Three Phase Separators – Inlet Devices

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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. That is why some believe that there is as much art as there is science to properly designing a (horizontal) three phase separator.

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 reviews different types of inlet devices, their effects on the gas-liquid separation, and sizing and selection details.

Inlet Device Importance

An inlet device should perform the following functions:

- **Separate Bulk Liquids**

Of the main functions of the inlet device is to improve the primary separation of liquid from the gas. Any bulk liquids separated at the inlet device will decrease the separation load on the rest of the separator and thus improve the efficiency. Good bulk separation will also make the separator operation less sensitive to changes in the feed stream. When mist extractors (mesh or vane pad) are utilized to enhance the liquid droplet separation, the amount of liquid in gas in the face of mist extractor (liquid loading) adversely affects the performance of the mist extractor. Therefore using an appropriate inlet device plays a major role in achieving required separation.

- **Ensure Good Gas and Liquid Distribution**

A properly sized inlet device should reduce the feed stream momentum and ensure the distribution of the gas and liquid(s) phases entering the vessel separation compartment, in order to optimise the separation efficiency. Mal-distribution of liquid can lead to a large spread in residence times, decreasing the separation efficiency. Also a gas mal-distribution at the entrance of the mist extractor or cyclone deck can locally overload the demister and cause severe carryover.

- **Prevent Re-entrainment and Shattering**

Re-entrainment of liquid droplets can be caused by blowing gas down or across the liquid surface at very high velocities. This phenomenon often occurs when vessels with deflector baffles or half pipes are operated at the higher gas flow rates than what they were designed for. Liquid shattering inside the inlet device can also happen in a vessel with no inlet device or with a deflector baffle when the feed stream’s liquid smashes into the plate and is broken up in extremely small droplets. This can create smaller droplets than were present in the feed stream, making the separation in the rest of the separator even harder. Selecting a proper inlet device and following common design guidelines for setting the distance between the bottom of the inlet device and highest liquid level inside the vessel should minimize this problem.

- **Facilitate De-foaming**

If the feed stream has a tendency to foam, an inlet device that prevents or even breaks down foam can significantly improve the separation efficiency of the vessel, reduce the size of the vessel and the use of chemicals.

Inlet Device Type

The following section provides some information about different types of inlet devices.

- **No Inlet Device**

The simplest form of vessels has no inlet device on the inlet nozzle.

- **Deflector Baffle**

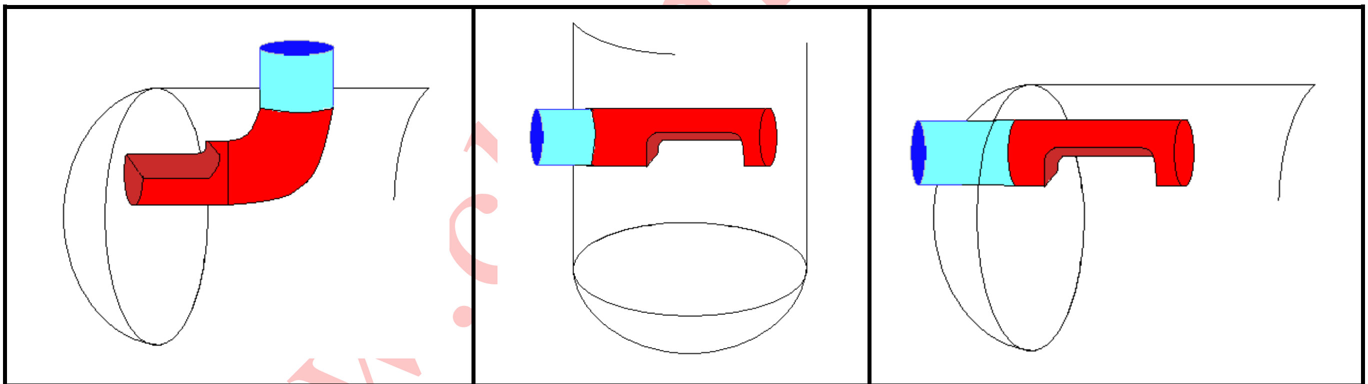
Deflector baffles are historically one of the most common types of inlet devices in oil and gas industries before inlet devices with higher separation efficiency become so popular. This device simply uses a baffle plate in front of the inlet nozzle to change the direction of the inlet stream and separate the bulk of the liquid from the gas. However, an increasing number of contractors and operators are moving away from traditional types of inlet devices towards more advanced designs with higher separation efficiencies.

