Three Phase Separators – Liquid Internals

Saeid R. Mofrad

25-Oct-2013

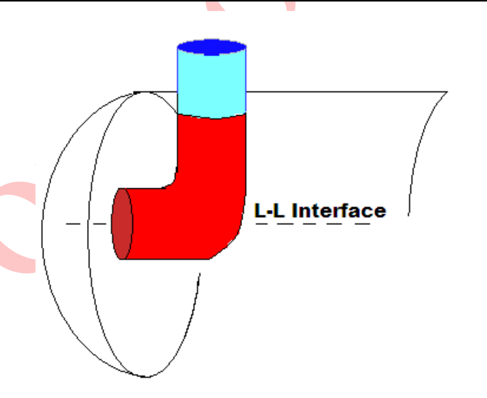
Introduction

This is the fourth in a series of papers which tries to provide the basic knowledge for sizing a three phase separator. The previous papers covered the gas-liquid separation theory, liquid-liquid separation fundamentals, the sizing and selection details of the devices on the gas inlet nozzle and internals required for separating liquid droplets from the gas (gas internals).

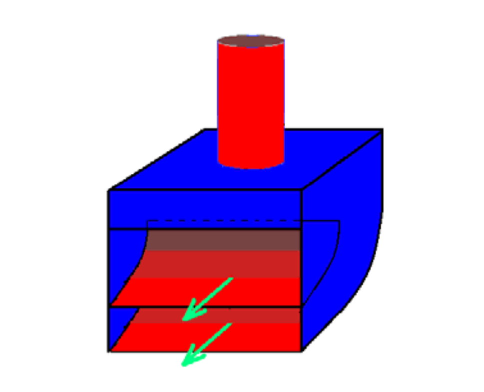
This note reviews the sizing and selection details of different devices on the liquid inlet and outlet nozzles, and other liquid internals and their effects on the separator size.

Inlet Devices

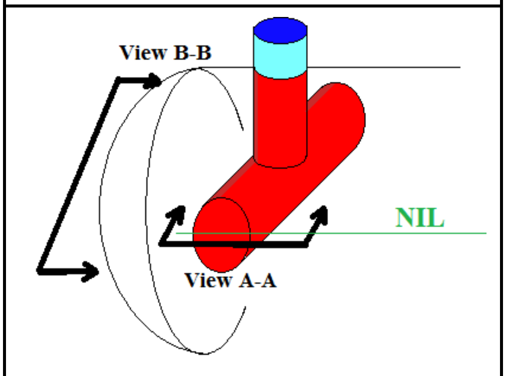
The inlet devices are installed on the inlet nozzle of a separator to introduce the feed steadily into the vessel. The feed stream to the three phase separator is usually multiphase flow and one of the inlet devices described in paper "Three Phase Separator – Inlet Devices" is installed on the inlet nozzle. However, sometimes the liquid and gas phases enter the three phase separator through two separate nozzles or the vessel is basically a liquid-liquid separator with no gas in the feed stream. In such applications, the main purpose of liquid inlet device is to direct the liquid phases to the interface level without disturbing it. However, some of the inlet devices offer more benefits by reducing the velocity of entering stream, redistributing the flow and even enhancing the phase separation. The following section provides some information about different types of liquid inlet devices:



1a. 90° Elbow



1b. Dual Vane



1c. Holed Pipe

- **90° Elbow**

The simplest form of device on the liquid inlet nozzle is a 90° elbow which is installed at the end of a short piece of pipe. As illustrated in Figure 1a, it is used in a horizontal vessel to bring the inlet liquid flow to the liquid-liquid interface and preferably towards the vessel dish end. The diameter of the inlet device is usually the same as the inlet nozzle.

- **Vane Distributor**

A dual vane type inlet device shown in Figure 1b can be used in place of a 90° elbow. Unlike 90° elbow that does not change (reduce) the velocity of liquid from the inlet nozzle to the exit, vane distributor provides larger exit area which reduces the agitation of phases at the entrance section of vessel and its adverse effect on the liquid-liquid separation.

