DESIGN OF EQUIPMENTS

1. (a) Process Design of Ammonia Absorption Column

Feed to the absorption tower is sodium chloride solution (Brine). Containing 300gms NaCl per liter of solution.

Composition of gaseous mixture used is (in mole fraction)

Ammonia = 64.82%

Carbon di oxide =18.03%

Water =17.14%

Ammonia composition in inlet gas stream.

Y_b=1.843 K mole NH_3/K mole inerts (bottom)

Assuming 95% of ammonia absorbed.

Y_t=0.0184 K mole NH_3/K mole inerts (top)

Brine solution flow rate L_t = 182683.71 kg/hr

Water flow rate L^1 = 136693.1508 kg/hr

Solubility data of ammonia in water at 1 atmosphere pressure and at 40^0C

Assuming iso-thermal process

X=moles of NH_3/moles of H_2O	Y= moles of NH_3/moles of inerts
0.2647	2.3628
0.2117	1.0822
0.1588	0.5605
0.1058	0.2816
0.0794	0.1865
0.053	0.1112
0.0423	0.0869
0.03176	0.0629
0.0264	0.052
0.0211	0.041
0.0169	0.0327
0.0127	0.0246
0.0105	0.02068

From this plot,

$(L^1/ G^1)_{min}$= (Yb-Yt)/(X_b^*-X_t)   ,X_t=0

= (1.843-.0184)/0.25

$(L^1/ G^1)_{min}$=7.2984

$(L^1/ G^1)_{min}$ = 1.2 * $(L^1/ G^1)_{min}$

$(L^1/ G^1)_{min}$ = 8.758

Therefore, X_b = 0.218

Flow of inerts rate at bottom $=G^1=867.1$ kmol/hr

Molecular weight of gas= 22.0378

Gas flow rate at bottom =Gb=36722.55 kg/hr

Gas flow rate at top = Gt= 18529.3695 kg/hr

Brine Solution flow rate at bottom $=L_b=209579.59$ kg/hr

Density of gas $\rho_g=0.8065$ kg/m^3

Density of liquid $\rho_L= 1191.66$ kg/m^3

Bubble cap tray design

(1) Tray spacing

chosen Tray spacing t_s =610mm =24 in

(2) Tray thickness

t_T = 3mm

(3) Estimation of plat diameter

$$L/G\ (\rho_G/\rho_L)^{0.5} = 209579.59/36722.65(0.8065/1191.66)^{0.5}$$

$$L/G\ (\rho_G/\rho_L)^{0.5} = 0.148$$

From flooding curve capacity parameter for tray spacing of 610 mm

$C_{SB,F}=0.33$ ft/sec

Surface tension of liquid (σ)= 75.5 dynes/cm

$$Unf = Csb \times \{ \sigma / 20 \}^{0.2} [(\rho_L - \rho_G) / \rho_G]^{0.5}$$

Unf = 16.54 ft/sec

For 90% flooding

Unf = 0.9*16.54 ft/sec

Unf = 4.525 m/sec

Volumetric flow rate of gas = 12.6481 m^3/sec

Net area available for gas flow (A_n)

A_n= 12.6481/4.525

A_n= 2.79 m^2

Net area = Column cross sectional area – Down comer area.

$A_n = A_c – A_d$

Lw / Dc = 0.7

sin (θc/2) = [(Lw/2) / (Dc/2)] = 0.7

⇒ θc = 88.85^0

Ac = (π/4) Dc^2 = 0.785Dc^2

Ad = (π/4) Dc^2 (θc/360^0) **-** (Lw/2) (Dc/2). cos(θc/2)

= 0.068Dc^2

Since An = Ac -Ad

2.79 = 0**.**785 Dc^2 - 0**.**068 Dc^2

⇒ Dc = 1.97 m

Taking Dc = 2m

Ac = 3.14 m^2

Ad =0.272 m^2

Lw = 1.4 m

Active area Aa = Ac -2Ad

Aa = 2.596 m^2

Liquid distribution area = Acz=10% Ac

Acz = 0.314 m^2

Waste peripheral area = Awz=5 %

Awz=0.157 m^2

Ap = Ac -2Ad - Acz – Awz

Ap = 2.125 m^2

(4) Selection of bubble cap

For tower of diameter 2m

Cap diameter = 100mm= 4 in

4 inch size bubble cap ,carbon steel US Standard gauge 12

OD=4.093 in

ID = 3.875 in

Height

Overall 3in

No of slots = 26

Type of slots = Trapezoidal shape

Slot width

Bottom = 0.333 in

Top = 0.107 in

Slot height = 1.25 in

Height shround ring = 0.25 in

Riser

OD= 2.718 in

ID = 2.5 in

Standard height

0.5 in skirt height = 2.5 in

1.0 in skirt height = 3.0 in

1.5 in skirt height = 3.5 in

Cap areas

Risers =4.8 in^2

Reversal =7.3 in^2

Annular =5.99 in^2

Slot =8.12 in^2

Cap =13.15 in^2

(5) pitch of bubble cap

Bubble caps are arranged on triangular pitch

l_p=150 mm

(6) **Ratio bubble cap area to perforated area (A_b/A_p)**

$(A_b/A_p)=0.4030$

(7) Total area of bubble caps

$A_b=0.8563\ m^2$

Total number of bubble caps = N_T = 110

(8) Weir height, h_w

h_w= skirt clearance + spround ring +slot heigh + static seal

h_w= 62.5 mm

(9) Tray dynamics calculation

Head loss through dispersion unit (dry cap + slot drop)

