Education Institute for

Equipment & Process Design

Doc.PV1001
Rev.1

Vertical Vessel

K.O Drum

D-1001

Design and Principles

Content

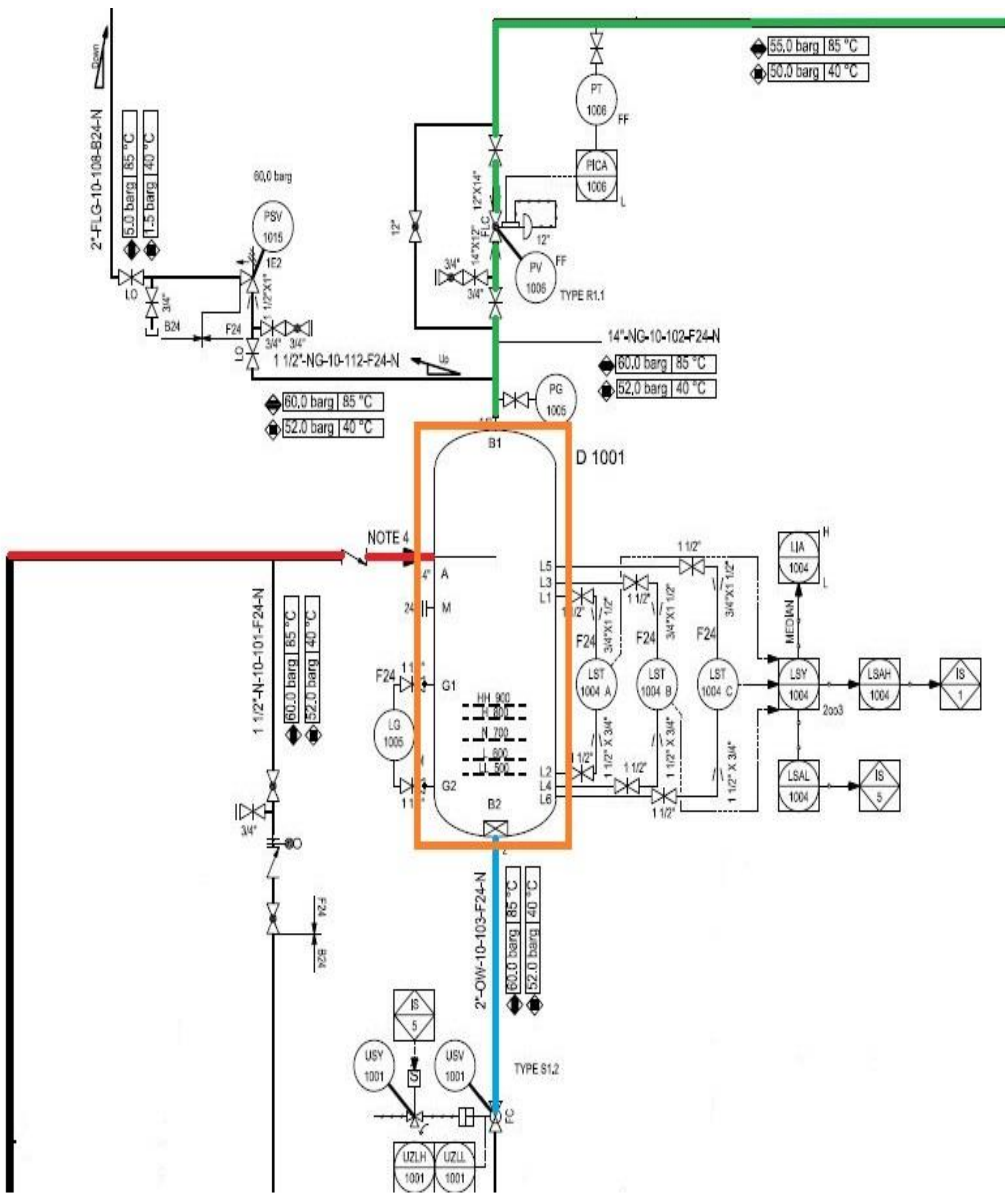
Description

The objective of this vessel is to separate liquid particle from the gas. The vessel is located at plant inlet to prevent condensate from upstream from entering fuel system.

