PROCESS DESIGN OF MAJOR EQUIPMENT

VAPOUR LIQUID EQUILIBRIUM DATA

Temperature in deg. F	Naphthalene mole fraction in liquid phase	Naphthalene mole fraction in vapor phase
505	0	0
500	0.05	0.1114
494	0.1	0.211
489	0.15	0.301
484	0.20	0.382
479	0.25	0.455
474	0.30	0.55521
469	0.35	0.58
465	0.40	0.63
461	0.45	0.683
457	0.5	0.727
453	0.55	0.767
449	0.60	0.803
445	0.65	0.836
442	0.7.	0.866
439	0.75	0.894
435	0.80	0.919
433	0.85	0.942
429	0.9	0.963
426	0.95	0.982
424	1.00	1.00

Assume feed is liquid at its bubble point =231.67 deg.

So q=1

Slope =(q\q-1) = ∞

Composition of feed

Naphthalene = 0.60 mole fraction (Z_f)

Toluene =0.0012 mole fraction

Dimethyl Naphthalene =0.3988 mole fraction

Feed flow rate =1253.166 Kmole\hr

Composition of Distillate

X_n = naphthalene mole fraction in distillate =0.9911

X_t = toluene mole fraction in distillate = 0.0027848

X_m =Dimethylnaphthalene mole fraction in distillate = $6.5x10^{-3}$

Flow rate of distillate = 532.31 Kmole \ hr

Composition of bottom stream

X_w =0.3040

X_{m1} = 0.6959

Using material balance

F =D +W

$FZ_f = DX_d + WX_w$

1235.166 x 0.6 =532.31 x0.9911 +Wx0.3040

W = 703.046 Kmole \ hr

Since the amount of toluene is very less , for design the tower club toluene with naphthalene and design the tower as binary distillation column for naphthalene and dimethylnaphthalene

From graph: minimum ($X_d \backslash R_m$ +1) = 0.53

From graph :minimum reflux = 0.87

Operating reflux ratio (1.5 R_m) = 1.305

L = DR

= 532.31 x1.035

= 694.667 Kmole \ hr

G =L +d

= 694.66 + 532.31

= 1226.97 Kmole \hr

$\overline{L}$ = L +qF

= 1767.428 Kmole \hr

$\overline{G}$ = G +(q-1)F

= 1226.97 Kmole \hr

Molecular Wt. Of feed =139.124 Kg\ Kmole

ENRICHING SECTION

TOP		BOTTOM
694.67	Liq. (Kmole \hr)	694.67
1226.98	Vap. (Kmole \hr)	1226.98
128.14	(M) avg liq	139.124
128.14	(M) avg. vap.	139.124
0.9911	X	0.60
0.9911	Y	0.80
217.78	T liq in deg.	231.11
218.33	T vap in deg.	231.11
88929.16	Liq flow rate (Kg \hr)	96645.265
157225.21	Vap. Flow rate (Kg\hr)	170702.36
849.30	ρ liq. (kg \m^3)	833.70
3.17	ρ vap.(kg \m^3)	3.22

STRIPPING SECTION

TOP		BOTTOM
1767.42	Liq. (Kmole \hr)	1767.42
1226.98	Vap. (Kmole \hr)	1226.98
139.124	(M) avg liq	147.47
133.6	(M) avg. vap.	147.4
0.60	X	0.3010
0.80	Y	0.52
231.67	T liq in deg.	245.56
231.11	T vap in deg.	246.11
245891.65	Liq flow rate (Kg \hr)	260642.63
169342.53	Vap. Flow rate (Kg\hr)	180942.74
833.70	ρ liq. (kg \m^3)	819.69
3.22	ρ vap.(kg \m^3)	3.45

$$\left[\frac{L}{G}\right]\left[\frac{\rho_G}{\rho_L}\right]^{0.5} = 0.03455 \text{ (at top)}$$

$$\left[\frac{L}{G}\right]\left[\frac{\rho_G}{\rho_L}\right]^{0.5} = 0.03518 \text{ (at bottom)}$$

Maximum at bottom of enriching section. Hence all calculations are based on properties at bottom of enriching section

TRAY TOWER DESIGN

Assume :

Plate spacing , t_s = 610 mm

Hole diameter , d_h =5 mm

Hole pitch , l_p =15 mm

Tray thickness , t_T =3 mm

$$\frac{\text{Hole area}}{\text{Perforated area}} = \frac{A_h}{A_p} = 0.10$$

Assume equilateral triangular pitch

Column diameter, Dc:

Based on entrainment flooding.

ll relations from Perry's handbook, 6th edition.

Fig. 18-10 , $C_{sb} = U_{nf}\left[\frac{20}{\sigma}\right]^{0.2}\left[\frac{\rho_g}{\rho_l - \rho_g}\right]^{0.5}$ ft/s.

C_{sb} = 0.0883 m\s

$\therefore \sigma$ = 17.29 dyn\cm

U_{nf} = 1.3990 m\s

Assume U_n = 0.8 U_{nf}

= 1.119 m/s.

Net area for flow , $A_n = A_c - A_d$

Vapour flow rate = $\frac{170702}{3600 \text{ x } 3.22} = 14.56$ m^3/s.

A_n = 14.56 / 1.119 = 13.159m^2.

L_w weir length

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

$$\text{Sin}\left(\frac{\theta_c}{2}\right) = \frac{L_w/2}{D_c/2}$$

$\theta_c = 97.2^0$

$A_c = \frac{\pi D_c^2}{2}$ = 0.785 D_c^2

A_d = 0.0878 D_c^2

A_n = 0.785 D_c^2 – 0.0878 D_c^2

D_c =4.34 m

A_c = 14.78 m

A_d =1.626 m^2

Active area, $A_a = A_c - 2A_d$ =11.52 m^2.

L_w= 4.43 x.75 = 3.255 m

Lets take 3.3 m

Perforated area,A_p

corrected θ_c = 99.o ^{0}C

$\alpha = 180 - \theta_c = 81\ ^0$C

Area of calming + distribution zone, A_{cz}

A_{cz} =2(L_w * t) , t=thickness

A_{cz} =2(3.3 * 120* 10^{-3}) =0.792 m^2 (that is 5.3% of A_c)

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

$A_{wz} = 0.0.348m^2$. (2.3% of A_c)

$A_p = A_c - 2\,A_d - A_{cz} - A_{wz}$

$= 14.56-3.552-0.198-0.348 = 10.682\ m^2$

$A_h = 0.1\ A_p = 1.0682\ m^2$

No. of holes, $n_h = \dfrac{1.0682}{\pi/4\left(5x10^{-3}\right)^2}$ = 54500holes.

Weir height, h_w =50 mm (atmospheric pressure)

Weeping check:

TOP of enriching section

Vapor flow rate = 13.77 m^3 /s (at top)

Vapor flow rate = 14.72 m^3 /s (at bottom)

A_h =1.0682 m^2

U_n = (13.77/1.0682) = 12.89 m/s.

$$h_d = K_1 + K_2 \frac{\rho_g U_h^2}{\rho_l}$$

Assume sieve plates

$K_1 = 0$, $K_2 = 50.8/C_v^2$

A_h / A_a =1.0682 /11.52 =0.09

$t_T/d_h = 0.6$

$C_v = 0.75$

$K_2 = 90.33$

$\therefore$ h_d =90.33 x (3.17 x12.89 x12.89) \849.14

$\therefore$ h_d =56.0 mm

$\therefore$ $h_{ow} = F_w$ x 664 x $\left[\dfrac{q}{L_W}\right]^{2/3}$

q_1 (liquid load) = $\dfrac{88929.16}{3600x849} = 0.029\ m^3/s$

$L_w = 3.255$ m

$$\frac{q}{L_W^{2.5}} = 4.92 , \quad \frac{L_W}{D_{cw}} = 0.75$$

$F_w = 1.03$

$h_{ow} = 25.326$ mm

Head loss due to bubble formation ,

$$h_\sigma = 409\left[\frac{\sigma}{\rho_l d_n}\right]$$

$$h_\sigma = 409\left[\frac{17.29}{833x5}\right]$$

$\therefore h_\sigma = 1.69$ mm liq.

