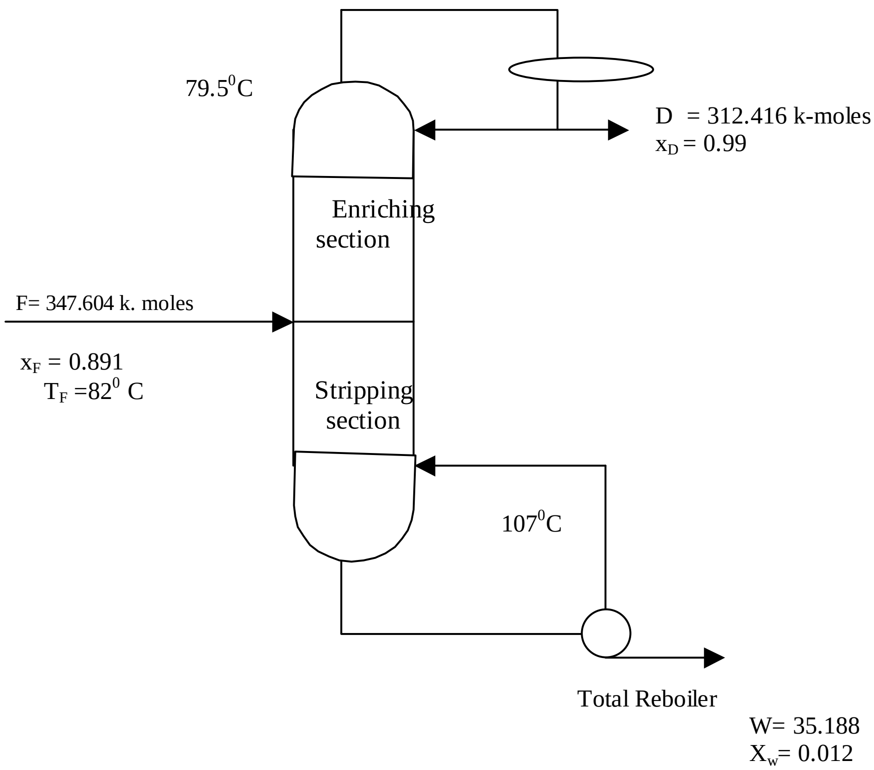
CHAPTER

MAJOR EQUIPMENT

DISTILLATION COLUMN:



Glossary of notations used

F = molar flow rate of feed, kmol/hr

D = molar flow rate of distillate, kmol/hr

W = molar flow rate of residue, kmol/hr.

x_F = mole fraction of MEK in liquid

x_D = mole fraction of MEKin distillate

x_W = mole fraction of MEKin residue

R_m = minimum reflux ratio

R = actual reflux ratio

L = molar flow rate of liquid in the enriching section, kmol/hr

G = molar flow rate of vapor in the enriching section, kmol/hr

$\bar{L}$ = molar flow rate of liquid in stripping section, kmol/hr

$\bar{G}$ = molar flow rate of vapor in stripping section, kmol/hr

$\bar{M}$ = average molecular weight of feed, kg/kmol
q = Thermal condition of feed

Feed = Saturated liquid at boiling point .

$\bar{M}$ = 72.218

$$\frac{x_D}{R_m+1} = 0.66$$

$$R_m+1 = \frac{x_D}{0.66} = \frac{0.99}{0.66} = 1.5$$

R_m = 1.5 – 1.00 = 0.5

R= 1.5 R_m = 0.75

$$\frac{x_D}{R+1} = \frac{0.99}{0.75 + 1} = 0.566$$

Number of trays from graph =14

L = RD = 0.75x312.416 = 234.312 K-moles

G =L+D = 234.312 + 312.416 = 546.728K-moles

q=1 (Feed is saturated liquid)

$\bar{L}$ = L+qf = 234.312 + 1(347.604) = 581.916 K-moles

$\bar{G}$ = G+(q –1) F = 546.728 +0 = 546.728 K-moles

(A) ENRICHING SECTION:

PLATE HYDRAULICS :

(1) Tray spacing (t_s) = 500 mm

(2) Hole diameter (d_h) =5mm

(3) Pitch (l_p) =3d_h = 3x 5 =15mm

$\triangle^{lar}$ pitch

(4) Tray thickness (t_T) =0.6 $d_{h\,=}$ 3mm

(5) $\frac{A_h}{A_p} = \frac{\text{Area of hole}}{\text{Area of pitch}} = 0.10$

(6) Plate diameter (D_c) :

$(L/G)(\rho_g/\rho_L)^{0.5} = 0.0246$ (maximum at top)

∴ Flooding check at top

(Ref :1, p: 18-7, fig :18-10)

$C_{sb,flood}$ = 0.3 ft/s
$C_{sb,flood}$ = capacity parameter (ft/s)
U_{nf} = Gas velocity through net area at flood (ft/s or m/s)

Properties

	Enriching section		Stripping section	
	Top	Bottom	Top	Bottom
Liquid (k-moles/hr)	234.312	234.312	581.916	581.916
Liquid (kg/hr)	16875.15	16917.33	42046.34	43047.82
Vapor (k-moles/hr)	546.728	546.728	546.728	546.728
Vapor (kg/hr)	39375.35	39419.09	39446.43	40444.75
x	0.99	0.9	0.8725	0.012
y	0.99	0.95	0.925	0.012
T_{liquid} (^{o} C)	79.5	81.5	82.0	107.0
T_{vapor}(^{o} C)	80.5	82.5	83.5	107.5
ρ_{vapor}(kg/m^3)	2.482	2.471	2.466	2.500
ρ_{liquid} (kg/m^3)	750.02	750.00	750.00	739.88
$(L/G)(\rho_g/\rho_L)^{0.5}$	0.0246	0.0246	0.061	0.0619
σ_{liq} (dyn/cm)	18.00	18.00	17.28	17.28
μ_{vapor}	00048	0.0048	0.0048	0.0048
μ_{liq}	0.27	0.27001	0.449	0.449001
D_{vapor} (m^2/s)	0.0599	0.0.0059	0.148	0.149
D_{liquid} (m^2/s)	$1.688\text{x}10^{-9}$	$1.688\text{x}10^{-9}$	$1.952\text{x}10^{-9}$	$1.952\text{x}10^{-9}$

Average conditions and Properties

	Enriching section	Stripping section
Liquid (k-moles/hr) (kg/hr)	234.312 16896.24	581.916 42547.08
Vapor (k-moles/hr) (kg/hr)	546.728 39397.22	546.728 39945.59
$\overline{T}_{liq}$ (^{O}c)	80.5	94.5
$\overline{T}_{vapor}$ (^{O}c)	81.5	95.5
$\overline{\rho}_{liq}$ (kg/m^3)	750.01	744.94
$\overline{\rho}_{vapor}$ (kg/m^3)	2.4765	2.483

$$C_{sb,\ flood} = U_{nf} \left[\frac{20}{\sigma}\right]^{0.2} \left[\frac{\rho_g}{\rho_L - \rho_g}\right]^{0.5}$$ (Ref; 1, pg: 18-7)

σ = liquid surface tension
ρ_g = gas density
ρ_L = liquid density

$$\therefore U_{nf} = 0.3 \left[\frac{18}{20}\right]^{0.2} \left[\frac{750.01 - 2.4765}{2.4765}\right]^{0.5} = 5.105 \text{ ft/s} = 1.556 \text{m/s}$$

Consider , 80% flooding

$U_n = 0.8\ U_{nf} = 1.2448$ m/s
U_n = Gas velocity

$$\text{Volumetric flow rate of vapor} = \frac{39397.22}{3600 \times 2.4765} = 4.419 \text{ m}^3/\text{s}$$

Net Area (A_n) = Volumetric flow rate of vapor = 4.419= 3.549m^2

Let $\frac{L_w}{D_c} = 0.75$

L_w = Weir Length

D_c = Column Diameter

Area of column (A_c) = $\frac{\pi}{4} D_c^2 = 0.785\, D_c^2$

$\sin(\theta_C/2) = (L_W/2)/(D_C/2) = 0.75$

$\theta c = 97.2^0$

Area of down comer (A_d) = $\left[\frac{\pi}{4} D_c^2 \frac{\theta c}{360} - \frac{Lw}{2} \frac{Dc}{2} \cos\left(\frac{\theta c}{2}\right)\right]$

$= 0.0879\, D_c^2$

$A_n = A_c - A_d.$

$0.785 Dc^2 - 0.0879\, Dc^2 = 3.549$

$D_c = 2.26$m.

