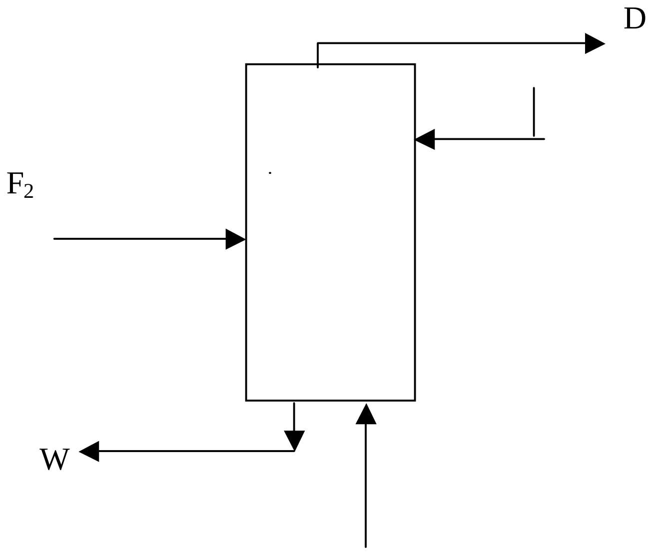
DESIGN OF MAJOR EQUIPMENT

DESIGN OF A DISTILLATION COLUMN TO SEPARATE O-XYLENE AND 1-3-5 TRIMETHYL BENZENE

PROCESS DESIGN :



F_2 =6455.38 kg/hr =58.42 kmol/hr, T=150^{0}C.

X_{OX} =0.673, X_{TMB} =0.327

D = 4463.83 kg/hr =42.11 kmol/hr,T=144^{0}C

X_{OX} = 0.99, X_{TMB} = 0.01

W = 1991.55 kg/hr = 16.69 kmol/hr, T=164 ^{0}C

X_{OX} = 0.044 , X_{TMB} =0.956

T-x-y data is generated assuming an ideal solution. Raoult's law was used at different temperatures to generate the data.

T **(^{0}C)**	**P_A** **(OX)** **(Kpa)**	**P_B** **(TMB)** **(Kpa)**	**X_A**	**X_B**
144.4	101.3	54.0	1.0	1.0
147.0	108.0	60.0	0.86	0.917
150.0	115.0	66.5	0.717	0.814
155.0	132.0	76.0	0.452	0.589
160.0	150.0	88.0	0.215	0.318
162.0	155.0	94.0	0.120	0.184
164.72	166.0	101.3	0.0	0.0

Streams F_2, D and W are all saturated liquid,

$q = 1$

$$\frac{q}{q-1} = \infty$$

From graph,

$$\frac{x_D}{R_m + 1} = 0.35$$

$X_D = 0.99$ => $R_m = 1.83$

Assume reflux ratio, $R = 1.5 R_m$

$$\therefore \quad \frac{L}{D} = 2.74$$

⇨ L = 115.38 kmol/hr.

$$\therefore \frac{x_D}{R+1} = \frac{0.99}{2.74+1} = 0.265$$

$$\frac{\overline{L} - L}{R} = q = 1$$

$\therefore \overline{L} = L + F = 115.38 + 58.42$

$= 173.80$ kmol/hr.

$$\frac{\overline{G} - G}{F} = q - 1 = 0$$

$\therefore \overline{G} = G = 157.49$ kmol/hr.

