VERTICAL GAS-LIQUID SEPARATOR CALCULATOR

Simon Learman

Blackmonk Engineering Ltd
www.blackmonk.co.uk

Contents

Introduction

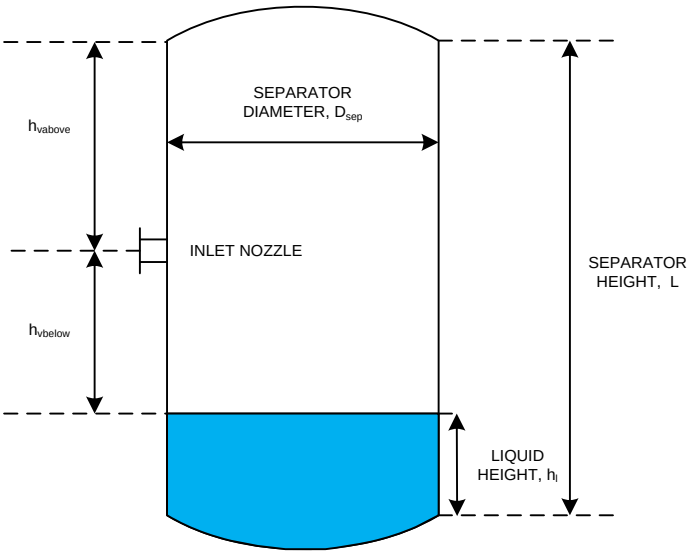
This document describes the basis and operation of the Blackmonk Engineering Vertical Gas-Liquid Separator Calculator.

The calculation methodology is based on that described in Chapter 8 of "Rules of Thumb for Chemical Engineers", 3rd Edition, Carl Branan, Gulf Publishing.

The calculator determines the vessel diameter and tan-to-tan height required to separate liquid from gas/vapour with a specified liquid hold-up time.

The calculator determines the Souders-Brown separator sizing factor automatically in addition to the maximum vapour velocities in the vessel and through the inlet nozzle.

System Diagram



Calculation Inputs

The following parameters are user specified inputs to the calculation:

Input	Description	Units
Liquid flow rate	Mandatory user specified liquid mass flow rate to the separator	kg/hr
Vapour flow rate	Mandatory user specified vapour mass flow rate to the separator	kg/hr

Liquid density	Mandatory user specified liquid density	kg/m^3
Vapour density	Mandatory user specified vapour density	kg/m^3
Liquid hold-up time	Mandatory user specified liquid hold-up time required in the vessel	min

Calculation Outputs

The following parameters are calculated by the software and displayed to the user:

Output	Description	Units
Liquid volumetric flow rate	Volumetric flow rate of liquid entering the separator vessel	m3/hr
Vapour volumetric flow rate	Volumetric flow rate of vapour entering the separator vessel	m3/hr
Mixture density	Density of the mixed liquid and vapour stream entering the separator	kg/m^3
Separation factor	Vertical gas-liquid separator separation factor	N/A
Separator sizing factor	Vertical gas-liquid separator Souders-Brown separator sizing factor	m/s
Maximum vapour velocity	Maximum vapour velocity in the vessel	m/s
Minimum separation area required	Minimum cross sectional area of the vessel required for separation based on the maximum vapour velocity	m^2
Minimum separator diameter	Minimum diameter of the vessel required for separation based on the maximum vapour velocity	m
Maximum inlet nozzle velocity	Maximum allowable velocity in the vessel inlet nozzle based on maximum momentum criteria	m/s
Minimum inlet nozzle velocity	Minimum allowable velocity in the vessel inlet nozzle based on minimum momentum criteria	m/s
Maximum inlet nozzle diameter	Inlet nozzle diameter calculated on the basis of the minimum inlet nozzle velocity criteria	m
Recommended inlet nozzle size	Maximum inlet nozzle diameter rounded up to the nearest standard pipe size	inch
Liquid hold-up volume	Volume of liquid corresponding to the required liquid hold-up time at the specified liquid flow rate	m^3
Liquid height	Height of liquid corresponding to the liquid hold-up volume based on the recommended separator diameter	m
Vapour height above centre line of inlet nozzle	Height above the inlet nozzle centre line to the top tan line of the vessel	m
Vapour height below centre line of inlet nozzle	Height below the inlet nozzle centre	m

	line to the maximum liquid level	
Vessel height tan to tan	Distance between the bottom and top tan lines of the vessel i.e. the vessel cylindrical heigh	m
Recommended separator diameter	Minimum separator diameter rounded up to the nearest 150 mm increment	m
Vessel L:D	The ratio of the vessel tan to tan height to the recommended separator diameter	N/A

Gas-Liquid Separator Design

The calculator sizes gas-liquid separators on the basis of maximum gas (or vapour) velocity within the vessel as given by the Souders-Brown equation.

