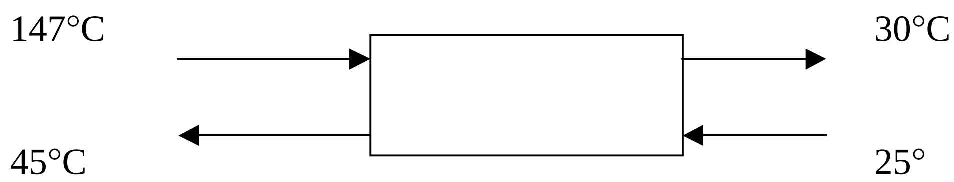
DESIGN OF HEAT EXCHANGER:



Hot HCl solution at 147 °C is to be cooled from that temperature to 30°C.

Let the cooling water is available at 25°C and it is heated to 45°C. Let m_c be the mass flow rate of water.

PROPERTIES:

COMPONENT	T_b °C	C_p kJ/kg °C	μ c.p	K W/m °C	ρ kg/m^3
Aq HCl	88.5	2.926	0.95	0.69	1072.4
Water	37.5	4.18	0.75	0.628	993.148

HEAT BALANCE:

m_h = 8132.95 / 3600 = 2.26 kg/sec

Q_h = $m_h C_p \Delta T$

= 2.26 x 2.926 x (147 – 30)

= 773.69 kW

Q_c = $m_c C_p \Delta T$

= m_c x 4.18 x (20)

m_c = 9.255 kg/sec

LMTD = [(147 – 45) – (45 – 25)] / ln [(147 – 45) / (45 – 25)]

= 32.16 °C

R = (147 – 30) / (45 – 25) = 5.8

S = (45 – 25)/ (147 – 25) = 0.164

From the graph; F_t = 0.9

∴ Actual LMTD = 32.16 x 0.9 = 28.94 °C

HEAT TRANSFER CALCULATION:

Let us assume HCl in shell side; Water in tube side.

Choose U_D= 500 W/m^2 ° C

∴ Cross Sectional Area = Q/ U_D ΔT

= 773.69 x 10^3/ 500 x 28.94

= 53.46 m^2

Let us choose ¾ " OD 16 BWG tubes.

∴ a_t= 0.3048 x 0.1963 = 0.0598 m^2/m.

Let us choose 12 ft pipe.

L = 3.66 m

∴ Heat transfer area per tube = 3.66 x 0.0598

= 0.219 m^2

∴ Number of tubes = 53.46/0.219 = 245 tubes

Now, let us choose TEMA P or S, 1 – 4 type of heat exchanger with 1" triangular pitch.

∴ N_t = 290

∴Actual area = 290 x 0.219

= 63.51 m^2

∴ $(U_D)_{corrected}$ = 773.69 x 10^3 / (63.51 x 28.94) = 441 W/m^2°C

TUBE SIDE VELOCITY:

A_t = n_t / n_p x π/4 x d_i^2

$= 290 / 4 \times \pi/4 \times (0.015748)^2$

$= 0.014\ m^2$

$\therefore\ v_t = m/ (\rho\ A_t) = 9.255/(993.148 \times 0.014) = 0.6656$ m/s

SHELL SIDE VELOCITY:

$S_m = (P' - d_0)\ L_s \times D_s/ P'$

$D_s = 540$ mm

$S_m = [(25.4 - 19.05) \times 10^{-3} \times (540 \times 10^{-3}) \times 0.3] / 2.54 \times 10^{-2}$

$= 0.022\ m^2$

$v_s = m/ \rho\ a = 2.26 / (1072.4 \times .022) = 0.9636$ m/s

HEAT TRANSFER COEFFICIENT CALCULATION:

SHELL SIDE:

$d_0 = 19.05 \times 10^{-3}$ m

$d_i = 15.75 \times 10^{-3}$ m

Reynold's Number $= \rho\ v\ d_o / \mu$

$= (1072.4 \times 0.9636 \times 19.05 \times 10^{-3})/0.95 \times 10^{-3})$

$=20721.68$

Prandtl's Number $= C_p\ \mu / K$

$= 2.926 \times 10^3 \times 0.95 \times 10^{-3} / 0.69$

$= 4.028$

For Reynold's number above 10000, Sieder – Tate equation holds good.

