Design Two-Phase Separators Within the Right Limits

Here is a proven, step-by-step method.

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Liquid/vapor separators are one of the most common types of process equipment. Many technical papers have been written on separator design and vast amounts of information are also available in corporate process engineering design guidelines. The basic equations used for sizing are widely known; however, subjectivity exists during the selection of the parameters used in these equations. This article attempts to address the basics of two-phase separator design and provide step-by-step procedures and examples for two-phase vapor/liquid separator design.

Two-phase separator types and selection

Two-phase separators may be oriented either vertically or horizontally. In some cases, it may be necessary to compare both designs to determine which is more economic. Separators may be designed with or without mist eliminator pads and may also have inlet diverters. Some separators may have proprietary impingement or settling internals. The vendor should be contacted to design these types of vessels. Vertical vapor/liquid separators are preferred for separating liquid from mixtures with a high vapor/liquid ratio while horizontal separators are preferred for separating vapor from mixtures with a low vapor/liquid ratio.

Background

Vapor/liquid separation is usually accomplished in three stages. The first stage, primary separation, uses an inlet diverter so that the momentum of the liquid entrained in the vapor causes the largest droplets to impinge on the diverter and then drop by gravity. The next stage, secondary separation, is gravity separation of smaller droplets as the vapor flows through the disengagement area. The final stage is mist elimination where the smallest droplets are coalesced so that larger droplets are formed which will separate by gravity.

For secondary separation, the allowable velocity must be calculated so that disengagement area can be subsequently determined. Performing a force balance on the liquid droplet settling out provides the necessary relationship. When the net gravity force, given by Eq. 1,

$$F_G = \frac{M_P (\rho_L - \rho_V)\, g}{g_c \rho_V} \qquad (1)$$

balances the drag force, given by Eq. 2,

$$F_D = \frac{(\pi / 8)\, C_D D_P^2 U_V^2 \rho_V}{g_c} \qquad (2)$$

the heavier liquid droplets will settle at a constant terminal velocity, U_T. Equating Eqs. 1 and 2 results in,

$$U_T = \sqrt{\frac{4g D_P \left(\rho_L - \rho_V\right)}{3 C_D \rho_V}} \qquad (3)$$

Hence, as long as $U_V < U_T$, the liquid droplets will settle out. Typically, the allowable vertical velocity, U_V, is set between $0.75U_T$ and U_T. Eq. 3 can be rearranged as Eq. 4, a Sauders-Brown type equation *(1)*:

$$U_T = K\sqrt{\frac{(\rho_L - \rho_V)}{\rho_V}} \tag{4}$$

where

$$\text{where } K = \sqrt{\frac{4gD_P}{3\,C_D}} \tag{5}$$

Practically, very small droplets cannot be separated by gravity alone. These droplets are coalesced to form larger droplets which will settle by gravity. Coalescing devices in separators force the gas to follow a tortuous path and the momentum of the droplets causes them to collide with other droplets or the coalescing device, forming larger droplets. The coalesced droplet diameter is not adequately predictable so the K values for mist eliminators are typically empirical. This is where subjectivity first enters separator design. There are several literature sources of K values such as the Gas Processor's Supplier Association (GPSA) "Engineering Data Book" *(2)*, numerous technical publications and vendor's recommendations. The GPSA *(2)* and York Mist Eliminator *(3)* values have been curve fitted and are given in Table 1.

When calculating U_T for a horizontal separator, a "no mist eliminator K value" should be used.

Table 1. Separator K values.

Mist Eliminator

$1 \leq P £ 15$	$K = 0.1821 + 0.0029P + 0.0460\text{Ln}(P)$	
$15 \leq P \leq 40$	$K = 0.35$	P, psia
$40 \leq P \leq 5{,}500$	$K = 0.430 - 0.023\text{Ln}(P)$	

GPSA

$0 \leq P \leq 1{,}500$	$K = 0.35 - 0.01(P - 100/100)$	P, psig

- 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.