- **90° Elbow**

This inlet device is used in the horizontal vessels to direct the inlet stream towards the vessel dish end. Long Radius (LR) elbows are normally preferred for this purpose and there is no straight run of pipe downstream of the elbow. However, Short Radius (SR) elbows can be used if installing LR elbow increases the height of the vapor space. They can be also provided with a straight run of pipe with a length equal to two times of the inlet nozzle diameter ($2d_1$) to direct the feed to the dish end rather than the surface of liquid inside the vessel and minimize the liquid re-entrainment.

- **Half Open Pipe**

Half open pipes are the modified versions of 90° elbow devices, suitable for both vertical and horizontal separators, with slightly improved bulk liquid removal and reasonable gas distribution. In this type, a piece of pipe with a length up to three times the inlet nozzle diameter ($3d_1$) is welded to the inlet 90° elbow.



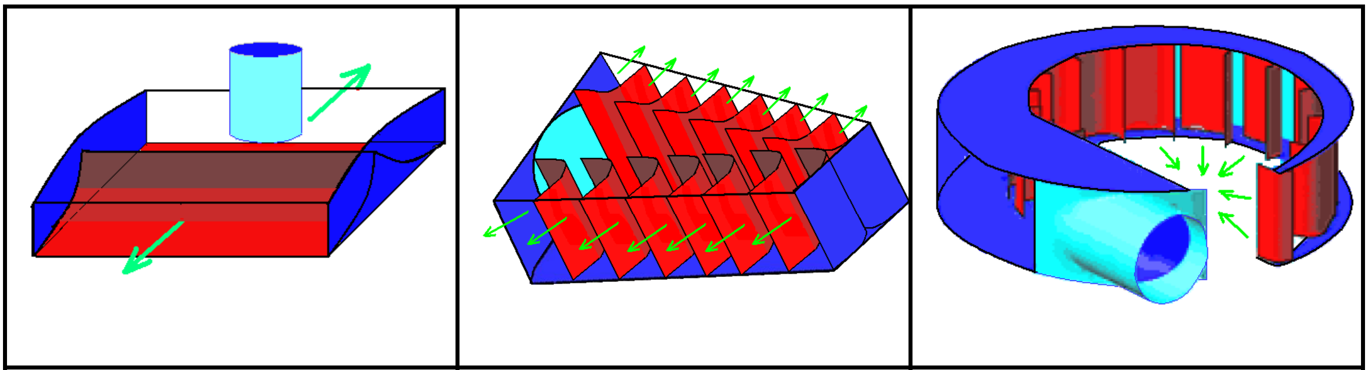
1a. Horizontal Vessel - Top Entry	**1b. Vertical Vessel**	**1c. Horizontal Vessel - Side Entry**

Figure 1 – Half Open Pipe Installation Configuration in Horizontal and Vertical Vessels

In horizontal vessels, the last section of the half open pipe should be horizontal, pointing opposite to the flow direction in the vessel and with its opening directed upward (Figure 1a). In vertical vessels, the last section is closed and its opening is directed downward (Figure 1b). The same configuration is used when the half open pipe is used for a horizontal vessel with a side nozzle (Figure 1c).

- **Vane Type Distributor**

The simplest form of the vane distributor is the dual vane inlet device (shown in Figure 2.a) which offers a reasonable flow distribution with low shear and pressure drop. In horizontal vessels, it is suited for top entry only. The benefits of this device compared with simpler deflectors such as deflector plates include reduced agitation and hence improved phase operational performance, more stable level control, and reduced foaming. For liquid slugging applications, usually where there is a long incoming flow line, this device provides excellent mechanical strength. The dual vane works by smoothly dividing the incoming flow into two segments using curved vanes to suit the overall geometry of the inlet nozzle. The gas phase readily separates and disperses along the vessel, whilst the liquid phase velocity is reduced and the flow directed to the vessel walls where it further disperses and falls into the bulk liquid layer at relatively low velocity.



