Mass Transfer Operations

Lec 9: Flash Distillation

Content

Introduction, Single-Stage Equilibrium Contact, Flash Distillation , Graphical Solution , Design of a Flash Drum

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Content

- Introduction,
- Single-Stage Equilibrium Contact,
- Equilibrium or Flash Distillation
- Graphical Solution
- Design of a Flash Drum

Introduction

- The unit operation distillation is a method used to separate the components of a liquid solution, which depends upon the distribution of these various components between a vapor and a liquid phase.
- All components are present in both phases.
- The vapor phase is created from the liquid phase by vaporization at the boiling point.
- The basic requirement for the separation of the components by distillation is that the composition of the vapor be different from the composition of the liquid with which it is in equilibrium at the boiling point of the liquid.
- Distillation is concerned with solutions where all components are appreciably volatile, such as in ammonia-water or ethanol-water solutions, where both components will be in the vapor phase.

Introduction Contd

- In evaporation, however, of a solution of salt and water, the water is vaporized but the salt is not.
- The process of absorption differs from distillation in that one of the components in absorption is essentially insoluble in the liquid phase. An example is absorption of ammonia from air by water, where air is insoluble in the water-ammonia solution.
- Distillation can be carried out by either of two main methods in practice:

i. The first method of distillation involves the production of a vapor by boiling the liquid mixture to be separated in a single stage and recovering and condensing the vapors.
   - No liquid is allowed to return to the single-stage still to contact the rising vapors.
   - There are three important types of distillation that occur in a single stage or still and that do not involve rectification: Equilibrium or flash distillation, simple batch or differential distillation, and simple steam distillation.

Introduction Contd

ii. The second method of distillation involves the returning of a portion of the condensate to the still.

- The vapors rise through a series of stages or trays, and part of the condensate flows downward through the series of stages or trays counter currently to the vapors.
- This second method is called *fractional distillation, distillation with reflux,* or *rectification.*

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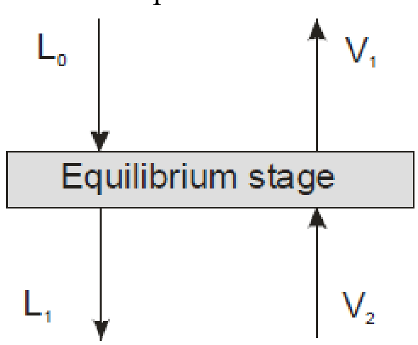
Single-Stage Equilibrium Contact

- A single-stage process can be defined as one in which two different phases are brought into intimate contact with each other and 'then are separated.
- During the time of contact, intimate mixing occurs and the various components diffuse and redistribute themselves between the two phases.
- If mixing time is long enough, the components are essentially at equilibrium in the two phases after separation and the process is considered a single equilibrium stage.



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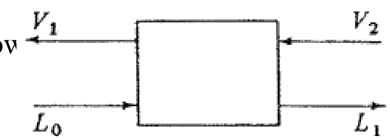
Single-Stage Equilibrium Contact

- If a vapor stream V_2 is in contact with a liquid stream L_0. The two streams V_1 and L_1 leaving the equilibrium stage is in equilibrium
- For a binary mixture of A and B, if sensible heat effects are small and the latent heats of both compounds are the same (Constant Molar Overflow), then
  - When 1 mole of A condenses, 1 mole of B must vaporize.
  - Hence, the total molar flow V_1 will equal the total molar flow V_2.
  - The total molar flow L_1 will equal the total molar flow L_0.
  - When CMO is valid, the compositions in streams V_1 and L_1 can be solved from only the material balance and the equilibrium relations.
  - The energy balance is not required since it is satisfied when the material balance is satisfied



Single-Stage Equilibrium Contact

- The overall material (or mole) balance for the system

$$V_2 + L_0 = V_1 + L_1$$

- Species balance (for species *i*)

$$V_2 y_{A2} + x_{A0} L_0 = y_{A1} V_1 + x_{A1} L_1$$

- The composition of the streams leaving the process (y_{Ai} and x_{Ai}) are related by the ***equilibrium distribution relation.***

$$y_i = \psi_1 (x_i)$$

Example

A vapor at the dew point and 200 kPa containing a mole fraction of 0.40 benzene (1) and 0.60 toluene (2) and 100 kmol total is brought into contact with 110 kmol of a liquid at the boiling point containing a mole fraction of 0.30 benzene and 0.70 toluene. The two streams are contacted in a single stage, and the outlet streams leave in equilibrium with each other. Assume constant molar overflow, calculate the amounts and compositions of the exit streams.

Data: Vapor pressure, P^{sat}, data: $\ln P^{sat} = A - B/(T + C)$, where P^{sat} is in kPa and T is in K.

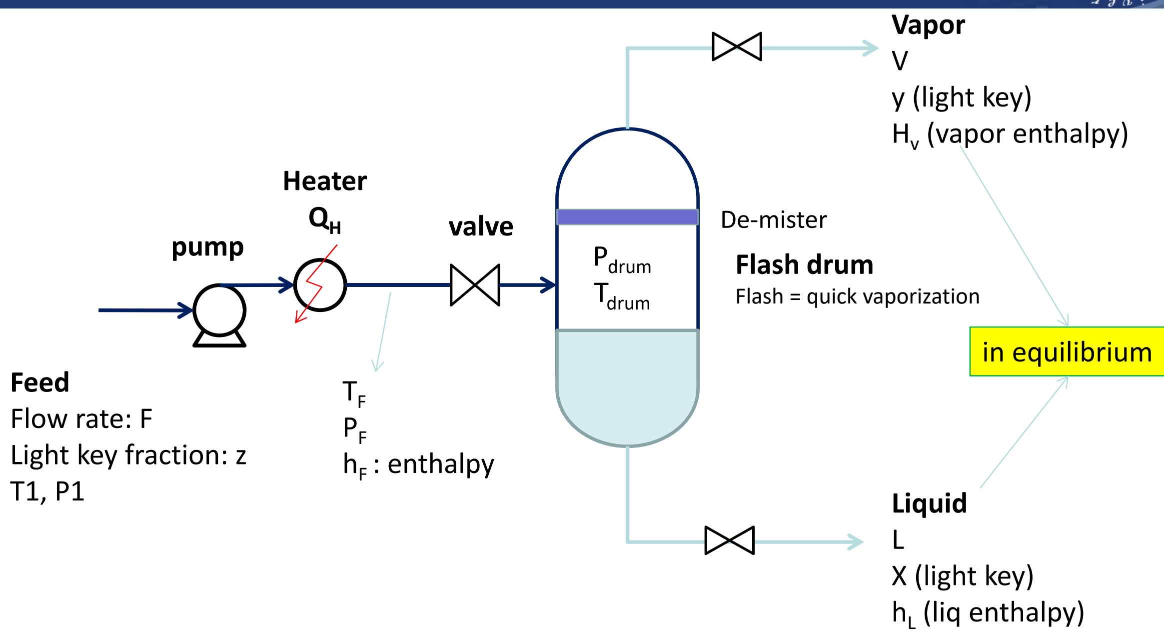
Compound	A	B	C
Benzene (1)	14.1603	2948.78	− 44.5633
Toluene (2)	14.2515	3242.38	− 47.1806

Example Contd

Equilibrium or Flash Distillation

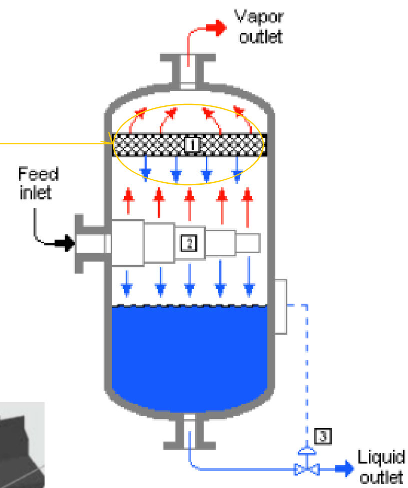
- Flash distillation can be considered one of the simplest separation processes
- In this process, a pressurized *feed stream*, which is in *liquid phase*, is passed through a throttling valve/nozzle or an expansion valve/nozzle (sometimes, the feed stream may be passed through a heater before being passed through the valve/nozzle, in order to pre-heat the feed) connected to a tank or drum, which is called a *"flash"* tank or drum.
- After being passed through the valve/nozzle, the feed enters the tank/drum, whose pressure is low; thus, there is a substantial pressure drop in the feed stream, causing the feed to *partially* vaporize.
- The vapor is allowed to come to equilibrium with the liquid, and the vapor and liquid phases are then separated