$D_c \cong 2.3$m

$L_w = 0.75\, D_c = 1.725$m.

$L_w \cong 1.7$m

$\therefore A_d = 0.0879(2.3)^2 = 0.465\ m^2$

$A_c = \frac{\pi(2.3)^2}{4} = 4.155 m^2$

$A_n = A_c - A_d = 4.155 - 0.465 = 3.69\ m^2$

Active area (A_a) = $A_c - 2A_d = 4.155 - 2(0.465) = 3.225\ m^2$

$\frac{L_w}{D_c} = \frac{1.7}{2.3} = 0.74$

$\therefore \theta c = 95.5^\circ$

$\therefore \alpha = 84.5^\circ$

$L_w = 0.74(2.3) \cong 1.7m$

(7) Perforated Area (A_p):

$A_{cz} = 2\{60mm\}$ x $L_w = 2 \text{ x } 65 \text{ x}10^{-3} \text{ x}1.7 = 0.221 \text{ m}^2$

$$\frac{A_{cz}}{A_c} = \frac{0.221}{4.155} = 0.0532$$

$A_{cz} = 5.32\% \ A_c$

$\alpha = \pi - \theta_c = 180 - 95.5 = 84.5^{\circ}$

A_{wz} is the waste zones area.

$$A_{wz} = 2\left[\frac{\pi}{4} D_c^2 \frac{\alpha}{360} - \frac{\pi}{4}(D_c - 0.05)^2 \frac{\alpha}{360}\right]$$

$$= 0.084 \text{ m}^2$$

$$\frac{A_{wz}}{A_c} = \frac{0.084}{4.155} = 0.0202$$

$A_{wz} = 2.02\% \ A_c$

A_p = Area of perforation.
$A_p = A_c - 2A_d - A_{cz} - A_{wz}$

$= 4.155 - 0.221 - 2\ (0.465) - 0.084$

$= 2.92 \text{ m}^2$

(8) Hole Area (A_h):

A_h = Area of holes.

$A_h = 0.1\ A_p = 0.292 \text{ m}^2$

n_h = number of holes.= $n_h = \dfrac{4\text{x } 0.292}{\pi(5 \text{ x } 10^{-3})^2} = 14872$

(9) $h_w = 50mm$

h_w = weir height

(10) Weeping check: (Sieve Tray)

(a) (Ref:1, p:18-9, eq:18-6)

$$h_d = K_1 + K_2(\rho_g/\rho_L)U_h^2$$

K_1 = 0 (for sieve tray)

U_h = Linear gas velocity through holes.

h_d = pressure drop across dry hole (mm liquid)

$K_2 = \frac{50.8}{Cv^2}$ (Ref :1, pg :18-9).

C_v = Discharge co-efficient. (Ref :1, fig: 18-14, pg :18-9)

For $\frac{A_h}{A_a} = 0.0905$

$\frac{t_T}{d_h} = 0.6$

$C_v = 0.75.$

$$\therefore K_2 = \frac{50.8}{0.75^2} = 90.31$$

$$(U_h)_{top} = \frac{39375.35}{2.482 \times 0.292 \times 3600} = 15.126 \text{ m/s} \qquad \text{(minimum)}$$

$$(h_d)_{top} = 90.31 \left[\frac{2.4765}{750.01}\right] (15.126)^2 = 68.23 \text{ mm of clear liquid .}$$

$$h_\sigma = 409 \left(\frac{\sigma}{\rho_L d_h}\right)$$ (Ref: 1, pg:18-7, eq:18-2 (a)

h_σ = head loss due to the bubble formation

$$h_\sigma = 409 \left(\frac{18}{750.01 \times 5}\right) = 1.963 \text{ mm of clear liquid}$$

$$h_{ow} = F_w \; 664 \left(\frac{q}{L_w} \right)^{2/3}$$ (Ref: 1, pg: 18-10, eq:18-12 (a)).

h_{ow} = height of crest over weir

F_w = weir constriction correction factor.

$$q = \frac{L_t}{\rho_L}$$

q = liquid flow per serration (m^3/s)

$$q = \frac{16896.24}{750.01 \times 3600} = 6.258 \times 10^{-3} \; m^3/s$$

$$\frac{q^1}{(L_w)^{2.5}} = \frac{99.197}{(5.577)^{2.5}} = 1.35$$ (Ref:1, pg:18-11, fig:18-16)

$$\frac{L_w}{D_c} = 0.74$$

$F_w = 1.01$

$$\therefore \; h_{ow} = 1.01\,(664) \left\{ \frac{6.258 \times 10^{-3}}{1.7} \right\}^{2/3} = 15.99 \text{ mm of clear liquid}$$

$h_d + h_\sigma$ = 68.23+1.963 = 70.193mm

$h_w + h_{ow}$ = 50+15.99 = 65.99mm

For $\frac{A_h}{A_a} = 0.09$

$h_{w} + h_{ow}$ = 65.99 mm

(Ref :1, pg:18-7, fig:18-11)

$h_{d} + h_\sigma$ = 18mm < 70.193 mm

∴ There is no weeping

(11) Flooding check:

Since the maximum flow rate is at the bottom, flooding checked at the bottom.

$h_{ds} = h_w + h_{ow} + \frac{h_{hg}}{2}$ (For sieve trays)

h_{hg} = liquid gradient across plate (mm liquid)

$(h_{ow})_{bottom}$ = 16 mm

h_{ds} = Calculated height of clear liquid over the dispersers.

$h_{ds} = 50+16+\frac{0.25}{2} = 66.125$ mm

U_a = linear gas velocity through active area.

$U_a = \frac{39397.22}{3600 \times 2.4765 \times 3.225} = 1.37$ m/s

$\rho_g = 2.4765$ kg/m^3

$F_{ga} = U_a (\rho_g)^{½}$ =1.768(FPS)

(Ref:1, pg:18-10, fig:18-15)

Aeration factor (ß) =0.59

Relative froth density (ϕ_t) =0.22

h_l^1 = pressure drop through aerated liquid

h_f = actual height of froth.

$h_l^1 = \beta\ h_{ds} = 0.59\ (66.125) = 39.1$mm

$h_f = \frac{h_l^1}{\phi_t} = \frac{39.1}{0.22} = 185.5$mm

$h_{da} = 165.2 \left(\frac{q_b}{A_{da}}\right)^2$ (Ref:1, Pg: 18-10, eq:18-14)

h_{da} = head loss under the down –comer

A_{da} = minimum area of flow under the down comes apron.

