Education Institute for

Equipment & Process Design

Doc.PV3002
Rev.1

Horizontal Vessel

Without Mist Eliminator

D-3002

Design and Principles

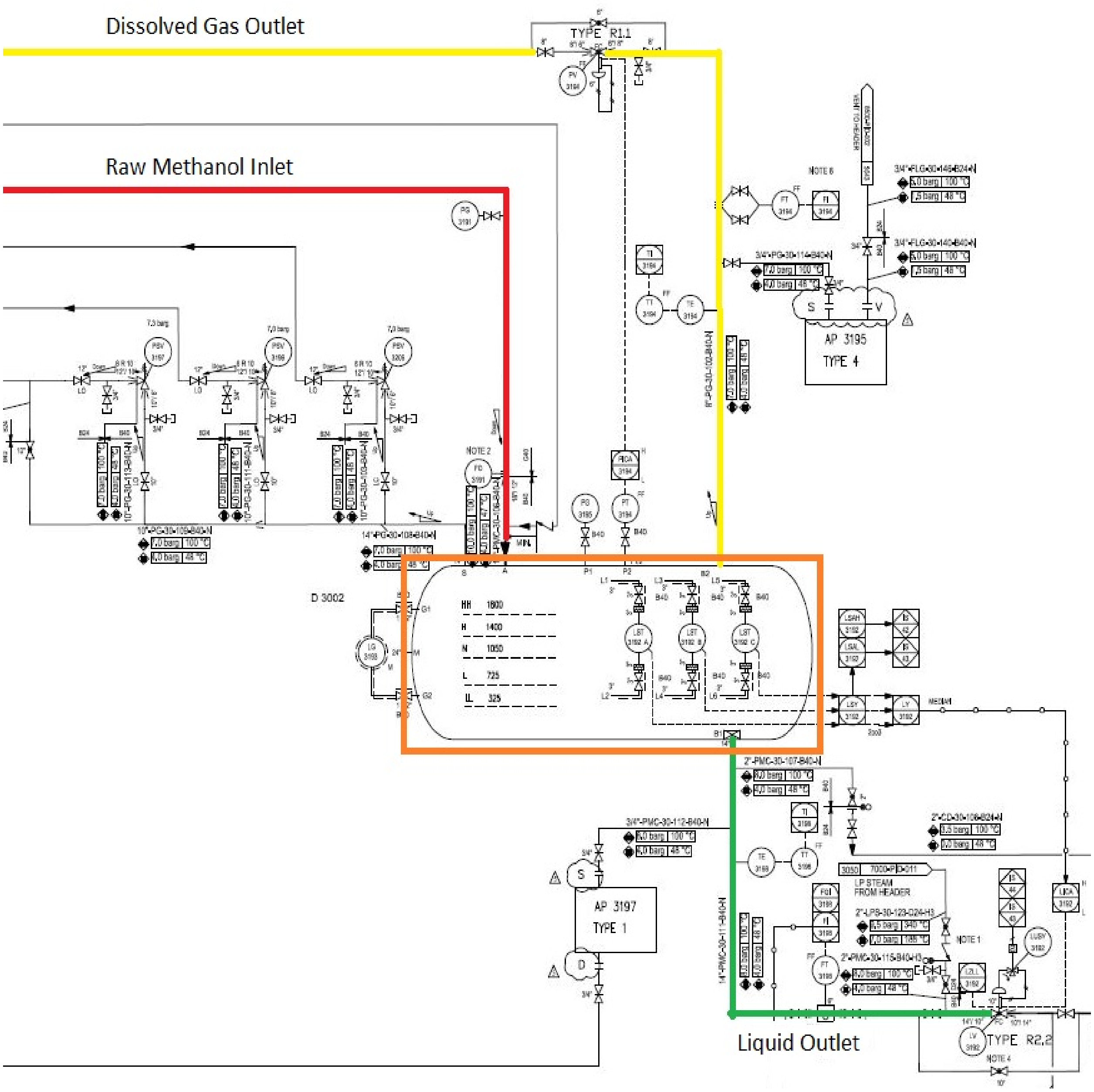
Content

Description

The objective of this vessel is to accumulate raw methanol produced and at the same time create the space/area for dissolved gas to be separated.

Operating Parameters

Operating temperature	47	°C	Operating pressure	4,0	bar g
Liquid Outlet					
Liquid flow	240105	kg/h	Liquid density	781	kg/m³
Vapor Outlet					
Gas flow	6599	kg/h	Gas density	5,69	kg/m³
Gas molecular weight	29,90	kg/kmol			


Dissolved Gas Outlet
Raw Methanol Inlet
Liquid Outlet
D 3002
AP 3195
TYPE 4
AP 3197
TYPE 1
TYPE R1.1
TYPE R2.2

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 liquid dominant, a horizontal vessel is selected since it provides more surface area or spacing for dissolved gas to separate.