- **Holed Tee Distributor**

The holed T-shaped distributor (as shown in Figure 1c) consists of a vertical pipe which brings the distributor with large holes or rectangular slots to the liquid-liquid interface level. The diameter of pipe and distributor is the same as inlet nozzle which is usually determined to maintain the liquid velocity below 1m/sec. Number of holes on the distributor section is calculated based on the liquid velocity of 0.3 m/sec in the hole. This device not only reduces the entering velocity of feed stream into the vessel minimizing flow turbulences but also distributes the liquid phases over a small fraction of vessel diameter reducing the width of dispersion band.

The following section provides some guidelines on the sizing of holed tee distributor:

$$A_{hole} = 3.14 \times d_{hole}^2 / 4 \qquad \text{(eq. 1)}$$

$$N_{hole} = Q_L / (A_{hole} \times V_{hole}) \qquad \text{(eq. 2)}$$

Abbreviations	
A_{hole}	Area of each hole
$L_{distributor}$	Length of distributor
Q_L	Liquid volumetric flow rate
d_{hole}	Diameter of holes, typically 13mm
N_{hole}	Number of holes
V_{hole}	Permissible liquid velocity in the hole
Pitch	Distance between two adjacent slots, 25mm

Tee distributor diameter, d_{tee}, is the same as the inlet nozzle and its length can be calculated by the equation below:

$$L_{distributor} = d_{tee} + (N_{hole} / R_{hole}) \times d_{hole} + (N_{hole} / R_{hole} + 2) \times \text{Pitch}$$

Number of rows (R_{hole}) should be specified so that the opening angle does not exceed 120° (±60°). Figure 2 shows the details of holed tee distributor.

- **Cyclone**

Liquid inlet nozzle can be equipped with cyclone device. The cyclone device creates extremely high angular acceleration in the tubes so that the heavier liquids (and solids if present) spin to the outside of the tubes and light fluid is displaced to the inner part of the tube. They are more complicated and expensive than other inlet devices but one of the main benefits of the cyclone in comparison to other inlet devices is that the separation begins from inside the tubes. The gravity separators rely on the differences in the fluid densities to separate under the force created by gravity (<1g force), however the fluid in the cyclone can experience acceleration up to 200 times the force due to gravity. This causes the small droplets to coalesce and produce much larger droplet at the cyclone exit which enables the liquid-liquid separation to occur at a faster rate.

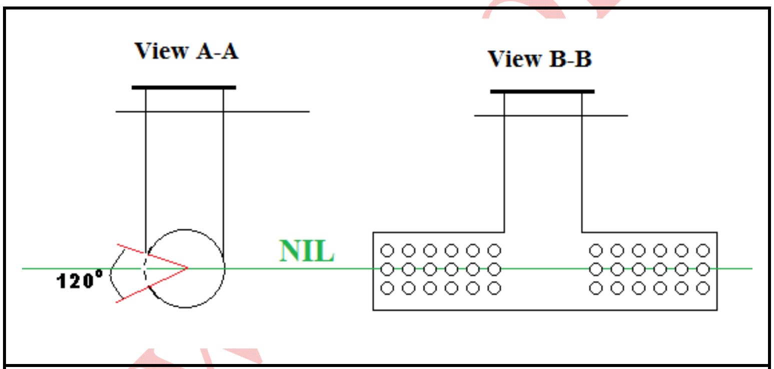


Figure 2 - Holed Tee Distributor Details

- **Perforated Pipe**

This liquid inlet devise is simply a piece of pipe dipped inside the vessel to the bottom of it for proper support. For liquid-liquid separators, the entire length of pipe can be perforated but for three phase separators as shown in Figure 3 the holes should be limited to normal liquid level (NLL).

For both applications, the number of holes can be specified based on equations 1 and 2. Holes are made on half of the pipe facing the dish end.

