

DESIGN OF A SIEVE PLATE DISTILLATION
COLUMN FOR THE SEPARATION OF ETHYLENE
OXIDE WATER MIXTURE

PROCESS DESIGN

Design a distillation column to separate ethylene oxide from ethylene oxide water system. In this system a small amount of ethylene and traces of acetaldehyde and formaldehyde are present. Comparing with the quantities of the ethylene oxide and water present in the system, the amount of ethylene and others are negligible. So it is considered as a binary system. The distillation column operates at a pressure of 1 atmosphere pressure (absolute). The feed entering is a mixture of 193.18 Kg moles of water, 95.133 Kg moles of ethylene oxide. The distillate is 99.9-mole % pure ethylene oxide and the residue will contain 0.1 mole % ethylene oxide.

Detailed design: Basis 1Hour operation

Total pressure = $P_T = 1.013 \times 10^5$ Pascals.

Vapour pressure of water P_W , Vapour pressure of Ethylene oxide, P_{EO} . All pressures in Pascals.

Liquid phase mole fraction of EO, $x = \frac{P_T - P_W}{P_{EO} - P_W}$

Vapour phase mole fraction of EO, $y = \alpha x / (\alpha - 1) + x$

$$(\alpha) = P_{EO}/P_W$$

TABLE: 5.1.1 VAPOUR-LIQUID DATA FOR ETHYLENE OXIDE SYSTEM

Temperature, K	P_W, Pa* 10⁻³	P_{EO}, Pa 10⁻³	(α)	(x)	(y)
283	1.054	101.32	96.12	1.0	1.0
293	2.021	113.55	56.185	0.89	0.99
303	3.69	125.18	33.9	0.80	0.99
313	6.45	172.818	26.79	0.57	0.97
323	10.83	235.63	21.57	0.402	0.94
333	17.60	314.89	17.89	0.282	0.88
343	27.60	408.39	14.80	0.193	0.78
353	42.04	524.39	12.47	0.12	0.63
363	62.42	660.00	10.573	0.065	0.424
373	90.47	830.68	9.18	0.014	0.115

Feed in moles, F = 193.18 + 95.133 + 2.47 = 290.78 Kg moles

Mole fraction of ethylene oxide in the feed, $x_F = 95.133/ 290.78$

$$= \mathbf{0.33}$$

Mole fraction of the ethylene oxide in the distillate, $x_D = \mathbf{0.99}$

Distillate amount, D = **94.65 Kg moles.**

Let W be the number of moles of residue and x_w be the mole fractions of the ethylene oxide in the residue.

By material balance:

$$F = D + W$$

$$290.78 = 94.65 + W$$

Therefore, $W = 196.66$ Kg moles.

Component material balance:

$$F \cdot x_F = D \cdot x_D + W \cdot x_w$$

$$290.78 \cdot 0.33 = 94.65 \cdot 0.99 + 196.06 \cdot x_w$$

Therefore, $x_w = 0.012$

Feed temperature = 35°C

Molecular weight of Distillate, $M_D = 0.99 \cdot 44 + 0.012 \cdot 18$

$$= 43.74$$

Molecular weight of Residue, $M_w = 0.012 \cdot 44 + 0.988 \cdot 18$

$$= 18.312$$

Molecular weight of Feed, $M_F = 26.58$

From the T-x-y diagram

Dew point = 93°C

Bubble point = 55°C

At 55°C, the specific heat values of EO and water are; 2.17 KJ/Kg K and 4.18 KJ/Kg K respectively.

Average C_{pL} value of the liquid = $(2.17 + 4.18)/2 = 3.175$ KJ/Kg K

At 93°C, the latent heat of evaporation of EO and water are; 461.45 KJ/Kg K and 2154.79 KJ/Kg K respectively.

$$\begin{aligned}\text{Enthalpy of liquid} &= H_L = C_{pL} \times M_F \times (T_L - T_F) \\ &= \mathbf{1687.83 \text{ KJ/K mole.}}\end{aligned}$$

Enthalpy of vapour = H_G

$$\begin{aligned}&= y_{EO} \times M_{EO} \{ C_{pEO} \times (T_G - T_F) + \lambda_{EO} \} + y_{H_2O} \times M_{H_2O} \{ C_{pH_2O} \times (T_G - T_F) \\ &+ \lambda_{H_2O} \} \\ &= \mathbf{37438.09 \text{ KJ/ Kg mole.}}\end{aligned}$$

The designed is considered at the temperature of the Feed. $H_F = 0$

$$\begin{aligned}(q) &= \frac{H_G - H_F}{H_G - H_L} \\ &= \frac{37538.09 - 0}{37538.09 - 1687.83} \\ &= \mathbf{1.05}\end{aligned}$$

Slope of the q-line is $q / (q-1) = 21$

The feed is sub-cooled.

