Education Institute for

Equipment & Process Design

Doc.PV3012
Rev.1

In -Line Separator with

Horizontal Flow Vane Pack

D-3012

Design and Principles

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Description

The objective of this vessel is to separate liquid particle from the gas. The vessel is located at the Suction of a compressor so that maximum droplet size contained in gas stream to the section should be max 10 micron. Efficiency of vane pack to be 98% and overall dp ≤ 50 mbar

Operating Parameters

PROCESS DESIGN CONDITION						
FLUID HANDLED			Syngas			
TOTAL FLOW	NORM/MAX		282200	/	310420 (2)	kg/h
PRESSURE	NORM/MAX		25	/	25	bara
TEMPERATURE	NORM/MAX		48	/	48	°C
GAS/VAPOR FLOW	NORM/MAX		281160	/	307320	kg/h
DENSITY @ T,P	20.2	kg/m³	@		47.7 bara, 48°C	
VISCOSITY	0.0120	cP	@		48°C	
LIQUID FLOW INLET	NORM/MAX		1040	/	3100 (3)	kg/h
LIQUID FLOW OUTLET	NORM/MAX		1040	/	3100	kg/h
DENSITY @ T,P	992	kg/m³	@		48°C	
VISCOSITY	0.60	cP	@		48°C	

Max liquid flow rate at B.L. considered for separator design is equal to 1% of process gas flow rate in rated condition.

Design Procedure

1. Select proper Orientation

2. Select and Size proper Inlet Device, Inlet and Outlet ID

3.Calculate Vessel Diameter

4. Calculate Vessel Height

5.Select and Size Manholes, Vent, Drain, Vortex Breaker

1st Step: Select proper orientation

Since the application is gas dominant a vertical vessel is selected.

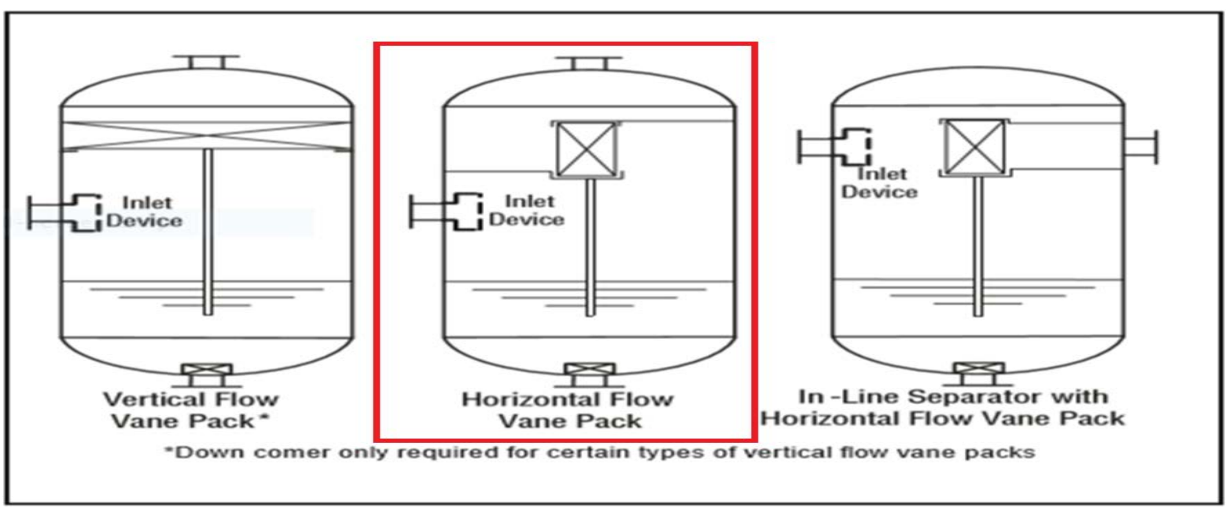
Due to its being at the suction of a compressor, an internal eliminator should be installed.