2a. Dual Vane	2b. Multivane	2c. Multivane (Only Vertical Vessel)

Figure 2 – The Different Types of Vane Inlet Devices

For services where there is a high gas flow relative to the liquid flow, the multi-vane inlet device provides excellent vapour distribution allowing a reduced height to the mass transfer or mist eliminator internals. The vane distributors work by smoothly dividing the incoming flow into various segments using an array of curved vanes to suit the overall geometry of the inlet nozzle and distributor length. To achieve this effect the vanes start with a wide spacing and gradually reduce the gap, giving the unit its characteristic tapering shape. It can be installed in both vertical and horizontal (top and side entry) three phase separators. Figure 2.b shows the internal details of multi-vane inlet distributor.

Some vendors have tried to employ the multivane distributor benefits together with tangential entry (which provides considerable centrifugal force) to improve the bulk separation. Figure 2.c shows a typical type of vane developed for vertical separators only.

- **Slotted Tee Distributor**

The slotted T-shaped distributor consists of a vertical pipe extended inside the vessel to bring the distributor to the right elevation and a slotted pipe with large holes or rectangular slots (perpendicular to the inlet pipe) ensuring a reduced feed stream velocity and minimized flow turbulence. It can be used in both vertical and horizontal (top entry only) separators.

The openings of the slots are usually 120 ° (±60°) and towards the dish end and liquid interface in horizontal and vertical vessels, respectively.

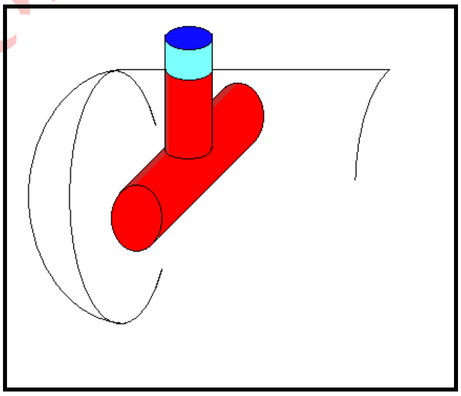


Figure 3 – Tee distributor

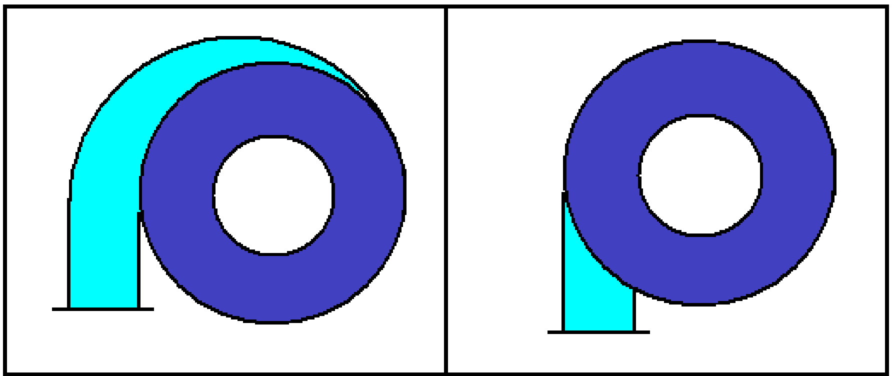
- **Tangential Inlet With Annular Ring**

Tangential inlet devices have been exclusively developed for vertical vessels. The feed flow radially enters the vessel and accelerates passing through the inlet device, the cyclonic action of the inlet device helps the liquid droplets flow on the inner wall of the vessel and the stripped gas to flow through the central section of the inlet device (annular ring) to the gas outlet nozzle.

There are two options with regards to the inlet nozzle arrangements shown in Figure 4. The type depicted in Figure 4a generates higher centrifugal force and slightly better separation efficiency. However, it is not recommended for pressures higher than 5.0 bar due to its construction difficulties at high pressures. Furthermore, both types can have a circular or rectangular inlet nozzle. A larger cross sectional area can be provided when a rectangular (with height larger than the width) nozzle is used.