Flash Distillation System



$P_{drum} < P_F$ so the more volatile component evaporates quickly (flashes) in the drum

Flash Distillation System



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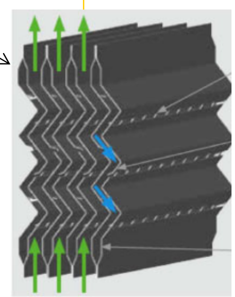


Flash Distillation System

Installed Units

Equilibrium or Flash Distillation

- The fraction that becomes *vapour goes up* to and is *taken off* at the ***top*** of the tank/drum
- The remaining *liquid* part *goes down* to and is *withdrawn* at the ***bottom*** of the tank/drum

- The overall material (or mole) balance for the system

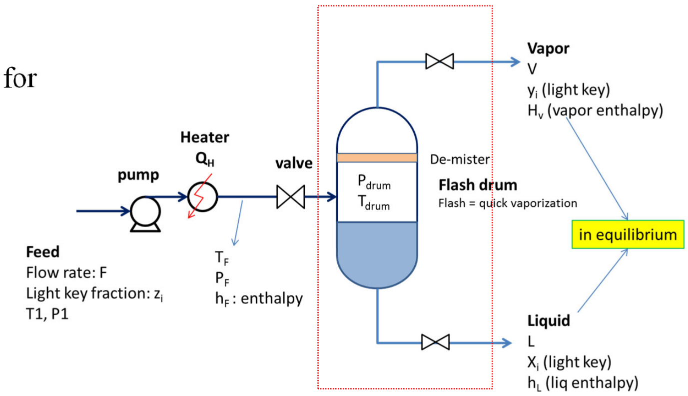
$$F = L + V$$

- Species balance (for species *i*)

$$z_i F = x_i L + y_i V$$

- The energy balance for this system is

$$h_F F + Q_{Flash} = h_L L + h_v V$$

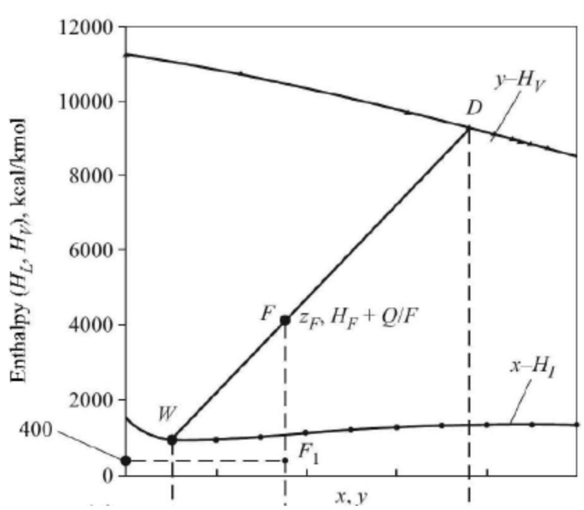


$$y_i = \psi_1 (x_i, P_{drum})$$

$$T_{drum} = \psi_2 (x_i, P_{drum})$$

Equilibrium or Flash Distillation

$$-\frac{L}{V} = \frac{y_i - z_i}{x_i - z_i} = \frac{H_v - (H_F + Q_{flash}/F)}{h_L - (H_F + Q_{flash}/F)}$$



Equilibrium or Flash Distillation

- As the flash distillation is usually operated adiabatically, then

$$Q_{Flash} = 0$$

$$h_F F = h_L L + h_v V$$

$$\Rightarrow \quad -\frac{L}{V} = \frac{y_i - z_i}{x_i - z_i} = \frac{H_v - H_F}{h_L - H_F}$$

Equilibrium or Flash Distillation

- To determine the amount of Q_H (or to determine the size of the heater), an energy balance around the heater is performed as follows

$$h_1 F + Q_H = h_F F$$

- If the feed contains only 2 components (*i.e.* the feed is a *binary* mixture),
  - Before being fed into the tank, the feed contains only one phase (*i.e.* liquid phase); thus the degree of freedom (F) is

$$F = C - P + 2$$

$$= 2 - 1 + 2 = 3$$

where p is the number of phases, C is the number of components

Equilibrium or Flash Distillation

- This means that before the feed is being fed into the tank, it requires 3 variables (*e.g.*, z, T, and P) to identify other properties of the system (*e.g.*, h, s)
  - After being fed into the tank, the feed is divided into 2 phases (i.e. liquid and vapour phases), which results in the degree of freedom of

$$F = C - P + 2$$
$$= 2 - 2 + 2 = 2$$

- It requires only 2 variables $\left(e.g.,\ x_i \text{ and } P_{drum} \text{ or } y_i \text{ and } T_{drum}\right)$ to obtain exact values of other properties

Binary Flash Distillation

- Let's consider the flash distillation system; the material balances of the system within the dashed boundary can be performed as follows

Overall balance $$F = L + V$$

Species balance $$z_i F = x_i L + y_i V$$

Re-arranging
$$y_i = \underbrace{-\frac{L}{V}}_{\text{slope}} x_i + \underbrace{\frac{F}{V} z_i}_{\text{intercept}} \qquad (1)$$

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Binary Flash Distillation

but $L = F - V$ → $y_i = \dfrac{V-F}{V} x_i + \dfrac{F}{V} z_i$

define

$\dfrac{V}{F} = f$: the *fraction* of the feed that *vaporises*

$\dfrac{L}{F} = q$: the *fraction* of the feed that *remains liquid*

f : depends on the enthalpy of the liquid feed, the enthalpies of the vapor and liquid leaving the separator $0 < f < 1$

Then $\dfrac{L}{V} = \dfrac{F-V}{V} = \dfrac{1-\dfrac{V}{F}}{\dfrac{V}{F}}$ or $\dfrac{L}{V} = \dfrac{1-f}{f}$

Binary Flash Distillation

→ $y_i = \underbrace{\dfrac{f-1}{f}}_{\text{slope}} x_i + \underbrace{\dfrac{1}{f} z_i}_{\text{intercept}}$ (2)

$0 < f < 1$ → Slope negative

- Alternatively, $V = F - L$

Then $\dfrac{L}{V} = \dfrac{L}{F-L} = \dfrac{\dfrac{L}{F}}{1-\dfrac{L}{F}}$ Or $\dfrac{L}{V} = \dfrac{q}{1-q}$

Also, $\dfrac{F}{V} = \dfrac{F}{F-L} = \dfrac{1}{1-\dfrac{L}{F}}$ Or $\dfrac{F}{V} = \dfrac{1}{1-q}$

Binary Flash Distillation

$$y_i = \underbrace{\frac{1}{q-1}}_{\text{slope}} x_i + \underbrace{\frac{1}{1-q} z_i}_{\text{intercept}} \qquad (3)$$

- Eqs. (1), (2), and (3) are, *equivalent* to one another, and they are the **"Material Balance Operating Line Equations"** for the flash drum.

