-P	6-P	8-P
10	16	12	10		
12	30	24	22	16	16
13¼	32	30	30	22	22
15¼	44	40	37	35	31
17¼	56	53	51	48	44
19¼	78	73	71	64	56
21¼	96	90	86	82	78
23¼	127	112	106	102	96
25	140	135	127	123	115
27	166	160	151	146	140
29	193	188	178	174	166
31	226	220	209	202	193
33	258	252	244	238	226
35	293	287	275	268	258
37	334	322	311	304	293
39	370	362	348	342	336

1½ in. OD tubes on 1⅞-in. square pitch

Shell ID, in.	1-P	2-P	4-P	6-P	8-P
12	16	16	12	12	
13¼	22	22	16	16	
15¼	29	29	25	24	22
17¼	39	39	34	32	29
19¼	50	48	45	43	39
21¼	62	60	57	54	50
23¼	78	74	70	66	62
25	94	90	86	84	78
27	112	108	102	98	94
29	131	127	120	116	112
31	151	146	141	138	131
33	176	170	164	160	151
35	202	196	188	182	176
37	224	220	217	210	202
39	252	246	237	230	224

For Triangular Pitches:

TUBE-SHEET LAYOUTS (TUBE COUNTS).—(*Continued*)
Triangular Pitch

¾ in. OD tubes on 15/16-in. triangular pitch

Shell ID, in.	1-P	2-P	4-P	6-P	8-P
8	36	32	26	24	18
10	62	56	47	42	36
12	109	98	86	82	78
13¼	127	114	96	90	86
15¼	170	160	140	136	128
17¼	239	224	194	188	178
19¼	301	282	252	244	234
21¼	361	342	314	306	290
23¼	442	420	386	378	364
25	532	506	468	446	434
27	637	602	550	536	524
29	721	692	640	620	594
31	847	822	766	722	720
33	974	938	878	852	826
35	1102	1068	1004	988	958
37	1240	1200	1144	1104	1072
39	1377	1330	1258	1248	1212

¾ in. OD tubes on 1-in. triangular pitch

Shell ID, in.	1-P	2-P	4-P	6-P	8-P
8	37	30	24	24	
10	61	52	40	36	
12	92	82	76	74	70
13¼	109	106	86	82	74
15¼	151	138	122	118	110
17¼	203	196	178	172	166
19¼	262	250	226	216	210
21¼	316	302	278	272	260
23¼	384	376	352	342	328
25	470	452	422	394	382
27	559	534	488	474	464
29	630	604	556	538	508
31	745	728	678	666	640
33	856	830	774	760	732
35	970	938	882	864	848
37	1074	1044	1012	986	870
39	1206	1176	1128	1100	1078

1 in. OD tubes on 1¼-in. triangular pitch

Shell ID, in.	1-P	2-P	4-P	6-P	8-P
8	21	16	16	14	
10	32	32	26	24	
12	55	52	48	46	44
13¼	68	66	58	54	50
15¼	91	86	80	74	72
17¼	131	118	106	104	94
19¼	163	152	140	136	128
21¼	199	188	170	164	160
23¼	241	232	212	212	202
25	294	282	256	252	242
27	349	334	302	296	286
29	397	376	338	334	316
31	472	454	430	424	400
33	538	522	486	470	454
35	608	592	562	546	532
37	674	664	632	614	598
39	766	736	700	688	672

1¼ in. OD tubes on 19/16-in. triangular pitch

Shell ID, in.	1-P	2-P	4-P	6-P	8-P
10	20	18	14		
12	32	30	26	22	20
13¼	38	36	32	28	26
15¼	54	51	45	42	38
17¼	69	66	62	58	54
19¼	95	91	86	78	69
21¼	117	112	105	101	95
23¼	140	136	130	123	117
25	170	164	155	150	140
27	202	196	185	179	170
29	235	228	217	212	202
31	275	270	255	245	235
33	315	305	297	288	275
35	357	348	335	327	315
37	407	390	380	374	357
39	449	436	425	419	407