- **Cyclone**

The cyclonic inlet device is used in horizontal and some vertical separators where there is a requirement for high momentum dissipation, foam reduction and high capacity. They work on the principle of enhanced gravity separation by accelerating any incoming stream to a high g-force, which particularly helps foam to break down into separate liquid and gas phases. Unlike most inlet devices that are positioned in the gas phase, the inlet cyclone is partly submerged in the liquid phase. The liquid phases are also separated centrifugally through the perimeter of the cyclone tubes and fall down in to the bulk liquid layers, whilst the gas forms a central vortex core and escapes through a top outlet hole into the gas space. The mixing elements on top of the cyclone outlet section usually provide a proper distribution of the cleaned gas to downstream devices. The device has a high pressure drop associated with it.



4a. Round Entry | 4b. Straight Entry

Figure 4 - Tangential Inlet Entry Arrangements

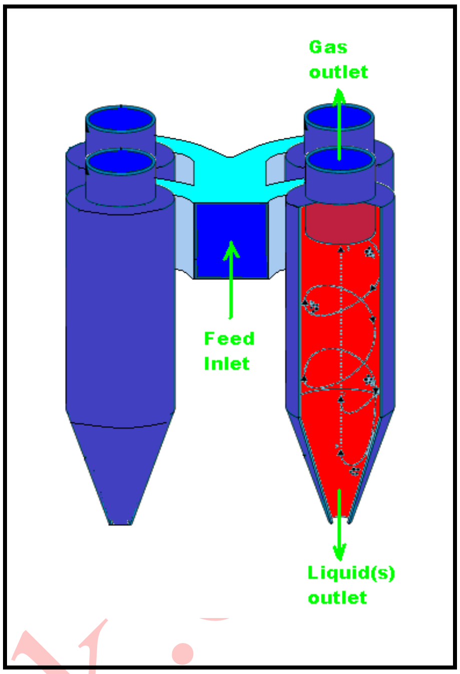


Figure 5– Multi Cyclone Inlet Device

The designs of the inlet cyclones have evolved over the past decades from short single (conventional cyclones) or dual cyclones into multi-cyclone arrangements (Figure 5). A main characteristic of the cyclone inlet device is its high flow capacity, meaning that more throughput is possible through any given size separator.

Selection Criteria

In order to make a proper selection, you need to know how different types of inlet devices perform in similar conditions. Table 1 evaluates to what extent they fulfil the functions described earlier in this note.

Table 1 - Comparison of Performance of Different Inlet Devices

Inlet Device Functions	No Inlet Device	Deflector Baffle	Half Open Pipe	Vane Type Distributor	Cyclone
Separate Bulk Liquids	Poor	Poor	Average	Good	Very Good
Ensure Good Gas and Liquid Distribution	Very Poor	Very Poor	Average	Good	Good
Prevent Re-entrainment of Liquid from the G/L Interface	Very Poor	Very Poor	Poor	Good	Good
Minimize Droplet Shatter	Poor	Very Poor	Average	Very Good	Very Good
Facilitate De-foaming	Very Poor	Very Poor	Poor	Average	Very Good

It may be concluded from Table-1 that it would always be necessary to install a sophisticated inlet device such as vane type distributors or cyclones. But, it should be noted that Table-1 compares the performance of different inlet devices in similar conditions. For example, the ability of half open pipe to prevent re-entrainment of the liquid from G/L interface is poor compared to the vane type distributor when they are installed at the same distance from the gas/liquid interface. However, this deficiency can be improved by providing enough height between the half open pipe and the interface level. In other words, the weakness of the inlet device can be compensated if proper engineering practices are taken into consideration.

Another example is the cyclone which is exceptionally effective in breaking the foam. But the fact is that using the cyclone is particularly essential when the amount of liquid is considerable. If the liquid flow rate is not high, most probably it is more reasonable to de-foam the liquid by providing the adequate residence time (not necessarily much more than what is required for the process operation or liquid-liquid separation) rather than an advanced technology device to enhance the de-foaming.

Furthermore, performance mentioned in Table 1 is expected from a correctly designed inlet device. Otherwise, using a wrongly designed cyclone can cause gas blow-by or liquid carry over which will increase foam formation instead of stopping it. Or having a high mixture velocity at the exit of the annual ring will result in re-entrainment of the liquid film which has been already collected on the separator wall.

In summary, the selection of the optimal inlet device differs from case to case. Therefore, it is important to understand how inlet device functions and the effect it has on the separation efficiency of the rest of the vessel. The following section describes other important parameters in selecting a proper inlet device.