Maximum Vapour Velocity

The maximum gas (or vapour) velocity is given by the Souders-Brown equation below:

$$u_{vapmax} = K\left[\frac{(\rho_l - \rho_v)}{\rho_v}\right]^{0.5} \quad \text{Equation 1}$$

Separator Sizing Factor, K

The Souders-Brown Separator Sizing Factor, K, is determined from the following correlation:

$$K = \left(\frac{1}{3.281}\right) exp\left(A + Bln(S_f) + Cln(S_f)^2 + Dln(S_f)^3 + Eln(S_f)^4 + Fln(S_f)^5\right) \quad \text{Equation 2}$$

Where:

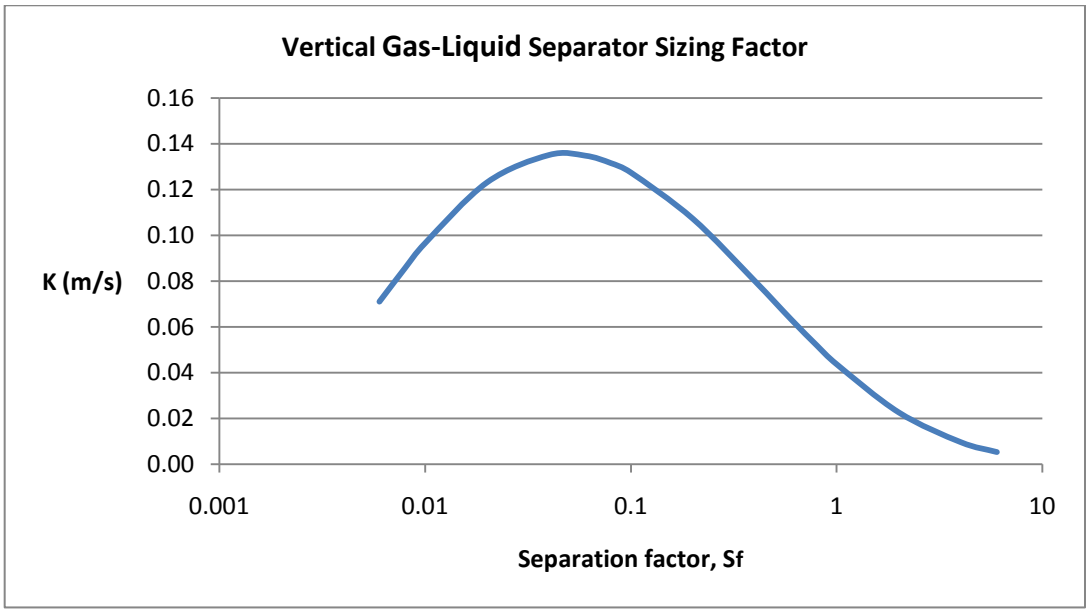
A = -1.942936
B = -0.814894
C = -0.179390
D = -0.0123790
E = 0.000386235
F = 0.000259550

The separation factor, S_f is calculated using the following equation:

$$S_f = \left[\frac{m_l}{m_v}\right]\left[\frac{\rho_v}{\rho_l}\right]^{0.5}$$ Equation 3

The Souders-Brown Separator Sizing Factor correlation is based on the data presented in the chart below for 5% of the liquid to be entrained in the vapour stream. This is considered adequate for normal design.