1½ in. OD tubes on 1⅞-in. triangular pitch

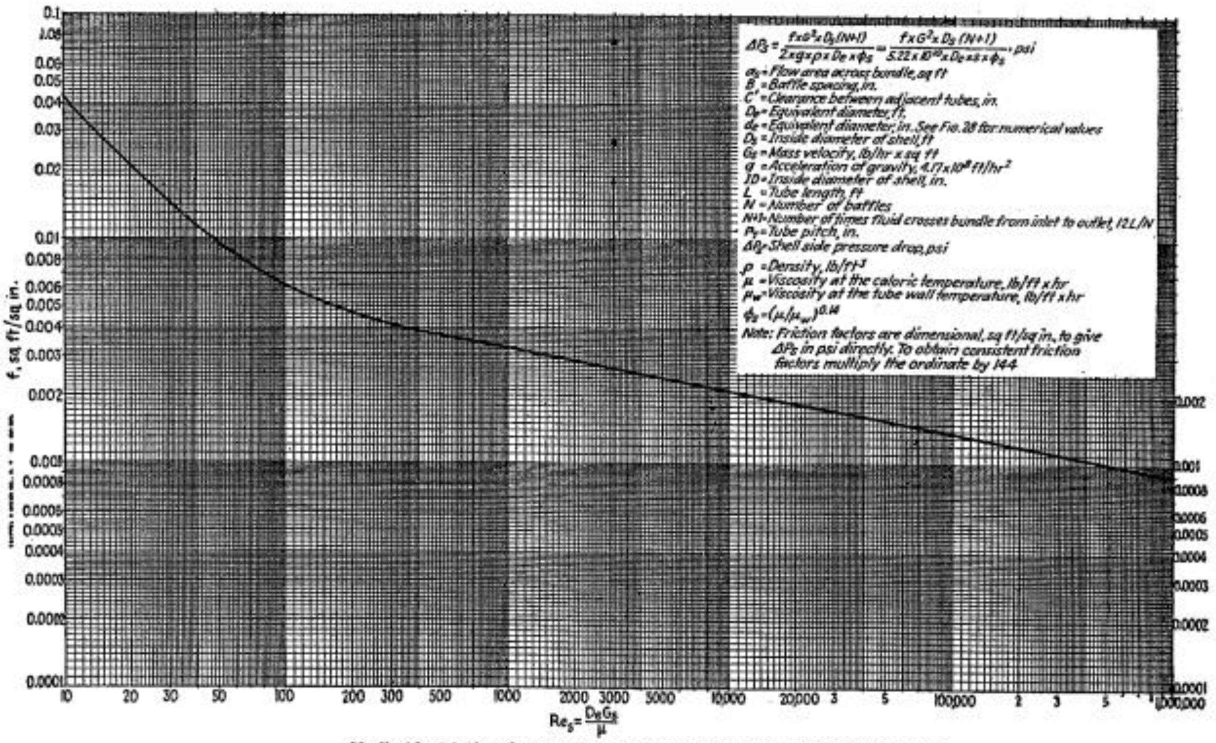
Shell ID, in.	1-P	2-P	4-P	6-P	8-P
12	18	14	14	12	12
13¼	27	22	18	16	14
15¼	36	34	32	30	27
17¼	48	44	42	38	36
19¼	61	58	55	51	48
21¼	76	72	70	66	61
23¼	95	91	86	80	76
25	115	110	105	98	95
27	136	131	125	118	115
29	160	154	147	141	136
31	184	177	172	165	160
33	215	206	200	190	184
35	246	238	230	220	215
37	275	268	260	252	246
39	307	299	290	284	275

A3. Table for Pipes/Tubes data:

HEAT EXCHANGER AND CONDENSER TUBE DATA

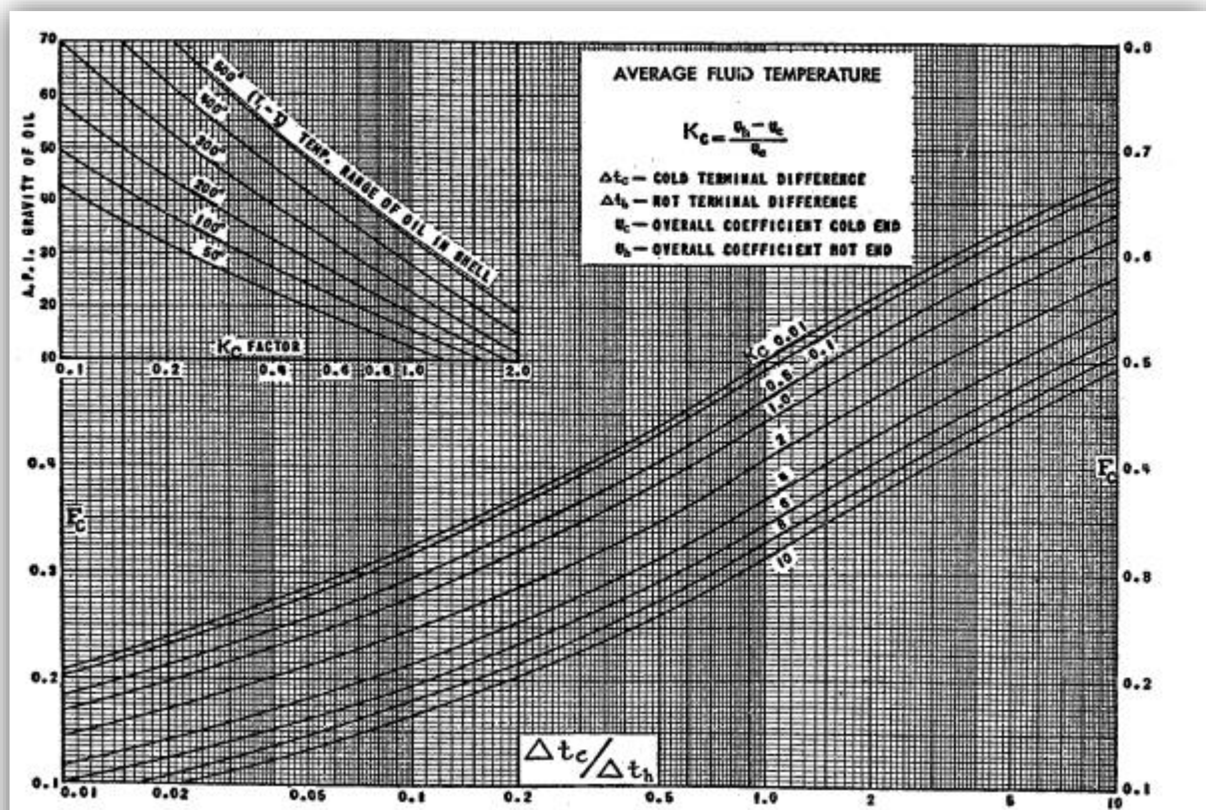
Tube OD, in.	BWG	Wall thickness, in.	ID, in.	Flow area per tube, in.²	Surface per lin ft, ft²		Weight per lin ft, lb steel
					Outside	Inside	
½	12	0.109	0.282	0.0625	0.1309	0.0748	0.493
	14	0.083	0.334	0.0876		0.0874	0.403
	16	0.065	0.370	0.1076		0.0969	0.329
	18	0.049	0.402	0.127		0.1052	0.258
	20	0.035	0.430	0.145		0.1125	0.190
¾	10	0.134	0.482	0.182	0.1963	0.1263	0.965
	11	0.120	0.510	0.204		0.1335	0.884
	12	0.109	0.532	0.223		0.1393	0.817
	13	0.095	0.560	0.247		0.1466	0.727
	14	0.083	0.584	0.268		0.1529	0.647
	15	0.072	0.606	0.289		0.1587	0.571
	16	0.065	0.620	0.302		0.1623	0.520
	17	0.058	0.634	0.314		0.1660	0.469
	18	0.049	0.652	0.334		0.1707	0.401
1	8	0.165	0.670	0.355	0.2618	0.1754	1.61
	9	0.148	0.704	0.389		0.1843	1.47
	10	0.134	0.732	0.421		0.1916	1.36
	11	0.120	0.760	0.455		0.1990	1.23
	12	0.109	0.782	0.479		0.2048	1.14
	13	0.095	0.810	0.515		0.2121	1.00
	14	0.083	0.834	0.546		0.2183	0.890
	15	0.072	0.856	0.576		0.2241	0.781
	16	0.065	0.870	0.594		0.2277	0.710
	17	0.058	0.884	0.613		0.2314	0.639
	18	0.049	0.902	0.639		0.2361	0.545
1¼	8	0.165	0.920	0.665	0.3271	0.2409	2.09
	9	0.148	0.954	0.714		0.2498	1.91
	10	0.134	0.982	0.757		0.2572	1.75
	11	0.120	1.01	0.800		0.2644	1.58
	12	0.109	1.03	0.836		0.2701	1.45
	13	0.095	1.06	0.884		0.2775	1.28
	14	0.083	1.08	0.923		0.2839	1.13
	15	0.072	1.11	0.960		0.2896	0.991
	16	0.065	1.12	0.985		0.2932	0.900
	17	0.058	1.13	1.01		0.2969	0.808
	18	0.049	1.15	1.04		0.3015	0.688
1½	8	0.165	1.17	1.075	0.3925	0.3063	2.57
	9	0.148	1.20	1.14		0.3152	2.34
	10	0.134	1.23	1.19		0.3225	2.14
	11	0.120	1.26	1.25		0.3299	1.98
	12	0.109	1.28	1.29		0.3356	1.77
	13	0.095	1.31	1.35		0.3430	1.56
	14	0.083	1.33	1.40		0.3492	1.37
	15	0.072	1.36	1.44		0.3555	1.20
	16	0.065	1.37	1.47		0.3587	1.09
	17	0.058	1.38	1.50		0.3623	0.978
	18	0.049	1.40	1.54		0.3670	0.831