$\therefore\ h_o\ d_o/ K = 0.023 \times N_{Re}^{0.8} \times N_{Pr}^{0.33} (\mu_b / \mu_w)^{0.14}$

$\mu_b = 1.2$ c.p

$\mu_w = 1.7$ c.p

$\therefore$ $h_o d_o/K = 0.023 \times (20721.68)^{0.8} (4.028)^{0.33} \times (1.2/ 1.7)^{0.14}$

$= 98.89$

$\therefore$ $h_o = 3582.1$ W/m^2 °C

TUBE SIDE:

Reynold's Number = ρ v d_i/ μ

$= 993.19 \times 0.6656 \times 15.75 \times 10^{-3}/$

$= 13882.41$

Prandtl's Number = C_p μ/ K

$= 4.18 \times 10^3 \times 0.75 \times 10^{-3}/ 0.69$

$= 4.54$

For this value of Reynold's number Dittus Bolter equation holds good.

$\therefore$ $h_i d_i/K = 0.023 \times N_{Re}^{0.8} \times N_{Pr}^{0.33}$

$= 0.023 \times (13882.41)^{0.8} \times (4.54)^{0.33}$

$= 78.078$

$\therefore$ $h_i = 3108$ W/m^2 K

Assuming dirt coefficient $h_d = 1000$ W/ m^2°C

We have,

$1/ U = 1/ h_o + D_o/D_i \times 1/ h_i + 1/ h_d + [D_o \ln (D_o / D_i)] / 2 \times K_w$

$\therefore$ $1/U= 1/ 3582.1 + (1/3108 \times 19.05/15.78) + 1/ 1000 + (19.05 \times 10^{-3} \ln(19.05/15.78) \times 1/32)$

$= 1.99 \times 10^{-3}$

$\therefore$U= 502.43 W/m^2°C

PRESSURE DROP CALCULATION:

TUBE SIDE:

Friction factor, f $= 0.079\ N_{Re}^{-0.25}$

$= 0.079 \times (13882.41)^{-0.25}$

$= 7.278 \times 10^{-3}$

h $= 4f\ L\ V_t^2 / 2g\ D_i$

$= 4 \times 7.278 \times 10^{-3} \times 3.66 \times 0.6656^2 / (15.75 \times 10^{-3} \times 2 \times 9.8)$

$= 0.153$ m

$\therefore\ \Delta P_L = \rho\ g\ h = 993.18 \times 9.8 \times 0.153$

$= 1.49$ kPa

$\therefore\ \Delta P_c = 2.5(\rho\ V_t^2/2)$

$= 2.5\ (993.18 \times 0.6656^2/2)$

$= 0.55$ kPa

$\therefore\ \Delta\ P_T = [\Delta P_c + \Delta P_L] \times N_p$

$= [1.49 + 0.55] \times 4$

$= 8.16$ kPa

SHELL SIDE:

From Perry,

$\Delta P_c = bf_k\ w^2\ N_c / \rho\ S_m^2\ (\mu_w/\mu_b)^{0.14}$

$= 2 \times 10^{-3} \times 0.08 \times 2.26^2 \times N_c \times 1.42^{0.14} / (1072.4 \times 0.022^2)$

$= 1.6537 \times 10^{-3}\ N_c$

$N_c = D_s[1 – 2(l_c/D_s)] / P_p$

$= 540 \times 10^{-3} [1 – 2(0.25)] / 2.54 \times 10^{-2}$

$= 10.63 \approx 11$

$\therefore\ \Delta P_c = 11 \times 1.6537 \times 10^{-3}$

$= 0.018$ kPa

MECHANICAL DESIGN:

Hastalloy is the material of construction, whose density is 8600 kg/m^3 and the permissible stress is f_t = 860 kg/cm^2

SHELL SIDE:

1. SHELL THICKNESS:

   $t_s = [P D/ (2fJ + P)] + C$

   P = 5 kg/cm^2 ; D = 540 mm; f = 860 kg/cm^2; J = 85%

   $\therefore t_s = [5 \times 540/ (2 \times 860 \times .85 + 5)] + 2$

   $= 3.84$ mm

   ≈ 4 mm

2. NOZZLE DIAMETER:

   Mass flow rate, $m = \rho A v$

   $\therefore A = m/\rho v$

   $= 2.26/1072.4 \times 0.9626$

   $= 5.18 \times 10^{-3}$

   $\therefore$ Diameter of the nozzle $= [5.18 \times 10^{-3} \times 4/\pi]^{1/2}$

   $= 0.0812$ m

   $= 8.12$ cm

3. NOZZLE THICKNESS:

   $t_n = [PD/(2 fJ – p)] + C$

   $= [5 \times 81.2/ \{(2 \times 860 \times 0.85) – 5\}] + 2$

   $= 2.2786$ mm

   ≈ 3 mm

4. HEAD THICKNESS:

   Assuming a torrispherical head, the thickness can be calculated as:

   $t_h = PR_cW/2fJ$

   P = 5

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

$= 1.34$

$\therefore t_h = (5 \times 540 \times 1.34)/(2 \times 860 \times 0.85)$

$= 2.47$ mm

Taking 2mm corrosion allowance we have,

$t_h = 2.47 + 2$

$= 4.47$ mm

≈ 5 mm

TUBE SIDE:

5. TUBE SHEET THICKNESS:

$t_{ts} = FG\,(0.25\ P/f)^{0.5}$

$= 1 \times 400\,(0.25 \times 5/860)^{0.5}$

$= 15$ mm

6. CHANNEL DESIGN:

a. Channel Length = 1.3 x (cross sectional area of tube/pass)/D_s

$= 1.3 \times 290/4 \times \pi/4 \times (1.5748)^2 / 54$

$= 3.39$ mm

≈ 4 mm

b. Channel thickness:

$t_c = G_c\,(kP/f)^{1/2}$

$= 400 \times (0.3 \times 5/860)^{1/2}$

$= 16.70$ mm

7. NOZZLE DESIGN:

$$\mathbf{m = \rho A v}$$

$A = m/\rho v$

$= 9.255/(993.18 \times 0.6656)$

$= 0.014\ m^2$

$\therefore$ Diameter of the nozzle = $d = (0.014 \times 4/\pi)^{1/2}$

$= 0.1335\ m = 13.35\ cm$

SUPPORT DESIGN:

For this shell and tube heat exchanger we use a saddle type of support.

1) SHELL WEIGHT:

$W_s = \pi\ (r_0^2 - r_i^2) \times h \times \rho$

$= \pi(0.546^2 - 0.54^2) \times 3.7 \times 8600$

$= 651.37\ kg$

2) TUBE WEIGHT:

$W_t = \pi/4 \times [r_o^2 - r_i^2]\ \ h\ \ \rho\ \ n_t$

$= \pi/4 \times [(17.4 \times 10^{-3})^2 - (15.75 \times 10^{-3})^2] \times 3.7 \times 290 \times 8600$

$= 396.4\ kg$

3) WEIGHT OF LIQUID:

$W_l = 700\ kg$

4) WEIGHT OF TIE ROD, END COVERS, BAFFLES:

$W_A = 500\ kg$

$\therefore$ Total weight = 652 + 397 + 700 + 500

= 2249 kg

Assume total weight to be equal to 2500 kg.

5) LONGITUDINAL BENDING MOMENT:

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

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

$L = 3.7m,\ H = 0.2\ m$

$Q = 2500/4 \times 2\ [3.7 + 4/3 \times 0.2]$

$= 1239.6\ kg$

Let us take A = 0.25 m

$\therefore$ M_1 = 1239.6 x 25 [1 – {1 – 25/366 + (54^2 – 20^2)/(2 x 25 x 366)}/{1 + 4/3 x 20/366}]

= 1239.6 x 25 [1 – (1.069/1.0728)]

= 104.56 kg cm

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

= 1239 x 366/4 [{1+2(54^2 – 20^2)/366^2}/{1+4/3x 20/366} – 25 x 4/366]

= 78702 kg cm

6) STRESSES IN SHELL AT THE SADDLE:

f_1 = M_1 / $k_1 \pi R^2 t$

= 104.56/(0.107 x π x 54^2 x 0.5)

= 0.213 kg/cm^2

f_2 = M_1/($k_2 \pi R^2 t$)

= 104.56/(0.192 x π x 54^2 x 0.5)

= 0.118 kg/cm^2

The stresses are well within the permissible limit.