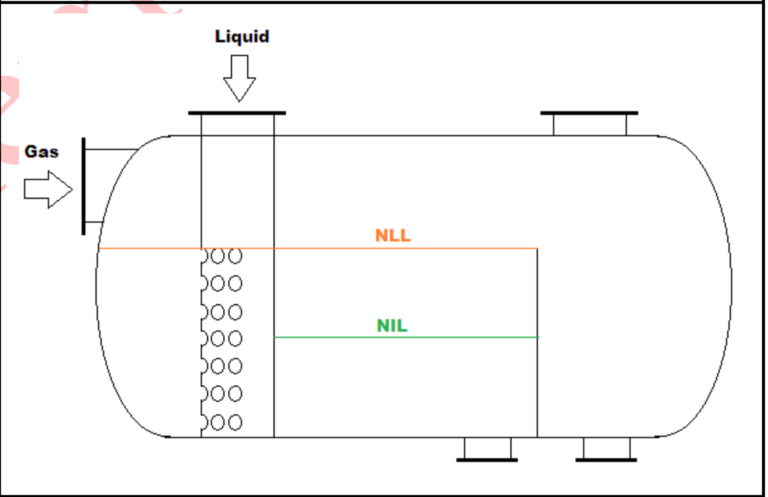


Figure 3 - Perorated Pipe Inlet Device for Three Phase Separator

Flow Straighteners

Flow straighteners are available in a range of perforations and styles for installation in horizontal or vertical vessels. Common applications include:

- Calming the inlet zone in horizontal separators especially when there is a liquid slug
- Liquid flow redistribution in long vessels
- Enhance interface level control
- Surge suppression in vessels installed in offshore FPSO applications
- Gas distribution upstream or downstream of mist eliminators (if extended over entire vessel cross section)

The flow distribution characteristic of perforated baffles is well established, however it is possible for designers to tailor the baffle design to achieve optimum distribution by adjusting the hole size, % open area, location of baffle(s), number of baffles (single, dual or multiple), the distance between them and their overlap.

- **Perforated Baffle Plate**

Perforated baffle plate is fitted downstream of the inlet device in the separator. The bulk liquids from the inlet device fall under gravity into the inlet processing zone, which is bounded by the perforated distribution baffle. Intended to distribute the liquid flow evenly over the cross-section, prior to entry into the liquid-liquid separation compartment, this baffle plays an important role in maximizing the liquid-liquid separation (Figure 4a).

4a. Perforated Baffle

4b. Calming Baffle

A dual perforated baffle plate assembly is often fitted in the gravity settler downstream of the inlet device with poor distribution to ensure that the flow streamlines entering the separation compartment are steady. The following section provides some guidelines on the design of perforated baffle plates:

- The height of perforated baffle is equal to the vessel diameter in liquid-liquid separators but usually limited to high-high liquid level (HHLL) in three phase separators. Extending the perforated baffle to cover the gas section of the vessel may not be acceptable if the gas contains materials that can plug the baffle holes.
- The distance between the first baffle and vessel TL should be at least 25% of the vessel diameter. This may need to be increased to accommodate the inlet device and to allow a reasonable flow path length of the feed to the baffle plate.
- The distance between the baffles in dual baffle arrangement should be 20% of the vessel diameter
- The Net Free Area is 30% for the first baffle and 50% for the second baffle with 12 mm diameter holes except for a vessel with plate pack where only one calming baffle with an NFA of 20% is required.
- The baffles should have a small opening (≤ 150 mm) at the bottom to allow for cleaning purposes.

More than two perforated baffle plates may be needed where the vessel is installed on the floating object (such as FPSO) where the sea harmonic motions are induced to the liquid inside the vessel. In this particular application in order to suppress the surge, longitude baffles may be required in conjunction with baffles perpendicular to liquid flow. Extending the height of perforated baffle to cover the entire cross sectional area of the separator is a common practice in this application

- **Calming Baffle Plate**

Perforated baffle plates are not recommended for dirty duties, due to the chance of fouling and blockage. In this situation, it is strongly recommended that calming baffle plates which offer higher opening percentage (shown in Figure 4b) to be employed.