From the equilibrium curve;

Intercept of the q-line = $x_D / (R_m + 1) = 0.88$

R_m is the minimum reflux ratio = $\mathbf{0.125}$

Actual reflux ratio is 1.5 times the minimum reflux ratio

$$R = 1.5 \times 0.125 = \mathbf{0.25}$$

Intercept of the original q-line = 0.792

From the equilibrium curve; the total number of theoretical trays in the distillation column = 6 (including reboiler)

Enriching section No of trays = **2**

Stripping section trays = **3**

Calculation of flow streams:

$L = L_0$, liquid flow rate.

$$\mathbf{L_0 = R \times D}$$

$$= 0.25 \times 94.65$$

$$= 23.66 \text{ Kg moles.}$$

Material balance on the enriching section:

$$G = L + B$$

G is the vapour flow rate.

$$G = 23.66 + 94.65 = 118.31 \text{ Kg moles.}$$

$$L' - L / F = q$$

$$L' = (1.05 \times 290.78) + 23.66$$

$$= 329 \text{ Kg moles}$$

$$G' - G / F = q - 1$$

$$G' = 132.849 \text{ Kg moles}$$

Consider four points in the column. The points chosen are

1. Top of the enriching section.
2. Bottom of the enriching section.
3. Top of the stripping section.
4. Bottom of the stripping section.

The different values at the four points is given below:

Table: 2

Data	Top pf enriching sec.	Bottom of enriching sec.	Top of stripping sec.	Bottom of stripping sec.
Liquid rate Kg moles/ hr	$L = 23.66$	23.66	$L' = 329$	329
Vapour rate Kg moles/ hr	$G = 118.31$	118.31	$G' = 132.849$	132.849
(x_D)	$x_D = 0.99$	$x_F = 0.33$	0.33	$x_W =$ 0.012
(y_D)	$y_D = 0.99$	0.91	0.91	18.312

Mav, liquid	43.74	26.58	26.58	18.312
Mav, vapour	43.74	41.22	41.22	6024.648
Liquid rate Kgs/ hr	1034.89	628.89	8744.82	2432.73
Vapour rate Kgs/ hr	5174.88	4876.74	5476.04	100
T°C, liquid	10.5	55	55	100
T°C, vapour	20	55	55	100
(ρ_L , Kg/m ³)	883.33	906	906	960
(ρ_G , Kg/m ³)	1.818	1.53	1.53	0.598
(L/G)* (ρ_L / ρ_G) ^{1/2}	0.009	0.005	0.06	0.061

Let assume;

Plate spacing = **600 mm**

Hole diameter $d_L =$ **5mm**

Hole pitch, triangular = **15mm**

Tray thickness = **3mm**

Total hole area/ perforated area = $A_h / A_p = 0.1$ (for triangular pitch)

Plate diameter is calculated as follows;

$$(L/G) * (\rho_L / \rho_G)^{1/2} = 0.06 \text{ (chosen from the table: 2)}$$

$$U_{nf} = C_{sbf} (\sigma/20)^{0.2} (\rho_L - \rho_G / \rho_G)^{0.5}$$

U_{nf} = vapour velocity through net area at flood, m/s.

C_{sbf} = capacity parameter = 0.28

(σ) = Liquid surface tension = 37.3 dynes/cm

Therefore, $U_{nf} = 2.7$ m/s

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

$$\text{Volumetric flow rate of vapour} = 5476.04 / 3600 \times 1.53 = 1 \text{ m}^3/\text{s}$$

A_c is the column area. A_d is the down comer area= 12% of A_c .

$$A_n = 1 / 2.7 = 0.37 \text{ m}^2$$

$$A_c = \pi/4 \times (D_c)^2$$

$$D_c = 0.59$$

$D_c = 0.75$ m. (Rounded for a standard value)

$$\begin{aligned} A_d &= 0.12 \times 0.4418 \\ &= 0.053 \text{ m}^2 \end{aligned}$$

$$\begin{aligned} \text{Active area } A_a &= A_c - 2 \times A_d \\ &= 0.3358 \text{ m}^2 \end{aligned}$$