$$\frac{\overline{L}}{G} = 1.036$$

From graph,

Total number of trays in enriching section = 13

Total number of trays in stripping section = 12

Feed tray = 14

Total number of ideal trays = 25

TOWER HYDRAULICS

	Enriching Section		***Stripping section***	
	Top	***Bottom***	***Top***	***Bottom***
Liq (kmol/hr.)	115.38	115.38	173.80	173.80
Gas (kmol/hr.)	157.49	157.49	157.49	157.49
X	0.99	0.673	0.673	0.044
Y	0.99	0.079	0.079	0.07
T_{liq} (^{0}C)	145.0	150.0	150.0	162.5
T_{vap} (^{0}C)	145.0	152.5	152.5	163.5
($\overline{M}$)$_{liq}$ kg/kgmol.	106.1	110.2	110.2	119.3
($\overline{M}$)$_{vap}$ kg/kgmol.	106.1	108.66	108.66	118.95
Liq (kg/hr.)	12241.82	12714.87	19152.76	20734.34
Vap (kg/hr.)	16709.69	17112.86	17112.86	18733.44
ρ_l (kg/m^3)	836.84	833.67	833.67	826.59
ρ_v (kg/m^3)	3.093	3.155	3.155	3.330
$\frac{L}{G}\left[\frac{\rho_g}{\rho_l}\right]^{0.5}$	0.0445	0.045	0.0679	0.07

$$\left[\frac{L}{G}\right]\left[\frac{\rho_G}{\rho_L}\right]^{0.5} = 0.07$$

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

TRAY TOWER DESIGN

Assume :

(1) Plate spacing , t_s = 500 mm

(2) Hole diameter , d_h =5 mm

(3) Hole pitch , l_p =15 mm

(4) Tray thickness , t_T =3 mm

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

Assume equilateral triangular pitch

(6) Column dia ,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} =0.28

$\therefore$ U_{nf} = 4.605 ft/s

Assume U_n =0.8 U_{nf}

= 3.684 ft/s =1.123 m/s.

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

Vapour flow rate = $\frac{18733.43}{3600 \text{ x } 3.33} = 1.56 \text{ m}^3/\text{s}$.

A_n = 1.56 / 1.123 = 1.389 m^2.

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

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

$\theta_c = 97.2^0$

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

$A_d = 0.0879\ D_c^2$

$A_n = 0.785\ D_c^2 - 0.0879\ D_c^2$

⇨ D_c =1.411 m

⇨ A_c = 1.56 m

⇨ A_d =0.175 m^2

Active area, $A_a = A_c - 2A_d$ =1.21 m^2.

L_w= 1.058 m

(7)Perforated area,A_p

$\theta_c = 97.2\ {}^0C$

$\alpha = 180 - \theta_c = 82.8\ {}^0C$

Area of calming + distribution zone, A_{cz}

$A_{cz} = 2(1.058 * 50 * 10^{-3}) = 0.1058\ m^2$.

$A_{wz} = 0.244\ m^2$.

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

$= 0.8602\ m^{2.}$

$A_h = 0.1\ A_p = 0.08602$

No. of holes, $n_h = \frac{0.08602}{\pi/4\left(5x10^{-3}\right)^2}$ = 4380 holes.

(9) Weir height , h_w =50 mm

(10) Weeping check :

Bottom of stripping section

Vapor flow rate = 1.56 m^3 /s

A_h = 0.08602 m^2

U_n = (1.56/0.08602) = 18.135 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 = 0.08602/1.21 =0.071

t_T/d_h = 0.6

⇨ C_v = 0.73

K_2 = 95.33

$$\therefore\ h_d = F_w \times 664 \times \left[\frac{q}{L_W}\right]^{2/3}$$

$$q_1 \text{ (liquid load) } = \frac{20734.34}{60 \times 826.59} = 0.418 \text{ m}^3\text{/min.}$$

L_w = 1.058 m =3.471 ft

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

F_w = 1.03

h_{ow} = 23.986 mm

Head loss due to bubble formation ,

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

$\therefore\ h_\sigma$ = 2.47 mm liq.

Now, $h_d + h_\sigma = 128.7$ mm liq.