- The intersection of the equilibrium curve and the operating line is the solution (answer) of the material balances (this plot is called **"McCabe-Thiele diagram"**) for the flash distillation,

- The *intersection* of the *equilibrium line* (curve) and the *operating line* is *the point* where the *system* (*i.e.* the flash tank) *reaches* the *equilibrium.*

Binary Flash Distillation

When $x_i = y_i$

Eqs. (1), becomes $$y_i = -\frac{L}{V} y_i + \frac{F}{V} z_i$$

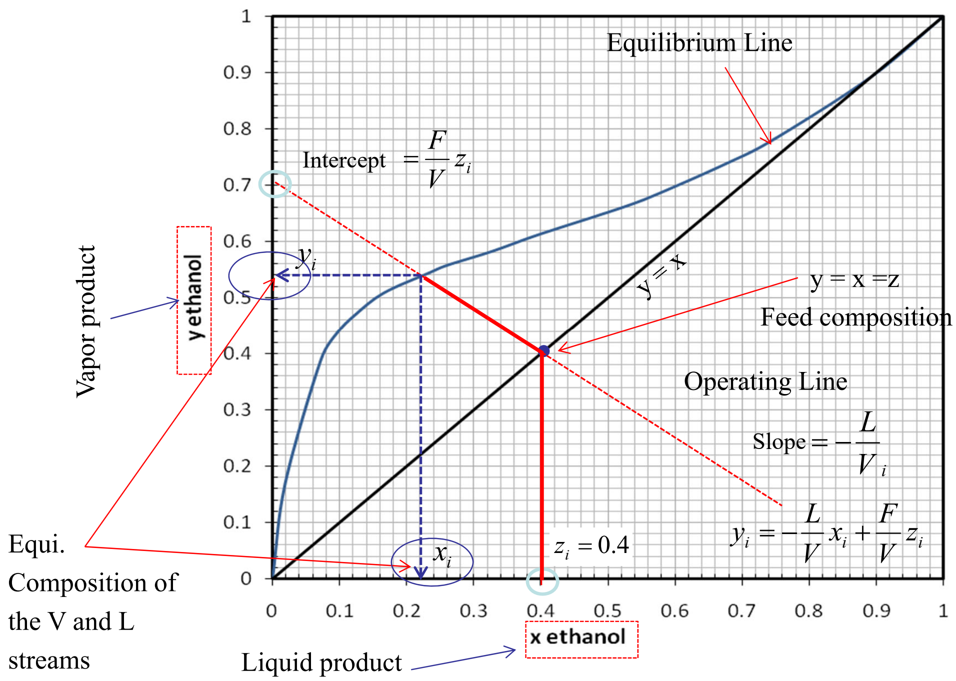
re-arrange to $$(1+\frac{L}{V}) y_i = \frac{F}{V} z_i \quad \text{Or} \quad \frac{V+L}{V} y_i = \frac{F}{V} z_i$$

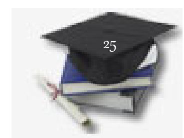
- However, since $V + L = F$ then $\frac{F}{V} y_i = \frac{F}{V} z_i$

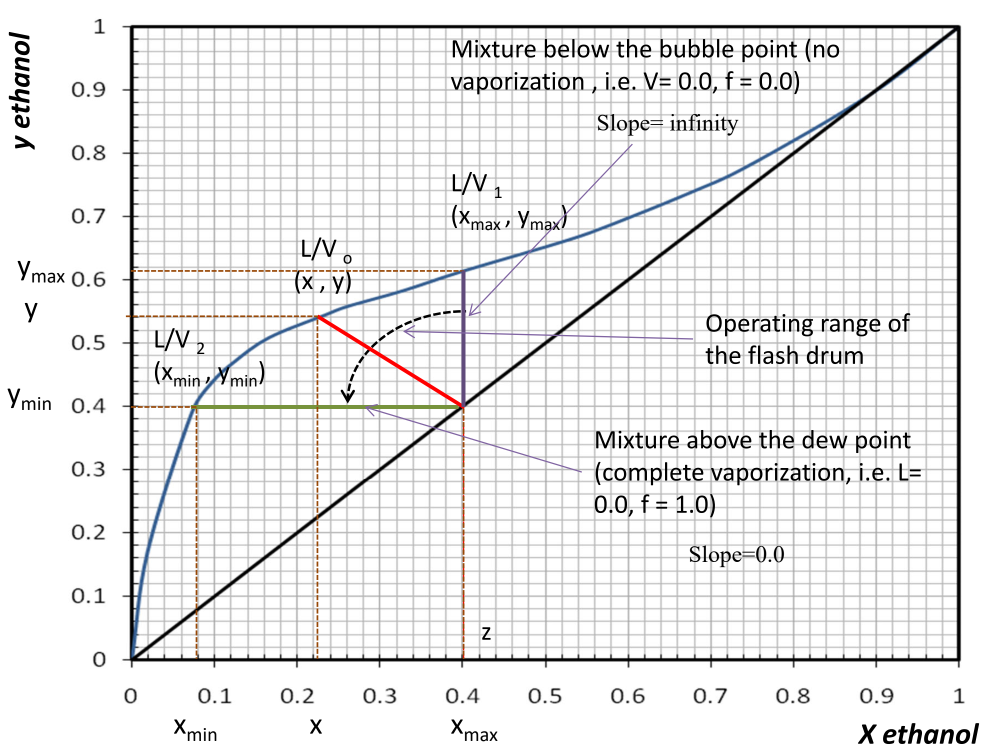
$$\Rightarrow x_i = y_i = z_i$$

- This means (or implies) that the *intersection* of the *operating line* and the $x_i = y_i$ *line* is, in fact, the ***feed composition***

The Graphical Solution for a Flash Distillation







Example

We are separating a mixture of methanol and water in a flash drum at 1 atm pressure. Equilibrium data are shown in the figure.

a) Feed is 50 mol% methanol, and 40% of the feed is vaporized. What are the vapor and liquid mole fractions and flow rates? Feed rate is 100 kg moles/hr.

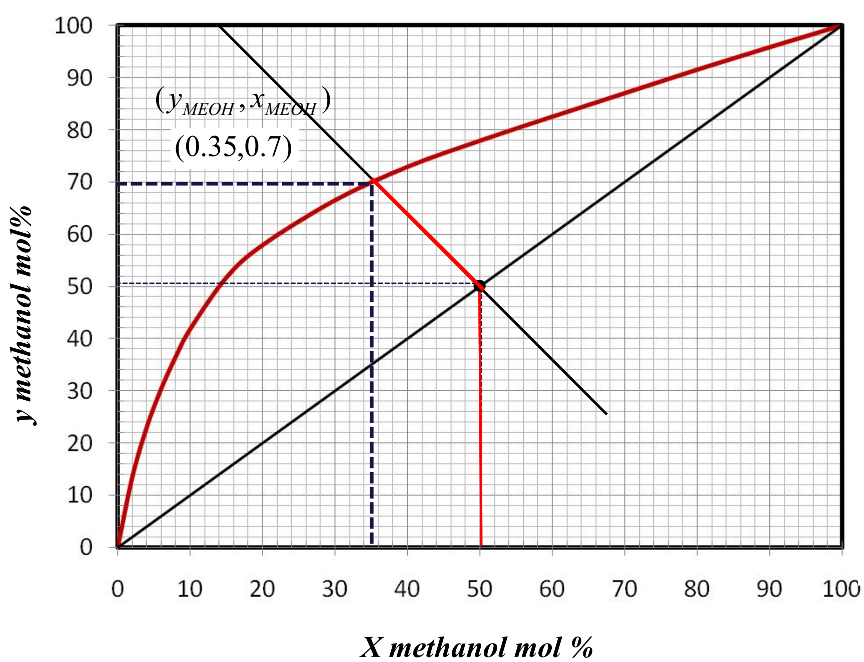
b) Repeat part A for a feed rate of 1500 kg moles/hr.

c) If the feed is 30% methanol and we desire a liquid product that is 20 mol% methanol, what V/F must be used? For a feed rate of 1,000 Ibmoles/hr, find product flow rates and compositions.