Perforated area (A_p)

$$\begin{aligned} \text{Weir length} &= 0.75 \times D_c \\ &= 0.55 \text{ m; (0.6 m, approximated to standard value)} \end{aligned}$$

$$\text{Weir height, } L_w = 50 \text{ mm}$$

$$(\theta_c) = 2 \sin^{-1} (L_w/D_c) = 106.26^\circ$$

$$(\alpha) = 180 - \theta = 73.74^\circ$$

$$\begin{aligned} \text{Area of coming zone, } A_{cz} &= 2 \times [0.6 \times 50 \times 10^{-3}] \\ &= 0.06 \text{ m}^2 \end{aligned}$$

$$\begin{aligned} \text{Area of the periphery waste, } A_{wz} &= 2 \{ [\pi/4 D_c^2 \alpha/360] - [\pi/4 (D_c^2 - 0.1^2) \\ \alpha/360] \} &= 0.004 \text{ m}^2 \end{aligned}$$

$$\begin{aligned} A_p &= A_c - 2 A_d - A_{cz} - A_{wz} \\ &= 0.2718 \text{ m}^2 \end{aligned}$$

$$A_h/A_p = 0.1$$

$$A_h = 0.2718 \times 0.1 = 0.02718 \text{ m}^2$$

$$\begin{aligned} \text{Number of holes } N &= 0.02718 / (\pi/4 \times 5 \times 10^{-3}) \\ &= 1385 \end{aligned}$$

Number of holes per plate = 1385

Check for weeping

Head loss across the hole (dry hole)

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

U_h = linear gas velocity through risers.

$K_1 = 0$. (for sieve plate tower)

$$K_2 = 50.8 / C_v^2$$

$$U_h = 1 / 0.02718 = 36.8 \text{ m/s.}$$

$$K_2 = 90.311$$

$h_d = 206.53$ mm liquid.

Liquid crest over the weir (how)

$$h_{ow} = 44300 * (q/L_w)^{0.704}$$

$$\begin{aligned} q &= 8744.82 / 3600 * 906 \\ &= 2.68 * 10^{-3} \text{ m}^3/\text{s.} \end{aligned}$$

$h_{ow} = 7.58$ mm liquid.

Head loss due to bubble formation

$$\begin{aligned} h_\sigma &= 409 * \sigma / \rho_L * d_L \\ &= 3.36 \text{ mm} \end{aligned}$$

$h_d + h_\sigma = 209.89$ mm liquid.

$$A_h / A_a = 0.081$$

$$h_w + h_{ow} = 57.58 \text{ mm liquid}$$

$$h_d + h_{\sigma} = 15 \text{ mm liquid (from graph)}$$

Since $h_d + h_{\sigma}$ calculated is higher than that obtained from the graph.

So no weeping will occur.

Down comer flooding

$$\text{Down comer back up} = h_{dc} = h_t + h_w + h_{ow} + h_{da} + h_{hg}$$

h_{dc} = Height in down comer, mm liquid.

h_t = total pressure drop across the plate, mm liquid.

h_w = height of the weir at the plate outlet, mm liquid.

h_{ow} = height of crest over weir, mm liquid.

h_{da} = head loss due to liquid flow under down comer apron, mm liquid.

h_{hg} = liquid gradient across plate, mm liquid.

$$h_t = h_{L'} + h_d$$

$h_{L'}$ = pressure drop through the aerated liquid

$$= \beta * h_{ds}$$

$$\beta = 0.0825 \ln(q/Lw) - 0.269 \ln(F*U_h) + 1.679$$

$$F*U_h = U_h * \rho G^{0.5}$$

$$= 275.064$$

$$\beta = 0.85$$

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

$$= 57.83 \text{ mm}$$

$$h_l = 50 \text{ mm}$$

$$\mathbf{h_t = h_d + h_l}$$

$$= 256.53 \text{ mm}$$

$$\mathbf{h_{da} = 165.2 (q'/A_{da})}$$

$$h_{ap} = 32.43 \text{ mm}$$

$$\mathbf{A_{da} = h_{ap} * h_w}$$

$$= 0.01615 \text{ mm}^2$$

$$h_{da} = 4.358 \text{ mm}$$

$$h_{dc} = 256.53 + 50 + 7.58 + 4.358 + 0.5$$

$$= 319.0 \text{ mm liquid.}$$

$$\mathbf{h'_{dc} = h_{dc} / \phi_{dc}}$$

$$\phi_{dc} = 0.6$$

$$h'_{dc} = 532 \text{ mm liquid.}$$

$$\text{Plate spacing} = 600 \text{ mm}$$

Since $h'_{dc} < \text{plate spacing}$ No down comer weeping will occur.

Column efficiency

The efficiency calculations are based on the average conditions properties in each section.

Enriching section:

Average viscosity of the liquid is calculated by using Kendall- Munroe equation.

$$\mu_m^{1/3} = x_1 \mu_1^{1/3} + x_2 \mu_2^{1/3}$$

μ_1 = viscosity of EO = 0.25 cp.

μ_2 = viscosity of water = 0.857 cp

x_1 & x_2 are the corresponding mole fractions.

μ_m = 0.41 cp.

