Three Phase Separators – Times Definition

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Introduction

For many, three phase separator sizing is a challenging job. This is mainly because of the number of process parameters involved, the variety of internals and possible internal configurations. In addition, the numbers of parameters that have to be checked to ensure proper separator sizing are relatively high and sometimes a combination of these criteria adds to the complexity of the calculation so that some believe that there is as much art as there is science to properly designing a (horizontal) three phase separator.

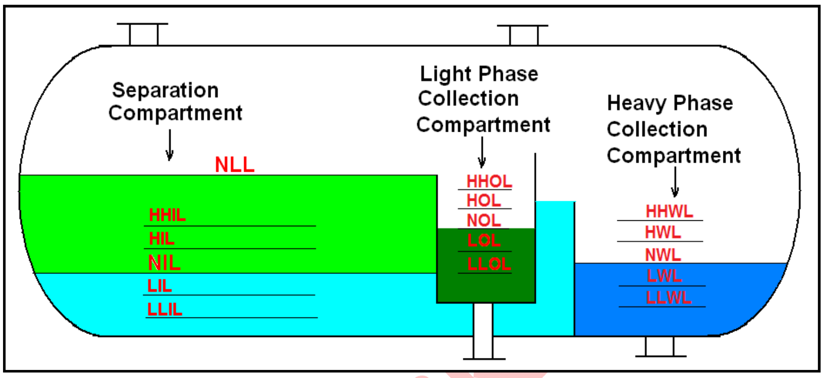

Figure 1 – Three Phase Separator Compartments and Levels

Nevertheless, I believe separator sizing is a simple set of calculations when you know the basic sizing principals such as gas-liquid separation theory, liquid-liquid separation fundamentals and the definitions of different terms and their importance. The next step is to obtain the required input data and try to find a size which satisfies these requirements and criteria. Without having the whole picture of what is going to be done, any simple exercise can turn into a cumbersome and complex iterative problem.

I am going to develop a series of notes to cover the basics of three phase separator sizing. This note is related to the terminology of time-related parameters, how to specify them and how important they are in sizing calculations.

Residence Time

Residence Time is the retention time of each phase in the separation compartment of the vessel, which is used as a criterion for phase separation. In other words, this is the effective time available for each phase droplets to be separated from the other phase.

For the heavy phase, the Residence Time is calculated based on the volume of liquid accommodated between vessel bottom and Normal Interface Level (NIL). For the light phase, the Residence Time is calculated based on the volume of liquid between NIL and Normal Liquid Level (NLL). Figure 1 depicts the same definitions for a three phase horizontal separator with an overflow weir. In summary:

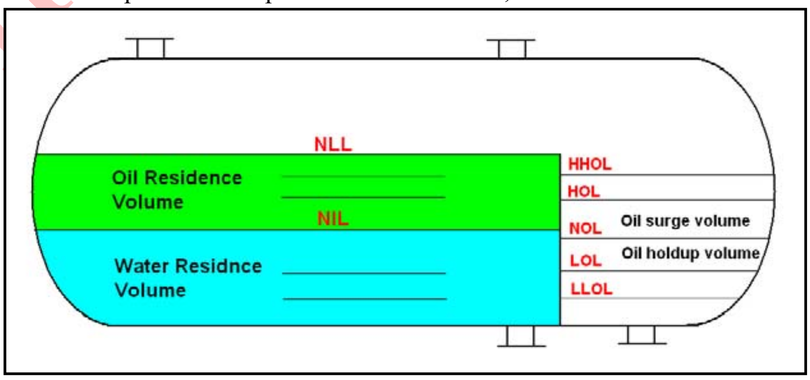

Figure 2 – Time Definition for Overflow Weir Configuration

- heavy phase Residence Time = the volume between vessel bottom and NIL / heavy phase inlet volumetric flow
- light phase Residence Time = the volume between NLL and NIL / light phase inlet volumetric flow

In no-internal, boot, submerged weir arrangements, NIL and NLL are controlled via a control system while for other arrangements NIL and NLL are fixed by weir height.

