

Three Phase Separators – Gas Internals

Saeid Rahimi

09-July-2013

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, number 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 performed, any simple exercise can turn into a cumbersome and complex iterative problem.

This series of notes is going to cover the basics of three phase separator sizing. This note reviews different types of the gas internal devices, their effects on the gas-liquid separation, and sizing and selection details. Gas inlet device has been already discussed in another note.

Gas-Liquid Separation Device Importance

Mist eliminators achieve the following objectives by either increasing the allowable gas velocity or reducing the liquid carry over:

- **Reduce Vessel Size**

Using a high efficiency mist eliminator enable designer to use the higher velocity of gas inside the vessel and downsize the separator. Refer to the next section where different gas internals ad their performances are discussed.

- **Increase Capacity**

Installing a mist eliminator inside an existing knock out drum makes it possible to run the vessel at a higher capacity.

In distillation, absorption and scrubbing columns where trays or packings are used, the vapor-liquid velocities are limited by the capacity of the trays or packing internals rather than the mist eliminator. To boost throughput in these units, one can operate closer to the flood point by installing mist eliminators at three locations. The first location is just above the feed inlet where liquid is being flashed. Without mist elimination at this stage, significant entrainment can be carried upward with the flashed gas. The second mist eliminator location is below the draw-off trays. Without it, the liquid entrainment into a draw-off tray can reduce the quality of the intermediate draw-off product. The third unit, located at the top of the tower, prevents liquid entrainment with the exiting gas. Removing mist at this point can provide higher quality gas products leaving the tower, or prevent product loss.

- **Cut Product Loss**

When the plant produces a valuable product, utilizing the mist eliminator for vessels where the product is carried away with gas can increase the product recovery and subsequently the plant revenue. If an expensive chemical is used in the process system reducing the chemical loss will be very attractive. A typical example is gas sweetening unit (absorber column or absorber overhead KOD gas outlet) when an Amine solution is used as a solvent to remove the sour components from the gas. If solvent is lost due to foaming as a result of feed gas containing appreciable amount of heavy hydrocarbon, which tend to condense in absorber column, increasing the liquid removal efficiency by adding a high efficiency mist eliminator will resolve the problem.

- **Protect Compressors**

Compressors are susceptible to erosion, corrosion and fouling that can unbalance the high speed rotating elements of the equipment when liquid entrainment is poorly controlled in the compressor inlet gas. Using high efficiency wire mesh mist eliminators can prevent potential maintenance problems in the high pressure equipment.

- **Improve Product Quality**

Mist removal is important in steam production systems. Solids carried with water droplets from steam drums can cause scaling on the downstream superheater tubes, resulting in localized overheating and equipment failure. In addition, if the steam is used in a high speed steam turbine to generate the electricity, the high purity steam with Total Dissolved Solid (TDS) levels of 10 ppb or lower will be needed. Removing the water droplet from the steam before leaving the steam drum plays an important role in achieving this design requirement.

- **Reduce Environmental Pollution**

When installed in pollution control scrubbers and air strippers, mist eliminators prevent hazardous materials from escaping to the environment. For such environmental applications, mist elimination is often required by regulatory authorities. A commonly encountered environmental application of mist eliminators is in sulfuric acid manufacturing, where corrosive mists are created in packed towers used for the drying of air and SO₃ absorption. Besides for pollution control, these mists must be efficiently removed to prevent corrosion in downstream equipment, such as ducts, blowers and heat exchangers.

Gas Internal Devices

- **No Outlet Device**

The simplest types of the vessels have no device on the outlet nozzles. In the absence of the gas outlet device in a horizontal vessel, the effective length of the vessel available for the removal of the liquid droplets from the gas stream will be from the inlet nozzle/device discharge to the edge of the outlet nozzle. This reduction in separation length is not important as long as the size of the vessel is governed by liquid hold up time rather than the gas-liquid separation. Otherwise, the actual length of the vessel should be specified by taking into account the liquid droplets' separation length, the size of inlet and outlet nozzles and the distance required between nozzle neck weld and the vessel tangent line weld.

- **Deflector Baffle**

A Deflector baffle with opening towards the vessel dish end on the outlet nozzle of a horizontal vessel ensures that the total length of the vessel is effectively used for the gas-liquid separation as the gas cannot exit the vessel unless it travels the entire length of the vessel.

The size of the deflector baffle on outlet nozzle is similar to the figure 6 of the Three Phase Separators – Inlet Devices.

- **Wiremesh Mist Extractor**

Wiremesh mist eliminator is often made of metal or plastic wire with typical diameter of 0.006 to 0.011 inch, loosely knitted in a form resembling a cylindrical net. This tube is flattened to a two-layer strip which is then crimped in a diagonal pattern. They are stacked to form a pad with typical thickness of 4 to 6 inches. Then, the pad becomes rigid by providing a frame (usually metal), a grid on each side and rods passing through the mesh.