Vapour phase viscosity

$$\begin{aligned} \mu'_m &= \frac{\sum y_i M_i \mu_i^{1/2}}{\sum y_i M_i^{1/2}} \\ &= 0.0093 \text{ cp.} \end{aligned}$$

Liquid phase diffusivity, Wilke- Chang equation is used.

$$D_L = 7.4 * 10^{-8} * (\phi M_{\text{water}})^{0.5} * T / \mu_m * v^{0.6}$$

$V = 46.4$

ϕ = Association factor = 2.6

T = temperature in K.

$$D_L = 3.775 * 10^{-5} \text{ cm}^2/\text{sec.}$$

Vapour phase diffusivity

$$D_G = 10^{-3} * T^{1.75} (1/M_{\text{water}} + 1/M_{\text{EO}})^{0.5} / P * [\sum v_{\text{EO}}^{1/3} + \sum v_{\text{Water}}^{1/3}]$$

$$D_G = 0.188 \text{ cm}^2/\text{sec.}$$

$$\begin{aligned} N_{scg} &= \mu G / \rho G * D_G \\ &= 0.3 \end{aligned}$$

Same calculations are carried out for the stripping section also. The values

$$\text{are; } \mu m = 0.324 \text{ cp}$$

$$\mu' m = 0.011 \text{ cp}$$

$$DL = 5.477 * 10^{-5} \text{ cm}^2/\text{sec.}$$

$$DG = .232 \text{ cm}^2/\text{sec.}$$

$$N_{scg} = 0.468$$

Table: 5.3 Average property values.

Property	Enriching section	Stripping section
Liquid flow rate, Kg moles/hr	23.66	329
Kg/hr	831.89	7384.7
ρ_L , Kg/m ³	894.76	933
μ_L , cp	0.41	0.324
D_L , cm ² /sec.	$3.775 \cdot 10^{-5}$	$5.477 \cdot 10^{-5}$
Vapour flow rate, Kg moles/hr.	118.31	132.849
Kg/hr	5025.81	3954.385
ρ_G , Kg/m ³	1.67	1.04
μ_G , cp	0.0093	0.0113
D_g , cm ² /sec	0.188	0.232
Nscg	0.3	0.468

AIChE method is used to calculate the efficiency.

Enriching section

$$E_{og} = 1 - e^{-N_{og}}$$

E_{og} – Point efficiency, N_{og} – Number of transfer units.

$$N_{og} = 1/(1/N_g + 1/N_L)$$

N_g - gas phase transfer units, N_L - liquid phase transfer units.

$$N_g = [0.776 + 0.0045 * hw - 0.238 U_a \rho G^{0.5} + 0.0712 * w] / N_{scg}^{0.5}$$

$$U_a = 1.83 \text{ m/sec.}$$

$$q = 2.58 * 10^{-4} \text{ m}^3/\text{sec}$$

$$D_f = [D_c + L_w]/2 = 0.67$$

$$w = q / D_f = 3.85 * 10^{-4} \text{ m}^3/\text{sec-m}$$

$$N_g = 0.79$$

$$N_L = K_L a * \theta_L$$

$$K_L a = (3.875 * 10^8 * D_L)^{0.5} (0.40 * U_a * \rho G^{0.5} + 0.17)$$

$$= 1.63 \text{ sec}^{-1}$$

$$\theta_L = h_L * A_a / 1000 * q$$

$$= 87.209$$

$$N_L = 142.15$$

Slope of the equilibrium curve are;

Top of the enriching section, $m_{top} = 0.01$

Bottom of the enriching section, $m_{\text{bottom}} = 0.455$

G_m is the gas flow rate, L_m is the gas flow rate.

$$G_m/L_m = 5$$

$$\begin{aligned}\lambda_{\text{top}} &= m_{\text{top}} * G_m / L_m \\ &= 0.05\end{aligned}$$

$$\begin{aligned}\lambda_{\text{bottom}} &= m_{\text{bottom}} * G_m / L_m \\ &= 2.275\end{aligned}$$

$$\lambda_{\text{avg}} = 1.165$$

$$N_{og} = 0.78$$

$$E_{og} = 1 - e^{-0.78} = \mathbf{0.544}$$

$$\text{Pectlet No, } N_{pe} = Z_L^2 / D_E * \theta_L$$

D_E = eddy diffusion coefficient

$$\begin{aligned}&= 6.675 * 10^{-3} * U_a^{1.44} + 0.922 * 10^{-4} * h_l - 0.00562 \\ &= 0.0177\end{aligned}$$

$$\begin{aligned}Z_L &= 2 * [D_c / 2 * \cos(\theta_c / 2)] \\ &= 0.45 \text{ m}\end{aligned}$$

$$N_{pe} = 0.131$$

$$\lambda_{\text{avg}} * E_{og} = 0.633$$

$$E_{mv} / E_{og} = 1.02$$

E_{mv} is the Murphree vapor efficiency.

$$\mathbf{Emv = 0.554}$$

$$\mathbf{Ea/Emv = 1/ [1+ Emv (\psi/(1-\psi))]}$$

Ea is the Murphree vapour efficiency corrected for recycle of liquid entrainment.

$$\psi = 0.09$$

$$\mathbf{Ea = 0.525}$$

$$\mathbf{Eoc = \log [1+ Ea*(\lambda_{avg} -1)]/ \log [\lambda_{avg}]}$$

Eoc is the overall column efficiency.

$$\mathbf{Eoc = 0.543}$$

$$\mathbf{Eoc = N_T/N_A}$$

N_A – Actual number of plates.

