MAJOR EQUIPMENT DESIGN

DISTILLATION COLUMN

Process Design

The feed rate for the tower is 297.6510 kmols/day

Therefore F = 297.6510 kmols/day

= 12.4021 kmols/hr

The mole fraction of carbitol in the feed is 0.639.

i.e $X_f = 0.639$

Neglecting the residual mono-glycol ether and other impurities, thus the mixture can be treated as binary mixture of carbitol and triglycol ether.

The distillate rate is 186.566 kmols/day

Therefore D = 186.566 kmols/day

= 7.7735 kmols/hr

The mole fraction of carbitol in the distillate is 0.99.

i.e $x_d = 0.99$

The residue rate is 111.048 kmols/day

Therefore W = 111.048 kmols/day

= 4.627 kmols/hr

The mole fraction of carbitol in the residue is 0.05

i.e $x_w = 0.05$

The feed is taken as saturated liquid, since it is coming from a Reboiler.

Therefore $q = (H_v - H_f)/(H_v - H_l)$

$= 1$

Therefore the slope of the q-line is $q/(q-1) = \infty$

Vapor pressure data

Temperature (K)	**Vapor pressure of MCB (mm Hg)**	**Vapor pressure of DCB (mm Hg)**
405	700	190
408	810	210
411	900	240
415	1000	260
418	1050	300
422	1150	330
426	1300	370
429	1400	400
433	1500	450
437	1700	500
441	1800	575
444	2000	625
448	2200	680
453	2400	740

Vapor liquid equilibrium data

Temperature (K)	**x_a (mole fraction of MCB in liquid)**	**y_a (mole fraction of MCB in gas)**
408	0.92	0.98
411	0.79	0.94
415	0.68	0.90
418	0.61	0.85
422	0.52	0.79
426	0.42	0.72
429	0.36	0.66
433	0.30	0.59
437	0.22	0.49
441	0.15	0.36
444	0.10	0.26
448	0.05	0.15
453	0.01	0.04

From graph:

Minimum reflux ratio (R_m) = 0.17857

Operating reflux ratio = 1.5 x R_m

= 0.2678

Slope of operating line x_d/(R+1) = 0.7808

From the graph the number of ideal stages is eight.

Therefore total no of trays in the column is seven.

Number of stages in enriching section is four.

Number of stages in stripping section is three.

Liq flow rate in enriching section L

L = D x R

= 7.7735 x 0.2678

= 2.0817 kmols/hr

Vapor flow rate in the enriching section G

G = L + D

= (1 + R)D

= 1.2678 x 7.7735

= 9.855 kmols/hr

Liq flow rate in the stripping section $\overline{L}$

$\overline{L}$ = L + qF

= 2.0817 + 12.4021

= 14.4838 kmols/hr

Vapor flow rate in the stripping section $\overline{G}$

$\overline{G}$ = G + (q − 1)F

= 9.855 kmols/hr

EVALUATION OF AVERAGE PROPERTIES OF THE MIXTURE

DENSITY CALCULATION

Liq phase calculations

Carbitol density at various temperatures

$(\rho)_{202°c} = 5.977 kmol/m^3$.

$(\rho)_{213°c} = 5.857 kmol/m^3$.

$(\rho)_{261°c} = 5.379 kmol/m^3$.

Triglycol ether (TGE) density at various temperatures

$(\rho)_{202°c} = 6.6209 kmol/m^3$.

$(\rho)_{213°c} = 6.5141 kmol/m^3$.

$(\rho)_{261°c} = 6.0870 kmol/m^3$.

Vapor phase calculations

Assuming ideal gas

PV = nRT

With P = 1 atm

R = 0.082 m^3atm/kmol k

T = temp in Kelvin

Carbitol density at various temperatures

$(\rho)_{204°c} = 0.025565 kmol/m^3$.

$(\rho)_{218°c} = 0.024835 kmol/m^3$.

$(\rho)_{282°c} = 0.21970 kmol/m^3$.

Triglycol ether density at various temperatures

$(\rho)_{204°c} = 0.25566 kmol/m^3$.

$(\rho)_{218°c} = 0.02483 kmol/m^3$.

$(\rho)_{282°c} = 0.021972 kmol/m^3$.

