DESIGN AND MANUFACTURE OF PROPYLENE GLYCOL MONOMETHYL ETHER

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Technology degree in Chemical Engineering

By

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INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **MOHANRAJ. P (Reg.No.38690009)** and **MUGESH. J (Reg.No.38690010)** who carried out this Project entitled **“DESIGN MANUFACTURE OF PROPYLENE GLYCOL MONOMETHYL ETHER”** under my supervision from June 2021 to October 2021.

Internal Guide

Dr. D. PRABHU M.S (Research), Ph.D.

Head of the Department

Dr. S. SATHISH, M.E., Ph. D

Submitted for Viva voce Examination held on______ October 2021.

Internal Examiner **External Examiner**

DECLARATION

We, **MOHANRAJ. P (Reg.No.38690009)** and **MUGESH. J (Reg.No. 38690010)** hereby declare that this Project Report entitled **“DESIGN MANUFACTURE OF PROPYLENE GLYCOL MONOMETHYL ETHER”** done by me under the guidance of **Dr. D. PRABHU M.S (Research), Ph.D.,** Sathyabama Institute of Science and Technology is submitted in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Chemical Engineering**.**

DATE:

PLACE:

SIGNATURE OF THE CANDIDATES

1. **MOHANRAJ P**

2. **MUGESH J**

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ABSTRACT

Propylene Glycol Monomethyl Ether (PGMME) is a methoxy alcohol derivative classified under the p-series glycol ethers. PGMME is largely demanded in the sectors of paints and coatings. It is also known as 1-Methoxy-2-Propanol. The present work focuses on the production of PGMME by reacting Methanol and PO in the presence of Tri-Ethyl Amine catalyst.

The project is aimed at Designing plant producing PGMME 13.032 MT/Day and the detail study of mass and energy balances were theoretically drafted. The corresponding design of Shell and Tube heat exchanger was done. The cost estimation and payout period for PGMME plant is calculated.

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SYMBOLS	DESCRIPTION	UNIT
C_P	Specific heat	KJ/Kg K
Q	Heat transfer rate	KW
M_s	Mass flow Rate	Kg/ hr
λ_s	Latent heat of vaporization	KJ/Kg
ΔT	Temperature difference	K
ρ	Density	Kg/m^3
μ	Viscosity	Pa.S
k	Thermal Conductivity	W/mK
LMTD	Logarithm mean temperature difference	K
F_T	Friction Factor	
U_o	Overall heat transfer coefficient	W/m^2 K
D_b	Bundle diameter	m
N_t	Number of tubes	
V_t	Linear velocity	m/s
N_{Re}	Reynolds Number	
N_{pr}	Prandtl number	
N_{nu}	Nusselt number	
h_i	Tube side heat transfer coefficient	W/m^2K
P_t	Tube pitch	m
D_s	Shell diameter	m
A_s	Cross Sectional area of shell	m^2
V_s	Velocity	m/s
D_e	Equivalent diameter	m
h_s	Shell side heat transfer coefficient	W/m^2K
ΔP	Pressure drop	Psi

CHAPTER 1

1. INTRODUCTION

The process involves the reaction of propylene oxide and methanol in the presence of Tri – Ethyl Amine catalyst in the continuous flow reactor. The reaction is exothermic reaction with the formation of by-product Di-Propylene Glycol Monomethyl Ether (DPGMME). The product stream from the reactor is sent to the first distillation column (Methanol column) where large amounts of Methanol are recovered at the top along with small traces of PO and TEA is recycled along with feed. PGMME & DPGMME is removed from the bottom is sent to PGMME distillation column. where in the PGMME stream is recovered as top product and DPGMME as bottom product.

All outlet streams are cooled to ambient temperature

1.1 RAW MATERIALS

- Propylene oxide
- Methanol

1.2 CATALYST

- Tri – ethyl amine

1.3 REACTIONS

1.3.1. PGMME Reaction

$C_3H_6O + CH_3OH + TEA \rightarrow C_4H_{10}O_2$

1.3.2. DPGMME Reaction

$C_4H_{10}O_2 + C_3H_6O \rightarrow C_7H_{16}O_3$

1.4 FEED CHARACTERISTICS AND CONDITIONS

1.4.1 Propylene Oxide (C_3H_6O)

Appearance : Clear Liquid

Color : 10 Hazen max

Distillation Range : 33 – 37 Deg c

Acidity-As acetic acid : 50 ppm

Nonvolatile residue : 10 mg/ 100 ml (Max

Aldehyde Content–Propanol : 50 ppm (Max)

Water : 200 ppm (Max)

1.4.2 Methanol (CH_3OH)

Grade : Commercial

Appearance : Clear colorless liquid

Moisture %(Max) : 0.5

Specific gravity at 25 Deg C : 0.790 – 0.795

Boiling Point Range (Deg C : 64.5

Purity % (Min) : 99.5

Density (g/ml) : 0.7913 at 20 Deg C

Odor : Pure material has a slight Alcoholic odor.

1.5 UTILITY SPECIFICATIONS

Table 1.5 : Steam

Steam	Normal	Design
Pressure (KSC g)	3	6
Temperature (Deg C)	156	212
Fouling factor (Hr. Sq.cm/ K Cal)	1×10^{-4}	

Table 1.5.2: Cooling Water

Cooling Water	Normal	Design
Supply Pressure (KSC g)	3.2	6
Return Pressure (KSC g)	1.5	6
Supply Temp (Deg C)	29 - 34	
Return Temp (Deg C)	43 (Max)	65

Table 1.5.3 : Nitrogen

Nitrogen	Normal	Design
Pressure	6	6
Temp	Ambient	212
Oxygen Content (PPM)	1000	-
Dew Point (Deg C)	-40	-
CO2 Content (PPM)	7	-
CO & Oil content	-	-

Table 1.5.4 : Instrument Air

Instrument Air	Normal	Design
Pressure	6	6
Temp	Ambient	65
Dew Point (Deg C)	-40	
Oil content	Free from oil	

Table 1.5.5 : Plant Air

Plant Air	Normal	Design
Pressure	6	6
Temp	Ambient	65
Dew Point (Deg C)	Saturated	
Oil content	Free from oil	