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

U_h= 14.64 m/s =liner gas velocity through risers

$$K_1= 3.73\ ((\rho_L - \rho_G) / \rho_G)^{1/5}\ (h_{sh})^{4/5}\ (Us)^{2/5}$$

h_{sh}=31.75 mm =cap slot height

Us = 21.94 m/s linear gas velocity through slots m/s

K_1= 47.45

K_2 calculation

(Annular area/riser area)=1.248

from plot of this area ratio Vs K_2

K_2=13

$$h_d=47.39 + 13*(0.8065/1191.66) * 14.64^2$$

h_d= 49.27 mm

height of crest over weir (h_{ow})

$h_{ow}=f_w * 664(q/l_w)^{2/3}$

q=liquid flow rate in m^3/s=0.04258 m^3/s

l_w =weir length =1.4 m

$q/ l_w^{2.5}$=14.93

f_w=1.1

h_{ow}=64.92 mm

Dynamic seal

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

$h_s = h_w$-height of slot

h_s =44.45 mm

let us assume h_{hg}=20 mm

h_{ds} = 119.37 mm

hydraulic gradient across plate

$h_{hg} = C_{vf} * h_{hg}^1$

$Ua\sqrt{\rho_G}$=3.585

There fore C_{vf} = 1

Uncorrected liquid gradient= h_{hg}^1=0.09 per row

No of rows = $1+[Z_l- (lp+d_c)]/l_p$

Z_l = mean liquid length=56.23 in

d_c= inside dia of cap = 3.878 in

l_p = cap pitch=6 in
No of rows =9

corrected liquid gradient= h_{hg}^1=0.09*9=0.72 in

$$h_{hg} = C_{vf} * h_{hg}^1$$

=1*0.72 in
= 20.57 mm
thus the estimated mean liquid depth is correct no recalculation is required.

Pressure drop through aerated liquid

$$\mathbf{h}^1_l = \beta\ \mathbf{h}_{ds}$$

β=aeration factor

F_{ga}=U_a $(\rho_G)^{1/2}$

= 15.98(.0503)$^{1/2}$
F_{ga} = 3.585

Ther fore β=0.58
Φ=0.18

$$\mathbf{h}^1_l = 0.58*119.37$$

$$\mathbf{h}^1_l = 69.23 \text{ mm}$$

Total pressure drop

h_t=h_d + $\mathbf{h}^1_l$
= 49.27+69.23
h_t = 118.5 mm

Head loss over downcomer apron

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

Take clearance, C = 1”

h_{ap} = h_{ds} - C = 119.37 – 25.4 = 93.97 mm

A_{da} = Lw x h_{ap} = 0.1315 m^2

∴ hda = 165.2[0.0318/ 0.1315] ^{2}

= 9.652 mm

Down comer backup

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

=118.5+62.5+64.92+9.652+20.17
= 275.742 mm

$h_{dc}^1 = h_{dc}/\phi_c$

where ϕ is the froth density

h_{dc}^1=275.745/0.5
= 551.484 mm

h_{dc}^1 less than the tray spacing of 610 mm.

No down comer weeping will occur

(10) Column efficiency

a) Point efficiency(E_{OG})

Number of gas phase transfer units:

$$N_g=(0.776 + 0.00457h_w - 0.238\ U_a\ \rho_g^{0.5} + 105W)/N_{scg}^{0.5}$$

h_w = weir height in mm =62.5 mm
U_a = gas velocity through active area=4.872 m/s
W= liquid flow rate in $m^3/(s.m)$ of width of flow path on plate=0.002944 $m^3/(s.m)$
N_{scg} = gas-phase Schmidt number ,$\mu_g/\rho_g D_g$
D_g= gas-phase diffusion co-efficient

$N_{scg}= 0.01673*10^{-3}/(0.8053*0.195*10^{-4})$
N_{scg} = 1.0644

$N_g=(0.776+0.00457*62.5-0.238*4.872*0.8065^{0.5}+105*0.002944)/1.066^{0.5}$

N_g = 3.015

Number of liquid phase transfer units:

$N_L = K_L.a.\theta_L$

K_L=liquid phase transfer coefficient
θ_L= residence time of liquid in the froth,sec
a=effective interfacial area for mass transfer ,m^2/m^3
h_L=effective clear liquid height,mm
q=liquid flow rate,m^3/sec

$\theta_L= h_L A_a/1000q$
= 69.23*2.596/1000*0.0488
= 4.0844

$(K_L a) = (4.127*10^8 D_L)0.5\ (0.21U_a\rho_g^{0.5} + 0.15)$
$= (4.127*10^8*1.5285*10^{-10})^{0.5}\ (0.21*4.872*0.8085^{0.5} + 0.15)$
= 0.2684

N_L=0.2684*3.682
= 1.096

$\lambda_t = m_t (G'/L')((1+Y_t)/(1+X_t))$
$= 15*(1/8.758)(1+0.01843)$
$= 1.744$

$\lambda_b = m_b (G'/L')((1+Y_b)/(1+X_b))$
$= 5.428*(1/8.758)((1+1.843)/(1+0.218)$
$= 1.446$