Mixture properties

$(\rho_l)\ kg/m^3$ = avg molecular wt/($x_1/\rho_{carbitol} + x_2/\rho_{TGE}$)

$(\rho_l)_{202°c} = 134.16/(0.99/5.977 + 0.01/6.6209)$

$= 802.65\ kg/m^3$

$(\rho_l)_{213°c} = 838.248\ kg/m^3$

$(\rho_l)_{261°c}$ = **885.248 kg/m^3**

$(\rho_v)_{204°c}$ = **3.4298 kg/m^3**
$(\rho_v)_{218°c}$ = **3.3550 kg/m^3**
$(\rho_v)_{282°c}$ = **3.233 kg/m^3**

The average properties in the enriching section and stripping section can be summarized into the table as below.

PROPERTY	**ENRICHING SECTION**		**STRIPPING SECTION**	
	TOP	**BOTTOM**	**TOP**	**BOTTOM**
Liq flow rate kmols/hr	**2.0817**	**2.0817**	**14.4838**	**14.4838**
Vap flow rate kmols/hr	**9.855**	**9.855**	**9.855**	**9.855**
Liq mole fraction x	**0.99**	**0.7**	**0.7**	**0.13**
Vap mole fraction y	**0.99**	**0.93**	**0.93**	**0.18**
Avg (liq) molecular wt g/mol	**134.16**	**138.80**	**138.80**	**147.92**
Avg (vap) molecular wt g/mol	**134.16**	**135.12**	**135.12**	**147.12**
Temp liq (°c)	**202**	**213**	**213**	**261**
Temp vap(°c)	**214**	**218**	**218**	**282**
Liq flow rate kg/hr (L)	**279.28**	**288.939**	**2010.38**	**2142.44**
Vap flow rate kg/hr(G)	**1322.14**	**1331.60**	**1331.60**	**1449.86**
Liq density ρ_l kg/m^3	**802.65**	**838.32**	**838.32**	**885.248**
Vap density ρ_v kg/m^3	**3.4298**	**3.35502**	**3.35502**	**3.233**
L/G**x$(\rho_v/ \rho_l)^{0.5}$**	**0.01380**	**0.013726**	**0.09550**	**0.08930**

ENRICHING SECTION DESIGN

1.TOWER DIAMETER CALCULATION

The maximum value of L/G**x**$(\rho_v/\rho_l)^{0.5}$ **is 0.1380 at the top of the section**

Choosing Intalox saddles, polypropylene

Nominal size = 25mm

Surface area = 206 m^2/m^3**.**

Є = 91%.

F_p **= 105 per meter**

From steam tables the density of water at 202ºc is 802.65kg/m^3**.**

$\psi = \rho_{water}/\rho_{liq} = 862.28/802.65 = 1.0742$

$\mu_l^{1/3}(mix) = x_1\mu_1^{1/3} + x_2\mu_2^{1/3}$

$= 0.99(0.4^{1/3}) + 0.01(0.92^{1/3})$

$= 0.7360$

μ_l **(mix) = 0.4 cp**

From graph (18-38)

$G^2Fp\psi\mu^{0.2}/(\rho_g*\rho_l*g) = 0.22$

Solving we obtain $G_f = 7.954\ kg/m^2s$

Choosing 65% flooding

We get $G = 0.65G_f = 5.17027 kg/m^2s$**.**

Therefore the cross sectional area of the tower

A_c **= mass flow rate/G**

= 1322.14/(3600 x 5.17027)

= 0.07103 m^2

The diameter of the column = $\{(4xA_c)/\Pi\}^{0.5}$

$D_c = 0.30073$ **m**

Taking the corrected D_c = 0.300 m

Therefore A_c = 0.07068m^2

= 0.76085ft^2

tower dia /packing dia (D_c/d_p) = 0.30/0.025

= 12 (> 10)

WETTING RATE

L_{min} = 279.28/(802.65x60x4.546097x10^{-3})Gallons/min

= 1.2756GPM

Degree of wetting

L_{min}/tower area in ft^2

= 1.2756/0.760855

= 1.676536 GPM/ft^2

Hence acceptable (greater than the limits of 0.5 GPM/ft^2).

PRESSURE DROP CALCULATIONS

Pressure drop can be calculated using the equation

$\Delta p = C_2 * 10^{(C3*Utl)} * \rho_g * U_{tg}^{\ 2}$ - equation 18.48

where

C_2, C_3 are constants to be evaluated from table 18.7

U_{tl}, U_{tg} are superficial liq and vapor flow rate (ft/sec).