Equipment Type	Contaminant Removed	Micron Rating Achievable	Pressure Drop Clean & Wet	Relative Operating Cost
Separator with internals	Liquids	3-40	Low 0.7 kPa-10.3 kPa	Low to higher
Filter – Separator	Liquids & Solids	1 micron	13.8 kPa or less	Higher
Gas Coalescer	Liquids & Solids	0.3 micron	13.8 kPa	Highest
Dry Gas Filter	Solids	Various	13.8 kPa or less	Higher

Vertical Separator with Vane Pack

Vertical separators with vane packs can be used instead of wire mesh for the following reasons: fear of fouling of the wire mesh, where corrosion and life of the demisting device requires a more robust design than mesh pads, to reduce separator size and cost compared to mesh, too high a liquid load for mesh.

Vertical separators with vane packs have a moderate turndown ratio, are suitable for slightly fouling service (straight or some single-pocket vanes only). The typical droplet removal efficiency for vane styles is provided in “Vane Separator Devices”, earlier in this Chapter. Vane separators are less efficient overall than wire mesh in most applications. Vertical separators with vanes are best utilized below 4825 kPa (ga). Higher efficiency can be obtained at pressures above 4825 kPa (ga) by using double pocket vanes. Vanes can tolerate higher liquid load than mesh pads. However, they are sensitive to slugs and require adequate bulk separation upstream, similar to mesh pads. Vane elements have a relatively low pressure drop typically 100 Pa to 1 kPa (ga)]. Vertical separators with vanes are a common alternative to mesh mist eliminators for reciprocating compressors because of their more robust mechanical design, which is advantageous in pulsating service.



This is the most compact vertical vessel using a vane pack. However, the design cannot handle significant liquids or Slugs during an upset.

Separator Type:	No Demisting Internals	Mesh Pad	Vert. Vane Pack	Horiz. Vane Pack	In-line Vane Pack	Axial Flow Multi-Cyclone	Horiz. Flood Mesh/ Vane	Vert. Flood Mesh/Vane	Flood Mesh/ Multi-Cyclone
Gas Handling									
Capacity	Low	Moderate	High	Very High	Very High	Very High	Very High	Very High	Very High
Turndown Capability	∞	4:1	3:1	3:1	3:1	2:1	4:1 or higher	4:1 or higher	4:1 or higher
Liquid Removal Efficiency									
Efficiency Overall	Low	Very High	Moderate	Low/Mod	Low/Mod	High	Moderate	High	High
Efficiency – Fine Mist	Very Low	Very High	Moderate	Moderate	Moderate	High-Very high	Very High	Very High	Very High
Liquid Handling Capacity									
Slugs	High	High	High	Very High	Very Low	High	High	High	High
Droplets	High	High	Moderate	Moderate	Low	High	High	High	High
Fouling Tolerance									
Particulate	Very High	Low	Moderate	Moderate	Moderate	Moderate	Low	Low	Low
Fouling Material	Very High	Very Low	Moderate	Moderate	Moderate	Moderate	Low	Low	Low
Pressure Drop	Very Low	Very Low	Low	Low	Low	High	Low	Low	High

2^{nd} Step: Select and Size proper Inlet Device

Half Pipe has proven itself to be not only effective in large capacities but cost-effective as well and in many applications is preferred to Diffuser whose performance is superior but too costly.

Type of Device	None	Baffle	Elbow	Half Pipe	Diffuser	Cyclone
Momentum Reduction	Poor	Good	Good	Good	Good	Good
Bulk Separation	Good	Poor	Average	Average	Good	Good
Prevent Re-entrainment	Good	Average	Average	Average	Good	Average
Substantial Liquid in Gas	Poor	Ave/Poor	Average	Average	Good	Good
Prevent Liquid Shatter	Good	Poor	Poor	Average	Good	Good
Low Differential Pressure	Good	Good	Good	Good	Good	Average
Prevent Foam Creation	Poor	Poor	Poor	Poor	Average	Good
Gas Distribution	Poor	Average	Average	Poor	Good	Avg/ Poor
Prevent Liquid Surge Entrainment	Good	Good	Good	Poor	Good	Good
Orientation	H/V	H/V	H/T	H/V	H/V/T	H/T
Three Phase	Poor	Average	Average	No	Good	Good

It is also necessary to maintain the inlet velocity head, J, within proper limits for the selected inlet device to insure good gas distribution and minimum liquid shattering.

