Education Institute for

Equipment & Process Design

TWO-PHASE AND THREE-PHASE SEPARATOR
DESIGN AND OPERATING PRINCIPLES

Content

TYPES OF COMMON GAS-LIQUID SEPARATORS

Vertical Separator — No Internals

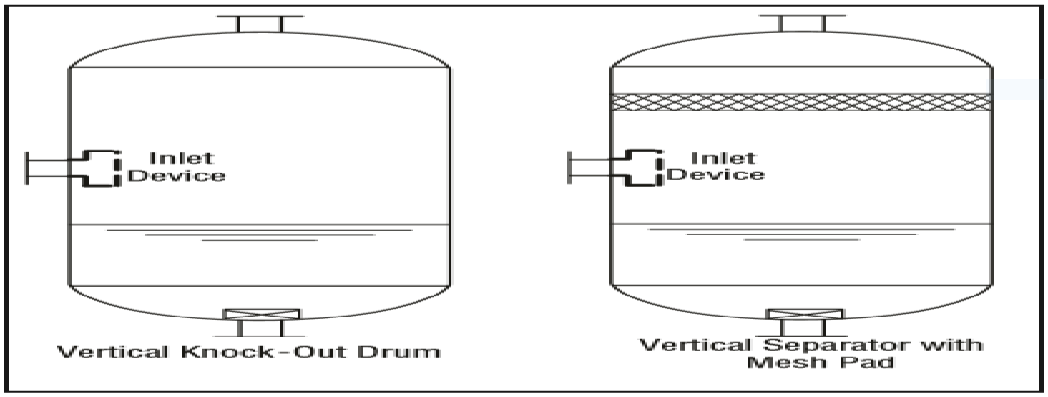
A vertical knock-out drum (Fig. 7-20) provides bulk separation of gas and liquid. It has unlimited turndown, very low pressure drop, can handle slugs well, and is tolerant of fouling.

Overall efficiency depends on the application but typically will be no more than 90%-95% when the vessel diameter is sized for gas flow. Separation efficiency typically decreases at higher pressure due to the presence of smaller droplets than at low pressure. Knock-out drums without internals are typically used for applications where there is little liquid present and a vertical configuration is preferred, where no internals are allowed due to the service (i.e. flare knock-out drums), fouling is a major consideration, when efficiency of separation is not a major consideration and no internal are preferred They are not recommended for applications where efficient separation is needed.

Vertical Separator with Mesh Pad

The addition of the mesh pad to the vertical separator improves the demisting capability of the separator. Vertical separators with mesh pads have moderate capacity, high liquid droplet removal efficiency, high turndown ratio, and low pressure drop. The overall efficiency of a separator with a mesh pad is dependent on the liquid droplet size distribution and the liquid load at the pad. A supplier can typically guarantee an overall efficiency of 99% at 7-10 microns for a conventional high efficiency wire mesh mist eliminator. For material balance purposes, an overall liquid removal efficiency of greater than 99% can be assumed for most applications. Vertical separators with mesh pads are recommended for applications where vapor flow is the controlling condition. They can handle a moderate liquid load to the pad in the form of droplets. The design K value can be affected by the liquid load to the device, therefore, proper selection of the feed inlet device is essential. Vertical wire mesh separators can be used when limited upstream pipe slugs are present, if sufficient liquid surge volume is included. They are not recommended for fouling service and for highly viscous liquids when the de-gassing requirement determines the vessel diameter.

Typical applications for vertical separators with mesh pads are compressor suction scrubbers and intermediate scrubbers in non-fouling service, general service separators of all types, production separators, inlet and outlet scrubbers for glycol/ amine contactors, upstream of filter-separators, and inlet scrubbers for gas export pipelines. Different styles of mesh elements are available metal, plastic, composite (wire and fiber), compound (different wire diameter, and/or weave density, and special drainage)], depending on the application. All of these factors will affect both the maximum gas capacity and the droplet removal efficiency. For many gas treating applications, however, conventional simple metal mesh mist eliminator are used. Mesh pads have a low pressure drops, typically about 249 Pa, depending on the pressure and liquid loading.



Vertical Separator with Vane Pack

Vertical separators with vane packs can be used instead of wire mesh for the following reasons: fear of fouling of the wire mesh, where corrosion and life of the demisting device requires a more robust design than mesh pads, to reduce separator size and cost compared to mesh, too high a liquid load for mesh.

Vertical separators with vane packs have a moderate turndown ratio, are suitable for slightly fouling service (straight or some single-pocket vanes only). The typical droplet removal efficiency for vane styles is provided in “Vane Separator Devices”, earlier in this Chapter.

Vane separators are less efficient overall than wire mesh in most applications. Vertical separators with vanes are best utilized below 4825 kPa (ga). Higher efficiency can be obtained at pressures above 4825 kPa (ga) by using double pocket vanes. Vanes can tolerate higher liquid load than mesh pads. However, they are sensitive to slugs and require adequate bulk separation upstream, similar to mesh pads. Vane elements have a relatively low pressure drop typically 100 Pa to 1 kPa (ga)]. Vertical separators with vanes are a common alternative to mesh mist eliminators for reciprocating compressors because of their more robust mechanical design, which is advantageous in pulsating service.

Vanes packs may be supplied as part of a package which includes the pressure vessel and internals, or as the vane element alone. Each supplier has proprietary vane pack styles and design correlations.

There are several styles available: straight vanes, single pocket vanes for vertical and horizontal flow, and double pocket vanes for horizontal flow. Pocket vanes are, however, more prone to fouling. The liquid collected by the vanes is typically drained by a pipe(s) to the sump of the separator and sealed.

The drain pipe(s) is submerged below the liquid level. Several different vane configurations may be used in a vertical separator: vertical flow of gas through the vanes, horizontal flow, inline separator with horizontal flow.

1.Vertical Flow Vane Separator

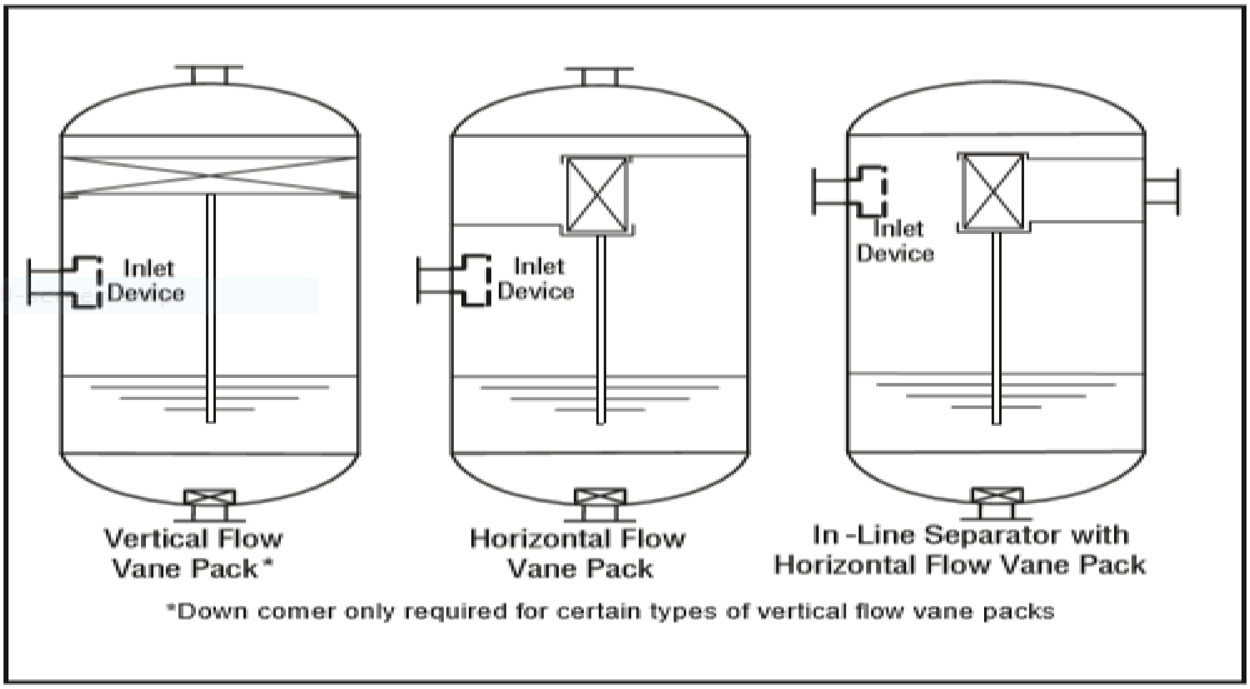
This configuration is similar to that of a vertical mesh separator. There is a liquid knockout section below the vane section which can handle higher liquid loads during upsets or small slugs. Vertical flow vane separators have the advantage that the gas flow path is vertical after the inlet and does not have to change direction to pass through the vane pack.