Now, $h_d + h_\sigma = 56+1.69 = 57.69$mm liq.

$h_w + h_{ow} =50 + 25.32 =75.32$ mm

$(A_h/ A_a) = 0.09$

Minimum value to avoid weeping , $h_d + h_\sigma = 18$mm (from fig. 18-11)

Since actual >minimum there is no weeping

Downcomer flooding :

$h_{dc} =h_t + h_w+ h_{ow}+ h_{da}+ h_{hg}$

Hydraulic gradient :

$h_d > 2.5\ h_{hg}$ mm

Let $h_{hg} = 0.5$ mm

$h_{ds} = h_w + h_{ow} +h_{hg}/2$

$h_{ow} =0.9 * 664 * (0.0325\backslash 3.255)^{2\backslash 3}$

$= 27.28$mm

$h_{ds} = 50 +27.28 +0.5\backslash 2 =77.53$ mm

$h_t = h_d+h^1_l$

$h^1_L = \beta h_{ds}$

$U_a = 1.27$ m/s = 4.19 ft/s

$\rho_a = 3.22$ kg/m^3 = 0.2008 lb/ft^3

$F_a = U_a \rho_g^{0.5}$

$= 1.8877$

$\beta = 0.60$

$\phi = 0.2$

$h_L' = 0.60 \times 77.53 = 46.518$ m

$h_f = h^1{}_1 / \phi_t = 232.59$ mm.

$D_f = (L_w + D_c)\backslash 2 = (4.34 + 3.255) \backslash 2 = 3.7625$m.

$$r_h = \frac{h_f D_f}{2h_f + 1000 D_f} = 0.2069 \text{ m.}$$

$$u_f = \frac{1000q}{h_1 D_f}$$

$$\frac{1000x0.0322}{46.51x3.76D_f} = 0.184 \text{ m\textbackslash s}$$

Reynolds modules

$$N_{reh.} = \frac{r_h u_f \rho_1}{\mu_1}$$

$$\frac{0.2069x0.184x833}{0.0003} = 105706.58$$

From pg. 18-19 : f=0.03

$$h_{hg} = \frac{1000 f u_f^2 L_f}{g r_h}$$

$L_f = D_c \cos(\theta_c/2) = 1.396$m.

$h_{hg} = 0.75$mm.

(b) Loss under downcomer, h_{da}

$h_{da} = 165.2\ (q/A_{da})^2$

Assume clearance C = 1" =25.4 mm.

$h_{ap} = 77.53 - C = 52.$ **13 mm**

$A_{da} = L_w h_{ap} = 3.225 \times 0.05213 = 0.1681\ m^2$

$h_{da} = 165.2\ (0.0322/0.1681)^2$

$= 31.64$ mm

$h_{dc} = h_l + h_w + h_{ow} + h_{da} + h_{hg}$

$=121.82 + 50 + 27.28 + 31.64 + 0.75$

$= 231.49$ mm

$h_{dc}' = \frac{h_{dc}}{\phi_{dc}} = \frac{231.49}{0.5} = 462.98$ mm liq.

$t_s = 610$ mm

As $h_{dc}' < t_s$ there is no flooding

Summary of tray calculations

$D_c = 4.34$m

$L_w = 3.255$m

$h_w = 50$ mm

$t_s = 500$ mm

$d_h = 5$ mm

$l_p = 15$ mm

$t_t = 3$ mm

$n_h = 54500$

COLUMN EFFICIENCY

	Enriching Section	Stripping Section
Liquid flow rate kmol/hr.	694.67	1767.428
Liq. flow rate : kg/hr.	92787.2145	253267.12
Vap. flow rate : kmol/hr	1226.98	1226.98
Vap. flow rate : kg/hr.	163963.789	175133.63
$\bar{\rho}_L$ (kg/m^3)	841.5	826.0
$\bar{\rho}_V$ (kg/m^3)	3.195	3.34
$\bar{\bar{T}}_{liq}$ (^{o}C)	224.72	138.61
$\bar{\bar{T}}_{vap}$ (^{o}C)	225.12	238.66
$\bar{\mu}_{liq}$, cP	0.300	0.1
$\bar{\mu}_{vap}$, cP	8.48x 10-^{3}	.0095
D_L , cm^2/s	8.8752 x 10^{-5}	9.204 x 10^{-5}
D_G , cm^2/s	0.04326	0.0449
σ	17.29	17.5
$\bar{x}$	0.7955	0.4505
$\bar{y}$	0.8955	0.66

Column Efficiency:

Enriching section

(a)Point Efficiency, E_{OG}

$$N_g = \frac{0.776 + 0.2285 h_W - 0.238 U_a \rho_g^{0.5} + 105 W}{N_{scg}^{0.5}}$$

W = liq. flow rate = (.0.03006 /3.7625)

= $8.13 * 10^{-3}\, m^3 / m.s$

U_a = 1.273m/s

h_w = 50 mm , $N_{Scg} = (\mu_g \backslash \rho_g D_g)$ = 0.824

N_g = 1.13

$N_L = K_L a \theta_L$

$K_L a = (3.875 \text{ x } 10^8 D_L)^{0.5} (0.4\, U_a \rho_g^{0.5} + 0.17)$

= 1.681 * 1.053

= 1.771m/s

$\theta_L = (h_L A_a) / (1000q)$

$h_L = \varphi_e (h_w + 15330\, C\, (q \backslash \varphi_e)^{2\backslash 3}$

C =0.327 + 0.0286exp((-0.1378 h_w)

C = 0.327

$K_s = U_a (\rho_g \backslash \rho_l - \rho_g)$

K_s = 0.07

φ_e =0.3303

h_L =332.92 mm

N_L = 22.14

$$\lambda = M \frac{G_m}{L_m}$$ M_{TOP} = 0.5125

$$\frac{G_m}{L_m} = \frac{157225.21}{88929.21} = 1.76$$

λ_t= 0.902

M_{BOTTOM} = 0.67

λ_b = 1.183

$\overline{\lambda} = 1.04$

$$N_{og} = \frac{1}{\frac{1}{N_g} + \frac{\lambda}{N_L}} = \frac{1}{0.993 + 0.046}$$

$\therefore$ $N_{og} = 0.974$

$E_{OG} = 1 - e^{-NOG} = 0.6181$

(b) Murphree Plate Efficiency, E_{mv}

$$N_{Pe} = \frac{Z_L^2}{D_E \theta_L}$$

$Z_L = D_c \cos(\theta_L/2) = 2.792$ m.

$D_E = 6.675 * 10^{-3} (U_a)^{1.44} + 0.922 * 10^{-4} h_L - 0.00562$

$= 6.48 \times 10^{-3}$ m^2/s

$N_{Pe} = 34.41$

$\lambda E_{OG} = 0.636$

From fig. 18.29a $\frac{E_{mv}}{E_{OG}} = 1.03$

$\therefore$ $E_{mv} = 0.66$

(c) Overall column efficiency, E_{oc}

$$E_{oc} = \frac{N_T}{N_A} = \frac{\log\left[1 + E_a(\lambda - 1)\right]}{\log \lambda}$$

$$\frac{E_a}{E_{MV}} = \frac{1}{1 + E_{MV}\left[\frac{\psi}{1 - \psi}\right]}$$

$$\frac{L}{G}\left[\frac{\rho_G}{\rho_L}\right]^{0.5} = 0.0348$$

Considering 80% flooding,

From fig, $\Psi = 0.08$

$\therefore E_a = 0.614$

$E_{oc} = 0.587$

$E_{oc} = N_t \setminus N_A$

$N_A = 8.605 \approx 9$ trays

$N_A = 9$ trays

Tower height, $= t_s * N_A$

$= 610 * 10^{-3} * 9 = 5.5m$

$\therefore H = 5.5m$

STRIPPING SECTION :

$$\left[\frac{L}{G}\right]\left[\frac{\rho_G}{\rho_L}\right]^{0.5} = 0.0902 \text{ (at top)}$$

$$\left[\frac{L}{G}\right]\left[\frac{\rho_G}{\rho_L}\right]^{0.5} = 0.0933 \text{ (at bottom)}$$

Maximum at bottom of stripping section. Hence all calculations are based on properties at bottom of stripping section

Assume :

Plate spacing , t_s = 610 mm

Hole diameter , d_h =5 mm

Hole pitch , l_p =15 mm

Tray thickness , t_T =3 mm

$$\frac{\text{Hole area}}{\text{Perforated area}} = \frac{A_h}{A_p} = 0.10$$

Assume equilateral triangular pitch

Column diameter D_c :

Based on entrainment flooding.