7) STRESS IN THE SHELL AT MID SPAN:

f_3 = M_2 / π R^2 t = 789702/(π x $54^{2 \text{ x } 0.5}$) = 17.18 kg/cm^2

Axial stress due to internal pressure:

F_p = pD/4t = 5 x 540/4 x (4-2) = 337.5 kg/cm^2

The combined stresses (f_p + f_1), (f_p – f_2) and (f_p + f_3) are well within limit. Hence the design can withstand the load.

DESIGN OF ABSORBER

E = 1397.56 kg/hr

Cl_2 = 1284.08

HCl = 6.98

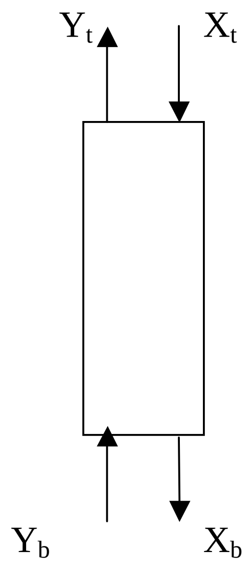
O_2 = 88.78

N_2 = 17.71

C = 1000 kg/hr

HCl = 220

H_2O = 780



G = 1657.28

O_2 = 88.78

N_2 = 17.71

Cl_2 = 1310.305

F = 1259.72

HCl = 453.495

H_2O = 780

Cl_2 = 26.225

G_m' = Molar flow rate of inert in the feed

L_m' = Molar flow rate of solvent (36 % HCl)

Y = Mole ratio of HCl in gas phase

X = Mole ratio of HCl in the liquid phase

$\therefore Y_b$ = 6.588/ (18.455 + 0.6325 + 2.77)

= 0.3014 kmol of HCl / kmol of inert in the feed.

At the top,

Y_t = 0.19123 / (18.455 +2.77 + 0.6325)

= 0.00889 kmol HCl / kmol inert

Gas flow rate at the bottom of the tower,

G_m = 1657.288 kg/hr

= 0.46 kg/sec

Average molecular weight of the feed gas

M_f = 0.231 x 36.5 + 0.648 x 71 + 0.0973 x 32 + 0.0222 x28

= 58.175 kg / kmol

∴ G_m = 0.46 / 58.78 = 0.0079 kmol/ sec

∴ Inert in the feed (G_m') = G_m x mole fraction of inert

= 0.0079 x 0.7684

= 0.00607 kmol/sec

X_t = mol of HCl /mol of inert in the solvent

X_t = 6.0274 / 43.33 = 0.139

$[L_m' / G_m']_{min} = (Y_b – Y_t) / (X_b^* - X_t)$

where X_b^* is the equilibrium composition of liquid stream which is obtained from the X-Y plot. The equilibrium data is given below:

X	**Y**	**X**	**Y**
0.01	1.105×10^{-7}	0.139	1.343×10^{-3}

0.02	1.013×10^{-6}	0.156	2.868×10^{-3}
0.0315	2.98×10^{-6}	0.1733	6.032×10^{-3}
0.043	6.78×10^{-6}	0.192	0.01317
0.055	1.46×10^{-5}	0.211	0.0288
0.067	3.08×10^{-5}	0.232	0.0622
0.08	6.58×10^{-5}	0.254	0.1376
0.094	1.39×10^{-4}	0.277	0.328
0.1074	3.0×10^{-4}	0.302	0.901
0.123	6.319×10^{-4}	0.329	4.71

From the graph we get, $X_b^* = 0.276$

$\therefore [L_m' / G_m']_{min} = (0.3014 - 0.00889) / (0.276 - 0.139)$

$= 2.135$

Taking $[L_m'/ G_m'] = 2.5 \times [L_m'/ G_m']$

$= 2.5 \times 2.135$

$= 5.3375$

$\therefore L_m' = G_m' \times 5.3375$

$= 0.00607 \times 5.3375$

$= 0.0324$ kmol/sec

Average molecular weight of the solvent;