$h_w + h_{ow} = 73.986$ mm

$(A_h / A_a) = 0.071$

Minimum value to avoid weeping , $h_d + h_\sigma = 14$ mm

Since actual >minimum there is no weeping

(11) Downcomer flooding :

(a) Hydraulic gradient :

$h_d > 2.5$ mm

Let $h_{hg} = 0.5$ mm

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

$= 74.236$ mm

$h_L = \beta h_{ds}$

$U_a = (1.56/1.21) = 1.29$ m/s $= 4.23$ ft/s

$\rho_a = 3.33$ kg/m^3 $= 0.2078$ lb/ft^3

$F_a = U_a \rho_g^{0.5}$

$\beta = 0.58$

$\phi = 0.2$

$h_L' = 44.36$ mm

(b) Loss under downcomer, h_{da}

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

Assume clearance C = 1” =25.4 mm.

$h_{ap} = h_{ds} - C = 48.836$ mm

$A_{da} = L_w h_{ap} = 0.0516$ m^2

$h_{da} = 3.00$ mm liquid

$h_l = h_d + h_L' = 170.66$ mm liquid

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

$= 170.66 + 50 + 23.986 + 3.00 + 0.5$

$= 248.146$ mm

$h_{dc}' = \frac{h_{dc}}{\phi_{dc}} = \frac{248.146}{0.5} = 496.29$ mm liq.

$t_s = 500$ mm

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

Summary of tray calculations

$D_c = 1.411$ m

$L_w = 1.058$ m

$h_w = 50$ mm

$t_s = 500$ mm

$d_h = 5$ mm

$l_p = 15$ mm

$t_t = 3$ mm

$n_h = 4380$ holes

(12) Column Efficiency (AIChe method) :

Enriching section

$L_{avg} = 115.38$ kmol/hr =12478.34 kg/hr

$G_{avg} = 157.49$ kmol/hr =16911.275 kg/hr

$T_{liq\text{-}avg} = 147.5\ ^0C$, $T_{vap\text{-}avg} = 148.75^0C$

$\rho_{Lavg} = 835.25$ kg/m^3

$\rho_{Gavg} = 3.124$ kg/m^3

Liquid vis$_{OX}$ at 147.5^{0}C = 0.24 cP

Liquid vis_{TMP} at 147.5^0C =0.2568 cP

$D_L = 8.8752 * 10^{-5}$ cm^2/sec

$D_G = 0.04326$ cm^2/sec

$N_{scg} = \mu_g/\rho_g D_g = 0.694$

Similar calculations are repeated for the stripping section

	Enriching Section	**Stripping Section**
Liq. flow rate : kmol/hr.	115.38	173.8
Liq. flow rate : kg/hr.	12478.34	19943.55
Vap. flow rate : kmol/hr	157.49	157.49
Vap. flow rate : kg/hr.	16911.275	17923.145
$\bar{\rho}_L$ (kg/m^3)	835.25	830.13
$\bar{\rho}_V$ (kg/m^3)	3.124	3.243
$\bar{T}_{liq}$ (^oC)	147.5	156.25
$\bar{T}_{vap}$ (^oC)	148.75	158.0
$\bar{\mu}_{liq}$, cP	0.2428	0.239
$\bar{\mu}_{vap}$, cP	938.38×10^{-5}	923.94×10^{-5}
D_L , cm^2/s	8.8752×10^{-5}	9.204×10^{-5}
D_G , cm^2/s	0.04326	0.0449
N_{scg}	0.694	0.634
$\bar{x}$	0.8315	0.3585
$\bar{y}$	0.89	0.43

Column Efficiency

Enriching section

(a)Point Efficiency, E_{OG}

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

$W = (4.15 * 10^{-3}/1.2345) = 3.3616 * 10^{-3}\ m^3 / m.s$

$U_a = (1.504/1.21) = 1.243$ m/s

$h_w = 50$ mm , $N_{Scg} = 0.694$

$N_g = 1.001$

$N_L = K_L a \theta_L$

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

$= 1.944$ m/s

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

$N_L = 96.714$

$\lambda = M \frac{G_m}{L_m}$ $M_{TOP} = 0.625$

$\frac{G_m}{L_m} = \frac{157.49}{115.38}$ $M_{BOTTOM} = 0.6$

$\overline{\lambda} = 0.835$ $\therefore\ \overline{M} = 0.612$

$$N_{og} = \frac{1}{\frac{1}{N_g} + \frac{1}{N_L}} = \frac{1}{0.999 + 8.633 x 10^{-3}}$$

$\therefore\ N_{og} = 0.992$

⇨ $E_{OG} = 1 – e^{-NOG} = 0.629$

(b) Murphree Plate Efficiency, E_{mv}

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

$Z_L = D_c \cos(\theta_L/2) = 1.28$ m.