Operating Parameters

Operating temperature	40	°C	Operating pressure	52,0	bar g
Vapor Outlet					
Gas flow 2)	133207	kg/h	Gas density	36,8	kg/m³
Gas molecular weight	16,74	kg/kmol			

Liquid for calculation: 1% of gas total wight with density of 950 kg/m3


2"-FLG-10-108-B24-N
5,0 barg
85 °C
1,5 barg
40 °C
60,0 barg
PSV 1015
PT 1006
PICA 1006
PV 1006
TYPE R1.1
55,0 barg
85 °C
50,0 barg
40 °C
14"-NG-10-102-F24-N
60,0 barg
85 °C
52,0 barg
40 °C
1 1/2"-NG-10-112-F24-N
PG 1005
60,0 barg
85 °C
52,0 barg
40 °C
D 1001
NOTE 4
1 1/2"-N-10-101-F24-N
60,0 barg
85 °C
52,0 barg
40 °C
LG 1005
HH 900
N 700
LL 500
LST 1004 A
LST 1004 B
LST 1004 C
LIA 1004
MEDIAN
LSY 1004
2oo3
LSAH 1004
LSAL 1004
2"-OW-10-103-F24-N
60,0 barg
85 °C
52,0 barg
40 °C
TYPE S1.2
USY 1001
USV 1001
UZLH 1001
UZLL 1001

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.

Since no downstream requirement is emphasized no de-mister pad is needed.

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

2nd 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	12	14	16	inch
Nozzle Area	0.072	0.099	0.129	m2
$\rho_{mixture}$	36.8	36.8	36.8	kg/m3
$V_{mixture}$	13.78	10.12	7.75	m/s
J	6988	3772	2211	kg/m. s2
Criterion	3750	3750	3750	kg/m. s2

So, both 14 and 16 inch are accepted but it is recommended 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, 14 inch is accepted.

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. 14 inch is selected.

Parameter	Value	Value	Value	Unit
Estimated ID	12	14	16	inch
Nozzle Area	0.072	0.099	0.129	m2
$\rho_{mixture}$	36.8	36.8	36.8	kg/m3
$V_{mixture}$	13.78	10.12	7.75	m/s
J	6988	3772	2211	kg/m. s2
Criterion	4500	4500	4500	kg/m. s2

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

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

According to GPSA, thanks to the fact that a vertical vessel without demister pad has been chosen, a K value of 0.046 is selected.

Parameter	Value	Unit
ρl	960	kg/m3
ρv	36.8	kg/m3
$K_{selected}$	0.046	
U_g	0.23	m/s
Q_g	1	m3/s
ID	2357	mm
Required-ID	2357	mm
Selected-ID	2400	mm

Notes

For ID calculation, the following equation has been utilized.

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

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
ρl	960	kg/m3
ρv	36.8	kg/m3
$K_{selected}$	0.8	
V_c	0.24	m/s
V_{max}	0.19	
Q_g	1	m3/s
ID	2580	mm
Required-ID	2580	mm
Selected-ID	2600	mm

Svercheck-Method

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

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

Notes

For ID calculation, the following equation has been utilized.

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

Uv = 0.75 UT

Svercheck Method-K value

K = 0.35 – 0.01 (764-100/100) = 0.28

For vertical vessel without mist eliminator

$K_{selected}$ = 0.28/2 = 0.14

Table 1. Separator K values.

Mist Eliminator

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

GPSA

0 ≤ P ≤ 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 seperators multiply K by 0.7–0.8.

Theoretical (no mist eliminator)

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

$C_D = \exp(Y)$

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

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

Notes:

D_p, ft

ρ, lb/ft³

μ, cP

1 micron = 3.28084 × 10^{-6} ft

Parameter	Value	Unit
ρl	960	kg/m3
ρv	36.8	kg/m3
$K_{selected}$	0.14	
U_g	0.7	m/s
U_v	0.52	
Q_g	1	m3/s
ID	1560	mm
Required-ID	1560	mm
Selected-ID	1550 or 1600	mm

Explanation, Comparison and Discussion

Different criteria have been used to size the vary separator and the difference in diameter results stem from the selected K that each licensor or criterion has set based on their experience. The following table provides the K value and diameter calculated.