$M_s = 0.122 \times 36.5 + 0.8779 \times 18$

$= 20.255$ kg/ kmol

$\therefore$Mass flow rate of inert,

$L' = L_m' \times M_s$

$= 0.0324 \times 20.255$

$= 0.656$ kg/sec

Gas flow rate at the bottom of the tower,

G_b = G' + (G_m' Y_b) x mol wt of HCl

= 0.00607 x 58.175 + (0.00607 x 0.3014 x 36.5)

= 0.4197 kg/sec

Liquid flow rate at the bottom of the tower,

L_b = L' + G_m' (Y_b - Y_t) x 36.5

= 0.656 + 0.00607 x (0.3014 – 0.00889) x 36.5

= 0.656 + 0.0648

= 0.7208 kg/ sec

Density of the feed gas,

ρ_g = (M x 273) / (22.7 x 303)

= (58.28 x 273) x (303 x 22.7)

= 2.3 kg/ m^3

Density of the solvent at 30°C = 1103.4 kg / m^3

To specify flooding conditions,

Choose 1" ceramic rasching rings as packing material with diameter

d = 25.4 mm

From perry,

Surface area a' = 190 m^2/m^3

ε = 0.74

F_b = 510 m^{-1}

Calculating $[L_b / G_b] [\rho_l / \rho_g]^{1/2}$ = (0.7208/0.4197) x $[2.3/ 1103.4]^{1/2}$

= 0.07842

For the above value from perry,

$$\frac{G_f^2 F_b \Psi \mu^{0.2}}{\rho_g \rho_l g} = 0.17 \longrightarrow (A)$$

$\Psi = \rho_{water} / \rho_{solvent} = 992.2 / 1103.4 = 0.889$

$\mu_l = 1.6 \times 10^{-3}$

Substituting all the values in the equation (A) ,

$[G_f^2 \times 510 \times 0.889 \times (1.6 \times 10^{-3})^{0.2}] / [2.3 \times 1103.4 \times 9.81] = 0.17$

$\therefore G_f^2 = 33.45$

$\therefore G_f = 5.78$ kg/m^2 sec

= 20822.1 kg/ m^2 hr

$\therefore$Cross sectional area of the tower (A) = G_b/ 80% of G_f

= 1511 / 0.8 x 20822.1

$\therefore$ A = 0.0907 m^2

$\therefore$ Diameter of the tower, $D_c = [0.0907 \times 4 / \pi]^{1/2}$

= 0.340 m

Diameter of tower / Diameter of the packing = 0.340/0.0254

= 13.3

Which is greater than 10

PRESSURE DROP CALCULATION:

LEVA'S CORRELATION:

$$\Delta P = C_2\, 10^{C_3 U_{tl}} \times \rho_g U_{tg}^2 \longrightarrow \text{(B)}$$

ΔP = Pressure drop in Inch H_2O / ft packing

ρ_g = Density of gas in lb/ft^3

U_{tg} , U_{tl} = Velocity of gases in ft/sec

C_2 & C_3 are constants

Superficial liquid flow rate, $\overline{L}$ = L' / cross sectional area of tower

= 0.656 / 0.0907

$= 7.2326\ kg/m^2 sec$

$= 5333.8\ lb / ft^2\ hr$

For this liquid flow rate constants C_2 & C_3 are obtained from the perry for the rasching rings,

$C_2 = 0.8$ & $C_3 = 0.0348$

Superficial gas flow rate

$\overline{G} = \overline{G}_b / \rho_g = 0.4197 / 0.0907 = 4.627\ kg/m^2\ sec$

$U_{tg} = \overline{G} / \rho_a = 1.2095 / 2.3 = 2.01\ m/sec$

$= 6.595\ ft/sec$

$U_{tl} = \overline{L} / \rho_l = 7.2326 / 1103.45 = 6.554 \times 10^{-3}\ m/sec$