A4. Figure for Friction factor in shell side with segmental Baffles 25%:



Shell-side friction factors for bundles with 25% cut segmental baffles.

A5. Figure for F_c and K_c factor:



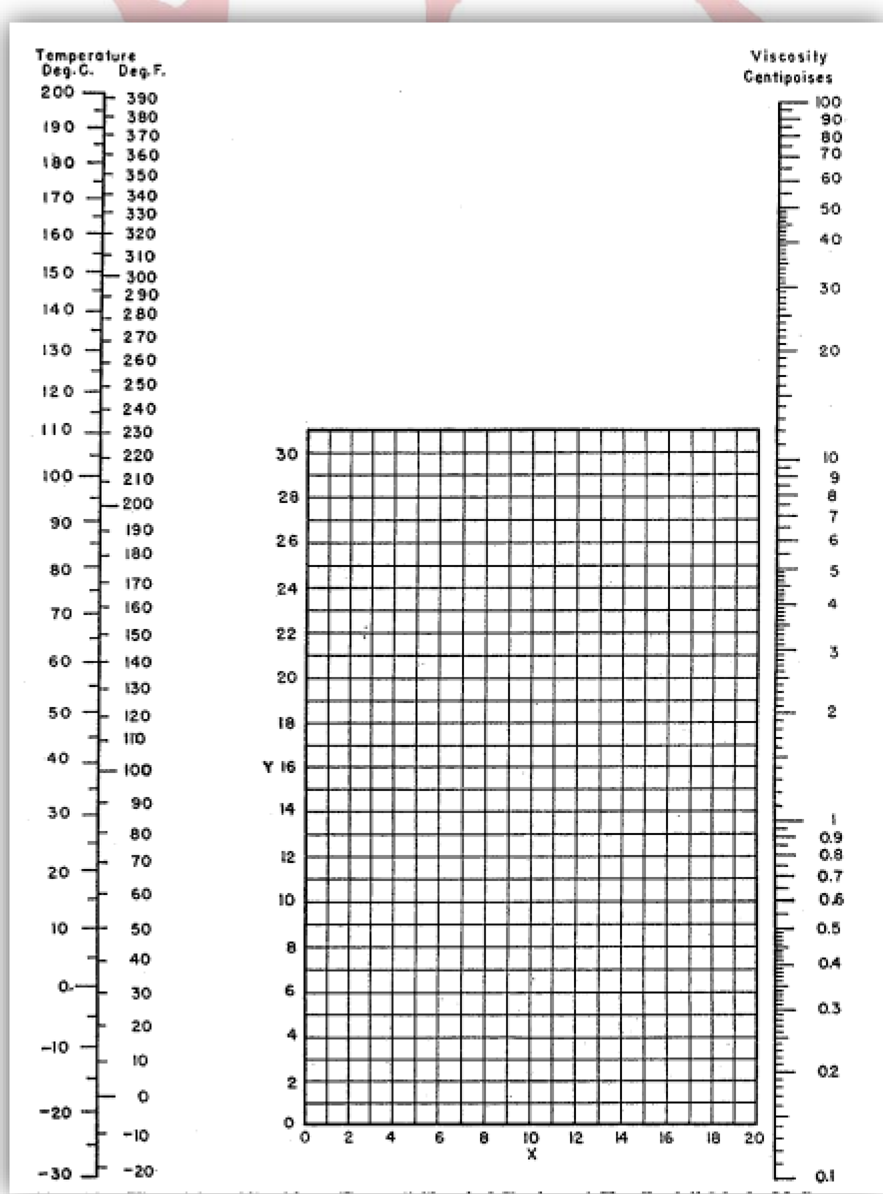
The caloric temperature factor F_c. (*Standards of Tubular Exchanger Manufacturers Association, 2d ed., New York, 1949.*)