Theoretical (no mist eliminator)

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

$C_D = \exp(Y)$

$Y = 8.411 - 2.243X + 0.273X^2 - 1.865\text{E}-2X^3 + 5.201\text{E}-4X^4$

$$X = Ln\left(\frac{0.95 + 8\rho_V D_P^3(\rho_L - \rho_V)}{\mu_V^2}\right)$$

Notes:
D_p, ft
ρ, lb/ft^3
μ, cP
1 micron = 3.28084×10^{-6} ft

If there is no mist eliminator, it is recommended to use one half of the above values *(2)* or the "theoretical" value K can be calculated from Eq. 5 if the liquid droplet size is known. The drag coefficient, C_D has been curve fitted and is given in Table 1 or can be obtained from Figure 7-3 in the GPSA "Engineering Data Book" *(2)*.

Before proceeding, it is worthwhile to clarify some definitions and criteria. Holdup is defined as the time it takes to reduce the liquid level from normal *(NLL)* to empty *(LLL)* while maintaining a normal outlet flow without feed makeup. 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 without any outlet flow. Some guidelines base "surge" on the volume between low *(LLL)* and high *(HLL)* liquid levels. Holdup time is based on the reserve required to maintain good control and safe operation of downstream facilities. Surge time is usually based on requirements to accumulate liquid as a result of upstream or downstream variations or upsets, for example, slugs. In the absence of specific requirements, surge time may be taken as one half of holdup time.

Vertical separators. For vertical separators, the vapor disengagement area is the entire cross-sectional area of the vessel so that vapor disengagement diameter can be calculated from Eq. 6:

$$D_{VD} = \sqrt{\frac{4\,Q_V}{\pi\,U_V}} \tag{6}$$

Technically, this is the mist eliminator diameter and the inside diameter of the vessel must be slightly larger so that the mist eliminator can be installed inside the vessel. Typically, the calculated value is taken up to the next six in. This value is taken as the required diameter of the vessel, D, and the corresponding cross-sectional area, A, is calculated using this diameter.

The next step in sizing a vertical separator is to determine the height.

For a two-phase vertical separator, the total height can be broken into sections, as shown in Figure 1. The separator height is then calculated by adding the heights of these sections, as per Eq. 7.

$$H_T = H_{LLL} + H_H + H_S + H_{LIN} + H_D \quad (7)$$

If a mist eliminator pad is used, additional height is added, as shown in Figure 1. The calculations of diameter and height are detailed in the "Design Procedures" section of this article.

Horizontal separators. For horizontal two-phase separators, the cross-section is occupied by both vapor and liquid, as shown in Figure 2. When sizing horizontal two-phase separators, usually a diameter is assumed, *LLL* is selected or calculated, *NLL* is set by liquid holdup, and *HLL* is set by liquid surge. The cross-sectional area between *HLL* and the top of the vessel is used for vapor disengagement. The length of the vessel is then calculated to accommodate holdup and surge or to facilitate vapor liquid separation. Hence, this approach to sizing horizontal separators, or variations of it, are iterative calculations.

The following will develop the basic equation used for calculating the size of a horizontal separator. For a horizontal separator cross section, a "volume balance" is written.

$$V_H + V_S = L\,(A_T - A_{VD} - A_{LLL}) \quad (8)$$

Holdup and surge volumes are calculated from holdup and surge times which are selected according to guidelines. The low liquid level area is a function of the low liquid level height, obtained from guidelines, and the vessel inside diameter. The minimum vapor disengagement area, A_{VD}, is typically specified as one to two ft or 20% of the vessel inside diameter, whichever is greater. The sizing method in the "Design Procedures" section of this article assumes this for A_{VD} and only increases it if the length required for vapor-liquid separation is much greater than the length required for holdup and surge, for a given diameter. Equation 8 is then a function of the inside diameter, *D*, and length, *L*.