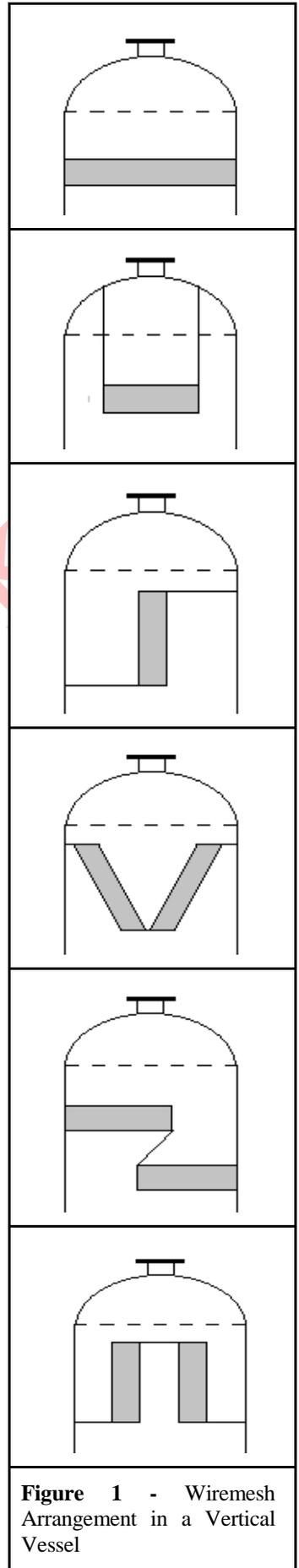


Figure 1 - Wiremesh Arrangement in a Vertical Vessel

Wiremesh mist extractors have been installed almost in any orientation. Figure 1 depicts some of these arrangements in a vertical vessel. In the vertical vessels, horizontal wiremesh mist extractors (vertical flow) are more preferred than vertical ones (horizontal flow) due to size reduction and ease of liquid removal. Other arrangements (V, Z and Π) are basically debottlenecking alternatives (revamping an existing vessel) only. The design of wiremesh mist eliminators in some of these arrangements is much more complicated than an ordinary wiremesh mist extractors. The main challenge when mist eliminators are used in arrangements other than vertical or horizontal flow is the even distribution of flow over the meshpad area which needs special vendor's design and guarantee. Inclined wiremesh mist eliminators in certain application such as sulfur condensers in Claus type sulfur recovery system have been used for years. The installation of mesh pad in diagonal orientation requires specialized geometry of the mist eliminator to fit the configuration of the equipment. Due to this limitation, a horizontally mounted mist extractor in housing has been used in recent applications instead.

Table 1 - Wiremesh Mist Extractor Standard K

Service	K _{std}	
	m/s	(ft/s)
Vertical flow	0.107	(0.35)
Horizontal flow	0.128	(0.42)

In horizontal vessels, the installation of wiremesh in the vertical and horizontal positions is quite popular as shown in Figure 2a. The V arrangement can also be considered for central outlet nozzle (two inlet nozzles) as shown in Figure 2b.

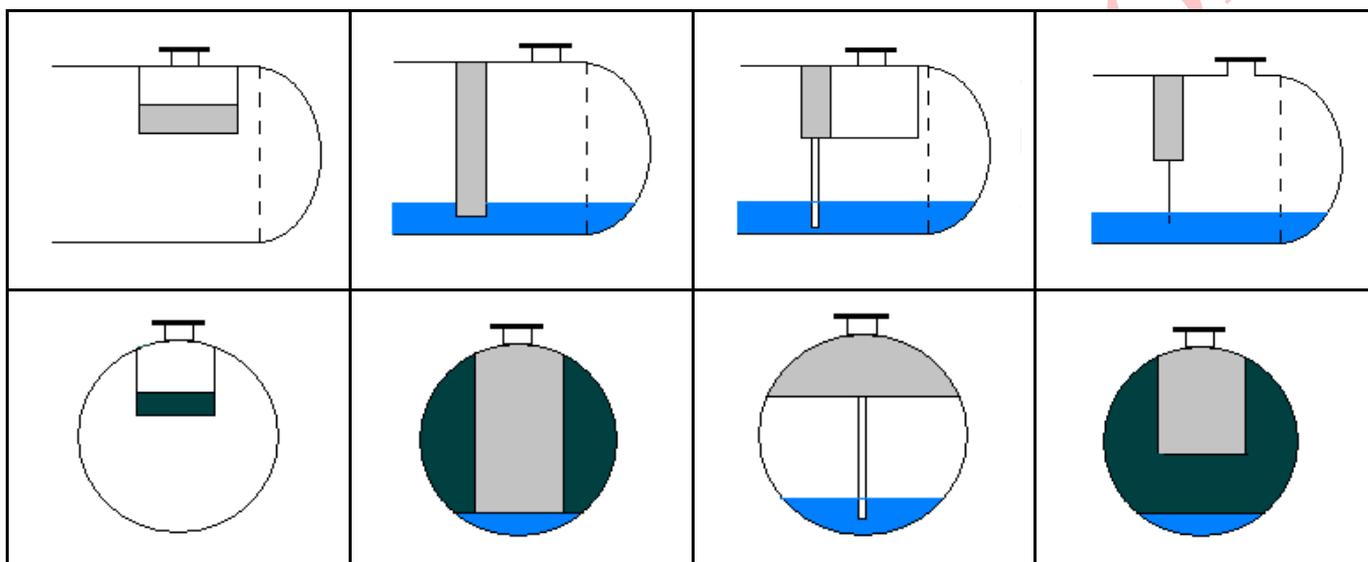


Figure 2a – Mist Extractor (Horizontal and Vertical installations) in Horizontal Vessel

The surface area of mist extractors is calculated using the vendor K value and the equation below:

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

$$K = K_{std} \times C_1 \times C_2$$

Where C₁ and C₂ are the pressure and liquid load correction factors, respectively. Refer to “Three Phase Separators – Times Definition” for further information. K_{std} for wiremesh has been specified in Table 1.

It should be noted that in applications where the vessel cross sectional area is governed by another process requirement (liquid hold up time, internals such as tray diameter, inlet device, etc), the mist extractor (if required) should have surface area required according to the area calculated above. In other words, considering a mist extractor which covers the full cross sectional area of a vertical vessel or entire vapor space of a horizontal vessel may cause liquid droplet removal efficiency to decline from the expected value as the actual velocity of gas through the oversized mist extractor can easily fall out of 30-110% designed flow range even during the normal operation.