ρ_g is avg vapor density (lb/ft^3).

Δp = pressure drop in inch water/ft packing

$U_{tl} = \overline{L}/(Ac * \rho_l)$

=284.11/(3600x0.7068x802.48x0.3048)

= 4.4647x10^{-3} ft/s.

$U_{tg} = \overline{G} /(Ac^* \rho_g)$

$= 1326.87/(3600x0.7068x3.39241x0.3048)$

$=5.0431$ ft/s.

Density of gas $\rho_g = 3.3924$ Kg/m^3 = 0.21177 lb/ft^3

$C_2 = 0.31$ $C_3 = 0.0222$

$\Delta p = C_2 *10^{(C3*Utl)}*\rho_g*U_{tg}$

$= 0.31*10^{(0.0222*0.004464)}*0.21177* 5.0431^2$

= 1.6700 in water/ft packing

= 139.06 mm water/m packing

STRIPPING SECTION DESIGN

1.TOWER DIAMETER CALCULATION

The maximum value of L/Gx$(\rho_v/ \rho_l)^{0.5}$ is 0.09550 at the top of the section

Choosing Intalox saddles, polypropylene

Nominal size = 25mm

Surface area = 206 m^2/m^3.

Є = 91%.

F_p = 105 per meter

From steam tables the density of water at 213^{o}c is 848.662kg/m^3.

$\psi = \rho_{water} /\rho_{liq} = 862.28/838.32 = 1.01233$

$\mu_l^{1/3}(mix) = x_1\mu_1^{1/3} + x_2\mu_2^{1/3}$

$= 0.7(0.4^{1/3}) + 0.3(0.94^{1/3})$

$= 0.7663$

μ_l (mix) = 0.45 cp

From graph (18-38)

$G^2 F p \psi \mu^{0.2}/(\rho_g * \rho_l * g) = 0.15$

Solving we obtain G_f = 7.038 kg/m^2s

Choosing 65% flooding

We get G = 0.65G_f = 4.574kg/m^2s.

Therefore the cross sectional area of the tower

A_c = mass flow rate/G

= 1331.60/(3600 x 4.574)

= 0.0808 m^2

The diameter of the column = $\{(4xA_c)/\Pi\}^{0.5}$

D_c = 0.3205 m

Taking the corrected D_c = 0.300 m

Therefore A_c = 0.07068m^2

= 0.76085ft^2

tower dia /packing dia (D_c/d_p) = 0.30/0.025

= 12 (> 10)

<u>WETTING RATE</u>

L_{min} = 2010.38/(838.32x60x4.546097x10^{-3})Gallons/min

= 8.791GPM

Degree of wetting

L_{min}/tower area in ft^2

= 8.791/0.760855

= 11.555 GPM/ft^2

Hence acceptable (greater than the limits of 0.5 GPM/ft^2).

PRESSURE DROP CALCULATIONS

Pressure drop can be calculated using the equation

$\Delta p = C_2 * 10^{(C3*Utl)} * \rho_g * U_{tg}^{\ 2}$ - equation 18.48

where

C_2, C_3 are constants to be evaluated from table 18.7

U_{tl}, U_{tg} are superficial liq and vapor flow rate (ft/sec).

ρ_g is avg vapor density (lb/ft^3).

Δp = pressure drop in inch water/ft packing

$U_{tl} = \overline{L} /(Ac* \rho_l)$

= 2076.41/(3600x0.7068x861.78x0.3048)

= 0.031067 ft/s.

$U_{tg} = \overline{G} /(Ac* \rho_g)$

= 1390.73/(3600x0.7068x3.29401x0.3048)

=5.443 ft/s.