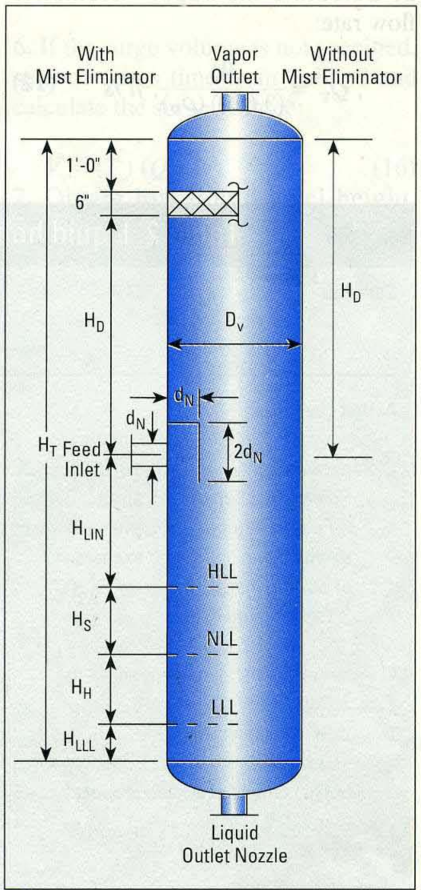


Figure 1. Vertical two-phase separator.

For horizontal separators, the liquid droplet to be separated from the gas has a horizontal drag force which is not directly opposite to gravity as in the vertical case. Without detailed treatment of two-dimensional particle motion, most literature sources recognize that the allowable horizontal velocity can be higher than the terminal velocity *(2, 5, 7)*. This can be shown simply by equating the "residence" times of the liquid droplet to be settled. That is, the time it takes to travel the horizontal length between inlet and outlet must be greater than the time it takes to settle the vertical distance to the liquid surface.

If a mist eliminator pad is used, additional height is added.

$$\frac{L}{U_{AH}} \geq \frac{H_V}{U_T} \quad (9)$$

This can be rearranged in terms of the allowable horizontal velocity.

$$U_{AH} \leq \frac{L}{H_V}\,U_T \quad (10)$$

The length, *L*, divided by the height of the vapor disengagement area, H_V, would always be greater than unity. The allowable horizontal velocity is a very subjective topic with several empirical approaches to modify the vertical "*K*" value available in the literature *(2, 5, 7, 8)*. For horizontal separator design, the subsequent design procedures use a "droplet settling approach" similar to the API procedure *(6)* which does not require empirical modification of the "*K*" value for vertical settlers. It should be noted that when calculating U_T for a horizontal separator, a "no mist eliminator *K* value" should be used.

Design Procedures

The following design procedures and heuristics are a result of a review of literature sources and accepted industrial design guidelines. The horizontal design procedure incorporates optimizing the diameter and length by minimizing the weight of the shell and heads. To add a degree of conservatism to the design, the volume available in the heads is ignored.

Vertical design procedure (See Figure 1):

1. Calculate the vertical terminal vapor velocity:

$$U_T = K\left(\frac{\rho_L - \rho_V}{\rho_V}\right)^{1/2},\ ft/s \quad (11)$$

Set $U_V = 0.75U_T$ for a conservative design. Calculate the *K* value from Table 1.