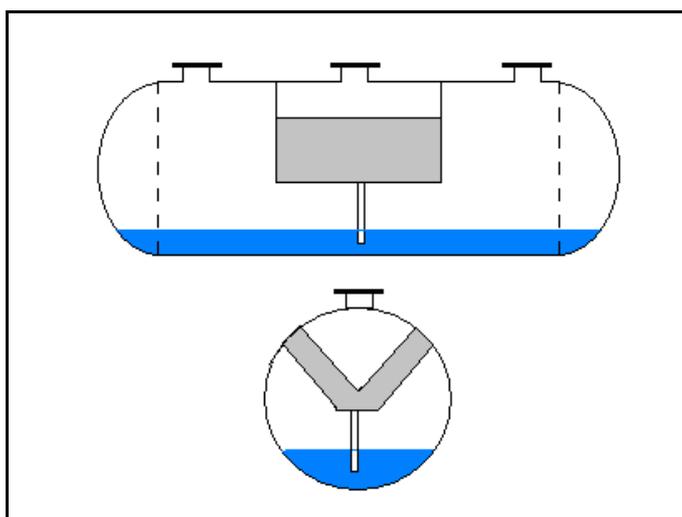


Figure 2b – V installation in Horizontal Vessel

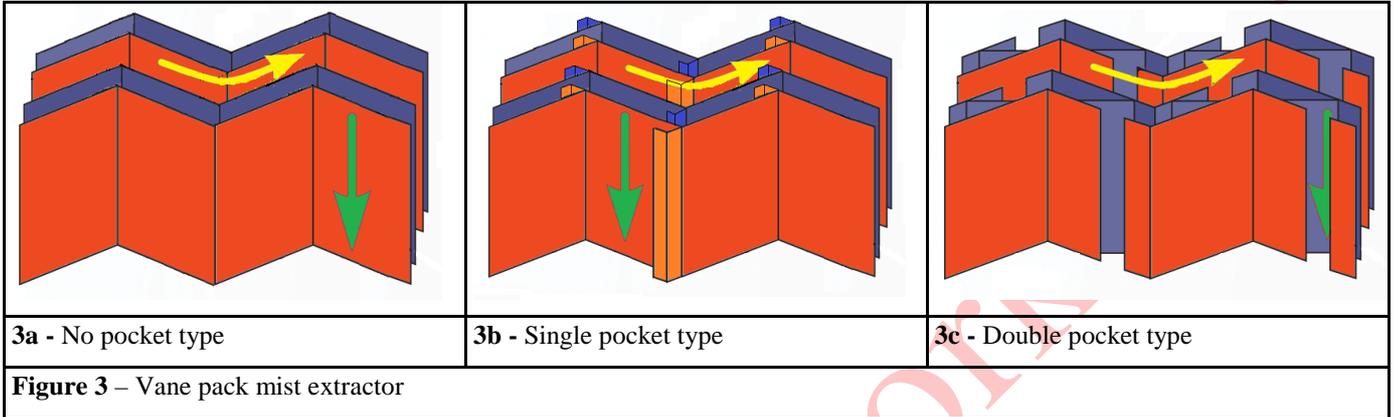
• **Vane Mist Extractor**

Vane mist extractors consist of closely spaced corrugated plates that force mist-laden gas to follow serpentine paths.

These devices are generally less efficient than wiremesh mist eliminators but they offer more resistance to plugging and less pressure drop. They are preferred in applications involving high vapor velocities, low available pressure drop, viscous waxy or foaming liquids, lodging or caking solids, slug of liquid or violent upsets.

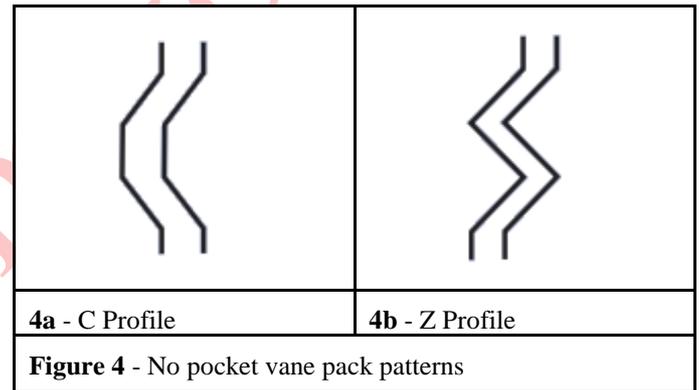
Table 2 - Vane Mist Extractor Standard K

Service	K _{std}	
	m/s	(ft/s)
Vertical flow	0.152	(0.50)
Horizontal flow	0.198	(0.65)
Double pocket (Horizontal or Vertical flow)	0.304	(1.0)



Vane mist extractors are usually available in metal or plastics and have various blade spacing and profile. They are in three types as shown in Figure 3:

- No pocket type is used for highly fouling services and vertical flow. No pocket vanes are usually fabricated in C or Z profile shown in Figure 4.
- Single pocket type is utilized for slightly fouling applications and horizontal flow through the vanes.
- Double pocket type is most suited for clean services. It can be used with horizontal (most preferred) and vertical flow.



From installation view point, there should be sufficient access for inspection, cleaning, maintenance and removal of the vane pack. In case of vertical vessel, the vessel should be provided with a full top flange or with manways. A full top flange allows for the installation of internals as a prefabricated box which is preferred if the vessel diameter is less than 1.2m. Alternatively two manholes can be provided; one upstream and one downstream of the vane pack. One manway upstream of the vane pack is the minimum requirement. In horizontal vessels, the vane pack is usually accessed through manways.