$h_{ap} = h_{ds} - c = 66.125-25.4 = 40.725\text{mm}$

$A_{da} = L_w \times h_{ap} = 1.7 \times 40.725\times10^{-3} = 0.069 \text{ m}^2$

$$h_{da} = 165.2 \left(\frac{6.266 \times10^{-3}}{0.069} \right)^2 = 1.36\text{mm}$$

h_t = total head loss across the plate

h_d= it's calculated at the bottom(maximum) = 68.68 mm

$h_t = h_d + h_l^1 = 68.68+39.1 =107.78$ mm

$h_{dc} = h_t + h_w + h_{ow} + h_{hg} + h_{da}$ (Ref :1, eg:18-3, pg:18-7)

$= 107.78 + 50 + 16 + 0.25 + 1.36$
$= 175.39$ mm

Taking (ϕ_{dc}) average = 0.50 ; ϕ_{dc} = relative froth density

h_{dc}^1 = actual back-up

$$h^1_{dc} = \frac{175.39}{0.5} = 350.78\text{mm} <500 \text{ mm}$$

∴ Flooding check is satisfied

i.e. There is no flooding.

(12) Column efficiency (AIChE METHOD):

(A) Point Efficiency: E_{OG}

$$N_g = \frac{0.776+0.00457h_w - 0.238\ U_a\ \rho_g^{0.5} +105\ w}{(N_{sc,g})^{0.5}}$$ (Ref :1, pg:18-15, eq:18-36)

N_g = gas phase transfer unit

$$N_{sc,g} = \frac{\mu_g}{\rho_g D_g} = \frac{0.0048 \times10^{-3}}{2.4765 \times 0.0059 \times10^{-4}} = 0.324$$

$N_{sc,g}$ = gas phase Schmidt number

$$U_a = \frac{39397.22}{3600 \times 2.4765 \times 3.225} = 1.37 \text{ m/s}$$

$$D_f = \frac{L_w + D_c}{2} = \frac{1.7+2.3}{2} = 2.0\text{m}$$

D_f = width of flow path on plate

W = liquid flow rate (m^3/sm)

$$W = \frac{q}{D_f}$$

$$q = \frac{16896.24}{750.01 \times 3600} = 6.26 \times 10^{-3} \text{ m}^3/\text{s}$$

$$W = \frac{6.26 \times 10^{-3}}{2.0} = 3.13 \times 10^{-3} \text{ m}^3/\text{m-s}$$

$$N_g = \frac{0.776+0.00457(50) - 0.238\,(1.37)\,(2.4765)^{0.5} + 105\,(3.13 \times 10^{-3})}{(0.324)^{0.5}}$$

N_g = 1.44

$N_L = K_{L\,a}\ \theta_L$ (Ref:1, pg: 18-15, eq:18-36 (a))

N_L = liquid phase transfer units
$K_{L\,a}$ = liquid phase transfer coefficient (m/s)
Q_L =Residence time of liquid in froth or spray zone.

$(D_L)_{average}$ = 1.688 $\times 10^{-9}$

$K_{L\,a} = (D_L)^{½}\ (0.40\ U_a\ \rho_g^{½} + 0.17)$ (Ref:1, pg:18-16, eg:18-40(a))

$K_{L\,a} = (3.875 \times 10^{8} \times 1.688 \times 10^{-9})^{½}\ (0.40 \times 1.37\ (2.4765)^{½} + 0.17)$

$K_{L\,a}$ = 0.833 m/s

$$\theta_L = \frac{h_L A_a}{1000 q_b}$$ (Ref:1, pg:18-16, eq:18-39)

h_l = liquid hold-up on plate

$$\theta_L = \frac{39.1 \times 3.225}{1000(6.26 \times 10^{-3})} = 20.14 \text{ s}$$

$N_L = 0.833 \times 20.14 \quad = 16.78$

$$\left.\begin{array}{l} m_{top} = 0.3375 \\ m_{bottom} = 0.413 \end{array}\right\} \quad \frac{G_m}{L_m} = 2.3333$$

$$\lambda_t = m_{top}\left(\frac{G_m}{L_m}\right) = 0.7875$$

$$\lambda_b = m_{bottom}\left(\frac{G_m}{L_m}\right) = 0.9637$$

$\bar{\lambda}_{avg} = 0.876$

λ = stripping factor

$$N_{og} = \frac{1}{\frac{1}{N_g} + \frac{\lambda}{N_L}}$$ (Ref: 1, pg:18-15, eq:18-34)

2.51 $$= \frac{1}{\frac{1}{1.44} + \frac{0.876}{16.78}} = 1.34$$

$E_{OG} = 1 - e^{-(N_{og})}$ (Ref:1, pg: 18-15, eq:18-33)

$E_{OG} = 1 - e^{-(1.34)} = 0.738$

(B) Murphee plate efficiency : E_{mv}

$\therefore \theta_L$ = Residence time of liquid = 20.14 s

which is large.

$$Npl = \frac{Z_l^2}{D_E \theta_l}$$

Z_l =Dc cos(θc/2)

= 1.55 m

$D_E=6.675\text{x}10^{-3}Ua^{1.44}+0.922\text{x}10^{-4}h_l - 0.00562$

$=0.0084\ m^2/s$

$$N_{pe} = \frac{1.55^2}{(0.0084\text{x}\ 20.14)}$$

=14.20

λ x Eog =0.876 x 0.738
= 0.646

$$\therefore \frac{E_{mv}}{E_{OG}} = 1.26 \qquad \text{(from graph)}$$

$\therefore E_{mv} = 0.93$

(C) Overall column efficiency : E_{oc}

$$E_{oc} = \frac{\log\{1+Ea(\lambda - 1)\}}{\log(\lambda)} \qquad \text{(Ref:1, pg:18-17, eq:18-46)}$$

E_a = Murphee vapor efficiency

$$\frac{E_a}{E_{mv}} = \frac{1}{1+E_{mv}\left(\frac{\psi}{1-\psi}\right)} \qquad \text{(Ref:1, pg:18-13, eq:18-37)}$$

ψ = fractional entrainment

For $\frac{L}{G}\left(\frac{\rho_g}{\rho_L}\right)^{0.5} = 0.0246$

For 80% flood

From (Ref:1, fig:18-22, pg:18-44)

ψ = 0.15

$$Ea = 0.93 \times \frac{1}{1 + 0.93 \times \frac{0.15}{1-0.15}} = 0.79$$

$$Eoc = \log \frac{1+0.79(0.876-1)}{\log(0.876)} = 0.78$$

N_A = Actual tryas;

N_T= theoretical trays.

$$N_A = \frac{N_T}{Eoc} = \frac{4}{0.78} = 5.14 \simeq 6$$

Height of enriching section = 6 x 0.500 = 3.00 m

(B) STRIPPING SECTION :

PLATE HYDRAULICS :

(1) Tray spacing (t_s) = 500 mm

(2) Hole diameter (d_n) = 5mm

(3) Pitch (l_p) =15mm

△ lar pitch

(4) Tray thickness (t_r) =3mm

(5) $\frac{A_h}{A_p} = 0.10$

(6) Plate Diameter (D_c) :

$(L/G)(\rho_g/\rho_L)^{0.5}$ = 0.0619 (maximum of top)

$C_{sb\ flood}$ =0.28 ft/s

U_{nf} = 1.434 m/s

Consider , 80% flooding .