Nomenclature

A	= vertical vessel cross-sectional Area, ft^2
A_{LLL}	= cross section For LLL (horizontal vessel), ft^2
A_T	= total cross sectional area (horizontal vessel), ft^2
A_{VD}	=vapor disengagement area required, ft^2
C_D	= drag coefficient
D	= vessel diameter, ft or in.
D_P	= droplet diameter, ft.
D_N	= nozzle diameter, in. (inlet or out let vapor/liquid as specified)
D_{VD}	= vapor disengagement diameter, ft
E	= welded joint efficiency
F_D	=drag force,lb$_f$
F_G	= gravity force, lb$_f$
g	= gravitational constant, 32.17 ft/s^2
g_c	= 32.17 (lbm/ft)/(lb$_f$-s^2)
H_D	= disgengagement height, ft
H_H	= holdup height, ft
H_{LIN}	= H_{LL} to inlet nozzle centerline height, ft
HLL	= high liquid level
H_{LLL}	= low Liquid Level height, ft
H_{ME}	= mist eliminator to top tank height, ft
H_S	= surge height, ft
H_T	= total vertical separator height, ft
H_V	= vapor disengagement area height, ft
K	= terminal velocity constant, ft/s
L	= vessel length, ft
LLL	= low liquid level
L_{MIN}	= vapor/liquid separation minimum length, ft
M_P	= droplet mass, lb$_f$
NLL	= normal liquid level
P	= pressure, psig or psia
Q_L	= liquid volumetric flow, ft^3/min
Q_M	= mixture volumetric flow, ft^3/s, ft^3f/min
Q_V	= vapor volumetric flow, ft^9/s, ft^9/min
S	= vessel material stress value, psi
T_H	= holdup time, min.
t_h	= head thickness, in
t_s	= shell thickness, in
U_{AH}	= allowable horizontal velocity, ft/s
U_T	= terminal velocity, ft/s
U_m	= mixture velocity, ft/s
U_V	= vapor velocity, ft/s
V_H	= holdup volume, ft^3
V_{LLL}	= LLL volume, ft^3
V_S	= surge volume, ft^3
V_T	= total volume (horizontal vessel), ft^3
W	= vessel weight, lb$_m$

Greek Letters

λ	= mixture liquid fraction
μ_V	= vapor viscosity, cP
ρ_L	= liquid density, lb/ft^3
ρ_M	= mixture density, lb/ft^3
ρ_V	= vapor density, lb/ft^3
ϕ	= liquid dropout time, s

2. Calculate the vapor volumetric flow rate:

$$Q_V = \frac{W_V}{(3{,}600)\,(\rho_V)},\ ft^3/s \qquad (12)$$

3. Calculate the Vessel (inside) diameter:

$$D_{VD} = \left(\frac{4\,Q_V}{\pi\,U_V}\right)^{1/2},ft \qquad (13)$$

Table 2. Liquid holdup and surge times.

Services	Holdup Times (NLL-HLL) min.	Surge Time (NLL-LLL) min.
A. Unit Feed Drum	10	5
B. 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
C. Reflux or product accumulator		
1. Reflux only	3	2
2. Reflux and product	3+	2+
• based on reflux (3 min.) + appropriate holdup time of overhead product (per B-1, 2,3)		
D. 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 boiler	5-8	2-4
• based on reboiler vapor expressed as liquid (3 min.) + appropriate holdup time for the bottom product (per D-1, 2)		
E. Compressor suction/interstage scrubber		
• 3 min between *HLL (HLA)* and *HLSD*		
• 10 min from bottom tangent line to *HLA*		
F. Fuel gas knockout drum		
• 20 ft slug in the incoming fuel gas line between *NLL* and *HLSD*		
G. Flare knockout drum		
• 20 to 30 min. to *HLL*		

Personnel	Factor	Instrumentation	Factor
Experienced	1.0	Well instrumented	1.0
Trained	1.2	Standard instrumented	1.2
Inexperienced	1.5	Poorly instrumented	1.5

If there is a mist eliminator, add 3 to 6 in. to D_{VD} to accommodate a support ring and round up to the next 6 in. increment to obtain D. If there is no mist eliminator $D = D_{VD}$.

4. Calculate the liquid volumetric flow rate:

$$Q_L = \frac{W_L}{(60)(\rho_L)}, ft^3/\text{min} \quad (14)$$

5. Select holdup time from Table 2 and calculate the holdup volume:

$$V_H = (T_H)(Q_L) \text{ ft}^3 \quad (15)$$

Table 3. Low liquid level height.

Vessel diameter	Vertical LLL < 300 psia	Vertical LLL > 300 psia	Horizontal LLL
≤ 4 ft	15 in.	6 in.	9 in.
6 ft	15 in.	6 in.	10 in.
8 ft	15 in.	6 in.	11 in.
10 ft	6 in.	6 in.	12 in.
12 ft	6 in.	6 in.	13 in.
16 ft	6 in.	6 in.	15 in.