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

$= 0.01921\ m^2/s$

$N_{Pe} = 1.714$

$\lambda\ E_{OG} = 0.525$

From fig. 18.29a , $\frac{E_{mv}}{E_{OG}} = 1.13$

$\therefore\ E_{mv} = 0.710$

(c) Overall column efficiency, E_{oc}

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

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

$$\frac{L}{G}\left[\frac{\rho_G}{\rho_L}\right]^{0.5} = 0.0445$$

Considering 80% flooding,

From fig, $\Psi = 0.08$

$\therefore E_a = 0.668$

$E_{oc} = 0.638$

$N_A = 20.36 \approx 20$ trays

$N_A = 20$ trays

Tower height, $= t_s * N_A$

$= 500 * 10^{-3} * 20 = 10$ m

$\therefore H = 10$ m

Stripping Section :

$$U_a = \frac{17923.145}{3600 \times 3.243 \times 1.21} = 1.26876 \text{ m/s.}$$

$W = (6.67 * 10^{-3} / 1.2345) = 5.406 * 10^{-3}$ m^3/ m.s

$\therefore N_g = 1.2916 : N_l = K_l a \theta_l$

$K_L a = 2.047$ m/s

$\theta_l = 30.94$sec.

$\therefore N_L = 63.34$

$M_{TOP} = 0.833$

$M_{BOTTOM} = 1.5$m

$$\lambda = 1.1665 \times \frac{157.49}{173.8} = 1.057$$

$\therefore N_{OG} = 1.271$

$\therefore E_{OG} = 0.719$

$D_E = 0.0251$ m^2/sec

$\therefore N_{Pe} = 2.381$

$\lambda E_{OG} = 0.76$

$\frac{E_{MV}}{E_{OG}} = 1.22$; $E_{MV} = 0.877$

$$\left[\frac{L}{G}\right]\left[\frac{\rho_G}{\rho_L}\right]^{0.5} = 0.0689$$

80% Flooding

$\therefore \psi = 0.04$

$E_a = 0.846$

$E_{OC} = 0.831$

$E_{OC} = (N_T/N_A) = 12/N_A$

$\Rightarrow \therefore N_A = 14.44 \approx 15$

$\therefore N_A = 15$ Trays

Tower Height = 15 * 500 * 10^{-3}

= 7.5 m

H = 7.5 m

Total height of column = 10 + 7.5 = 17.5 m

MECHANICAL DESIGN OF DISTILLATION COLUMN

I) Shell thickness :

$$t_s = \frac{PD_i}{2f_tJ - P} + C$$

Material Carbon Steel

$J = 0.85$, $C = 3$ mm

$P = 1.1\ P_i = 1.1 \times 1.013 = 1.1143 \times 10^5$ Pa

$f_T = 9.5$ Kgf/mm^2

$t_s = 3.98 = 4$ mm

Assume a t_s of 10 mm

II ***1) Axial stresses due to pressure :***

$$f_{ap} = \frac{PD_i}{4(t_s - C)} = \frac{1.1143\text{x}1.411\text{x}10^3}{4(10-3)}$$

= 56.15 Kg/cm^2

2) Stresses due to dead loads :

a) Compressive stress due to the weight of shell upto a height X.

$$f_d = \text{(weight of shell) / (c/s of shell)} = \frac{\pi/_4\left(D_o^2 - D_s^2\right)\rho_s X}{\pi/_4\left(D_o^2 - D_s^2\right)} = 0.77X$$

b) Compressive stress due to insulation upto a height X

$f_{dins} = \pi(D_{ins}\ t_{ins}\ \rho_{ins}\ X)/\pi\ D_s(t_s\text{-}C)$

Let $t_{ins} = 75$ mm and $\rho_{ins} = 770$ Kg/m^3

$f_{dins} = 2.1307 \times 9.115$

c) Compressive stresses due to liquid in the column upto height X.