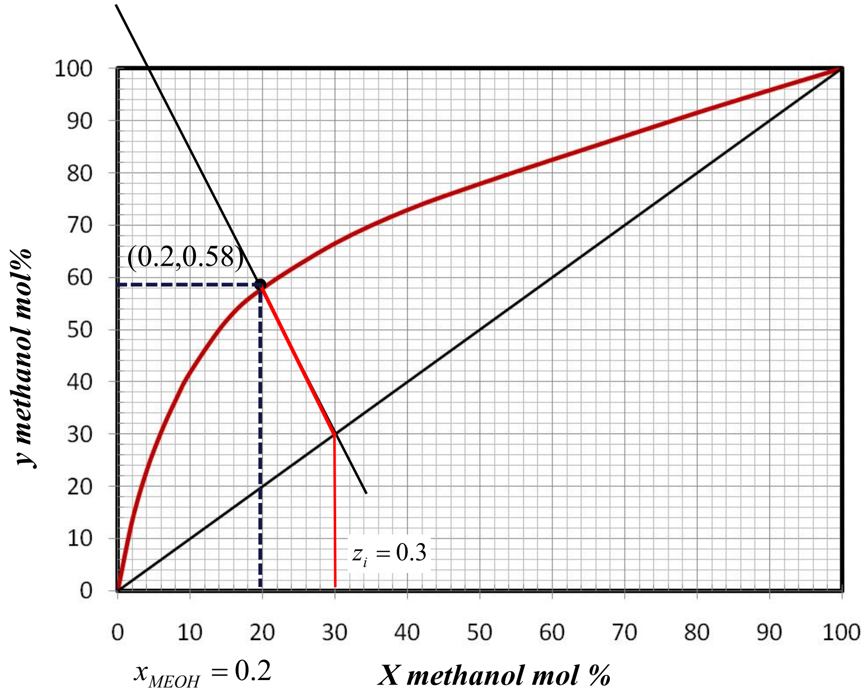
d) We are operating the flash drum so the that the liquid mole fraction is 45% methanol. L = 1500 kg moles/hr, and V/F = 0.2. What must the flow rate and composition of the feed be?

e) Find the dimensions of a vertical flash drum for part C.

Example Contd



Example Contd



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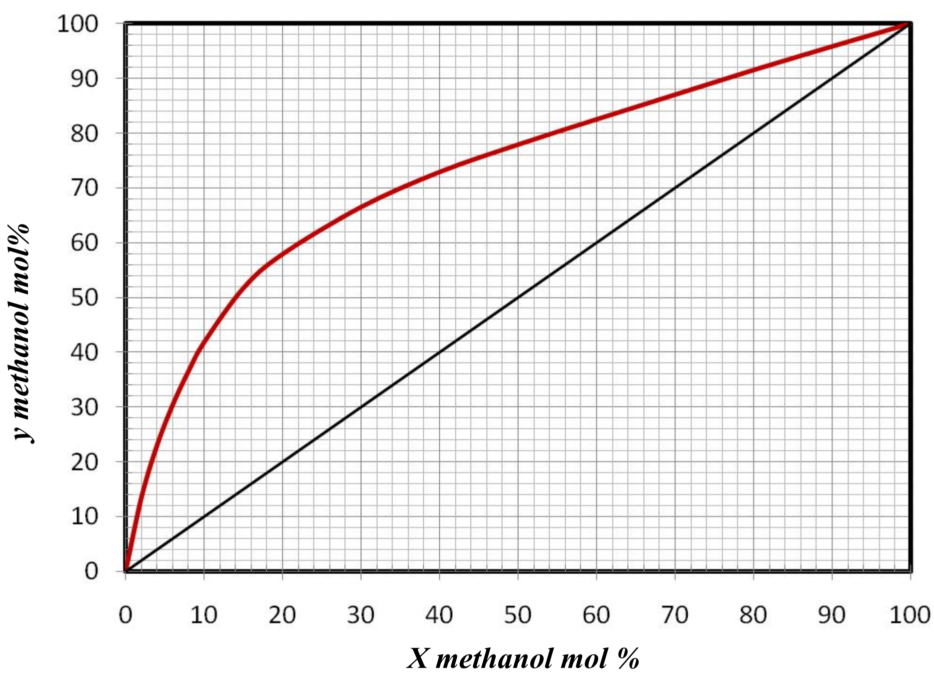
Example Contd



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Example Contd

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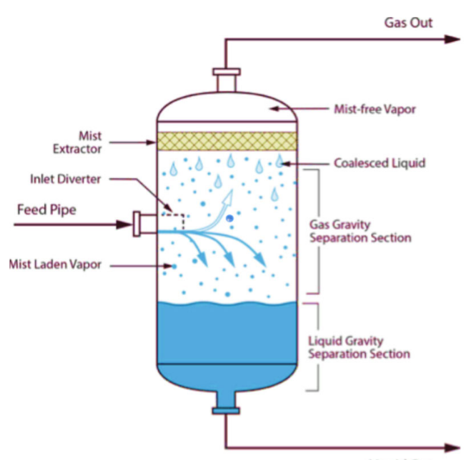
Design of Two Phase Separator Vessel
(Design of Flash Drum)



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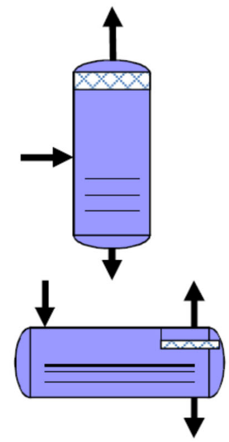
Introduction

- Horizontal vs. Vertical
  - Vertical preferred when:
    - small liquid load
    - limited plot space
    - ease of level control is desired



•Horizontal preferred when:

•large liquid loads are involved, consequently hold-up will set the size

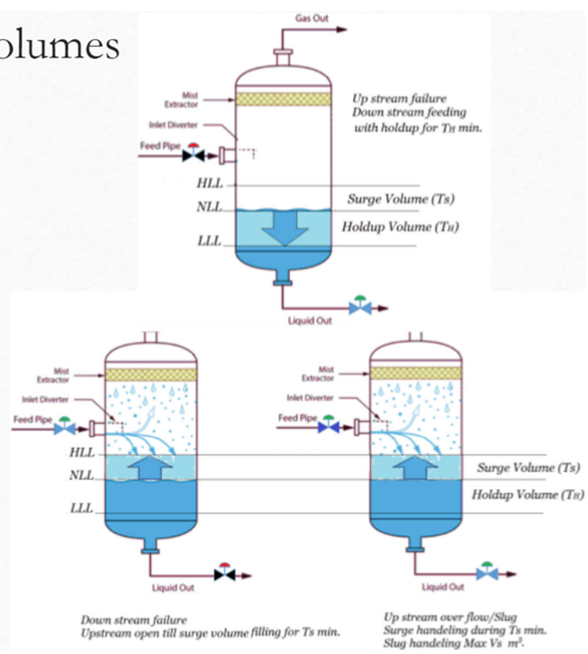
•three phases are present

Holdup & Surge Volumes

:Holdup & Surge Volumes

:Holdup
Holdup is defined as the time it takes to reduce the liquid level from normal (NLL) to empty (LLL) while maintaining a normal outlet now without feed makeup.
i.e. : Deadline to feeding downstream during upstream maintenance/failure.

:Surge
Surge time is defined as the time it takes for the liquid level to rise from normal (NLL) to maximum (HLL) while maintaining a normal feed with out any outlet flow .
i.e. : Deadline to receiving feed while downstream maintenance or max. volume of extra liquid to be handled via upstream pulse.