A6. Table and Figure for Viscosities:

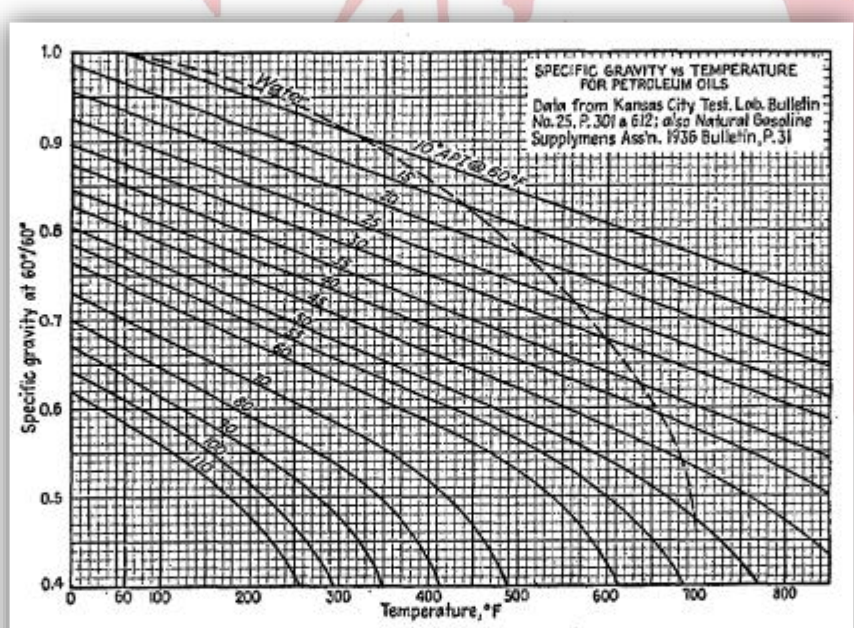
Liquid	X	Y	Liquid	X	Y
Acetaldehyde	15.2	4.8	Freon-21	15.7	7.5
Acetic acid, 100%	12.1	14.2	Freon-22	17.2	4.7
Acetic acid, 70%	9.5	17.0	Freon-113	12.5	11.4
Acetic anhydride	12.7	12.8	Freon-114	14.6	8.3
Acetone, 100%	14.5	7.2	Glycerol, 100%	2.0	30.0
Acetone, 35%	7.9	15.0	Glycerol, 50%	6.9	19.6
Allyl alcohol	10.2	14.3	Heptane	14.1	8.4
Ammonia, 100%	12.6	2.0	Hexane	14.7	7.0
Ammonia, 26%	10.1	13.9	Hydrochloric acid, 31.5%	13.0	16.6
Amyl acetate	11.8	12.5	Isobutyl alcohol	7.1	18.0
Amyl alcohol	7.5	18.4	Isobutyric acid	12.2	14.4
Aniline	8.1	18.7	Isopropyl alcohol	8.2	16.0
Anisole	12.3	13.5	Mercury	18.4	16.4
Arsenic trichloride	13.9	14.5	Methanol, 100%	12.4	10.5
Benzene	12.5	10.9	Methanol, 90%	12.3	11.8
Brine, $CaCl_2$, 25%	6.6	15.9	Methanol, 40%	7.8	15.5
Brine, NaCl, 25%	10.2	16.6	Methyl acetate	14.2	8.2
Bromine	14.2	13.2	Methyl chloride	15.0	3.8
Bromotoluene	20.0	15.9	Methyl ethyl ketone	13.9	8.6
n-Butane	15.3	3.3	Naphthalene	7.9	18.1
Isobutane	14.5	3.7	Nitric acid, 95%	12.8	13.8
Butyl acetate	12.3	11.0	Nitric acid, 60%	10.8	17.0
Butyl alcohol	8.6	17.2	Nitrobenzene	10.6	16.2
Butyric acid	12.1	15.3	Nitrotoluene	11.0	17.0
Carbon dioxide	11.6	0.3	Octane	13.7	10.0
Carbon disulfide	16.1	7.5	Octyl alcohol	6.6	21.1
Carbon tetrachloride	12.7	13.1	Pentachloroethane	10.9	17.3
Chlorobenzene	12.3	12.4	Pentane	14.9	5.2
Chloroform	14.4	10.2	Phenol	6.9	20.8
Chlorosulfonic acid	11.2	18.1	Phosphorus tribromide	13.8	16.7
Chlorotoluene, ortho	13.0	13.3	Phosphorus trichloride	16.2	10.9
Chlorotoluene, meta	13.3	12.5	Propane	15.3	1.0
Chlorotoluene, para	13.3	12.5	Propionic acid	12.8	13.8
Cresol, meta	2.5	20.8	Propyl alcohol	9.1	16.5
Cyclohexanol	2.9	24.3	Propyl bromide	14.5	9.6
Dibromoethane	12.7	15.8	Propyl chloride	14.4	7.5
Dichloroethane	13.2	12.2	Propyl iodide	14.1	11.6
Dichloromethane	14.6	8.9	Sodium	16.4	13.9
Diethyl oxalate	11.0	16.4	Sodium hydroxide, 50%	3.2	25.8
Dimethyl oxalate	12.3	15.8	Stannic chloride	13.5	12.8
Diphenyl	12.0	18.3	Sulfur dioxide	15.2	7.1
Dipropyl oxalate	10.3	17.7	Sulfuric acid, 110%	7.2	27.4
Ethyl acetate	13.7	9.1	Sulfuric acid, 98%	7.0	24.8
Ethyl alcohol, 100%	10.5	13.8	Sulfuric acid, 60%	10.2	21.3
Ethyl alcohol, 95%	9.8	14.3	Sulfuryl chloride	15.2	12.4
Ethyl alcohol, 40%	6.5	16.6	Tetrachloroethane	11.9	15.7
Ethyl benzene	13.2	11.5	Tetrachloroethylene	14.2	12.7
Ethyl bromide	14.5	8.1	Titanium tetrachloride	14.4	12.3
Ethyl chloride	14.8	6.0	Toluene	13.7	10.4
Ethyl ether	14.5	5.3	Trichloroethylene	14.8	10.5
Ethyl formate	14.2	8.4	Turpentine	11.5	14.9
Ethyl iodide	14.7	10.3	Vinyl acetate	14.0	8.8
Ethylene glycol	6.0	23.6	Water	10.2	13.0
Formic acid	10.7	15.8	Xylene, ortho	13.5	12.1
Freon-11	14.4	9.0	Xylene, meta	13.9	10.6
Freon-12	16.8	5.6	Xylene, para	13.9	10.9