U_n =1.1472 m/s

Volumetric flow rate of vapor =4.4939 m^3/s

Net area (A_n) =3.917 m^2

Column diameter (D_c) =2.4 m
L_w =1.778 m
Value of L_w taken as 1.75 m.
$\frac{L_w}{D_c}$ = 0.73
L_w = 1.75 m

θ_c = 93.8^0
α = 86.2^0

A_c = 4.524 m^2
A_d = 0.462 m^2
A_n = 4.062 m^2
A_a = 3.6 m^2
A_{cz} = 0.192 m^2 (5.17% of A_c)
A_{wz} = 0.026 m^2 (2.00% of A_c)
A_p = 3.126 m^2
A_h = 0.3126 m^2
n_h = 16685

(9) h_w =50mm

(10) Weeping check (Top) :

(a) $(h_d)_{top}$ = 57.54 mm of clear liquid

$(h_d)_{bottom}$ = 93.83 mm of clear liquid

(b) h_σ = 1.89 mm of clear liquid

(c) h_{ow} =30.194 mm of clear liquid

$h_w + h_{ow}$ = 80.194 mm
$h_d + h_\sigma$ = 59.43 mm

From graph, $h_d + h_\sigma$ = 18mm < 59.43 mm

$\therefore$ There is no weeping.

(11) Flooding check (Bottom)

h_{ow} = 30.445 mm
h_{ds} =80.57 mm ; β =0.60 ; ϕ_t = 0.2
h_l^l =48.342 mm
h_f = 241.71mm
h_{ap} = 55.17 mm
A_{da} = 0.097 m^2
h_{da} = 4.6 mm
h_t = 107.192 mm
h_{dc} = 192.687 mm
h_{dc}^l = 385.374 mm < 500 mm

∴ There is no flooding

(12) Column Efficiency (AIChE METHOD):

(A) Point Efficiency :E_{OG}

(a) N_g =2.384

(b) θ_L = 10.88 s.

(c) K_la = 0.83 m/s

N_L = 9.03
λ = 1.215
N_{og}=1.805
E_{oG}=0.83

(B) Murphee plate efficiency :E_{mv}

Z_l = 1.64 m
D_E = 7.94x10^{-3} m^2/s
θ_L = 10.88 s
N_{pe} = 31.31
λ x Eog = 1.0

$\frac{E_{mv}}{Eog}$ = 1.7

E_{mv} = 1.411

(C) Overall column efficiency :

ψ = fractional entrainment

For $\frac{L}{G}\left(\frac{\rho_g}{\rho_L}\right)^{0.5} = 0.0619$

$\psi = 0.05$

$E_a = 1.312$

$E_{oc} = 1.276$

$N_A = \frac{9}{0.83}$

$= 11$

Height of stripping section = 11 x 0.500 = 5.5 m

Total height of the column = Enriching section + stripping section

= 3.00 + 5.5

= 8.5 m

Summary of the Distillation Column

Enriching section

Tray spacing = 500 mm

Column diameter = 2.3m

Weir length = 1.7m

Weir height = 50 mm

Hole diameter = 5 mm

Hole pitch = 15 mm, triangular

Tray thickness = 3mm

Number of holes = 14872

Flooding % = 80

Stripping section

Tray spacing = 500 mm

Column diameter = 2.4m

Weir length = 1.75 m

Weir height = 50 mm

Hole diameter = 5 mm

Hole pitch = 15 mm, triangular

Tray thickness = 3mm

Number of holes = 16685

Flooding % = 80

DISTILLATION COLUMN

6.2 MECHANICAL DESIGN

Specifications:-

Inside Dia :- 2.4m = 2400mm

Ht of top engaging section = 40cm.

Working pressure = 1atm = 1.032 kg/cm^2

Design pressure = 1.032 x 1.1 = 1.135 kg/cm^2

Shell material = Carbon steel (Sp. gr. = 7.7)

Permissible tensile abs tress = 950 kg/cm^2

Insulation material = asbestos

Density of insulation = 2700 kg/m^3

Tray spacing = 500 mm

Insulation thickness = 50 mm

Down comer & plate material = S.S

Sp.gr of SS = 7.8

SKIRT = 2m

Shell thickness:-

$$t_s = \frac{P.D_t}{2fj - p} + C$$

t_s = shell thickness

P= design p^r

D_I = ID of shell

f = allowable stress

J = joint factor (0.85)

C= corrosion allowance (2 mm)

$$t_s = \frac{1.135 \times 2400}{2 \times 0.85 \times 950 - 1.135} + 2$$

= 3.68 mm.

Taking min shell thickness of 6mm

Shell out side Do = 2400+2x6 = 2412mm

The column is provided with torispherical head on both ends.

For torrispherical head, or radius

=> Ro = Do = 2412 mm

r_o = 6% Ro
= 0.06 x 2412
= 144.72 mm
= 145 mm

Calculation of head thickness

$$t = \frac{0.885\ Prc}{f \times E - 0.1P} + C$$

r_c = crown radium

E = joint efficienc

f = allowable stress

C = corrosion allowance

$$t_s = \frac{0.855 \times 1.135 \times 2412}{950 \times 0.85 - 0.1 \times 1.135} + 2$$

= 5.00 mm

Take head thickness to be 8mm approximate blank diameter can be found out as;

$$\text{Diameter} = OD + \frac{OD}{24} + 2\,S_f + \frac{2}{3}\,icr$$

$S_f = 800$ mm

$$\text{Diameter} = 2412 + \frac{2412}{24} + 2 \times 800 + \frac{2}{3} \times 145$$
$$= 4209.2$$
$$= 4210\text{mm}$$

$$\text{Wt of head} = \frac{\pi d^2 t}{4} \times \rho$$
$$= \frac{\pi \times (4.210)^2 \times 0.006}{4} \times 7700$$
$$= 643.13\text{kg.}$$

Calculation of thickness with Hight ;-

Carbon steel material
IS 2002 – 1962 Grade I

Tensile strength $R_{20} = 37$ kgf/cm^2

Yield stress = $0.55\ R_{20}$
= 20.35 kgf/cm^2

$$f_{ap} = \frac{p.di}{4(ts-c)}$$

$$= \frac{1.135 \times 2400}{4 \times (6 - 2)}$$

$$= 170.25\ \text{kg/cm}^2$$

fap = tensile stress due to internal pr (kg/cm^2)

Stresses due to dead load (compressive) :-

Σ w = (w_t . of the shell + attachment)
+ (w_t . of plate). (w_t of liquid hold up)
+ (w_t . of the head)

$w_1 = w_t$ of shell = πdit fs . X

$w_2 = w_t$ of insulation $= \frac{\pi}{9} (do^2 \text{ in-} do^2) \text{Sins} . X$

$w_h = w_t$ of head = 643.13 kg.

$W_p = w_t$ of each plate $= (A_n - A_h) \times t_2 . \rho_r + h_w + (t_s - h_{ap}) \times t_2 \times \rho_p + W_a$

$W_L = w_t$ of liquid $= (A_a * H_L + A_d * h_{dl}) f_L$

$$\Sigma w = w_1 + w_2 + w_h + (w_p + w_L) \times \frac{X}{t_s}$$

$w_1 = w_t$ of shell $= \pi (2.4) \times 6 \times 10^{-3} \times 7700 (X)$

$= 348.34 X$

$w_2 = w_t$ of insulation $= \frac{\pi}{4} (2.512^2 - 2.412^2) \times 2700$

$= 1044.17 X$ kg.

$w_h = w_t$ of head = 643.13 kg.

$w_p = w_t$ of each plate.

$= (4.062 - 0.3276) \times 0.003 \times 7800$
$+ [0.05 + (0.500 - 0.0552)] \times 0.003 \times 7800$
$+ w_a$

$w_p = 150$ kg.