$= 0.0215\ ft/sec$

$\rho_g = 0.143\ lb/ft^3$

Substituting the values in equation (B) we get,

$\Delta P = 5$ inch of water / Ft of packing

= 415.2 mm of H_2O/ m of packing

DEGREE OF WETTING:

Wetting rate L_p = Liquid rate ($\overline{L}$) / specific area of packing

Specific area = 190 m^2/m^3

$L_p = 7.2326 / (1103.45 \times 190)$

$= 3.449 \times 10^{-5}\ m^3/m\ sec$

$= 1.336\ ft^3/ft\ hr$

It is recommended that wetting rate for all packing should be 0.85 ft^3/ft hr, except for rings of diameter greater than 3 inch. For all the remaining packing materials the value is 1.3 ft^3/ ft hr.

TOWER HEIGHT CALCULATION:

$Z = H_{OG} N_{OG}$

H_{OG} = Height of overall gas phase transfer unit

N_{OG} = Number of overall gas phase transfer unit

$H_{OG} = H_G + m [G_m/L_m] \times H_L$

CORNELL'S RELATION:

$$H_G = \frac{0.017 \times \Psi \times D^{1.24} \times Z^{0.99} \times S_{cg}^{0.5}}{(L f_1 f_2 f_3)^{0.6}}$$

D = Diameter of the column, m

Z = Packed height, m

L = Liquid rate kg/m^2 sec

$F_1 = [\mu_{l\,/}\, \mu_w]^{0.6}$, $f_2 = [\rho_m/\rho_l]^{1.25}$, $f_3 = [\sigma_w / \sigma_l]^{0.8}$

S_{cg} = Gas phase Schmidt number = $\mu_g/ (\rho_g D_g)$

D_g = Diffusivity of gas

$f_1 = [1.6/ 1.0]^{0.6} = 1.078$

$f_2 = [1000/ 1103.4]^{1.25} = 0.8842$

Now,

$\sigma_w = 72.8$ dyne/cm

$\sigma_l = \sigma_w \bar{x}_w + \sigma_m \bar{x}_x$ (solvent surface tension)

$\sigma_m^{1/4} = P (\sigma_l)$

P = Parachor = $P_h + P_{Cl} = 15.5 + 55.2 = 70.7$

$\sigma_m^{1/4} = (15.5 + 55.2)(0.03474) = 2.456$

$\sigma_m = 36.39$ dyne/cm

$\therefore \sigma_l = 0.122 \times 36.39 + 0.8779 \times 72.8$

$= 68.35$ dyne/cm

$f_3 = [72.8/68.35]^{0.8} = 1.0517$

$S_{cg} = \mu_g/ \rho_g D_g$

$D_g = [T^{1.75} \times 10^{-3} [\{M_A + M_B\} / M_A M_B]^{1/2}] / [P \{ (\Sigma v)_A^{1/3} + (\Sigma v)_B^{1/3}\}^2]$

$M_A = 36.5$; $M_B = 71.0$

$(\Sigma v)_A = 16.5 + 19.5 = 36$

$(\Sigma v)_B = 19.5 \times 2 = 39$

P = 1 atm, T = 303 °K

$\therefore D_g = [10^{-3} \times (303)^{1.75} \{ 107.5 / 2591.5\}^{0.5}]/ 1 \times [36^{1/3} + 39^{1/3}]^2$

$= 0.359 \times 10^{-5}$ m^2/sec

$\mu_g = 0.014$ cp

$\rho_g = 2.3$ kg/m^3

$S_{cg} = 0.014 \times 10^{-3} / (2.3 \times 0.359 \times 10^{-5})$

$= 1.695$

Corresponding to the 80% flooding for ceramic rasching rings;

$\Psi = 70$ m

$\therefore H_G = [0.017 \times 70 \times 0.34^{1.24} \quad Z^{1/3} \quad (1.695)^{0.5}] \ /[7.2326 \times 1.078 \times 0.884 \times 1.0517)^{0.6}]$