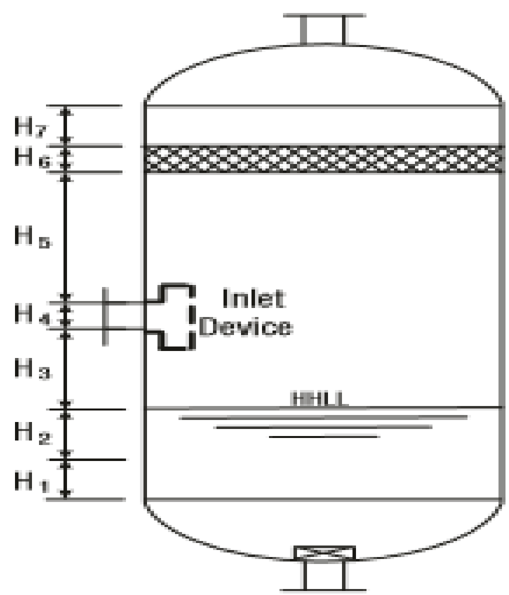
Method	GPSA	FW	Svercheck	Licensor
K-Value	0.046	0.038	0.14	0.14
Diameter	2400	2600	1550	1550

4th Step: Height Calculation

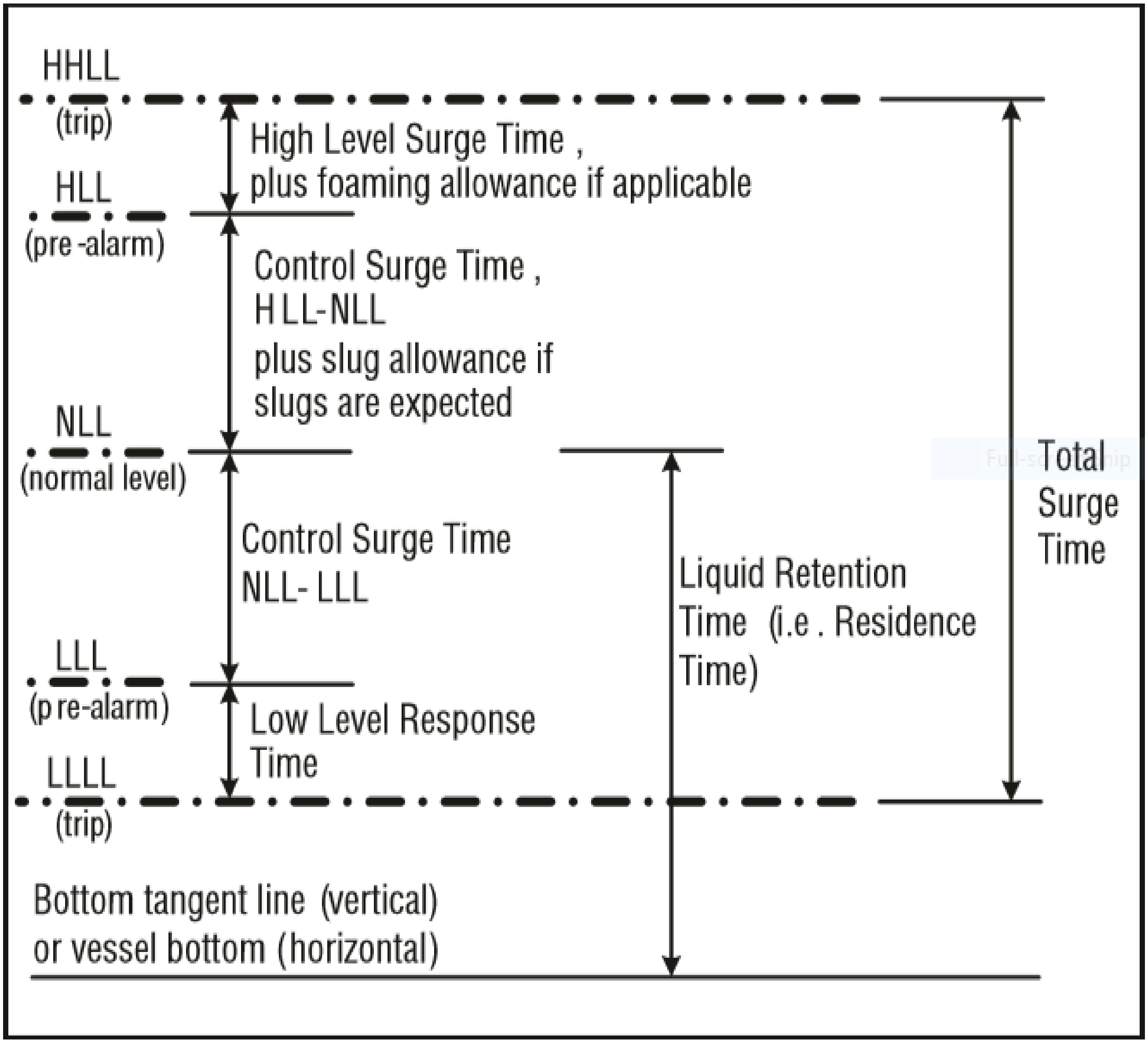
Each and every licensor and company has developed a design basis procedure for sizing vessels. In this article, a GPSA-based method, Foster-Wheeler-based method and the Licensor method will be explored.