N_T – theoretical number of plates.

Therefore, Actual number of plates in the enriching section;

$$\mathbf{N_A = 2/ 0.543 = 4 \text{ plates.}}$$

$$\mathbf{\text{Height of enriching section} = 4 * 600 = 2.4 \text{ meters.}}$$

Stripping section

$$E_{og} = 1 - e^{-N_{og}}$$

E_{og} – Point efficiency, N_{og} – Number of transfer units.

$$N_{og} = 1/(1/N_g + 1/N_L)$$

N_g - gas phase transfer units, N_L - liquid phase transfer units.

$$N_g = [0.776 + 0.0045 * hw - 0.238 U_a \rho G^{0.5} + 0.0712 * w] / N_{scg}^{0.5}$$

$$U_a = 2.347 \text{ m/sec.}$$

$$q = 2.19 * 10^{-3} \text{ m}^3/\text{sec}$$

$$D_f = [D_c + L_w]/2 = 0.67$$

$$w = q / D_f = 3.26 * 10^{-3} \text{ m}^3/\text{sec-m}$$

$$N_g = 0.43$$

$$N_L = K_L a * \theta_L$$

$$\begin{aligned} K_L a &= (3.875 * 10^8 * D_L)^{0.5} (0.40 * U_a * \rho G^{0.5} + 0.17) \\ &= 1.642 \text{ sec}^{-1} \end{aligned}$$

$$\theta_L = hL * A_a / 1000 * q$$

$$= 10.27$$

$$N_L = 16.86$$

Slope of the equilibrium curve are;

Top of the enriching section, $m_{top} = 0.455$

Bottom of the enriching section, $m_{bottom} = 14$

Gm is the gas flow rate, Lm is the gas flow rate.

$$Gm/Lm = 5$$

$$\lambda_{top} = m_{top} * Gm / Lm$$

$$= 0.03276$$

$$\lambda_{bottom} = m_{bottom} * Gm / Lm$$

$$= 1.008$$

$$\lambda_{avg} = 1.008$$

$$Nog = 0.419$$

$$\mathbf{Eog = 1 - e^{-0.78} = 0.3421}$$

$$\text{Pectlet No, } Npe = Z_L^2 / D_E * \theta_L$$

DE = eddy diffusion coefficient

$$= 6.675 * 10^{-3} * Ua^{1.44} + 0.922 * 10^{-4} * hl - 0.00562$$

$$= 0.022$$

$$Z_L = 2 * [Dc/2 * \cos(\theta_C/2)]$$

$$= 0.45 \text{ m}$$

$$Npe = 0.105$$

$$\lambda_{avg} * Eog = 0.1180$$

$$Emv/Eog = 1.02$$

Emv is the Murphree vapor efficiency.

$$\mathbf{Emv = 0.3525}$$

$$E_a/E_{mv} = 1 / [1 + E_{mv} (\psi/(1-\psi))] = 0.966$$

E_a is the Murphree vapour efficiency corrected for recycle of liquid entrainment.

$$\psi = 0.09$$

$$E_a = 0.341$$

$$E_{oc} = \log [1 + E_a(\lambda_{avg} - 1)] / \log [\lambda_{avg}]$$

E_{oc} is the overall column efficiency.

$$E_{oc} = 0.341$$

$$E_{oc} = N_T/N_A$$

N_A – Actual number of plates.

N_T – theoretical number of plates.

Therefore, Actual number of plates in the stripping section;

$$N_A = 3 / 0.341 = 9 \text{ plates.}$$

Height of enriching section = 9 * 600 = 5.4 meters.

Total height of the tower = 2.4 + 5.4 = 7.8; (8 meters approximated)

SUMMARY OF THE PROCESS DESIGN OF THE

DISTILLATION COLUMN

1. Number of Plates in enriching section = 4
2. Number of plates in stripping section = 9
3. Feed plate = 6th plate
4. Plate spacing = 600 mm
5. Height of the column = 9 meters
6. Diameter of the column = 0.75 meters
7. Hole diameter = 5 mm
8. Hole pitch, triangular = 15 mm
9. Tray thickness = 3 mm
10. Number of holes = 1385
11. Weir length = 60 cm
12. Weir height = 5cm
13. Flooding permitted = 80%
14. Down comer back up (with aeration) = 532 mm liquid
15. Down comer back up (without aeration) = 319.0 mm liquid
16. Enriching efficiency = 54.3%
17. Stripping section efficiency = 34.1%

MECHANICAL DESIGN OF THE DISTILLATION

COLUMN

Inner diameter of the column, $D_i = 750 \text{ MM}$

Operating pressure of the distillation column = 1 atmosphere.

$$= 101.3 \text{ K N/m}^2$$

Design pressure = 10 % more than the operating pressure.