$\lambda = (\lambda_t + \lambda_b)/2$
$= 1.595$

$$\therefore \quad N_{OG} = \frac{1}{1/N_G + \lambda / N_L}$$

$= 0.5595$

$E_{OG} = 1- e^{-NOG} = 0.4285=42.85\%$

(b) Murphree Plate Efficiency(E_{MV})

Pecklet Number $N_{pe} = (z_L)^2/ (D_E.\theta_L)$

$Z_L = D_C. \text{Cos} (\theta c/2)$
$= 1.46$ m

$D_E = 0.0124 + 0.0171U + 0.0025 Q/ Z_L + 0.015h_w$

h_w=weir height ,inch
Q=liquid flow rate ,gal/min
U= gas flow rate,ft/sec
D_E= eddy-diffusion coefficient, ft^2/sec

$D_E = 0.0124 + 0.0171*15.98+ 0.0025* 126.42 + 0.015*2.5$
$= 0.4492\ ft^2/sec$
$= 0.1369\ m^2/sec$

$N_{pe} = (1.46)^2/ (0.1369*4.0844)$
$= 3.835$

$\lambda E_{OG} = 1.595*0.4285=0.6834$

$\therefore (E_{MV}/ E_{OG})=1.18$

$E_{MV}=1.18*0.4285=0.5056=50.56\%$

(c) Overall column efficiency(E_{OC})

$L/G\{\rho_G/\rho_L\}^{0.5} = 0.148$

at 90 % of the flooding , $\psi = 0.051$

$$E_{\alpha} / E_{MV} = \frac{1}{1 + E_{MV} [\psi/(1- \psi)]}$$

$E_{\alpha} / E_{MV} = 0.9735$

$E_{\alpha} = 0.9735*0.5056= 0.4922$

The overall efficiency is given by the equation :

$$E_{OC} = \frac{\log[1 + E_{\alpha} (\lambda - 1)]}{\log \lambda}$$

$$E_{OC} = \frac{\log[1 +0.4922 (1.592 - 1)]}{\log 1.592}$$

$= 0.5501=55.01\%$

N_t =number of theoretical trays=4
N_c=number of actual trays

$E_{OC} = N_t / N_c$

$N_c= 4/0.5501$
$=7.27\approx 8$

tower height=(Tray Spacing x Actual number of trays)

= 0.610*8=4.88

tower height(H_T)=5

(b) Mechanical Design of Absorption Column

Diameter of the tower D_i = 2.0m

Working pressure = 1 atm=1.0329 kg/m^2

Design pressure p_d = 1.1362 kg/m^2

Shell material Plain Carbon steel

Permissible tensile stress (f_t)= 950kg/cm^2

Insulation thickness = 100mm

Density of insulation = 770 kg/m^3

Tray spacing = 610mm

Top disengaging space = 1m

Bottom separator space = 2m

Skirt height = 2m

Density of material column = 7700 kg/m^3

Wind pressure = 130 kg/m^2

1) Shell thickness

t_s= PD$_i$/(2fJ-P) + C

P= design pressure in kg/cm^3

f=allowable tensile stress kg/cm^3

C= corrosion allowance

J=joint factor

t_s= (1.1362*2000)/(2*950*0.85-1.1362)

t_s = 4 mm

minimum thickness allowable is 6mm

t_s= 6mm

2) **Head Design**

Shallow dished and torisherical head

Thickness of head is given by

$t_h = PR_C W/2fJ$

R_c=crown radius

W=stress intensification factor

$W = 0.25(3 + \sqrt{(R_C/R_K)}$

R_k= knuckle radius ,6% of crown radius.

W= 1.7706

$t_h = 1.1362*2000*1.7706/2*950*0.85$

$t_s = 2.491$ mm

minimum thickness is $t_s = 6$mm

3) **Shell thickness at different heights**

At a distance ‘X’ m from the top of the shell the stress are;

Axial Stress: (compressive)

$$f_{ap} = \frac{p_i D_i}{4(t_s - C)}$$

$$= 1.1362*2000/4*(6-2)$$

$$= 142.025 \text{ kg/m}^3$$

4)Compressive stress due to weight of shell up to a distance ‘X’

$$f_{ds} = \frac{\pi/4 * (D_o^2 - D_i^2)\rho_s X}{\pi/4 * (D_o^2 - D_i^2)}$$

$$= \rho_s X$$

$$= 0.77X \text{ kg/m}^3$$

5) Compressive stress due to weight of insulation

$$f_{d(ins)} = \frac{\pi D_{ins} t_{in} \rho_{ins}}{\pi D_m (t_s - C)}$$

$$f_{d(ins)} = \frac{2212*100*770*X}{2006*(6-2)}$$

$$f_{d(ins)} = 2.122X$$

6) compressive Stress due to the weight of the liquid and tray

$$f_d = \frac{W_{liq}}{\pi D_m(t_s\text{-}C)}$$

W_{liq} = ((X-top space)/TS+1) $(\pi d^2/4)\rho_L$

W_{liq} = ((X-1)/0.61)+1) $(\pi*2^2/4)*1193$

= [61.44X-27.03] kg/cm

f_d=[61.44X-27.03]/(π*2.006*(6-2))

f_d = [24.37X-10.722] kg/cm^2

7) Stress due to the weight of the attachments

The total weight of the attachments

W_a = (2670 + 140X)