* From Perry, J. H., "Chemical Engineers' Handbook," 3d ed., McGraw-Hill Book Company, Inc., New York, 1950.

	X	Y
76°API natural gasoline	14.4	6.4
56°API gasoline	14.0	10.5
42°API kerosene	11.6	16.0
35°API distillate	10.0	20.0
34°API mid-continent crude	10.3	21.3
28°API gas oil	10.0	23.6



A7. Figure and Table for specific Gravities:

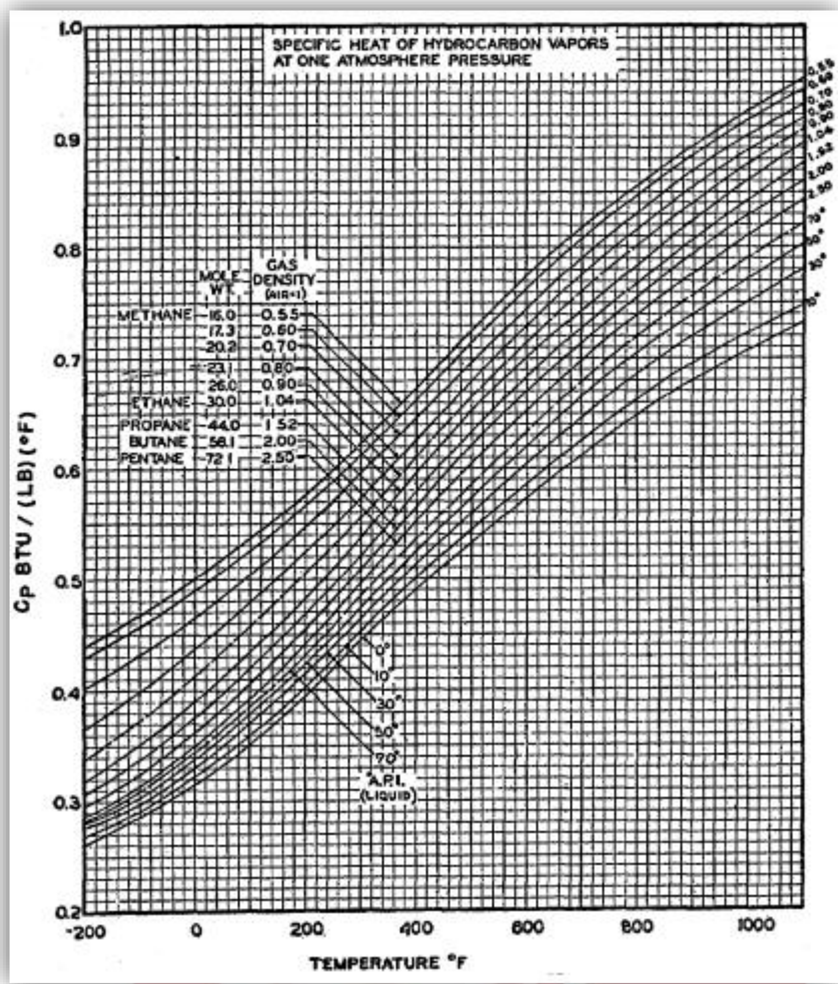


Specific gravities of hydrocarbons.