Phase Separation Time

Phase Separation Time is the required time to achieve a desired liquid-liquid separation. The different ways of determining this parameter have been discussed in a note titled "How to Specify Liquid-Liquid Separation". But in short, one way is to define it typically based on experimental data or operational experience obtained in similar services or applications. For example, API -12J specifies the water-oil Separation Time (shown in Table 1) as a function of oil API gravity. GPSA data on the same parameter for other mixtures is shown in Table 2.

Table 1 –Phase Separation Time for Water-Oil Mixture (as per API-12J)

Oil Gravities	Separation Time (minutes)
Above 35° API	3 to 5
Below 35° API	
Temperature >37 °C	5 to 10
27°C < Temperature < 37 °C	10 to 20
15 °C < Temperature < 27 °C	20 to 30

Table 2 –Phase Separation Time for other Mixtures (as per GPSA)

Mixture	Separation Time (minutes)
Ethylene Glycol / Hydrocarbon	20 to 60
Amine / Hydrocarbon	20 to 30
Caustic / Propane	30 to 45
Caustic / Heavy Gasoline	30 to 90

There is another way to calculate the Phase Separation Time which is based on the cut-off diameter (the smallest droplet that has to be completely removed from continuous phase) in order to achieve the required concentration of each phase in the other one. According to this method, the terminal velocity of the targeted droplet is calculated through the following equations. Terminal velocity of 10in/min (4 mm/s) is usually used when the following equation results in higher values.

$$V_t = \sqrt{\frac{4gD_p}{3C'}\frac{(\rho_H - \rho_L)}{\rho_C}}$$

Where C′ (drag coefficient) can be calculated through the relation below (regressed form of the graph of C′ vs $C'Re^2$ published in GPSA 12^{th} edition, FIG. 7-4).

$$C' = 0.344 + 3.079\times10^{-8}\ X + 64.91/X^{0.5} + 3514.81/X^{1.5} - 7201.95/X^2$$

Where $X = \dfrac{1.31\times10^7\,\rho_C\,D_p^3\,(\rho_H - \rho_L)}{\mu_C^2}$

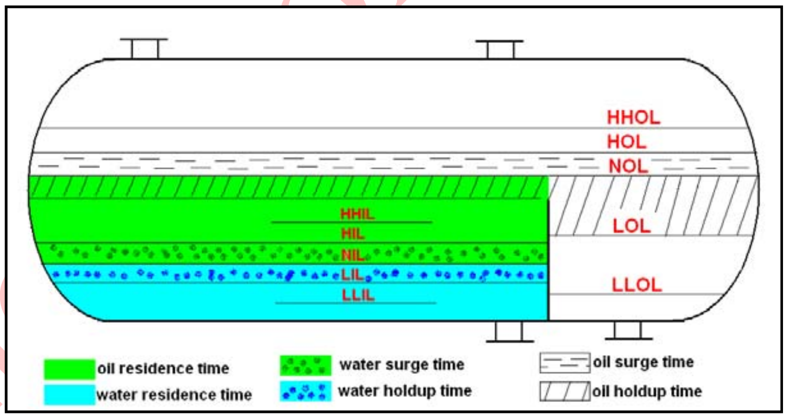

Figure 3 – Time Definition for Submerged Weir Configuration

Then the Separation Time is calculated based on the maximum distance that each liquid phase's droplet should travel to reach the interface. In accordance with this:

- light droplet Separation Time = distance between vessel BTL and NIL / light phase droplet rising velocity (where C = H)
- heavy droplet Separation Time = distance between NLL and NIL / heavy phase droplet settling velocity (where C = L)

For a three phase separator with a boot, this distance for both phases can be considered as the vessel bottom to NLL.

A correct design should guarantee that the Residence Time of each phase inside the vessel is more than the Separation Time of other phase's droplet. This means that the droplet from each phase reaches the interface before the continuous phase leaves the separation compartment.