With vane pack the minimum inner diameter of 0.6 and 1.5m is recommended for the vertical and horizontal vessel, respectively.

• **Wiremesh-Vane Combination**

There are two applications in which the combination of wiremesh and vane mist extractors has been particularly advantageous:

1. Using meshpad upstream of vane mist extractor (Figure 5a) can be considered as a debottlenecking option. In this case, the mesh pad operates at higher velocity (beyond re-entrainment point). It serves as an agglomerator to coalesce fine liquid droplets and produce larger droplets which can be easily captured by downstream vanes. In this application the overall K value is increased to the vane mist extractor's.

Table 3 – Wiremesh-Vane Combination Standard K

Service	K _{std}	
	m/s	(ft/s)
Mesh + Vane (Horizontal flow)	0.198	(0.65)
Vane + Mesh (Horizontal flow)	0.128	(0.42)

- Installing a vane unit upstream of the mesh pad (Figure 5b) combines the superior efficiency of mesh with the superior liquid and solid handling capacity of vanes. In this arrangement, vane mist extractor upstream of mesh pad removes larger droplets, greatly reducing mist load and shielding a mesh pad from a very heavy mist load. Fine droplets are then separated in the wiremesh mist extractor. The combination K factor for this arrangement is limited to wiremesh mist extractor K value.

The wiremesh-vane combination's K factor has been illustrated in Table 3.

- Fiber Bed**

Fiber beds consist of packed fibers – typically cellulose, special glass, or plastic – between either two concentric screens or two flat parallel screens.

From droplet separation¹ view point, there are two types of fiber beds:

- Diffusion fiber beds which are usually utilized for a process gas that contains a significant level of submicron mist or soluble particulate matter. This device employs collecting fiber diameter of 8-10 microns to separate the particle size in the range of 0.1-3 microns. In order to achieve this, the gas velocity in the bed is reduced to about 0.05 to 0.25m/s (typically 0.10m/s).
- Impaction fiber beds are utilized when lower separation efficiencies are needed. This device employs collecting fiber diameter of 10-40 microns to separate the particle size in the range of 1-3 microns while the velocity of gas through the bed is maintained between 1.25 to 2.5m/s.

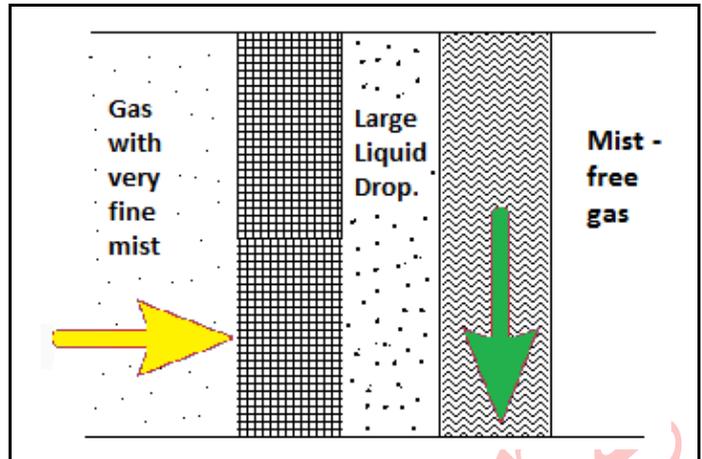


Figure 5a – Mesh-vane combination

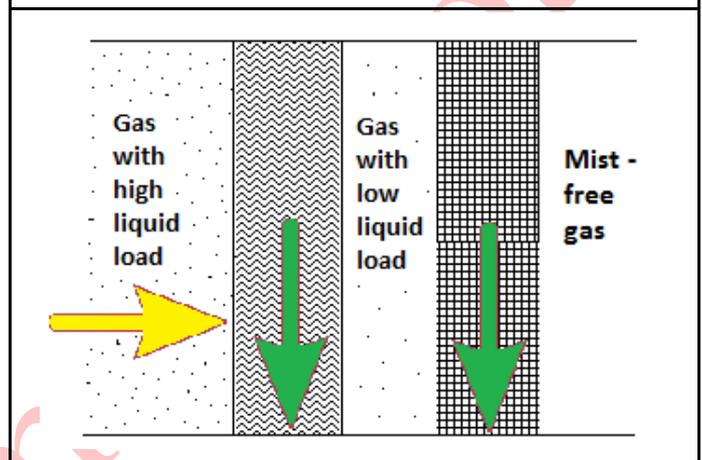


Figure 5b – Vane-mesh combination

From installation view point, fiber beds can be forward (flow from out to in – Figure 6) or reverse flow (flow from in to out – Figure 7). Moreover, the fiber beds can be installed directly on the tubesheet (flanged or flangeless style) or on the piece of pipes welded to the tubesheet (called candle collectively). While flanged or flangeless fiber elements in large sizes (diameter from 0.2 to 0.75m and length from 0.2 to 7.5m) are usually used in low pressure systems mainly for environmental reasons (such as controlling stack opacity, meeting exit emission standards, removing overall pollutants), candle type fiber bed separator have been widely used in process applications and typically with an outer and inner diameter of 4" and 3" respectively and with a length of either 36" or 72".

When choosing an installation style for a particular application, the engineer should be aware of process, mechanical, safety and maintenance tradeoffs. For example, reverse flow installation is almost always the preferred style that achieves an optimal balance of gas velocities, however in a fouling environment or if mercury is present in the feed, the dirt or mercury can accumulate inside the fiber beds and eventually block them. For this application, a pre-filtering stage with the forward flow may be used.