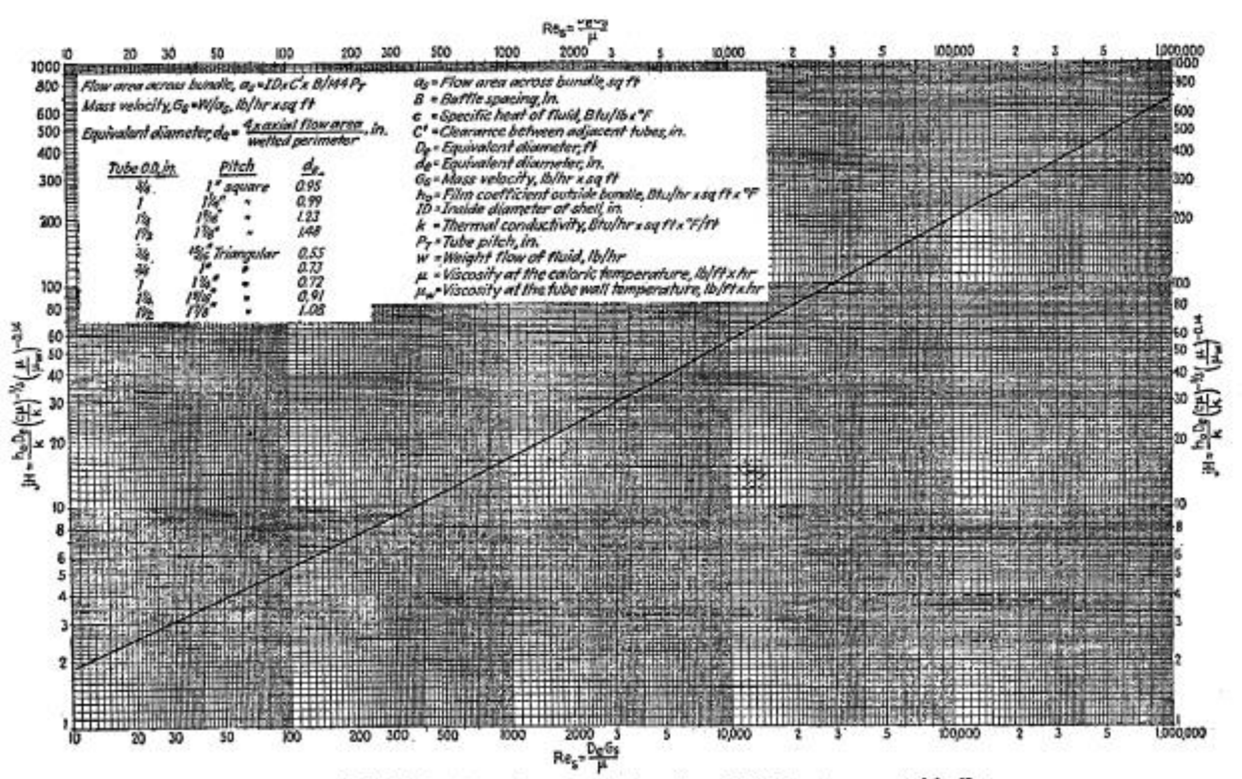
Specific Gravities and Molecular Weights of Liquids

Compound	Mol. wt.	s*	Compound	Mol. wt.	s*
Acetaldehyde	44.1	0.78	Ethyl iodide	155.9	1.93
Acetic acid, 100 %	60.1	1.05	Ethyl glycol	88.1	1.04
Acetic acid, 70 %	......	1.07	Formic acid	46.0	1.22
Acetic anhydride	102.1	1.08	Glycerol, 100 %	92.1	1.26
Acetone	58.1	0.79	Glycerol, 50 %	......	1.13
Allyl alcohol	58.1	0.86	n-Heptane	100.2	0.68
Ammonia, 100 %	17.0	0.61	n-Hexane	86.1	0.66
Ammonia, 26 %	......	0.91	Isopropyl alcohol	60.1	0.79
Amyl acetate	130.2	0.88	Mercury	200.6	13.55
Amyl alcohol	88.2	0.81	Methanol, 100 %	32.5	0.79
Aniline	93.1	1.02	Methanol, 90 %	......	0.82
Anisole	108.1	0.99	Methanol, 40 %	......	0.94
Arsenic trichloride	181.3	2.16	Methyl acetate	74.9	0.93
Benzene	78.1	0.88	Methyl chloride	50.5	0.92
Brine, $CaCl_2$ 25 %	......	1.23	Methyl ethyl ketone	72.1	0.81
Brine, NaCl 25 %	......	1.19	Naphthalene	128.1	1.14
Bromotoluene, ortho	171.0	1.42	Nitric acid, 95 %	......	1.50
Bromotoluene, meta	171.0	1.41	Nitric acid, 60 %	......	1.38
Bromotoluene, para	171.0	1.39	Nitrobenzene	123.1	1.20
n-Butane	58.1	0.60	Nitrotoluene, ortho	137.1	1.16
i-Butane	58.1	0.60	Nitrotoluene, meta	137.1	1.16
Butyl acetate	116.2	0.88	Nitrotoluene, para	137.1	1.29
n-Butyl alcohol	74.1	0.81	n-Octane	114.2	0.70
i-Butyl alcohol	74.1	0.82	Octyl alcohol	130.23	0.82
n-Butyric acid	88.1	0.96	Pentachloroethane	202.3	1.67
i-Butyric acid	88.1	0.96	n-Pentane	72.1	0.63
Carbon dioxide	44.0	1.20	Phenol	94.1	1.07
Carbon disulfide	76.1	1.26	Phosphorus tribromide	270.8	2.85
Carbon tetrachloride	153.8	1.60	Phosphorus trichloride	137.4	1.57
Chlorobenzene	112.6	1.11	Propane	44.1	0.59
Chloroform	119.4	1.49	Propionic acid	74.1	0.99
Chlorosulfonic acid	116.5	1.77	n-Propyl alcohol	60.1	0.80
Chlorotoluene, ortho	126.6	1.08	n-Propyl bromide	123.0	1.35
Chlorotoluene, meta	126.6	1.07	n-Propyl chloride	78.5	0.89
Chlorotoluene, para	126.6	1.07	n-Propyl iodide	170.0	1.75
Cresol, meta	108.1	1.03	Sodium	23.0	0.97
Cyclohexanol	100.2	0.96	Sodium hydroxide, 50 %	......	1.53
Dibromo methane	187.9	2.09	Stannic chloride	260.5	2.23
Dichloro ethane	99.0	1.17	Sulfur dioxide	64.1	1.38
Dichloro methane	88.9	1.34	Sulfuric acid, 100 %	98.1	1.83
Diethyl oxalate	146.1	1.08	Sulfuric acid, 98 %	......	1.84
Dimethyl oxalate	118.1	1.42	Sulfuric acid, 60 %	......	1.50
Diphenyl	154.2	0.99	Sulfuryl chloride	135.0	1.67
Dipropyl oxalate	174.1	1.02	Tetra chloroethane	167.9	1.60
Ethyl acetate	88.1	0.90	Tetra chloroethylene	165.9	1.63
Ethyl alcohol, 100 %	46.1	0.79	Titanium tetrachloride	189.7	1.73
Ethyl alcohol, 95 %	......	0.81	Toluene	92.1	0.87
Ethyl alcohol, 40 %	......	0.94	Trichloroethylene	131.4	1.46
Ethyl benzene	106.1	0.87	Vinyl acetate	86.1	0.93
Ethyl bromide	108.9	1.43	Water	18.0	1.0
Ethyl chloride	64.5	0.92	Xylene, ortho	106.1	0.87
Ethyl ether	74.1	0.71	Xylene, meta	106.1	0.86
Ethyl formate	74.1	0.92	Xylene, para	106.1	0.86