Size of Flash Drum

- The designer of a flash system needs to know
  - The pressure and temperature of the flash drum,
  - The size of the drum,
  - The liquid and vapor compositions and flow rates.
  - The pressure, temperature, and flow rate of the feed entering the drum.
  - How much the original feed has to be pressurized and heated

- The pressures must be chosen so that at the feed pressure, P_{Feed} , the feed is below its boiling point and remains liquid, while at the pressure of the flash drum, P_{drum} , the feed is above its boiling point and some of it vaporizes

Size of Vertical Drum

STEP 1 : Calculate the vapor liquid separation factor

$$F_{lv} = \frac{W_L}{W_V}\sqrt{\frac{\rho_V}{\rho_L}}$$

W_L and W_V are liquid and vapor flow rates (weight/time, (e.g., lb/h)

STEP 2 : Calculate the vapor velocity factor

where $$K_{drum} = \exp[A + B\ln F_{lv} + C(\ln F_{lv})^2 + D(\ln F_{lv})^3 + E(\ln F_{lv})^4]$$

K_{drum} empirical constant that depends on type of drum (ft/s). $0.1 < K_{drum} < 0.35$

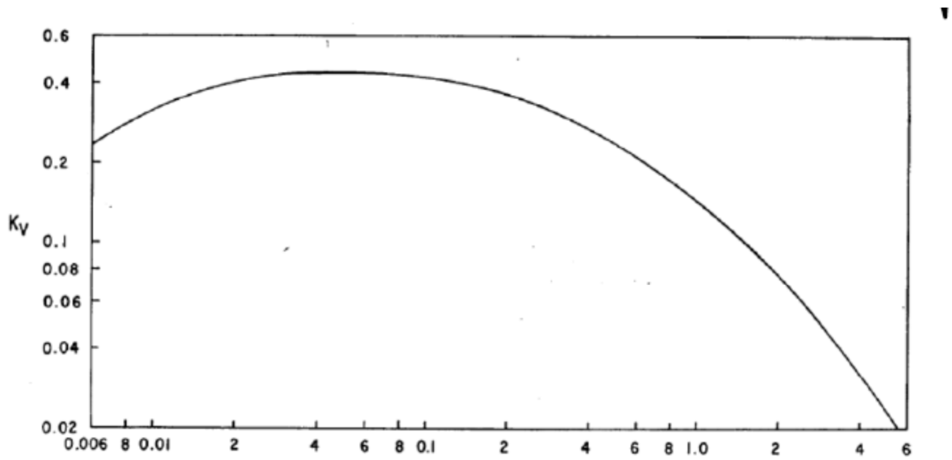
constants

A = -1.877478097 D = -0.0145228667

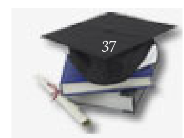
B = -0.8145804597 E = -0.0010148518

C = -0.1870744085

Size of Vertical Drum



$$F_{lv} = \frac{W_L}{W_V}\sqrt{\frac{\rho_V}{\rho_L}}$$



Separator K Values		
Mist Eliminator		
1 ≤ P ≤ 15 ≤	K = 0.1821 + 0.0029P + 0.0460Ln(P)	P: the absolute pressure in psi
15 ≤ P ≤ 40	K = 0.35	
40 ≤ P ≤ 5500	K = 0.430 - 0.023Ln(P)	
No Mist Eliminator		

$$K = \sqrt{\frac{4gD_p}{3C_D}}$$

$$C_D = \exp(Y)$$

$$Y = 8.411 - 2.243X + 0.273X^2 - 1.865 \times 10^{-2} X^2 + 5.201 \times 10^4$$

$$X = LN\left(\frac{0.95 + 8\rho_V D_p^3(\rho_L - \rho_V)}{\mu_v^2}\right)$$

While

D_p	ft
ρ	lb/ft^3
μ	cp

Size of Vertical Drum

$$K_{GPSA} = 0.35 - 0.0001 \times (P - 100) \qquad , \; 0 \le P \le 1500 \qquad P \;\; in \;\; psig$$

GPSA: Gas Processor's Supplier Association

:Notes

If there is no mist eliminator, it is recommended to use one half of the above values.

- Most vapors under vacuum K= 0.20.
- For Glycol and Amine solutions. Multiply K by 0.6-0.8.
- For vertical vessels without mist eliminators, divide *K* by 2.
- For compressor suction scrubbers, mole sieve scrubbers and expander inlet separators multiply K by 0.7-0.8

Size of Vertical Drum

STEP 3 : Calculate the maximum vapor velocity u_{perm}

$$u_{perm} = K_{drum} \sqrt{\frac{\rho_L - \rho_V}{\rho_V}}$$

u_{perm} = max permitted vapor velocity (ft/s)

Usually and for safety issues,

$$U_v = 0.75 \, u_{perm} \text{ (ft/s)}$$

STEP 4 : Find drum cross sectional area from vapor velocity and flow rate values

$$D_{VD} = \sqrt{\frac{4\, Q_V}{\pi\, U_V}} \quad , ft$$

Size of Vertical Drum

where

Q_v : the vapor volumetric flow rate
$$Q_v = \frac{W_v}{3600\rho_v}, \frac{ft^3}{s}$$

or

$A_c = Q_v / U_v$
$$\Rightarrow \quad D_{vert} = \sqrt{\frac{4A_c}{\pi}}$$

- 3 to 6 inches need to be added in the diameter if the mist eliminator is present in the vessel.
- This increase will accommodate the support ring.
- The calculated diameter then rounded to the next 6 inches.
- If there is no mist eliminator then $D = D_{vd}$.

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Size of Vertical Drum

STEP 5 : Approximate the vapor liquid inlet nozzle based on the following criteria

– max v=100/√ρ , ft/sec
– min v= 60/√ρ , ft/sec

or estimate the feed line nozzle diameter using the equations below:

$$d_N \geq \left(\frac{4Q_m}{\frac{60\pi}{\sqrt{\rho_m}}} \right)^{0.5}, ft$$

Where

$$\rho_m = \rho_L \times \lambda + \rho_\omega \times (1 - \lambda) \text{ , lb/ft}^3 \qquad \lambda = \frac{Q_L}{Q_L + Q_v}$$

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Size of Vertical Drum

$$Q_m = Q_L + Q_V, \frac{ft^3}{s}$$

Q_L : the volumetric flow rate of liquid

$$Q_L = \frac{W_L}{3600\,\rho_L}, \frac{ft^3}{s}$$

Q_v : the vapor volumetric flow rate

$$Q_v = \frac{W_v}{3600\rho_v}, \frac{ft^3}{s}$$

W_L and W_V are liquid and vapor flow rates (weight/time, (e.g., lb/h)

STEP 6 : Make preliminary sizing as in the following figure

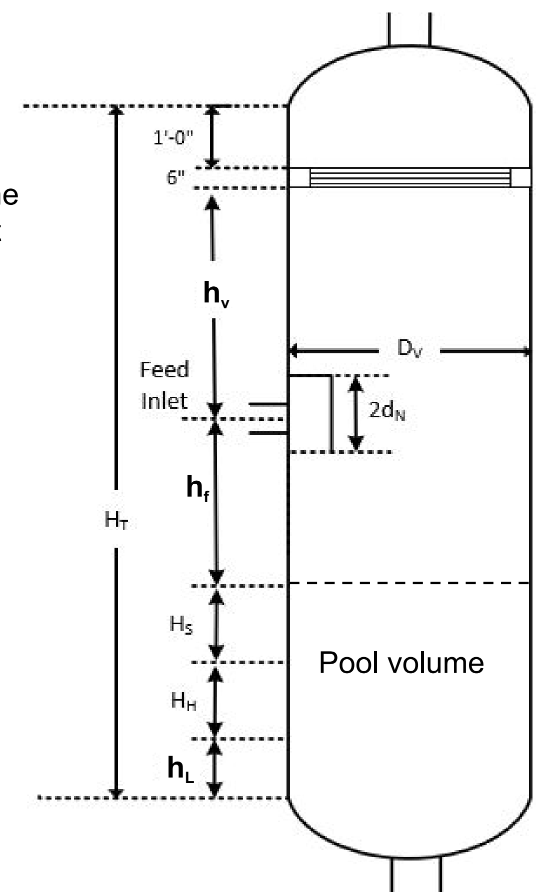
- The height of the drum above the centerline of the feed nozzle, $\mathbf{h_v}$, (the disengagement height) should be 36 in plus one-half the diameter of the feed line if no mist eliminator is present .

$$\mathbf{h_v} = \text{Min. of} \begin{cases} 0.5\,D_V \\ 36'' + \frac{1}{2}\textit{diameter of feedline} \end{cases}$$

The minimum of this distance is 48 in.

- If mist eliminator is present

$$\mathbf{h_v} = \text{Min. of} \begin{cases} 0.5\,D_V \\ 24 + 1/2d_N, in \end{cases}$$



- The height of the center of the feed line ab the maximum level of the liquid pool, h_f, sh be 12 in plus one-half the diameter of the f line.