Design pressure, $P_i = 1.1 * 101.3 \text{ K N/m}^2$

$$= \mathbf{0.113 \text{ N/mm}^2}$$

Design temperature = $\mathbf{100^\circ \text{ C}}$

Material of construction of the shell and the covers is Stainless steel

18Cr/8Ni Ti stabilized.

Design stress of the material at $100^\circ\text{C} = \mathbf{150 \text{ N/mm}^2}$

Design of the covers to the column:

Standard ellipsoidal head with major axis: minor axis = 2:1.

The minimum thickness required is given by the formula

$$\text{Thickness, } e = \frac{P_i * D_i}{2 * J * f - 0.2 * P_i} + C$$

$$P_i = \text{Design pressure} = 0.113 \text{ N/mm}^2$$

$$D_i = \text{Inner diameter of the column} = 750 \text{ mm}$$

$$J = \text{the weld joint efficiency} = 0.85$$

The weld joint is double welded butt joint and radio graphed.

F = the design stress of the material of construction.

C = corrosion allowance given to the material = 2mm (generally)

$$\begin{aligned} \text{Therefore, } e &= 0.113 * 0.75 / [2 * 0.85 * 150 - 0.2 * 0.113] \\ &= \mathbf{2.3 \text{ mm.}} \end{aligned}$$

But minimum thickness required for construction is 6 mm. So the minimum required thickness of the cover is taken as **6 mm**.

Stress analysis of the vessel

Stress analysis of the material of construction and the column are carried with the assumptions sated in the require location and the specification of the material of construction.

Material construction = Stainless steel 18Cr/8Ni-Ti stabilized.

Design stress of the material = 150 N/mm²

Density of the material = 7830 Kg/m³

Young's modulus = 200000 N/mm²

Design pressure = 0.113 N/mm²

Corrosion allowance = 2 mm

Inner diameter of the column = 750 mm

Height of the column between the two tangent lines = 9000 mm

Shell is butt welded with weld joint efficiency = 0.85

Top disengaging section = 1000 meters

Bottom separation section = 2000 meters

Skirt height = 3000 mm

No of trays = 13

Tray spacing = 600 mm

Tray support rings = 60 x 60 x 100 mm

Insulation = 50 mm thick

Mineral wool density = 130 kg/m³

Maximum wind velocity = 160 Km/hr

Seismic forces = Neglected

Tray loading excluding liquid = 1 KN/m² of plate area

Tray loading including liquid = 1.2 KN/m² of plate area

Calculation of minimum thickness of the shell.

Thickness of the shell, $t_s = \frac{P_i \cdot D_i}{2 \cdot J \cdot f - P_i} + C$

$$= 0.113 \cdot 0.75 / [2 \cdot 150 \cdot 0.85 - 0.113]$$

$$= 2.5 \text{ mm}$$

But the minimum thickness of the material used for construction of the shell is 6 mm. So the minimum thickness = 6 mm.

For stability of the shell the column is divided into five parts and thickness is increased from top to bottom of the shell, as 6 mm, 8 mm, 10 mm, 12 mm & 14 mm respectively.

For all other calculations the average thickness is used. The average thickness = $t_s = 10\text{mm}$

Stress analysis

Axial stress due to pressure = $f_{ap} = \frac{P_i \cdot D_i}{4 \cdot (t_s - C)}$

$$= 0.113 \cdot 750 / [4 \cdot (10 - 2)]$$

$$= \mathbf{2.64 \text{ N/mm}^2}$$

Stress due to dead weight of the vessel:

Stress due to the dead weight of the vessel:

$$\text{Dead weight of the vessel} = \mathbf{W_v = C_v \cdot \pi \cdot \rho_m \cdot D_m \cdot g \cdot (H_v + 0.8 \cdot D_m) \cdot t_s \cdot 10^{-3}}$$

W_v = total weight of the shell, excluding internal fittings, such as plates.

C_v = a factor to account for the weight of nozzles, man ways, internal supports etc.

$$= 1.15 \text{ for distillation columns.}$$

H_v = Height of the column between the tangent lines.

$$\text{Acceleration due to gravity} = g = 9.81 \text{ m/s}^2$$

Thickness of the wall = t_s .