A8. Figure for C_p values of Petroleum Products:



A9. For D_e of Shell side:



Shell-side heat-transfer curve for bundles with 25% cut segmental baffles.

A10. Cost index for 2010

CE Plant Cost Index	607.5
Equipment	740.0
Tanks	649.8
Process Machinery	725.4
Pipes, Valves & Fittings	963.3
Process Instruments	418.4
Pumps, Compressors	1069.2
Electrical equipment	558.5
Structural supports & misc.	801.7
Construction Labor	336.1

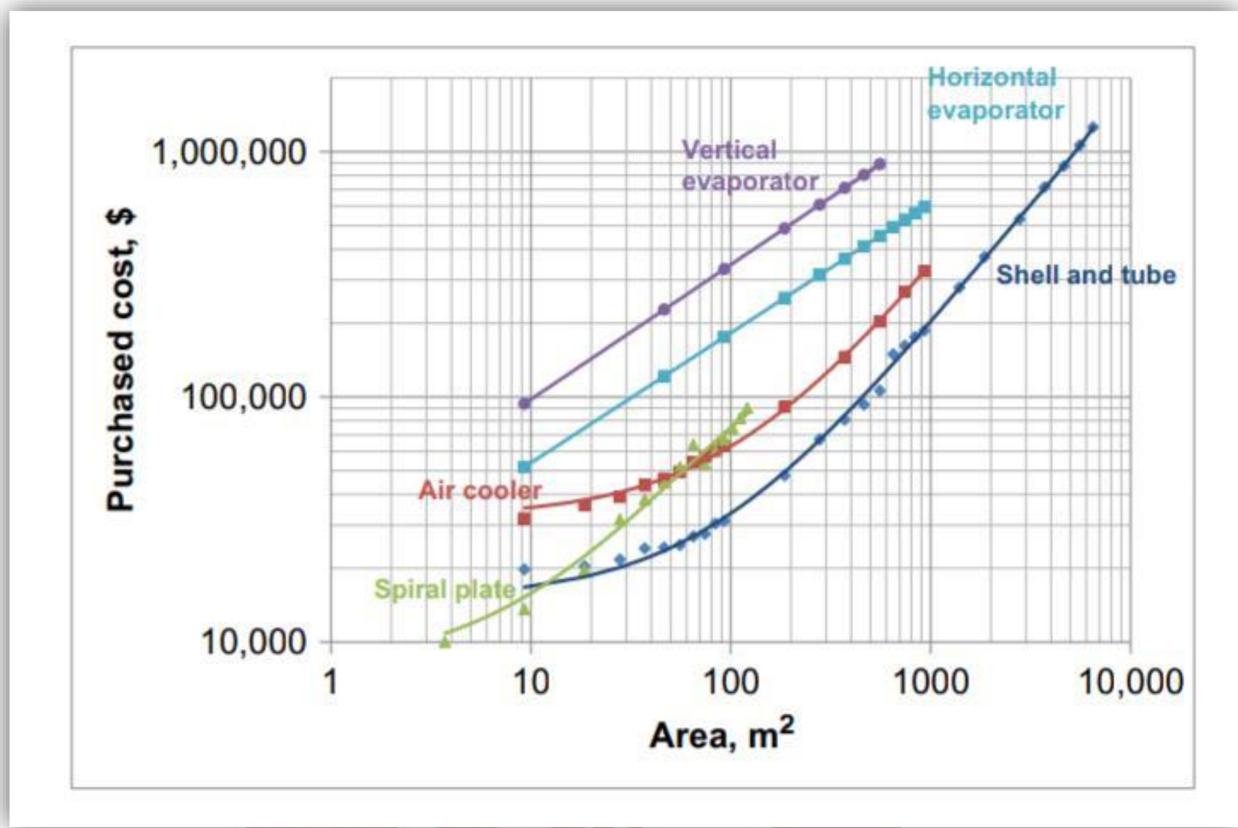
A11. Constant values for cost estimation