Table 4. Inlet nozzle sizing.

$$d_N \geq \left(\frac{4Q_m}{\pi 60/\sqrt{\rho_m}}\right)^{1/2}, \text{ ft}$$

$$Q_M = Q_L + Q_V, \text{ ft}^3/\text{s}$$

$$\rho_m = \rho_L\lambda + \rho_V(1-\lambda), \text{ lb/ft}^3$$

$$\lambda = \frac{Q_L}{Q_L + Q_V}$$

Table 5. L/D ratio guidelines.

Vessel Operating Pressure (psig)	L/D
0 < P ≤ 250	1.5-3.0
250 < P ≤ 500	3.0-4.0
500 < P	4.0-6.0

6. If the surge volume is not specified, select a surge time from Table 2 and calculate the surge volume:

$$V_s = (T_s)(Q_L) \text{ ft}^3 \quad (16)$$

7. Obtain low liquid level height, H_{LLL}, from Table 3.

8. Calculate the height from low liquid level to normal liquid level:

$$H_H = \frac{V_H}{(\pi/4) D_V^2}, ft \quad (17)$$

1 ft minimum

9. Calculate the height from normal liquid level to high liquid level (or high level alarm):

$$H_S = \frac{V_S}{(\pi/4) D_V^2}, ft \quad (18)$$

6 in minimum

10. Calculate the height from high liquid level to the centerline of the inlet nozzle:

$H_{LIN} = 12 + d_N$, in. (with inlet diverter)

$H_{LIN} = 12 + \frac{1}{2} d_N$, in. (without inlet diverter) (19)

Note: d_N is calculated as per Table 4.

11. Calculate the disengagement height, from the centerline of the inlet nozzle to:

a. the vessel top tangent line if there is no mist eliminator or

b. the bottom of the demister pad.

$H_D = 0.5\, D_V$ or a minimum of

$H_D = 36 + \frac{1}{2} d_N$, in. (without mist eliminator) (20)

$H_D = 24 + \frac{1}{2} d_N$, inches (with mist eliminator)

12. If there is a mist eliminator, take 6 in. for the mist eliminator pad and take 1 ft. from the top of the mist eliminator to the top tangent line of the vessel.

13. Calculate the total height, H_T, of the vessel:

$$H_T = H_{LLL} + H_H + H_S + H_{LIN} + H_D + H_{ME}, \text{ ft} \quad (21)$$

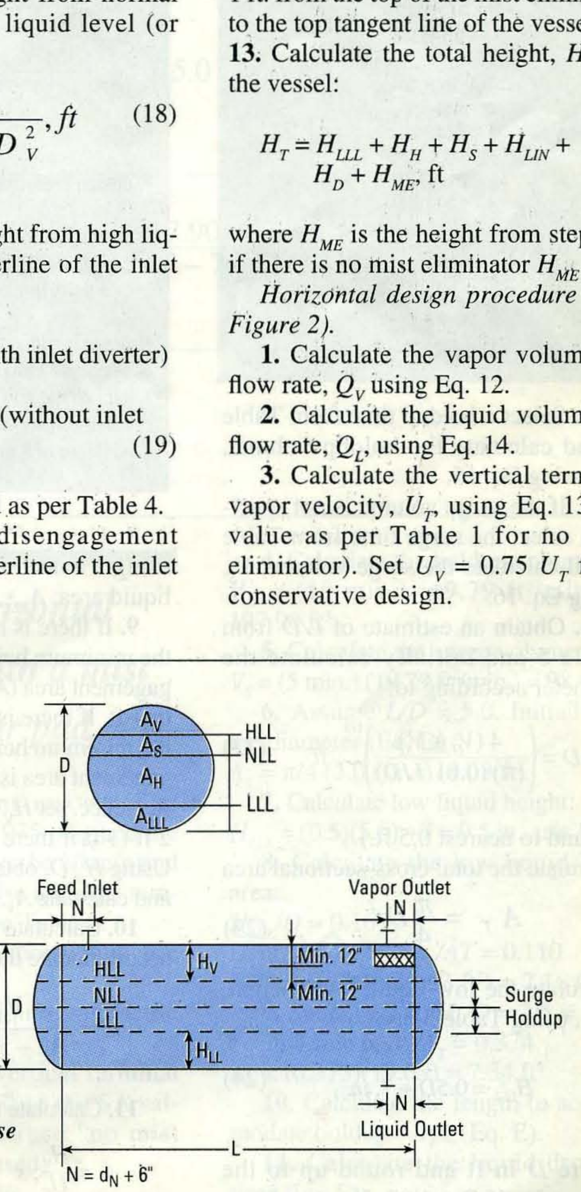
where H_{ME} is the height from step 12; if there is no mist eliminator $H_{ME} = 0$.