Liquid Degassing Time

Liquid Degassing Time is defined as the time required for the gas bubbles larger than specific size (normally 200 micron) to escape from the liquid. This is to ensure that gas entrainment in the liquid leaving the vessel is negligible. For a three phase separator containing low viscosity liquid which meets liquid-liquid droplet separation (mentioned above), this requirement is often easily achievable. This is because of the high density difference between gas bubbles and the liquid which facilitates the degassing process. However, when the viscosity of the liquid is too high, the degassing criterion will determine the vessel size. Liquid Degassing Time can be calculated through the following equation:

$$V_t = \sqrt{\frac{4gD_p}{3C'}\frac{(\rho_l - \rho_g)}{\rho_g}}$$

Where C′ is as specified before and

$$X = \frac{1.31\times10^7 \rho_g \; D_p^3 (\rho_l - \rho_g)}{\mu_l^2}$$

Usually, the degassing requirement is applicable to one of the liquid phases in the vessel (either light or heavy phase), not both of them. For example, for a sour water surge drum where a small amount of oil is separated from sour water, water degassing can be a process need.

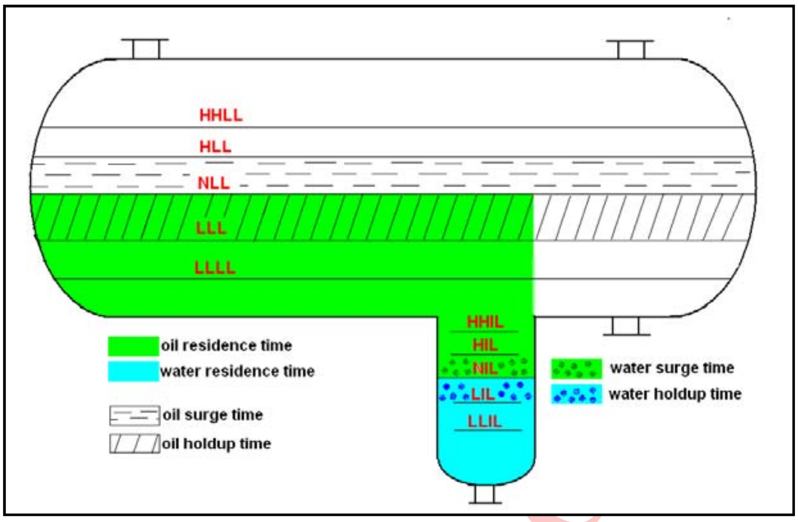

Figure 4 – Time Definition for Boot Configuration

In the same system, the amount of entrained gas in the oil is normally not important. So, depending on phases for which degassing is required, one of the following equations can be used:

- heavy phase Degassing Time = distance between vessel bottom and NIL / gas bubble raising (terminal) velocity
- light phase Degassing Time = distance between NLL and NIL / gas bubble raising (terminal) velocity

A correct design should guarantee that the Residence Time of each phase inside the vessel is more than the Liquid Degassing Time. This means that gas bubbles have already been removed from the liquid before leaving the separation compartment.

If degassing of both phases is required, the entrained gas in the heavy liquid phase should travel from vessel bottom to interface and then through the light liquid phase to reach liquid surface. Therefore:

- The minimum length of separation compartment = heavy phase Degassing Time x heavy phase axial velocity + light phase Degassing Time x light phase axial velocity

Holdup Time

Holdup Time is defined as the duration that the vessel can supply liquid to downstream equipment, unit or plant if incoming flow is cut off. For example, in a sour water surge drum, water is gathered from different sources, so the sour water surge drum’s function is to hold sufficient amount of water so that the downstream unit to can operate irrespective of the inlet flow variations (many of sour water producers are intermittent/highly variable flow). Holdup Time is usually defined by the Client depending on the function of the vessel and the fluctuation of the feed and the sensitivity of downstream equipment to the variation of flow. It is usually specified for the main process fluid (water in this example) which is important from the plant operation viewpoint. According to this definition, the Holdup Time is used to set the distance between Low Liquid Level (LLL) and NLL.

For some of the arrangements, such as the bucket, overflow weir and double weir, Holdup Time is supplied from a separate compartment than the separation compartment called the collection compartment. Separation and collection compartments are common in some other arrangements such as no-internal, boot and submerged weir. Figures 3 and 4 show the residence and holdup times for submerged weir and boot arrangements.