Figure 1: Separator Sizing Factor Chart



Volumetric Flow Rates

The volumetric flow rates of the liquid and vapour components of the feed stream to the separator are calculated using the equations below:

$$Q_l = \frac{m_l}{\rho_l}$$ Equation 4

$$Q_v = \frac{m_v}{\rho_v}$$ Equation 5

Mixture Density

The density of the mixed feed stream is calculated using:

$$\rho_{mix} = \frac{m_l + m_v}{Q_l + Q_v}$$ Equation 6

Separator Diameter

The minimum separation area required is calculated using:

$$A_{min} = \frac{Q_v}{u_{vapmax}}$$ Equation 7

From which the minimum required separator diameter is determined:

$$D_{min} = \left(\frac{4A_{min}}{\pi}\right)^{0.5}$$ Equation 8

The recommended separator diameter is determined by rounding up the calculated minimum separator diameter to the nearest 150 mm increment to be consistent with standard rolled plate dimensions.

$$D_{sep} = \left[Roundup\left(\frac{D_{min}}{0.150}\right) to\ whole\ number\right] \times 0.150$$ Equation 9

Separator Inlet Nozzle Design

The separator inlet nozzle is sized based on the following correlations for the maximum and minimum nozzle velocities:

$$u_{nozmax} = \frac{121.98}{\rho_{mix}^{0.5}}$$ Equation 10

$$u_{nozmin} = \frac{73.19}{\rho_{mix}^{0.5}}$$ Equation 11

The maximum inlet nozzle diameter is then determined from:

$$d_{inlet\ max} = \left[4\left(\frac{Q_l + Q_v}{\pi u_{nozmin}}\right)\right]^{0.5}$$ Equation 12

The recommended inlet nozzle size is determined by selecting the next largest standard pipe size based on the maximum inlet nozzle diameter.

Liquid Hold-Up Volume

Liquid hold-up volume is calculated based on the liquid flow rate to the separator and the specified required liquid hold-up time.

$$V_l = Q_l \tau \qquad \text{Equation 13}$$

The height of liquid corresponding to the required liquid hold-up volume is given by:

$$h_l = \frac{4V_l}{\pi D_{sep}^2} \qquad \text{Equation 14}$$

Vapour Height

The vapour height above the centre line of the inlet nozzle to the top tan line of the vessel is calculated based on the following correlation:

$$h_{vabove} = 0.9 + \frac{d_{inlet}}{2} \text{ for } h_{vabove} \geq 1.2 \qquad \text{Equation 15}$$

$$h_{vabove} = 1.2 \text{ for } 0.9 + \frac{d_{inlet}}{2} \leq 1.2 \qquad \text{Equation 16}$$

The vapour height below the centre line of the inlet nozzle to the maximum liquid level is calculated based on the following correlation:

$$h_{vbelow} = 0.3 + \frac{d_{inlet}}{2} \text{ for } h_{vabove} \geq 0.45 \qquad \text{Equation 17}$$

$$h_{vbelow} = 0.45 \text{ for } 0.3 + \frac{d_{inlet}}{2} \leq 0.45 \qquad \text{Equation 18}$$

Separator Vessel Tan-to-Tan Height

The tan-to-tan height of the separator vessel is given by:

$$L = h_l + h_{vabove} + h_{vbelow}$$ Equation 19

Vessel Length:Diameter Ratio

It is recommended that the vessel length to diameter ratio is maintained between 3 and 5.

$$3 \leq L{:}\, D_{sep} \leq 5$$ Equation 20

Calculation of Vertical Gas-Liquid Separator

The calculation routine is described in the following steps:

1. Calculate liquid and vapour volumetric flow rates using Equation 4 and Equation 5
2. Calculate mixture density using Equation 6
3. Calculate Separation Factor, S_f using Equation 3
4. Calculate Separator Sizing Factor, K using Equation 2
5. Calculate maximum vapour velocity using Equation 1
6. Calculate minimum separation area required using Equation 7
7. Calculate minimum separator diameter using Equation 8
8. Calculate recommended separator diameter using Equation 9
9. Calculate maximum and minimum inlet nozzle velocities using Equation 10 and Equation 11
10. Calculate the maximum inlet nozzle diameter using Equation 12
11. Determine the recommended inlet nozzle diameter based on standard pipe sizes
12. Calculate the liquid hold-up volume using Equation 13
13. Calculate the liquid height using Equation 14
14. Calculate the vapour height above and below the inlet nozzle using Equation 15, Equation 16, Equation 17 and Equation 18
15. Calculate the vessel tan-to-tan height using Equation 19
16. Calculate the vessel length:diameter ratio using Equation 20
17. Generate warning if L:D < 3 or L:D > 5