Density of gas ρ_g = 3.29401 Kg/m^3 = 0.20565 lb/ft^3

$C_2 = 0.31$ $C_3 = 0.0222$

$\Delta p = C_2 * 10^{(C3*Utl)} * \rho_g * U_{tg}$

$= 0.31*10^{(0.0222*0.0.31067)}*0.20565* 5.443^2$

= 1.8917 in water/ft packing

= 157.60 mm water/m packing

AVERAGE CONDITIONS FOR ENRICHING AND STRIPPING SECTION

PROPERTY	ENRICHING SECTON	STRIPPING SECTION
Liq flow rate kmols/hr	2.0817	14.4838
Liq flow rate kgs/hr	284.10	2076.41
Vapor flow rate kmols/hr	9.855	9.855
Temp of liq °c	207.5	247.5
Temp of vap °c	211	250
Density of liq ρ_{liq} kg/m^3	820.485	861.784
Density of vap ρ_{vap} kg/m^3	3.39241	3.2940
μ_l cp	0.425	0.46
μ_{vap} cp	0.010025	0.010756
σ_{liq} dynes/cm	12.622	15.6123
D^l_{AB} cm^2/sec	16.408×10^{-6}	17.58×10^{-6}
D^V_{AB} cm^2/sec	0.05278	0.06082
Liq Schmidt number N_{sl}	315.609	303.627
Vap Schmidt number N_{sg}	0.559	0.5368

TOWER HEIGHT CALCULATION

ENRICHING SECTION

The height of the enriching section can be given by

$Z = H_{og} * N_{og}$

Where

$H_{og} = H_g + m*G_m/L_m*H_l$

$N_{og} = N_T ln(\lambda/\lambda-1)$

λ is the stripping factor given by mG_m/L_m

$H_g = 0.029*\psi*D_c^{1.11}*Z^{0.33}*S_{cg} / (L*f_1*f_2*f_3*f_4)^{0.5}$

From fig 18.65

$\psi = 50$

$D_c = 0.3m$

L = 284.10/(0.7068x3600)

= 1.11653 kg/s m^2

$f_1 = (\mu_l/\mu_{water})^{0.16}$

$= (0.425/1.0)^{0.16}$

= 0.872

$f_2 = (\rho_{water}/\rho_l)^{1.25}$

$= (1000/820)^{1.25}$

= 1.0322

$f_3 = (\sigma_{water}/\sigma_l)^{0.8}$

$= (72.8/12.622)^{0.8}$

$= 4.0625$

$H_g =$

$0.029*50*(0.3)^{1.11}*(Z)^{0.33}*(0.559)^{0.5}/(1.11653*0.872*1.3022*4.0625)^{0.5}$

$= 0.5365*(Z)^{0.33}$

By Cornell method eqn 18-56

$H_l = (\varphi C/3.28)(\mu_l/\rho_l D_l)^{0.5}(z/3.05)^{0.15}$

Liquid rate = 5.2147 Kg/m^2 s

φ = 0.035m (from fig 18-60) **C = 0.8 (from fig 18-59)**

$H_l = 0.035*0.8/3.28 * (315.69)^{0.5} * (Z/3.05)^{0.15}$

$= 0.1282*(Z)^{0.15}$

$H_{og} = 0.5365*(Z)^{0.33} + 0.1214*4.734*0.1282*(Z)^{0.15}$

$= 0.5365*(Z)^{0.33} + 0.0737*(Z)^{0.15}$

$N_{og} = N_T \ln\lambda/(\lambda-1)$

λ is the stripping factor given by mG_m/L_m

m is the slope of equilibrium line in enriching section.