Surge Time

Surge Time is defined as the duration that the vessel can accommodate inlet flow rate if outgoing flow cuts off. The Surge Time is used to set the distance between NLL and High Liquid Level (HLL) where a high alarm is triggered. Holdup and Surge times are usually provided by the Client in project design criteria, a typical one has been shown in Table 3.

As the project criteria usually specify the total time between LLL and HLL, engineers usually take half of this value as Surge Time. That is why as a normal practice, NLL is set as half of the distance between LLL and HLL. In general, 2 to 3 minutes is supposed to be sufficient for Surge Time.

Table 3 – Holdup and Surge Time for Different Services

Service	Holdup Time + Surge Time (minutes)
Feed Surge Drum	10 to 20 minutes
Reflux Drum	5 minutes on reflux flow + 2 minutes on product flow to storage or 10 minutes on product flow to another column
Other Separators	10 minutes if liquid is sent to a heater 5 minutes if liquid is sent to another vessel via a pump 3 minutes if liquid is sent to another vessel via gravity

Furthermore, if operational slugs are expected, the adequacy of available volume between NLL and HLL to accommodate the slugs should be checked. Slug volume is normally the output of pipeline simulation software. If the volume of slug is not known, 2 to 5 seconds of flow with the maximum feed (gas and liquid) velocity and 100% liquid filing of the pipe can be taken as that volume.

Gas-Liquid Separation Time

Gas-liquid separation time is the time required for a liquid droplet to settle down from a gas and reach the liquid level. This time is calculated based on the terminal velocity of the targeted liquid droplet.

$$V_t = \sqrt{\frac{4gD_p}{3C'}\frac{(\rho_l - \rho_g)}{\rho_g}}$$

Where C′ is as specified before and

$$X = \frac{1.31\times10^7 \rho_g\ D_p^3 (\rho_l - \rho_g)}{\mu_g^2}$$

If the flow rate of the light phase is more than 5% of the total inlet liquid flow rate, then the light phase density should be used in the above calculation.

For a vertical separator, if the gas velocity is limited to 0.8 to 0.9 times of the terminal velocity, liquid droplet separation will be achieved. For a horizontal separator, it shall be demonstrated that minimum droplet size will settle out of a moving gas stream before the gas leaves the vessel. This can be done by comparing gas-liquid separation time with the liquid droplet residence time.

- liquid droplet Separation Time = height of vapor space above liquid level / droplet setting (terminal) velocity
- liquid droplet Residence Time = vessel length / gas axial velocity

Abbreviation	
A	Mist extractor surface area, ft^2
C′	Drag coefficient
C1	Pressure correction factor
C2	Liquid load correction factor
C3	Foaming correction factor
D_p	Particle diameter, m
g	Gravity acceleration, 9.8 m/s^2
HHLL	High-High Liquid Level
HLL	High Liquid Level
K	Gas load factor (empirical constant)
L	Vessel Length
LL	Liquid load, gpm/ft^2
LLL	Low Liquid Level
LLLL	Low-Low Liquid Level
NLL	Normal Liquid Level
NIL	Normal Interface Level
Re	Reynolds number
V	Velocity, m/sec
X	Equal to $C' Re^2$
μ	Continuous phase viscosity, cP
ρ	Fluid density, Kg/m^3
Subscript	
g	Gas
l	Liquid
p	Liquid droplet / gas bubble
t	Terminal
C	Continuous (liquid) phase
H	Heavy (liquid) phase
L	Light (liquid) phase

If the separator is equipped with a mist extractor device for enhancing liquid droplet separation from the gas, the gas-liquid separation is guaranteed by maintaining the gas velocity below the maximum recommended gas velocity at the face of the mist extractor by vendor. The following formula along with data presented in Tables 4 to 7 can be used to calculate the maximum allowable gas superficial velocity.

$$V_g = K\sqrt{\frac{\rho_l - \rho_g}{\rho_g}}$$

Table 4 - Wiremesh Mist Extractor Standard K

Service	K m/s	(ft/s)
Vertical flow	0.107	(0.35)
Horizontal flow	0.128	(0.42)

Revised on 12-Feb-2015

Where K = Standard K × C_1× C_2 × C_3

The removal efficiency of a mist extractor is typically 99% of liquid droplets larger than 3-10 microns and 10-40 microns for wiremesh and vane types, respectively. For wiremesh, this can be achieved by the vendor through changing the mesh thickness, the density of the pad and the diameter and material of the wire. For vane mist extractor, plate depth, spacing, number of turns and material can be varied to meet the required removal efficiency.