2.Horizontal Flow Vane Separator

In this configuration the gas flows vertically up from the inlet section and then must make a turn to flow horizontally through the vane pack, hence proper spacing must be allowed for good gas distribution. Typically, the height of the vane pack is larger than the width, which permits a smaller vessel diameter than the vertical flow vane design. In horizontal flow the allowable K value is often higher depending on the style of vane used. The horizontal flow vane separator is a common configuration for reciprocating compressors since it is compact and lower in cost.

3.Horizontal Flow Vane Separator (In-Line)

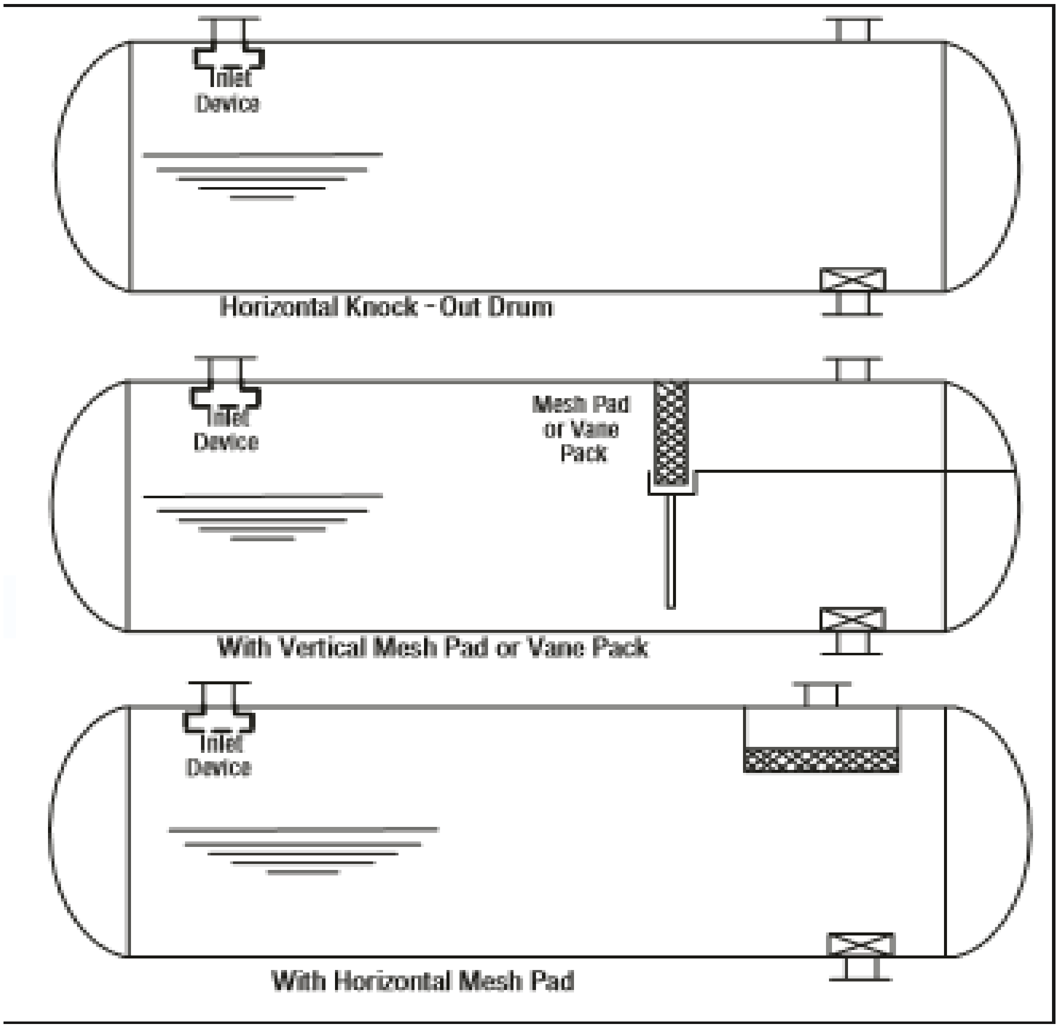
This is the most compact vertical vessel using a vane pack. However, the design cannot handle significant liquids or slugs during an upset.



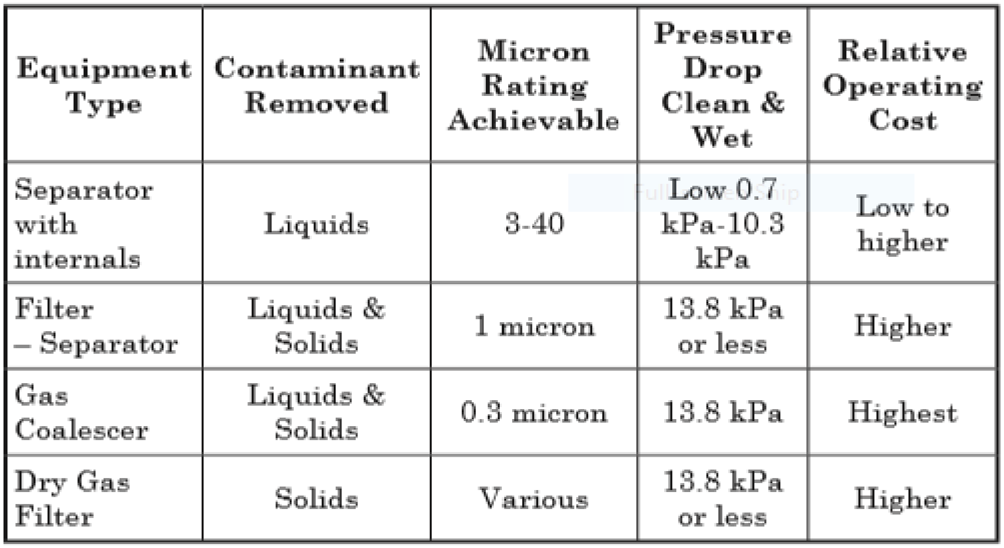
Horizontal Separator — No Internals

Horizontal separators-without internals provide bulk separation of gas and liquid. The design is typically used for liquid surge applications where the vapor flow is very low, for fouling services, or where internals are not desirable. The equipment has unlimited turndown, low pressure drop, can handle slugs and high liquid fractions, and is insensitive to fouling. The separation efficiency is dependent on the inlet droplet size distribution and Stokes' Law settling, based on the diameter, length, and liquid levels in the separator. Where gas flow controls sizing knock-out drums are typically designed to remove 250–500-micron droplets. Overall efficiency of 90-95% can be assumed. Where liquid holdup controls the vessel size higher efficiency is possible. Separators-without internals are recommended where internals must be kept to a minimum such as flare knock-out drums (no bolted internals of any kind) and drums handling fouling fluids. They are not recommended where efficient demisting is required.