$F_{d(att)}$ = (2670 + 140X)/(Π*2006*4)

= 10.59 + 0.55X

8) total compressive dead weight stress at height X

f_{ds}=27.812 X – 19.755

9) stress due to wind load at distance X

$\mathbf{f_{ws}}$ **=** $1.4*P_w X^2/\Pi*D_o(t_s\text{-}c)$

= $(1.4*130*X^2)/(\Pi*201.2*.4)$

= $0.7198X^2$

10) stress in upwind side

$f_{max}= f_{ws}+f_{ap}-f_{dx}$

$0.8*950= 0.7198X^2+142.025-27.812X+19.755$

$0.7198X^2-27.812X-597.917=0$

X=53.32 m

11) stress in down side

$f_{max} = f_{ws} + f_{ap} + f_{dx}$

$0.7198X^2 - 27.812X - 882.28 = 0$

X=49.30 m

From this ,For whole tower 6mm thickness is enough.

12) Skirt design

The material of construction for skirt is carbon steel IS:2062-1962

Minimum weight of vessel

$W_{min} = \Pi(D_i + t_s)\, t_s (H-2)\gamma_s + 2W_H$

H=10.5 (Total height of tower including skirt height)

$\gamma_s = 7700 kg/m^3$ (specific weight of shell material)

$W_H = 2670kg$ (weight of head)

$W_{min} = \Pi(2+0.006)\,(0.006)(10.5-2)7700 + 2*2670$

$W_{min} = 8688.27$ kg

Maximum weight of vessel

$W_{max} = W_s + W_i + W_l + W_a$

$W_s = 10800kg$(weight of shell during test)

$W_i = 4200kg$ (weight of insulation)

$W_l = 36128$ kg (weight of water during test)

$W_a = 4400$ kg (weight of attachments)

$W_{max} = 55528$ kg

Wind load

$P_W = K_1 p_w HD$

For minimum weight of column,D=2m

$P_w(min) = 0.7*130*10.5*2 = 2457$ kg

$P_w(max) = 0.7*130*10.5*2.2 = 2702.7$ kg

Minimum wind moment

$M_W(min) = P_W(min)*H/2$

$= 2457*10.5/2$

$= 16584.75$ kg m

Maximum wind moment

$M_W(min) = P_W(min)*H/2$

$= 2702.7*10.5/2$

$= 18243.22$ kg m

Bending stresses

$$f_b(min) = \frac{4M_w(min)}{\Pi*D^2*t}$$

$$= \frac{4*16584.75}{\Pi*2^2*t}$$

$= 0.5279/t$ kg/cm^2

$$f_b(max) = \frac{4M_w(max)}{\Pi*D^2*t}$$

$$= \frac{4*18243.22}{\Pi*4*t}$$

$=0.5806/t$ kg/cm^2

Minimum dead load stress

$F_{ds}(min) = W_{min}/\Pi dt$

$= 8688.27/\Pi*2*t$

$= 0.1382/t$ kg/cm^2

Maximum dead load

$F_{ds}(max) = W_{max}/\Pi dt$

$= 0.8837$ kg/cm^3

Maximum tensile stress without any eccentric load

$f_z= f_{bs}(max)-f_{fs(min)}$

980*0.8= 0.0529/t

t= 0.0771mm

Maximum compressive stress without any eccentric load

$f_z=f_{bs(max)}-f_{bs(min)}$

$f_z= 0.125 E (t/D_o)$

$= 0.125*2.04*10^6*t/2$

= 127500t

127500t=0.5806/t+0.5279/t

t=2.94 m

Minimum skirt thickness is 7mm,by providing 1mm corrosion allowance

t_s=8mm

Design of skirt bearing bolts

Maximum compressive stress between bearing plate and foundation

$f_c= W_{max}/A + M_w/2$

$A=\Pi(D_o-l)/2$

l=outer radius of bearing plate minus outer radius of skrit

$Z=\Pi R_m^2\ l$

$R_m=(D_o-l)/2$

$f_c= \quad 55528/(\Pi(2-l)l) + 18243.22/(\Pi(2-l)^2 l$

The allowable compressive stress of concrete foundation varies from 5.5 to 9.5 MN/m^2

$0.55*10^6 = \quad 55528/(\Pi(2-l)l) + 18243.22/(\Pi(2-l)^2 l$

l=0.021m

As required width of bearing plate is very small a 100 mm width is selected

l=0.1 m

therefore $f_c= 0.122*10^6$

thickness of bearing plate

$t_{bp}=l\sqrt{(3f_c/f)}$

$= 100\sqrt{(3*0.122*10^6/96*10^6)} =$ 61.2 mm

Bearing plate thickness of 61.2 mm is required

As the plate thickness required is larger than 20mm gussets may be used to reinforce the plate.

For l/b=1

$M(max) = M_Y = 0.199 f_c l^2$

$= 0.119*0.122*10^6*0.1^2$

$= 145.18$ kg

$t_{bp} = \sqrt{(6M_{max}/f)}$

$= 9.52$ mm

if gussets are used at 100mm spacing ,bearing plate thickness of 10mm will be sufficient

$f_{min} = W_{min}/A – M_w/Z$

$= 8688/\Pi(2-l)l + 18234.22/\Pi(2-l)^2 l$

$= 30641$ kg/m^3

$j = W_{min} R / M_w$

R=moment arm for that weight of vessel.