Table 1.5.6 : Electricity

Electricity	
For all motors	415 V, 50 3 Phase + 6%

CHAPTER 2

2. PROCESS DESCRIPTION

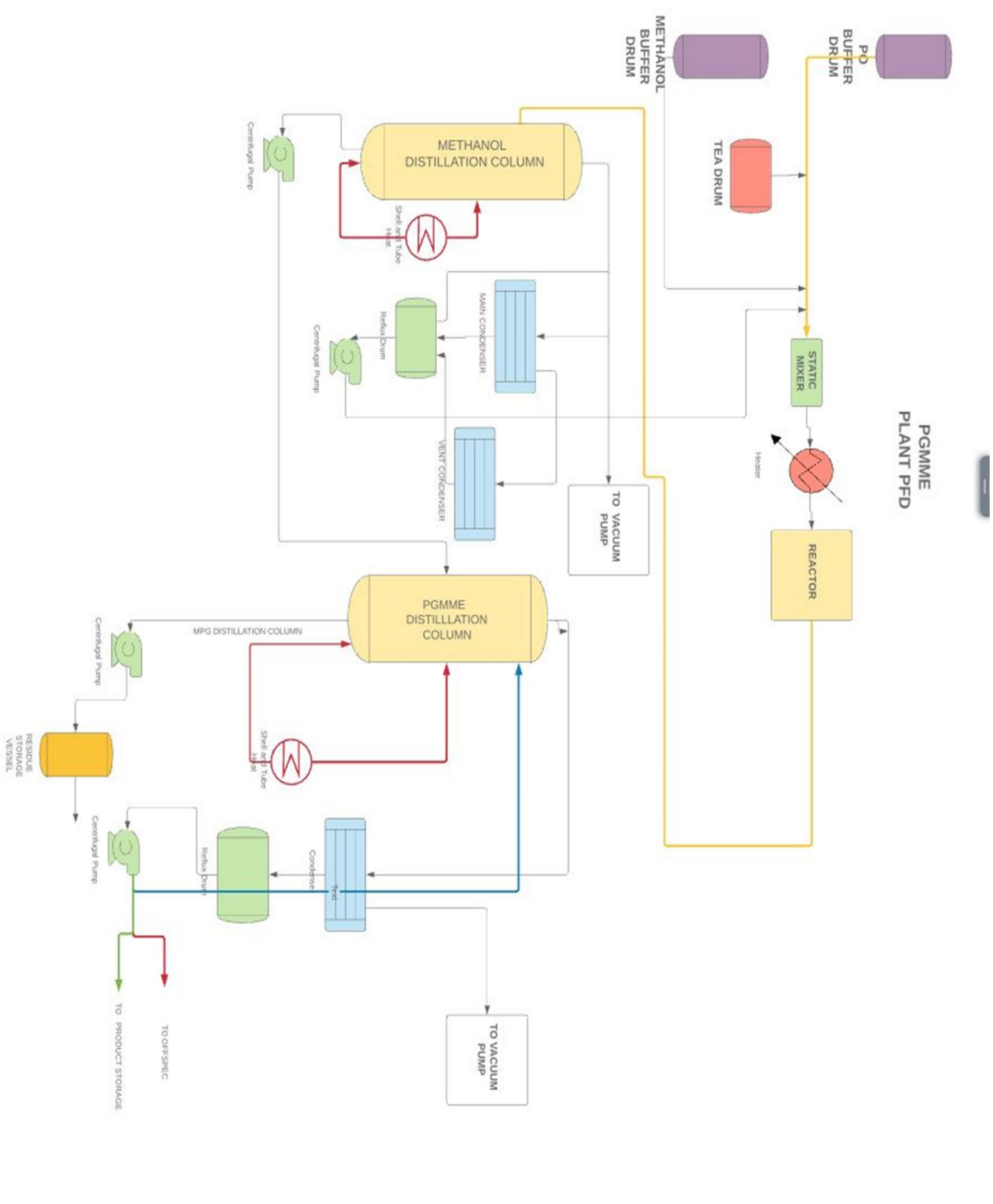


Figure 2.1 : Figure of Process Flow Diagram

2.1 PROCESS THEORY

In both the reactions, propylene oxide molecule adds to the hydroxyl group of the ether alcohol to yield higher derivatives The yield ratio of MPGMME Isomer — I, MPGMME Isomer — II and DPGMME depends on the composition of the initial Propylene Oxide to Methanol mole ratio. The excess methanol is distilled out in the methanol distillation column and recycled back to the reactor through reflux pump. DPGMME is fractionated from the product PGMME in the PGMME distillation column.

2.2 REACTION SECTION

The reactor section comprises of the catalyst addition, premixing, pre-heater and the reactor. The catalyst is injected to the system as and when required to maintain a concentration of around 2% in the reactor feed. The catalyst is not used in the reaction and is flashed in the first column along with excess methanol and recycled back to system through the recycle methanol stream.

The normal operating pressure of the reactor is around 2.5 KSC g and the maximum is limited to 3.5 KSC g. Since the catalyst added during in order to ensure even mixing of the Propylene Oxide, Methanol and the catalyst a static mixer is provided before entering the feed pre-heater.

2.3 METHANOL DISTILLATION SECTION

Methanol is used in excess in the process of manufacture of PGMME to minimize the production of the byproduct. The excess methanol and catalyst are distilled in this column md recycled back to the reactor. The column is operated under vacuum at 400 mbar absolute pressure. The top temperature of the column will be around 50 Deg C and bottom temperature at around 108 Deg C.

The falling film type reboiler uses a forced circulation using the circulation pump. The column is packed with structured packing for improved efficiency of separation. Methanol is condensed in two stages Methanol distillation condenser with cooling water and Methanol vent condenser using glycol water. The uncondensed vapor released from the methanol distillation reflux drum is condensed. Crude

PGMME is withdrawn from the bottom of distillation column is to PGMME distillation column.

2.4 PGMME Distillation Section

Crude PGMME with byproducts like DPGMME and higher residue glycol ethers formed in the reactor is removed in this section. PGMME distillation column is operating at around 200 mbar absolute pressure with a top temperature of 85 Deg C and bottom temperature of 113 Deg C. Falling film reboilers with forced circulation and structured packing have again be used here also as in methanol distillation column. The PGMME vapor are condensed using cooling water md collected in the reflux drum.

The DPGMME and higher glycol ethers are removed from the system as residue from the bottom of the column. The product is cooled in the exchanger and taken to product storage vessels.

CHAPTER 3

3. MATERIAL BALANCE

A material balance is an accounting of all the materials that enters, leaves, accumulates, disappears in a process unit in a given time.

3.1 LAW OF CONSERVATION OF MASS

All material balance calculations are based on the law of conservation of mass, which states that matter can be neither created nor destroyed during the process.

Table 3.1 : Chemicals and Molecular Weight

S. No	Chemical Name	Chemical Formula	Mol. wt.
1	Propylene Oxide	C_3H_6O	58
2	Methanol	CH_3OH	32
3	Tri Ethyl Amine (TEA)	$N(CH_2CH_3)_3$	101
4	PGMME - 1	$C_4H_{10}O_2$	90
5	PGMME - 2	$C_4H_{10}O_2$	90
6	DPGMME	$C_7H_{16}O_3$	148
7	Moisture	H_2O	18

We are dividing the plant into two sections and we are considering nine streams for the convenience of mass balance.

- Reaction stream
- Distillation stream

3.2 PROCESS STREAMS

- PO from buffer storage
- Methanol from buffer storage
- Tri Ethyl Amine from TEA pot
- Static Mixture to reactor inlet

- Reactor outlet to methanol distillation column
- Methanol column distillate & overhead stream
- Methanol column bottom stream
- PGMME distillate column distillate stream
- PGMME bottom stream.

3.2.1 *PO Buffer*

Composition :

PO : 99.975%
H2O : 0.025%
Flow Rate : 350 Kg / hr.
PO : 349.9125 Kg / hr.
H2O : 0.0875 Kg / hr.

3.2.2 *Methanol Buffer*

Composition :

Methanol : 99.95%
H2O : 0.05%
Flow Rate : 200 Kg / hr.
PO : 1999.9 Kg / hr.
H2O : 0.1 Kg / hr.

3.2.3 *Tri Ethyl Amine (TEA) buffer Storage*

Composition :

TEA : 100%
Flow Rate : 6.25 Kg / hr.

3.2.4 *Static Mixture*

Stream Flow Rate :

Methanol : 199.90 Kg / hr.
TEA : 6.25 Kg / hr.
PO : 349.9125 Kg /hr.

Recycle Methanol : 1550 Kg / hr.
Moisture : 0.968 Kg / hr.
Total : 2106.25 Kg / hr.

3.2.5 Material Balance for Reactor

Assume all PO is converted to PGMME & DPGMME. By stoichiometry the amount of methanol consumed for the reaction is

$C_3H_6O + CH_3OH + TEA \rightarrow C_4H_{10}O_2$
58 **32** **60**

58 Kg of PO reacts to form 90 Kg of PGMME.

90 / 58 = X / 349.9125
X = 542.97
= 543 Kg

Amount of Product formed is 543 Kg / hr.
Amount of methanol is consumed is 543 – 349.9125 = 193.04 Kg / hr.
Excess methanol = 1550 +(200-193.04)
= 1557 Kg /hr.

- TEA – a catalyst finds no mass reduction so reactor outlet composition is 6.25 Kg/hr.
- Moisture doesn't take part in Reaction

We have found PGMME-1, PGMME-2 and concentration in reactor outlet as per stoichiometry we should get

90/58 = X/349.9125
= 543 Kg
Therefore, X * 245 = PGMME / Day
= 13032 Kg / Day

but actually, we are uptraining 11.35 Metric ton / Day. So, the rest is PGMME-2 or DPGMME.

11.35/24 = 472.91 Kg/hr.

but the product specification is

PGMME-1 = 99.67%
PGMME-2 = 0.25 %
H_2O = 0.08%
So PGMME in product = 472.91 * 0.996 = 471.349 Kg
PGMME-2 = 1.1863 kg
H_2O = 0.373 Kg

DPGMME AND PGMME-2 calculated by knowing PGMME bottom concentration.

As per specification,

PGMME-1 = 9.92%
PGMME-2 = 40%
DPGMME = 0.08%
543 = 472.91 + Bottom
Bottom product per hour = 70.09 Kg.
PGMME-1 = 6.95 Kg
PGMME-2 = 28.03 Kg
DPGMME = 35.045 Kg
H_20 = 0.05 Kg
PGMME = 471.349 + 6.95 = 478.29 Kg
PGMME-2 = 129.22 Kg
H_2O = 0.434 Kg

3.2.6 Reactor Outlet Stream Composition in Kg/hr.

PO = Nil
Methanol = 1556.098 Kg/hr.
H_2O = 0.968 Kg/hr.
PGMME-1 = 472.83 Kg/hr.
PGMME-2 = 39.57Kg/hr.
DPGMME = 30.54 Kg/hr.
TEA = 6.25 Kg/hr.