$f_{d\ liq.} = (\sum$ liq wt. per unit height$)\ X/(\pi\ D_s\ (t\text{-}C))$

Top 1.05 m does not contain any liquid

Assume wt. of attachment (pipes, ladders platforms etc.)

= 160 Kg/m_2

Assume wt. of liquid and trays etc. = 92 Kg/cm^2

Assume wt. of entire column (approx) = 150000 Kg/cm^2

Tray spacing = 0.5 m

Liquid and tray ht. for X m height

$F_{liq.} = [[X-1.05/0.5] + 1]\ \pi \times (1.404)^2/4 \times 92$

= 284.87 X - 156.68

$f_{dliq.} = 0.0923\ X - 0.05074$

d) *wt. of attachments = Total wt. upto* $X/\ \pi D_m\ (t_s - C)$

Assume an elliptical head with ratio of major to minor axis 2:1. The head will have the same thickness as the shell i.e. 10 mm.

wt. of head = 2000 Kg (approx)

$f_d = (2000 + 160\ X)\ 10/\ \pi \times 1.404 \times 100 \times (10-3)$

$f_d = 6.478 + 0.4534\ X$

Total compressive dead wt. stress at ht. X

e) $f_{dx} = 0.77X + 2.130\ X\ 0.02\ X - 0.05074 + 6.478 + 0.4534$

$f_{dx} = 3.4464X + 6.4278$

f) *Bending moment due to wind load :*

$M_{wz} = 0.7\ P_w\ D_o\ X^2/2$

Assume wind pressure = 130 $Kg/m^2 = P_w$

$M_{wz} = 70.71\ X^2$

Stress due to wind pressure, $f_{wx} = 1.4\ P_w\ X^2/\ \pi D_o\ (t_s-C)$

$f_{wx} = 0.5326\ X^2$

g) Tensile or compressive stress due to seismic load

$f_{sx} = M_{sx}/ /4$ D2o $(t_s\text{-C})$

$M_{sx} = C_w$ X2/3 (3H - X)/H2

H = 13.5 m, Assume seismic coefficient C = 0.08

$M_{sx} = 1777.78\ X_2 - 43.89\ X_3$

$F_{sx} = 3.347\ X_2 - 0.826$ X3

Determination of X :

$f_{wz} + f_{ap} - f_{dx} = f_{fmax} = 0.9$ ft

$0.5326\ X^2 + 55.87 - (3.4464\ X + 6.518 + 0.8\ X\ 950) = o$

X = 39.9 m

The entire c column (height = 13.5 m) is stable with the thickness of 10 mm.

(III) Nozzles :

(1) Feed Nozzle (liquid feed)

Mass flow rate = 2766.6 Kg/hr.

V = 2 m/s

P = 833.67 Kg/m^3

dia of nozzle, $d_n = 2.42$ cm

(2) Outlet of the top :

$\therefore D_n = 0.1916$ m

(3) Outlet of the bottom for the liquid :

$\therefore D_n = 39.89$ cm

(4) Nozzle dia for reflux:

D = 3.05 cm

(IV) Trays (sectional) :

Dia = 1.411 m (25% wt.)