Where,

$$J = (\rho V^2)$$

The maximum mixed phase velocity head range used in the industry guidelines varies for the different inlet devices. Some typical maximums are:

•6000-9000 max. typ, up to 15 000 max kg/m s2 for diffuser distributor

•975-2250 max kg/m. s2 for no inlet distributor

•1500-3750 max kg/m. s2 for inlet half pipe or elbow distributor

•1500-3750 max kg/m. s2 for v-baffle or other simple inlet diverter designs

In addition, some users limit the inlet vapor phase velocity to 9 m/s or 18 m/s. The velocity should always be below the erosion velocity for the service.

In order to calculate head velocity, at first, we need to perform the followings:

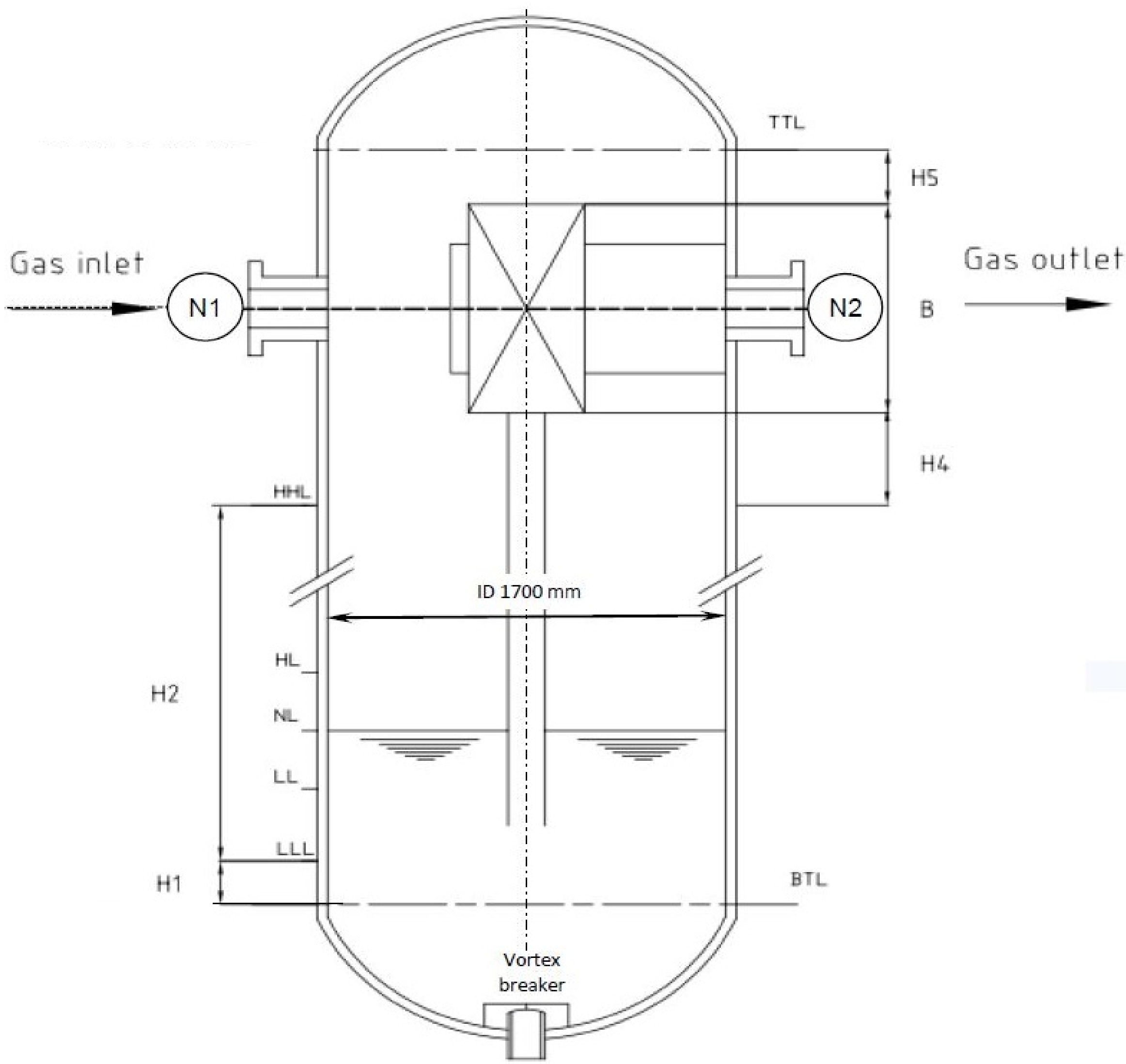
1. Estimation of inlet nozzle ID; Consider inlet pipe ID near the vessel as first and best estimation.