3.2.7 Material Balance for Methanol Distillation Column

Methanol Overhead :

Methanol = 1550.7 Kg
TEA = 6.25 Kg
Moisture = 0.3907 Kg

Methanol Bottom :

PGMME = 478.29 Kg
DPGMME = 30.43 Kg
PGMME -2 = 38.36411 Kg
Moisture = 0.434 Kg

3.2.8 Material Balance for PGMME Distillation Column

Overhead Product Composition :

PGMME = 465.0104 Kg
PGMME-2 =1.16 Kg
H2O = 0.373 Kg

Bottom Product Composition :

PGMME = 7.5 Kg
PGMME-2 = 2.38456 Kg
H2O = 0.0614 Kg
DPGMME = 30.763 Kg

CHAPTER 4

4. ENERGY BALANCE

An energy balance is a consideration of the energy input, output, and consumption or generation in a process or stage. In establishing an energy balance, all sources of thermal energy are put on the input side, and all items of heat utilization on the output side.

4.1 LAW OF CONSERVATION OF ENERGY

Law of conservation of energy states that energy can be neither created nor destroyed during the process although it can be converted from one form to another.

4.2 ENERGY BALANCE FOR PREHEATER

For process fluid MCp ΔT

= 2106.25 Kg/hr. * 1182.17105 KJ/Kg 0 K * (343.15 K – 303.15 K)

= 99597311.47 KJ/hr.

= 27666.08 KW

For steam MCp ΔT

= 199.287 Kg/hr. * 1.851 KJ/Kg 0 K * (478.15 k – 405.15 k)

= 27666.08 KW

4.3 ENERGY BALANCE FOR REACTOR

Mass flow of PO = 350 Kg/hr.
Mass flow of methanol = 1750 Kg/hr.
Mass flow of PGMME = 478 Kg/hr.
Mass flow of DPGMME = 54 Kg/hr.
Mass flow of unreacted methanol = 1060 Kg/hr.
Inlet temp. of PO = 303 K
Inlet temp. of Methanol = 303 K
Outlet temp. of PGMME = 374 K
Cp of Po = 2.07 KJ/Kg0 C
Cp of Methanol = 2.56 KJ/Kg0 C

Cp of PGMME = 2.476 KJ/Kg0 C

Cp of DPGMME = 2.25 KJ/Kg0 C

Heat of formation of PO = -30238 KJ/Kg

Heat of formation of methanol = -7.435 KJ/Kg

Heat of formation of PGMME = -31714 KJ/Kg

Heat of formation of DPGMME = -25400 KJ/Kg

Calculation:

Methanol heat input = MCp ΔT

= 1750 * 2.56 (374 – 303)

= 134400 KJ/Kg

PO heat input = 350 * 2.07 * 7

= 22119.2 KJ/Kg

Heat of Reaction of PGMME:

$\Delta H_R = (H_F)_P – (\Delta H_F)_R$

= -317.14 – (-302.38 – 7.435)

= - 1466.825 KJ/Kg

Heat of Reaction of DPGMME:

= - 25400 – (- 8500 – 11.83)

= 35083.435 KJ/Kg

ΔHR = 33616.61 KJ/Kg

Total heat input = 156519.2 KJ/Kg

Heat output of methanol = 117122.428 KJ/Kg

Heat output of PGMME = 12271.5 KJ/Kg

Heat output of DPGMME = 60784.64 KJ/Kg

Total heat output = 190178.658 KJ/Kg

Heat Balance for Reactor:

Heat input + Heat formation = Heat output

156519.2 + 33616.61 = 190178.658 KJ/Kg

190135.81 KJ/Kg = 190178.658 KJ/Kg

4.4 ENERGY BALANCE FOR DISTILLATION COLUMN

q_c – Amount of heat removed from condenser

q_r – Amount of heat removed from reboiler

X_F – Weight fraction of A in feed

h_F – Enthalpy of feed

V_1 - Amount of vapors

H_1 – Enthalpy of vapors

Y_1 – Weight fraction of A in vapors

L_o – Amount of Reflux

X_o – Weight fraction of Ain reflux

H_o – Enthalpy of reflux

D – Distillate

X_D – Weight fraction of A in distillate

H_D – Enthalpy of distillate

W – Amount of residue

X_x – Weight fraction of A in residue

H_x – Enthalpy of residue.

Law of Conservation of Energy :

Energy input = Energy output

Assume no heat loss

Overall Energy Balance Equation :

$q_r + F\ h_F = D\ h_D + W\ h_w + q_c$

4.4.1 Energy Balance for Methanol Distillation Column

q_r = 229431.09 KW

F = 2106.25 Kg/hr.

h_f = 288.20385 KJ/Kg. K

D = 1557.3407 Kg/hr.

H_D = 193.9209 KJ/Kg. K

W = 543.829 Kg/hr.

h_W = 680.335423 KJ/Kg. K

q_C = 231002.2332 KW

$q_r + F\ h_F$ = 229439.8809 + 210.25 * 288.2038

= 231188.8963 KW

$DH_o + Wh_w + q_c$ = 1557.3407 * 193.9302 + 543.829 * 680.33543 + 231002.233

= 231188.88 KW

4.4.2 Energy Balance for PGMME Distillation Column

q_r = 64.833183 KW

F = 543.4 Kg/hr.

h_f = 287.31364 KJ/Kg. K

D = 466.5434 Kg/hr.

h_D = 619.5255 KJ/Kg. K

W = 76.867 Kg/hr.

h_W = 59.9841 KJ/Kg. K

q_C = 35.39 KW

$q_r + F\ h_F$ = 64.8331183 + 543.4 * 287.313

= 108.2014 KW

$DH_o + Wh_w + q_c$ = 466.5434 *619.5255 + 76.867 * 590.984 + 35.39

= 108.2014 KW

CHAPTER 5

5. EQUIPMENT DESIGN

Table 5.1: Shell and Tube Heat Exchanger

	Process Fluid (Gas mixture)	**Service Fluid**
Inlet Temp.(K)	405	293
Outlet Temp.(K)	303	308
Heat transfer rate (Q (KW)	7788.9	
Mass flow rate m_h(Kg/sec)	8.283	

Table 5.2: Properties of Gas and Water at Mean Temperature

Properties	Gas (359K)	Water (300.5K)
ρ (Kg/m3)	643.80	996.4
µ (Pa.S)	4.876*10-5	10-3
K (W/mK)	0.125	0.609
cp (KJ/KgK)	19.91	4.187

Q = (m_h cp ΔT) hot = (mc cp_w ΔT) cold

7788.9= mc × 4.187 × (308 − 293)

Mc = 124.0 Kg / Sec

$$\text{LMTD} = \frac{(T_1 - T_2) - (t_1 - t_2)}{ln\frac{(T_1 - T_2)}{(t_1 - t_2)}}$$

$$= \frac{(405-313)-(308-293)}{ln\frac{(405-313)}{(308-293)}}$$

= 42.45 K

ΔTm = LMTD * FT

$$FT = \frac{\left[\sqrt{R^2+1}\ln\frac{(1-S)}{(1-RS)}\right]}{[(R-1)ln\frac{2-S\left(R+1-\sqrt{R^2+1}\right)}{2-S\left(R+1+\sqrt{R^2+1}\right)}}]$$

$$R=\frac{(T_1-T_2)}{(t_1-t_2)} \qquad S=\frac{(t_1-t_2)}{(T_1-T_2)}$$

$$R = \frac{(327.15-313)}{(308-293)} = 6.133$$

$$S = \frac{(308-293)}{(327.15-293)} = 0.1339$$

$$FT = \frac{[\sqrt{6.1332^2+1}\ \ln\frac{(1-0.1339)}{(1-6.133*0.1339)}]}{[(6.133-1)ln\frac{2-0.1339\left(6.133+1-\sqrt{6.133^2+1}\right)}{2-0.1339\left(6.133+1+\sqrt{6.133^2+1}\right)}]}$$

= 0.8773

ΔTm = LMTD * FT = 42.45 * 0.8773

= 37024 K.