GPSA

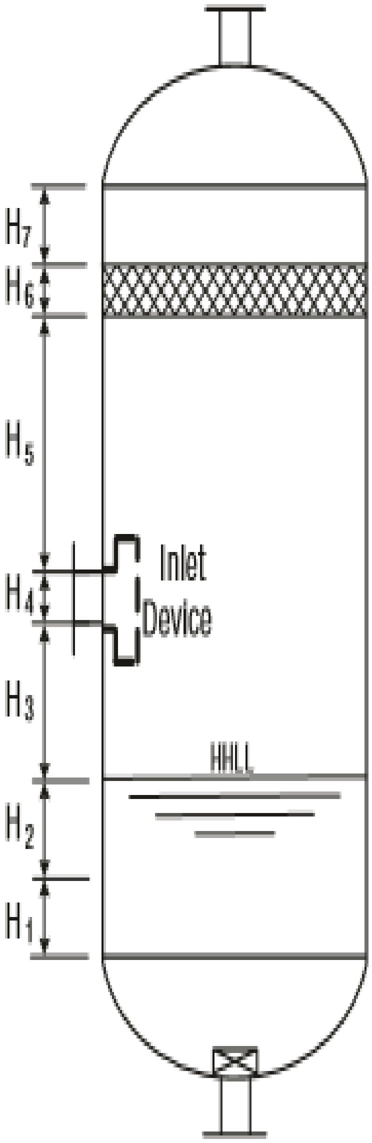
Dim	Section	Distance
H_1	Bottom Tangent to LLLL	300–450 mm, can be lower depending on instrument mount
H_2	LLLL to HHLL	Per required surge time or retention time
H_3	HHLL to Feed Nozzle Bottom	300–600 mm for diffuser 0.25 D for all other inlet devices, with 600 mm minimum
H_4	Nozzle Diameter	Larger of 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 mini-mum 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	LICENSOR	Unit
H1	450	500	mm
H2	50	400	mm
H3	587.5	300	mm
H4	355	355	mm
H5	1200	1000	mm
H6	-		mm
H7	150		mm
HT	2750	2550	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 10 minutes has been

selected for Flash drums. The licensor general retention time table is given in next-page