Horizontal design procedure (See Figure 2).

1. Calculate the vapor volumetric flow rate, Q_V using Eq. 12.

2. Calculate the liquid volumetric flow rate, Q_L, using Eq. 14.

3. Calculate the vertical terminal vapor velocity, U_T, using Eq. 13, (K value as per Table 1 for no mist eliminator). Set $U_V = 0.75\ U_T$ for a conservative design.



■ *Figure 2. Horizontal two-phase separator.*

Table 6. Cylindrical height and area conversions.

$Y = (a + cX + eX^2 + gX^3 + iX^4)/(1.0 + bX + dX^2 + fX + X^4)$

H/D to A/A_T
$Y = A/A_T$
$X = H/D$

$a = 4.755930E\text{-}5$
$b = 3.924091$
$c = 0.174875$
$d = -6.358805$
$e = 5.668973$
$f = 4.018448$
$g = -4.916411$
$h = -1.801705$
$i = -0.145348$

A/A_T to *H/D*
$Y = H/D$
$X = A/A_T$
$a = 0.00153756$
$b = 26.787101$
$c = 3.299201$
$d = -22.923932$
$e = 24.353518$
$f = -14.844824$
$g = -36.999376$
$h = 10.529572$
$i = 9.892851$

Table 7. Wall thickness, surface area and approximate vessel height.

	Wall Thickness (in.)	Surface Area (ft²)
Shell	$\frac{PD}{2SE-1.2P}+t_c$	πDL
2:1 Elliptical Heads	$\frac{PD}{2SE-0.2P}+t_c$	$1.09D^2$
Hemispherical Heads	$\frac{PD}{4SE-0.4P}+t_c$	$1.571D^2$
Dished Heads	$\frac{0.885PD}{SE-0.1P}+t_c$	$0.842D^2$
Appropriate Vessel Height	$W=\left(490\frac{lb}{ft^3}\right)\left(\frac{t}{12}\right)(A_s+2A_H)$	

Notes:

P, design pressure, psig (typically, operating pressure + (15-30) psi or 10-15%, whichever greater

T, design pressure, °F (typically, operating pressure +25-50°F if T_{op} > 200°F, if T_{op} < 200°F, 250°F
- under 650°F does not reduce wall thickness
- if overpressure caused by boiling, should be T_{BP}

D, diameter, in.
S, allowable stress, psi (Reference 9)
E, joint efficiency, (0.6-1.0), 0.85 for spot examined joints, 1.0 for 100% x-ray joints
t_c, corrosion allowance, in, typically o to q in.
t, in., larger of t_s and t_H (to nearest q in.)

4. Select a holdup time from Table 2 and calculate the holdup volume, V_H, using Eq. 15.

5. If the surge volume is not specified, select the surge time from Table 2 and calculate the surge volume, V_S, using Eq. 16.

6. Obtain an estimate of *L/D* from Table 5 and initially calculate the diameter according to:

$$D=\left(\frac{4\,(V_H+V_S)}{(\pi)\,(0.6)\,(L/D)}\right)^{1/3},\ ft \qquad (22)$$

(Round to nearest 0.5 ft.)

Calculate the total cross-sectional area

$$A_T=\frac{\pi}{4}D^2 \qquad (23)$$

Calculate the low liquid level height, H_{LLL}, using Table 3 or

$$H_{LLL}=0.5D+7,\ in. \qquad (24)$$

where *D* in ft and round up to the nearest in., if $D \leq 4'0''$, $H_{LLL} = 9$ in.