2. Calculate $\rho_{mixture}$ and subsequently $V_{mixture}$

3. Calculate J by multiplying $\rho_{mixture} \times (V_{mixture})^2$ and compare it with the last-page criterion.

Parameter	Value	Value	Value	Unit
Estimated ID	26	28	30	inch
Nozzle Area	0.34	0.39	0.45	m2
$\rho_{mixture}$	20.39	20.39	20.39	kg/m3
$V_{mixture}$	12.34	10.64	9.26	m/s
J	3106	2309	1752	kg/m. s2
Criterion	2250	2250	2250	kg/m. s2

So, the inlet device sizing should at least be 28 inch to meet the momentum requirement but the vendor has chosen to reduce the momentum to help the separation and taken recommended practice that inlet piping diameter match the velocity requirement of the inlet to the separator 10 pipe diameters upstream of the separator to provide a flow regime which is fully developed before entering the separator. Thus 30 inch has been selected by vendor.



Vapor Outlet Section

The sizing of the vapor outlet nozzle should be such that given the above placement of the mesh pad, the velocity is not high enough to cause channeling of the gas through the mesh pad. The nozzle outlet size is typically based on the lesser of that required for piping pressure drop, or a maximum velocity head criterion. Typical ranges for the maximum velocity head allowed for the vapor outlet are 4500–5400 kg/m • s2. In addition, some users limit the absolute velocity to 18 m/s. The pipe size can be decreased to the appropriate size based on pressure drop considerations, 5-10 pipe diameters downstream of the separator, as required. 30 inch is selected.

Parameter	Value	Value	Value	Unit
Estimated ID	22	26	30	inch
Area	0.24	0.34	0.45	m2
Vg	17.23	12.33	9.26	m/s
ρVg2	5998	3074	1734	Kg/m. s2
Criterion	4500	4500	4500	Kg/m. s2

Liquid Outlet Nozzle

Many users limit the liquid outlet nozzle velocity based on pump suction line criteria

Liquid line type	ΔP (bar/km)		Max. Velocity. (m/s) (2)			
	Norm.	Max.	To 2”	3” to 6”	8” to 18”	from 20”
Unit lines - Liquid at bubble point with dissolved gas - Non boiling liquid	0.6 2.3	1.0 3.5	0.6 0.9	1.0 1.2	1.4 1.8	1.8 2.4

Parameter	Value	Value	Value	Unit
Estimated ID	2	3	4	inch
Area	0.002	0.004	0.008	m2
Vl	0.42	0.19	0.1	m/s
Criterion	Max 1.5	Max 1.5	Max 1.5	m/s

Surprisingly 3’ is selected

3rd Step: Calculate Vessel Diameter

Each and every licensor and company has developed a design basis procedure for sizing vessels. In this article, a GPSA-based method, Foster-Wheeler-based method and the Licensor method will be explored.

GPSA

1. Use the following equation and next-page K-values to calculate terminal velocity

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

where

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

De-rating factor to K-value for pressure

Pressure, kPa (ga)	De-rating For Mesh Demisters At Elevated Pressure
Atmospheric	1.00
1034	0.90
2068	0.85
4137	0.80
7929	0.75

Typical Saunders Brown K values for mist eliminator devices

Device	Typical Souders-Brown K Value* m/s
Mesh Vertical Flow to Mesh	0.11
Mesh Horizontal Flow to Mesh	0.13
Vane (simple profile) — Vertical Flow to Vane	0.15
Vane (simple profile) — Horizontal Flow to Vane	0.20
Vanes with single or double pockets — Vertical and Horizontal Flow to Vane	0.20 to 0.30
Vertical Flow To Axial cyclone	0.15 to 0.24
Combination Vane / Mesh Vertical Flow	0.15
Combination Vane / Mesh Horizontal Flow	0.20
Axial cyclone Combinations Vertical Flow	0.15 to 0.24