Horizontal Separator Configurations

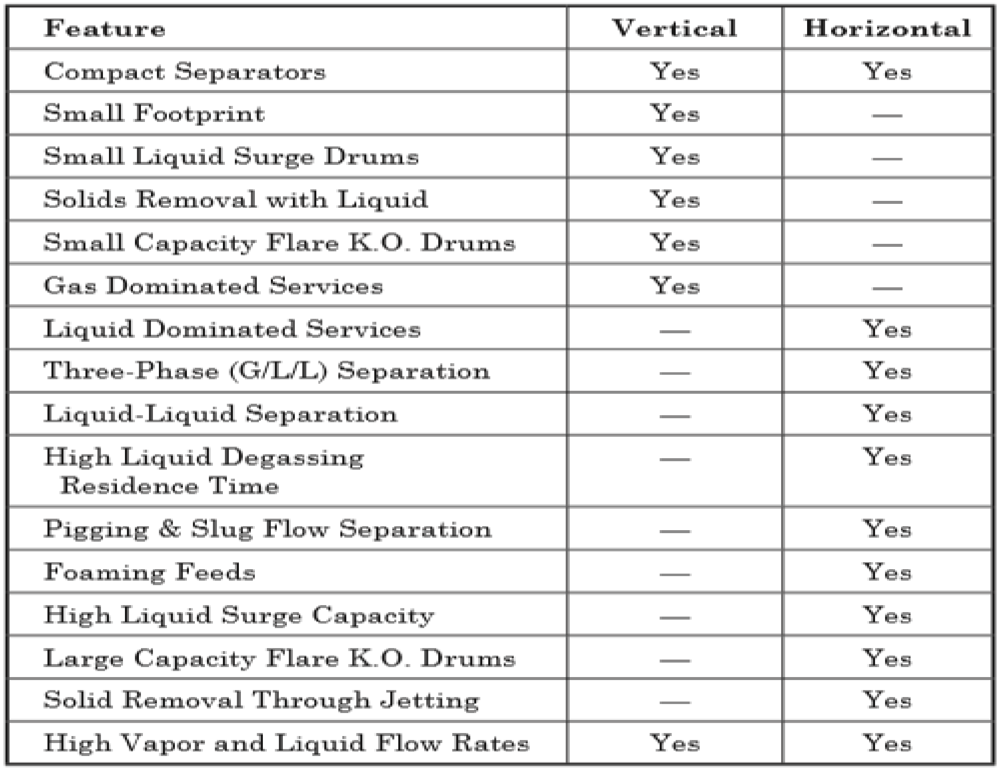


General Gas Separation Selection



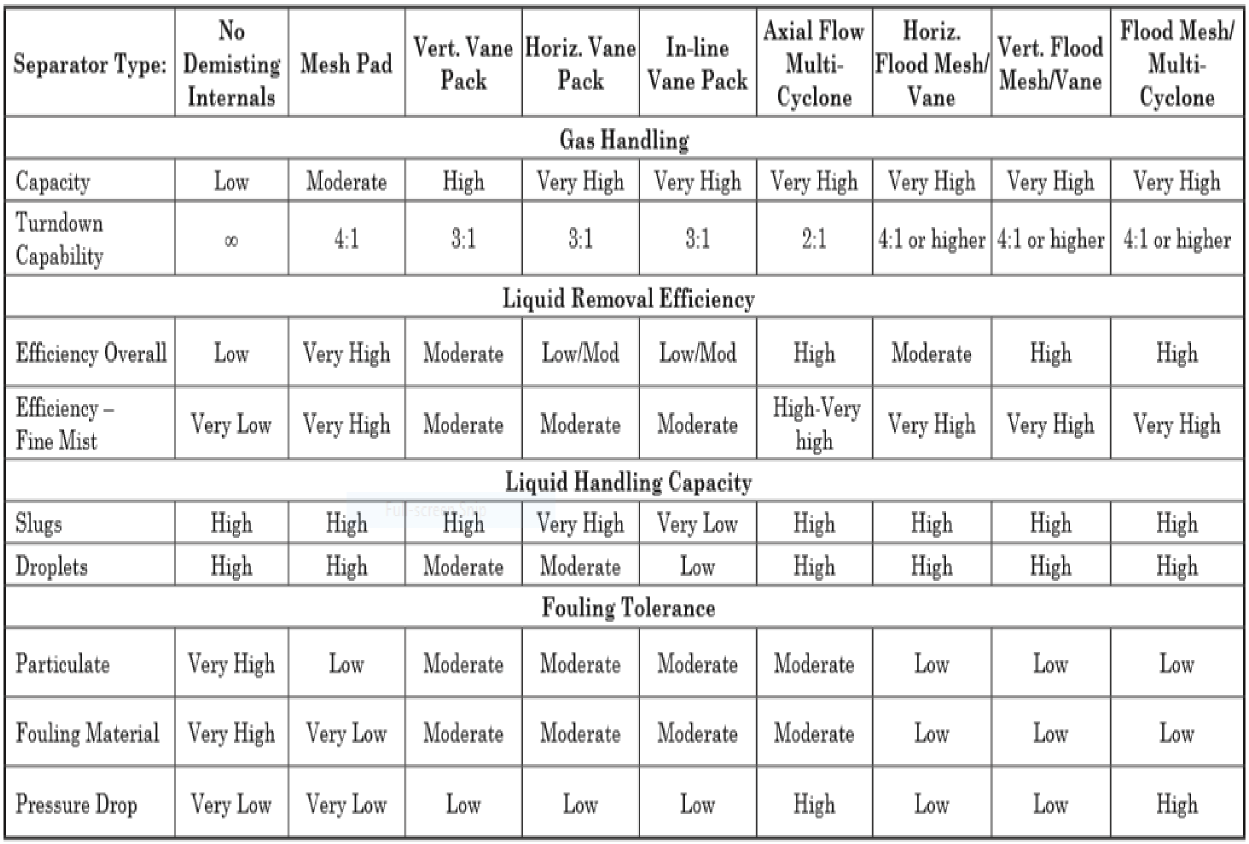
Equipment Type	Contaminant Removed	Micron Rating Achievable	Pressure Drop Clean & Wet	Relative Operating Cost
Separator with internals	Liquids	3-40	Low 0.7 kPa-10.3 kPa	Low to higher
Filter – Separator	Liquids & Solids	1 micron	13.8 kPa or less	Higher
Gas Coalescer	Liquids & Solids	0.3 micron	13.8 kPa	Highest
Dry Gas Filter	Solids	Various	13.8 kPa or less	Higher

Factors that Determine Vessel Orientation



Feature	Vertical	Horizontal
Compact Separators	Yes	Yes
Small Footprint	Yes	—
Small Liquid Surge Drums	Yes	—
Solids Removal with Liquid	Yes	—
Small Capacity Flare K.O. Drums	Yes	—
Gas Dominated Services	Yes	—
Liquid Dominated Services	—	Yes
Three-Phase (G/L/L) Separation	—	Yes
Liquid-Liquid Separation	—	Yes
High Liquid Degassing Residence Time	—	Yes
Pigging & Slug Flow Separation	—	Yes
Foaming Feeds	—	Yes
High Liquid Surge Capacity	—	Yes
Large Capacity Flare K.O. Drums	—	Yes
Solid Removal Through Jetting	—	Yes
High Vapor and Liquid Flow Rates	Yes	Yes