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

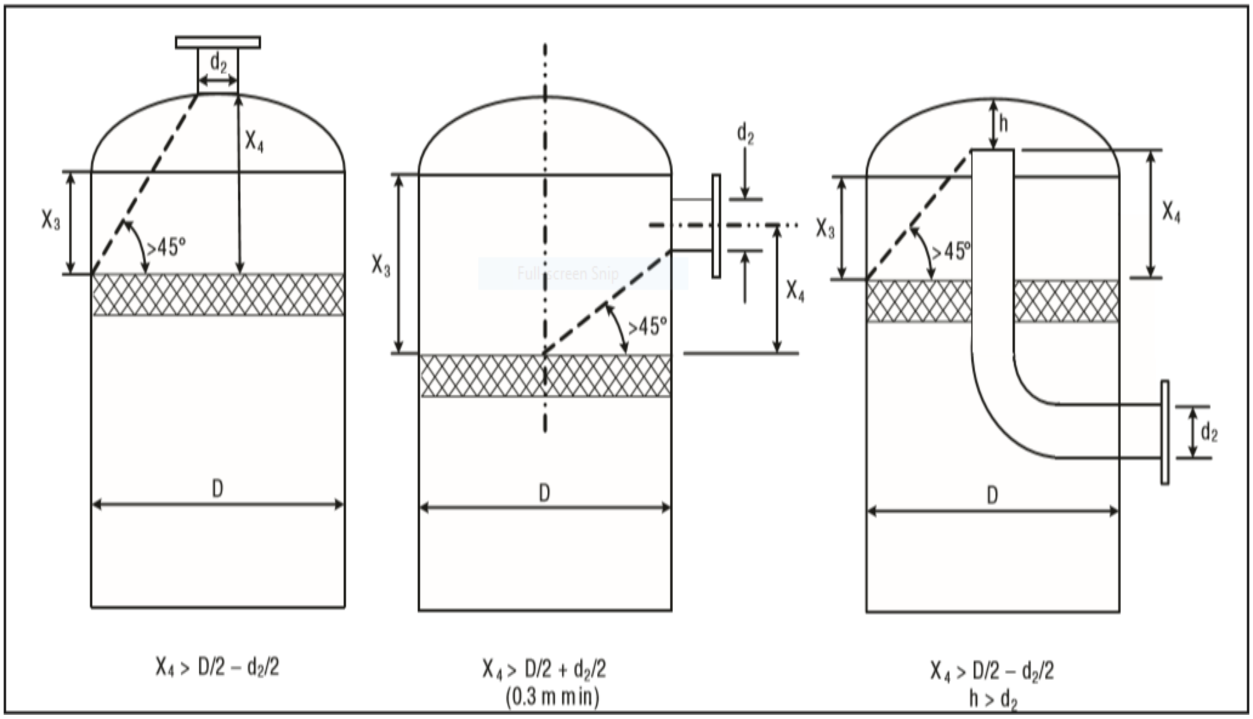
H4 is the size of inlet Half Open pipe which is the same size of upstream pipe for both licensor and GPSA.

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

Retention Time provided by the licensor

Hydraulic retention time (hold up requirements) is defined between low level (LL) and high level (LH).

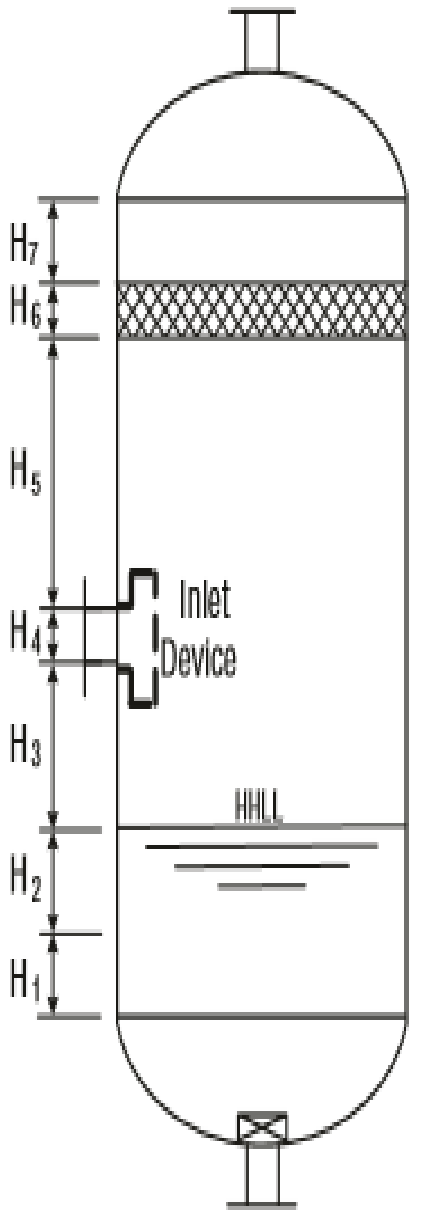
Type of service	Retention time
Feed surge drum	30 minutes
Reflux only	5 minutes
Column feed	
on flow control	15 minutes
on cascade level/flow control	8 minutes
Reboiling by fired heater on feed to heater	8 minutes
Reboiling by thermo siphon on circulation	10 to 30 seconds
Products to storage	
without pump	5 minutes
with pump	7 minutes
Feeds and products feeding another unit	
on flow control	15 minutes
on cascade/level flow control	8 minutes
Tanks	Individually, according to the agreement
Steam drum (LL to empty), min	
From high level to empty	12 minutes
From low level to empty	10 minutes
Deaerator, min	15 minutes


d2
X4
X3
>45°
D
X4 > D/2 – d2/2
d2
X3
>45°
X4
D
X4 > D/2 + d2/2
(0.3 m min)
h
X3
>45°
X4
d2
D
X4 > D/2 – d2/2
h > d2