All relations from Perry's handbook, 6th edition.

Fig. 18-10 , $C_{sb} = U_{nf}\left[\frac{20}{\sigma}\right]^{0.2}\left[\frac{\rho_g}{\rho_l - \rho_g}\right]^{0.5}$ ft/s.

C_{sb} =0.0.43 ft\s

$\therefore$ σ =17.5 dyn\cm

U_{nf} = 1.232 m\s

Assuming 80% flooding

$U_n = 0.8\ U_{nf}$

=0.9858 m/s.

Net area for flow , $A_n = A_c - A_d$

Vapour flow rate = $\frac{180942.74}{3600 \text{ x } 3.45} = 14.56\,m^3/s.$

$A_n = 14.56 / 0.98858 = 14.77 m^2$.

L_w weir length

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

$\sin\left(\frac{\theta_c}{2}\right) = \frac{L_w/2}{D_c/2}$

$\theta_c = 97.2^0$

$A_c = \frac{\pi D_c^2}{2} = 0.785\ D_c^2$

$A_d = 0.0878\ D_c^2$

$A_n = 0.785\ D_c^2 - 0.0878\ D_c^2$

$D_c = 4.66$ m

$A_c = 16.61$ m

$A_d = 1.85\ m^2$

Active area, $A_a = A_c - 2A_d = 12.89\ m^2$.

$L_w = 4.6 \times .75 = 3.45$m

Perforated area, A

$\alpha = 180 - 97.2 = 82.82\ ^0C$

Area of calming + distribution zone, A_{cz}

$A_{cz} = 2(L_w * t)$, t=thickness

$A_{cz} = 2(3.45 * 120 * 10^{-3}) = 0.828\ m^2$ (that is 5.05% of A_c)

$A_{wz} = 0.3928 m^2$. (2.3% of A_c)

$A_p = A_c - 2\ A_d - A_{cz} - A_{wz}$

$= 16.61 - 2 \times 1.85 - 0.828 - 0.3928 = 11.67\ m^2$

$A_h = 0.1\ A_p = 1.167\ m^2$

No. of holes, $n_h = \frac{1.167}{\pi/4 \left(5 x 10^{-3}\right)^2}$ = 59468holes.

Weir height , h_w =50 mm (atmospheric pressure)

Weeping check :

TOPof enriching section

U_n = 12.5 m/s.

$$h_d = K_1 + K_2 \frac{\rho_g U_h^2}{\rho_l}$$

Assume sieve plates

$K_1 = 0$, $K_2 = 50.8/C_v^2$

A_h / A_a =1.0682 /11.52 =0.09

$t_T/d_h = 0.6$

$C_v = 0.75$

$K_2 = 90.33$

$\therefore$ h_d =90.33 x (3.22 x12.5 x12.5) \833.7

h_d =54.5mm

$$h_{ow} = F_w \text{ x } 664 \text{ x } \left[\frac{q}{L_W}\right]^{2/3}$$

$$q_1 \text{ (liquid load) } = \frac{24445891.65}{3600x833.70} = 0.0819 \text{ m}^3/\text{s}$$

L_w = 3.255 m

F_w = 1.04

h_{ow} = 56.36 mm

Head loss due to bubble formation ,

$$h_\sigma = 409\left[\frac{\sigma}{\rho_l d_n}\right]$$

$$h_\sigma = 409\left[\frac{17.5}{833.70x5}\right]$$

$\therefore h_\sigma$ = 1.717mm liq.

Now, $h_d + h_\sigma$ = 54.5+1.715 = 56.25mm liq.

$h_w + h_{ow}$ =50 +56.34 =106.21 mm

(A_h / A_a) = 0.09

Minimum value to avoid weeping , $h_d + h_\sigma$ = 16mm (from fig. 18-11)

Since actual >minimum there is no weeping

Downcomer Flooding

$h_{dc} = h_t + h_w + h_{ow} + h_{da} + h_{hg}$

Hydraulic gradient :

$h_d > 2.5\ h_{hg}$ mm

Let $h_{hg} = 0.5$ mm

$h_{ds} = h_w + h_{ow} + h_{hg}/2$

$h_{ow} = 1.03 * 664 * (0.088\backslash 3.45)^{2\backslash 3}$

$= 58.68$mm

$h_{ds} = 50 + 58.68 + 0.5\backslash 2 = 108.93$ mm

$h_t = h_d + h^1{}_1$

$h^1{}_L = \beta h_{ds}$

$U_a = 1.13$ m/s = 3.70 ft/s

$\rho_a = 3.45 kg/m^3 = 0.2150 lb/ft^3$

$F_a = U_a \rho_g^{0.5}$

$= 1.7177$

$\beta = 0.61$

$\phi = 0.22$

$h_L' = 0.61 \times 1108.93 = 66.26$ m

$h_f = h^1{}_1 / \phi_t = 301.18$mm.

$D_f = (L_w + D_c)\backslash 2 = (4.6 + 3.45)\backslash 2 = 4.025$m.

$$r_h = \frac{h_f D_f}{2h_f + 1000 D_f} = 0.2619\text{m.}$$

$$u_f = \frac{1000q}{h_1 D_f}$$

$$\frac{1000x0.088}{66.26x4.025} = 0.3311\ \text{m\textbackslash s}$$

Reynolds modules

$$N_{reh.} = \frac{r_h u_f \rho_1}{\mu_1}$$

$$\frac{0.2619x0.3311x819.69}{0.0001} = 710986.05$$

From pg. 18-19 : f=0.03

$$h_{hg} = \frac{1000 f u_f^2 L_f}{g r_h}$$

$L_f = D_c \, Cos(\theta_c/2)$ = 0.3.042m.

h_{hg} = 4.02mm.

(Loss under downcomer, h_{da}

$h_{da} = 165.2\ (q/A_{da})^2$

Assume clearance C = 1" =25.4 mm.

h_{ap} = 108.93 – C = 83.23 mm

$A_{da} = L_w h_{ap}$ = 3.45 x0.08323= 0.2945 m^2

$h_{da} = 165.2\ (0.088/0.2942)^2$

= 14.81 mm

$h_{dc} = h_l + h_w + h_{ow} + h_{da} + h_{hg}$

=109.80+ 50 + 58.68+ 14.81 + 4

= 237.29 mm

$$h_{dc}' = \frac{h_{dc}}{\phi_{dc}} = \frac{237.29}{0.5} = 474.58 \text{ mm liq.}$$

t_s = 610 mm

As $h_{dc}' < t_s$ there is no flooding

Summary of tray calculations

D_c = 4.6m

L_w = 4.01m

h_w = 50 mm

t_s = 610 mm

d_h = 5 mm

l_p = 15 mm

t_t = 3 mm

n_h = 59468holes

COLUMN EFFICIENCY 0F STRIPING SECTION

Striping section

(a)Point Efficiency, E_{OG}

$$N_g = \frac{0.776 + 0.2285 h_W - 0.238 U_a \rho_g^{0.5} + 105 W}{N_{scg}^{0.5}}$$

W = liq. flow rate = 0.021 m^3 / m.s

U_a = 1.163m/s

h_w = 50 mm , N_{Scg} = $(\mu_g \backslash \rho_g D_g)$ = 0.834

N_g = 1.154

$N_l = K_L a\theta_L$

$K_L a$ = (3.875 x $10^8 D_L)^{0.5}$ (0.4 $U_a \rho_g^{0.5}$ + 0.17)