$W_L = w_t$. of liq

$= [3.6 \times 48.342 \times 10^{-3} + 0.462 \times 0.192687] \times 744.94$

$= 205.2$ kg

$$\Sigma w = 348.34 x + 1044.17x + (150 + 205.2) \frac{X}{0.500} + 643.13$$

$= 2102.51 X + 643.13$

Stress due to dead level (compressive) at dist X:

$$f_{dw} = \frac{\Sigma w}{\pi\, di\,(ts - 6)}$$

$$= \frac{2102.51\, X + 643.13}{\pi \times 2400 \times (6 - 2) \times 10^{-1}}$$

$$= 6.971\, X + 2.132\ kg/cm^2$$

Stress due to wind load at a dist X:-

$$f_{wx} = \frac{1.4\, Pw\, X^2}{\pi\, do\,(ts - c)}$$

This design is being due for a wind pressure of 150 kg/m^2

$\therefore P_w = 150\ kg/m^2$

$$f_{wx} = \frac{1.4 \times 150 X^2}{\pi \times 241.2 \times (6 - 2) \times 10^{-1}}$$

$$= 0.693\, x^2\ kg/cm^2$$

Resultant longitudinal stress in the up wind

$Ft_{max} = f_{ax} + f_{ap} - f_{dw}$

$950 \times 0.5 = 0.693\, X^2 - (6.971X + 2.132) + 170.25$

$\Rightarrow 0.693X^2 - 6.971\, X - 302.618 = 0$

$$X = \frac{6.971 \pm \sqrt{[6.971^2 + 4\,(0.693)\,(302.618)]}}{2 \times 0.693}$$

$= 26.52$ m

Resultant longitudinal stresses:- at down wind sides:-

$- Fc_{ax} = - f_{wx} + f_{ap} - f_{dw}$

$$Fc_{max} = \frac{1}{3}\ (\text{yield stress}) = \frac{1}{3} \times 20.35$$

$$= 6.783\ kg/cm^2$$

$- 6.783 = - 0.693x^2 + 170.25 – (6.971X + 2.132)$

$\Rightarrow 0.693x^2 + 6.971x – 174.898 = 0$

$$X = \frac{- 6.971 \pm \sqrt{6.971^2 + 4 \times (0.693)(174.898)}}{2 \times 0.693}$$

$$= - \frac{6.971 \pm 23.096}{2 \times 0.693}$$

$= 11.64$ m.

Which suggests that the design is safe. Since the design is being made on the basis of higher diameter, so the design is assumed to before for the entire length of the tower.

Design of skirt support:-

Specifications:-

Top disengaging space = 1.25 m

Bottom separator space = 2.25 m

Skirt Hgt = 2m.

Total Height of column including skirt height-

$H = 8.50 + 2.00 +1.25 + 2.25$ m

$H = 14$ m

Wt. of shell $w_1 = \pi d_i \times t \times fs \times H = 4876.76$ kg.

Wt of insulation $w_2 = \frac{\pi}{4} (2.152^2 – 2.412^2) \times 2760 \times 14$

$= 14618.38$kg

Wh = Wf. Of Head = 643.13 kg.

Wp = Wt. Of plate = 150kg.

$$\sum W = W_1 + W_2 + (W_P + WL) \frac{H}{t_s} + Wn$$

$$= 4876.76 + 14618.38 + (150 + 205^{.2}) \times \frac{14}{0.5} + 643.13$$

$= 30083.87$ kg

Wind Load:

$$f_{wb} = \frac{(K\ P_1\ H\ D_O).\ (H/2)}{\frac{\pi}{4} D_O^2 .\ t}$$

$$= \frac{2K\ P_1\ H^2\ D_O}{\pi\ D_O^2\ t.}$$

$K = 0.7$, $P_1 = 128.5$ kg/m^2

$$f_{bw} = \frac{2 \times (0.7)\ (128.5 \times 14^2 \times 2.412)}{\pi \times (2.412)^2 \times t \times 10^4}\ \text{kg/cm}^2$$

$$f_{bw} = \frac{4653.289}{t} = \frac{0.46533}{t}\ \ \text{kg/cm}^2$$

$$f_{ds} = \frac{w\ \ ,}{\pi Dmt.}$$

Dm = Di + t = 2400 + 6 = 2.406 m

$$f_{ds} = \frac{30083.87}{\pi \times 2.406 \times t} = \frac{3980.05}{t} = 39.8\ \text{kg/cm}^2$$

Seismic load:

$$f_{sb} = \frac{8}{3}\ \frac{c\ w\ H}{\pi Do^2 t}$$

C= 0.08

$$fsb = \frac{8}{3} \times \frac{0.08 \times 30083.87 \times 14}{\pi \times (241.2)^2 \times t}$$

$$= \frac{0.492}{t}\ \text{kg/cm}^2$$

max possible tensile stress:-

$j \times f = f_{ds} - f_{sb}$

$$807.5 \geq \frac{39.8}{t} - \frac{0.492}{t}$$

$$807.5 \geq \frac{39.308}{t}$$

$t \geq 0.0486$cm. We can have t = 6mm

max permissible compressive stress:-

$jt \geq f_{ds} + f_{sb}$

$$807.5 \geq \frac{39.8}{t} + \frac{0.492}{t}$$

$$807.5 \geq \frac{40.292}{t}$$

$$t \geq \frac{40.292}{807.5}$$

$t \geq 0.0499$ cm

choose skirt thickness = 6mm

Skirt bearing plate:

$$fc = \frac{\sum W}{A} + \frac{M_s}{2}$$

$$= \frac{30083.87 \times 4}{\pi (270^2 - 240^2)} + \frac{Msb}{2}$$

$$M_{sb} = \frac{2}{3} CWH.$$

$$Z = \frac{(D_{op}^4 - D_{os}^4) \times \pi}{D_{op} \times 32}$$

$$= \left(\frac{270^4 - 240^4}{32 \times 270}\right) \times \pi$$

$$fc = \frac{30083.87 \times 4}{\pi(270^2 - 240^2)} + \frac{2}{3} \frac{0.08 \times 30083.87 \times 14}{\frac{\pi (270^4 - 240^4)}{32 \times 270}}$$

= 2.5035 + 0.0309

= 2.5344 kg/cm^2

This is much less than permissible compressive stress of concrete.

$M_{max} = fc . b.l^2/2$

$$f = \frac{6 M_{max}}{bt_B^2} = \frac{3 f_{cl}^2}{t_B^2} = \frac{3 \times 2.5344 \times 15^2}{t_B^2} \text{ kg/cm}^2$$

$= \underline{1710.72}$ kg/cm^2

t_B^2

$f = 9.6\ MN/m^2 = 9.5 \times 10^2\ N/cm^2$

$= 96\ kgf/cm^2$

$$t_B = \sqrt{\frac{1710.72}{96}}$$

$t_B = 4.22\ cm = 42.2mm$

Bolting chair has to be used.

Assume $W_{min} = 2{,}50{,}00$ kg.

$$f_c = \frac{2{,}50{,}00 \times 4}{\pi(270^2 - 240^2)} - \frac{2}{3} \times \frac{0.08 \times 30083.87 \times 1400}{\dfrac{\pi \times (270^4 - 240^2)}{32 \times 270}}$$

$= 3.09–2.08$

$= 1.01\ kg/cm^2$

$$j = \frac{Mwt}{Ms} = \frac{W_{min} R}{Ms.}$$

$$Ms = \frac{2}{3}(8.08) \times 30083.87 \times 1400$$

$= 2.246 \times 10^6$

$M_{wt} = W_{min} \times R$

$= 2{,}50{,}00 \times 270$

$= 67.5 \times 10^5$

$$j = \frac{67.5 \times 10^5}{2.246 \times 10^6}$$

$= 3.005$

$j > 1.5$ anchor bots are not required.

MINOR EQUIPMENT

CONDENSER

7.1 PROCESS DESIGN:

(I) Preliminary Calculations:

(a) Heat Balance:

Vapor flow rate $(\bar{G})$ = 546.728 K-moles/hr.
= 39375.35 kg/hr
= 10.94 kg/s

Vapor Feed Inlet Temperature =80.5 ^{0}c.

