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Vertical Vapor-Liquid Separator Sizing

Use this calculation procedure to perform preliminary sizing of vapor-liquid separation vessels

This procedure includes helpful worksheets to obtain the necessary physical properties
for the calculation of the vessels

The spreadsheet includes both english and metric units.

Advanced users: Click on the sheet named "Dimensions" for customization options

Do not rename sheets in this workbook, do not move cells in this workbook
Some sheets are protected, but protection may be removed.

Revision History :

Vertical Vapor-Liquid Separator Sizing

Applicable to: Vapor-liquid separation vessels either with or without mesh pads

Assumptions of Method:

-- Two phase flow is treated as a homogenous mixture for connection velocity calculations.

-- Sizing is developed based primarily on operating pressure, tolerable carry-over, and velocity

Guidelines shown herein are designed to minimize the pressure/temperature losses experienced through the separation vessel. The pressure losses resulting from a vessel designed with these guidelines should be nearly neglible. If the pressure drop must be known, consult the following reference for two-phase flow correlations:

Walas, Stanely M., "*Chemical Process Equipment: Selection and Design*", Butterworth-Heinemann, 1990, p. 115, ISBN: 0-7506-9385-1

Nomenclature:

M_L	=	Mass flow of liquid entering vessel (lb/h)
M_V	=	Mass flow of vapor entering vessel (lb/h)
ρ_L	=	Liquid density (lb/ft^3)
ρ_V	=	Vapor density (lb/ft^3)
ρ_{mix}	=	Two-Phase mixture density (lb/ft^3)
K	=	Separator sizing factor (ft/s)
V_{max}	=	Maximum allowable vapor velocity in separtor (ft/s)
A_x	=	Vessel cross sectional area (ft^2)
r	=	Vessel radius (ft)
D	=	Vessel diameter (ft)
V_{vconn}	=	Two-Phase velocity in inlet connection (ft/s)
V_{Lconn}	=	Liquid velocity in liquid outlet connections (ft/s)
A_{xvconn}	=	Vessel inlet cross sectional area (ft^2)
A_{xLconn}	=	Vessel liquid outlet cross sectional area (ft^2)
Q_L	=	Volumetric liquid flow entering vessel (ft^3/h)
Q_V	=	Volumetric vapor flow entering vessel (ft^3/h)
λ	=	Volumetric flow factor

References:

Branan, Carl, "*Rules of Thumb for Chemical Engineers*", Gulf Publishing Company, Houston, 1998, p. 128.

Ludwig, Ernest, "*Applied Process Design, Volume 1*", Butterworth-Heinemann, Newton, 1990, p. 265.

Private communication, Mr. Tom Yohe, Swenson Equipment, 2002.

Walas, Stanely M., "*Chemical Process Equipment: Selection and Design*", Butterworth-Heinemann, Newton, 1999, p. 615.

Calculation Details:

Begin by defining how much entrainment can be tolerated. Entrainment describes the amount of liquid that can be tolerated in the vapor exiting the vessel.

- ☐ Up to 5% by weight (not often acceptable)
- ☐ Up to 2.5% by weight, with mesh pad
- ☐ Up to 2.5% by weight, no mesh pad
- ☐ Less than 1% by weight, with mesh pad
- ☐ Less than 1% by weight, no mesh pad

Mesh pads are integral "pads" of wire or plastic. The goal with a mesh pad is to provide the maximum amount of area for the fine liquid droplets to adhere to as possible. Some applications, especially fouling applications, can cause problems with mesh pads.

The 2.5% by weight options may be acceptable in some case depending on the downstream equipment. For evaporation systems, always employ the options for less than 1% by weight carryover.

Use mesh pads with caution. Service much be clean the proper mesh pad material much be chosen to avoid corrosion of the pad.