$\therefore H_G = 0.127 Z^{1/3}$

$H_L = [\Phi C/3.28] \times [\mu_l / \rho_l D_l]^{0.5} \times [Z / 3.05]^{0.15}$

Φ = Correction factor for a given packing in m

C = Correction factor for high gas rate

$\rho_l = 1103.4$ kg/m^3

$\mu_l = 1.6 \times 10^{-3}$

$\Phi = 0.07$ m

C = 0.6 (for 80% flooding)

$D_l = 7.4 \times 10^{-8} (\Phi M_B)^{1/2} T/ \mu_B V_A^{0.6}$

V_A = molar volume of solute A at its normal boiling temperature

= 30.68 cc/gmol

ρ_A = 1.48 gm/cc = 0.0405 gmol/cc

M_B = 20.25

D_e = $[7.4 \times 10^{-8} (\Phi M)^{0.5} T] / [\mu V_m^{0.6}]$

= $[7.4 \times 10^{-8} (2.6 \times 20.255)^{0.5} \times 303] / 1.6 \times (30.68)^{0.6}$

= 1.3037×10^{-5} cm^2/sec

$H_L = [0.07 \times 0.6/3.28] \times [1.6 \times 10^{-3} /(1103.4 \times 1.303 \times 10^{-9})]^{0.5} [Z / 3.05]^{0.15}$

$H_L = 0.3613 Z^{0.15}$

$H_{OG} = 0.127 Z^{1/3} + m (G_m/L_m) \times 0.3613 Z^{0.15}$

m = Slope of equilibrium curve = 1.4106

L_m/G_m = Slope of operating line = 5.3375

$H_{OG} = 0.127 Z^{1/3} + 1.4106 \times 1/5.3375 \times 0.3613 Z^{0.15}$

$\therefore H_{OG} = 0.127 Z^{1/3} + 0.09545 Z^{0.15}$

Calculation of N_{OG}:

$$N_{OG} = \int_{Y_b}^{Y_t} dy/(y - y^*) + ½ \ln[(1 + Y_B) / (1 + Y_T)]$$

Y^* is generated from the x – y plot:

Y	Y^*	$Y - Y^*$	$1/(Y - Y^*)$
0.004	0.001	3×10^{-3}	333.33

0.06	0.005	0.055	18.18
0.16	0.004	0.156	6.41
0.18	0.006	0.174	5.747
0.22	0.007	0.213	4.69
0.26	0.01	0.25	4.0
0.30	0.014	0.286	3.49

The plot of $1/ Y - Y^*$ vs Y is made and area under the curve is calculated.

Area under the curve = [2 x 0.002] x 2073

= 8.292

$\therefore N_{OG} = 8.292 - ½ \ln [(1 + 0.3014) / (1 + 0.00889)]$

$= 8.1647$

$\therefore Z = H_{OG} N_{OG} = 1.0369 Z^{1/3} + 0.779 Z^{0.15}$

Solving the equation by trial and error method we get,

Z = 2.3 m

MECHANICAL DESIGN OF ABSORBER:

Material of construction is chosen as Hastalloy.

Density of Hastalloy = 8600 kg/m^3

Tensile strength = 860 kg/cm^2

Compressive strength = 689 kg/cm^2

Shell thickness:

$t_s = P_i r_i / f_t J + C = 1 \times 17.0/800 + 2$ mm

= 2.2 mm

COMPRESSIVE STRESSES:

1. Due to shell weight:

   F_{c1} = weight/ cross sectional area

   $= \rho\ X$

   $= 8600\ X$

2. Weight due to insulation:

   Insulation material chosen is asbestos

   Taking insulation thickness $t_i = 3\text{cm}$

   Density of insulator (ρ_i) $= 2200\ \text{kg/m}^3$

   $\therefore f_{c2} = \rho_i\, t_i/t_s\ X$

   $= 2200 \times 3/ 0.22\ X$

   $= 30000\ X$

3. Stress due to internals:

   $f_{c3} = 125\, d_i^2/ (d_o^2 - d_i^2)\ X$

   $d_i = 0.34$ m, $d_o= d_i + t_i + 2t_s= 0.3744$ m

   $\therefore f_{cs} = [125 \times (0.34)^2 / [0.3744^2 - 0.34^2]]\ X$

   $= 588\ X$

4. Wind load:

   Pressure due to wind load

   $P_w= 0.0024\ V_w^2$

   V_w = wind velocity in miles/hour = 501 miles/hr

   $\therefore\ P_w= 0.0024\ (50)^2= 6\ \text{lb/ft}^2 = 0.28728\ \text{kg/m}^2$

   $f_w = P_w\ d_{eff}\ \ X^2/ 2\ \pi\ r_o^2\ (t_s - c) = 0.28728 \times 0.3944 \times X^2 / 2\pi \times (0.1872)^2 \times 0.2 \times 10^{-3}$