- **Separation Requirements**

The first parameter to check is whether a high performance inlet device is required from a process point of view or not. If there is no specific separation requirement other than bulk liquid separation and the major portion of the liquid droplets are relatively large (typically larger than 150-200 microns), most probably a vertical KOD with one of the simplest inlet devices (may be NO inlet device) is sufficient.

On the other hand, using a high performance inlet device is essential in some other applications where the ratio of liquid to gas in the feed stream is high and mist extractors (mesh or vane pads) are used to enhance the quality of gas leaving the vessel. In such applications, the amount of residual liquid in the gas stream in the face of the mist extractor plays a major role in achieving the desired separation efficiency in the mist extractor. Therefore, a high performance inlet device which efficiently performs the primary separation and uniformly distributes the gas across the vessel area prevents the mist extractor from being overloaded with the liquid.

Therefore, depending on the ratio of liquid to gas in the feed stream and the selected gas-liquid separation device (permissible liquid loading in the face of mist extractor) a proper inlet device should be selected. Otherwise, to take in to account the liquid overloading effect into vessel sizing, the mist extractor K value should be de-rated as pointed out earlier in “Three Phase Separators – Time Definition”. To calculate the amount of liquid at the entrance of the mist eliminator, the feed stream’s liquid fraction can be multiplied by the factors specified in Table 2.

Table 2 – Efficiency of Different Inlet Devices for Bulk Liquid Removal

Inlet device	No inlet device	Deflector baffle	Half open pipe	Multi-vane distributor	Cyclone
Separation efficiency	< 0.5	0.5	0.8	0.95	> 0.95

- **Space and Cost Considerations**

In some applications where vessel size is significantly important (such as offshore installations or where the size of equipment is limited by transportation restrictions), reducing the size of the vessel can be a great advantage. Utilizing a higher performance inlet device is one of the methods. For example, if the diameter of vertical KOD mentioned above is large, installing a half open pipe on the inlet nozzle can cause a great reduction in the length of the vessel. On the other hand, adding a half open pipe in horizontal vessel with top nozzle may result in a larger vessel diameter as accommodating the half open pipe will need the larger vapor space (the distance between HHLL and the top of the vessel).

Furthermore, it should be noted that theses kind of changes may not always be economically attractive. For example, according to Table 3, where the effects of different inlet devices on the length of a vertical vessel have been summarized, replacing the half open pipe with vane distributor in a vertical KOD of 2000 mm diameter can result in about 0.55D (0.25D in the distance between HLL and inlet device + 0.3D in the distance between the inlet device and top TL) which is about 1000 mm. Therefore, if the only reason for this upgrade is to reduce the vessel size, the equipment cost saving due to 1000 mm reduction in the length can be offset by the higher cost of the inlet device, vendor and contractor engineering costs and delay in procurement, etc.

- **Other Parameters**

There are some other parameters to look into while selecting/designing an inlet device for a three phase separator:

Flow regime: annular dispersed and mist flow regimes in the inlet pipe need special attention and inlet devices with higher surface area such as multivane inlet distributor of tangential inlet with annular ring are recommended when low liquid carry over is essential. Almost all inlet devices can be made mechanically appropriate to handle liquid dominant flow regimes such as bubble and intermittent (slug or plug) flow regimes without vibration. The most desired flow regimes in the vessel inlet pipe are stratified (smooth or wavy) flow regimes. The design of inlet piping to achieve this flow regime should be considered for special services in which a low liquid entrainment rate is required but mist extractors are not allowed due to any reason (i.e. the possibility of mist pad plugging).

Pressure drop: the pressure drop of the inlet device increases as the number of internals and changes in the direction of inlet flow increases but it usually remains in the order of a few Pascals. Inlet cyclones usually create higher pressure drop than other inlet devices, therefore they are not recommended if the allowable pressure drop is very limited.