ρ_m = density of the vessel material, Kg/m^3

D_m = mean diameter of the vessel

$$= (D_i + t_s * 10^{-3}), \text{ m}$$

For a steel vessel; $W_v = 240 * C_v * D_m * (H_v + 0.8 * D_m)$

$H_v = 9000 \text{ mm}$, $C_v = 1.15$, $t_s = 10 \text{ mm}$, $D_m = 760 \text{ mm}$

$$W_v = 240 * 1.15 * 0.76 * (9 + 0.8 * 0.76) * 10$$

$$= 20153.74 \text{ N}$$

Stress due to dead weight of the vessels, $f_d = 131723.38 \text{ N/m}^2$.

Stress due to the weight of the plates

Plate area, $a_p = \pi/4 * D_i^2$

$$= 0.411 \text{ m}^2$$

Weight of the plate = $\rho_m * t * a_p$; t is the thickness of the plate.

$$= 101.5 \text{ N}$$

Total weight of plates = $101.5 * 13 = 1321.1 \text{ N}$

Stress due to the weight of plates, $f_p = 2996 \text{ N/m}^2$

Stress due to weight of insulation

The insulating material is mineral wool with density = 130 Kg/m^3

Approximate volume of insulation = $\pi * 9 * 0.75 * 50 * 10^{-3}$

Weight of insulation = $1.06 * 130 * 9.81$

$$= 1351.8 \text{ N}$$

The weight of the insulation is doubled to account the extra fittings.

Stress due to insulation + extra fittings, $f_{ins} = 2550.56 \text{ N/m}^2$

Total dead weight = $20153.74 + 1321.1 + 2703.6$

$$= 24178.44 \text{ N}$$

Total stress due to dead weights = 0.136 N/mm^2

Wind loading:

The dynamic pressure is taken as 1280 N/m^2

Mean diameter including thickness and insulation = 870 mm .

Loading (per linear meter) = 1113.6 N/m .

Bending moment at bottom tangent line = $M_x = 1113.6 * 9^2/2$

$$= 45100.8 \text{ N-m}$$

Longitudinal and circumferential stress due to pressure:

At bottom tangent line, the pressure stresses are given by:

$\sigma_L = \frac{P_i * D_i}{4 * t}$; t is the thickness at the bottom.

$$= 0.113 * 750 / 4 * 14$$

$$= 1.513 \text{ N/mm}^2$$

$\sigma_h = \frac{P_i * D_i}{2 * t}$

$$= 3.026 \text{ N/mm}^2$$

Stress due to dead weight, $\sigma_w = \frac{W_v}{\pi * (D_i + t) * t}$

$$= 0.71 \text{ N/mm}^2$$

$D_o = 778 \text{ mm}$ = outer diameter of the column

$$I_v = \pi * (778^4 - 750^4) / 64$$

$$= 2.45 * 10^9 \text{ m}^4$$

$$\sigma_b = Mx / I_v * (Di/2 + t)$$

$$= 7.16 \text{ N/mm}^2$$

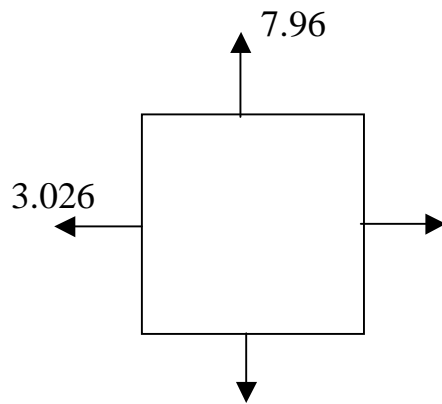
Resultant longitudinal stress is given by;

$$\sigma_z = \sigma_L + \sigma_w \pm \sigma_b$$

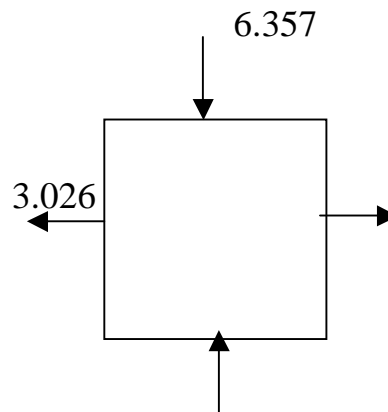
σ_w is compressive therefore it is negative.

$$\sigma_z \text{ (up-wind)} = 1.513 - 0.71 + 7.16 = \mathbf{7.96 \text{ N/mm}^2}$$

$$\sigma_z \text{ (down-wind)} = 1.513 - 0.71 - 7.16 = \mathbf{-6.357 \text{ N/mm}^2}$$



(Up-wind)



(Down-wind)

$$\text{Critical buckling stress} = \sigma_c = [E/\sqrt{3} * (1 - \nu^2)] * t / Rp$$

$$= \mathbf{321 \text{ N/mm}^2}$$

The maximum compressive stress will occur when the vessel is not under pressure.