Stainless steel t = 2 mm

(V) Skirt Design for support:

Dia of skirt = 1.411 m

Ht . of skirt = 1.35 m

High carbon steel, f_T = 1400 Kg/Cm^2

(a) **Stresses :**

(1) Due to dead wt . $= \dfrac{\Delta W}{\pi D_{ak} T_{ak}}$

$$= \frac{1500000}{\pi x 140.4 x t_{ak}}$$

$$= \frac{338.38}{t_{sk}}$$

(2) Due to wind load:

$$= \frac{0.7 x 130.0 x (17.5 + 1.35)^2 x 1.411 x 1000}{\pi \left[\frac{141.4}{2}\right]^2 t_{sk}}$$

$$= \frac{290.54}{t_{sk}}$$

(3) due to seismic load :

$$f_{ab} = \frac{2}{3} \frac{CHW}{\pi D_{ok} t_{sk}} = \frac{1023.13}{t_{sk}}$$

Max. tensile stress = $\dfrac{1517.3}{t_{sk}} - \dfrac{338.38}{t_{sk}} = 1400$

$\therefore t_{sk} = 0.842$ mm

$= 0.842$ mm

Assume $t_{sk} = 10$mm

Base plate design:

Let dia = 2m

Circumference = 2000 π mm

Let bolt spacing = 600 mm

No. of bolt = $\frac{2000}{600} = 10.47$

Assume 12 bolts

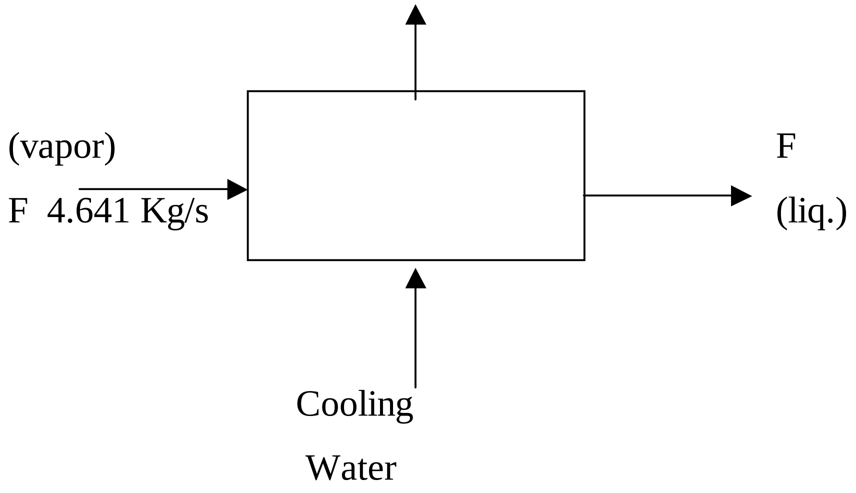
Using M 18 bolts

Minor dia of bolts = 14.480 mm $\therefore$

DESIGN OF MINOR EQUIPMENT

DESIGN OF A TOTAL CONDENSOR

PROCESS DESIGN :



Hot vapors enter at 145°C and are condensed and leave at the same temperature.

Cooling water is available at 25°C can be heated upto 45°C.

T_{bulk} = (25+45)/2 = 35°C, T_{cond} = 145°C

T_{wall} = (145+35)/2 = 90^0C

Condensate avg temp. = (90 + 145)/2 = 117.5°C

(1) Heat balance :

M_cC_{pc} $(\Delta T)_c$ = Q_c

Q_c = 5.76×10^9 J/hr = 1.6×10^6 J/s.

C_{pc} = 4180 J/Kg K

$\Delta T_c = 45 - 25 = 20°C$

$\therefore m_c$ = 7.363 Kg/s = 19.14 Kg/s.

(2) LMTD : $145 \dashrightarrow 145$

$45 \dashrightarrow 25$

No. temp. cross

$\therefore F_T = 1$

LMTD = 109.69°C

Assume U_d = 330 W/m^2 °K

1” O.D. with a triangular pitch, P_T = 1.25 inch

L = 3.66m, d_0 = 2.54 cm = 0.0254m

UA ΔT = Q_c = 1.6×10^6 J/s

$\therefore A = 44.20\ m^2 = N_t\ \pi\ d_o\ L$

$\therefore N_t = 151.34 \cong 152$ tubes

TEMA P, 1 - 1 shell and tube

Shell ID = 19¼” = 489mm

N_t = 152 tubes

$\therefore (U_d)_{\text{corrected}} = 328.60\ W/m^2K$

$(A)_{\text{corrected}} = 44.39m^2$

Properties of condensate and vapor at 117.5 °C

Properties	**K (W/m K)**	**P (Kg/m^9)**	**U (C$_p$)**	**C$_p$ (J/Kg °K)**	**λ (J/Kg)**
Vapor		0.093	$938.38\text{x}10^{-5}$	-----	$3.4494\text{x}10^{3}$
Condensate	0.1558	836.84	0.2428	1991.1	-----