Let Condensation occur under Isothermal conditions i.e $F_T = 1$.

Condensate outlet temperature = 80.5 ^{0}C

$\therefore$ Average Temperature = 80.5 ^{0}C

Latent heat of vaporisation (λ)= 4.184 x { 105.93 (0.99)+134.38 (0.01) }

= 444.43 KJ/kg

q_h = (mass flow rate of condensing vapor) x (latent heat of vapor)

q_h = heat transfer by the condensing vapor .

q_h =10.94 x 444.43 = 4862.06 KJ

10% overload is taken
q'_h = 1.1 x 4862.06 = 5348.27 KJ

q_C= mass flow rate of cold fluid x specific heat x $\triangle$t

q_c = heat transfer by the cold fluid.

Assume : $q'_h = q_{c.}$

Inlet temperature of water = 25 ^{0}C.

Let the water be untreated water.

$\therefore$ Outlet temperature of water (maximum) = <u>40 ^{0}C</u>

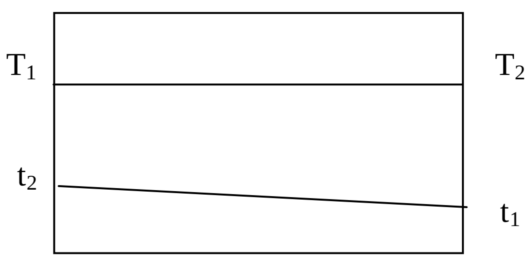
$\therefore$ $\triangle t$ = 42-24= 18 ^{0}C

$\overline{Cp}$ = 4.187 KJ/kg K.

$$m_c = \frac{5348.27x10^3}{4.187x10^3x18} = 70.97 \text{ kg/s.}$$

(b) <u>LMTD Calculations:</u>

assume : counter current



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

T_1 = 80.5^{0}C; T_2 = 80.5 ^{0}C ; t_1 =24 ^{0}C ; t_2 =42 ^{0}C

$\therefore$ LMTD = 46.93 ^{0}C

(C) Routing of fluids :

Vapors - Shell side

Liquid - Tube side

(D) Heat Transfer Area:

(i) $q_h = q_C = UA\,(\triangle T)_{LMTD,corrected}$.

U= Overall heat transfer coefficient ($W/m^2 K$)

Assume : U =567.83W/m^2K

$$\therefore A_{assumed} = \frac{5348.27x10^3}{567.83 \text{ x } 46.93} = 200.69 \text{ m}^2$$

(ii) Select pipe size:

Outer diameter of pipe (OD) = ¾" = 0.0191 m

Inner diameter of pipe (ID) =0.620" = 0.0157m

Let length of tube =16' = 4.88m

Let allowance = 0.05m

Heat transfer area of each tube ($a_{heat-transfer}$) $= \pi$ x OD x (Length – Allowance)

$= \pi$ x 0.0191 x (4.88 – 0.05)

= 0.289 m^2

$$\therefore \text{Number of tubes } (N_{tubes}) = \frac{A_{assumed}}{a_{heat\text{-}transfer}} = \frac{200.69}{0.289}$$

= 695

(iii) Choose Shell diameter:

Choose TEMA : P or S. ¾" OD tubes in 1" $\triangle^{lar}$ pitch.

1 - 2	Horizontal Condenser

$\therefore N_{tubes}$ (Corrected) = 716

Shell Diameter (D_c) =787 mm.

$\therefore A_{corrected} = 206.924 m^2$

$\therefore U_{corrected} = 550.75\ W/m^2K$

(iv) Fluid velocity check :

(a) Vapor side – need not check
(b) Tube side

$$\text{Flow area } (a_{tube}) \text{ Per pass} = \frac{a_{pipe} \times N_{tubes}}{N_{tube\ passes}}$$

$$a_{pipe} = \text{C.S of pipe} = \frac{\pi (ID^2)}{4}$$

$$\therefore a_{tube} = \frac{\pi}{4} (0.0157)^2 \times \frac{716}{2} = 0.0697\ m^2/\text{pass}$$

$$\text{Velocity of fluid in pipe } (V_{pipe}) \quad v_p = \frac{m_{pipe}}{\rho_{pipe} \times a_{tube}}$$

m_{pipe} = mass –flow rate of fluid in pipe.
ρ_{pipe} = Density of fluid in pipe (water)

$$\therefore v_p = \frac{70.97}{1000 \times 0.0697} = 1.018\ m/s$$

$\therefore$ fluid velocity check is satisfied

(II) Film Transfer Coefficient :

Properties are evaluated at ^{t}film :

$$ {}^{t}\text{film} = \left[\frac{t_v + 1 \{ t_v + \frac{(t_1 + t_2)}{2} \}}{2} \right] = \left[\frac{80.5 + \{ 80.5 + \frac{(24+42)}{2} \}]}{2} \right] = 68.63\ ^0C $$

a) Shell side:

$$ \text{Reyonld's Number (Re)} = \frac{4\,\Gamma}{\mu} = \frac{4}{\mu} \quad \frac{W}{(N_{tubes})^{2/3} \times L} $$

$$ = \frac{4}{0.000265} \times \frac{10.94}{(716)^{2/3} \times 4.88} = 422.6 $$

For Horizontal condenser :

$$ Nu = 1.51 \left\{ \frac{(0D)^3 (\rho)^2 g}{\mu^2} \right\}^{1/3} (Re)^{-1/3} $$

$$ = 1.51 \left\{ \frac{0.0191^3 (750)^2 \times 9.81}{(0.265 \times 10^{-3})^2} \right\}^{1/3} (422.6)^{-1/3} = 164.62 $$

$$ Nu = \frac{h_o\,(OD)}{K} $$

h_o = outside heat transfer coefficient (W/m^2K)

k = Thermal conductivity of liquid.

$$ h_o = \frac{164.62\ (0.134)}{0.0191} = 1154.9\ W/m^2K $$

b) Tube side:

$$G_t = \frac{m_{pipe}}{a_{tube}}$$

G_t= Superficial mass velocity

$$G_t = \frac{70.97}{0.0697} = 1018.2 \text{ kg/m}^2\text{s}$$

$$Re = \frac{(ID)\, G_t}{\mu} = \frac{0.0157 \times 1018.2}{0.8 \times 10^{-3}} = 20043.3$$

$$Pr = \frac{\mu C_p}{K} = \frac{0.8 \text{ X } 10^{-3} \times 4.187 \times 10^{3}}{0.578} = 5.79$$

$$\frac{hi\,(ID)}{K} = 0.023\,(Re)^{0.8}\,(Pr)^{0.3}$$

h_i = inside –heat transfer coefficient

$$h_i = \frac{0.023\,(20043.3)^{0.8}\,(5.79)^{0.3}}{0.0157} \times 0.578$$

h_i = 3951.93 W/m^{2}K

Fouling factor
(Dirt –coefficient) = 0.003
=5.28 x 10^{-4} (W/m^{2}K)$^{-1}$

$$\frac{1}{U_0} = \frac{1}{h_o} + \frac{(OD)}{(ID)}\frac{1}{h_i} + \text{wall resistance} + \text{Fouling factor}$$

U_o = overall heat –transfer coefficient

$$\frac{1}{U_0} = \frac{1}{1154.9} + \frac{0.0191}{0.0157} \times \frac{1}{3951.93} + 4.028\text{x}10^{-5} + 5.28\text{x}10^{-4}$$

U_0 =574.63 W/m^{2}K

$U_0 > U_{assumed}$

(III) Pressure Drop Calculations :

a) Tube Side :