8. Using H_{LLL}/D, obtain A_{LLL}/A_T using Table 6 and calculate the low liquid area, A_{LLL}.

9. If there is no mist eliminator pad, the minimum height of the vapor disengagement area (A_V) is the larger of 0.2*D* or 1 ft. If there is a mist eliminator pad, the minimum height of the vapor disengagement area is the larger of 0.2*D* or 2 ft. Hence, set H_V to the larger of 0.2*D* or 2 ft (1 ft if there is no mist eliminator). Using H_V/D, obtain A_V/A_T using Table 6 and calculate A_V.

10. Calculate the minimum length to accommodate the liquid holdup/surge:

$$L=\frac{V_H+V_S}{A_T-A_V-A_{LLL}},\ ft \qquad (25)$$

11. Calculate the liquid dropout time,

$$\phi=\frac{H_V}{U_V},\ s \qquad (26)$$

12. Calculate the actual vapor velocity, U_{VA}:

$$U_{VA}=\frac{Q_V}{A_V},\ ft/s \qquad (27)$$

13. Calculate the minimum length required for vapor-liquid disengagement, L_{MIN}:

$$L_{MIN}=U_{VA}\phi,\ \text{ft} \qquad (28)$$

14. If $L < L_{MIN}$, then set $L = L_{MIN}$. (Vapor/liquid separation is controlling). This simply results in some extra holdup. If $L_{MIN} >> L$, then increase H_V and repeat from the step 9. If $L > L_{MIN}$, the design is acceptable for vapor/liquid separation. If $L >> L_{MIN}$, (Liquid holdup is controlling), *L* can only be decreased and L_{MIN} increased if H_V is decreased. H_V may only be decreased if it is greater than the minimum specified in the step 9.

Table 8. Conditions for the horizontal separator (See Example calculation).

	Mass Flow (lb/h)	ρ (lb/ft^3)
Vapor	$W_V = 145{,}600$	$\rho_V = 4.01$
Liquid	$W_L = 46{,}100$	$\rho_L = 38.83$

Table 9. Selection of head types.

1. 2:1 elliptical heads are typically used when $D < 15$ ft and $P > 100$ psig.
2. Hemispherical heads are typically used when $D > 15$ ft regardless of P.
3. Dished heads with knuckle radius = $0.6D$ are typically used when $D < 15$ ft and $P < 100$ psig.

Notes:
P = design pressure
D = drum diameter

(Calculations would have to be repeated from the step 9 with reduced H_V). Calculate L/D. If $L/D > 6.0$ then increase D and repeat calculations from the step 6. If $L/D < 1.5$, then decrease D and repeat calculations from the step 6.

15. Calculate the thickness of the shell and heads according to Table 7.

16. Calculate the surface area of the shell and heads according to Table 7.

17. Calculate the approximate vessel weight according to Table 7.

18. Increase and decrease the diameter by 6 in. increments and repeat the calculations until L/D has ranged from 1.5 to 6.0.

19. With the optimum vessel size (minimum weight), calculate normal and high liquid levels:

$$A_{NLL} = A_{LLL} + V_H/L \tag{29}$$

With A_{NLL}/A_T obtain H_{NLL} from Table 6

$$H_{HLL} = D - H_V \tag{30}$$

Example: Size a horizontal separator with a mist eliminator pad to separate the following mixture. 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. See Table 8.

$$Q_V = \frac{145{,}600\ lb/h}{\left(3{,}600\frac{s}{h}\right)\left(4.01\frac{lb}{ft^3}\right)} = 10.09\ ft^3/s$$

■ *Equation A.*

$$Q_L = \frac{46{,}100\ lb/h}{\left(60\ \frac{\min}{h}\right)\left(38.83\frac{lb}{ft^3}\right)} = 19.79\ ft^3/s$$

■ *Equation B.*

$$U_T = (0.13)\sqrt{\frac{38.83 - 4.01}{4.01}} = 0.38,\ ft/s$$

■ *Equation C.*

$$D = \left(\frac{4(197.90 + 98.95)}{\pi(0.6)(5.0)}\right)^{1/3} = 5.01\ ft/s,\ use\ 5.0 ft$$

■ *Equation D.*

$$L = \frac{V_H + V_S}{A_T - A_V - A_{LLL}},\ L = \frac{197.90 + 98.95}{19.63 - 7.34 - 2.16},\ 29.3,\ say\ 29.5\ ft$$

■ *Equation E.*

$$\phi = \frac{2.0\ ft}{0.29\ ft/s} = 6.90\ s$$

■ *Equation F.*

Size a horizontal separator with a mist eliminator pad.