Shell Side Heat transfer Coefficient :

$$h_o = 1.467 \left[\frac{K^3 P_L^2\, g}{\mu_L^{\ 2}} \right]^{1/9} (Re)\ –1/3$$

$$Re = \frac{4 \text{ x } 4.641}{0.2428 \text{ x } 10^{-3} \text{ x } \pi \text{ x } 0.0254 \text{ x } 152} = 6303.70$$

$$h_o = 1.467 \left[\frac{(0.1558)^9\ (836.84)^2 \text{ x } 9.81}{(0.2428 \text{ x } 10^{-3})^2} \right]^{1/3} \text{ x } (6303.70)^{-1/3}$$

∴ ho = 600.716 W/m^2°K

Tube side heat transfer coefficient

Tube O.D 1" 15 DWO

Wall thickness = 0.154 inch

ID = 0.742 inch = 1885

$A_{flow} = \pi/4\ (ID)^2 = 2.79 \times 10^{-4}\ m^2$

$$G = \frac{1914}{1.52 \times 2.79 \times 10^{-4}} 452\ .95\ Kg/m^2\ 5$$

Properties of water at 35°C

K	ρ	μ	C_p
(W/m K)	(Kg/m^9)	(C_p)	
0.62	993	1.01	4.18 x 109

$$Re = \frac{GD}{\mu} = 8452.14$$

$$P\tau = \frac{C_p\mu}{K} = 6.809$$

$$Nu = 0.023\ (Re)^{0.8}\ (Pr)^{0.4} = 68.63$$

$$\frac{H_\tau D_\tau}{K_\tau} = 68.63$$

$\therefore\ h_\tau = 2257.82\ W/m^2K$

$$h_{io} = h_i \frac{d_o}{d_i}$$

$$U_c = \frac{h_{io} h_o}{h_{io} + h_o}$$

$\therefore\ U_c = W/m^2K$

Assume a dirt coefficient of 1500 W/m^2K

$$\therefore\ U_d = \frac{U_c x1500}{U_c + 1500}$$

$\therefore$ $U_d = 374.29$ W/m^{2}K

Assumed U_d 328.60 W/ m^{2}°K

$\therefore$ Satisfactory heat transfer design

Pressure drop calculations:

Shell side

$$f = 0.0035 + \frac{0.264}{Re^{0.42}} = 0.010195$$

$$\Delta P = \frac{4f \{D_e\ L/B]\ G^2}{2d_e\ p_v\ \phi}$$

$$\phi = \left[\frac{\mu}{\mu_w}\right]^{0.14} = 1.03$$

Let B = 3 De = 3 x 489 = 1467 mm

L = 3 .66m

$P_t = 0.03175$ m, $C = P_t - d_0 = 6.35 \times 10^{-3}$

$$d_e = \frac{\left(\frac{1}{2}\ P^2 t \sin 60\ -\ \frac{1}{2}\frac{\pi}{4}\ D_o^2\right)}{\frac{1}{2}\pi\, d_o}$$

$= 4.59 \times 10^{-3}$ m

$$A = \frac{D_5\ C\ B}{P_T} = 0.1434 m^2$$

$$G = \frac{1.784}{0.03869} = 32.36\ Kg/\ m^2\ s$$

$\therefore \Delta P = 59.246\ KN/m^2$

$\Delta P_{max} = 70KN/m^2$

$\therefore$ ΔP is within acceptable limits

Tube side pressure drop:

$$f = 0.0035 + \frac{0.264}{0.42} = 9.42 \times 10^{-3}$$

$$\Delta P = \frac{4f\,[Ln]\,G^2}{2d_t p} = 586.45\ N/m2$$

$\Delta P_{max} = 70{,}000\ N/m^2$.