Vertical Gas-Liquid Separator Comparison Chart



Separator Type:	No Demisting Internals	Mesh Pad	Vert. Vane Pack	Horiz. Vane Pack	In-line Vane Pack	Axial Flow Multi-Cyclone	Horiz. Flood Mesh/ Vane	Vert. Flood Mesh/Vane	Flood Mesh/ Multi-Cyclone
Gas Handling									
Capacity	Low	Moderate	High	Very High	Very High	Very High	Very High	Very High	Very High
Turndown Capability	∞	4:1	3:1	3:1	3:1	2:1	4:1 or higher	4:1 or higher	4:1 or higher
Liquid Removal Efficiency									
Efficiency Overall	Low	Very High	Moderate	Low/Mod	Low/Mod	High	Moderate	High	High
Efficiency – Fine Mist	Very Low	Very High	Moderate	Moderate	Moderate	High-Very high	Very High	Very High	Very High
Liquid Handling Capacity									
Slugs	High	High	High	Very High	Very Low	High	High	High	High
Droplets	High	High	Moderate	Moderate	Low	High	High	High	High
Fouling Tolerance									
Particulate	Very High	Low	Moderate	Moderate	Moderate	Moderate	Low	Low	Low
Fouling Material	Very High	Very Low	Moderate	Moderate	Moderate	Moderate	Low	Low	Low
Pressure Drop	Very Low	Very Low	Low	Low	Low	High	Low	Low	High

Gas-liquid separation vessels can typically be divided into four general regions

•Inlet Section

•Gravity Separation

•Gas Polishing Section

•Liquid Accumulation Section (Outlet Section)

The first stage, primary separation, uses an inlet diverter so that the momentum of liquid entrained in the vapor causes the largest droplets to impinge on the diverter and then drop by gravity. The next stage, secondary separation, is gravity separation of smaller droplets as the vapor flows through the disengagement area. The final stage is mist elimination where the smallest droplets are coalesced so that larger droplets are formed which will separate by gravity. For secondary separation, the allowable velocity must be calculated so that the disengagement area can be subsequently determined.

Performing a force balance on the liquid droplet settling out provides the necessary relationship. When the net gravity force $F_G = \frac{M_P(\rho_L - \rho_V)g}{g\rho_V}$ balances the drag force $F_D = \frac{(\pi/8)C_D D_P^2 U_V^2 \rho_V}{g_c}$. The heavier liquid droplets will settle at a constant terminal velocity. Equating these two forces results in

$$U_T = \sqrt{\frac{4g D_P(\rho_L - \rho_V)}{3C_D\rho_V}} \qquad (3)$$

Here as long as $U_v < U_T$ the liquid droplets will settle out. Typically, the allowable vertical velocity U_v is set between 0.75 U_T and U_T. This could be rearranged to a Saunders-Brawn equation.

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

where

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

In vessels with no internals, gravity settling is the only mechanism of separation. Thus, terminal velocity of the minimum particle size desired for separation is critical. For vertical vessels, a liquid droplet will settle out of the gas phase when the vertical gas velocity is less than the droplet's terminal velocity. The terminal droplet velocity can be obtained by using the appropriate settling law expression, or an industry experience K value. The K value can be calculated by assuming a minimum droplet size that must be removed and equating Equation 7-11 and Equation 7-12. The target droplet diameter, or K value, is selected to prevent excessive entrainment based on experience. In either case a target droplet size of about 250 to 500 microns is typically used for many gas-liquid gravity separator designs.

This approach has been found to be adequate to prevent substantial liquid carryover for most applications. The maximum allowable K value used for design, for light hydrocarbon applications, is frequently reduced further at elevated pressures from that calculated by Equation 7-11. This is intended to account for the fact that as the pressure increases, the surface tension for light hydrocarbons decreases, as well as the high gas density, resulting in a higher likelihood of a smaller mean droplet size entering the separator.

If applied for a typical vessel L/D ratio of 3:1 or greater, would result in a effective axial flow K factors (L/H *K) greater than 1.0. In practice, the effective K used has been limited by either calculation of the incipient re-entrainment velocity, an empirical approach.

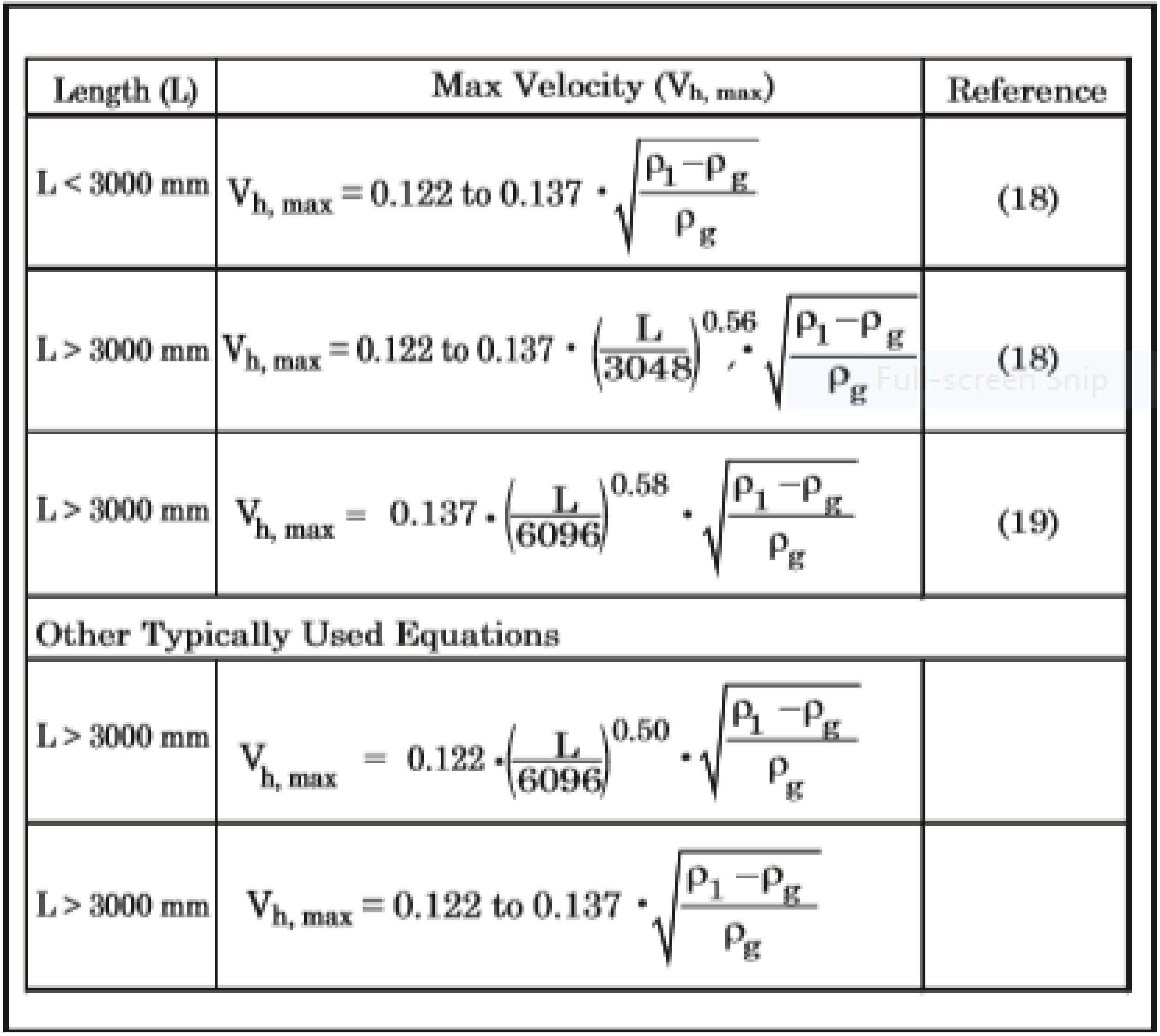
Liquid Gravity Separation Section For Vertical Separators with Downstream Mist Eliminators

The gravity separation section for a vertical separator should be designed to allow a majority of the liquid to drop out upstream of the mist eliminator, to provide an even distribution of the gas to the gas polishing section, and to minimize re-entrainment from the liquid surface below the feed. This can be accomplished without over sizing the vessel diameter, if adequate space is provided above and below the feed nozzle, and the Inlet Section is properly specified (appropriate inlet piping configuration/size, and inlet device). In the past, it was common to oversize the vessel diameter compared to the mist eliminator, in order to provide a more conservative and flexible design. The appropriate approach for a new application depends on the risk tolerance of the owner, and the nature of the application.