m (top) = 0.1

m (bottom) = 0.1428

m (avg) = 0.1214

$G_m/L_m = 9.855/2.0817$

$= 4.734$

$\lambda = 0.5750$

$N_T = 4$

$N_{og} = 4\ln 0.5750/(0.5750-1)$

$= 5.2144$

$Z = H_{og} * N_{og}$

$= \{0.5365*(Z)^{0.33} + 0.0737*(Z)^{0.15}\}5.2144$

$= 2.796*(Z)^{0.33} + 0.3844*(Z)^{0.15}$

Solving the above equation by trail and error, we get

Z = 5.35m

Therefore height of enriching section is 5.35m

STRIPPING SECTION

The height of the stripping section can be given by

$Z = H_{og} * N_{og}$

Where

$H_{og} = H_g + m*G_m/L_m*H_l$

$N_{og} = N_T ln(\lambda/\lambda-1)$

λ is the stripping factor given by mG_m/L_m

$H_g = 0.029*\psi*D_c^{1.11}*Z^{0.33}*S_{cg} / (L*f_1*f_2*f_3*f_4)^{0.5}$

From fig 18.65

$\psi = 50$

$D_c = 0.3m$

$L = 2076.41/(0.7068x3600)$

$= 8.160$ kg/s m^2

$f_1 = (\mu_l/\mu_{water})^{0.16}$

$= (0.46/1.0)^{0.16}$

$= 0.8831$

$f_2 = (\rho_{water}/\rho_l)^{1.25}$

$= (1000/861.78)^{1.25}$

$= 1.204$

$f_3 = (\sigma_{water}/\sigma_l)^{0.8}$

$= (72.8/15.612)^{0.8}$

$= 3.427$

$H_g =$

$0.029*50*(0.3)^{1.11}*(Z)^{0.33}*(0.559)^{0.5}/(6017.69*0.8831*1.204*3.427)^{0.5}$

$= 0.052*(Z)^{0.33}$

By Cornell method eqn 18-56

$H_l = (\varphi C/3.28)(\mu_l/\rho_l D_l)^{0.5}(z/3.05)^{0.15}$

Liquid rate = 8.160 Kg/m^2 s

φ = 0.07m (from fig 18-60) C = 0.8 (from fig 18-59)

$H_l = 0.07*0.8/3.28 * (303.627)^{0.5} * (Z/3.05)^{0.15}$

$= 0.2516*(Z)^{0.15}$

$H_{og} = 0.0527*(Z)^{0.33} + 0.86751*0.25167*(Z)^{0.15}$

$= 0.0527*(Z)^{0.33} + 0.21826*(Z)^{0.15}$

$N_{og} = N_T \mathit{ln}\lambda/(\lambda-1)$

λ is the stripping factor given by mG_m/L_m

m is the slope of equilibrium line in stripping section.

m (top) = 0.3

m (bottom) = 2.25

m (avg) = 0.1.275

G_m/L_m = 0.6804

λ = 0.86751

N_T = 3

$N_{og} = 3\mathit{ln}0.8675/(0.8675-1)$

= 3.218

$Z = H_{og} * N_{og}$

$= \{0.0527*(Z)^{0.33} + 0.21826*(Z)^{0.15}\}3.218$

$= 0.1673*(Z)^{0.33} + 0.7023*(Z)^{0.15}$

Solving the above equation by trail and error, we get

Z = 0.84m

Therefore height of stripping section is 0.84m

Total height of the tower is

Z = (5.35+0.84)

= 6.19m

(B) MECHANICAL DESIGN OF DISTILLATION COLUMN

Diameter of the tower D_i = 0.3m

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 = 50mm

Density of insulation = 770 kg/m^3

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 (2 mm)

J=joint factor

t_s= (1.1362*300)/(2*950*0.85-1.1362) + C

t_s = 2.2112 mm

minimum thickness allowable is 6mm

t_s= 6mm

2) Head Design

Shallow dished and torispherical head

Thickness of head is given by

$t_h = PR_C W/2fJ$

R_c=crown radius,300mm

W=stress intensification factor

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

R_k= knuckle radius ,6% of crown radius.

W= 1.7706 mm

$t_h = 1.1362*300*1.7706/2*950*0.85$

$t_s = 0.3737$ 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: (tensile)

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

$$= 1.1362*300/4*(6-2)$$

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

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

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

$$f_{d(ins)} = \underline{412*50*770*X}$$

$$306*(6-2)$$

$$f_{d(ins)} = 1.1015X$$

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

$$f_d = \frac{\Sigma \text{ liq and packing wt/unit height}*X}{\pi D_m(t_s-C)}$$

For the chosen packing, 25mm plastic intalox saddles

$\varepsilon = 0.91$

approximate wt/m^3 kg/m^3 = 76

Number of elements per m^3 = 55800

Total volume of the packing = $\Pi*D_c^2*h/4$

= $0.4375m^3$

Total void volume = 0.91*0.4375

= $0.3981m^3$

Total volume of the actual packing = $0.039379m^3$

Average density of the liq in the column is 841.13kg/m^3.