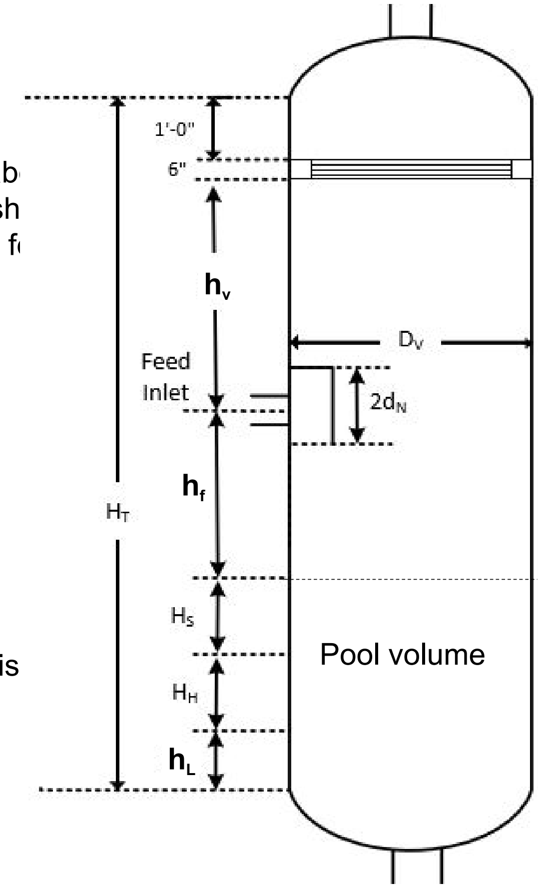
- With inlet diverter:

$$h_f = 12 + d_N, in$$

- Without inlet diverter:

$$h_f = 12 + 1/2 d_N, in$$

- The minimum distance for this free space is 18 in.



STEP 7: Select the holdup time from the table to calculate the holdup volume

$$V_H = \tau_H Q_L, ft^3$$

Liquid Holdup and Surge Times		
Services	Holdup Time min	Surge Time min
Unit Feed Drum	10	5
Separators		
1. Feed to Column	5	3
2. Feed to other drum or tankage		
a. With pump or through exchanger	5	2
b. Without pump	2	1
3. Feed to fired heater	10	3
Reflux or Product Accumulator		
1. Reflux only	3	2
2. Reflux and product	3+	2+
Column Bottoms		
1. Feed to another column	5	2
2. Feed to other drum or tankage		
a. With pump or through exchanger	5	2
b. Without Pump	2	1
3. Feed to fired heater	5 to 8	2 to 4

Correction Factors			
Personnel	Factor	Instrumentation	Factor
Experienced	1	Well Instrumented	1
Trained	1.2	Standard Instrumented	1.2
Inexperienced	1.5	Poorly instrumented	1.5

Size of Vertical Drum

$$\rightarrow \quad H_H = \frac{V_H}{\frac{\pi}{4} D_v^2}, ft$$

The min. value is 1 ft (12 in)

STEP 8: Select the surge time from the table to calculate the surge volume

$$V_S = \tau_s Q_L, ft^3$$

$$\rightarrow \quad H_S = \frac{V_S}{\frac{\pi}{4} D_v^2}, ft$$

The min. value is 0.5 ft (6 in)

Size of Vertical Drum

STEP 9 : Select the low liquid level height (**h_L**) from the table

Low Liquid Level Height			
Vessel Diameter	Vertical		Horizontal
	< 300 psia	> 300 psia	
ft	in	in	in
≤4	15	6	9
6	15	6	10
8	15	6	11
10	6	6	12
12	6	6	13
18	6	6	15

STEP 10 : Calculate (H_T)

$$H_T = h_v + h_f + H_S + H_H + H_L + H_{ME}$$

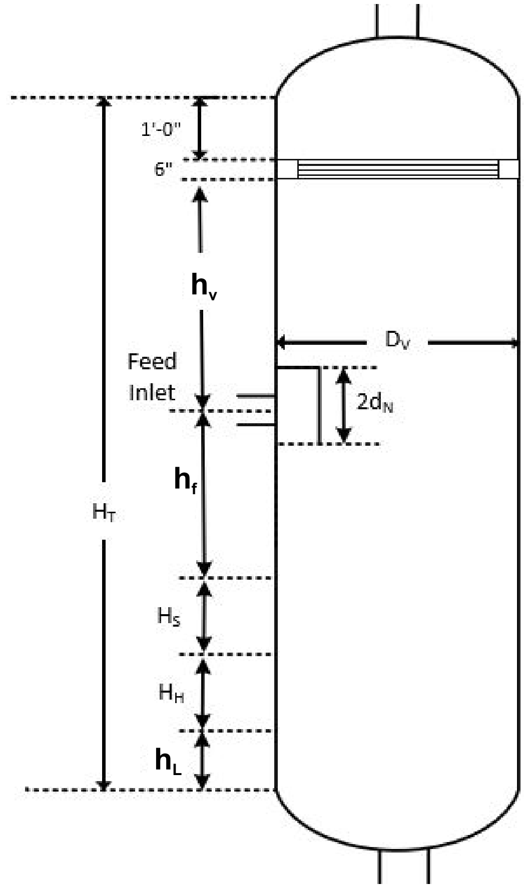
H_{ME} will be zero for no mist eliminator

STEP 11 : Check geometry

From rules of thumb of L/D ratio find length and inner dimensions

Table 7. L/D ratio guidelines.

Vessel operating pressure, psig	L/D
$0 < P \leq 250$	1.5–3.0
$250 < P < 500$	3.0–4.0
$500 < P$	4.0–6.0



Size of Vertical Drum

Vertical drums: $3.0 < L_{total} / D < 5.0$

IF $\frac{L}{D} < 3$ increase V_{pool}

IF $\frac{L}{D} > 5$ Use horizontal drum

STEP 12 : Nozzle sizing

Liquid Outlet:

1~4 m/s (min 2").

Vapor Outlet:

15~30 m/s or $\rho V^2 = 3750$ Pa.

Note: All units in SI system. $D = \sqrt{\frac{4Q}{\pi U}}$

Example

A vertical flash drum is to flash a liquid feed of 1500 lbmol/h that is 40 mol% n-hexane and 60 mol% n-octane at 101.3 kPa (1 atm). We wish to produce a vapor that is 60 mol% n-hexane. Solution of the flash equations with equilibrium data gives $x_H = 0.19$, $T_{drum} = 378K$, and V/F = 0.51. What size flash drum is required? Assume ideal gas and ideal mixtures for liquid.

$\rho_H = 0.659$ g/mL and $\rho_O = 0.703$ g/mL at 20°C.

$MW_H = 86.17$ and $MW_O = 114.22$.

Liquid Density

$$\frac{1}{\rho_L} = \frac{x_H}{\rho_H} + \frac{x_O}{\rho_O} = \frac{0.19}{0.659} + \frac{0.81}{0.703}$$

$$\rho_L = 0.69\ g/ml$$

Vapor Density

$$\rho_v = p\,\overline{MW}_v / RT$$

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Solution

$$\overline{MW}_v = y_H MW_H + y_O MW_O$$

but $y_H = 0.60$ and $y_O = 0.40$,

$$\overline{MW}_v = 97.39\ \text{lb/lbmol}$$

$$\rho_v = \frac{(1.0\text{atm})(97.39\text{g/mol})}{(82.0575\ \frac{\text{mL atm}}{\text{mol K}})(378\text{K})} = 3.14 \times 10^{-3}\ \text{g/mL}$$

Kdrum Calculation

$$V = (V/F)(F) = (0.51)(1500) = 765\ \text{lbmol/h}$$

$$W_v = (V)(\overline{MW}_v) = (765)(97.39) = 74{,}503\ \text{lb/h}$$

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Solution Cont.d

$$L = F - V = 735 \text{ lbmol/h}$$

The average liquid molecular weight is

$$\overline{MW}_L = x_H MW_H + x_O MW_O$$

$$= (0.19)(86.17) + (0.81)(114.22) = 108.89.$$

$$W_L = (L)(\overline{MW}_L) = (735)(108.89) = 80{,}034 \text{ lb/h}$$

$$F_{lv} = \frac{W_L}{W_v}\sqrt{\frac{\rho_v}{\rho_L}} = \frac{80034}{74503}\sqrt{\frac{3.14 \times 10^{-3}}{0.6960}} = 0.0722$$

$$K_{drum} = \exp[A + B\ln F_{lv} + C(\ln F_{lv})^2 + D(\ln F_{lv})^3 + E(\ln F_{lv})^4]$$