Horizontal separators-without internals provide bulk separation of gas and liquid. The design is typically used for Liquid surge applications where the vapor flow is very low, for fouling services, or where internals are not desirable. The equipment has unlimited turndown, low pressure drop, can handle slugs and high liquid fractions, and is insensitive to fouling. The separation efficiency is dependent on the inlet droplet size distribution and Stokes' Law settling, based on the diameter, length, and liquid levels in the separator

2nd Step: Select and Size proper Inlet Device

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	14	16	18	inch
Nozzle Area	0.1	0.13	0.16	m2
ρmixture	168	168	168	kg/m3
Vmixture	4.1	3.14	2.48	m/s
J	2831	1659	1036	kg/m. s2
Criterion	2250	2250	2250	kg/m. s2

So, the minimum sizing should at least be 16 inch to meet the requirement. The licensor has chosen 18 inch to not only better control its momentum and as a result help the bulk separation but also be more conservative and on the safe side.

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.

Parameter	Value	Value	Value	Unit
Estimated ID	8	6	4	inch
Area	0.032	0.018	0.008	m2
V_g	9.93	17.66	39.73	m/s
$\rho V_g 2$	561	1774	8984	Kg/m. s2
Criterion	4500	4500	4500	Kg/m. s2

Liquid Outlet Nozzle

Since it is going to be discharged to another vessel, the maximum velocity should be 3 m/s and the average velocity should be 2 m/s.

Parameter	Value	Value	Value	Unit
Estimated ID	8	12	14	inch
Area	0.032	0.07	0.099	m2
V_l	2.63	1.17	0.85	m/s
Criterion	Max 3	Max 3	Max 3	m/s

The minimum sizing is 8 and 10, 12 and 14 are all acceptable but the licensor has selected 14 inch. The Licensor could have selected 12 inch but since there is a Coriolis flowmeter downstream the drum the Licensor has selected 14 to control the velocity.

3rd Step: Calculate Vessel Diameter

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

Svercek

1. Calculate the vapor volumetric flow rate, Q_V in m3/s
2. Calculate the liquid volumetric flow rate, Q_L in m3/min
3. Calculate the vertical terminal vapor velocity, UT and set UV = 0.75 UT

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

where

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

Table 1. Separator K values.

Mist Eliminator

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

GPSA

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

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

$C_D = \exp(Y)$

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

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

Notes:

D_p, ft

ρ, lb/ft^3

μ, cP

1 micron = 3.28084×10^{-6} ft

4. Select a hold-up time from next-page Table and calculate the hold-up volume, VH
5. Select a surge time from next-page Table and calculate the surge volume, VS
6. Estimate a L/D and initially calculate the diameter according to the following Equation:

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

7. Calculate the total cross-sectional area.
8. Set HLLL and by using HLLL/D obtain ALLL/AT and calculate ALLL

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

9. Set HV to 0.2D or 0.3048 m, whichever is greater; then by using HV/D, obtain AV/AT

10. Calculate the minimum length to accommodate the liquid hold-up/surge:

$$L = \frac{V_H + V_S}{A_T - A_V - A_{LLL}},$$

11. Calculate the liquid dropout time

$$\phi = \frac{H_V}{U_V}, s$$

12. Calculate the actual vapor velocity

$$U_{VA} = \frac{Q_V}{A_V};$$

13. Calculate the minimum Length required for vapor-liquid disengagement, LMIN:

$$L_{MIN} = U_{VA}\phi$$

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.