Gas-Liquid Gravity Separation Section for Horizontal Separators with Downstream Mist Eliminators

The goal of the gravity separation section for a horizontal separator is to remove a majority of the liquid droplets from the gas prior to the mist eliminator, to minimize surface re-entrainment due to waves and droplet shear at the gas liquid interface, and to promote an even gas flow distribution to the mist eliminator. To accomplish this, it is necessary to limit the gas velocity through the vapor space. For most applications, an approach of applying Stokes' Law to establish a vertical terminal vertical velocity, and then designing for the gas flow velocity and length to drop out say a 250–500-micron droplet would result in high horizontal velocity (greater than that typically used commercially). As an alternative several different approaches have been used: 1) base the design on the maximum velocity which will drop out a target drop size in the length available, yet is below the calculated incipient re-entrainment velocity from the liquid surface (See "Surface Re-entrainment" section earlier in this Chapter)5, 2) use an empirical equation for maximum gas velocity based on the density expression ((ρl-ρg)/ρg)0.5, times an factor based on a length ratio, and the height to the interface 3) limit the maximum gas velocity based the gas and liquid density function times a constant, 4) a combination of limiting maximum gas velocity based on an the density function times an empirical equation or a value, combined with a check of incipient re-entrainment velocity. Several typical equations for the maximum allowable horizontal velocity are provided in table below.

Typical Equations for Maximum Gas Velocity for Horizontal Separators with Mist Eliminators



Length (L)	Max Velocity ($V_{h,\,max}$)	Reference
L < 3000 mm	$V_{h,\,max} = 0.122 \text{ to } 0.137 \cdot \sqrt{\frac{\rho_1 - \rho_g}{\rho_g}}$	(18)
L > 3000 mm	$V_{h,\,max} = 0.122 \text{ to } 0.137 \cdot \left(\frac{L}{3048}\right)^{0.56} \cdot \sqrt{\frac{\rho_1 - \rho_g}{\rho_g}}$	(18)
L > 3000 mm	$V_{h,\,max} = 0.137 \cdot \left(\frac{L}{6096}\right)^{0.58} \cdot \sqrt{\frac{\rho_1 - \rho_g}{\rho_g}}$	(19)
Other Typically Used Equations		
L > 3000 mm	$V_{h,\,max} = 0.122 \cdot \left(\frac{L}{6096}\right)^{0.50} \cdot \sqrt{\frac{\rho_1 - \rho_g}{\rho_g}}$	
L > 3000 mm	$V_{h,\,max} = 0.122 \text{ to } 0.137 \cdot \sqrt{\frac{\rho_1 - \rho_g}{\rho_g}}$	

Inlet Section

The efficiency of a gas-liquid separator or a gas-liquid-liquid separator can be affected significantly by the flow regime and piping configuration upstream of the separator. Flow patterns that produce fine liquid droplets which are more difficult to separate are not desirable. The inlet flow regime depends on the flow rates and physical properties of the phases (including liquid surface tension), and on the feed pipe characteristics (diameter, length, vertical/ horizontal, location of fittings). Certain flow regimes cause more small droplets to form than others. Slug flow should be avoided and stratified-wavy and annular flows can form small droplets in the feed pipe. The piping configuration to the separator should not hinder the working of the separator. Piping bends should be avoided close to the inlet of separators because they cause the flow to begin to rotate in the pipe. CFD modeling and field experience have shown that generally the swirling flow cannot be effectively gravity separated until the swirling is stopped, either by it dissipating with distance or by the use of straightening vane devices in the separator inlet.

The following design considerations can greatly improve separator performance: avoid the following configurations within 5-10 pipe diameters of the separator: elbows in the horizontal plane, two out of plane elbows, valves and other flow disturbances, and high pressure drop which may cause flashing and atomization. The inlet piping design upstream should minimize low points and pockets. In addition, it is recommended that inlet piping diameter match the velocity requirement of the inlet to the separator 10 pipe diameters upstream of the separator to provide a flow regime which is fully developed before entering the separator.

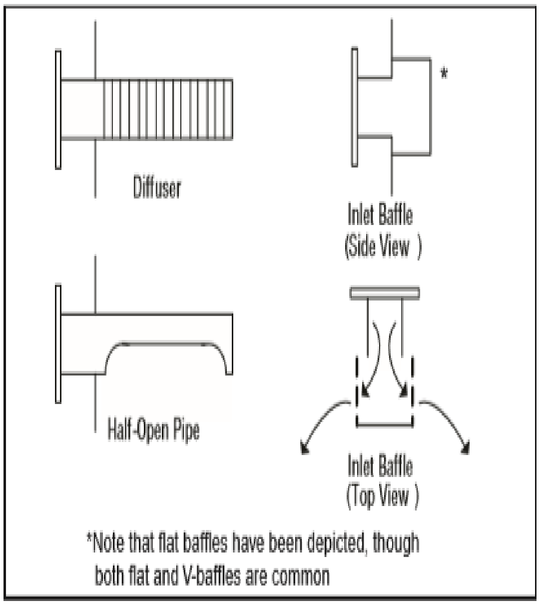
Inlet Devices — Proper selection of the inlet device is critical in separator design. Inlet devices should reduce the momentum of the inlet stream, initiate gas-liquid separation with minimum creation of fine droplets, and distribute gas flow evenly throughout the inlet and gravity separation section of the vessel. Testing and CFD modeling have shown that if the fluid is distributed poorly separation efficiency will suffer greatly. The use of inlet diffusers for vertical separators and for horizontal separators with high gas flow has become common in recent years.

A diffuser reduces droplet fracture as well as providing improved gas distribution inside the separator.

A diffuser installed on separator feed with a high liquid to gas ratio can also help relieve the downstream mist elimination device of more than 90% of the inlet liquid load.

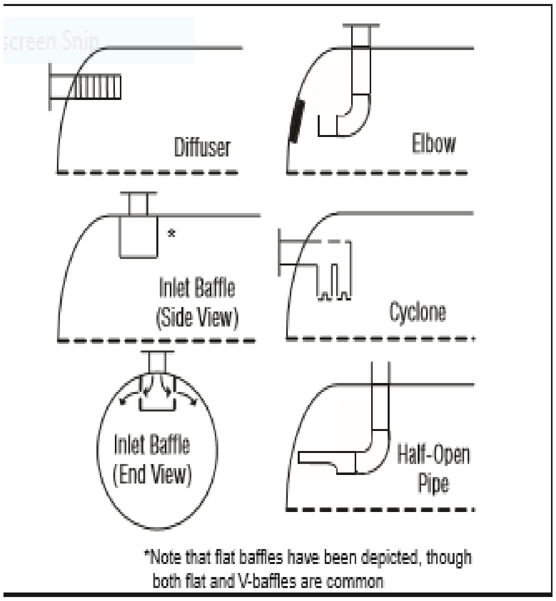
There are several types of inlet devices used in the industry. The more common devices are shown below.