$R = 0.42\ D_o^l$

R= 8688*0.42*2.2/18243.22

R= 0.44

As the value is less than 1.5 , the vessel will not be steady by its own weight.

There fore anchor bolts are to be used

$P_{bolt}*n = f_{min}*A$

$= 30641*3.14*(2-0.1)*0.1$

$=1828$

For hot rolled carbon steel f=5.73*10^6 kg/m^2

$(a_r n) f = n P_{bolt}$

$a_r n = 319$ m^2

For 12X1.5 ,a_r=63mm^2

Number of bolts=319/63=5 bolts

(13) Nozzles

Diameter of liquid inlet and outlet nozzles = 180mm

Diameter of gas inlet and outlet nozzles =75 mm

Thickness of nozzles t=10mm

(14) Bubble cap Tray

Number of bubble caps=110

Diameter of bubble cap(d_c)=100mm=4in

Cap pitch(p)=150mm=6in

Distance between extreme rows of caps

$l-(p+d_c)$

l=length of liquid travel=1.428m=56.23 in

number of rows= $1+(l-(p+d_c))/p$

$=1+(1-(56.23-(6+4))/6$

= 9 rows

n_r=number of caps for center row

$n_r= (D_c-(d_c+3))/p$

$n_r= (80-(4+3))/6$

$n_r= 13$

2. (a)Process Design of Heat exchanger

Heat exchanger used is shell and tube.

The ammoniated brine entering from Ammonia Absorption Column must be cooled from 40^0C to 30^0C using cooling water available at 20^0C.

Shell side:

Feed (m_h)=58.216 kg/sec
Inlet temperature (T1)= 40^0C
Outlet temperature(T2)= 30^0C

Tube side :

Inlet temperature (t1)= 20^0C
Outlet temperature(t2)= 30^0C

1) Heat balance

$Qh=m_h C_p (T2-T1)$
= 58.216*3.555*(40-30)
= 2069.59 KW

At steady state.

Qh=Qc=mc Cp (t2-t1)
2069590=mc*4.18*(30-20)
mc=49.53 kg/sec

2) LMTD

LMTD=10^0C

F_T=LMTD correction factor.

R=1.00 & S=0.5
From graph of F_T Vs S
F_T =0.8
LMTD(corrected)=0.8*10=8^0C

3) Heat transfer area:

Choose overall heat transfer coefficient= 1000 W/(m^2K)

Q = UA(LMTD)

A=2069590/1000*8
A=258.698m^2

4) Tube selection

¾ in OD ,10 BWG Tubes

OD=3/4 in=19.05 mm

ID=0.62 in=15.75 mm

Length of tube =L=20ft=6m

Heat transfer area per tube =0.3648 m^2

Number of tubes= 258.698/0.3648=709

TEMA P or S, Floating head type:

Nearest tube count from tube count table

N_T= 740

6 tube passes and 1 shell pass

¾ in tubes arranged in triangular pitch

shell ID(D_f)=838mm=33in

Corrected heat transfer area=0.3648*742=269.952 m^2

Corrected over all heat transfer coefficient (U)=958.31 W/(m^2K)

5) Average properties of fluids

a) shell side (ammoniated brine) at 35^{0}C

ρ=987.086 kg/m3

μ=1.62*10^{-3} Ns/m^2

Cp=3.555KJ/kg.K

k=0.49 w/m.k

b)tube side (water) at 25^{0}C

ρ=999 kg/m3

μ=8.966*10^{-4}Ns/m^2

Cp=4.18 KJ/kg.K

k=0.608w/m.k

5) Tube side velocity

Number of passes $N_P=6$

Flow area $=(\Pi*ID^2/4)*N_T/N_P$

$=(3.14*0.01575^2/4)*740/6$

$A_a =0.024\ m^2$

$V_t=m_c/ (A_a\ \rho)$

$=49.53/(0.024*999)$

$=2.072$ m/s

velocity is with the range.

6) Shell side velocity

$S_m=[(P^l-D_o)L_s]D_s/ P^l$ $\quad$ P^l =pitch=25.4 mm

$L_S=0.8\ D_s$

$=[(25.4-19.05)670]838/ 25.4$

$=0.1404\ m^2$

$V_s=m_h/(\rho\ S_m)$

$=58.216/(987*0.1404)$

$=0.42$ m/s

$N_b+1=L/L_S$

$=6/0.67$

$N_b=9$ baffles

7) Shell side heat transfer coefficient

$N_{NU}=j_H\ N_{re}(N_{Pr})^{1/3}$ $\quad$ N_{Nu}=nusselt number

$N_{Re}=V_sD_o\rho/\mu$ $\quad$ N_{Re}=Reynolds number

$=0.42*0.01905*987/0.00162$

$=4874.68$ $\quad$ N_{Pr}=Prandtl number

$j_h=10^{-2}$

$N_{Pr}=\mu C_p/k$

$=0.00162*3555/0.49$

$=11.746$

$N_{NU}=10^{-2}*4874.68*(11.746)^{1/3}$

$=110.8$

$h_o=110.8*0.49/0.01905$
$=2849.98\ w/m^2.K$

8) Tube side heat transfer coefficient

$N_{Nu}=0.023(N_{Re})^{0.8}\ (N_{Pr})^{0.3}$

$N_{Re}=36361.1$
$N_{Pr}=5.502$

$N_{Nu}=0.023(36361.1)^{0.8}\ (5.502)^{0.3}$
$=184.406$

$h_i=6820.5899\ w/m^2.K$

9) overall heat transfer coefficient

dirt coefficient on shell side=h_{od}=5000 $w/m^2.K$
dirt coefficient on tube side=h_{id}=5555.55 $w/m^2.K$