According to Saunders-Brown K-value , thanks to the fact that a vertical vessel with demister pad has been chosen, a K value of 0.3 is selected. Furthermore, since the performance of demister pad varies according to operating pressure, the selected K should be de-rated in accord with last-page Table.

$$K_{\text{de-rated}} = 0.2 \times 0.85 = 0.16$$

Parameter	Value	Unit
ρ_l	992	kg/m3
ρ_v	20.2	kg/m3
$K_{selected}$	0.16	
U_g	1.1	m/s
Q_g	4.22	m3/s
ID	2202	mm
Required-ID	2200	mm
Selected-ID	2200	mm

Notes

For ID calculation, the following equation has been utilized.

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

The vessel has been sized based on rated capacity and the resulting vessel diameter is 2200 mm. In comparison to vessel sizing based on normal capacity, the resulting vessel diameter is 2100 mm. The vendor has selected 1700 mm as vessel diameter which is due to in-line packed vane.

Foster-Wheeler

The basis of sizing is the critical velocity V_c (m/s)

$$V_c = 0.048\left(\frac{\rho l - \rho g}{\rho g}\right)^{0.5}$$

The maximum gas velocity is $K \times V_c$

K is a coefficient depending on the service, and the use or the absence of wire mesh.

Recommended K values are given hereafter for different services.

Service	Without wire mesh	With wire mesh
Production separator	1.7	2.2
Fuel gas drum	0.8	1.7
Compressor suction drum	0.8	1.7
Glycol or amine contactor inlet drum	0.8	1.7
Reflux drum	1.7	2.2
Steam drum	-	1.3

If a vane pack internal is used, the recommended K value is 3.3.

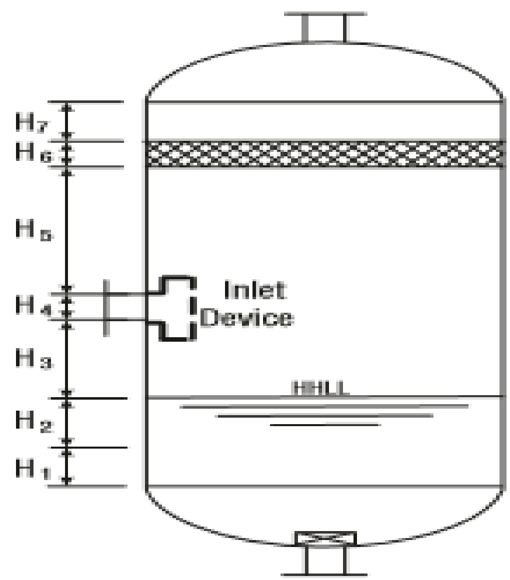
Parameter	Value	Unit
ρ_l	992	kg/m3
ρ_v	20.2	kg/m3
$K_{selected}$	3.3	
V_c	0.33	m/s
V_{max}	1.09	
Q_g	4.22	m3/s
ID	2215	mm
Required-ID	2215	mm
Selected-ID	2200	mm