= 1.8m/s

θ_L = $(h_L A_a)$ / (1000q)

$h_L = \varphi_e (h_w + 15330\ C\ (q \backslash \varphi_e)^{2\backslash 3}$

C =0.327 + 0.0286exp((-0.1378 h_w)

C = 0.327

$K_s = U_a (\rho_g \backslash \rho_l - \rho_g)$

K_s = 0.0742

φ_e =0.3081

h_L =80.86 mm

N_L =21.36

$$\lambda = M \frac{G_m}{L_m}$$

M_{TOP} = 0.8

$$\frac{G_m}{L_m} = \frac{157225.21}{88929.21} = 0.9886$$

λ_t=0.8164

M_{BOTTOM} = 1.6

λ_b = 0.9582

$\bar{\lambda} = 0.88$

$$N_{og} = \frac{1}{\frac{1}{N_g} + \frac{\lambda}{N_L}} = \frac{1}{0.86695 + 0.044}$$

$E_{OG} = 1 - e^{-NOG} = 0.66$

Murphree Plate Efficiency, E_{mv}

$$N_{Pe} = \frac{Z_L^2}{D_E \theta_L}$$

$Z_L = D_c \cos(\theta_L/2) = 3.04$ m.

$D_E = 6.675 * 10^{-3} (U_a)^{1.44} + 0.922 * 10^{-4} h_L - 0.00562$

$= 6.48 \times 10^{-3}$ m^2/s

$N_{Pe} = 75.41$

$E_{OG} = 0.64$

From fig.18.29 $\frac{E_{mv}}{E_{OG}} = 1.04$

$\therefore E_{mv} = 0.672$

Overall column efficiency, E_{oc}

$$E_{oc} = \frac{N_T}{N_A} = \frac{\log\left[1 + E_a(\lambda - 1)\right]}{\log \lambda}$$

$$\frac{E_a}{E_{MV}} = \frac{1}{1 + E_{MV}\left[\frac{\psi}{1-\psi}\right]}$$

$$\frac{L}{G}\left[\frac{\rho_G}{\rho_L}\right]^{0.5} = 0.038$$

Considering 93% flooding,

From fig,

$\Psi = 0.093$

$\therefore E_a = 0.632$

$E_{oc} = 0.625$

$E_{oc} = N_t \backslash N_A$

$N_A = 4.8 \approx 5$ trays

$N_A = 9$ trays

Tower height, $= t_s * N_A$

$= 610 * 10^{-3} * 5 = 3.05m$

$\therefore$ H = 3.05m

Mechanical design of Distillation column

Diameter =4.6m

Operating pressure =1 atm =1.032 Kg\ cm^2

Design pressure = 1.1 x1.032 = 1.132 Kg\ cm^2

Operating temperatur =245.5^{0}C

Design temperatur = 250^{0}C

Shell material - carban steel

Shell – double weled but joint

Skirt height =2m

Tray spacing = 610mm

Top disengaingn space =0.3m

Bottom separator space = 0.4m

Allowable stress = 1187 Kg\ cm^2

Insulation material – asbestos

Density of insulation =575 kg\ m^3

Head torspherical

Material –carbon steel

Skirt support

Height = 2m

Material =carbon steel

Nozzles

No. Of nozzles =5

Tray sieve type

No. Of tray =8

Hole diameter =5mm

Thickness =3mm

Weir height =50 mm

Material for tray – stainless steel

Calculations of shell thickness :

Considering the vessel as an internal pressure vessel.

t_s = (PD_I\2fj-P)+ C

t_s = Thickness of shell (mm)

P = Design pressure ($kg/cm^{2)}$ =1.1362 kg/cm^2

D_i = Diameter of the shell (mm) = 4600mm

f = Allowable /permissible tensile stress (kg/cm^2) = 1187

C = Corrosion allowance (mm) =2mm

J = Joint Efficiency.

Considering double welded bolt joints with backing strip

J = 85% = 0.85

$$t_s = \frac{1.1362 \times 4600}{2(950 \times 0.85)-1.1362} + 2 = \underline{4.95\text{ mm}}$$

Taking the thickness of the shell as t_s = 6mm

Head shallow dished & torispherical head.

$$t_h = \frac{PR_cW}{2fJ}$$

R_c = Crown radius = outer diameter of the shell = 4600+ 2(6) =4612mm

R_L = knuckle radius = 0.06 R_c

W= Stress intensification factor

W =0.25 (3+ $(Rc\backslash Rk)^{0.5}$

$$t_h = \frac{1.1362 \times 4612 \times 1.77}{2 \times 1187 \times 0.85} = \underline{4.59\text{mm}}$$

Thickness of head is t_h =6mm =0.236 inches

Weight of head:

$$\text{Diameter} = OD + \frac{OD}{3} + 2Sf + \frac{2}{3} icr$$

OD = outside diameter of shell = 4612mm = 181.5(inches)

icr = inside cover radius = 0.75 inches

Sf = straight flange length = 1.5 inches

$$\text{Diameter} = 181.5 + \frac{181.5}{3} + 2\ (1.5) + \frac{2}{3}(0.75)$$

Diameter (d) = 192.56 inches

$$\text{Weight of head} = \frac{\pi}{4}(4.89)^2 (6 \times 10^{-3}) x7700$$

$$= \underline{867.22\ kg}$$

weight of head ~ 2675kg

(3) Calculation of stresses:

(i) Axial tensile stress due to pressure

$$f_{ap} = \frac{P_{di}}{4(t_s - c)} = \frac{1.1362x4600}{4\ (6-2)} = \underline{653.315\ Kg/cm^2}$$

This is same throughout the column height

(ii) Circumferential stress :

$2\ f_{ap} = 2x\ 653.315 = \underline{326.66\ Kg/cm^2}$

(iii) compressive stress due to dead loads:

Compressive stress due to weight of shell up to a distance x metre.

$$f_{ds} = \frac{\text{weight of shell}}{\text{Cross-section area of shell}}$$

$$f_{ds} = \frac{(\pi/4)\ (D^2o - Di^2) f_s\ x}{(\pi/4)\ (Do^2 - Di^2)}$$

Di&Do - Internal & external diameters of shell

S_s - density of shell.

Also,

$$f_{ds} = \frac{\text{weight of shell per unit height x X}}{\pi D_m (t_s - c)}$$

Dm = Mean diameter of the shell (cm)

t_s = thickness of the shell (cm)

C = Corrosion allowance (cm)

$f_{ds} = S_s\ (x)$

S_S = 7700kg/cm^2

= 0.0077kg/cm^2

f_{ds} = 0.77x kg/cm^2

Compressive stress due to weight of insulation at height (x) m

$$f_{d(ins)} = \frac{\pi \text{ Dins tins Sins } (x)}{\pi D_m (t_s - c)}$$

Dins = Diameter of insulation

tins = Thickness of insulation

Sins = Density of insulation

D_m = Mean diameter of shell

$$= \frac{[\text{ Dc} + (\text{ Dc}+2\ t_s)]}{2}$$

<u>Assume</u> : asbestos in the insulation material.

Sins = 575 kg/m^3 = 0.000575 kg/cm^3

tins = 75mm = 7.5cm

Dins = Dc+2 t_s +2tins

Dins = 4600 + 2(6) + 2(75) = <u>4762mm</u> = <u>476.2cm</u>

D_m = <u>4600+ (4612)</u> =<u>4606mm</u> = <u>460.6cm</u>

$$2f_d(ins) = \frac{\pi\ (476.2)\ 7.5 \times 0.000575}{\pi\ (460.2)\ (0.6 - 0.2)}$$

= 2.23 x kg/cm^2

(b) Compressive stress due to liquid & tray in the column up to height (x) m.