1. Calculate the vapor volumetric flow rate (Eq. A).

2. Calculate the liquid volumetric flow rate (Eq. B).

3. Calculate the vertical terminal velocity (Eq. C): $K = 0.13$ (GPSA value divided by two since "no mist eliminator" value is used)
$U_V = 0.75U_T = 0.29$ ft/s

4. Calculate the holdup volume:
V_H = (10 min.) (19.79 ft^3/min.) = 197.90 ft^3

5. Calculate the surge volume:
V_S = (5 min.) (19.79 ft^3/min.) = 98.95 ft^3

6. Assume $L/D = 5.0$. Initially set the diameter (Eq. D)
$A_T = \pi/4$ (5.0 ft)^2 = 19.63 ft^3.

7. Calculate low liquid height:
H_{LLL} = (0.5)(5.0) +7 = 9.5 in., use 10 in.

8. Calculate the low liquid level area:
$H_{LLL}/D = 0.167$
Using Table 6, $A_{LLL}/AT = 0.110$
A_{LLL} = (0.110) (19.63 ft^2) = 2.16 ft^2

9. Set H_V = 2 ft, $H_V/D = 2/5 = 0.4$
From Table 6, $A_V/A_T = 0.374$
A_V = (0.373)(19.63) = 7.34 ft^2

10. Calculate the length to accommodate holdup/surge (Eq. E).

11. Calculate the liquid dropout time (Eq. F).

12. Calculate the actual vapor velocity (Eq. G).

13. Calculate L_{MIN} = (1.37 ft/s)(6.90 s) = 9.45 ft

14. $L >> L_{MIN}$ but H_V is minimum and cannot be reduced so L cannot be reduced.

L/D= 29.5/5.0 = 5.9

15. Calculate the thickness of the shell and heads according to Table 7:

- Table 9, use 2:1 elliptical heads
- Assume E = 0.85
- Assume SA 516 70 Carbon Steel, Design Temp. = 650°F
- From *(9)*, S = 17,500 psi
- Assume corrosion allowance = 1/16 in.
- P = 975 x 1.1 = 1,072 psig (See Eq. H).

use t_s = 2-3/8 in. (See Eq. I)

use t_H = 2-1/4 in., and use t = 2-3/8 in.

16. Calculate the surface area of the shell and heads according to Table 7:

$A_S = \pi(5.0\ ft)\ (29.5\ ft) = 463.38\ ft^2$

and

$A_H = (1.09)\ (5.0\ ft)^2 = 27.25\ ft^2$

17. Calculate the approximate vessel weight (Eq. J): = 50,224 lb.

18. Try D = 5.5 ft and repeat calculations until minimum weight of shell and heads is obtained. CEP

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$$U_{VA} = \frac{10.09\ ft^3/s}{7.34\ ft^2} = 1.37\ ft/s$$

■ *Equation G.*

$$t_s = \frac{(1{,}072)(60)}{2(17{,}500)(0.85) - (1.2)(1{,}072)} + \frac{1}{16} = 2.322\ in$$

■ *Equation H.*

$$t_H = \frac{(1072)(60)}{2\ (17500)(0.85) - (0.2)(1072)} + \frac{1}{16} = 2.240\ in.$$

■ *Equation I.*

$$W = \left[\left(490\ \frac{lb}{ft^3}\right)\frac{(2.375\quad in)}{(12\quad in/ft)}(463.38\quad ft^2 + (2)(27.25)\quad ft^2)\right]$$

■ *Equation J.*

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