Design of the skirt- support for the vessel.

A skirt support consists of a cylindrical or conical shell welded to the base of the vessel. A flange at the bottom of the skirt transmits the load to the foundations. Skirt support is recommended for vertical vessels, as they do not impose concentrated loads on the shell; they are particularly suitable for use with tall columns subject to wind loading.

The skirt thickness must be sufficient to withstand the dead-weight loads and bending moments imposed on it by the vessel; it will not be under the vessel pressure..

The resultant stresses in the skirt will be;

$$\sigma_s \text{ (tensile)} = \sigma_{bs} - \sigma_{ws}$$

$$\text{And } \sigma_s \text{ (compressive)} = \sigma_{bs} - \sigma_{ws}$$

$$\sigma_{bs} = 4 * Ms / [\pi * (Ds + t) * t * Ds]$$

$$\sigma_{ws} = W / [\pi * (Ds + t) * t]$$

where, Ms = maximum bending moment, evaluated at the base of the skirt,

(due to wind seismic and eccentric loads)

W = total weight of the contents of the vessels.

Ds = inside diameter of the skirt, at the base.

(t) = skirt thickness, first assumes it to be **14 mm** .

The skirt thickness should be such that under the worst combination of wind and dead-weight loading the following design criteria are not exceeded:

σ_s (tensile) not greater than $f_s J \sin\theta$

σ_s (compressive) not greater than $0.125 \cdot E \cdot (t/D_s) \sin\theta$

Where; θ is the angle of skirt, f_s maximum allowable stress, J weld joint efficiency.

The maximum dead weight will occur when the vessel is full of water.

$$\text{Approximate weight} = \pi \cdot 0.75^2 \cdot 9 \cdot 1000 \cdot 9.81 / 4 = 39005.3 \text{ N}$$

$$\text{Weight of the vessel} = 24178.44 \text{ N}$$

$$\text{Total weight} = 63183.74 \text{ N}$$

$$\text{Bending moment} = 11113.6 \text{ N/m} \cdot 12^2 / 2 = 801792 \text{ N-m}$$

$$\begin{aligned} \sigma_{bs} &= 4 \cdot 801792000 / [\pi \cdot (87+14) \cdot 14 \cdot 878] \\ &= 93.10 \text{ N/mm}^2 \end{aligned}$$

$$\begin{aligned} \sigma_{ws} \text{ (testing)} &= 63183.74 / (\pi \cdot (878 + 14) \cdot 14) \\ &= 1.6 \text{ N/mm}^2 \end{aligned}$$

$$\begin{aligned} \sigma_{ws} \text{ (operating)} &= 39005.3 / (\pi \cdot (878 + 14) \cdot 14) \\ &= 1 \text{ N/mm}^2 \end{aligned}$$

$$\text{Maximum, } \sigma_s \text{ (compressive)} = 93.10 + 1.6 = 94.7 \text{ N/mm}^2$$

$$\text{Maximum, } \sigma_s \text{ (tensile)} = 93.10 - 1 = 92.10 \text{ N/mm}^2$$

$$J \cdot f_s \cdot \sin\theta = 125.56$$

σ_s (tensile) not greater than $f_s J \sin\theta$

$$0.125 * E * (t/D_s) * \sin\theta = 392.58$$

σ_s (compressive) not greater than $0.125 * E * (t/D_s) \sin\theta$

Both of the above said conditions are satisfied so the thickness of the skirt = 14 mm, allowing 2 mm for corrosion allowance.

The thickness of the skirt = 16 mm

Nozzle design:

Nozzles are designed for accommodate a liquid velocity of 1m/sec.
And a vaopur velocity of 20m/sec.

Feed nozzle:

The feed is entering in the liquid sate and the nozzle is to be designed to accommodate the liquid velocity.

Feed composition

Ethylene oxide (EO) = 4185.72 Kg/hr

Water = 3477.24 Kg/hr

Ethylene = 69.16 Kg/hr

Component	Mole fraction	Density
Ethylene oxide	0.33	851.61 Kg/m ³
Ethylene	0.01	212.1 Kg/m ³
Water	0.664	993.719 Kg/m ³

Average density = $\sum x \cdot \rho = 965 \text{ Kg/m}^3$

Volumetric flow rate = $7766/965 = 0.002 \text{ m}^3/\text{sec}$

Velocity of the fluid through the nozzle = **1m/sec**

Therefore, $\pi \cdot D_i^2 / 4 \cdot V = 0.002$

D_i is the diameter of the nozzle = 50.4 mm

Diameter of the Bottom nozzle = 36mm

Diameter of the reflux nozzle = 37mm