The U value is obtained from the 8.05- 625 W m2 o/c Outside diameter is 25mm the wall thickness is 1.6mm.

d_i = d_o − 2(t) = 25 − (2 × 1.6) = 21.8 mm

Heat transfer area

$$A = \frac{Q}{U\Delta T_m}$$

$$A = \frac{7788.9}{625 \times 37.24}$$

A = 334.64 m2

The preferred length of the tube is 12ft (3.66m)

Area of one tube = π d_0 l = π × 25 × 10^{-3} × 3.66 = 0.2875m2

$$N_t = \frac{\text{heat transfer area}}{\text{area of one tube}} = \frac{334.64}{0\cdot2875} = 1164 \text{ tubes.}$$

Bundle diameter

$$D_b = d_O \left(\frac{N_t}{K_1}\right)^{\frac{1}{n_1}}$$

K1 = 0.0402 n1 = 2.617

$$D_b = 20*10^{-3} (1164 / 0.0402)^{1/2.617}$$

$$= 1.267 \text{ m}$$

5.2 TUBE SIDE DESIGN

Cross sectional area of tube $= \frac{\pi}{4} d_i^2$

$= \frac{\pi}{4} 21.8* 10^{-3} = 3.732* 10^{-4}$ m^2

Tube pre pass $= \frac{\text{Tube no of tube}}{\text{Number of passes}}$

$= \frac{1164}{6} = 194$

Total flow rate of tube side fluid = (tube C.S. A) × (no. of tubes per pass)

$= 3.732 \times 10^{-4} \times 194 = 0.0724$ m^2

Mass velocity (tube side) $= \frac{\text{flow rate of tube side fluid}}{\text{total flow area of tube}}$

$= \frac{124}{0.0724}$

= 1712.68 Kg / sm^2

Linear velocity $= \frac{\text{mass velocity fluid}}{\text{density}}$

$V_t = \frac{1712.68}{996.4}$

V_t = 1.718 m / s

Reynolds number $N_{Re} = \frac{\text{di vt}\rho}{\mu}$

$= 21.8 \times 10^{-4} \times 1.718 \times 996.4 / 10^{-3}$

= 37317.571

Prandtl number $N_{Pr} = \frac{\text{cp}\mu}{\text{k}}$

$= 4.187 \times 10^{-3} / 0.609 = 6.875$

Nusselt number $N_{Nu} = 0.023 N_{Re}^{0.8} N_{Pr}^{0.4}$

$= \frac{\text{hi k}}{\text{di}} = 0.023 * 37317.571^{0.8} * 6.875^{0.4}$

= 226.03

$h_i = 226.03 * (0.609 / 21.8 * 10^{-3}) = 6314.34\ \text{W/m}^2\text{k}$

5.3 SHELL SIDE DESIGN

Cross sectional area of shell AS $= \frac{(P_t - d_0)}{p_t} D_s l_B$

$P_t = 1.25 \times do = 31.25$mm.

Ds = Db + clearance

$= 1.267 + (22 \times 10^{-3}) = 1.289$ m

$l_B = (1 / 5)\ DS = (1 / 5) \times 1.289 = 0.2578$ m.

AS $= (31.25*10^{-3} - 25*10^{-3}) / 31.25 \times 10^{-3} * (1.289*$ 02578)

$= 0.0664\text{m}^2$

Mass velocity $G_S = \frac{w_s}{A_s} = 8.283 / 0.0664$

$= 124.62\ \text{Kg / sm}^2$

Velocity v_s = G S ρ = 0.866 m /s

Reynolds number N_{Re} = De GS μ

equivalent diameter D_e = $\frac{1\cdot 27}{d_0} P_t^2 - (0 \cdot 785 d_0^2)$

$= \frac{1\cdot 27}{25 \times 10^{-3}}((31.25 \times 10^{-3})2 - (0 \cdot 785 \times (25 \times 10^{-3})^2))$

= 0.02468 m

N_{Re} = (0.02468 × 124.62) / (4.876 × 10^{3})

= 63,076.73

Prandtl number N_{Pr} = c_{pu} / k = (19.09 × 10^{-3} * 4.87*10^{-5})/0.125

= 7.7664

Nusselt number N_{Nu} = $j_h\, N_{Re}\, N_{Pr}^{1/3} / (\mu / \mu_w)^{-0.14}$

j_h = 1.8 × 10^{-3}

N_{Nu} = $h_s D_e / k = 1.8 \times 10^{-3} \times 63076.73 \times 7.7661^{1/3}$

h_s = 224.84 × (0.125 / 0.02468) = 1202.04W / m^2 ⁄ K

overall heat transfer co efficient $\frac{1}{U_0} = \frac{1}{h_s} + \frac{1}{h_{s_d}} + \frac{\ln\left(d_0/d_i\right)}{2k_w} + \frac{d_0}{d_i}\left(\frac{1}{n_{id}}\right) + \frac{d_0}{d_i}\left(\frac{1}{h_i}\right)$

kw − thermal conductivity of metal

$$=\frac{1}{1202.04} + \frac{1}{4000} + \frac{25*10^{-3}\ln\left(\frac{25}{21\cdot 8}\right)}{2*378} + \frac{25}{21.8}\left(\frac{1}{4000}\right) + \frac{25}{21.8}\left(\frac{1}{6314.34}\right)$$

$= 0.00155.$

$\mu_O = 643.192 W/m^2K$

Pressure Drop

$\Delta Pt = Np\ (8\ j_f\ (L / di)\ (\mu / \mu_W)^{-0.14} + 2.5)\ \rho\ v_t^{\ 2} / 2$

$j_t = 3.6 * 10^{-3}$

$= 6\ (8 \times 3.6 \times 10^{-3}\ (3.66 / 21.8 \times 10^{-3}) + 2.5) \times 996.4 \times 1.7182^2/2$

$= 64,716.495\ N / m2$

$\Delta Pt = 9.386$ psi

$\Delta Ps = 8ji\ (L / l_B)\ (D_s / D_e)\ (\rho v_s^2 / 2)\ (\mu / \mu_w)^{-0.14}$

$= 8 \times 3.8 * 10^{-2} \times (3.66 / 0.2578)(1.289 / 0.02468) 643.8 * 0.8662^2/2$

$= 54,417.2109\ N / m2$

$\Delta Ps = 7.89$ psi

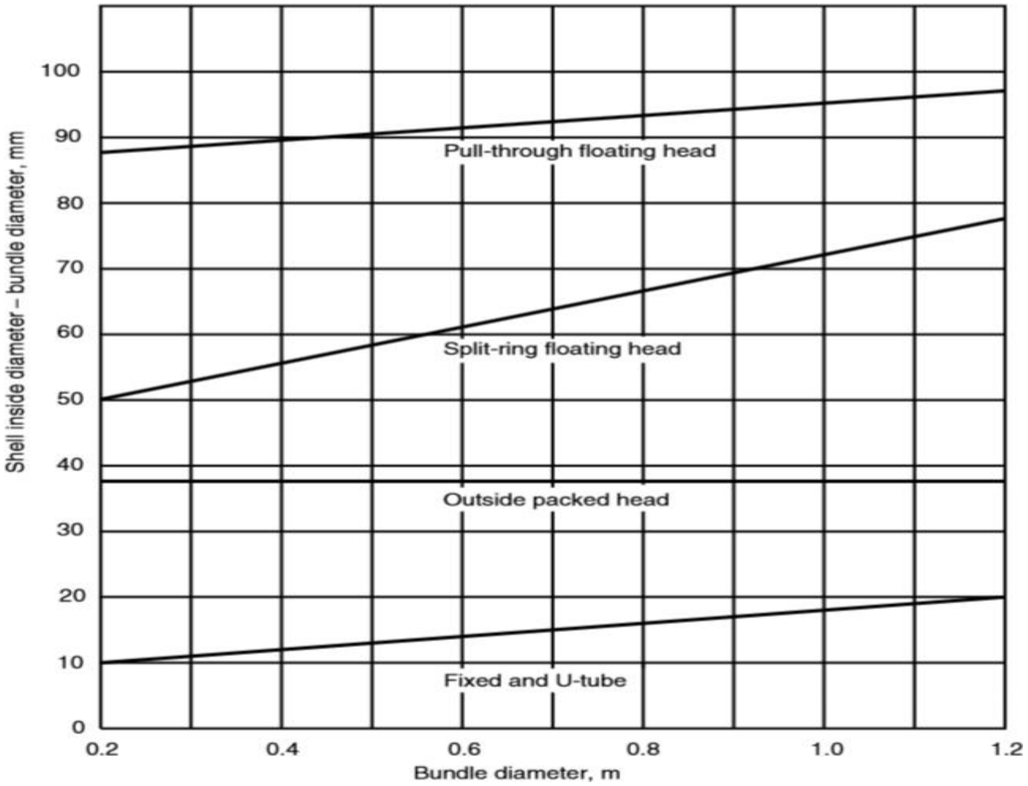
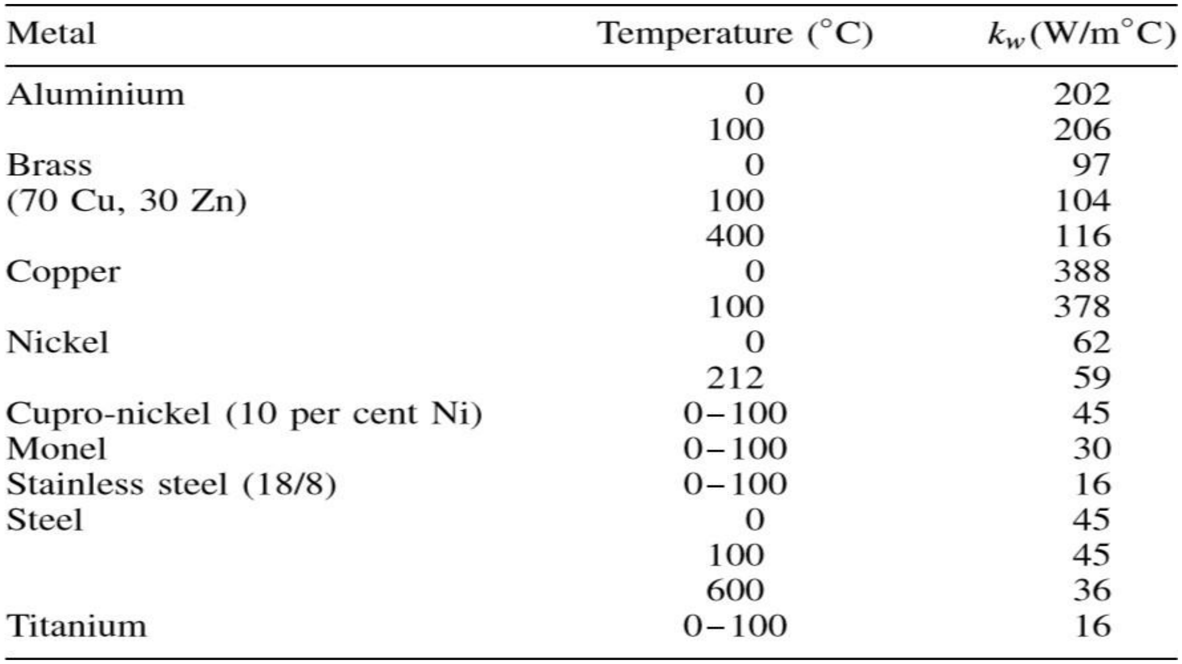