Liquid & tray weight fox height (x)

$$F_{liq} = \left[\frac{(x-1)}{(0.4572)} + 1\right] \frac{\pi Di^2}{4} \times S_{liquid}$$

$$F_{liq} = \left[\frac{(x - \text{top disengaging space})}{\text{Tray spacing}} + 1\right] \frac{\pi Di^2}{4} \times S_{liquid}$$ (Ref: 3, pg :294)

$$= \left[\frac{x - 0.3}{0.61} + 1\right] \frac{\pi (4.6)^2}{4} \times 850$$

$$= \underline{(x + 0.31) 3145.9 \text{ kg.}}$$

$$f_d(liq) = \frac{F_{liq}}{\pi D_m (t_s - c)}$$

$$= \frac{(x + 0.31)\, 3145.9}{\pi (460.6)(0.6-0.2)} = \underline{(40.40x - 12.4) \text{ kg/cm}^2}$$

(d) Tensile stress due to wind loads in self supporting vessel

$$f_{wx} = \frac{M_w}{z}$$

M_w = bending moment due to wind load

$$= \frac{\text{wind load x distance}}{2}$$

$$= \frac{0.7\, P_w\, D_m\, X^2}{2}$$

z=modulus for the area of shell = $\frac{\pi}{4} D^2 m\, (t_s - c)$

$$f_{wx} = \frac{0.7\, P_w\, D_m\, x^2}{} = \frac{1.4\, Pw \quad x^2}{}$$

$$2 \quad \frac{\pi}{4} D_m^2 (t_s - c) \qquad \pi D_m (t_s - c)$$

P_w = wind pressure

P_w = 25 lb/ft^2

= $\underline{121.9 \text{ kg/m}^2}$

$$M_w = \left(\frac{0.7 \times 121.9 \times 4.606}{2}\right) x^2 = 392.518\ x^2$$

$$Z = \frac{\pi}{4} (4.606)^2 \ (0.006 - 0.002) = \underline{0.0664}$$

392.518

f_{wx} = (392.518)\ 0.0664 = 5902.4 x^2 kg/m^2 . = 0.5902 x^2 kg/m^2

Stresses due to seismic load are neglected.

Calculations of resultant longitudinal stress (upwind side)

Tensile:

ft,max = $f_{wx} + f_{ap} - f_{ds}$

f_{wx} = stress due to wind load.

f_{ap} = Axial tensile stress due to pressure

f_{ds} = Stress due to dead loads.

ft,max = 0.5902 x^2 + 653.315 – 0.77x

ft,max =fJ

f = allowable stress = 1187kg/cm^2

J= Joint factor = 0.85

ft,max = 1187 (0.85) = $\underline{1008.95 \text{ kg/cm}^2}$

0.5902 x^2 - 0.77x +653.315 = 1008.95

0.5902 x^{2} – 0.77x – 355.63 =0

a =0.5902, b = -0.77, c = - 355.63

$$x = \frac{-\ b^1 \pm \sqrt{b^2 - 4\,ac}}{2a} = \frac{0.77 \pm \sqrt{0.77 + 4\,(0.5902)\,355.63}}{2(0.5902)}$$

x = 25.07m

Calculation of resultant longitudinal stress (downwind side) compressive :

ft,max = fwx - fap + fds

$$fc,max = 0.125\ E\ \frac{t}{Do}$$

E= Elastic modulus = $2x10^5$ MN/m^2 $=2x10^6$ kg/cm^2

t = Shell thickness = 6mm.

D_o = 4612 mm

$$fc,max = 0.125 \times 2x10^6 \left(\frac{6}{4612}\right) = \underline{325.23 kg/cm^2}$$

Consider, $325.23= 1.0604\ x^2 – 163.33 + 0.77\ x$

$1.0604\ x^2 + 0.77x – 812.12 = 0$

a= 0.5902, b = 0.77, c= - 978.41

$$x= \frac{- 0.77 \pm \sqrt{0.77^2 + 4\ (0.5902)\ (978.41)}}{2(0.5902)}$$

x= 40.06m

∴ The calculated height is greater than the actual tower height. So we conclude that the design is safe and thus design calculations are acceptable.

∴ A thickness of 6mm is sufficient throughout the length of the shell.

Design of skirt support :

Total height of column including skirt height (H) = 8.2+2+0.3+0.4

= 10.9m

Minimum weight of vessel (W_{min}) ={ $\pi(D_i+t_s)t_s$ (H-skirt height)s

+2 (2670) }

D_i = diameter of shell = 4.6m

t_s = 0.006m

S_s = Density of material

$W_{min} = \pi$ (4.6+ 0.006) 0.006 (10.9-2) 7700+2(2670)

= 11286.83kg.

Maximum weight of column (W_{max}) = $W_w + W_i + W_e + W_a$

W_s = weight of shell during test = 5452.13 kgs.

W_i = weight of insulation $= \frac{\pi}{4} (d^2_{ins} - d^2 o)\ H\ S_{ins}$

$= \frac{\pi}{4} \{ 4.891^2 - 4.612^2 \}\ 10.9\ (575)$

= 13037.96 kgs

W_e = weight of water during test $= \frac{\pi}{4} Di^2 (H-2)$ Swater

$= \frac{\pi}{4} (4.6)\ (10.9-2)\ 1000$

= 156139.64kgs

Wa = weight of attachments = 7100 kgs

W_{max} = 11286.83+13037.96+5452.13+7100 = 63195.55kgs

Period of vibration at minimum dead weight

$$T_{min} = 6.35 \times 10^{-5} \left(\frac{H}{D}\right)^{3/2} \left(\frac{W_{min}}{t_s}\right)^{½}$$

= 0.312 s

∴ K_2 = a coefficient to determine wind load =2 (Ref: 5, pg:147)

period of vibration at maximum dead weight

$$T_{max} = 6.35 \times 10^{-5} \left(\frac{H}{D}\right)^{3/2} \left(\frac{W_{max}}{t_s}\right)^{½}$$

$$= 6.35 \times 10^{-5} \left(\frac{10.9}{4.60}\right)^{3/2} \left\{\frac{36876.92}{0.006}\right\}^{½}$$

= 0.952s

k_2 =2

Total load due to wind acting on the bottom & upper part of vessel

$P_W = k_1\ k_2\ P_w\ HD$

K_1 = coefficient depending upon safe factor

= 0.70 (for cylindrical surface)

P_W = wind load

P_W = wind pressure = 1000 N/M^2 = 100 kg/m^2

For minimum weight condition $D = D_i$ = 4.6 m

For maximum weight condition $D = D_{ms}$ = 4.89 m

$\therefore (P_W)_{min}$ = 0.7x2x100x4.6x10.9

= 7019.6kg

$(P_W)_{max}$ = 0.7x2x100x4.89x10.9

= 7462.14kg

Minimum & maximum wind moments

$(M_W)_{min} = (P_W)_{min} \times \frac{H}{2}$ =38256.82 kg

$(M_W)_{max} = (P_W)_{min} \times \frac{H}{2}$ = 40668.66 kg.m

As the thickness of the skirt is expected to be small, assume

$D_i \simeq D_o$ = 1.7m

$$\sigma_{zwm}(min) = \frac{4\ M_{W(min)}}{\pi D^2 t}$$

$$= \frac{4x\ 38256.82}{\pi(4.6)^2 t}$$

= 2303.15/t Kg/m^2

$$fzwm(max) = \frac{4\times40668.663}{\pi(4.6)^2 t}$$

$$= \frac{2448.35}{t}\ Kg/m^2$$

Minimum and maximum dead load atresses:

$$fzw\,(min) = \frac{W_{min}}{\pi Dt} = \frac{11286.83}{\pi(4.6)t} = \frac{781.41}{t}\ \ Kg/m^2$$

$$fzw\,(max) = \frac{W_{max}}{\pi Dt} = \frac{36826.92}{\pi(4.6)t} = \frac{2553.09}{t}\ \ Kg/m^2$$

Maximum tensile stress without any eccentric load is computed as follows.