$$f_d = \frac{(76+841.13*0.3981)/0.4375*X}{\Pi D_m(t_s- c)}$$

$$= 24.42X \text{ kg/cm}^2$$

7) Stress due to the weight of the attachments

The total weight of the attachments

The weight of the head is taken as 1020kgs

$$W_a = (1020 + 140X)$$

$$F_{d(att)} = (1020 + 140X)/(\Pi*30.6*0.4)$$

$$= 26.525 + 3.640X \text{ kg/cm}^2$$

8) Total compressive dead weight stress at height X (sum of 2-7)

$$f_{ds}=29.9315X + 26.525$$

9) Stress due to wind load at distance X

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

$= (1.4*130*X^2)/(\Pi*31.2*.4)$

$= 4.642X^2$

10) Stress in upwind side

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

$0.8*950 = 4.642X^2+142.025-29.9315X-26.525$

$4.642X^2-29.9315X-644.5 = 0$

solving for X

X = 15.2177 m

11) stress in down side

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

$4.642X^2-29.9315X-928.55 = 0$

X = 17.730 m

From this, whole tower of 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=11.29 (Total height of tower including skirt height)

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

$W_H = 1020$ **kg (weight of head)**

$W_{min} = \Pi(0.3+0.006)\ (0.006)(11.29-2)7700 + 2*1020$

$W_{min} = 2171.33$ **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= 656.67 kg (weight of water during test)

W_a= 4400 kg (weight of attachments)

W_{max}=20056.67 kg

Wind load

$P_W= K_1 p_w HD$

For minimum weight of column,D = 0.3m

P_w(min)= 0.7*130*11.29*0.3 = 308.217 kg

P_w(max)= 0.7*130*11.29*0.312 = 320.54 kg

Minimum wind moment

M_W(min) = P_W(min)*H/2
= 308.217*11.29/2
= 1739.88 kg m

Maximum wind moment

M_W(min) = P_W(min)*H/2
= 320.54*11.29/2
= 1809.44 kg m

Bending stresses

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

$$= \frac{4*1739.88}{\Pi * 0.3^2 * t}$$

$$= 2.461/t \quad kg/cm^2$$

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

$$= \frac{4*1809.88}{\Pi * 0.3^2 * t}$$

$$= 2.5604/t \ \ kg/cm^2$$

Minimum dead load stress

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

$= 2171.33 / \Pi * 0.3 * t$

$= 0.23038/t \ \ kg/cm^2$

Maximum dead load

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

$= 0.21280/t \ kg/cm^2$

Maximum tensile stress without any eccentric load

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

980*0.8= 0.0994/t

t= 0.1449mm

Maximum compressive stress without any eccentric load

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

$f_z = 0.125\ E\ (t/D_o)$

$= 0.125*2.04*10^6*t/0.3$

$= 850000t$

850000t = 2.5604/t+2.461/t

t=2.4305 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

$Z = \Pi R_m^2\, l$

$R_m = (D_o - l)/2$

$f_c = 20056/(\Pi(0.3-l)l) + 1809.44/(\Pi(0.3-l)^2 l$

The allowable compressive stress of concrete foundation varies from 5.5 to 9.5 MN/m²

$0.55*10^6 = 20056/(\Pi(0.3-l)l) + 1809.44/(\Pi(0.3-l)^2 l$

l=57mm

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

l=0.1 m

therefore $f_c = 0.50253*10^6$ **kg/m²**

thickness of bearing plate

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

$= 100\sqrt{(3*0.5026*10^6/96*10^6)} = 12.53$ **mm**

Bearing plate thickness of 12.53 mm is required

As the plate thickness required is less than 20mm, no reinforcement is required.

$f_{min} = W_{min}/A - M_s/Z$

$= 2171.33/\Pi(0.3-0.1)0.1 + 1739.88/\Pi(0.3-0.1)^2 0.1$

$= 103897 kg/m^2$

The modulus value is taken, less than zero implies that the vessel must be anchored to the concrete foundation by means of anchor bolts to

prevent overturning owning to the bending moment induced by the wind or seismic load.

Therefore anchor bolts are to be used

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

where P_{bolt} **= load on one anchor bolt**

f_{min} **= stress determined by eqn 10.211**

A = area of the contact between bearing plate and foundation

= 103897.5*3.14*(0.3-0.1)*0.1

= 6528.07 kg/m²

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

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

$$a_r n=1139.2\ mm^2$$

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

Number of bolts=11392/63=18 bolts

Therefore 18 bolts are to be distributed equally.