Equipment	Size unit, S	Size range	Constant C,£	Constant C,$	Index n	Comment
Agitators						
Propeller	driver power, kW	5–75	1200	1900	0.5	complete unit
Turbine			3700	6100	0.5	
Boilers						
Packaged						oil or gas fired
up to 10 bar	kg/h steam	$(5-50) \times 10^3$	35	60	0.8	
10 to 60 bar			60	100	0.8	
Centrifuges						
Horizontal basket	dia., m	0.5–1.0	35,000	58,000	1.3	
Vertical basket			35,000	58,000	1.0	
Compressors						
Centrifugal	driver power, kW	20–500	580	960	0.8	electric, max. press 50 bar
Reciprocating			800	1350	0.8	
Conveyors						
Belt	length, m	2–40				
0.5 m wide			1200	1900	0.75	
1.0 m wide			1800	2900	0.75	
Crushers						
Cone	t/h	20–200	2300	3800	0.85	
Pulverisers	kg/h		2000	3400	0.35	
Dryers						
Rotary	area, m^2	5–30	7000	11,500	0.45	carbon steel
Pan		2–10	4700	7700	0.35	
Evaporators						
Vertical tube	area, m^2	10–000	7000	11,500	0.53	carbon steel
Falling film			13,000	21,000	0.52	
Filters						
Plate and frame	area, m^2	5–50	2700	4400	0.60	cast iron
Vacuum drum		1–10	10,500	17,000	0.60	carbon steel
Furnaces						
Process	heat abs, kW					
Cylindrical		10^3-10^4	220	360	0.77	carbon steel
Box		10^3-10^5	340	560	0.77	× 2.0 for SS
Reactors						
Jacketed, agitated	capacity, m^3	3–30	9300	15,000	0.40	carbon steel
			18,500	31,000	0.45	glass lined
Tanks						
Process	capacity, m^3					
vertical		1–50	1450	2400	0.60	atmos. press
horizontal		10–100	1750	2900	0.60	carbon steel
Storage						
floating roof		50–8000	1700	2900	0.55	× 2.5 for
cone roof		50–8000	1400	2300	0.55	stainless

Equipment	Unit for Size	Size	α	β	n
Filters					
Plate and frame	Capacity (m^3)	0.4–1.4	128,000	89,000	0.5
Vacuum drum	Area (m^2)	10–180	−73,000	93,000	0.3
Furnaces					
Cylindrical	Duty (MW)	0.2–60	80,000	109,000	0.8
Box	Duty (MW)	30–120	43,000	111,000	0.8
Packings					
304 Raschig rings	m^3		0	8000	1.0
Ceramic Intalox saddles	m^3		0	2000	1.0
304 SS Pall rings	m^3		0	8500	1.0
PVC structured packing	m^3		0	5500	1.0
304 SS structured packing	m^3		0	7600	1.0
Pressure vessels[a]					
Vertical, CS	Shell (kg)	160–250,000	11,600	34	0.85
Horizontal, CS	Shell (kg)	160–5000	10,200	31	0.85
Vertical, 304 SS	Shell (kg)	120–250,000	17,400	79	0.85
Horizontal, 304 SS	Shell (kg)	120–50,000	12,800	73	0.85
Pumps and drivers					
Single stage centrifugal	Flow (l/s)	0.2–126	8000	240	0.9
Explosion proof	Power (kW)	1–2500	−1100	2100	0.6
Reactors					
Jacketed, agitated	Volume (m^3)	0.5–100	61,500	32,500	0.8
Jacketed, agitated, glass lined	Volume (m^3)	0.5–25	12,800	88,200	0.4
Floating roof	Capacity (m^3)	100–10,000	113,000	3250	0.65
Cone roof	Capacity (m^3)	10–4800	5800	1600	0.70
Trays					
Sieve trays	Diameter (m)	0.5–5.0	130	440	1.8
Valve trays	Diameter (m)	0.5–5.0	210	400	1.9
Bubble cap trays	Diameter (m)	0.5–5.0	340	640	1.9
Utilities[b]					
Cooling tower and pumps	Flow (l/s)	100–10,000	170,000	1500	0.9
Mechanical refrigeration	Duty (kW)	50–1500	24,000	3500	0.9
Water ion exchange plant	Flow (m^3/h)	1–50	14,000	6200	0.75

Equipment	Units for Size, *S*	S_{Lower}	S_{Upper}	*a*	*b*	*n*	Note
Agitators & mixers							
Propeller	driver power, kW	5.0	75.0	4,300	1,920	0.8	
Spiral ribbon mixer	driver power, kW	5.0	35.0	11,000	420	1.5	
Static mixer	Liters/s	1.0	50.0	780	62	0.8	
Boilers							
Packaged, 15 to 40 bar	kg/h steam	5,000.0	200,000.0	4,600	62	0.8	
Field erected, 10 to 70 bar	kg/h steam	20,000.0	800,000.0	−90,000	93	0.8	
Centrifuges							
High-speed disk	diameter, m	0.26	0.49	63,000	260,000	0.8	
Atmospheric suspended basket	power, kW	2.0	20.0	37,000	1,200	1.2	
Compressors							
Blower	m^3/h	200.0	5,000.0	4,200	27	0.8	
Centrifugal	driver power, kW	132.0	29,000.0	8,400	3,100	0.6	
Reciprocating	driver power, kW	100.0	16,000.0	240,000	1.33	1.5	
Conveyors							
Belt, 0.5 m wide	length, m	10.0	500.0	21,000	340	1.0	
Belt, 1.0 m wide	length, m	10.0	500.0	23,000	575	1.0	
Bucket elevator, 0.5 m bucket	height, m	10.0	35.0	14,000	1,450	1.0	
Crushers							
Reversible hammer mill	tonne/h	20.0	400.0	400	9,900	0.5	
Pulverizers	kg/h	200.0	4,000.0	3,000	390	0.5	
Crystallizers							
Scraped surface crystallizer	length, m	7.0	280.0	41,000	40,000	0.7	
Distillation columns							
See pressure vessels, packing, and trays							
Dryers							
Direct contact rotary	area, m^2	11.0	180.0	−7,400	4,350	0.9	1
Pan	area, m^2	1.5	15.0	−5,300	24,000	0.5	2
Spray dryer	evap rate kg/h	400.0	4,000.0	190,000	180	0.9	
Evaporators							
Vertical tube	area, m^2	11.0	640.0	17,000	13,500	0.6	
Agitated falling film	area, m^2	0.5	12.0	29,000	53,500	0.6	

Graph for Heat exchanger:



Thank You