On the other hand, with large multiple-element installations, the forward flow style has some disadvantages. In order for each element to be completely removed from the vessel, it must be withdrawn through the tubesheet hole. This means that either the entire top of the vessel must be removed, or the vessel must be designed such that the distance between the tubesheet and the vessel ceiling exceeds the filter bed's height above the tubesheet. As a general rule, once a vessel's diameter exceeds roughly 2 to 3 m – which often makes a full body flange impractical or very expensive – the required vessel height must be increased to accommodate the element removal. With the reverse flow the elements are removed from the vessel by first detaching from the

¹ Mist collection mechanisms fall into one of three categories: 1) Impaction: a particle is collected as it impinges upon the target. 2) Interception: a particle is removed from the gas stream as it cannot squeeze between the openings in a target. 3) Diffusion: a particle is collected by a target because of its random (Brownian) motion in the gas stream. First two mechanisms are the primary methods for removal of larger particles from the gas stream and the last one is the main separation mechanism for submicron particles.

tubesheet, and then by moving them sideways to beneath a manway, and extracting them one at a time through the opening. Therefore, the reverse flow style allows a shorter vessel.

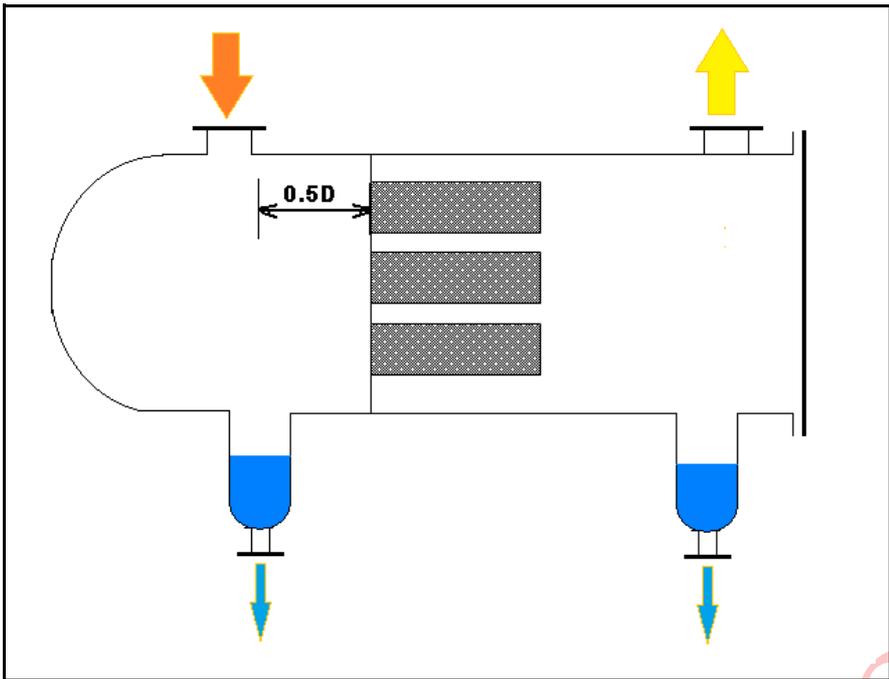


Figure 6 - Horizontal vessel with reverse flow fiber beds

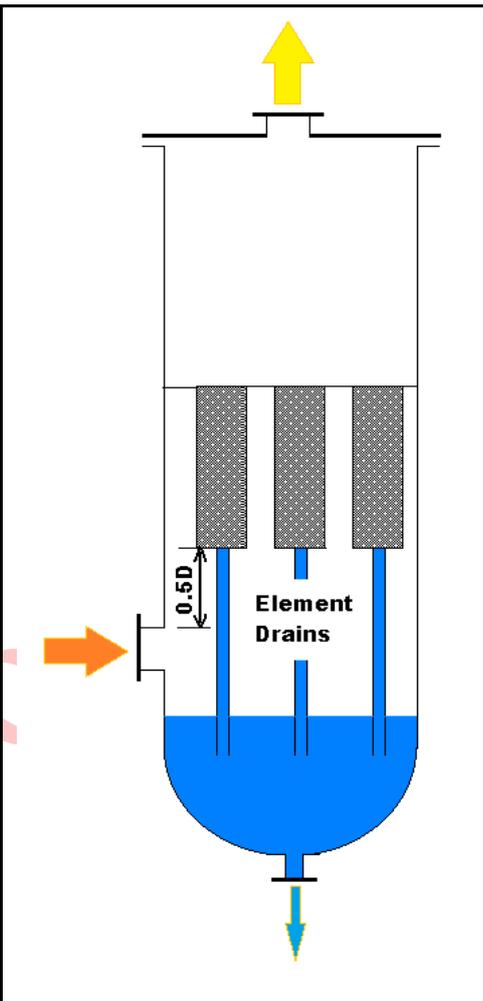


Figure 7 - Vertical vessel with forward flow fiber beds

Candle arrangement resolves the problems associated with access for maintenance, inspection and leak test associated with installing elements directly on the tubesheet as tubes are welded to the tubesheet in the candle arrangement. Furthermore, the candle arrangement is advantageous particularly in a vertical vessel with reverse flow as the length of tube can be specified to provide adequate liquid hold up time and level instrument nozzles (Figure 8). Using welded pipe on the tubesheet makes it possible to reduce the space between two adjacent fiber elements (and subsequently the vessel diameter) compared to the spacing required for the access to the flanged / flangeless fiber bed types. With candle arrangement, fiber bundle along with tubesheet should be removed for maintenance.