Common vertical vessels inlet devices



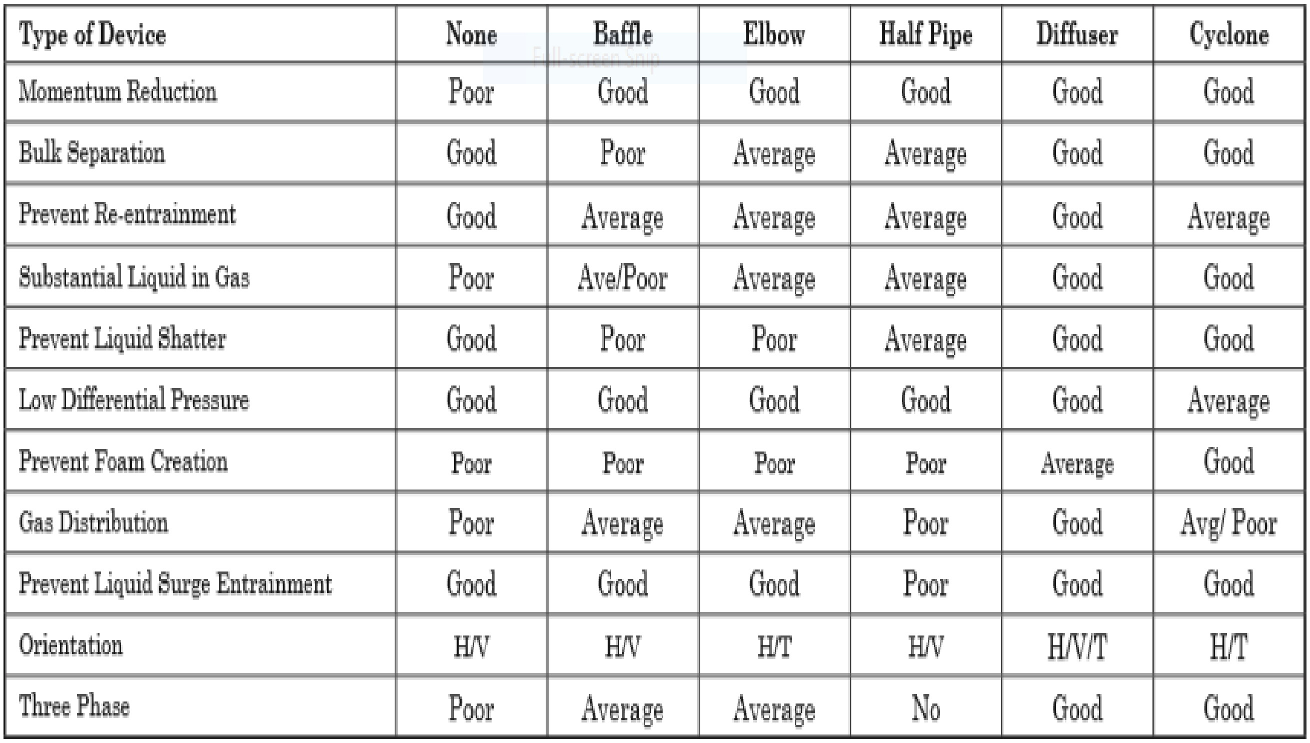
*Note that flat baffles have been depicted, though both flat and V-baffles are common

Common horizontal vessels inlet devices



*Note that flat baffles have been depicted, though both flat and V-baffles are common

Typical inlet device performance



Type of Device	None	Baffle	Elbow	Half Pipe	Diffuser	Cyclone
Momentum Reduction	Poor	Good	Good	Good	Good	Good
Bulk Separation	Good	Poor	Average	Average	Good	Good
Prevent Re-entrainment	Good	Average	Average	Average	Good	Average
Substantial Liquid in Gas	Poor	Ave/Poor	Average	Average	Good	Good
Prevent Liquid Shatter	Good	Poor	Poor	Average	Good	Good
Low Differential Pressure	Good	Good	Good	Good	Good	Average
Prevent Foam Creation	Poor	Poor	Poor	Poor	Average	Good
Gas Distribution	Poor	Average	Average	Poor	Good	Avg/ Poor
Prevent Liquid Surge Entrainment	Good	Good	Good	Poor	Good	Good
Orientation	H/V	H/V	H/T	H/V	H/V/T	H/T
Three Phase	Poor	Average	Average	No	Good	Good

It is also necessary to maintain the inlet velocity head, J, within proper limits for the selected inlet device to insure good gas distribution and minimum liquid shattering.

Where,

$$J = (\rho V^2) .$$

The maximum mixed phase velocity head range used in the industry guidelines varies for the different inlet devices. Some typical maximums are:

•6000-9000 max. typ, up to 15 000 max kg/m s2 for diffuser distributor

•975-2250 max kg/m. s2 for no inlet distributor

•1500-3750 max kg/m. s2 for inlet half pipe or elbow distributor

•1500-3750 max kg/m. s2 for v-baffle or other simple inlet diverter designs

In addition, some users limit the inlet vapor phase velocity to 9 m/s or 18 m/s. The velocity should always be below the erosion velocity for the service.

Gas Polishing Section

Selection of the appropriate device for gas polishing should be based on consideration of the application, operating pressure, likely feed droplet size range, allowable downstream carryover requirement, and the relative acceptability of the user for more compact and complex solutions.

Mechanism of Mist Carryover for Gas-Liquid Mist Eliminator Devices

Mist eliminators are commonly used in gas-liquid separation to aid gravity separation in the removal of liquid so that more efficient, smaller separators may be used. To be effective, a mist eliminator must accomplish two basic functions. First, it must have a means to capture liquid. Second, it must be able to drain the captured liquid without allowing re-entrainment into the gas streams. There are two mechanisms of liquid carryover from a mist eliminator. In the first mechanism, carryover is due to droplets of mist which are simply not captured by the device. The droplets might be too small to be captured or velocities are too low, causing low efficiency for impaction-type mist extractors. The second is re-entrainment of liquid after it has already been captured in the mist eliminator.

The majority of separator failures are caused by re-entrainment. This is the mechanism that occurs as the gas throughput is increased beyond the tolerable limit. Gas moving through the mist extractor exerts a drag force on the liquid film of the mist eliminator, causing it to be pulled toward the trailing edge of the device. If the drag is excessive, the liquid will be torn off the element and carried away by the gas stream. As flow rate increases, the contact efficiency of most mist eliminators improves.

Therefore, increasing gas flow yields improved droplet capture, but also increases re-entrainment which results in liquid carryover and limits separation capacity.

The most common style of mesh mist eliminator used in gas processing is a 100 mm to 150 mm thick crimped wire mesh pad with 144 to 192 kg/m3 bulk density. High droplet removal efficiency for droplets 10 microns and larger is common for the above design. Other designs include fiber mesh, mixed wire and fiber mesh, multiple mesh density layers, and special drainage channels. The goals are either to increase removal efficiency at lower droplet diameters, promote better drainage and in turn less carryover, increase throughput for a given mist eliminator area, reduce fouling, or a combination of the above. Manufacturers should be contacted for specific designs. Mesh pads are not recommended for dirty or fouling service as they tend to plug easily and can dislodge at high differential pressure.

Proper drainage of the mesh mist eliminator is essential to the operation of the unit. As the gas velocity increases at a given inlet liquid loading, the liquid continues to drain until a limiting load point is reached, at which point substantial liquid will carry over with the gas flow. Most mesh mist eliminator designs are based on the load point velocity. The load point will depend on the mist eliminator orientation, since the drainage mechanism is different as the pad orientation changes.