Liquid-Liquid Separation Devices

- **No Separation Device**

A vessel with no liquid-liquid separation device is called open settler in which liquid–liquid separation is achieved by the gravity separation. The separation of droplets larger than 100-150 microns is typically considered as a practical limit for the gravity separators. Separators with no separation device (such as plate pack or coalescing mat) are preferred for fouling services.

The droplet separation in this type of separator is accomplished according to the equation in the Phase Separation Time section of the paper "Three Phase Separator - Time Definition" with maximum droplet terminal velocity of 0.004m/s (10in/min).

Since the gravity separation usually need a long residence time (30-60 minutes for some of the mixtures), liquid–liquid separation devices described below have been developed to enhance the droplet separation and subsequently reduce the size of the vessel.

- **Plate Pack**

The plate packs comprise an assembly of inclined cross-flow flat or corrugated plates, which enhance the liquid-liquid gravity separation by reducing the settling distance of liquid droplets. In comparison to an open settler where the light and heavy droplets should travel form BL to NIL and NLL to NIL respectively, the droplet traveling distance in the plate pack is reduced to the distance between two adjacent plates. In the light phase, entrained heavy phase drops settle onto the top surface of the plates where they coalesce, forming a film of liquid which then drains off the surface of the plate to the interface. In the heavy phase, entrained light phase drops rise to the bottom surface of the plates and flow up to the interface in the same manner. The enhanced gravity separation by the plate pack generally results in a smaller vessel than open settler.

A plate pack is only effective for the separation of primary dispersions where the droplets are large enough for their movement to be primarily caused by gravity. In practice this means that the plate pack will separate the droplets larger than about 30-50 microns.

The plates' type, inclination and spacing to achieve the required separation are specified based on the following guidelines:

- Flat plates are generally preferred choice since the flow remains laminar in them up to much higher flow rates than is possible with corrugated plates.
- The solids removal capacity of plate pack is moderate, but can be improved by increasing the inclination of the plates and/or by using corrugated rather than flat plates. Both measures, however, will adversely affect liquid/liquid separation. In clean service the angle of the plates with the horizontal plane is 45 degrees, but if solids are present the angle should be steeper (typically 60 degrees) to facilitate the removal of the solids. If many solids are present, the use of corrugated rather than flat plates should be considered.
- The plate spacing in fouling service should be at least 40 mm, whereas in clean service the plate spacing may be as little as 10 mm. The choice of corrugated rather than flat plates and/ or the increase of the plate spacing will reduce the fouling risk but will also reduce the separation efficiency of the plate pack of given overall dimensions (width x height x length).

Figure 5 – Plate Pack

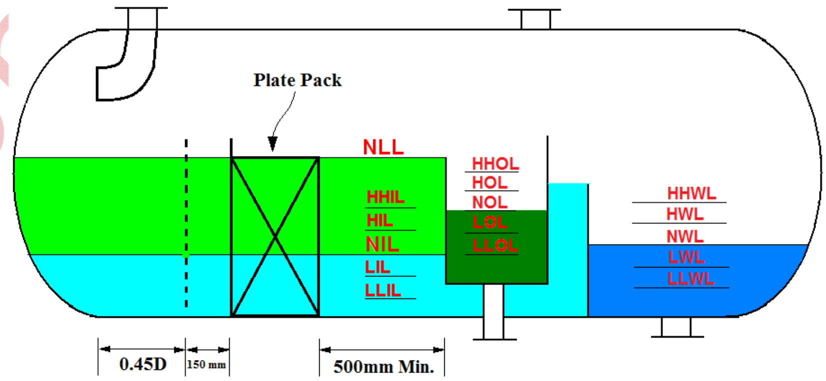


Figure 6 – Overall Configuration of Three Phase Separator with Plate Pack

The following guidelines are used to specify the dimensions of a horizontal three phase separator with the plate pack:

- In practice, setting the liquid levels to meet the holdup time and droplet separation requirements usually result in a very low axial velocity but as a preliminary design, the surface area of the plate pack is specified so that the axial velocity of each phase does not exceed 0.015m/sec.
- The distance between the perforated/calming baffle plates and the front of plate pack should be 150 mm.
- There should be at least 500mm between the back of the plate pack and the weir or boot in order to minimize the disturbance of the separation process.
- When the gas-liquid interface level is fixed by a weir plate, the top of the plate pack will be at normal liquid level (NLL). In other configurations (where NLL is maintained by control system), the top of plate pack should be at

HHLL. For all configurations, a cover plate with height of 50mm should be fitted on the top of the plate pack to prevent liquid bypassing the plate pack.