Foster-Wheeler

SERVICES	TIME (MINUTES)
Feed Surge Drum	
A. to heater	5
B. to others	3 without pump
	5 with pump
Reflux Drum	5
Fractionation tower bottom : the largest of	
A. product to next process	5
B. product to other column	5
C. product to storage tank	3 without pump
	5 with pump
Steam flash drum (process units)	5
Steam drum (utility generation)	10
Desalter	15
Deaerator (note1)	15
Atmospheric degassing drum	15
Others Drums	3 without pump
	5 with pump

DATA SHEET SYMBOL	VERTICAL DRUM	HORIZONTAL DRUM
HHLA/HHLS (HLL)		
	at least 1 to 2 min. with 150 mm min. to verify : min. 10% of control range IF only HLL : HLA-HLL : 10% of control range	at least 1 to 2 min. with 100 mm min. to verify : min. 10% of control range IF only HLL : HLA-HLL : 10% of control range
HLA		
	liquid hold up time to be considered with 300 mm min.	liquid hold up time to be considered with 300 mm min.
LLA		
	at least 1 to 2 min. with 200 mm min. to verify : min. 10% of control range IF only LLL : LLA-LLL : 10% of control range	at least 1 to 2 min. with 100 mm min. to verify : min. 10% of control range IF only LLL : LLA-LLL : 10% of control range
LLLA/LLLS (LLL)		
	300 mm min., but to be compatible with time required to close a SDV	150 mm min., but to becompatible with time required to close a SDV
Tangent line (1)		



Height Elements	FW	LICENSOR	Unit
H1	300	500	mm
H2	50	400	mm
H3	-	300	mm
H4	355	355	mm
H5	-	1000	mm
H6	-		mm
H7	-		mm
HT	-	2550	mm

Svercek Method

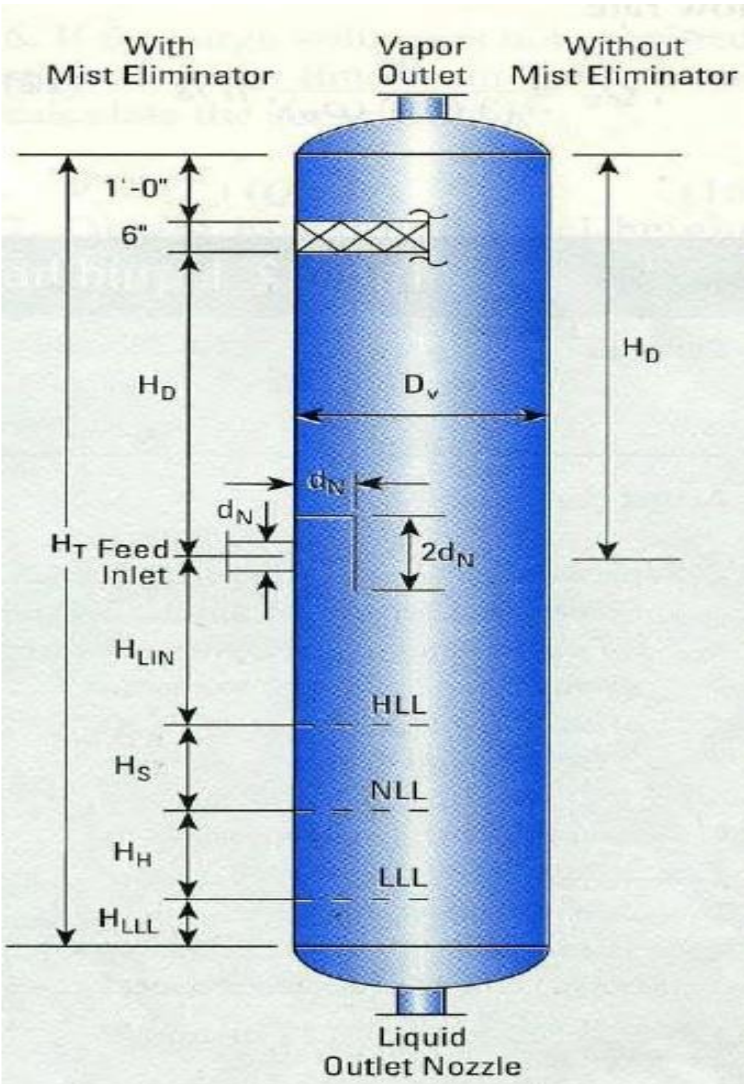


Table 3. Low liquid level height.