The vessel diameter is determined based on the number of fiber elements and the fact that the beds should fill not more than 35% to 50% of the cross section of the vessel.

$$n = \frac{Q_g}{V_g \pi d l}$$

where

$$D / d = (n / 0.35 \text{ to } 0.5)^{0.5}$$

and

n: Number of elements

Q_g : Gas volumetric flow, m^3/s

V_g : Allowable velocity, m/s

d: Fiber element diameter, m

l: Fiber element length, m

D: Vessel diameter, m

- **Cyclone**

Cyclone mist eliminators consist of multiple cyclone tube elements, mounted into a tubesheet. The flow through these elements can be horizontal (Figure 9) or vertically upward. The element diameter is 2" or 3", selected based on geometric considerations. The units are provided in easily handled subassemblies, which are installed through normal vessel manways.

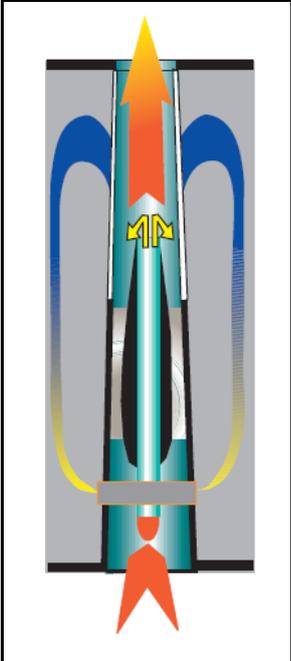


Figure 10 – Cyclone tube

Different technologies have been utilized inside tube elements to create centrifugal force. In the one shown in Figure 10, the gas and mist enter the cyclone inlet (red arrow) and flow through a swirl element which imparts a very high centrifugal force. The droplets are flung outward and are coalesced into a liquid film on the cyclone inner wall. This liquid film is purged out of the cyclone through slits in the wall (blue arrow), along with a small portion of the gas flow, into an outer chamber where most of the gas and liquid separate. The gas along with some remaining mist is educted back into a low pressure zone of the cyclone (yellow arrow) and the remaining entrainment is removed before the gas is discharged (orange arrow).

Cyclone mist eliminators are typically for use in a slightly fouling environment where the gas pressure is very high (and wiremesh and vane mist eliminators' performance is adversely affected by the system pressure – C_1 factor above) and a compact separator is required.

Cyclone mist eliminators are normally supplied as a complete package of vessel and internals based on a vendor-proprietary design.

- **Flow Straightener**

In some designs, the liquid calming baffle is extended to cover the whole cross-sectional area of the vessel. This provides some control on the gas distribution through the separator stages, helping to minimize mal-distribution effects on the downstream demisting equipment and maximizing the efficiency of the gas-liquid separation process.

Using perforated plate as flow straightener is not recommended for dirty duties, due to the chance of fouling and blockage. In this situation, if the even gas distribution is essential a flow straightener with larger openings or proprietary designs can be employed.

Perforated plate should not be installed in horizontal orientation as it increases the risk of liquid re-entrainment.

Selection Criteria

Table 4 compares the different aspects of various gas-liquid separation devices. The following section also provides some explanations about the table headers and other important parameters in selecting a proper demisting device.

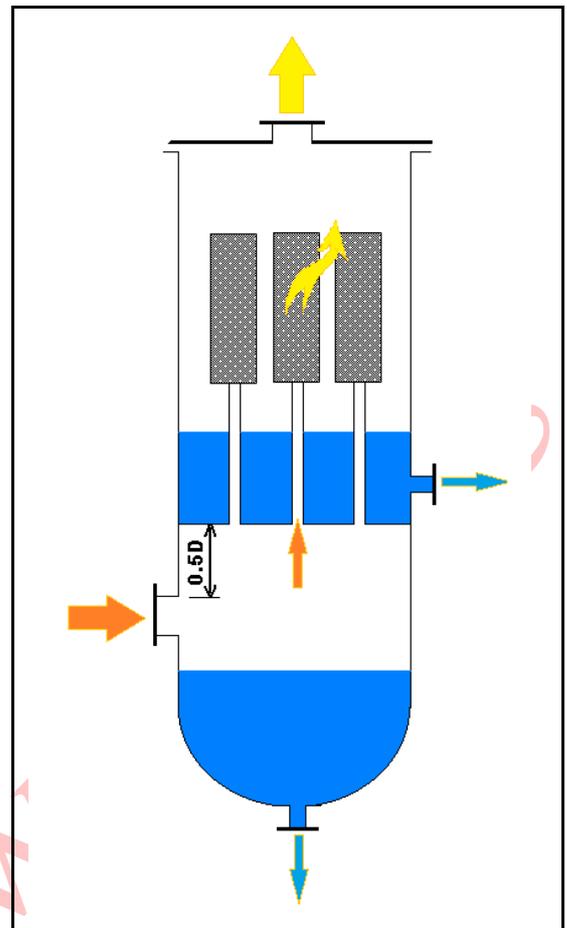


Figure 8 - Vertical vessel with reverse flow fiber beds (candle arrangement)

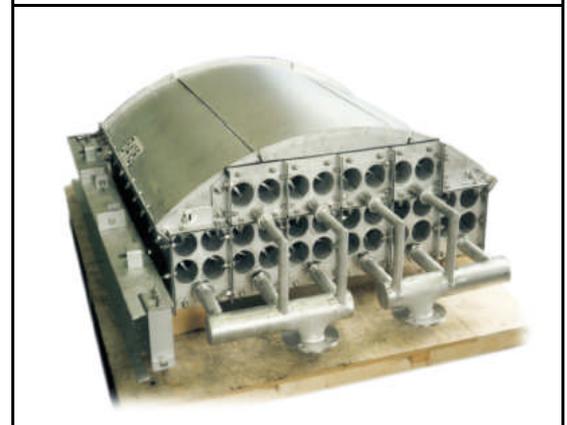


Figure 9 - Cyclone mist eliminator for a horizontal vessel, including housing and liquid collection piping