$K_{drum} = 0.4433,$ $\quad 0.1 < K_{drum} < 0.35$

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Solution Cont.d

u_{perm} Calculation $(K_{drum} = 0.35)$

$$u_{perm} = K_{drum}\sqrt{\frac{\rho_L - \rho_v}{\rho_v}}$$

$$= (0.35)\sqrt{\frac{0.6960 - 0.00314}{0.00314}} = 5.2 \text{ ft/s}$$

➡ $U_v = 0.75\ (5.2) = 3.9$ ft/s

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Solution Cont.d

Drum cross sectional area Calculation

$$A_c = \frac{V(\overline{MW}_v)}{U_v\ (3600)\rho_v}$$

$$= \frac{(765)(97.39)(454\ g/lb)}{3.9\ \ (3600)(0.00314\ g/mL)(28316.85\ mL/ft^3)}$$

$= 27.1\ ft^2$

$$D = \sqrt{\frac{4A_c}{\pi}} = 5.87\ ft$$

Use 6 ft diameter

If use $h_{total}/D = 4$, $h_{total} = 4 \times (6\ ft) = 24\ ft$

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Example

Size a vertical separator with a mist eliminator pad to separate the following mixture .

W_v =145600 lb_m/h ($\rho_v = 4.01\ lb_m/ft^3$)

W_L =46100 lb_m/h ($\rho_L = 38.83\ lb_m/ft^3$)

The operating pressure is 975 psig and the holdup and surge are to be 10 min and 5 min respectively. Use a design temperature of 650°F .

$$F_{lv} = \frac{W_L}{W_V}\sqrt{\frac{\rho_V}{\rho_L}}$$

F_{lv} =0.102 ➡ K_v =0.41

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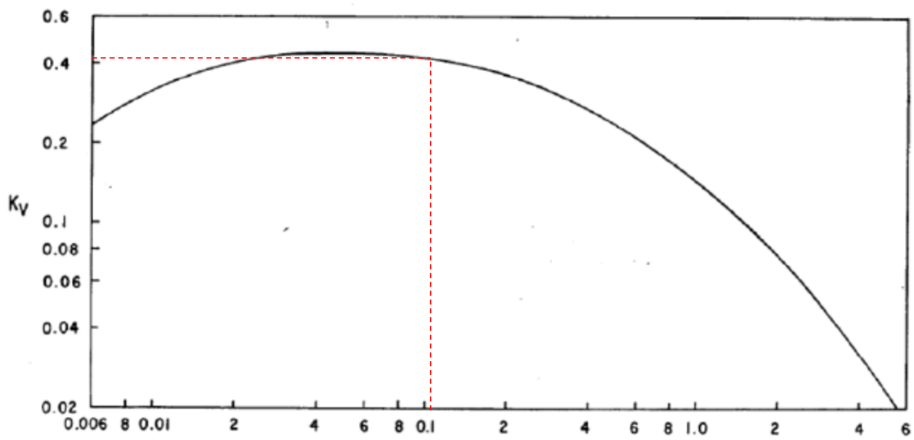
Solution Cont.d



$$F_{lv} = \frac{W_L}{W_V}\sqrt{\frac{\rho_V}{\rho_L}}$$

Solution Cont.d

$K = 0.430 - 0.023 Ln(P)$ ➡ $K = 0.2714$

$$K = \sqrt{\frac{4gD_p}{3C_D}}$$ ➡ $K = 0.2766$ (μ=0.01cP, Dp=300 micron)

$K_{GPSA} = 0.35 - 0.0001 \times (P - 100)$ ➡ $K_{GPSA} = 0.2625$

$K = K_{min} = 0.2625$

Note: There is a mesh pad, so $K_{final} = K$.

Solution Cont.d

$$u_{perm} = K_{drum}\sqrt{\frac{\rho_L - \rho_V}{\rho_V}} \quad = 0.77 \text{ ft/s}$$

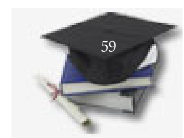
$$U_v = 0.75\ u_{perm} = 0.58 \text{ ft/s}$$

$$Q_v = \frac{W_v}{3600\rho_v}, \frac{ft^3}{s} \quad = 10.09 \text{ ft}^3\text{/s}$$

$$D_{VD} = \sqrt{\frac{4\,Q_V}{\pi\,U_V}} \quad = 4.7 \text{ ft (56.4 in)}$$

There is a mesh pad, so add 3~6 inch for support ring and round to the next 6 inch. Therefore:

$$D_{VD} = 5 \text{ ft (60 in)}$$



Solution Cont.d

$$Q_L = \frac{W_L}{3600\,\rho_L}, \frac{ft^3}{s} \quad = 0.33 \text{ ft}^3\text{/s} \; = 19.8 \text{ ft}^3\text{/min}$$

$$V_H = \tau_H Q_L, \text{ft}^3 \quad = 3 \text{ min} \times 19.8 = 59.4 \text{ ft}^3 \; \Rightarrow \; H_H = 3.026 \text{ ft}$$

$$V_S = \tau_s Q_L, \text{ft}^3 \quad = 2 \text{ min} \times 19.8 = 39.6 \text{ ft}^3 \; \Rightarrow \; H_s = 2.01 \text{ ft}$$

Vertical vessel with D=5 ft. & P>300 Pisa $\quad h_L = 6$ in

With mist eliminator:

$$\mathbf{H_{ME} = 6\ in/12 + 1\ ft. = 1.5\ ft}$$

Solution Cont.d

$$d_N \geq \left(\frac{\frac{4Q_m}{60\pi}}{\sqrt{\rho_m}} \right)^{0.5} \quad , ft$$

$d_N \geq 0.71$ ft (8.5 in.) → **10" Selected**

$$h_f = 12" + \frac{1}{2} diameter\ of\ feedline$$

h_f **= 12 + 5 in = 17 in**

h_v = Min. of

- $0.5\ D_V$
- $24 + 1/2 d_N, in$

h_V = 24 + 0.5 (10) = 29 in

Solution Cont.d

$$H_T = h_v + h_f + H_S + H_H + H_L + H_{ME}$$

H_T = = 2.4+ 1.4+3.026+2.01+0.5+1.5= 10.84 ft

H_T / D = 10.84 / 5 = 2.16

P=960.5 psig > 500 psig→ L/D: 4~6

Table 7. L/D ratio guidelines.

Vessel operating pressure, psig	L/D
$0 < P \leq 250$	1.5–3.0
$250 < P < 500$	3.0–4.0
$500 < P$	4.0–6.0

H_T/D is lower than the value specified in table 7.
then take

H_T / D = 5 Then H_T = 25 ft

Solution Cont.d

Nozzle Sizing:

Inlet Nozzle:

7~13 m/s or

$\rho V^2 = 1000$ Pa (for no inlet device)

$\rho V^2 = 1500$ Pa (for half open pipe)

Liquid Outlet:

1~4 m/s (min 2").

Vapor Outlet:

15~30 m/s or $\rho V^2 = 3750$ Pa.