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.

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)

$H_D = 0.5\ D_V$ or a minimum of

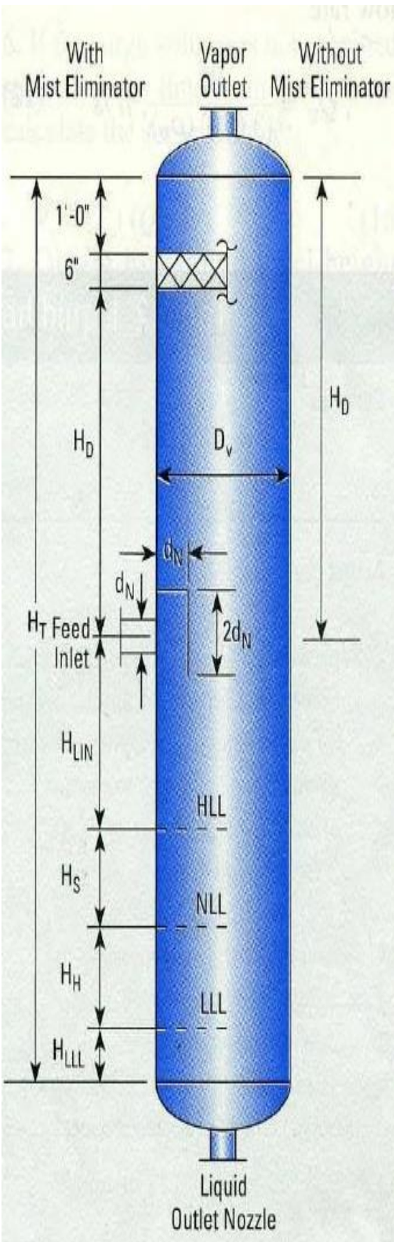
$H_D = 36 + \frac{1}{2} d_N$, in. (without mist eliminator) (20)

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

Table 2. Liquid holdup and surge times.

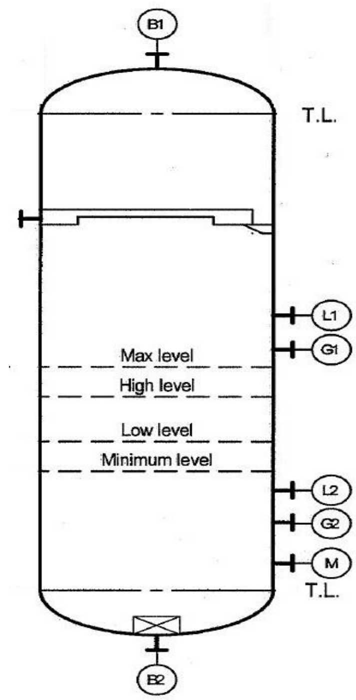
Services	Holdup Times (NLL-HLL) min.	Surge Time (NLL-LLL) min.
A. Unit Feed Drum	10	5
B. Separators		
1. Feed to column	5	3
2. Feed to other drum or tankage		
a) with pump or through exchanger	5	2
b) without pump	2	1
3. Feed to fired heater	10	3
C. Reflux or product accumulator		
1. Reflux only	3	2
2. 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



Height Elements	Svercek	LICENSOR	Unit
HLLL	150	500	mm
HH	50	400	mm
Hs	150	300	mm
HLIN	700	355	mm
HD	1100	1000	mm
H6	-		mm
H7	25		mm
HT	2200	2550	mm

Method	GPSA	FW	Svercek	Licensor
Diameter	2400	2600	1550	1550
Height	2650		2000	2550



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 licensor and FW is 24'.

Neither Drain nor vent valve has been installed.

Parameter	FW	Licensor
Manhole	20-24	24
Vent	2	2
Drain	3	2
Vortex Breaker	Yes	Yes