Re = 20043.3

$f = 0.079\ (Re)^{-1/4} = 0.079\ (20043.3)^{-1/4} = 6.64 \times 10^{-3}$

f = friction factor

Pressure Drop along the pipe length $(\triangle P)_L = (\triangle H)_L \times \rho \times g$

$$= \frac{4fLVp^2}{2g(ID)} \times \rho \times g$$

$$= \frac{4 \times 6.64 \times 10^{-3} \times 4.88 \times 1018.2^2 \times 9.81}{2 \times 9.81 \times 0.0157 \times 1000}$$

$$= 4.266 \text{ KPa}$$

Pressure Drop in the end zones $(\triangle P)_e = \frac{2.5\ \rho\ Vp^2}{2} = \frac{2.5 \times 1000 \times 1.018^2}{2} = 1.29591 \text{ KPa}$

Total pressure drop in pipe $(\triangle P)_{total} = [4.26 + 1.296]\ 2 = 11.1 \text{ KPa} < 70 \text{ KPa}$

b) Shell side: Kern's method

$\therefore$ Baffle spacing (B) = Ds =787 mm

$C^1 = 2.54 \times 10^{-2} - 0.0191 = 0.0063$

P_T = pitch = 2.54×10^{-2} m

$$a_{shell} = \frac{\text{shell diameter} \times C^1 \times B}{P_T} = \frac{0.787 \times 0.0063 \times 0.787}{2.54 \times 10^{-2}}$$

$$= 0.155\ m^2$$

$$De = \frac{4\left\{\frac{P_T}{2} \times 0.86\, P_T - \frac{1}{2}\ \frac{\pi}{4}\ (OD)^2\right\}}{\frac{(\pi\ do)}{2}} = \frac{4\left\{\frac{(25.4 \times 10^{-3})^2}{2} \times 0.86 - \frac{\pi}{8}(0.0191)^2\right\}}{\frac{\pi\,(0.0191)}{2}}$$

$$= 18.29mm.$$

$$Gs = \text{Superficial velocity in shell} = \frac{m_{shell}}{a_{shell}} = \frac{10.94}{0.155} = 70.58\ kg/m^2s$$

$$(N_{Re})_s = \frac{G_s\, D_c}{\mu} = \frac{70.58 \times 18.29 \times 10^{-3}}{8.5 \times 10^{-6}} = 151955$$

$$f = 1.87\ (151955)^{-0.2} = 0.172$$

∴ Shell side pressure drop

$$(\triangle P)_s = \left[\frac{4\, f\, (N_b + 1) D_s\, Gs^2\ \ g\,]}{2\ g\ De\ \rho_{vapor}}\right] \times 0.5$$

$$N_b = 0$$

$$\therefore \quad \triangle Ps = \left[\frac{4(0.172)\ (1)\ (0.787)\ (70.58)^2\ 9.81}{2 \times 9.81\ (18.29 \times 10^{-3}) \times 2.482}\right] \times 0.5$$

$= 14.84$ KPa (It very near to permissible pressure drop) .

7.2 MECHANICAL DESIGN:

(a) Shell Side:

Material carbon steel (Corrosion allowance = 3mm)
Number of shells =1
Number of passes =2

Working pressure = 1 atm = 0.101 N/mm^2
Design pressure = 1.1 x 0.101 = 0.11 N/mm^2
Temperature of the inlet = 80.5 ^{0}C
Temperature of the outlet =80.5 ^{0}C

Permissible Strength for
Carbon steel = 95 N/mm^2

b) Tube side :

Number of tubes =716
Outside diameter =0.0191m
Inside diameter = 0.0157m
Length = 4.88m
Pitch, $\triangle^{lar}$ = 25.4 x 10^{-3} m
Feed =Water.
Working Pressure =1 atm = 0.101 N/ mm^2
Design Pressure =0.11 N/mm^2
Inlet temperature =24 ^{0}C.
Outlet temperature = 42 ^{0}C

Shell Side :

$$t_s = \frac{PD_i}{2fJ-P}$$

t_s = Shell thickness
P = design pressure =0.11 N/ mm^2
Di = Inner diameter of shell = 0.787 m =787 mm
f = Allowable stress value = 95 N/mm^2
J= Joint factor = 0.85

$$t_s = \frac{0.11 \times 0.787}{2 \times 95\ (0.85) - 0.11} = 0.54 \text{ mm}$$

Minimum thickness = 6 + 3 = 9 mm (Including corrosion allowance)
$\therefore t_s$ = 10 mm

Head : (Torrispherical head)

$$t_h = \frac{PR_C W}{2fJ}$$

t_h = thickness of head

$$W = \frac{1}{4}\{3 + \sqrt{R_c / R_k}\}$$

R_c = Crown radius = outer diameter of shell =787mm
R_k = knuckle radius = 0.06 R_C

$$\therefore W = \frac{1}{4}\{3 + \sqrt{R_c / 0.06\, R_c}\} = 1.77$$

$$\therefore t_h = \frac{0.11 \times 787 \times 1.77}{2 \times 95 \times 0.85} = 0.95 \text{ mm}$$

Minimum shell thickness should be = 10 mm

$\therefore t_h$ = 10mm

Since for the shell, there are no baffles, tie-nods & spacers are not required.

Flanges :

Loose type except lap-joint flange.
Design pressure (p) =0.11 N/mm2
Flange material : IS:2004 –1962 class 2
Bolting steel : 5% Cr Mo steel.
Gasket material = Asbestos composition
Shell side diameter =787mm
Shell side thickness =10mm

Outside diameter of shell =787 + 10x 2 = 807mm

Determination of gasket width :

$$\frac{d_o}{d_i} = \left[\frac{y - pm}{y - p(m+1)}\right]^{1/2}$$

y= Yield stress

m= gasket factor

Gasket material chosen is asbestos with a suitable binder for the operating conditions.
Thickness = 10mm
m= 2.75
y=2.60 x 9.81 = 25.5 N/mm^2

$$\frac{d_o}{d_i} = \left[\frac{25.5 - 0.11\,(2.75)}{25.5 - 0.11\,(2.75 + 1)}\right]^{½} = 1.0004$$

d_i = inside diameter of gasket = outside diameter of shell
=807+ 5mm
=812 mm

d_o = outside diameter of the gasket
= 1.004 (812)
= 816 mm

Minimum gasket width = $\frac{816 - 812}{2}$ = 2 mm
But minimum gasket width = 6mm
∴ G= 812 + 2 x 6 = 824 mm

G = diameter at the location of gasket load reaction.

Calculation of minimum bolting area :

Minimum bolting area (A_m) = $A_g = \frac{W_g}{S_g}$

S_g = Tensile strength of bolt material (MN/m^2)

Consider , 5% Cr-Mo steel, as design material for bolt

At 80.5^{0}C.

$S_g = 138 \times 10^6$ N/m^2

$$A_m = \frac{0.6037 \times 10^6}{138 \times 10^6} = 4.375 \times 10^{-3}\ m^2$$

Calculation for optimum bolt size :

$$g_1 = \frac{g_o}{0.707} = 1.41 \ g_o$$

g_l = thickness of the hub at the back of the flange
g_o = thickness of the hub at the small end = 10+ 2.5 =12.5mm

Selecting bolt size M18x2

R = Radial distance from bolt circle to the connection of hub & back of flange
R= 0.027
C= Bolt circle diameter = ID +2 (1.415 g_o + R)

C= 0.787 +2 (1.41 (0.0125)+0.027)=0.876 m

Estimation of bolt loads :

Load due to design pressure (H) = $\frac{\pi}{4} G^2 P$

$$H = \frac{\pi}{4} (824)^2 (0.11) = 0.0586 \times 10^6 \text{ N}$$

Load to keep the joint tight under operating conditions.