Wire Mesh Mist Eliminator

Courtesy of ACS Separations and Mass Transfer Products

Vane Mist Eliminators

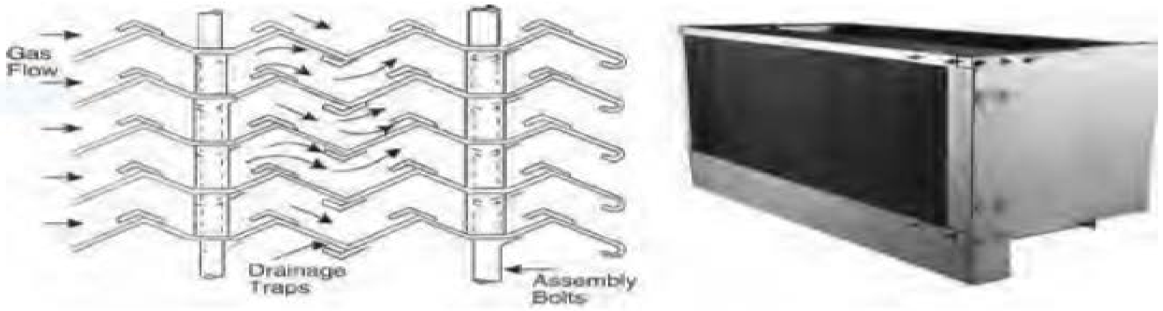
Vane or chevron-type mist eliminators (vane-pack) use relatively closely spaced blades arranged to provide sinusoidal or zig-zag gas flow paths. The changes in gas flow direction combined with the inertia of the entrained liquid droplets cause impingement of the droplets onto the plate surface, followed by coalescence and drainage of the liquid to the liquid collection section of the separator. Vane packs may be installed in either horizontal or vertical orientations. Various vane styles are available, including those with and without pockets (both single and double pockets) to promote liquid drainage.

Vanes with pockets, allow a higher gas throughput per flow area due to enhanced drainage, but are not typically used in highly fouling service. Fig. 7-11 shows a horizontal, pocketed vane-type mist eliminator. Vane capacity is reduced for vertical up flow applications relative to horizontal flow. Key performance parameters for vanes are droplet removal efficiency and gas handling capacity. Capture efficiency for a given droplet size depends on the vane design, gas velocity, gas viscosity and other parameters. Simple vanes with no pockets are typically capable of capturing 40 microns droplets, pocketed vanes are capable of 20 microns, and highly complex vanes of 10-20 microns at favorable operating conditions. Maximum vane capacity is set to limit re-entrainment. The Souder-Brown equation (Equation 7-11) and the load/sizing K factor are frequently used for describing the capacity of vane-type mist eliminators. Manufactures provide typical K factors for the various styles. The capacity for a particular vane service may be limited due to the liquid load to the device, liquid viscosity, foaming tendency, liquid surface tension, gas mal-distribution, and flow surges. These factors are not necessarily directly related to the Souders-Brown K value. Manufacturer guidance is necessary for a Design.

Testing has shown that for mesh type mist eliminators the low pressure air-water droplet removal efficiency experimental results correlate reasonably well with higher pressure gas-hydrocarbon liquid systems. Vane packs on the other hand show a drop-off in removal efficiency as pressure increases. This is primarily due to the decreased allowable design gas velocity caused by the increased gas density. As gas velocity decreases, droplet inertia decreases, and the droplets tend to follow the gas streamlines through the vane passages more easily. As a result, droplets are able to exit the vane pack without being captured. Mesh pads also rely on velocity/droplet inertia to remove liquid droplets via impingement, but they are less susceptible to efficiency reduction than vane packs because mesh pads have far more collection “targets”, i.e. wire/fiber filaments.

Turndown is generally more of a concern with vane-packs than wire mesh, with droplet removal efficiency decreasing measurably as velocity decreases from design. Vane packs are more tolerant to dirt and fouling than mesh due to the large passage size.

Cross-Section of Vane Element Mist Extractor and Typical Vane Pack

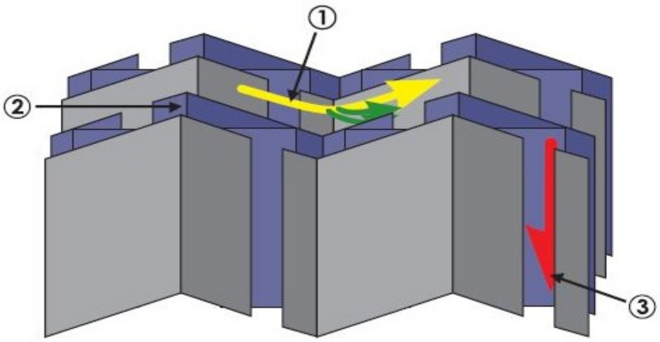


Vane Pack (above) courtesy of Sulzer Chemtech

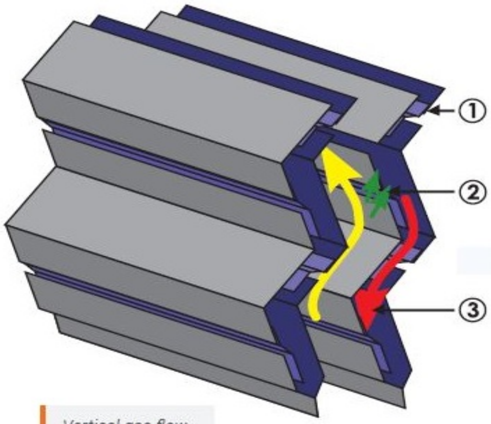
How a High Capacity FLEXICHEVRON® Mist Eliminator Works

1. Double pocket hooks direct the collected liquid (green arrow) away from the main gas stream (yellow arrow).
2. The collected liquid (green arrow) flows into separate channels (purple).
3. The separate channels move the liquid away from the gas (red arrow).

Because the liquid is now isolated from the gas stream and less subject to reentrainment, gas velocities can be increased in both horizontal and vertical gas flow configurations.



Horizontal gas flow.



Vertical gas flow.

Performance of High Capacity FLEXICHEVRON® Mist Eliminators in Air/Water System

Using double pocket FLEXICHEVRON mist eliminators, it is possible to efficiently remove droplets smaller than 10 microns in diameter in clean service even at higher pressures. Droplet size separation efficiency will be affected by physical properties of the gas and liquid phases, gas velocity, liquid and gas densities, and liquid surface tension.

Separation Efficiency and Sizing Considerations for Wire Mesh Mist Eliminators

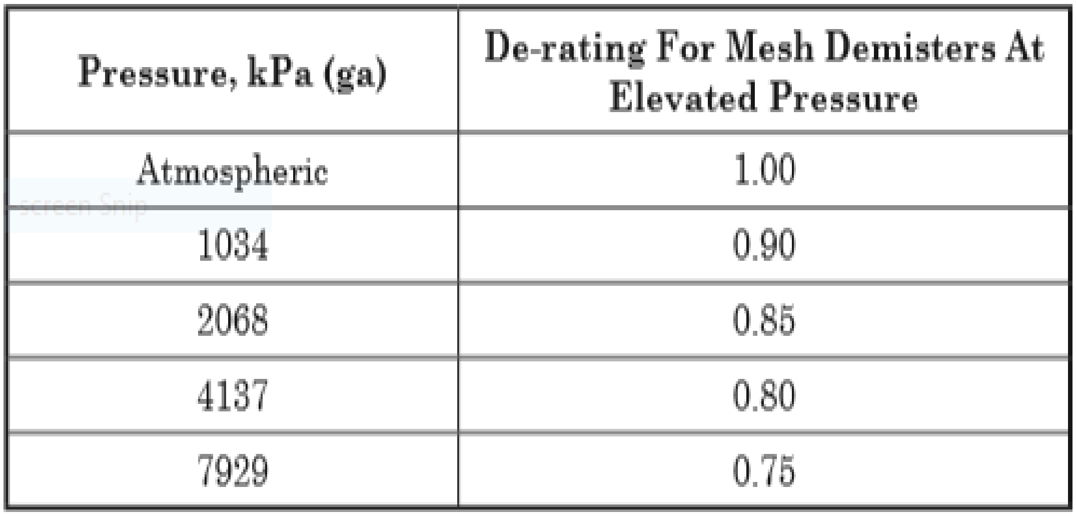
The work horse mist eliminator of the process industry for more than 60 years has been the conventional crimped wire mesh mist eliminator (single wire filament, and density). This design is still applicable for a wide variety of gas processing applications. Today however, there is a wide variety of advanced designs using the concept of composites (polymer fibers woven into the wire mesh), complex multi-layer (different density and or filament size in layers), drainage channels, or other concepts. Each design will have its own characteristic droplet removal efficiency at standard conditions, ability to tolerate liquid load, and throughput capacity. Difficult applications in the gas treating industry are those with small droplet size (low temperature treating separators, low surface tension high pressure light hydrocarbons), high viscosity (glycols, sulfur) and stringent outlet specifications (low temperature treating, amines and glycols). Internals suppliers should be consulted to provide the optimum alternatives for these applications.