$1/U=1/h_o+(D_o/D_i)(1/h_i)+D_o\ln(D_o/D_i)/(2k)+1/\ h_{od}+(D_o/D_i)(1/h_{id})$

$1/U=1/2849.98+(19.05/15.75)(1/6820.5899)+0.01905*\ln(19.05/15.75)/(2*50)$
$+1/\ 5000+(19.05/15.75)(1/5555.55)$

$U=1018.57\ w/m^2.K$

Assumed value and design value are almost same.

Pressure drop calculation
a) Tube side pressure drop

tube side Reynolds number=N_{Re}= 36361.1

friction factor=f=$0.079(N_{Re})^{-1/4}$

$=0.079(36361.1)^{-1/4}$

$=5.72*10^{-3}$

$\Delta P_L=(4fLv_t^2/2gD_i)*\rho_t g$

$= (4*5.72*10^{-3}*6*2.072^2/2*9.8*15.75*10^{-3})*999*9.8$
$= 2995.92\ N/m^2$

$\Delta P_E= 2.5(\rho_t v_t^2/2)$
$= 2.5(999*2.072^2/2)$
$= 5345\ N/m^2$

$(\Delta P)_T = N_p(\Delta P_L+\Delta P_E)$
$= 6*(2995.92+5345)$
$= 50045.52\ N/m^2$

b) Shell side pressure drop (Bell's method)

shell side Reynolds number=N_{Re}=4874.68

$f_k=0.18$

pressure drop for cross flow zones
$\Delta P_C = (bf_k w^2 N_C/\rho_f S_m^2)(\mu_w/\mu_f)$
N_c= number of tube rows crossed in one cross flow section.

$N_c=D_s[1-2(L_C/D_s)]/P_P$

Where L_c baffle cut,25% of D_s
$P_P=((\sqrt{3})/2)P^I$

$N_c=838[1-2*0.5]/22$
$N_c= 19$

$\Delta P_C = (2*10^{-3}*0.18*58.216^2*19)/(987*0.1404^2)$

$\Delta P_C = 1.19$ K Pa

pressure drop in end zones

$\Delta P_E = \Delta P_C(1+N_{cw}/N_c)$

$N_{cw}=0.8L_C/P_P$,number of cross flow rows in each window.

$N_{cw}= 8$

$\Delta P_E= 1.19*(1+8/19)$

$\Delta P_E= 1.69$ K Pa

pressure drop in window zones

$\Delta P_w= bw^2(2+0.6N_{cw})/(S_m S_w \rho)$

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

S_w=area for flow through window zone.
S_{wg}= gross window area
S_{wt}= area occupied by tubes

$S_{wg}= 170\ in^2$, for D_S=33in & $L_C/D_S=0.25$

$S_{wt}= (N_T/8)(1- F_C)\ \Pi D_O^2$

$S_{wt}= (740/8)(1-0.66)\ \Pi\ 0.01905^2$

$S_{wt}= 0.0358\ m^2$

$S_W=(0.1096-0.0358)=0.0737\ m^2$

$$\Delta P_W = \frac{5*10^{-5}*58.216^2*(2+0.6*8)}{0.1404*0.0737*987}$$

$\Delta P_W = 1.127$ Kpa

$(\Delta P_S)_T = 2\Delta P_E + (N_b-1)\Delta P_C + N_b\ \Delta P_w$
$(\Delta P_S)_T = 2*1.69 + (8-1)*1.19 + 8*1.127$
$(\Delta P_S)_T = 20.726$ Kpa

2. (b)Mechanical design of Heat Exchanger

(a) Shell side details

Material : carbon steel

Number of shell passes: one

Working pressure: 0.1N/mm^2

Design pressure : 0.11N/mm^2

Inlet temperature: 40^{0}C

Out let temperature:30^{0}C

Permissible stress for carbon steel: 95N/mm^2

(b) Tube side details

Number tubes: 740

Number of passes: 6

Outside diameter: 19.05mm

Inside diameter : 15.75

Length: 6m

Pitch triangular:1 inch

Working pressure: 0.1 N/mm^2

Design pressure: 0.11N/mm^2

Inlet temperature : 20^{0}C

Outlet temperature: 30^{0}C

Shell side

(1) Shell thickness

t_s= PD/(2fJ+P)
= 0.11*838/(2*95*0.85+0.11)
= 0.57

Minimum thickness of shell must be=6.3 mm
Including corrosion allowance shell thickness is 8mm

(2) Head thickness.

Shallow dished and torisphrrical

t_s=PR_cW/2fJ
= 0.11*838*1.77/(2*95*1)
= 0.858

minimum shell thickness should be 10mm including corrosion allowance.