$H_p = \pi$ g (2b) m p

b= Gasket width = 6mm = 0.006m

$H_p = \pi (0.824) (2 \times 0.006) \times 2.75 \times 0.11 \times 10^6 = 9.39 \times 10^3$ N

Total operating load (W_o) = H+H_p
= 0.06799×10^6 N

Load to seat gasket under bolt –up condition =W_g.

W_g. = π g b y

= $\pi \times 0.824 \times 0.006 \times 25.5 \times 10^6$

$W_g = 0.396 \times 10^6$ N

$W_g > W_0$

$\therefore W_g$ is the controlling load
$\therefore$ Controlling load = 0.396×10^6 N

Actual flange outside diameter (A) = C+ bolt diameter + 0.02

= 0.876 +0.018+ 0.02
= 0.914 m

Check for gasket width :

A_b = minimum bolt area = $44 \times 1.54 \times 10^{-4}$ m^2

$$\frac{A_b S_g}{\pi GN} = \frac{(44 \times 1.54 \times 10^{-4})138}{\pi \times 0.824 \times 0.012} = 30.1 \text{ N/mm}^2$$

$2y = 2 \times 25.5 = 51$ N/mm^2

$$\frac{A_b S_g}{\pi GN} < 2y$$

i.e., bolting condition is satisfied.

Flange Moment calculations :

(a) For operating conditions :

$W_Q = W_1 + W_2 + W_3$

$W_1 = \frac{\pi}{4} B^2 P$ = Hydrostatic end force on area inside of flange.

$W_2 = H - W_1$

W_3= gasket load = $W_Q - H = H_p$

B= outside shell diameter = 807 mm

$$W_1 = \frac{\pi}{4} (0.807)^2 \times 0.11 \times 10^6 = 0.056 \times 10^6 \text{ N}$$

$W_2 = H - W_1 = (0.0586 - 0.056) \times 10^6 = 0.0026 \times 10^6$ N

$W_3 = 9.39 \times 10^3$ N

$W_o = (0.056 + 0.0026 + .00939) \times 10^6$

$= 0.06799 \times 10^6$ N

M_o = Total flange moment = $W_1 a_1 + W_2 a_2 + W_3 a_3$

$a_1 = \frac{C - B}{2}$; $a_2 = \frac{a_1 + a_3}{2}$; $a_3 = \frac{C - G}{2}$

C=0.876 ; B=0.807 ; G=0.824

$a_1 = \frac{0.876 - 0.807}{2} = 0.0345$

$a_3 = \frac{C - G}{2} = \frac{0.876 - 0.824}{2} = 0.026$

$a_2 = \frac{a_1 + a_3}{2} = \frac{0.0345 + 0.026}{2} = 0.0303$

$M_o = [0.056 (0.0345) + 0.0026 (0.0303) + 0.00939 (0.026)] \times 10^6$

$= 2.255 \times 10^3$ J

(b) For bolting up condition :

M_g = Total bolting Moment = $W a_3$

$W = \frac{(A_m + A_b)}{2} S_g$.

$A_m = 2.869 \times 10^{-3}$

$A_b = 44 \times 1.5\ 4 \times 10^{-4} = 67.76 \times 10^{-4}$

$S_g = 138 \times 10^6$

$W = \left(\frac{2.869 \times 10^{-3} + 67.76 \times 10^{-4}}{2}\right) \times 138 \times 10^6 = 0.666 \times 10^6$

$M_g = 0.666 \times 10^6 \times 0.026 = 0.017 \times 10^6$ J

$M_g > M_o$

$\therefore M_g$ is the moment under operating conditions

$M = M_g = 0.017 \times 10^6$ J

Calculation of the flange thickness:

$$t^2 = \frac{MC_FY}{BS_{FO}}$$

C_F= Bolt pitch correction factor = $\sqrt{\underline{B_S} / (2d + t)}$

$$B_s = \text{Bolt spacing} = \frac{\pi C}{n} = \frac{\pi(0.876)}{44} = 0.0625 \text{ m}$$

n= number of bolts = 44

Let $C_F = 1$

S_{FO} = Nominal design stresses for the flange material at design temperature.

$S_{FO} = 100 \times 10^6$ N

$M = 0.017 \times 10^6$ J

B = 0.807 m.

$$K = \frac{A}{B} = \frac{\text{Flange diameter}}{\text{Inner Shell diameter}} = \frac{0.914}{0.807} = 1.13$$

Y = 15

$$t = \sqrt{\frac{0.017 \times 10^6 \times 1 \times 15}{0.807 \times 100 \times 10^6}} = 0.06 \text{ m}$$

d = 18 x 2 = 36mm

$$C_F = \sqrt{\frac{0.063}{2(36 \times 10^{-3}) + 0.06}} = 0.69$$

$C_F = (0.83)^2$

t = 0.0622 x 0.83 = 0.05 m

t = 50mm = 0.05m

Tube sheet thickness : (Cylindrical Shell) .

$T_{1s} = G_c \sqrt{KP / f}$

G_c = mean gasket diameter for cover.
P = design pressure.
K = factor = 0.25 (when cover is bolted with full faced gasket)
F = permissible stress at design temperature.

$t_{1s} = 0.824 \sqrt{(0.25 \times 0.11 \times 10^6) / (95 \times 10^6)} = 0.014$ m

Channel and channel Cover

$t_h = G_c \sqrt{(KP/f)}$ (K = 0.3 for ring type gasket)

$= 0.824 \sqrt{(0.3 \times 0.11/ 95)}$

= 0.015 m = 15 mm

Consider corrosion allowance = 4 mm.

t_h=0.004 + 0.015 = 0.019 m.

Saddle support:

Material: Low carbon steel

Total length of shell: 4.88 m

Diameter of shell: 0.807 mm

Knuckle radius = 0.06 x 0.807 = 0.0484 m = r_o

Total depth of head (H)= $\sqrt{(D_o r_o/2)}$

$= \sqrt{(0.807 \times 0.0484 /2)}$

= 0.1398 m

Weight of the shell and its contents = 3750.43 kg = W

R=D/2=403.5 mm

Distance of saddle center line from shell end = A =0.5R=0.2 m.

Longitudinal Bending Moment

$M_1 = QA[1-(1-A/L+(R^2-H^2)/(2AL))/(1+4H/(3L))]$

$Q = W/2(L+4H/3)$

$= 3750.43\ (4.88 + 4 \times 0.1398/3)/2$

$= 9500.6$ kg m

$$M_1=9500.6\times0.2 \left\{ 1- \frac{(1-0.2/4.88+(0.4035^2-0.1398^2)/(2\times4.88\times0.202))}{(1+4\times0.1398/(3\times4.88))} \right\}$$

$= 12.79$ kg-m

Bending moment at center of the span

$M_2 = QL/4[(1+2(R^2-H^2)/L)/(1+4H/(3L))-4A/L]$

$M_2 = 9380.4$ kg-m

Stresses in shell at the saddle

(a) At the topmost fibre of the cross section

$f_1 = M_1/(k_1\pi R^2 t)$ $\quad\quad k_1=k_2=1$

$=12.79/(3.14 \times 0.4035^2 \times 0.01)$

$= 2500.54$ kg/m^2

The stresses are well within the permissible values.

Stress in the shell at mid point

$f_2 = M_2/(k_2\pi R^2 t)$

$= 180.8$ kg/cm^2

Axial stress in the shell due to internal pressure

$f_p = PD/4t$

$= 0.11 \times 10^6 \times 0.787 /(4 \times 0.01)$

$= 216.4$ kg/cm^2

$f_2 + f_p = 397.23$ kg/cm^2

The sum f_2 and f_p is well within the permissible values.