(tensile) $fz = \sigma_{zwm}(min) - fzw\,(min)$

$fz = fJ$

$$118.7\times10^5\times0.85 = \frac{2303.15 - 781.41}{t}\ \ Kg/m^2$$

Therefore $t = 1.5\ x10^{-4}$ m

$= 0.15$ mm

Maximum compressive load:

Compressive: $fz = fzwm(max) + fzw\,(max)$

$fz = 0.125\ E(t/Do)$

$= 0.125\times2\times10^5\times10^6\times(t/4.612)$

$$\frac{2448.35+2553.09}{t} = 5.42\times10^9 t$$

Therefore $t = 7.14\times10^{-4}$ m

As per IS 2825-1969,minimum corroded skirt thickness is 7 mm. Providing 1 mm corrosion allowance, a standard 8 mm thick plate can be used for skirt.

Design of skirt bearing plate:

Maximum compressive stress between plate and foundation:

$$fc = \frac{Wmax}{A} + \frac{Ww(max)}{Z}$$

$A = \pi(4.6 - l)\ l$

l - 0uter radius of bearing plate - outer radius of skirt support

$Z = \pi R_m^2 l$

$R_m = \underline{Do - l}$

$$A = \pi(4.6 - l)l$$

$$R_m = \frac{(4.6 - l)}{2}$$

$$Z = \pi \frac{(4.6 - l)^2}{4} l$$

$$fc = \frac{36876.92}{\pi(4.6 - l)l} + \frac{40668.663}{\pi \frac{(1.82 - l)^2}{4} l}$$

Allowable compressive strength of concrete foundation values from 5.5 - 9.5 MN/m^2

Assume :5.5 -9.5 MN/m^2

$$5.5 \times 10^5 = \frac{36876.92}{\pi(4.6 - l)l} + \frac{40668.663}{\pi \frac{(1.82 - l)^2}{4} l}$$

$$l = \frac{0.0191}{(4.6 - l)} + \frac{0.0302}{(4.6 - l)^2}$$

By hit and trial method. l = 0.02 m

Therefore 20 mm is the width of the bearing plate

Thickness of bearing plate ,$t_{bp} = l(3fc/t)^{1/2}$

fc- maximum compressive load at l = 0.02 m = 0.23×10^6 Kg/m^2

$$t_{bp} = 20[(3 \times 0.23 \times 10^6)/(118.7 \times 10^5)]^{1/2}$$

$= 4.23$ mm

$\simeq 6$ mm

Minimum stress between the bearing the plate and the concrete foundation:

$$f_{min} = \frac{W_{min}}{A} - \frac{M_{w(min)}}{Z}$$

$$= \frac{156139.64}{[\pi(1.82-0.02)0.02]} - \frac{40668.63}{[\pi(1.82-0.02)^2 0.02]}$$

$= 7548.63\ Kg/m^2$

$$J = \frac{W_{min} D}{(M_w)_{max}}$$

$$= \frac{(7513.23 \times 4.6)}{13054.05}$$

$= 0.8498$

Therefore this is less then 1.5,the vessel will not be steady by its own weight

Therefore anchor bolts has to be used.

$P_{bolt}(n) = f_{min}\ A$

$= 7548.63 \times 3.14 \times (4.6 - 0.02)0.02$

$= 853.73\ Kg$

MINOR EQUIPMENT DESIGN

Condenser

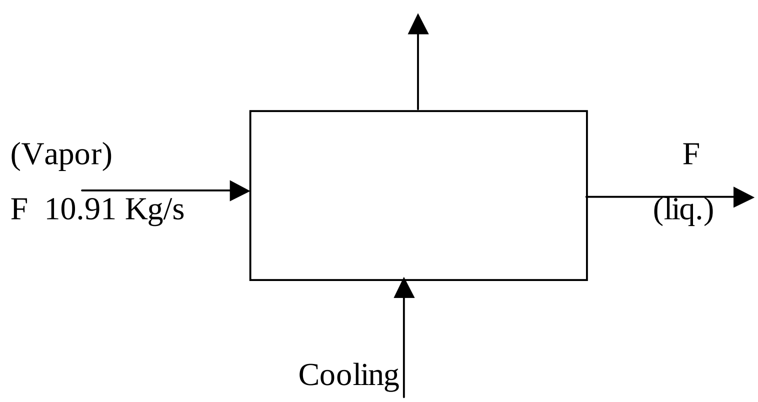
Process Design

Design of a overhead condenser for the vapor mixture of the given in mole fraction ,the temp. of the mixture is 218.33deg. and water comes at 25deg. And out at 40.

Hot fluid enters at 218.33deg. and leaves at 218.33deg.

Cold fluid enters at 25deg. and leaves at 40deg..

<u>PROCESS DESIGN :</u>



Condensation occurs at isothermal condition, correction factor F_t =1.

Assume feed is saturated at 218.33deg.

Properties are evaluated at 218.33deg.

μ_g = Viscosity = 9.47×10^{-3} cp.

ρ_g = Density = 3.177 kg/m^3.

c_{pg} = Heat capacity =1.73 KJ/kg deg.

λ =Latent Heat =320.24KJ/Kg

Vapor flow rate = 43.67 Kg\sec.

Here flow rate is high so we use four condensers in parallel.

So flow rate = 43.67\4 =10.91kg\sec

Heat load =mλ

=10.91x320.24

=3483.14×10^3 Kg\sec

Using this.

Mass of process water required = 55.45 kg/s.

The rang of U for organic solvent and water is (289.3 to 567.8 w\m^{2}k)

Assuming counter current operation ΔT_{ln} = 188.28 deg.

Assuming U heat transfer coefficient = 300 W/m^{2}K

A = Q /U (ΔT_{ln}) =(3483.14x10^3)\300x188.28 =61.66m^2.

Assuming length of pipe to be 10 ft. and we take 1 inch O.D.,16 BWG tube,

I.D. of tube =0.022m

External area =0.0797 m^2\m

N_t =61.66\0.0797x3.048 = 253

From Perry for 1-1 STHE TEMA P for 1in. OD on 1.25 inch Triangular pitch

N_t = 278 for Shell diameter = 0.635 m.

So corrected area =67.523 m^2.

Corrected U =273.94 W/m^{2}K

Area of tube =0.785D_i x D_i

=3.4994x10^{-4} m^2

area per pass = 0.0528 m^2\sec

velocity =(55.45)\1000x0.0528

=1.050 m\sec

Tube side heat transfer coefficient:

Property at 32.5deg.

ρ = 1000 kg/m^3

k = 0.578 W/mK

μ = 1 cp.

c_p= 4.187 KJ/kg deg

G_t = 549.82 kg/m^{2}K

Prandtl number (N_{Pr}) = (c_p μ)\k = 7.2

Reynolds's number (N_{Re}) =($D_i v\rho$)\μ =23100

For turbulent conditions Dittus Boelter equation.

$$\frac{h_i d_e}{k} = 0.023\ (N_{Re})^{0.8}\ (N_{Pr})^{0.33}$$

h_i = 3386.56W/m^2K

FILM COEFFICIENT

Shell side – Distillate

Temp. of wall=124.165deg.

Film temp. =171.24deg.

Property at this temp.

ρ = 855.12 kg/m^3

k = 0.112 W/mK

μ = 0.28cp.

c_p= 1.71 KJ/kg deg

Baffle spacing B = 0.406 m.

G_s = 10.91kg\s

Reynold's number (N_{Re}) = $\dfrac{4\times \textit{Mass}\text{ flow rate of condensate}}{\mu \times N_t^{2/3} \times L\text{ength of tube}}$

=1178.153

$h_s = 1.151[\quad]^{1/3}[N_{Re}]^{-1/3}$

h_s =678.313 W/m^2K

the dirt factor is 5.283x10^{-4} W/m^2K

over all heat transfer cofficient

1\U =(D_o\$D_i$)x1\$h_i$ +1\ h_s +5.283x10^{-4}

U = 426.92 W/m^2K

Calculated U = 426.92W/m^2K assuming U= 300 W/m^2K

$\therefore$ Design is okay.