$\therefore$ ΔP is within acceptable limits.

MECHANICAL DESIGN OF CONDENSOR

(1)Shell thickness

$$t_s = \frac{P_i r_i}{f_T J - P_i} + C$$

P_I = Design pressure = 1.05 atm

Material : cast steel

$f_T = 9.5$ kgf/mm^2

$r_i = (489/2) = 244.5$ mm

Joint efficiency , J = 0.85

C = 3 mm

$\therefore$ $t_s = 3.32$ mm

From IS 4503 table $(t_s)_{min} = 6.3$ mm

$\therefore$ $t_s = 7$ mm

(2) Tube thickness

15 BWG ; $t_T = 0.154$ in = 3.9116 mm

From IS 4503 $(t_T)_{min} = 1.6$ mm

$\therefore$ $t_T = 3.9116$ mm

(3) Tube sheet

$$t = CD_s \sqrt{\frac{p}{f_T}}$$

C = 0.8 , t_{ts} =13.22 mm

From IS 4503 $(t_{ts})_{min} = 15$ mm

$\therefore$ $t_{ts} = 15$ mm

(4) Channel design

$B \times D_s = 1.3\ a_{flow}$

$B \times 489 \times 10^{-3} = 1.3 \times 2.78 \times 10^{-4} \times 152$

$\therefore\ B = 112.34$ mm

(5) Nozzle design

Tube side ; $m = aV$

$V = 2$ m/s

$15.04 = 993 \times 2 \times d_n^2$

$d_n = 98.2$ mm

$B = 3d_n = 294.6$ mm

$B = 295$ mm

Channel thickness = $t_{shell} = 7$ mm

Shell side nozzle

$V = 20$ m/s , $4.641 = 3.093 \times 20 \times\ d_n^2$

$d_n = 309.1$ mm

Nozzle thickness

$$t_{Ntube} = \frac{P_i r_i}{f_T J - P_i} = 0.04 \text{ mm.}$$

$t_{N\ tube} = 1$ mm

$t_{Nshell} = 0.13$ mm

$t_{Nshell} = 1$ mm

(7) Tie Rod

Dia = 10 mm

Number of tie rods = 4

(8) Spacers

Dia = 10 mm

(9) Channel cover thickness

C= 0.3

t_c = 2 mm

(10) Support design :

Rankines formula : $$P/A = \frac{f_a}{1 + \frac{1}{18000}\left[\frac{1}{k}\right]^2}$$

P : wt of material + liquid

Wt of tube sheet = $\pi/4[D_s^2 - n\, d_o^2]t_{ts} \times \rho_s \times 2$

= 2.55 kg

Wt of channel = $\pi\, D_s\, t\, B\, \rho \times 2$

= 0.85 kg

Wt of tubes = $n\, t\, L\, \rho\, 2\, \pi D_o$ = 136.72 kg

Wt of shell = $t_s\, L\, \pi\, D_s\, \rho$ = 324.71 kg

Wt of liquid = $\pi/4\, L\, [D_s^2 - n\, D_o^2]\rho_L + [\, 2 \times \pi/4\, D_s^2\, L\,]\, \rho_L$

= 1766.84 kg

Total weight = 2231.67 kg

15 % extra for tie rods, baffles etc.

Weight = 2566.4 kg

Assume L = 1 m , $f_a = 9.5 \times 9.8 \times 10^6$ N/m^2

K/l = 100 ; K ≈ 1 cm

Rolled steel equal angles

A = 1.73×10^{-4} cm^2

L = 30 mm , B = 30 mm

P/A = 4.9586×10^7 N/m^2

=5.985×10^7N/m^2

therefore the support will not buckle under the load.