Example of Mesh Pads

Courtesy Koch-Otto York Separation Technology Bulletin ME5601-3

Less than 1% by weight entrainment, with mesh pad

Define the necessary process information:

Nominal Pressure Inside Vessel	=	3.5	psia	Pressure Converter	406.8 in W.C. =	14.696	psia
Mass Flow Rate of Liquid, M_L	=	330693	lb/h		29.921 in Hg =	14.696	psia
Mass Flow Rate of Vapor, M_V	=	20943	lb/h				
Liquid Density, ρ_L	=	64.5	lb/ft^3	Liquid Density Worksheet			
Vapor Density, ρ_V	=	0.025	lb/ft^3	Vapor Density Worksheet			

(Absolute Pressure)

This type of vessel is considered a "high" efficiency separator with a mesh pad. For pressure operation, we'll define K as 0.25 ft/s and for vacuum operation, K will be taken as 0.20 ft/s. Alternatively, you can define your own K value below: Your K-value would be 0.2 ft/s

K = 0.2 ft/s or, Enter your own K-value = ______ ft/s

Now, calculate the maximum velocity for the system:

$$V_{max} = K\,[(\rho_L - \rho_V)/\rho_V]^{0.50} = 10.16 \text{ ft/s}$$

Override to a custom vessel size: ______ ft

Next, determine the vessel diameter from the maximum vessel velocity:

$$A_x = \pi r^2 = (\pi D^2/4) = M_V / (V_{max}\,\rho_V)$$

$$D = \left\{ \frac{4}{\pi} \cdot \frac{20943 \text{ lb}}{\text{h}} \cdot \frac{\text{s}}{10.16 \text{ ft}} \cdot \frac{\text{ft}^3}{0.025 \text{ lb}} \cdot \frac{\text{h}}{3600 \text{ s}} \right\}^{0.50} = 5.40 \text{ ft}$$

round up to the nearest 6" size = 5.5 ft

Actual vapor velocity at 5.5 ft = 9.79 ft/s

For preliminary sizing of the inlet connection and the vapor outlet, base the connection sizes on the two-phase velocity.

Below are some guidelines:

System Pressure (psia)	Two-Phase Velocity Range (ft/s)
0.50 - 5	150 - 170
5 - 15	180 - 200
15 - 20	200 - 225
20 - 30	225 - 250
30 - 50	250 - 300
> 50	300 - 350

Begin by selecting a vapor connection size:

Step #1 Click here and select an inlet connection size for the velocity calculation

Step #2 Click Here to Import Connection Data

Inlet and Vapor Outlet Connection Data

Outside Diameter	20	in
Wall Thickness	0.594	in
Inside Diameter	18.812	in
Flow Area	1.93018	ft^2

Calculate the density of the incoming two-phase mixture:

$\lambda = Q_L / (Q_L + Q_V) = 0.00608$

$\rho_{mix} = \rho_L \lambda + \rho_V(1-\lambda) = 0.4172 \ lb/ft^3$

$$V_{vconn} = \frac{(M_V + M_L)}{A_{xvconn}\,\rho_{mix}} = \frac{351636 \ lb}{h} \cdot \frac{1}{1.93018 \ ft^2} \cdot \frac{ft^3}{0.4172 \ lb} \cdot \frac{h}{3600 \ s} = 121.30 \ ft/s$$

This connection size will be used for both the inlet connection and the vapor outlet connection.

Check velocity in connection to be sure that is less than or within the range listed above. Adjust connection diameter until this requirement is met.

For the sizing of the liquid outlet connection, remember that these vessels will often be level controlled. If the vessel will not be level controlled, you may want to perform some calculations based on a desired hold up volume. We'll proceed by sizing the connection for a nominal velocity of 0.50 to 3.0 ft/s for the liquid flow:

Begin by selecting a liquid connection size:

Step #1 Click here and select a liquid outlet connection size for the velocity calculation

Step #2 Click Here to Import Connection Data

Liquid Outlet Connection Data

Outside Diameter	8.625	in
Wall Thickness	0.322	in
Inside Diameter	7.981	in
Flow Area	0.34741	ft^2

$V_{Lconn} = M_L / (A_{xLconn}\ \rho_L)$

V_{Lconn} =	330693 lb		ft^3	h
	h	0.34741 ft^2	64.5 lb	### s

V_{Lconn} = 4.10 ft/s

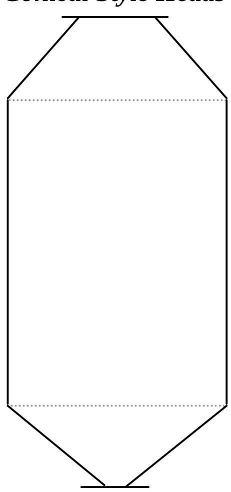
Expected range is 0.50 to 3.0 ft/s, depending on hold up volume requirements.