PRESSURE DROP CALCULATION

TUBE SIDE

N_{Re} = 3386.54

$F = 0.079 (N_{Re})^{-1/4} = .0.01305$

$H=(4 \times f \times v^2 \times L)\backslash(2gD)$

$=0.332m$

$P= \rho gH$

$=3.161kN\backslash m^2$

$\Delta P =(2.5\rho v^2)\backslash 2$

$=1.378 kN\backslash m^2$

$\Delta P_{Total} = 2(1.378+3.161)$

$=9.078 kN\backslash m^2$

which is very less than permissible, therefore design is okay

SHELL SIDE

T_{Vapour} =218.33deg.

$\delta_m = (p^1- D)l_s D_s \backslash p^1$

here ,

p^1 = pitch =1"

D_s = shell diameter = 635 mm

$\delta m =((31.75 – 25.4) x635x635) \backslash(2x31.75)$

$\delta m =.040 m^2$

PRESSURE DROP CALCULATION

End zones Δp_e ,two end zones.

Cross flow zones Δp_c ,(N_b –1) cross

Window zones Δp_w , N_b zones

$\Delta p_c =b\ f_k w^2 N_c (\mu_w\backslash \mu_b)$

$b =2x10-^3$

w = 10.91 Kg\s

$\delta m =0.040 m^2$

$N_c = D_s (1 –2(l_c\backslash D_s))\backslash P_p$

$P_p == (1.732\backslash 2) p^1$ mm

$=27.4$ mm

$P_n = 0.5\ p^1 \quad = 15.875$ mm

$l_c =$ 25% of shelldia.

$N_c = 12$

$\Delta p_c = 3.41\ KN\backslash\ m^2$

$\Delta p_w = (\ b\ x\ (\ W)^2\ (2 + 0.6\ x\ N_{cw}\ )\ )\backslash\ (S_w\ x\ \delta m\ x\rho\ )$

$N_{cw} = 0.8\ l_c \backslash\ P_p$

$= (0.8\ x0.25\ x635) \backslash\ 27.4$

$= 4.63$

$S_w = S_{wg} - S_{wt}$

$S_{wg} = 0.1806\ m^2$) (from perry hand book)

$S_{wt} = (\ (N_t)\ (\ 1 - F_c\ )\Pi D_0^{\ 2})\backslash 8$

$S_{wt} = 0.026$

$\Delta p_w = 14.265\ KN\backslash\ m^2$

$\Delta p_e = \Delta p_c(\ 1 + N_{cw}\backslash\ N_c)$

$= 3.41(1+4.63\backslash 12)$

$= 4.725\ KN\backslash\ m^2$

Total pressure drop:

$0 + 14.265 + 2\ x\ 4.725$

$23.716\ KN\backslash m^2$

But actual pressure is 40% of this = $9.486\ KN\backslash m^2$

MECHANICAL DESIGN OF CONDENSER:

SHELL SIDE:

Material: Carbon steel

No. Of shells: 1

No. Of passes: 2

Fluid: naphthalene vapour

Internal diameter : 635m

Working pressure: 0.1 N/mm^2

Design pressure: 0.0.106 N/mm^2

Inlet temperature: 218 .33^{0}C

Outlet temperature: 218 .33^{0}C

Allowable stress: 950 Kg/Cm^2

TUBE SIED:

Material: Stainless steel (IS grade 10)

No. Of tubes: 278

Outside diameter: 25.4mm

Length: 3.048m

Fluid: water

Pitch: 31.75mm (triangular)

Allowable stress: 10.06 Kg/m

Working pressure: 1atm

Design pressure: 1.06Kg/cm^2

Inlet temperature: 25ºC

Outlet temperature: 40ºC

SHELL SIDE

SHELL THICKNESS:

$t_s = (P_d \times D_S)/(2fJ-P_d)$

$= (0106 \times 635)/((2 \times 95 \times 0.85)-0.106)$

$= 0.41$ mm

But minimum thickness of shell is 6 mm

Therefore with corrosion allowance of 2mm

Thickness of shell = 8 mm

NOZZLE DIAMETER

M = Mass velocity/sec

= 10.91Kg/sec

Density ρ =850 kg/m^3

Assume velocity to be 10 m/sec

$(\pi \times d_n^2 \times \rho \times v)/4 = M$

$d_n^2 = (10.91 \times 4)/(10 \times 3.14 \times 850)$

$d_n = 0.0404$m

NOZZLE THICKNESS

$t_n = (P_d \times d_n)/(2fJ-P)$

$= (0.106 \times 40)/(2 \times 95 \times 0.85-0.106)$

$= 0.026$ mm

Nozzle thickness with corrosion allowance = 5 mm

HEAD THICKNESS:

$t_h = (P_d \times R_c \times W)/(2fJ)$

$W = (1/4)(3+(R_c/R_K)^{1/2})$

R_c - crown radius = 635mm

R_K - Knuckle radius 6% of shell I.D.= 38.1mm

W = 1.77

$t_h = 0.737$mm

Using same thickness as that of the shell = 8 mm

BAFFLE ARRANGEMENT:

Transverse baffles

Number of baffles =1

Baffle Spacing = D_s = 635 mm

Thickness of baffles = 6 mm

Height of baffle = 0.75 × D_s

= 477mm

TIE RODS AND SPACERS:

For shell diameter D_s = 635 mm

No. Of tie rods = 6

No. of spacers =

Diameter of rods = 13 mm

FLANGE CALCULATION:

Flange material = IS: 2004-1962 class 2

Bolting steel =5% Cr M_o steel

Gasket material =asbestos composition

Shell inside diameter =635 mm

Shell thickness t_s = 9mm

Shell outside diameter = $(2\times t_s)+635$

= (2×8) +635

= 653 mm

Allowable stress of flange material = 100 MN/m^2

Allowable stress of bolting material = 138 MN/m^2

GASKET WIDTH:

$G_o/G_i = [(y-P_d m)/(y-p_d(m+1))]^{1/2}$

m-Gasket factor =2.75

Y-Minimum design seating stress =25.5 MN/m^2

$G_o/G_i = [25.5-(0.106\times2.75)/25.5-(0.106\times3.75)]^{1/2}$

= 1.003

Minimum gasket width N =10 mm

Basic gasket seating width b_o = N/2

=5 mm< 6.3 mm

Let, inside diameter of gasket =inside diameter of shell =635 mm

G_i = 656

Mean gasket width $=G_i+N$

$=657mm$

therefore G =657mm

Estimation of bolt load:

Load due to design pressure $H = (\pi G^2 P_d)/4$

$= (\pi \times 0.657^2 \times 0.106)/4$

$= 0.035$ MN

Effective gasket sitting width $b = b_o = 6.27$ mm since $b<6.3$ mm

Load to keep joint tight under pressure $H_p = \pi(2b)GmP_d$

$= 3.14\times0.0125\times0.657\times2.75\times0.106$

$= 0.0075MN$

Total operating load $W_o = H+H_p$

$=0.035+0.0075$

$= 0.042$ MN

Load to seat gasket under bolting up condition $W_b = \pi bGP_d$

$=3.14\times0.657\times0.00627\times0.106$

$= 0.328MN$

Since $W_b>W_o$, controlling load =0.328MN

Minimum bolting area:

Total cross sectional area of bolt under operating condition $A_{m1}=W_o/S_b$

S_b-nominal bolt stress at design temperature of 218.33ºC=138 MN/m^2

Therefore A_{m2} =0..328/138

$=2.37 \times 10^{-3}\ m^2$

Total cross sectional area of bolt required for gasket seating $A_{m2} = W_b/S_a$

S_a-nominal bolt stress at ambient temperature (30ºC)=138 MN/m^2

Therefore A_{m1} =0..042/138

$=3.04 \times 10^{-4}\ m^2$

Since $A_{m2} > A_{m1}$, $A_m = A_{m2} = 2.37 \times 10^{-3}\ m^2$

Calculation of optimum bolt size:

$C = 2(R+g_1)+B$

Choosing bolt M-18 × 2

Total number of bolts = G/(18 × 2)

= 664/36

= 18

so we take No. Of bolt = 20

Actual number of bolts = 220

R-radial clearance from bolt to point of connection of hub and back of flange = 27mm

B-inside diameter of flange =outside diameter of shell =0.654 m

$g_1 = g_o/0.707$,let g_o= 8 mm

$g_1 = 1.415\ g_o$

C =2(0.027 + 1.415 x 0.008) + 0.654

= 0.7306m

Therefore bolt circle diameter = 0.7307 m

Flange outside diameter:

A = C + bolt diameter + 0.02

= 0. 7307 + 0.018 + 0.02

= 0.795 m

Check of gasket width:

A_b-root area of bolt (m^2)-1.54 ×10^{-4} m^2

S_g-allowable stress for bolting material at atmospheric temperature =138 MN/ m^2

Therefore, $A_bS_g/\pi GN = 20.69$

Since 20.69 > 2y

Condition is satisfied.