   $= 2572.88\ X^2$

TENSILE STRESSES:

1) With load:

$f_{tensile} = f_{wind} + f_{all} - \sum f_{ci}$ (1)

$f_{tensile} = 860 \text{ kg/cm}^2$

$f_{all} = P_i r_i / 2 (t_s – C) = 1 \times 17/ 2 \times 0.02 = 425 \text{ kg/cm}^2$

$= 425 \times 10^4 \text{ kg/m}^2$

$\sum f_{ci} = 39188 X$

Substituting all the values in equation (1)

$860 \times 10^4 = 2572.88 X^2 – 39188X + 425 \times 10^4$

solving the equation we get;

X = 49 m

2) Without load:

$F_{tensile} = f_{wind} - \sum f_{ci}$

$860 \times 10^4 = 2572.88 X^2 – 39188 X$

Solving the above equation,

X = 65.92 m

The height of the tower obtained with and without load is greater than 2.3 m.

∴ The thickness calculated is valid.

COMPRESSIVE STRENGTH:

$f_{compression} = 689 \text{ kg/m}^2$

1) With load:

$f_{comp} = f_{wind} – f_{all} + \sum f_{ci}$

$689 \times 10^4 = 2572.88 X^2 – 425 \times 10^4 + 39188 X$

On solving the equation,

$X = 58.62$ m

2) Without load:

$f_{comp} = f_{wind} + \sum f_{ci}$

$689 \times 10^4 = 257.88 X^2 + 39188 X$

On solving we get,

$X = 44.69$ m

Since the calculated value is greater than the actual height of the tower, hence the thickness can withstand the compressive and tensile forces.

SKIRT DESIGN:

The cylindrical shell for the skirt is designed for the combination of the stresses due to vessel dead weight, wind load. The skirt thickness is uniform and is designed to withstand the maximum values of tensile or compressive stresses.

1) Due to dead weight:

$f_{db} = \sum W / \pi D_o t_{sk}$

Weight of the shell = 1819 kg

Liquid load = 0.46 kg

Packing weight = 140 kg

Weight of cooling coils = 40 kg

$\therefore \sum W = 2000$kg

Choose skirt thickness to be 5 mm

$f_d = \sum W / \pi D_o t_s$

$D_o = 0.3444$ m

$f_d = 2000 / (\pi \times 0.3444 \times 5 \times 10^{-3})$

$= 33.15$ kg/cm^2

2) Due to wind load:

$P_{lw} = K\ p_1\ h_1\ D_0$

$p_1 = 50\ kg/m^2$

$h_1 = 2.3\ m$

$D_0 = 0.3444\ m$

$P_{lm} = 0.7 \times 50 \times 2.3 \times 0.3444$

$= 30.912\ kg/m^2$

Bending moment due to wind at the base of the tower is determined by:

$M_w = P_{lw} \times H/2$

$= 30.912 \times 2.3/2$

$= 35.548$

$\therefore$ The stresses $f_{wb} = M_w / Z = 4\ M_w / \pi\ D_{ok}^2\ t_{sk}$

$\Rightarrow f_{wb} = 4 \times 35.5488 / \pi \times 0.384 \times 5 \times 10^{-3}$

$= 23574.03\ kg/m^2$

Maximum compressible stress on the skirt

$= f_{wb} + f_{db}$

$= 23574.03 + 331572.8$

$= 355146.82\ kg/m^2$

$= 35.51\ kg/cm^2$

Since allowable compressible stress for 5mm thick plates is 689 kg/cm^2, which is much more than the actual stress, hence the designed vessel can withstand the load.