Figure 5.1: Shell- Bundle Clearance

Table 5.3: K_1 and n_1 Value

Triangular pitch, $p_t = 1.25d_o$					
No. passes	1	2	4	6	8
K_1	0.319	0.249	0.175	0.0743	0.0365
n_1	2.142	2.207	2.285	2.499	2.675
Square pitch, $p_t = 1.25d_o$					
No. passes	1	2	4	6	8
K_1	0.215	0.156	0.158	0.0402	0.0331
n_1	2.207	2.291	2.263	2.617	2.643

Table 5.4: Conductivity of Metals



Metal	Temperature (°C)	k_w (W/m°C)
Aluminium	0	202
	100	206
Brass	0	97
(70 Cu, 30 Zn)	100	104
	400	116
Copper	0	388
	100	378
Nickel	0	62
	212	59
Cupro-nickel (10 per cent Ni)	0–100	45
Monel	0–100	30
Stainless steel (18/8)	0–100	16
Steel	0	45
	100	45
	600	36
Titanium	0–100	16

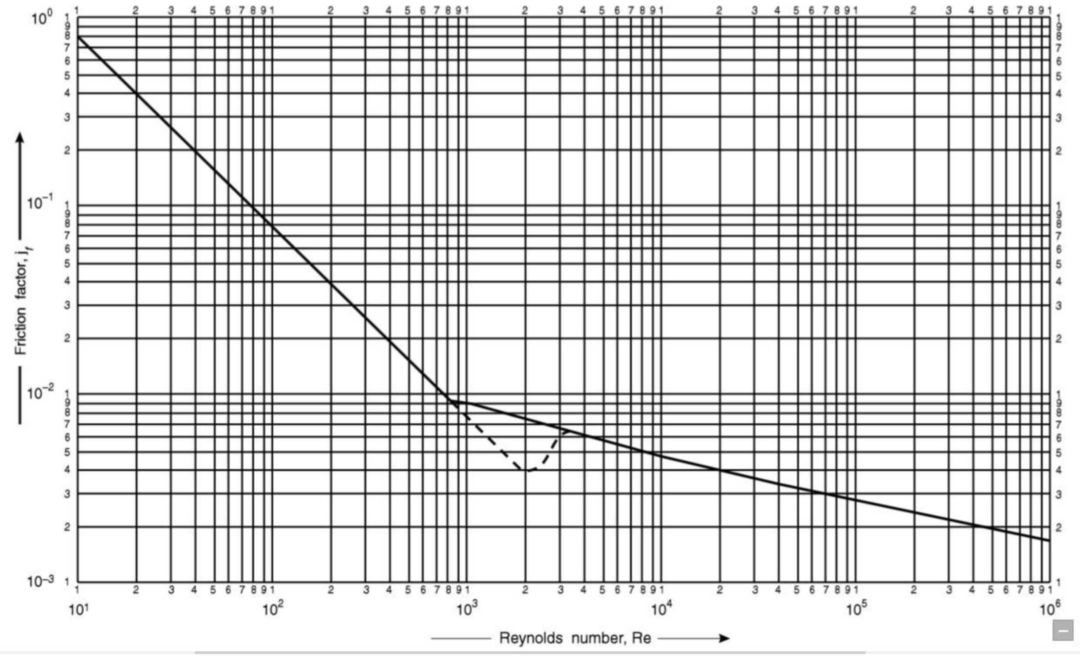


Figure 5.2: Tube Side Friction Factor

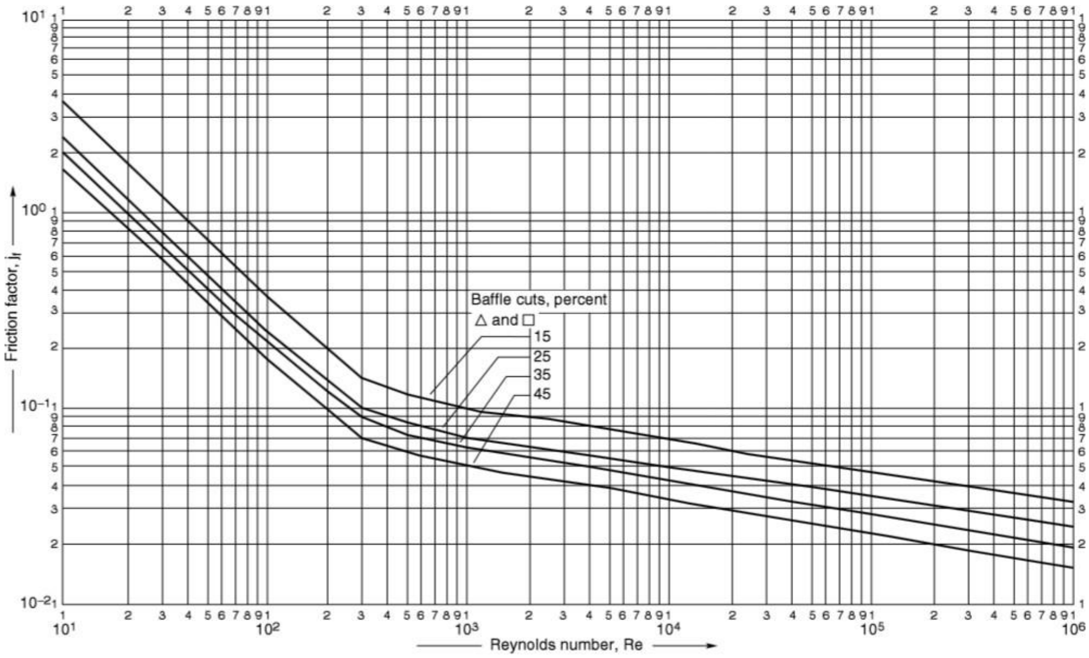


Figure 5.3: Shell Side Friction Factor, Segmental Baffles

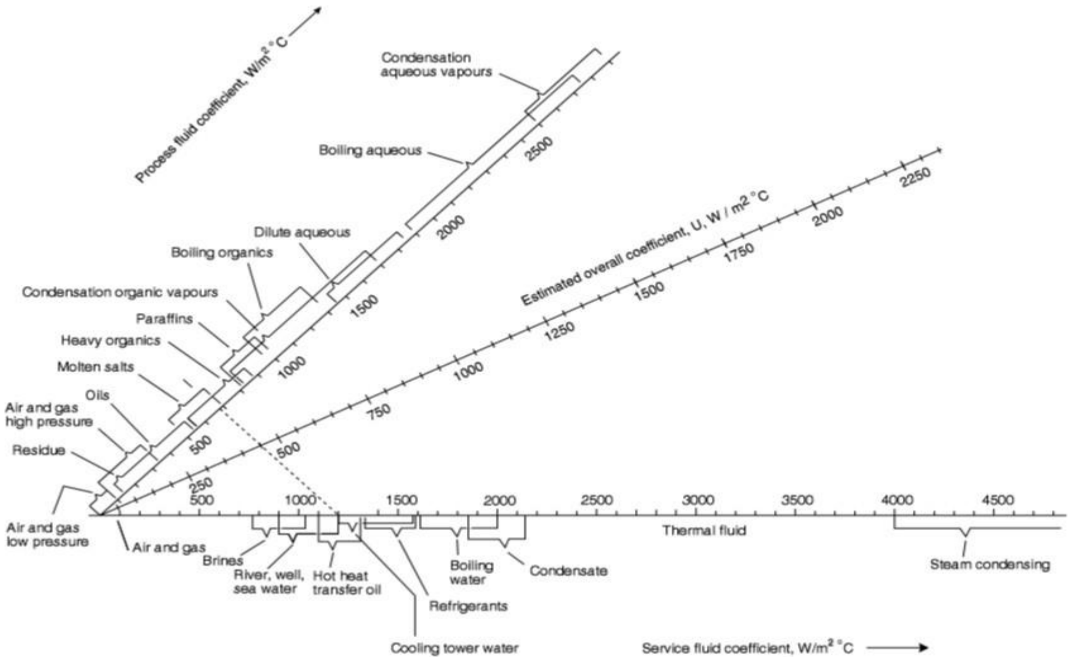
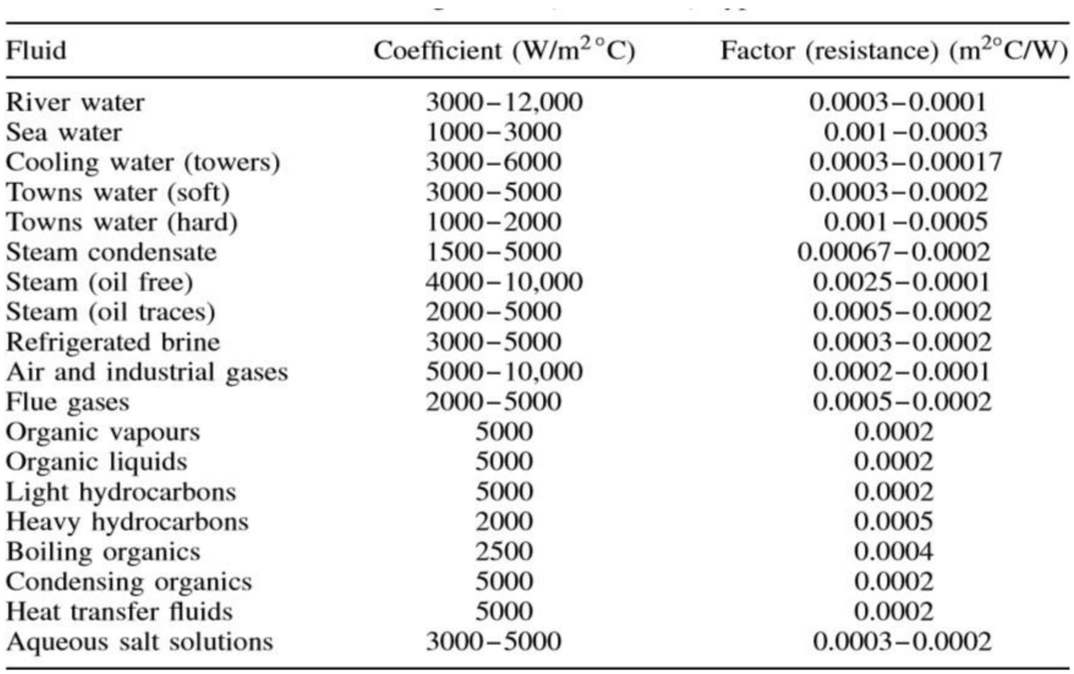


Figure 5.4: Overall Coefficients (Join Process Side Duty to Service Side and Read u from Center Scale)

Table 5.5: Fouling Factors (Coefficient), Typical Values



Fluid	Coefficient (W/m^2°C)	Factor (resistance) (m^{2}°C/W)
River water	3000–12,000	0.0003–0.0001
Sea water	1000–3000	0.001–0.0003
Cooling water (towers)	3000–6000	0.0003–0.00017
Towns water (soft)	3000–5000	0.0003–0.0002
Towns water (hard)	1000–2000	0.001–0.0005
Steam condensate	1500–5000	0.00067–0.0002
Steam (oil free)	4000–10,000	0.0025–0.0001
Steam (oil traces)	2000–5000	0.0005–0.0002
Refrigerated brine	3000–5000	0.0003–0.0002
Air and industrial gases	5000–10,000	0.0002–0.0001
Flue gases	2000–5000	0.0005–0.0002
Organic vapours	5000	0.0002
Organic liquids	5000	0.0002
Light hydrocarbons	5000	0.0002
Heavy hydrocarbons	2000	0.0005
Boiling organics	2500	0.0004
Condensing organics	5000	0.0002
Heat transfer fluids	5000	0.0002
Aqueous salt solutions	3000–5000	0.0003–0.0002

CHAPTER 6

6. COST ESTIMATION

The present fixed capital investment cost

= Original cost (Cost index A / Cost index B)

= $1.623 * 10^{10} * (573.6/550.8)$

FCIC = Rs $1.69 * 10^{10}$

6.1 ESTIMATION OF TOTAL INVESTMENT COST

1. Purchased equipment cost: (15 – 40 % of FCI)
   Assume 30 % of FCI = Rs $5.07 * 10^9$

2. Installation cost: (25 45 % of PEC)
   Assume 35%
   = Rs $1.7745 * 10^9$
3. Instrument and control installed: (6 – 30% of PEC)
   Assume 25% of PEC = Rs 1.2675×10^9

4. Instrument and control installed: (6 – 30% of PEC)
   Assume 25% of PEC = Rs 1.2675×10^9

5. Piping installation cost: (10 – 80% of PEC)
   Assume 60% = Rs. 3.042×10^9