Flange moment computations:

$W_o = W_1 + W_2 + W_3$ (under operating condition)

$W_1 = (\pi B^2 P_d)/4$

$= (3.14\times0.654^2\times0.106)/4$

= 0.035MN

$W_2 = H – W_1$

$H = (\pi G^2 P_d)/4$

$=(3.14\times0.657^2\times0.106)/4$

=0.0359 MN

$W_2 = .0359 - 0.035$

$= 9.175 \times 10^{-4} MN$

$W_3 = W_o - H$

$= 0.042 - 0.0359$

$= 0.0061 MN$

Total flange moment,

$M_o = W_1 a_1 + W_2 a_2 + W_3 a_3$

$a_1 = (C - B)/2$

$= 0.065$ m

$a_3 = (C-G)/2$

$= 0.064$ m

$a_2 = (a_1 + a_3)/2$

$= 0.0645$ m

$M_o = 0.065 \times 0.035 + 0.0645 \times 0.00091 + 0.0064 \times 0.0061$

$= 2.724 \times 10^{-3}$ MNm

Bolting up condition:

Total flange moment $M_g = Wa_3$

$W = (A_m + A_b)\, Sg/2$

$= 0.376$ MN

$a_3 = 0.064$m

Therefore $M_g = 0.0240$ MNm

Since $M_g > M_o$ for moment under operating condition, M_g is controlling.

Therefore $M = M_g = 24 \times 10^{-3}$ MNm

Flange thickness:

$t^2 = (MC_F Y)/BS_T$

$K = A/B$

= Outer diameter of flange/ inner diameter of flange

= 0.795/0.654

= 1.21

Y =14

Assume $C_F = 1$

Therefore thickness 't' = 0.0719m

Actual bolt spacing $B_S = \pi C/n$

$= (3.14 \times 0.785)/20$

$= 0.123$ m

Bolt pitch correction factor $C_F = [B_S/(2d+t)]^{1/2}$

$=[0.123/(2 \times 0.018+0.0719)]^{1/2}$

$=1.06$

Therefore $C_F^{1/2} = 1.03$

Actual flange thickness = $C_F^{1/2}$ t

$= 1.03 \times 0.0719$

$= 0.074$ m

<u>TUBE SIDE</u>:

TUBE THICKNESS:

$t_t = Pd_o/2fJ+P$

J =1 foe seamless tube

Therefore $t_t = (1..06 \times 25.4)/(2 \times 1006+1.06)$

$= 0.0136$ mm

No corrosion allowance since the tube is made of stainless steel

Thickness of tube = 1mm

TUBE SHEET:

$t_S = FG\, [0.25P/f]^{1/2}$

F-The value of F varies according to type of heat exchanger, for most cases it is taken as

G =657 mm

Therefore $t_S = 657[(0.25 \times 1.55)/1006]^{1/2}$

$= 11.25$mm

CHANNEL AND CHANNEL COVER:

$t = G[KP/f]^{1/2}$

K =0.3 for ring type gasket

Material of construction is carbon steel

So allowable stress f =950 Kg/cm^2

Therefore $t = 657[(0.3 \times 1.06)/950]^{1/2}$

$= 12.68$ mm

With corrosion allowance t =15 mm

NOZZLE THICKNESS:

Assume inlet and outlet diameter = 75 mm

Thickness of nozzle $t_h = Pd/2fJ\text{-}P$

$= (1.06 \times 75)/(2 \times 0.85 \times 950 - 1.06)$

$= 0.0426$ mm

with corrosion allowance thickness = 6mm

<u>SADDLE SUPPORT DESIGN</u>:

Material -Low carbon steel

Vessel diameter=0.654 mm

Length of shell =3.048 m

Torispherical head:

Crown radius =635 mm

Knuckle radius =63.5 mm

Working pressure =1Atm

Shell thickness = 8 mm

Head thickness = 8mm

Corrosion allowance = 2mm

Permissible stress = 950 Kg/cm^2

R-Vessel radius = 425.5

Distance of saddle center line from shell end $A = 0.45 \times R$

$= 147.15\text{mm} < 0.2L$

Longitudinal bending moment:

The bending moment at the support is;

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

A =147.15 mm

Q =W/2[L+4H/3]

W-Weight of fluid and vessel.

Weight of shell material:

$W_1 = [\pi(D_o^2 - D_i^2)L\rho_{shell\ material}] /4$

$\rho_{shell\ material}$ - 7700 Kg/m^3

$W_1 = [3.14(0.654^2 - 0.635^2)\times3.048\times7700] /4$

$= 451$Kg

Weight of tubes:

$W_2 = n[\pi(D_o^2 - D_i^2)L\rho_{tube\ material}] /4$

$\rho_{tube\ material}$ -7800 Kg/m^3

$W_2 = 278[3.14(0.0254^2 - 0.022^2)\times3.048\times7800] /4$

$= 869.55$Kg

Weight of tube sheet:

$W_3 = (2\pi D^2 t\rho)/4$

$= (2\times3.14\times0.635^2\times0.0120\times7800)/4$

$= 62.85$Kg

Liquid load in the shell:

$W_4 =$(shell volume -tube volume)ρ_{liquid}

$=[(\pi D_s^2 L)/4 - (n\pi d_o^2 l)/4]\times1175$

$=[(\pi\times0.654^2\times3.048)/4 - (278\times\pi\times0.0254^2\times3.08) /4]\times850$

$= 508.05$ Kg

Liquid load in tubes:

$W_5 = n\pi d_i^2 l\rho_{liquid} /4$

$=(278\times3.14\times0.022^2\times3.048\times1000)/4$

$= 321.9$Kg

Therefore total weight $W_T = W_1 + W_2 + W_3 + W_4 + W_5$

$= 450.91 + 869.55 + 62..85 + 508.05 + 321.9$

$= 2213.38$ Kg

Hence, Q =2213.38/2[3.048+(4×0.257)/3]

= 3752.416Kgm

$M_1 = (3752.416\times0.147)[1-\{(1-0.147\backslash 3.048)+(0.327^2 - 0.257^2/2\times0.147\times3.048)/(1+4\times0.257/3\times3.048)\}]$

=57.23 Kgm

The bending moment at the center of the span is given by:

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

$= (3752.416\times3.048/4)[\{0.90- (4\times0.147/3.048)]$

$= 2021.80$Kgm

Stress in shell at the saddle:

At the top most fiber of the cross-section,

$f_1 = M_1/(K_1\pi R^2t)$

For an angle of 120º ,$K_1 = 0.197$ m

t-thickness of shell = 8 mm

$f_1 = 57.23/(0.197\times3.14\times0.327^2\times0.008)$

$= 10.81$ Kg/cm^2

At the bottom most fiber of the cross-section

$f_2 = M_1/(K_2\pi R^2t)$

For an angle of 120º ,$K_2 = 0.192$ m

$f_2 = 57.23(0.192\times3.14\times0.327^2\times0.008)$

1

$= 11.09$ kg/cm^2

Stress in the shell at mid point:

$f_3 = M_2/(\pi R^2t)$

$= 2021.8/(3.14\times0.327^2\times0.008)$

$= 75.27$Kg/cm^2

Thus the values of stresses are within the limited range

Hence the designed support is acceptable.