MINOR EQUIPMENT DESIGN

CONDENSER

Process Design

The reflux condenser, condenses vapor of the column and send it as the reflux.
The vapor flow rate is 9.855kmols/hr.
T_{vap} = 202ºc. (sat vap).
Molecular wt of vap = 134
Heat of condensation $\lambda_{202^o c}$ = 21000Btu/lbmol
= 364.52kJ/kg.
= 48846kJ/kmol.
Heat load Q = 9.855×48846
= 481377.33kJ/hr.
= 133.71kW.
Let the overload be 10%.

Therefore Q = 1.1×133.71kW
= 147.0875kW.

Let water at a temp of 25ºc be used to condense the vapor.
Fixing the outlet temp of water as 35ºc.
The water flow rate

$W_c = 147.0875/C_{pwater}\times(T_{out} - T_{in})$
= 147.0875/4.187×10
= 3.512kg/s.

T_{vap} = 202ºc,

$\Delta T_{lmtd} = \{(202-35)-(202-25)\}/ln\{(202-35)/(202-25)\}$
= 171.95ºc

Let us assume an overall heat transfer coefficient,(U) of 567.83J/m^2sºc.
As the heat load is very low, we shall use a DPHE.

Required area for heat transfer is A
= $Q/\Delta T_{lmtd}\times U$
= 147.08875/(171.95×567.83)
= 1.369m^2.

Choosing 2” NPS, 40SCH and 1.25” as the tubes.

Inner dia of 2” NPS pipe = 5.25cm
Outer dia of 2”NPS pipe = 6.032cm
Inner dia of 1.25” NPS pipe = 3.505cm
Outer dia of 1.25” NPS pipe = 4.216cm

Taking the length of the pipe as 6 ft (1.828m)
Length available for heat transfer = 1.528m
Heat transfer area, outside area of inner pipe = $L \times \Pi \times d_0 \times 2 \times N$
where N, is the number of hairpins.
Therefore , $N = A/(L \times \Pi \times d_0 \times 2)$

$= 1.369m^2/(\Pi \times 1.528 \times 0.04216 \times 2)$
$= 3.382$

Taking the number of hairpins N as 4.

Therefore the corrected heat transfer area = $1.61906m^2$
Corrected overall heat transfer coefficient = $480W/m^{2o}c$

Location of the fluids , the vapor is taken in the annulus and water in the tube.

OVERALL HEAT TRANSFER COEFFICIENT CALCULATION (U_d)

The overall heat transfer coefficient is given by the equation

$1/U_d = 1/h_o+(D_o/D_i)(1/h_i)+ \{x_w D_o/(D_w k)\}+$ dirt factor

where,

h_o, h_i are outside and inside heat transfer coefficients.
x_w,D_w are wall thickness and mean wall diameter.
k is wall material thermal conductivity.

1)ANNULUS SIDE (carbitol vapors)

The individual heat transfer coefficient

$$h_o = 0.725\{[K^3 \times \rho^2 \times g \times \lambda]/[D \times \mu \times \Delta T]\}^{0.25}$$

where,

K is the thermal conductivity of condensate = 0.12461W/mK

ρ is the density of condensate = 802.65kg/m^3.

g is acceleration due to gravity = 9.81m/s^2.

λ is the heat of condensation = 364.52kJ/kg

D is the outside dia of the tube = 0.04216m

μ is the viscosity of the condensate = 0.4cp

ΔT is temp difference of the condensate and the wall = 202-116

= 86^{o}c.

Therefore, h_o = 959.92W/m^{2}K

2) Inside heat transfer coefficient (tube side)

$$h_i d_i/K = 0.023\times(Re)^{0.8}\times(N_{Pr})^{0.4}$$

Where,

Re is the Reynolds number.

N_{Pr} is the prandtl number.

$Re = DV\rho/\mu$

$= 4\times$Mass flow rate$/(\Pi D\mu)$

$= 4\times3.512/(\Pi\times0.03505\times0.85\times10^{-3})$

$= 150092.0$

$N_{Pr} = C_P\mu/K$

$= 4.18\times10^3\times0.85\times10^{-3}/0.16$

$= 5.82$

Therefore

$h_i d_i/K = 0.023\times\times(150092)^{0.8}\times(5.82)^{0.4}$

$= 643.84$

$h_i = 643.84\times K/d_i$

$= 643.84\times0.61/0.03505$

$= 11205.3$W/m^{2}K

3) Wall Resistance can be expressed as

Mean temp of the wall is 116^{o}c.