- The length of the plate pack is calculated based on liquids' cross sectional velocity and droplets settling/rising time between plates as specified under Phase Separation Time section of paper "Three Phase Separator – Times Definition".
- The minimum length of plate pack is 300mm. The required length of plate pack for usual separation is hardly more than 1500mm but if the required length is more than 1500mm, two plate packs with minimum distance of 20% of vessel diameter between them should be used.

- **Coalescing Media**

This media consists of metallic or non-metallic wires, fibers or a mixture of them which promotes the droplet size growth by coalescing them into easily separated drops by gravitational force in the separation compartment of the vessel downstream of the coalescing element.

Depending on the wire and/or fiber diameter, density, thickness and material of construction, the coalescing media will separate the droplets larger than about 10-30 microns.

Coalescing mat have limited solid handling capacity, therefore prefiltration may be required if solids are present. The pressure drop through clean coalescing media can be as high as 1000 mm liquid.

Figure 7 – Coalescing Media

The following guidelines are used to specify the dimensions of a horizontal three phase separator with the coalescing media:

- The distance between the second perforated/calming baffle plate (dual arrangement) and the front of coalescing media is 150 mm.
- The depth of the coalescing mat is specified by the vendor but a typical depth if 500mm to 700 mm can be used in absence of vendor data.
- To separate the coalesced droplets emerging from the coalescing media, the length of vessel downstream of coalescing media is calculated based on the gravity separation equation and droplets size from 500 to 1,000 microns.
- There should be at least 500mm between the back of the coalescing media and the weir or boot in order to minimize the disturbance of the separation process.
- In practice, setting the liquid levels to meet the holdup time and droplet separation requirements usually result in a very low axial velocity but the surface area of the coalescing mat should be sufficiently large to limit the average axial velocity of each phase from 0.015m/sec to 0.03m/sec.
- The height of coalescing media can be specified based on the guidelines presented for the plate pack. However, it may be advantageous from the gas demisting perspective to extend the coalescing media to cover entire vessel cross section.

Using a dense coalescing media (which may be needed to achieve a stringent outlet stream specification – usually in the ppm range) should be carefully considered for three phase separators. This is because the high resistance of the coalescing mat can hinder the free flow of liquid through the mat and cause liquid to flow over the top of the media bypassing the coalescing stage. To avoid this, the height of coalescing media can be extended above the normal (high or high-high) liquid level or a very low axial phase velocity is required which will unnecessarily result in a large vessel. That is why the separation of very small droplets is usually done in a liquid-liquid separator (after the gas is separated from bulk of liquid in a three phase separator) where there is no gas interface and flow of liquid can be maintained through the coalescing media with a reasonable pressure drop[1].

From the design prospective, it is also possible to install a plate pack downstream of the coalescing media in order improve the droplet settling process.

[1] The main capture mechanism for submicron droplets is Brownian motion (the frequent random movements of microscopic particles) which increases with longer residence time in the media (greater mat thickness or lower fluid velocity), and closer packing of fibres and higher temperature.

- **Cartridge Elements**

Similar to the gas demisting applications, polymer based fibers processed into fine fibers of varying diameters with tapered pore structures are used in form of the cartridge element inside the liquid-liquid separator to perform difficult separations. Similar to separators with coalescing mat, the coalescing stage (fiber elements) in this type of vessel is also followed by a settling zone that uses the phases' difference in density to separate the coalesced droplets. The liquid droplets larger than 2 microns can be separated with this internal.

The sizing details of liquid-liquid separators with cartridge elements or other technologies such as gas floatation, hydrocyclone, centrifuge, etc. are not discussed in this paper.