(3) Transverse Baffles

Baffle spacing =0.8*D_c
= 670.4mm

number of baffles,

N_b+1=L/L_S=6000/670.4=9
N_b=8

Thickness of baffles, t_b=6mm

(4) Tie Rods and spacers

For shell diameter, 700-900mm
Diameter of Rod = 13mm
Number of rods=6

(5) Flanges

Design pressure=0.11 N/mm^2
Flange material IS:2004-1962,class 2
Bolting steel :5% Cr-Mo steel
Gasket material: asbestos composition
Shell thickness: 8mm=g_o
Outside diameter of shell: 854 mm
Allowable stress of flange material : 100MN/m^2
Allowable stress of bolting material : 138MN/m^2

Determination of gasket width

$d_O/d_i = [(y-Pm)/(y-P(m+1))]^{0.5}$

Assume a gasket thickness of 1.6mm

y = minimum design yield seating stress = 25.5 MN/m^2

m = gasket factor = 2.75

$d_O/d_i = [(25.5-0.11*2.75)/(25.5-0.11(2.75+1))]^{0.5}$

d_O/d_i = 1.002m

let d_i of gasket equal 864mm

d_o= 1.002*d_i

d_o= 0.8657 m

Minimum gasket width = 0.801(1.002-1)/2 = 0.0008m

Taking gasket width of N= 0.010m

d_o=0.885

Basic gasket seating width,b_o=5mm

Diameter of location of gasket load reaction is

$G=d_i+N$

=0.864+0.01

= 0.874 m

Estimation of Bolt loads.

Load due to design pressure

$H= \pi G^2P/4$

$= 3.14*0.874^2*0.11/4$

= 0.066 MN

Load to keep joint tight under operation

$H_p=\pi G(2b)mp$

= 3.14*0.874*(2*0.00559)*2.75*0.11

= 0.01 MN

Total operating load

W_o=H+H_p

=0.066+0.01

=0.076 MN

Load to seat gasket under bolting condition

$W_g = \pi Gby$

= 3.14*0.874*0.00559*25.5

= 0.3914 MN

$W_g > W_o$,controlling load=0.3914MN

Calculation of optimum bolting area

$A_m = A_g = W_g/S_g$

= 0.3914/138

= $2.836*10^{-03}$ m^2

Calculation of optimum bolt size

Bolt size,M18 X 2

Actual number of bolts =44

Radial clearance from bolt circle to point of connection of hub or nozzle and back of flange = R = 0.027 m

$C = nB_s/\pi$ = 0.9243

C =ID + 2(1.415g + R)

= 0.854 +2[(1.415)(0.008)+0.027]

= 0.9301m

Choose C = 0.93m

Bolt circle diameter = 0.93m

Calculation of flange outside diameter

A=C+ bolt diameter +0.02

=0.93+0.018+0.02

= 0.968

let A=0.97 m

check for gasket width

$A_b S_G / (\pi GN) = 34.055 < 2y$,

where S_G is the Allowable stress for the gasket material

Flange moment computation

(a) For operating condition

$W_o=W_1+W_2+W_3$

$W_1=\prod B^2 P/4$

$=\prod *0.854^2*0.11/4$

= 0.063 MN

W_2=H-W1

=0.0646-0.063

= 0.063MN

$W_3=W_o-H=H_p$

= 0.01 MN

M_o=Total flange moment

$M_o=W_1a_1 + W_2a_2 + W_3a_3$

a_1=(C-B)/2=(0.93-0.854)/2

a_1=0.038 m

a_3=(C-G)/2=(0.93-0.865)/2

a_3=0.0325 m

$a_2=(a_1 + a_3)/2$= (0.038+0.0325)/2=0.03525 m

M_o=0.038*0.063+0.03525*0.0016+0.0325*0.01

$M_o= 2.775*10^{-3}$ MN-m

(b) For bolting condition

$M_g=Wa_3$

$W=(A_m+A_b)*S_g/2$

$A_b=44*1.54*10^{-4} = 6.76*10^{-3}\ m^2$

$A_m= 2.836*10^{-03}\ m^2$

$W=(2.836*10^{-3}+6.76*10^{-3})*138/2$

W= 0.6621 MN

$M_g= 0.6621*0.0325$

= 0.02333 MN-m

$M_g>M_o$,Hence moment under operating condition M_g is controlling, $M_g=M$

Calculation of flange thickness

$t^2 = M\ C_F\ Y / (B\ S_F)$, S_F is the allowable stress for the flange material

K =A/B = 0.97/0.854 = 1.135

For K = 1.15, Y = 14

Assuming C_F =1

$t^2 = 0.02333*1*14/(0.854*100)$

t= 0.0618 m=61.8 mm

Actual bolt spacing $B_S = \pi C/n = (3.14)(0.93)/(44) = 0.066m$

Bolt Pitch Correction Factor

$C_F = [B_s / (2d+t)]^{0.5}$

$= (0.066/(2*0.018+0.076)^{1/2}$

= 0.7675

$\sqrt{C_F}=0.87612$

Actual flange thickness = $\sqrt{C_F}*t$

= 0.8761*0.0618

= 0.04713 m

= 47.13 mm

Standard flange thickness available is 50 mm

Channel and channel Cover

$t_h = G_c\sqrt{(KP/f)}$

$= 0.865*\sqrt{(0.3*0.11/95)}$

$= 0.016$m =16mm

t_h=18mm including corrosion allowance

Tube sheet thickness

$t_{ts} = FG\sqrt{(0.25P/f)}$

$= 1*0.874\sqrt{(0.25*0.11/95)}$

= 14.7 mm

t_{ts}=15mm

t_{ts}=18 mm including corrosion allowance.