6. Electrical installation cost: (10 – 40% of PEC)
   Assume 35% of PEC = Rs 1.7745×10^9

7. Building process and auxiliary: (10 − 70% of PEC)
   Assume 60% = Rs 3.042×10^9

8. Service facilities: (30 − 80% 0f PEC)

Assume 50% = Rs 2.535×10^9

9. Yard improvement: (10 − 15% of PEC)
   Assume 10% = Rs 5.07×10^8

10. Land: (4 − 8% of PEC)
    Assume 6% = Rs 3.042×10^8

11. direct cost = PEC + Installation Cost Instrument + Piping + Electrical + Building + Service + Yard + Land
    $= 1.9316 \times 10^{10}$

6.2 INDIRECT COST

Expenses which are not directly involved with material and labor of actual installation or complete facility

1. Engineering and supervision: (5 − 30% of DC)
   Assume 25% = Rs 4.829175×10^9

2. Construction expenses: (6 − 30% of DC)
   Assume 16% = Rs 3.090×10^9

3. Contingency: (5 − 15% of DC)
   Assume 12% = Rs 2.318004×10^9

4. Indirect Cost = Engineering & Supervisions + Construction & contractor + Contractor + Contingency
   = Rs2.9554551×10^{10}

6.3 FIXED CAPITAL

investment Fixed capital investment (FCI) = DC + IC

= Rs 2.955455×10^{10}

Working capital investment: 10 – 20% of FCI

Assume 16% = Rs 4.7287816×10^9

Total capital investment: = FCI + WC

= Rs 3.4283279×10^9

6.4 ESTIMATION OF TOTAL PRODUCT COST (TPC)

6.4.1 Fixed Charges

1. Depreciation: (10% FCI &2 − 3% of building)

   = Rs 3.0315051×10^9

2. Local taxes: (1 − 4% of TPC) Assume 3%

   = Rs8.8663653×10^8

6.4.2 Direct Production

1) Raw material: (10 − 50% 0f TPC) Assume 40%

   = Rs 8.919287×10^9

2) Operating labor (OL): (10 − 20% of TPC) Assume 15%

   = Rs 3.344732×10^9

3) Direct supervisory and electric labor: (10 − 25% of OL) Assume 20%

   = Rs 6.68946×10^9

4) Utilities: (10 − 20% of TPC) Assume 15%

   = Rs 3.3447326×10^9

5) Maintenance: (2 − 10% of FCI) Assume 8%

   = Rs 2.06881×10^8

6) Operating supplies (OS): (0.5 − 1% of maintenance) Assume 15%

   = Rs 2.06881×10^8

7) Laboratory charges: (10 − 20%of OL) Assume12%

= Rs4.0136 × 10^8

8) Patent and royalties (0 − 6% of TPC) Assume 4%

= Rs 8.919287 × 10^8

Direct Production Cost = 2.01422 × 10^{10}

Plant overhead cost: (5 − 15% of TPC) Assume 10%

= Rs 2.2298 × 10^9

Manufacturing cost = direct production cost + fixed charges + plant overhead cost

= 2.68317 × 10^{10}

6.5 GENERAL EXPENSES

1) Administration cost: (15% operating Labor Supervision & maintenance)

= Rs 9.567 × 10^8

2) Distribution and selling price: (2 − 20% of TPC) Assume 15%

= Rs 4.024755 × 10^9

3) Research and development cost: (5% of TPC)