$\{x_w D_o/(D_w k)\} = 0.00355\times0.04216/(0.03849\times45)$

$= 8.64109\times10^{-5}$ m^{2}K/W

4) Dirt factor of 0.0005 is assumed.

Therefore,

$$1/U_d = 1/h_o+(D_o/D_i)(1/h_i)+ \{x_wD_o/(D_wk)\}+ \text{dirt factor}$$

$$= 0.0889/(0.07366\times11205.3) + (1/959.92) + 8.64109\times10^{-5} + 0.0005$$

$$= 1.73588\times10^{-3}.$$

$$U_d = 576.076 W/m^2K$$

Since the $U_{assumed} < U_d$, the design is acceptable from heat transfer point of view.

PRESSURE DROP CALCULATIONS

1)TUBE SIDE

$$\Delta P_T=(4fLv_t^2/2gD_i)\times\rho_t g$$

Tube side Reynolds number=N_{Re}= 150092.0

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

$=0.079(150092)^{-1/4}$

$=4.013\times10^{-3}$

Tube side velocity v_t = 3.656m/s

$\Delta P_T =$

$$= (4\times4.013\times10^{-3}\times14.624\times3.656^2/(2\times9.8\times0.03505)\times996\times9.8$$

= 44.54 kPa.

2) ANNULUS SIDE

$$\Delta P_A= (4fLv_a^2/2gD_H)\times\rho g$$

Annulus side Reynolds number can be calculated as

$= D_H\times$ Mass flow rate/($\mu\times$area of annulus)

$= 0.01064\times0.3668/(0.0097\times10^{-3}\times7.683\times10^{-4})$

$= 508.91\times10^3$

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

$=0.079(508910)^{-1/4}$
$=2.957\times10^{-4}$

Annulus side velocity is 138.784m/s at one end negligible at other end.
Therefore the annulus side velocity = (138.78 + 0) × 0.5
= 69.392m/s.

$\Delta P_A =$

$= (4\times2.957\times10^{-4}\times14.624\times69.392^2/(2\times9.8\times0.01064))\times3.34\times9.8$
$= 13.0728$ kPa.

Hence the pressure drops are acceptable.

Mechanical Design

Let the material of construction be 15C-8, carbon steel.

σ_T(tensile strength) = 410 N/mm^2.

σ_y(yield strength) = 220N/mm^2.

The pressure in the annulus is taken as 1 atm.

The design pressure be taken as

$$P = 1.25\times1 \text{ atm}$$
$$= 1.25\text{atm}$$

1)The total load of the bolt is given by

$$F_a = \text{Pressure} \times \text{annular cross sectional area}$$
$$= (1.25\text{-}1)\times7.683\times10^{-3}$$
$$= 19.461\text{N}$$

2)The total load capacity of the bolt is given by

$$= C(A_r)^{1.418}$$
$$= 2.29(A_r)^{1.418}$$

Therefore , stress area of the bolt $A_r = (19.461/4.52268)^{-1.418}$

$$= 4.52268\text{mm}^2.$$

3)From table 9.8, for the obtained A_r ,

bolt dia d = 3mm

pitch = o.5mm.

4) Initial tension load in a bolt

$$F_i = 2805d$$
$$= 4815\text{N}$$

5) Effect of applied load on bolt stress

The final load on the bolt = K F_a + F_i , K for asbestos gasket = 0.6

$$F = 0.6\times19.461 + 4815$$
$$= 4826.67\text{N}$$

5) Number of bolts,

An empirical rule for the number of bolts in pipe joints is given by

$$N = 0.024D_c + 2 , \quad D_c = \text{dia of cylinder } 60.32\text{mm}$$

$$N = 3.44768$$

As a standard we can provide 6 bolts

6) The maximum spacing of the bolt in any fluid tight joint

$$s \leq 6d$$

$$s = 6d$$

$$s = 18\text{mm}$$

7) The extension at one end is the same as that of the pipe.

The bolt circle diameter is given by

$$D_2 = D_1 + 3.2d$$

$$D_1 = 1.8D + 20$$

$$= 128.576\text{mm}$$

$$D_2 = 128.57 + 3.2\times3$$

$$= 138.176\text{mm}$$

8) The flange thickness is given by

$$t = 0.35D + 9 \text{ mm}$$

$$= 0.35\times60.32 + 9$$

$$= 31.12\text{mm}$$