Table 4 – The Comparison of Performance for Different Gas Internals

Gas Internal	Gas Handling Capacity*	Liquid Handling Capacity*	Solid Handling Capacity*	Cost	Typical efficiency (Micron)**	Pressure drop (mm WC)
No internal	2	No limit	No limit	Nothing	150	Nothing
Wiremesh	5	5	3	1	10	25-50
Vane Pack	5-15	10	10	2-3	40	10-100
Wiremesh + Vane	5-15	10	3	4	40	40-150
Vane + Wiremesh	5	10	10	4	10	40-150
Fiber bed (diffusion)	1	1	1	10	1	50-500
Fiber bed (impaction)	1	1	1	10	3	100-250
Cyclone	15-20	10	10	3-5	10	200-350

*1 is the lowest and the others are scaled. **100% of particles larger than specified

Gas handling capacity indicates that for a particular separation how compact a separator can be. The higher gas handling capacity results in the smaller gas cross sectional area. For example, the gas handling capacity of an existing KOD can be doubled (5/2) with installing wiremesh or the gas cross sectional area for a cyclone separator can be at least third (5/15) of a wiremesh separator in the same service.

Liquid handling capacity indicates the sensitivity of the internal to the amount of liquid at its entrance. This indirectly shows what type pretreatment, (simple or sophisticated) inlet device or upstream vessel is needed in order to ensure the liquid load at the face of demister does not caused overloading, flooding and subsequently liquid re-entrainment.

Solid handling capacity shows the capability of internal in handling dirty fouling gases. This includes gases containing solids, wax, asphaltene or any sort of substance that can deposit on the demisting device and plug it.

Cost illustrates the direct cost of internals. The effect of demister type on the vessel overall size and cost needs to be considered. In almost all circumstances, the cost of internal is negligible compared to the overall saving in the vessel installed cost.

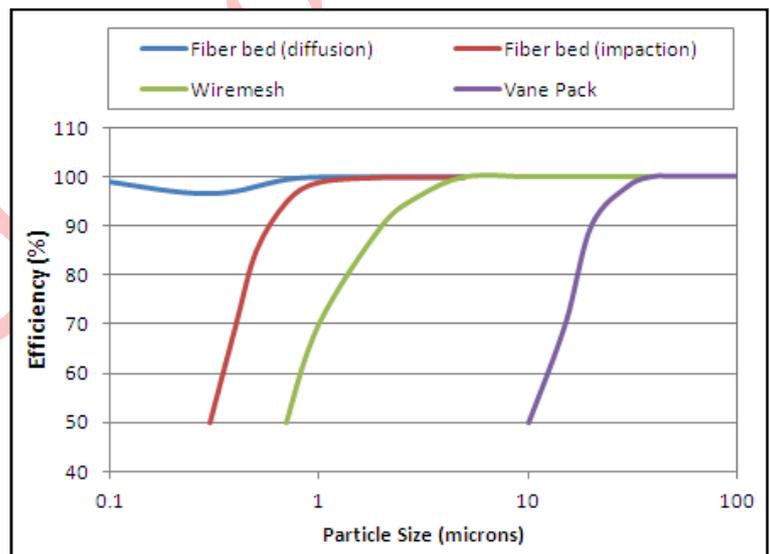


Figure 11 – Liquid droplet separation efficiency (typical)

Typical efficiency shown in the table can be considered for typically 100% of liquid particles larger than specified. This is usually based on the test data for water and air system at ambient conditions and designed gas velocity. The separation efficiency of cyclone device can be considered similar to the wiremesh mist eliminator.

As illustrated in Figure 11, the efficiency of all various types of demisting devices reduces as the target droplet size gets smaller. The effect of other process parameters on the separation efficiency depends on the type of mist eliminator (main separation mechanism). The separation efficiency of mist extractors that utilize the impaction mechanism increases with reducing the vane spacing/strand diameter, gas density -for instance, at higher pressures- and viscosity, and increasing the gas velocity and vane length/pad density and thickness. The droplets that can not be captures efficiently by impaction effects are separated by interception mechanism that theoretically applies to wiremesh and fiber mist eliminators. Mist eliminators which employ the diffusion mechanism (diffusion fiber beds) offer higher separation efficiency at higher temperature, longer residence time in the mist eliminator (due to greater pad density or thickness or lower gas velocity), and closer packing of fibers, and lower pressure.

Pressure drop across the demisting device is not usually a governing factor unless the system operating pressure is extremely low.

Sizing Considerations

Besides K factor and gas velocity considerations which determine the gas cross sectional area of the vessel, there are some design practices for the proper location of the mist extractor which specifies the length of the vessel. This is mainly to achieve uniform flow into and out of the mist extractor. If spacing is too close, the gas will pass through only part of the mist eliminator causing localized high velocities with possibility of liquid re-entrainment. Furthermore, the liquid droplet separation efficiency in the low-velocity parts of the mist eliminator drops if the velocity falls below operating range.

For a horizontal vessel, the minimum length of vessel upstream and downstream of (wiremesh or vane pack) mist extractor is 1.0D and 0.5D respectively. Figure 12 shows different possible configurations.