Table 3 – The Effect of Different Inlet Devices on the Length of the Vertical Vessel

Inlet device	HHLL to Inlet device	Inlet device height (Note 1)	Inlet device to top TL (KOD)	Inlet device to wiremesh
No inlet device	0.5 D (min 300mm)	d_1	1.0 D (min 1200mm)	0.7 D (min 900mm)
Deflector Baffle	0.3 D (min 300mm)	2 d_1	1.0 D (min 900mm)	0.5 D (min 600mm)
Half open pipe	0.3 D (min 300mm)	d_1	0.9 D (min 900mm)	0.45 D (min 600mm)
Vane type distributor	0.05 D (min 150mm)	d_1 + 20 mm	0.6 D (min 600mm)	d_1 (min 300 mm)

Notes:

1) The inlet nozzle size (d_1) also varies with the type of inlet device. Using high performance inlet devices allows the designer to use higher momentum for the inlet nozzle sizing. This leads to the reduction in the size of the inlet nozzle which directly contributes to the length of the vertical vessel and can be important (as discussed above) in the size of horizontal vessels. Refer to the nozzle sizing section for further information.

2) The effect of the inlet device on the size of a horizontal separator is not that straight forward. On one hand, using a high performance inlet device (as illustrated in Table 2) can reduce the size of the vapor space through improving (not de-rating) the separation efficiency of mist extractors. On the other hand, the vapor space may be governed by other factors, such as maximum filling level or accommodating the gas outlet device (refer to the paper "Three Phase separators – Gas Internals"). For example, some of the gas outlet devices need vapor space of at least 40% of the vessel diameter in which any inlet device of ordinary size can be accommodated. But in any condition, the vapor space should be sufficiently high to accommodate the feed inlet device plus minimum 150 mm between the bottom of the inlet device and HHLL. See the following section for the size of the inlet device.

Foam services: cyclones are the only inlet device with proven capability to break the foams. The primary purpose of the inlet cyclone is that of foam elimination inside a separator. Many crude oils exhibit moderate or severe foaming tendency and the traditional approach to these problems is through a combination of oversized equipment using foam breaking packs and chemicals.

Nozzle size: using a high performance inlet device enables the designer to use higher momentum for inlet nozzle sizing. This can reduce the nozzle size and subsequently the length of the vessel. It can also be of great advantage especially when the entire vessel mechanical design can be adversely affected by an extraordinarily large opening.

Solid: a vessel with no inlet device is preferred. Cyclones are not suitable for this service as they further accelerate the inlet fluid for separation purpose which can create an extremely erosive environment. If an inlet device is inevitable, it should have 1-2 mm extra thickness for erosion.

Fouling services: Inlet devices with narrow openings such as slotted tee distributors should be used with extra precaution in the fouling services. They are not recommended if the feed's wax, solid, scale or asphaltene content are high.

Sizing Considerations

The following section covers the sizing requirements of the various inlet devices:

- **Deflector Baffle**

Figure 6 shows the typical dimensions on a deflector baffle.

- **90° Elbow**

The diameter of the elbow should be the same as the inlet nozzle. Figure 7 shows the minimum height of vapor space to accommodate LR and SR elbows. Furthermore, the elbow should be installed as close as possible to the tangent line considering reinforcement and fabrication requirements (150 mm).

An impingement baffle should be installed opposite to the elbow to protect the drum shell. The impingement baffle diameter should be twice the elbow diameter, as of a minimum.

- **Half Open Pipe**

Similar to 90 degree the diameter of the half open pipe is the same as that of the inlet nozzle. However, the length of the device is usually 3 times the inlet nozzle diameter ($3d_1$) out of which $2d_1$ is dedicated to the opening cut.

A half open pipe can also be fitted downstream of a LR or SR elbow when it is used in horizontal vessels – top entry depending on available vapor space (Refer to Figure 7 for details). For a horizontal vessel, an impingement baffle should be installed opposite to the elbow to protect the drum shell. The impingement baffle diameter should b twice the elbow diameter, as of a minimum.

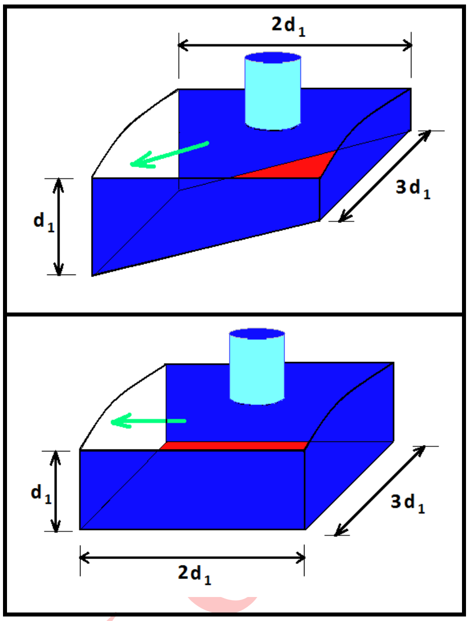


Figure 6 - Deflector Baffle Dimensions

- **Vane Type Distributor**

In a horizontal vessel, the length of a multi-vane distributor is between 3 to 5 times the inlet nozzle diameter.