= Rs 1.341585 × 10^9

Therefore, general expenses (GE) = Rs 6.323047 × 10^9

Total Product Cost = Manufacture cost + general expenses

= Rs 3.31547544 × 10^9

6.6 GROSS EARING COST

Price of PGMME = Rs. 52232.5/ ton

Total income = 52232.5 × 356 × 2400

= Rs 4.4627448×10^{10}

Gross earning = total income − total production cost

= 1.147269×10^{10}

Tax on gross earning 50%

= 5.736346×10^{9}

Net profit = gross earning − tax on gross earning

= 5.7363468×10^{9}

Rate of return = (net profit / total capital investment) × 100

= 16.732 %

6.7 BEP

Total Variable Cost = (Direct labor + 80% utilities) + material cost

= $(13.34473263 \times 10^{9} + 2.675786 \times 10^{9}) + 8.919287 \times 10^{9}$

= Rs 1.49398×10^{10}

Fixed cost = Fixed Charges + Building Process & auxiliaries + Land Cost

= $(4.45963 \times 10^{9} + 3.042 \times 10^{9} + 3.042 \times 10^{8})$

= Rs 7.80584349×10^{9}

BEP = (Fixed cost / (Total variable – net Profit))

= $7.80584349 \times 10^{9} / (1.49398057 \times 10^{10} - 5.7363468 \times 10^{9})$

= 0.84814

6.8 PAYOUT PERIOD

= FCI/ (net profile + Depreciation)

= $2.955455 * 10^{10} / (5.7363468 * 10^{9} + 3.0315051 * 10^{9})$

= 3 years 9 month

CHAPTER 7

7. INSTRUMENTATION AND PROCESS CONTROL

7.1 INTRODUCTION

Instrumentation and control are the nervous system of industrial complexes, power generation, and basically all the processes that require some intelligence to accomplish the task of producing a product or process.

Examples of other benefits obtained by applying control systems are evident in environmental controls, which help to manage the waste and regulate the interface between the system and the environment. One application in this area is seen in control of emissions which use specialized instruments and controls to decrease the impact of pollutants in the atmosphere.

The growth of the computer industry and its techniques has provided expanding technology in the controls area, consequently producing more efficient and sophisticated systems. These systems now control more precisely the production of goods and information given to operators to refine the quality of products and services. This course will walk you through the elements that make a control system and present to you the most common instrumentation used in industry

7.2 DEFINITIONS

Instrumentation:

Use of technology and devices to detect and control physical and chemical characteristics of materials; this includes motion, light, color, acidity, etc.

Control System :

A system that takes the information from instruments of a process manipulating it using logic (algorithms) then applying the results to a process or system to change its characteristics.

Process Control

A control system that is used in the process and chemical industries. A process control has the characteristic of automatically regulating a process.

Variables

Are defined as the characteristic of the process. Some variables are temperature, speed, humidity, viscosity, density, etc. There are two basic types of variables: measured or controlled, and manipulated.

Control Loop

Control loop is a control system architecture that will manage a process using elements that sense, adjust, and act upon the process.

Table 7.1: Comparison Between Closed and Open Loops

Open Loop	**Closed Loop**
A measurement is detected	A measurement is detected
Monitoring is performed (usually manually)	Measurement is compared to a set value
No adjustment is made	Adjustment is made to the process
Return to measurement	Return to measurement, repeating the adjustment until the set value and measurement are equal.
Examples	
A conveyor belt carrying material	Tank level control
A measurement is made (scale)	A level sensor feeds measurement to a transducer
An alarm bell performs monitoring	A comparison is made to set point at the controller
Reporting: Activation of alarm is made if weight is exceeded	Action: If level is low a signal is sent to an inlet valve to open. If level is high or equal to the set point a signal is set to inlet valve to close

7.3 PROCESS CONTROL AND INSTRUMENTATION

The manipulation of the error signal is processed by a mathematical operator called a control algorithm. An example of an algorithm is the PID or Proportional, Integral, Derivative algorithm. This Algorithm uses:

- The mathematical constant K or proportional multiplier actuating the final control element in a linear way proportional to the value of the error
- The integral operator to produce an actuator signal based on the history of the previous errors
- The derivative operator to produce an actuator signal anticipating the next change based on the slope of the error function

Other algorithms are available easily today in the controllers; an example could be the rate-lag operator which uses a combination of PID elements.

Amplifier

The amplifier increases the intensity of the signal until it is large enough to be able to be used by the actuator.

Actuator

It is an electromechanical device that takes the actuation signal and converts it into motion following the actuation signal. This motion could be a position as in the case of a solenoid valve.

Final Control Element

It is the element which controls in such a way the flow of a process, liquid, or gas.

CHAPTER 8

8. PLANT LOCATION AND LAYOUT

8.1 INTRODUCTION

The layout of process units in a plant and the equipment within these process units must be planned. This layout plays an important part in determining construction and manufacturing costs and thus must be planned carefully with attention being given to future problems that may rise. Since each plant differs in many and no two-plant sites are exactly alike, there is no ideal plant layout. However, proper layout in each case will include arrangements of processing areas, storage areas and handling areas in efficient co-ordination and with regard to such factor as

- New site development or addition to previously developed site
- Type and quality of product to be produced
- Type of process and product control
- Operational convenience and accessibility
- Economic distribution of utilities and services
- Type of building and building code requirements
- Health and safety consideration
- Waste disposal requirement
- Auxiliary equipment’s
- Space available and space required
- Roads and rail roads

8.2 PLANT LOCATION

The major factors in the selection of plant sites are

1) Raw materials
2) Markets
3) Energy supply
4) Climate
5) Transportation facilities
6) Water supply.

i) Local Community Considerations :

The proposed plant must be fit in with and be acceptable by the local community. The plant must be in a safe location so that it does not impose a significant risk to the community. In the new site, the local community must be able to provide adequate facilities for the plant personal like banks, recreations and schools.

ii) Land (Site Consideration)

Sufficient suitable land must be available for the proposed plant and for future expansions. The land should ideally be flat, well drained and have suitable load-bearing characteristics. A full site evaluation would be made to determine the need for pilling or other special foundations.

iii) Availability of Water

Water is needed by every processing plant for various purposes. The plant site must have adequate amount of water at all times of the year. For economic reasons and to avoid wastage of water, the processing industry must have water treatment plant. Also, there must be a provision to collect rain water.

iv) Climate

Adverse climate conditions at a site will increase costs. Abnormally low temperatures will require the provision of additional insulation and special heating for equipment and pipe runs. Stronger structures will be needed at locations subjected to high winds or earth quake.

v) Political and Strategic Considerations:

Capital grants, tax concessions and other inducements are often given by government to direct new investment to preferred locations; such as areas of high unemployment.

vii) **Flood and Fire Protection** :

Industrial plants should not be located along rivers or near large water bodies s there are risks of flood damage. Before a plant site is chosen, the regional history of natural events of this type should be examined and the consequences of such occurrences must be considered. Protection from losses by fire is another important factor in selecting a plant location. In case of a major fire, assistance from outside fire departments should be available. Fire hazards in the immediate area surrounding the plant site must not be overlooked.

8.3 PLANT LAYOUT

- Maintenance workshops
- Stores for maintenance and operating supplies
- Laboratories for process control
- Fire stations and other emergency services
- Utilities, steam boilers, compressed air, power generation, transformer
- station
- Offices for general administration
- Canteens and other amenity buildings such as medical centers and car park.

When roughing out the preliminary site layout, the process units will normally be sited first and then arranged to give a smooth flow of materials through the various processing steps. The location of ancillary buildings should be decided next. They should be arranged so as to minimize the time spent by personnel in travelling between buildings.

Administration officers and laboratories in which a relatively large number of people will be working should be located away from potentially hazardous processes.