Nomenclature

A_{min} = Minimum separation area required (m^2)
d_{inlet} = Recommended inlet nozzle diameter (m)
$d_{inlet\ max}$ = Maximum inlet nozzle diameter (m)
D_{min} = Minimum separator diameter (m)
D_{sep} = Recommended separator diameter (m)
h_l = Liquid height in separator (m)
h_{vabove} = Vapour height above inlet nozzle centre line to top tan line (m)
h_{vbelow} = Vapour height below inlet nozzle centre line to maximum liquid level (m)
K = Souders-Brown Separator Sizing Factor ($m.s^{-1}$)
L = Vessel tan-to-tan height (m)
m_l = Liquid mass flow rate to separator ($kg.s^{-1}$)
m_v = Vapour mass flow rate to separator ($kg.s^{-1}$)
Q_l = Liquid volumetric flow rate to separator ($m^3.s^{-1}$)
Q_v = Vapour volumetric flow rate to separator ($m^3.s^{-1}$)
S_f = Separation factor (dimensionless)
u_{nozmax} = Maximum velocity through separator inlet nozzle ($m.s^{-1}$)
u_{nozmin} = Minimum velocity through separator inlet nozzle ($m.s^{-1}$)
u_{vapmax} = Maximum vapour velocity in separator ($m.s^{-1}$)
V_l = Liquid hold-up volume in separator (m^3)
ρ_l = Liquid density ($kg.m^{-3}$)
ρ_v = Vapour density ($kg.m^{-3}$)
ρ_{mix} = Mixture density ($kg.m^{-3}$)
τ = Liquid hold-up time (s)

Example

The following example was adapted from the GPSA Data Book Example 7-3 page 7-8.

Description:

A vertical separator is required to handle 76320 kg/hr of gas with a density of 33.4 kg/m^3. The feed to the separator also contains 2500 kg/hr of liquid with a density of 500 kg/m^3. A liquid hold-up time of 90 minutes is required.

Requirement:

Determine the separator diameter and height required.

Solution:

Calculated Separator Sizing Factor, K = 0.089 m/s (cf GPSA published value of 0.089 m/s)

Calculated maximum vapour velocity, u_{vapmax} = 0.33 m/s (cf GPSA published value of 0.33 m/s)

Calculated minimum separator diameter, D_{min} = 1.563 m (cf GPSA published value of 1.560 m)

Recommended separator diameter, D_{sep} = 1.650 m

Calculated separator tan-to-tan height, L = 5.158 m

Calculated L:D = 3.13

Vertical Gas-Liquid Separator Calculator Screenshot:

INPUTS

Liquid flow rate	m_l	2500	kg/hr
Vapour flow rate	m_v	76320	kg/hr
Liquid density	ρ_l	500	kg/m3
Vapour density	ρ_v	33.4	kg/m3
Liquid hold-up time	τ_l	90	min

OUTPUTS

Liquid volumetric flow rate	Q_l	5.00	m3/hr
Vapour volumetric flow rate	Q_v	2285.03	m3/hr
Mixture density	ρ_{mix}	34.42	kg/m3
Separation factor	S_f	0.008	
Separator sizing factor	K	0.089	m/s
Maximum vapour velocity	u_{vapmax}	0.33	m/s
Minimum separation area required	A_{min}	1.918	m2
Minimum separator diameter	D_{min}	1.563	m
Maximum inlet nozzle velocity	u_{nozmax}	20.79	m/s
Minimum inlet nozzle velocity	u_{nozmin}	12.48	m/s
Maximum inlet nozzle diameter	$d_{inlet\ max}$	0.255	m
Recommended inlet nozzle size	d_{inlet}	10	inch
Liquid hold-up volume	V_l	7.500	m3
Liquid height	h_l	3.508	m
Vapour height above centre line of inlet nozzle	h_{vabove}	1.200	m
Vapour height below centre line of inlet nozzle	h_{vbelow}	0.450	m
Vessel height tan to tan	**L**	**5.158**	**m**
Recommended separator diameter	**D_{sep}**	**1.650**	**m**
Vessel L:D	**L:D**	**3.13**	