For a vertical vessel, the length of a multi-vane distributor can be as high as the vessel diameter. However, a shorter vane distributor is needed to accommodate the required number of vanes while obtaining a reasonable opening between two adjacent vanes.

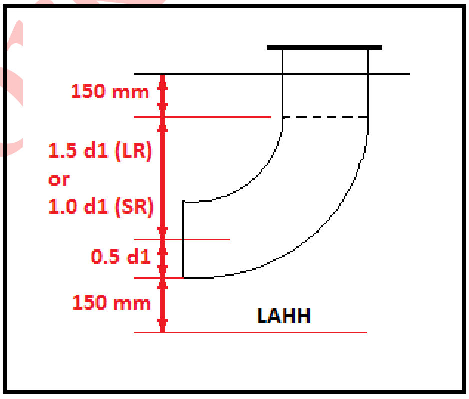


Figure 7 – Inlet Elbow Dimensions

In other words, a specific number of vanes should be installed with particular pitch in order to achieve the targeted performance. This can be a trial and error exercise, starting with an assumed length, followed by specifying the size and number of vanes, and finally checking if this number of vanes can meet other manufacturing requirements (consult with vendor) in the assumed length or not.

The height of the vane is the same as the inlet nozzle. Additional height for the inlet elbow should be added to the vane distributor height when it comes to determining the minimum vapor space in horizontal vessels to accommodate the inlet device.

Vane distributors are not recommended if:

- Vessel diameter is less than 500mm.
- Inlet nozzle diameter is smaller than 150mm.
- Inlet nozzle diameter is larger than 1/3 of the vessel diameter.

To prevent vibration of the vanes, special considerations should be given to the design and construction of the vane distributors when the vane height is in excess of 800mm or exceptionally high flow rates are possible or liquid slugging is expected.

- **Slotted Tee Distributor**

The slotted tee distributor can be sized based on the superficial velocity of the inlet fluid in the slot through the following equation (1):

$$V_{slot} = \frac{C_1 \, \sigma \, (\rho_L/\rho_G)^{0.5}}{\mu_G}$$

Other details and dimensions of inlet distributor can be calculated using the formulas below:

$N_{slot} = Q_T / (C_2 \times A_{slot} \times V_{slot})$

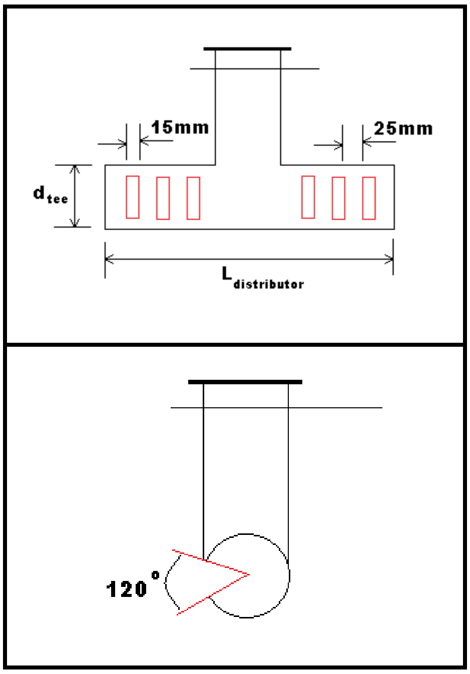


Figure 8 –Tee Distributor Details

$A_{slot} = L_{slot} \times W_{slot}$

$L_{slot} = 120\ \pi\ d_{tee} / 360$

$Q_T = Q_G + Q_L$

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

$L_{distributor} = d_{tee} + N_{slot} \times W_{slot} + (N_{slot} + 2) \times Pitch$