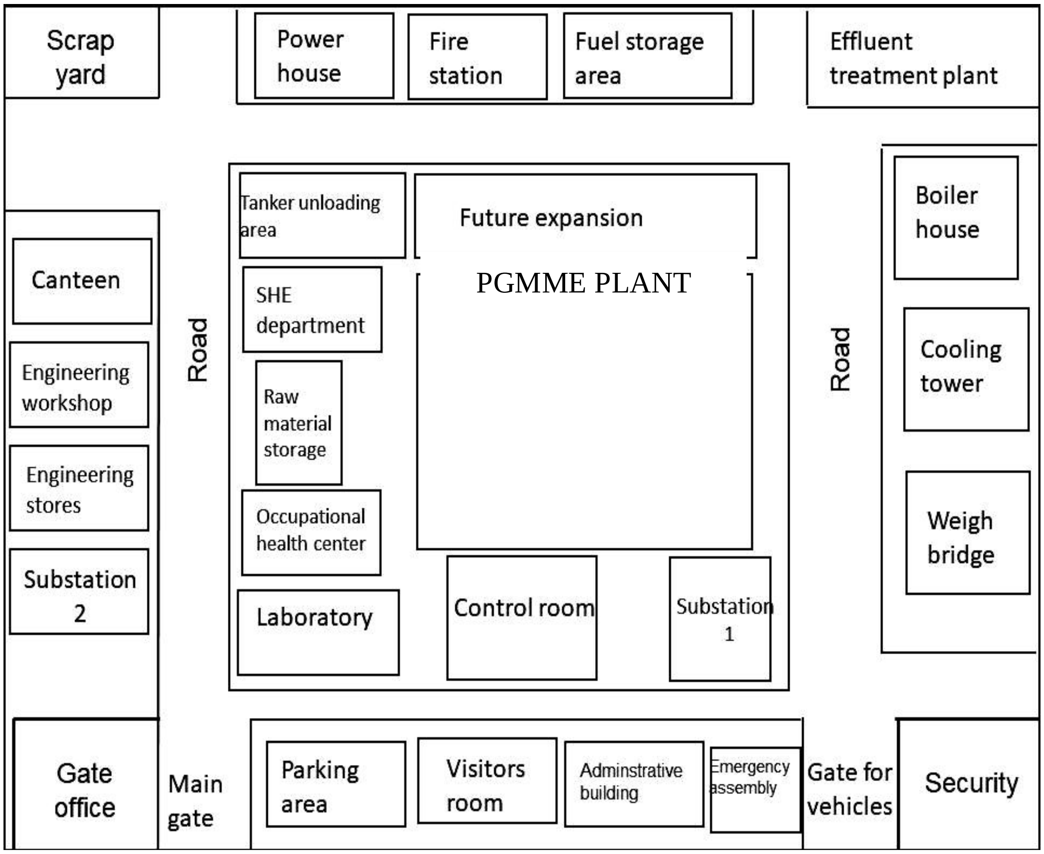


Figure 8.1: Plant Layout

CHAPTER 9

9. PRODUCT CHARACTERISTICS AND CONDITION

9.1 PROPYLENE GLYCOL MONO METHYL ETHER

Chemical Name : 1 Methoxy 2 Propanol

Empirical Formula : $CH_4 H_{10} O_2$

Appearance : Volatile liquid, Clear liquid, Hygroscopic

Density 201Deg C : 0.920-0.923 g/cc

Density (g/ml) :7913 at 20 Deg C

Solubility in water : Freely mixable with water at room temperature.

Refractive Index : 1.402 to 1.404

Melting Point : - 97 Deg C

Boiling Point : 120.1 Degc

Flash Point : 32 Deg C (90 Deg F)

9.2 DI-PROPYLENE GLYCOL MONO METHYL ETHER

Molecular Formula : $C_7 H_{16} O$

Appearance : Clear liquid

Molecular Weight : 148.2

Density : 0.951

Melting Point : -117DegC

Boiling Point : 183.3 Deg C

CHAPTER 10

10. PROCESS SAFETY AND ENVIRONMENT ASSESSMENT

10.1 GENERAL SAFETY INSTRUCTION

All plant personal shell complies with safety rules which generally apply on petrochemical plants. Chief operator shall strictly enforce all applicable safety regulation to safeguard personal and equipment under their charge. All personal employed in the plant should become acquainted with the dangers of chemical poisoning and recommended measures for such emergencies. This is also not necessary to each person or visiting within the fenced in the area of plant.

In addition, they have to be in possession of a valid permanent or temporary company ID card which is to be carried constantly and shown on request while within fence limits. Entering and leaving is permitted through the main gate guard. Useful specify information is part of this chapter. Within the entire area of the plant there is strictly no smocking. People who have consumed alcohol or other intoxicant are to have the plant under proper guidance immediately. Matched lighters and cigarettes are to be deposited with the man at the gate.

Within the plant limits the Tamil Nadu regulations apply. Right of way at inter section has the vehicle coming from the left. Cars shall not be parked on pit-cover or in front of fire hydrants. Parking is generally allowed only on marked parking areas or placed specially allocated to the drivers.

Personal is strongly advised to be dressed in accordance with safety requirements. For heavy industry as there is a requirement for the warning of safety shoes without nails and when required safety clothes and eye protection.

Sampling can exclusively be performed by authorized personal with suitable containers and tools. Metal containers must be grounded during sampling operation to prevent dangerous electrostatic accumulation. Protective gloves and glasses shell be mandatory with sampling

10.2 FIRE SITUATION

Leaks and flammable liquids spills are potentials fires and require emergency action. On leaks or spills the operator shall:

- Alert the supervisors for possible shut down.
- If the location of the leaks is known, shut down the affected systems, isolating the section of pipe or equipment which has failed. In acid or
- caustic service, maintenance man or supervisors must wear the safety dresses and eye protection.
- If source of leaking is not known, shut down the affected area until the location of source has been determined.
- Notify maintenance super intendant and plant super intendant.
- The maintenance crew shall be carefully to the procedure established for doing emergency work.

In the fire case the stuff must be trained to operate the firefighting equipment. They have to become so familiar, that they instinctively do the right thing and do it quickly. The effect is obtained while the fire is small. In the very beginning fire is to be fight by fire extinguishers. Carried by hand they should be filled with dry powders and located well distributed all the plant.

10.3 ORDINARY MAINTENANCE PROCEDURE

It is operators' duty to overseas the work of maintenance personal when they work within the plant area. All work permits shall be signed by the chief operator.

- Neither liquid nor pressure shall be present in lines or vessel.
- Connection with steam, gas, other units etc., shall be blanked and isolated by double valves with intermediate drain open.
- Plugs shall be removed from the exchangers and pumps, and no trace of liquids shall be prevented.
- Explosimeters test shall absolutely negative as regards the presence of flammable vapors in vessel.

- All pumps shall be disconnected and electric motor switch shall be open. For these works, the chief operators shall particularly check the following:
- The equipment and the surrounding area shall be thoroughly checked and purged. Wells shall be scaled
- A steam hose shall be available and ready to use.
- Equipment shall be disconnected and isolated.
- Manholes and vent to atmosphere shall be open.
- Whenever possible, welding shall be performed under steam. The chief operator will have the following works performed by plant personal.
- Cleaning and lubricating of valve streams.
- Complete cleaning of unit and checking of discharge pipes to kept clean.

10.4 HANDLING AND STORAGE

- Product is classified as flammable liquid and hence when it is shipped by rail, water or highways, it shall be packed in authorized containers.
- Danger and no smoking signs have to be posted at the tank and the store house.
- Every tank shall be earthed to prevent static electricity from accumulating .
- Every tank shall be tightly sealed and should be provided with vent pipes and Flame arrester.
- Around storage tanks dykes shall be built to keep the liquid from flowing out in case of damage to the tank.
- Whenever product is being handled the area shall be posted with ‘no smoking ‘signs. if leak or spill occurs, the container shall be removed.

10.5 STARAGE AND HANDLING OF SMALL CONTAINERS

- The storage and handling of methanol is glass containers is not recommended except in small amounts for laboratory use. safety cans with flowing outlet equipped with tight fitting caps or valves shall be used
- All indoor storage should be provided with automatic sprinklers
- Before drums are opened, they shall be supported and grounded.

10.6 TANK TRUCKS

- Truck breaks shall be set additional precaution, the wheels shall be blocked.
- Before any connection or contact is made between tanker and unloading line or other unloading equipment the tank truck should be electrically grounded.
- All containers to be filled from the truck shall be bonded (electrically connected) and grounded to the truck before operation is started.
- Air pressure shall never be used for unloading tank trucks of methanol.

10.7 DRUMS

- When filled drums are stored indoors, they shall be stored in non-combustible, well-ventilated structures.
- Drum storage area should be separated from other areas with approved fire doors.
- All storage shall provide with automatic sprinklers or other suitable extinguishing system.
- Other combustible acids or oxidizing materials shall not be stored nearby.

10.8 WASTE DISPOSAL

- All local and state regulations concerning waste disposal to streams, municipal treatment plants or into the ground shall be determined and complied with.

- Small quantities of product can be disposed by burning should be done in remote area, safely away from building and other combustibles.

- Waste mixtures containing product shall not allowed to enter drains or sewers where there is a danger of becoming ignited.

- Large quantity of waste mixture can be disposed of by atomizing in combustion chamber.

CHAPTER 11

11. CONCLUSION

Thus, the project based on manufacturing of PGMME with 13.032 Ton / Day with Propylene oxide and Methanol as feed and Tri Ethyl Amine as catalyst. The corresponding material balance and energy balance for the whole process was performed. The design calculation for methanol condenser have been calculated. The economic considerations of plant were analyzed. The rate of return for PGMME production is 16.732%. Payback period is found to be 3 years and 9 months. Thus, the project covers all the aspects required for manufacturing of PGMME and could be implemented in reality.

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