Nozzles

Tube side nozzles diameter=180 mm

Shell side nozzles diameter = 180 mm

Thickness of nozzles =t=10mm

Saddle support

Material: low carbon steel

Total length of shell: 6 m

Diameter of shell: 854 mm

Knuckle radius : 51.24 mm

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

$= \sqrt{(854*51.24/2)}$

= 148 mm

Weight of the shell and its contents = 11943kg = W

R=D/2=427 mm

Distance of saddle center line from shell end = A =0.5R=214 mm

Longitudinal Bending Moment

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

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

$= 11943(6 + 4*0.148/3)/2$

$= 47756.075$ kg m

$M_1 = 477560*0.214[1-(1-0.214/6+(0.427^2-0.148^2)/(2*6*0.214))/(1+4*0.148/(3*6))]$

$= 1004.63$ kg-m

Bending moment at center of the span

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

$M_2 = 81085.6$ kg-m

Stresses in shell at the saddle

(a) At the topmost fibre of the cross section

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

$=1004.63/(3.14*0.427^2*0.01)$

$= 17.35$ kg/cm^2

the stresses are well within the permissible values.

Stress in the shell at mid point

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

$= 604.45$ kg/cm^2

Axial stress in the shell due to internal pressure

$f_p = PD/4t$

$= 0.11*836/4*10$

$= 225.53$ kg/cm^2

$f_2 + f_p = 829.98$ kg/cm^2

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

Chapter-7

Pollution and safety in process industries

The bulk of the solids in distiller waste in the soda ash plant is made up of chloride. This arises from the fact that the waste contains all the chloride from the salt used, chlorine is not utilized in the process.

Calcium chloride in solution permeates the soil bed and contaminates sources of water supply. Only to a very limited extent is any portion of the waste allowed by municipal authorities to be sent to rivers or any public waterways and that only after complete settling. Also fish in the river were killed by the calcium chloride and the free lime carried in the liquor.

The preparation of chlorine gas or hydrochloric acid from calcium chloride in the waste went no longer be considered workable in view of the present more economical methods for preparing such materials.

Waste Disposal: Large volumes of liquid wastes containing suspended and dissolved solids are produced in an ammonia – soda plant. The largest volume occurs from the distiller operation where for every ton of product soda ash, nearly 10 m^3 of liquid wastes are produced, containing about one ton of calcium chloride, one-half ton of sodium chloride, and other soluble and insoluble impurities. Traditionally this liquid waste, after settling of suspended solids in large basins, was discharged into local waterways. In the United States, federal guidelines , suggesting limits on suspended solids and pH of liquid wastes discharged to local waterways, are used in the development of local discharge permits. The guidelines also specified no discharges from new ammonia – soda ash plants. Although processes have been proposed to reduce or eliminate waste streams, it is felt that in the United States, with its abundant reserves of natural ash, the guidelines will prohibit installation of new ammonia – soda plants. In addition to regulations governing liquid wastes, local restrictions have been placed on gaseous emissions from soda ash plants to protect air quality. The cost to comply with the environmental regulations and the increasing operating costs relative to natural ash have contributed heavily to the shutdown of synthetic soda ash plants in the United States.

HEALTH AND SAFETY

Exposure to soda ash is ordinarily not hazardous but soda ash dust may produce temporary irritation of the nose and throat. Although some become accustomed to working in ht dust and suffer relatively little discomfort, others are allergic to alkaline materials and develop a condition of dermatitis. Tests have shown that dermal effects due to soda ash range from a transient reddening and inflammation to mild burns to abraded skin areas. The skin irritations experienced by workmen exposed to soda ash dust in hot weather are usually more severe because soda ash is likely to dissolve in perspiration.

Soda ash is corrosive to the eyes. It produces severe corneal, iridal, and conjunctival effects (tissue destruction). Soda ash is harmful if ingested and may be corrosive to the lining of the stomach. A private communication has indicated that the acute oral LD_{50} on for soda ash is 2.8 g/kg.

Potential Health Effects of Soda ash

Eye: Contact with eyes may cause severe irritation, and possible eye burns.
First aid: Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower lids. Get medical aid immediately

Skin: Contact with skin causes irritation and possible burns, especially if the skin is wet or moist.
First aid: Get medical aid. Flush skin with plenty of soap and water for at least 15 minutes while removing contaminated clothing and shoes.

Ingestion: May cause irritation of the digestive tract.
First aid: Do not induce vomiting. If victim is conscious and alert, give 2-4cupfuls of milk or water. Never give anything by mouth to an unconscious person. Get medical aid immediately.

Inhalation: May cause irritation of the respiratory tract with burning pain in the nose and throat, coughing, wheezing, shortness of breath and pulmonary edema.

First aid: Remove from exposure to fresh air immediately. If not breathing,give artificial respiration. If breathing is difficult, give oxygen.Get medical aid if cough or other symptoms appear

Chronic: Prolonged or repeated inhalation may cause nosebleeds, nasal congestion, erosion of the teeth, perforation of the nasal septum,chest pain and bronchitis.

Handling and storage

Handling: Wash thoroughly after handling. Remove contaminated clothing and wash before reuse. Do not get in eyes, on skin, or on clothing. Keep container tightly closed. Avoid ingestion and inhalation.

Storage: Store in a tightly closed container. Store in a cool, dry,well-ventilated area away from incompatible substances.