Outlet Devices

- **Vortex breaker**

One of the internals that is usually installed on the liquid outlet nozzle especially if the outlet liquid is routed to a pump or a control valve is vortex breaker. This device is installed on the liquid outlet nozzle in order to prevent gas entrainment in the outlet liquid due to vortex formation. Liquid vortex as illustrated in Figure 8 happens when the height of liquid above the outlet nozzle drops below a specific level. Gas carryover along with liquid can cause cavitation in downstream pump on control valve and damage the equipment. To solve this problem, one of the following methods can be utilized:

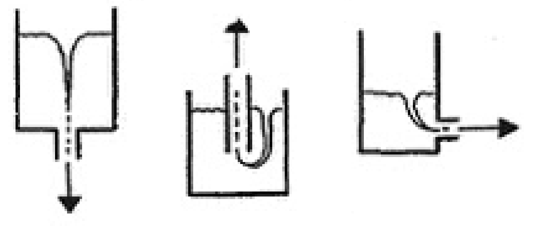


Figure 8– Gas Entrainment due to Liquid Vortex

- The minimum liquid level in the vessel (typically low-low liquid level) can be set high enough to avoid vortex formation. This height can be estimated using the following equation:

$$h = d + 8217\,Q / d^{1.5}$$

  Where h (minimum submergence height) and d are in mm and Q (liquid outlet nozzle flow rate) is in m^3/h.
- A vortex breaker with the following specification can be utilized.

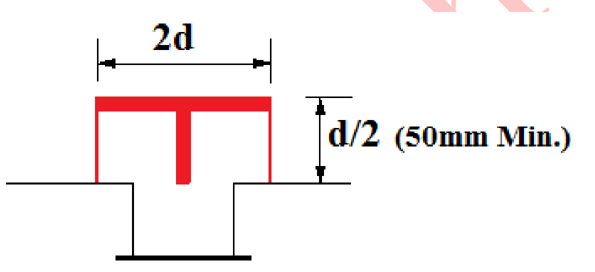


Figure 9a - Flush Outlet Side View

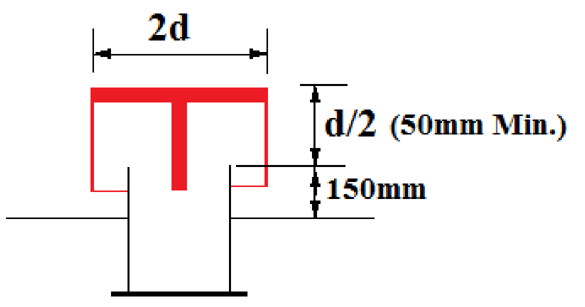


Figure 9b - Elevated Outlet Side View

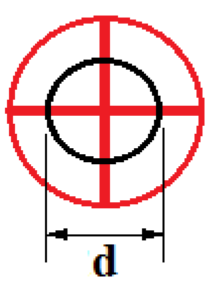


Figure 9c - Flush Outlet Top View

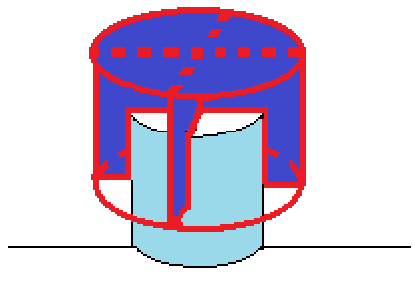


Figure 9d - Elevated Outlet 3D View

Depending on application, different vortex breakers can be used but for three phase separators the types shown in Figure 9 have been widely used. Installing an elevated vortex breaker on light phase outlet nozzle is common for three phase separators with heavy phase boot.

Minimum number of baffle is four however it can be increased to twelve when outlet nozzle diameter (d) is more than 20inch.

Nozzle Design

The diameter of the liquid outlet nozzle is chosen such that the liquid velocity does not exceed 1m/sec. The minimum diameter of this nozzle is usually 2 in.

Contact

Please visit www.linkedin.com/groups/Chemwork-3822450 should you have any comment, question or feedback or feel free to contact S.Rahimi@gmail.com.