4th Step: Height Calculation

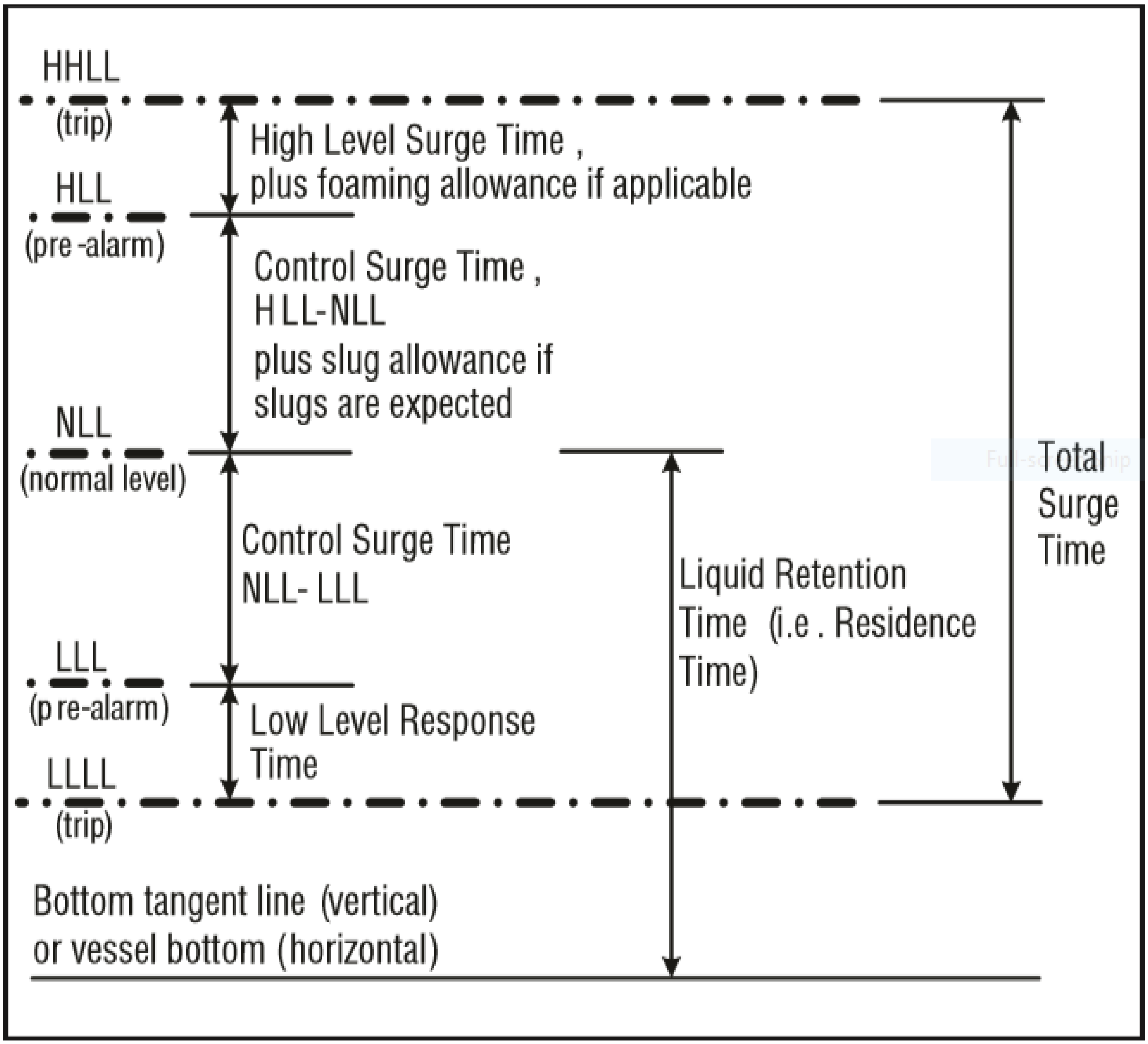
Each and every licensor and company has developed a design basis procedure for sizing vessels. In this article, a GPSA-based method, Foster-Wheeler-based method and the Licensor method will be explored.