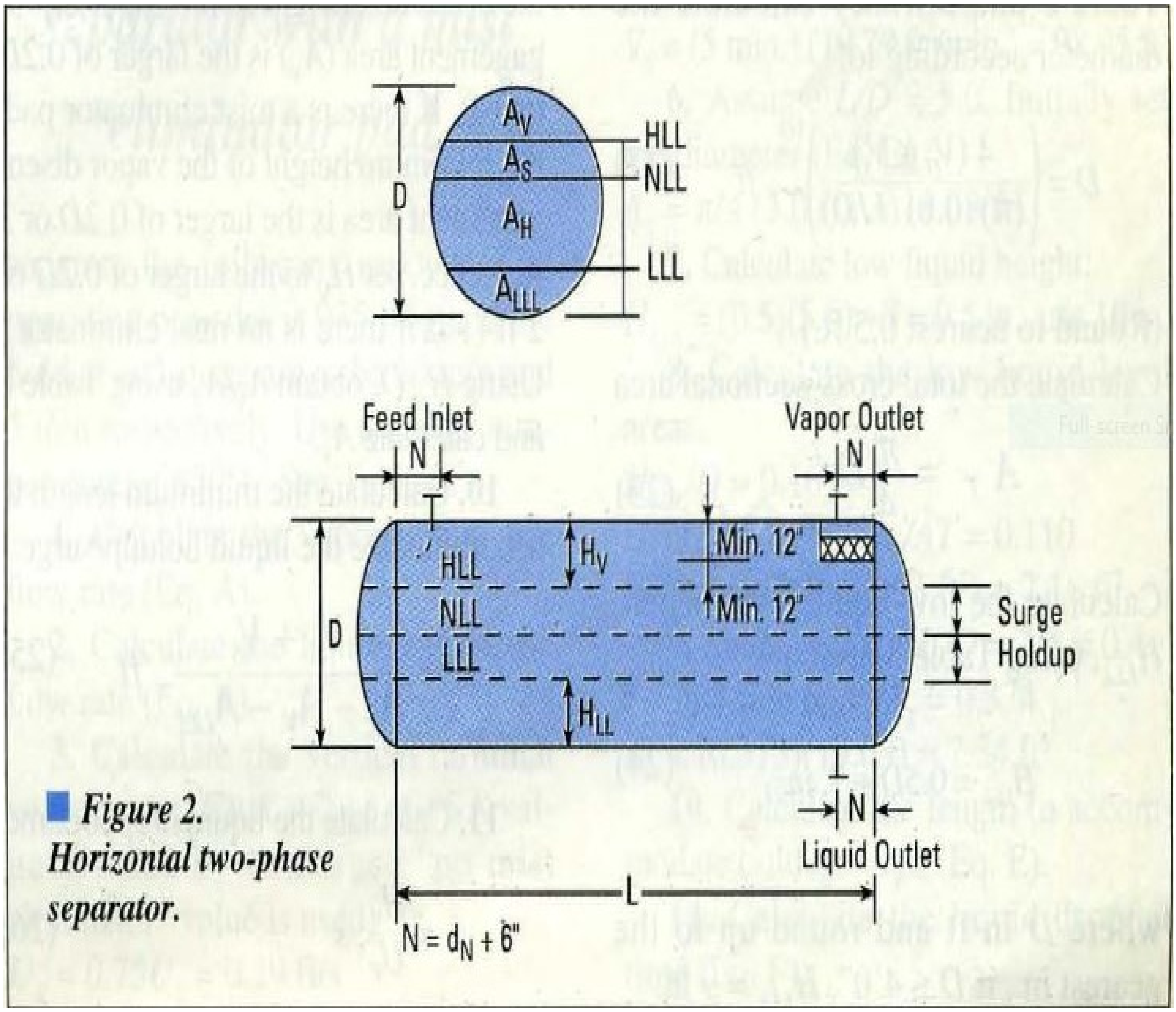


Figure 2.
Horizontal two-phase separator.

Steps	
1	$Q_V = \frac{6599}{5.69 \times 3600} = 0.322$ m3/s
2	$Q_L = \frac{240105}{781 \times 60} = 5.12$ m3/min
3	$U_T = 0.05\sqrt{\frac{781-5.69}{5.69}} = 0.58$ m/s $U_V = 0.75 \times 0.58 = 0.43$ m/s
4,5	$V_H = 2 \times 5.12 = 10.24$ m3 $V_S = 1 \times 5.12 = 5.12$ m3
6	L/D = 3 $D = \left(\frac{4 \times (10.24+5.12)}{\pi \times 0.6 \times 3}\right)^{\frac{1}{3}} = 2.21$ m

Steps	
7	$A_T = \frac{\pi}{4} \times 2.215 \times 2.215$ = 3.85 m2
8	$H_{LLL} = 0.725$ m H_{LLL} /D = 0.327 ϴ = 2×ACOS (1-2×0.327) = 2.43 A_{LLL}/AT = (2.43-SIN(2.43))/2/π = 0.284 A_{LLL} = 0.28 $\times 3.85 = 1.09$ m2
9	$H_V = 0.2 \times 2.215 = 0.443$ m more than 0.3048 m H_V /D = 0.2 ϴ = 2×ACOS(1-2×0.2) = 1.85 A_V/A_T = (1.85-SIN(1.85))/2/π = 0.14 A_V = 0.14 $\times 3.85 = 0.54$ m2

10	L = $\frac{10.24+5.12}{3.85-1.09-0.54}$ = 6.95 m
11	$\varphi = \frac{0.44}{0.43}$ = 1.01
12	$U_{VA} = \frac{0.32}{0.54} = 0.58\ m/s$
13	$L_{MIN} = 1.01 \times 0.58 = 0.59$

Step 14: It is clear that L >> LMIN so Hv is reduced to minimum specified which is 0.3048 m and in doing so, the vessel length reduces from 6.95 m to 6.3 m. The final results are provided below:

Parameter	Svercek	Licensor
D	2215 mm	2125 mm
L	6300 mm	6450 mm

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 licensor is 24'.

There is no need to have Vent on this drum since there is a control valve to flare system and if purging is required then by use of these means the task could be performed.

The drain valve sized by licensor is 2'.

Parameter	Licensor
Manhole	**24**
Vent	**Not required**
Drain	**2**
Vortex Breaker	**Yes**