Where

σ : liquid surface tension. mN/m
ρ_L: liquid density, kg/m3
ρ_G: gas density, kg/m3
μ_G: gas viscosity, cP
C_1: 7 x 10^{-5} (Metric unit)
C_2: 2 when the flow is split between the two sides of the distributor (tee type) and 1 if a slotted pipe distributor is used.
W_{slot}: width of slot, 15mm
Pitch: the distance between two adjacent slots, 25mm

- **Tangential Inlet With Annular Ring**

Inlet nozzle is usually sized by determining the velocity required to satisfy the following requirements:

- Liquid bulk separation
- Inlet stream momentum (ρV^2)
- Foaming separation requirement
- Prevent erosion if erosive materials are present

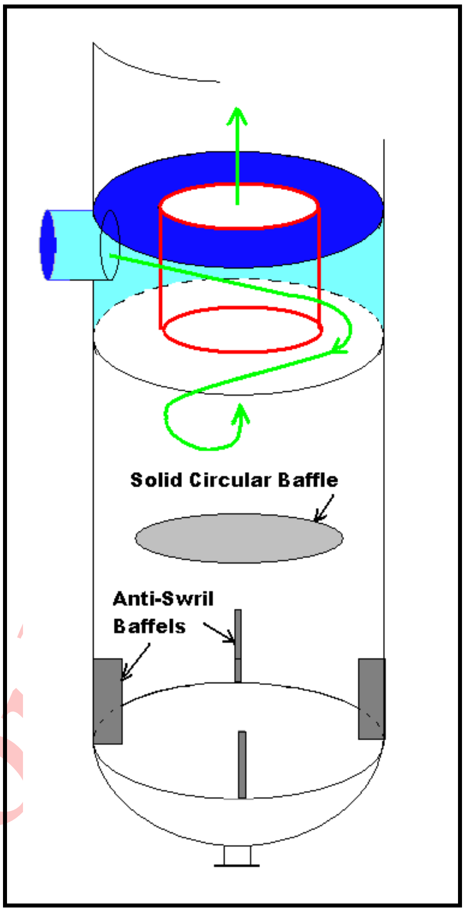


Figure 10 – Tangential Inlet with Annular Ring

The annular ring width is usually the same as the inlet nozzle diameter. The ring height should be 2.5 times the inlet nozzle diameter. The diameter of the vessel is also linked with inlet nozzle size and it is the larger of:

- 3.0 and 3.5 times of inlet nozzle width/diameter for rectangular and circular inlet nozzles, respectively.
- Vessel diameter required to maintain the gas velocity in the vessel cross sectional area below 3m/sec.

Furthermore, one solid circular baffle with diameter to allow superficial velocity of 45mm/sec through the annular gap (with minimum gap of 50 mm) should be installed at least 150 mm above HHLL. Four vertical anti-swirl baffles should be provided below NLL. These baffles should be extended from 150 mm below the NLL to the bottom TL. The baffle width should be about 10% of the drum diameter.

- **Cyclone**

There are some general guidelines about cyclone inlet device sizing; however, the best approach is to ask the vendor to provide the size of this device.

Nozzle Design Details

A feed stream can enter a horizontal vessel from top or dish ends. When the feed nozzle is on top of the vessel, the inlet device is usually faced toward the dish end to make the most use of the space available in the head cap section.

The diameter of the inlet nozzle is a function of the feed flow rate and the pressure. The criterion for nozzle sizing is that the momentum of the feed should not exceed an allowable limit. The maximum allowable inlet momentum can be increased by fitting inlet devices into the inlet nozzle. The following table shows the allowable ρV^2 criterion for different inlet devices which can be customized based on the inlet device vendor recommendation.

Table 4 – Inlet Nozzle Sizing Criteria

Inlet device	No inlet device	Deflector baffle	Half open pipe	Multi-vane distributor	Cyclone (conventional)	Multi-cyclone
$\rho_m V_m^2$, kg/ms (pa)	1,000	1,400	2,100	8,000	1,0000	35,000

Where

ρ_m is the mean density of the mixture in the feed pipe in kg/m³
V_m is the velocity of the mixture in the inlet nozzle in m/s.

Where the inlet feed is practically gas phase, ρV^2 can be increased to 8000 Pa regardless of the type of inlet device. Erosional and 80% of sonic velocity are other limitations that should be met for inlet nozzle design.

Contact

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