GPSA

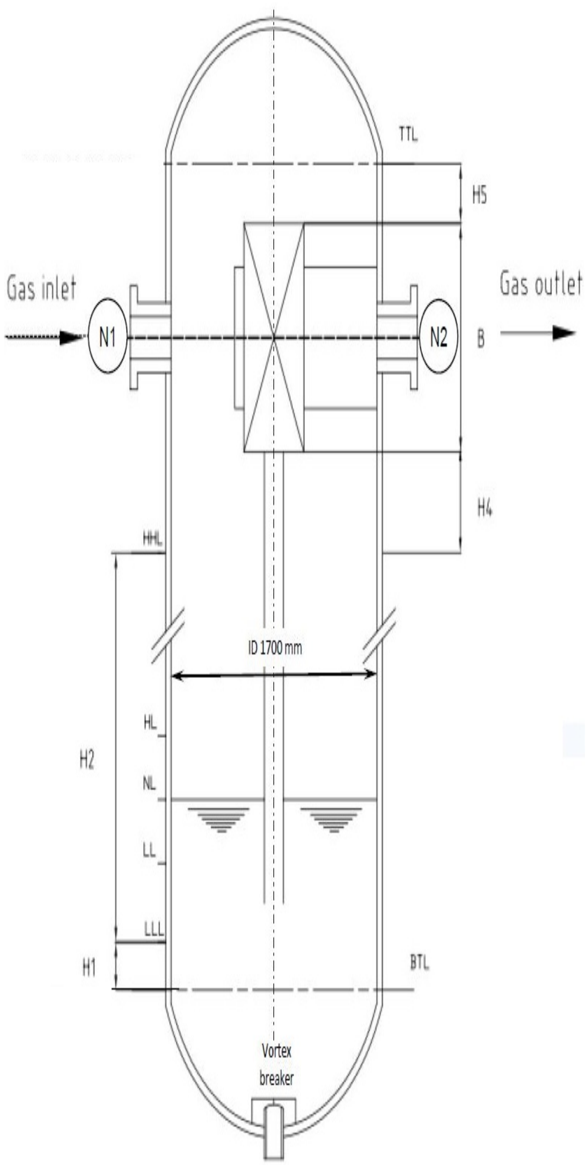
Dim	Section	Distance
H_1	Bottom Tangent to LLLL	300–450 mm, can be lower depending on instrument mount
H_2	LLLL to HHLL	Per required surge time or retention time
H_3	HHLL to Feed Nozzle Bottom	300–600 mm for diffuser 0.25 D for all other inlet devices, with 600 mm minimum
H_4	Nozzle Diameter	Larger of piping size or velocity head criteria
H_5	Nozzle Top to Mist Eliminator Bottom	300–900 mm for diffuser 0.5D for all other inlet devices
H_6	Mist Eliminator	100-150 mm typical
H_7	Mist Eliminator to Top Tangent	150 mm minimum or per Fig. 7-38



Retention/Surge Time



Service	Control Surge Time LLL to HLL	Retention time
Compressor Drum	2 minutes	—
Flash Drum	2-5 minutes	—
Reflux Drum	5 minutes on product plus reflux	—
Surge Drum Upstream of a Tower	5-10 minutes	—
Surge Drum Upstream of a Fired Heat	10 minutes	—
Net Product to Storage	5 Minutes	
Amine Flash Drum	—	5-10 minutes, depending on presence of hydrocarbons
Glycol Flash Drum	—	10-20 minutes depending on presence of hydrocarbons
Refrigeration Accumulator	5 minutes, or based on system or storage requirements	—
Refrigeration Economizer	3 minutes	—
Heat Medium Surge Drum	Maximum liquid expansion, based on 25% to 75% full	—



Height Elements	GPSA	Vendor	Unit
H1	450	150	mm
H2	150	650	mm
H4	425	500	mm
B	2400*	2400	mm
H5	150	100	mm
			mm
			mm
H_T	3600	3800	mm

Calculation, Explanation, and Discussion

H1 mostly depends on instrument mount position and the number of instrument devices used . The Licensor for most of his vertical vessel has selected 500 mm in accord with his FCS and ESD Control System, whereas in GPSA 450 mm is selected as the basis.

H2 is a function of retention time. Likewise, in GPSA a retention time of 2-5 minutes has been selected for Flash drums.