Next, select one of the two common head designs for the separator. Conical heads are generally less expensive to manufacture while ellipsoidal heads can help keep the vessel height minimized:

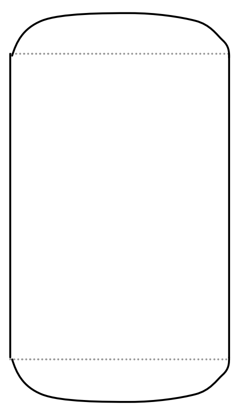
- Conical Heads
- Ellipsoidal Heads

Detailed drawing on next page

Conical Style Heads



Ellipsoidal Style Heads



All dimensions in inches

Separator Drawing, Ellipsoidal Style Heads

A. 2 x 1" Pressure Connections

B. 1" Level Control Connections

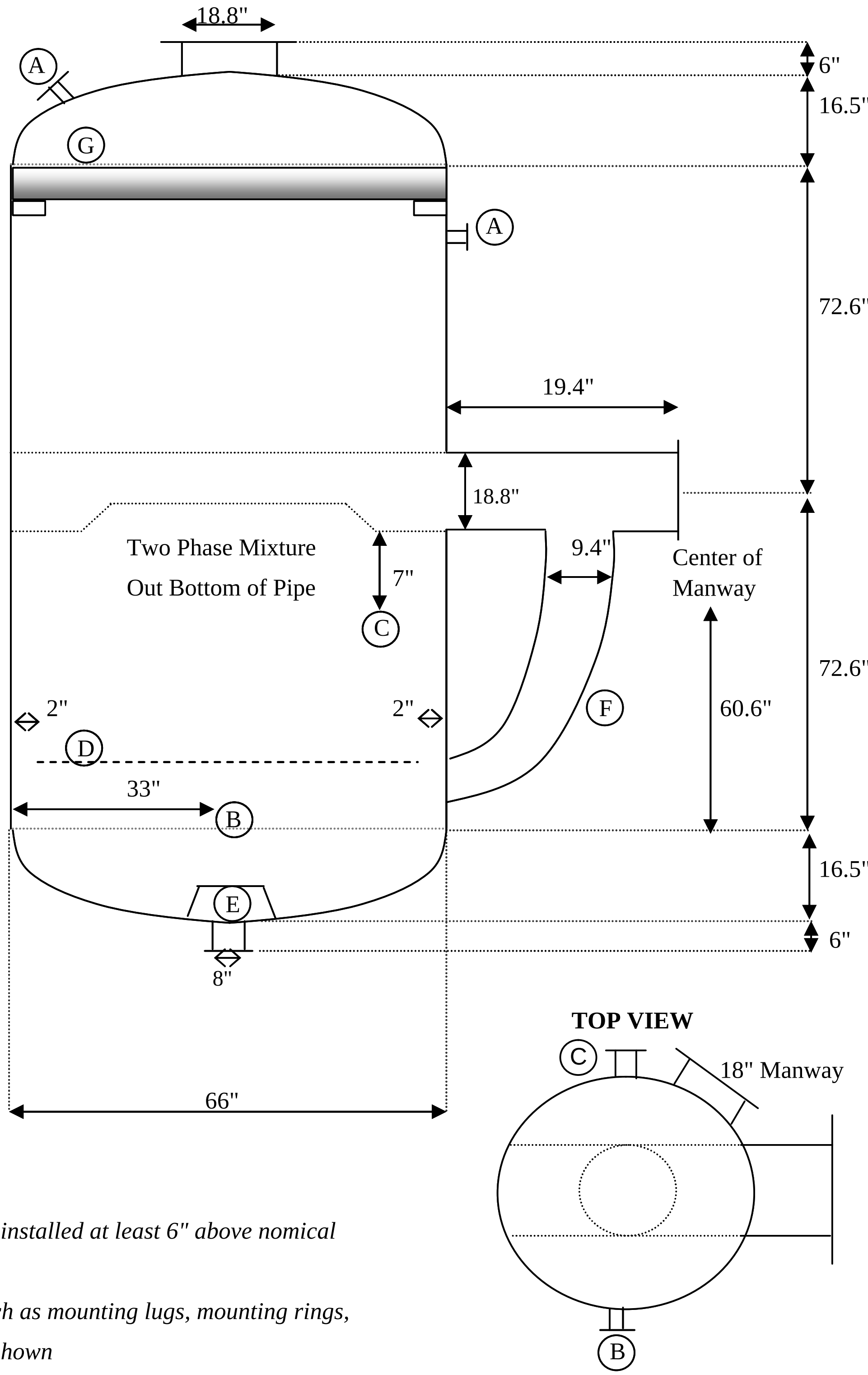
C. 6" Peephole with Light

D. Perforated Calming Sheet

E. Vortex Breaker

F. Liquid Disengagement Arm

G. 6" High Efficiency Mesh Pad



NOTES

i. Calming sheet should be installed at least 6" above nomical liquid level

ii. Support mechanisms such as mounting lugs, mounting rings, or vessel legs are not shown

Connection Selection Tool

Units of Measure	Imperial	
Type of Piping	Carbon Steel	
Nominal Pipe Size	4	
Schedule	40	
Enter Custom Pipe Values		
	Imperial	
Outside Diameter	4.5	in
Wall Thickness	0.237	in
Inside Diameter	4.026	in
Flow Area	0.08840461	ft2

Return to Calculation by Clicking on the tab marked "English" or "Metric"

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Liquid Density Calculation Worksheet

1. For pure fluids, check the table below
   If your fluid is not listed, consult one of many good source in print or online.

2. For mixtures, use a weighted average of the liquid densities of each component:
   $\rho_{mix} = \Sigma x_i \rho_i$

Mass Fractions	Liquid Densities	Weighted Densities	
0.2	62	12.4	
0.1	95	9.5	
0.3	55	16.5	
0.5	58	29	
		0	
		0	
		67.4	Estimated Mixture Density

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Vapor Density Calculation Worksheet

1. For pure vapor below 10 bar or 150 psi, employ the ideal gas law:

English Units