Note: All units in SI system. $D=\sqrt{\frac{4Q}{\pi U}}$

:Example

Inlet Nozzle:

$Q=Q_L+Q_V$

1. Based on CEP method: 8.5"<D

2. $\sqrt{\frac{4\times0.295}{\pi\times13}} < D < \sqrt{\frac{4\times0.295}{\pi\times7}} \rightarrow$ 6.7"<D<9.1"

3. No inlet device: $\rho V^2 = 1000 \rightarrow V=\sqrt{\frac{1000}{\rho_m}}=3.5$ m/s $\rightarrow$ D>12.9"

1,2,3 $\rightarrow$ $D_F = 10"$ (Selected)

Liquid Outlet:

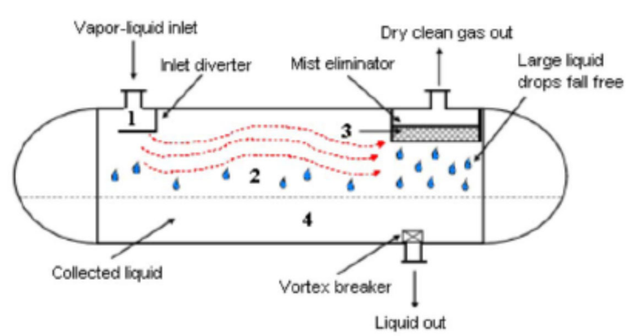
$\sqrt{\frac{4\times0.009}{\pi\times4}} < D < \sqrt{\frac{4\times0.009}{\pi\times1}} \rightarrow$ 2.1"<D<4.3" $\rightarrow$ $D_L=3"$

Vapor Outlet:

$\sqrt{\frac{4\times0.286}{\pi\times30}} < D < \sqrt{\frac{4\times0.286}{\pi\times15}} \rightarrow$ 4.3"<D<6.1"

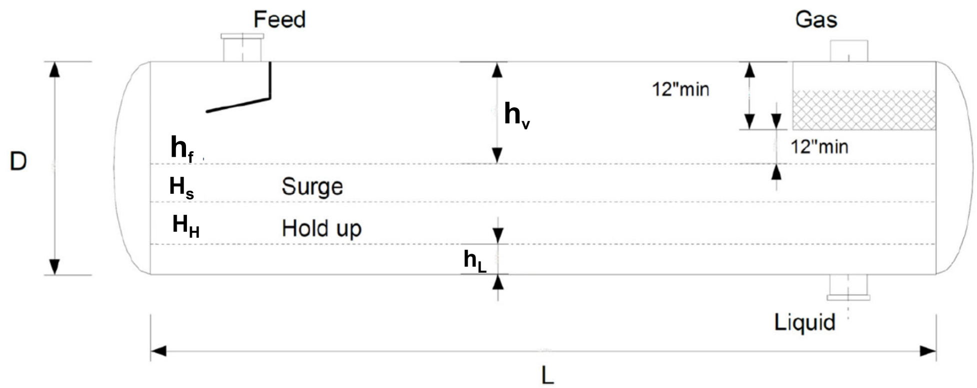
$\rho V^2 = 3750 \rightarrow V=\sqrt{\frac{3750}{\rho_v}}=7.6$ m/s $\rightarrow D=\sqrt{\frac{4\times0.286}{\pi\times7.6}} \rightarrow$ D=8.6" $\rightarrow D_V=6"$

Design of Horizontal Flash Drum

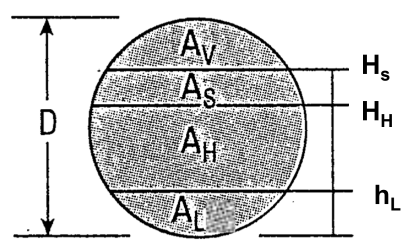


Design of Horizontal Flash Drum

- Horizontal flash drums are used for large flow rates because additional disengagement area is formed by making the column longer and horizontal columns are cheaper than vertical ones.



Design of Horizontal Flash Drum



- The cross-sectional area between H_s and the top of the vessel (A_v) is used for vapor disengagement
- H_H is set by liquid holdup, and H_s is set by liquid surge

Design of Horizontal Flash Drum

1. Calculate the vapor volumetric flow rate, Q_V
2. Calculate the liquid volumetric flow rate, Q_L,
3. Calculate the vertical terminal velocity, U_v,
4. Select a holdup time and calculate the holdup volume, V_H
5. If the surge volume is not specified, select surge time and calculate the surge volume, V_s.
6. Obtain an estimate of L/D from table 7 and initially calculate the diameter according to equation

$$D = \left(\frac{4(V_H + V_S)}{\pi (0.6)(\frac{L}{D})} \right)^{1/3}, ft$$

Round the value to the nearest 0.5 ft.

Table 7. L/D ratio guidelines.

Vessel operating pressure, psig	L/D
$0 < P \leq 250$	1.5–3.0
$250 < P < 500$	3.0–4.0
$500 < P$	4.0–6.0

Design of Horizontal Flash Drum

7. Calculate the cross-sectional area of the vessel.

$$A_T = \frac{\pi}{4} D^2, ft^2$$

8. Calculate the low liquid level height

$$h_L = 0.5D + 7, in$$

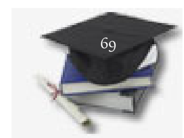
where D in ft and round the value to the nearest inch

$$\text{if } D \leq 4'0'', h_L = 9 \text{ in.}$$

9. Using h_L/D, obtain A_L/A_T using table and calculate the low liquid area.

Design of Horizontal Flash Drum

Cylinderical Height and Area Conversions	
$Y = \dfrac{a + cX + eX^2\ gX^3 + iX^4}{1.0 + bX + dX^2 + fX + \ X^4}$	
H/D to A/A_T	A/A_T to H/D
$Y = A/A_T$	$X = A/A_T$
$X = H/D$	$Y = H/D$
$a = 4.75930\text{x}10^{-5}$	a = 0.00153756
b = 3.924091	b = 26.787101
c = 0.174875	c = 3.299201
d = -6.358805	d = -22.923932
e = 5.668973	e = 24.353518
f = 4.018448	f = -14.844824
g = -4.916411	g = -36.999376
h = -1.801705	h = 10.529572
i = -0.145348	i = 9.892851



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Design of Horizontal Flash Drum

10. If there is no most eliminator pad, the minimum height of the vapor disengagement area $\mathbf{h_V}$ is the larger of 0.2D or 1 ft.

- If there is a most eliminator pad, the minimum height of the vapor disengagement area is the larger of 0.2D or 2 ft. Hence, set h_v to a larger of 0.2D or 2ft.
- Using h_V/D, obtain A_V/A_T, and calculate A_v.

13. Calculate the minimum length to accommodate the liquid holdup and surge.

$$L = \frac{V_H + V_L}{A_T - A_V - A_L}, ft$$

14. Calculate liquid dropout time

$$\phi = \frac{h_V}{U_V}, s$$

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Design of Horizontal Flash Drum

15. Calculate the actual vapor velocity

$$U_{vA} = \frac{Q_v}{A_V}, ft/s$$

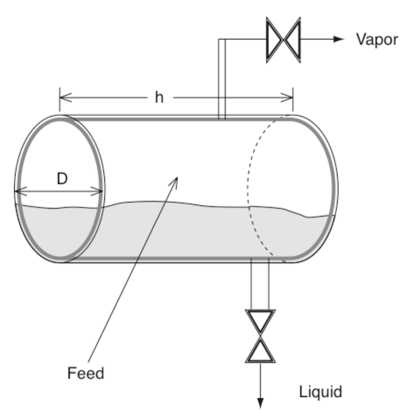
16. Calculate the minimum length required for vapor-liquid disengagement.

$$L_{min} = U_{vA}\phi, ft$$

- If L < L_{min} then set L = L_{min}.
- If L_{min} >> L, then increase h_V and repeat from the step 10.
- If L_{min} << L, then decrease the h_v if it is greater than the minimum specified value.
- Adjust the value of D to keep the L/D between 1.5 to 6.
    - If V/D > 6.0 then increase D and repeat calculations from the step 6.
    - If LID < 1.5, then decrease D and repeat calculations from the step 6.

Design of Horizontal Flash Drum

- Alternatively, $K_{horizontal} = 1.25\, K_{vertical}$



- Use $K_{horizontal}$ to calculate u_{perm} then A_c using the equations described before

$$\Rightarrow \quad A_T = \frac{A_c}{0.2} \qquad \Rightarrow \quad D_{horizontal} = \sqrt{\frac{4A_T}{\pi}}$$

- From rules of thumb of L/D ratio find length and inner dimensions

Table 7. L/D ratio guidelines.

Vessel operating pressure, psig	L/D
$0 < P \leq 250$	1.5–3.0
$250 < P < 500$	3.0–4.0
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