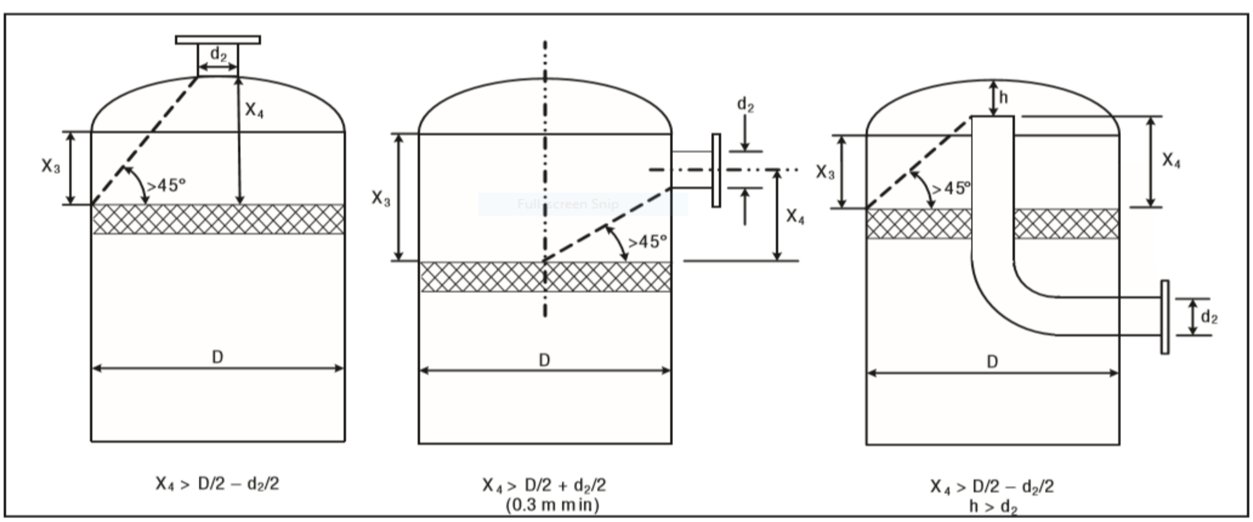
H3 in GPSA for Half Open pipes is 0.25D and has been the basis for calculation.

H4 is the size of inlet Half Open pipe which is the same size of upstream pipe for both vendor and GPSA.

H5 in GPSA for Half Open pipes is 0. 5D and has been the basis for calculation.

H6 is the Vane pack length, which is based on vendor data and varies vendor by vendor.

H7 in GPSA is minimum 150 mm but in other sketch in GPSA there is a formula for X4 which connects the upper part of demister pad to outlet nozzle which cannot be used for comparison here.



Manholes, Drain and Vents

Foster-Wheeler

Size of manholes

For vessel diameter < 1000 mm

Flanged vessel shall be considered if equipment contains internals

Otherwise, size of manholes = 18"

For vessel diameter ≥ 1000 mm

Toxic service size of manholes = 24"

Non-toxic service size of manholes = 20"

(Or up to 24" if internals need to be removable through manhole.)

The drain of the vessel shall always be at the lowest point of a vessel. For vertical vessels they shall be connected to the bottom outlet line at the low point. For horizontal vessels the drain point shall be directly on the bottom of the drum at the lowest point ensured through vessel slope (1:100).

Volume or diameter of vessel (m^3 or mm)	Vent diameter	Drain diameter
V ≤ 15 OR D ≤ 2500	2"	2"
15 < V ≤ 75 or 2500 < D ≤ 4500	2"	3"
75 < V ≤ 220 or 4500 < D ≤ 6000	3"	4"
220 < V ≤ 420 or D > 6000	4"	4"
V > 420	6"	4"

Licensor Criteria

Manhole

Manhole size 24 inches (*1)

Manhole installation for tray tower:

For tray towers, manholes are to be provided at top, bottom, feed point and draw-off point of tower and for each 20 trays or 15 m elevation distance, whichever is the shorter distance, as minimum.

(*1) In case there is restriction for diameter, minimum 20" should be used.

Hand hole or inspection hole

Preferable size	8 inches
Minimum size	6 inches

Vent and drain

Vent and drain for vessels will normally be provided at the minimum length on overhead or bottom line in accordance to the following table:

Volume or diameter of vessel (m^3 or mm)	Vent diameter (inches)	Drain diameter (inches)
V < 75 or D <= 4,500	2	2
75 < V <= 220 4,500 < D <= 6,000	3	3
20 < V <= 420 or D > 6,000	4	4
V > 420	6	4

Note: Vent and drain connections are not necessarily located on vessels.

Comparison

The size of manhole for both Vendor and FW is 24'.

In site both vent and drain size are set to 3'

The Inspection handhole is sized to 8' in site.

Vent sizing in site is 2'.

Parameter	FW	Vendor
Manhole	20-24	24
Vent	2	2
Drain	2	2
Vortex Breaker	Yes	Yes
Inspection		8