Standard K values indicated in Tables 4 and 5 should be corrected for high pressures. For a wiremesh mist extractor, this is normally due to the reduction in surface tension of the liquid phase that occurs with increasing pressure. For a vane type mist extractor, this is primarily a result of the decreasing allowable gas velocity with increasing pressure caused mainly by increased gas density. As gas velocity decreases, droplet inertia decreases and the droplets tend to follow the gas streamlines more easily through the vane passages, and exit the vane pack without being captured. The reduction in vane pack removal efficiency with pressure is sharper than wiremesh, however, in absence of vendor data, Table 6 can be followed. It is highly recommended to obtain K values from the vendor when the pressure is above 800 psig.

K value is also a function of the amount of entrained liquid reaching the mist extractor. As would be expected, K decreases with increasing inlet liquid loading. For typical wiremesh extractor, liquid loads greater than typically 1 gpm/ft^2 (0.04 m^3/min m^2) are considered high and will require de-ration of the standard K factor, to prevent excessive entrainment carryover. Vane type mist extractors are also impacted by inlet liquid loading, but generally have considerably more tolerance towards liquids than mesh pads. Table 7 introduces a correlation for the correction of the standard K with respect to liquid load at the face of the mist extractor.

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C_2 depends upon the liquid handling capacity of mist extractor, the efficiency of inlet device and the effectiveness of gravity separation upstream of mist extractor. It can be assumed as 1.0 for the first trial and then estimated based on selected internals and the overall performance of the primary separation section of vessel.

Some references introduce C3 of 0.6-0.8 for foaming service such as amine and glycol. Consult the internal supplier.

Table 5 - Vane Type Mist Extractor Standard K

Service	K m/s	(ft/s)
Single Pocket – Vertical flow	0.152	(0.50)
Single Pocket – Horizontal flow	0.198	(0.65)
Double Pocket – Vertical/Horizontal flow	0.305	(1.0)

Table 6 – Pressure Correction Factor

Pressure (psig)	Pressure Correction Factor (C_1)
Atmospheric	1.0
150	0.90
300	0.85
600	0.80
1150	0.75

1. It is highly recommended to contact vendor if pressure is above 800 psig or liquid surface tension in less than 0.005N/m.
2. For high vacuum applications, pressure correction factor should be obtained from vendor. In such applications, size of wiremesh is normally specified based on pressure drop rather than liquid droplet removal requirements.
3. Valid as long as flow rate is within 30-110% of design flow rate.

Table 7 – Liquid Load Correction Factor

Mist Extractor type	Liquid Load Correction Factor (C_2)
Wiremesh	1 – 0.030 (LL – 1)
Vane	1 – 0.015 (LL – 2)

$C_2 = 1$ if $LL \leq 1$ gpm/ft^2 for Wiremesh
$C_2 = 1$ if $LL \leq 2$ gpm/ft^2 for Vane

For the efficiency of different types of inlet devices, refer to "Three Phase Separators - Inlet Devices".

If liquid load in face of wiremesh is above 8gpm/ft^2, it is recommended to install a vane upstream of the wiremesh mist extractor.

Operator Intervention Time

Operator Intervention Time is the available time between the level at which alarm is initiated and the level where (individual equipment, unit or total plant) trip command is triggered. This time is given to operators to take action and prevent shutdown. In other words, it is utilized to fix the distance between Low Liquid Level (LLL) above Low-Low Liquid Level (LLLL) and High-High Liquid Level (HHLL) above High Liquid Level (HLL).

Typically, 1 to 2 minutes is sufficient for operator intervention in the control room and 5 minutes for action outside the control room.

Contact

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