ρ_{vap} =	P (MW) / R T =	2.5 psia	18 lb / lb-mole	lb-mole °F / 11 ft^3 psia	/ 235 °F

= 0.018 lb / ft^3

Metric Units

ρ_{vap} =	P (MW) / R T =	0.4 bar	18 g / mol	mol °C / 0.08 L bar	/ 112.7 °C

= 0.768 g / L or kg / m^3

2. For pure vapors above 10 bar or 150 psi, employ the Redlick-Kwong relationship to calculate the compressibility:

$Z^3 - Z^2 + (A-B-B^2) Z - AB = 0$

where:

$A = \frac{0.4278\ Pr}{Tr^{2.5}}$ and $B = \frac{0.08664\ Pr}{Tr}$

Tr = T / Tc

Pr = P / Pc

Lookup Chart for Critical Temperatures and Pressures

English Units

Tc = 455.36 °F Operating Temperature = 392 °F

Pc = 734.8 psia Operating Pressure = 50 psia

Tr = 0.86086 °F Pr = 0.068046 psia

A = 0.042336 B = 0.006848

Z = #### Solver Cell = 0.000 (set equal to zero)

If you have Solver installed, press "Ctrl+s" to solve

Then, compressibility can be added to the gas equation for improved accuracy:

ρ_{vap} =	P (MW) / R T Z =	50 psia	85 lb / lb-mole	lb-mole °F / 11 ft^3 psia	/ 392 °F	/ 0.964

= 1.049 lb / ft^3

Lookup Chart for Critical Temperatures and Pressures

<u>Metric Units</u>

Tc = 235.2 °C Operating Temperature = 400 °C

Pc = 50.6 bara Operating Pressure = 10.13 bara

Tr = 1.700680 °C Pr = 0.200198 bara

A = 0.022706 B = 0.010199

Z = #### Solver Cell = 0.000 (set equal to zero)

If you have Solver installed, press "Ctrl+d" to solve

Then, compressibility can be added to the gas equation for improved accuracy:

<u>Metric Units</u>

ρ_{vap} =	P (MW) / R T Z	=	10.13 bar	85 g / mol	mol °C / 0.08 L bar	/ 400 °C	/ 0.988

= 26.2 g / L or kg / m^3

3. For vapor mixtures where the density is not known consult the following online calculation which utilizes Peng-Robinson:
http://www.questconsult.com/~jrm/thermot.html

If one or more of your components are not available in the component list at this site, you may have to utilize another EOS along with Kay's method and generalized compressibility charts.