For a vertical vessel, the distance between inlet device and mist eliminator depends on the type of inlet device as explained in Three Phase Separators – Inlet Devices. The length of the vessel downstream of the (wiremesh or vane pack) mist extractor depends on the location and configuration of the outlet nozzle as depicted in Figure 13.

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.

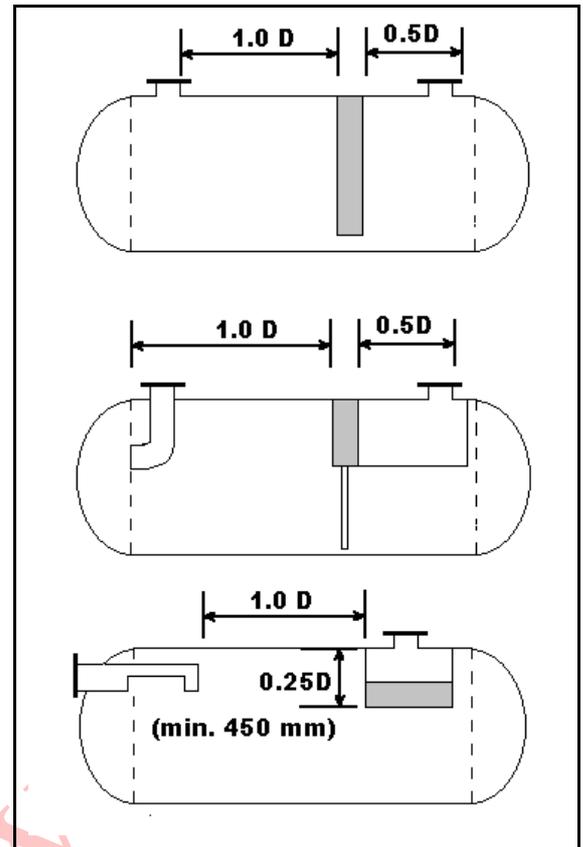


Figure 12 – Horizontal Vessel Spacing

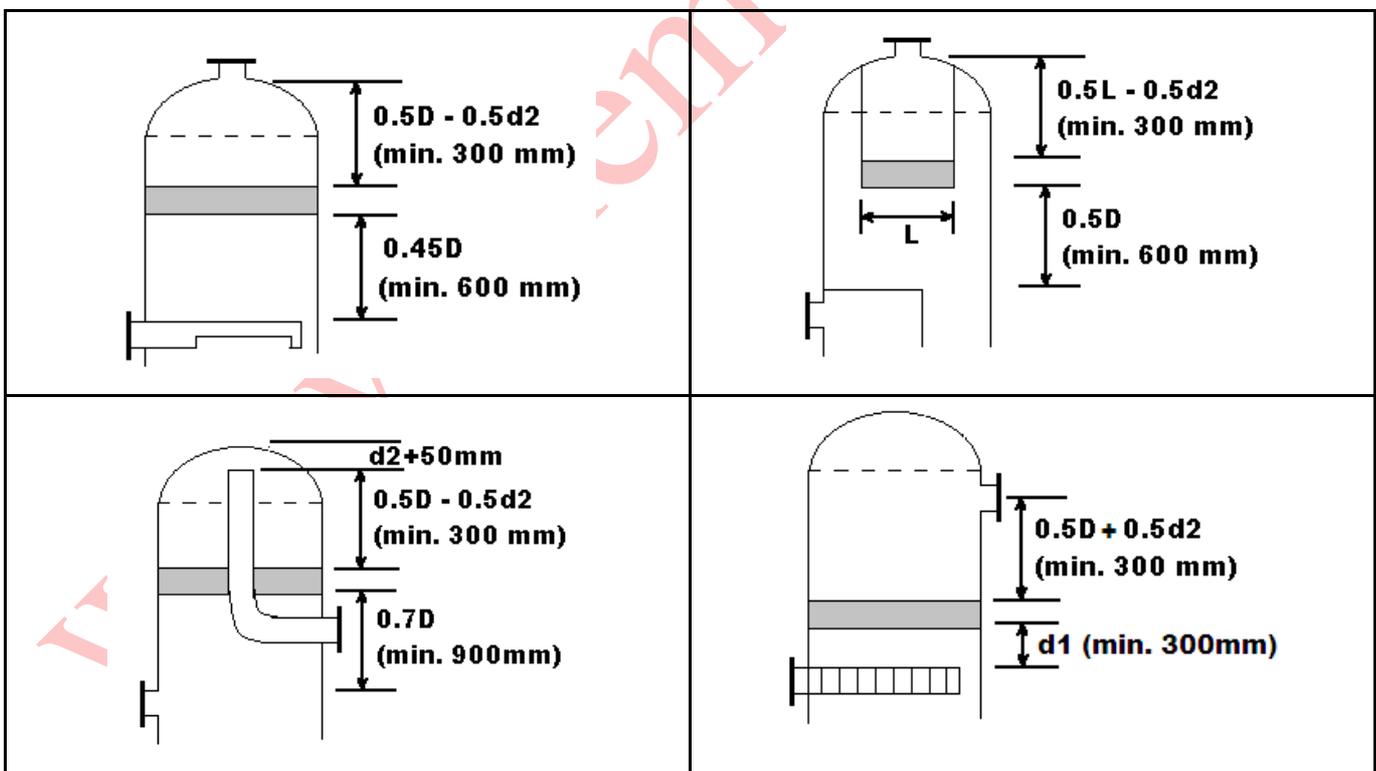


Figure 13 – Vertical Vessel Spacing for Different Inlet and Outlet Devices (d_1 : inlet nozzle diameter & d_2 : outlet nozzle diameter)