For any selected style, mist eliminator supplier can provide the d95 (droplet size for 95% removal efficiency), and for a given an estimated inlet droplet size distribution, an overall separation efficiency. Sizing for wire mesh mist eliminators is based on operating the mist eliminator at a maximum flow rate which is a safe distance from the flood point at the operating conditions. The Souders-Brown K value (Equation 7-11) has been found to be a good correlating factor for determining this velocity. A conventional, 192 kg/m3, 0.3 mm filament, crimped wire mesh mist eliminator, will typically have a design K value of 0.11 m/s, for vertical flow to the mist eliminator, at low pressure, low liquid/ gas load, and liquid viscosity of 1.0 mPa.s or lower. In horizontal gas flow, a design K value of 0.13 is typical for these conditions. At other conditions, the design K value may be lower, due to the liquid/gas flow parameter(Φ) to the device(Φ=Wg/Wl(ρg/ ρl)0.5), liquid viscosity, foaming tendency, liquid surface tension, gas mal-distribution, and flow surges. Note, that the average droplet size to the separator, the type of inlet distributor, and the device spacing in the vessel can affect the gas/liquid flow parameter at the mist eliminator for a given set of inlet conditions to the separator.

For gas treating applications, liquid viscosity is important mainly for high viscosity fluids, such as glycols and sulfur. Surface tension is important for low surface tension light hydrocarbon fluids, typically found in low temperature gas processing. Fabian10 proposed that it is prudent to de-rate mist eliminators at pressures above 690 kPa (ga). This de-rating is not for pressure per se, but rather for the potential for local high velocity areas, as the mist eliminator becomes more compact at higher pressures. These de-rating factors are shown in Fig. 736. Systems known to foam, such as amines and glycols should be de-rated, in a similar manner to a system factor for trays or packing in these services. In addition, it is common to apply a system factor to the gas design flow rate, which can vary from 1.05 to 1.2 depending on the application (i.e. inlet production, steady state gas processing, gas compression). For many services in the gas treating industry that handle light hydrocarbons gases and liquids at low liquid load, with a conventional wire mesh mist eliminator, use of a K value of 0.11, de-rated per Fig. 7-36, will provide an acceptable design.

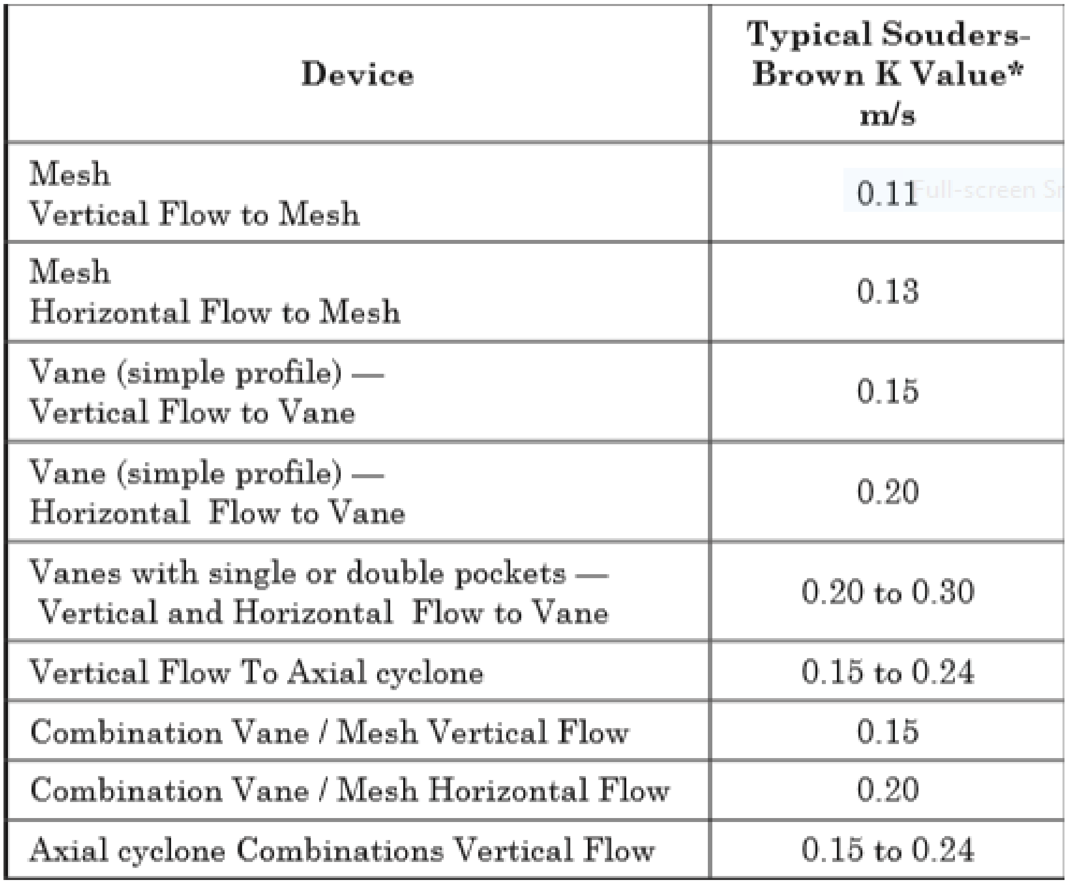
The addition of the mesh pad to the vertical separator improves the demisting capability of the separator. Vertical separators with mesh pads have moderate capacity, high liquid droplet removal efficiency, high turndown ratio, and low pressure drop. The overall efficiency of a separator with a mesh pad is dependent on the liquid droplet size distribution and the liquid load at the pad. A supplier can typically guarantee an overall efficiency of 99% at 7-10 microns for a conventional high efficiency wire mesh mist eliminator. For material balance purposes, an overall liquid removal efficiency of greater than 99% can be assumed for most applications. Vertical separators with mesh pads are recommended for applications where vapor flow is the controlling condition. They can handle a moderate liquid load to the pad in the form of droplets. The design K value can be affected by the liquid load to the device, therefore, proper selection of the feed inlet device is essential. Vertical wire mesh separators can be used when limited upstream pipe slugs are present, if sufficient liquid surge volume is included. They are not recommended for fouling service and for highly viscous liquids when the de-gassing requirement determines the vessel diameter.

De-rating factor to K-value for pressure



Pressure, kPa (ga)	De-rating For Mesh Demisters At Elevated Pressure
Atmospheric	1.00
1034	0.90
2068	0.85
4137	0.80
7929	0.75

Typical Saunders Brown K values for mist-eliminator device



Device	Typical Souders-Brown K Value* m/s
Mesh Vertical Flow to Mesh	0.11
Mesh Horizontal Flow to Mesh	0.13
Vane (simple profile) — Vertical Flow to Vane	0.15
Vane (simple profile) — Horizontal Flow to Vane	0.20
Vanes with single or double pockets — Vertical and Horizontal Flow to Vane	0.20 to 0.30
Vertical Flow To Axial cyclone	0.15 to 0.24
Combination Vane / Mesh Vertical Flow	0.15
Combination Vane / Mesh Horizontal Flow	0.20
Axial cyclone Combinations Vertical Flow	0.15 to 0.24

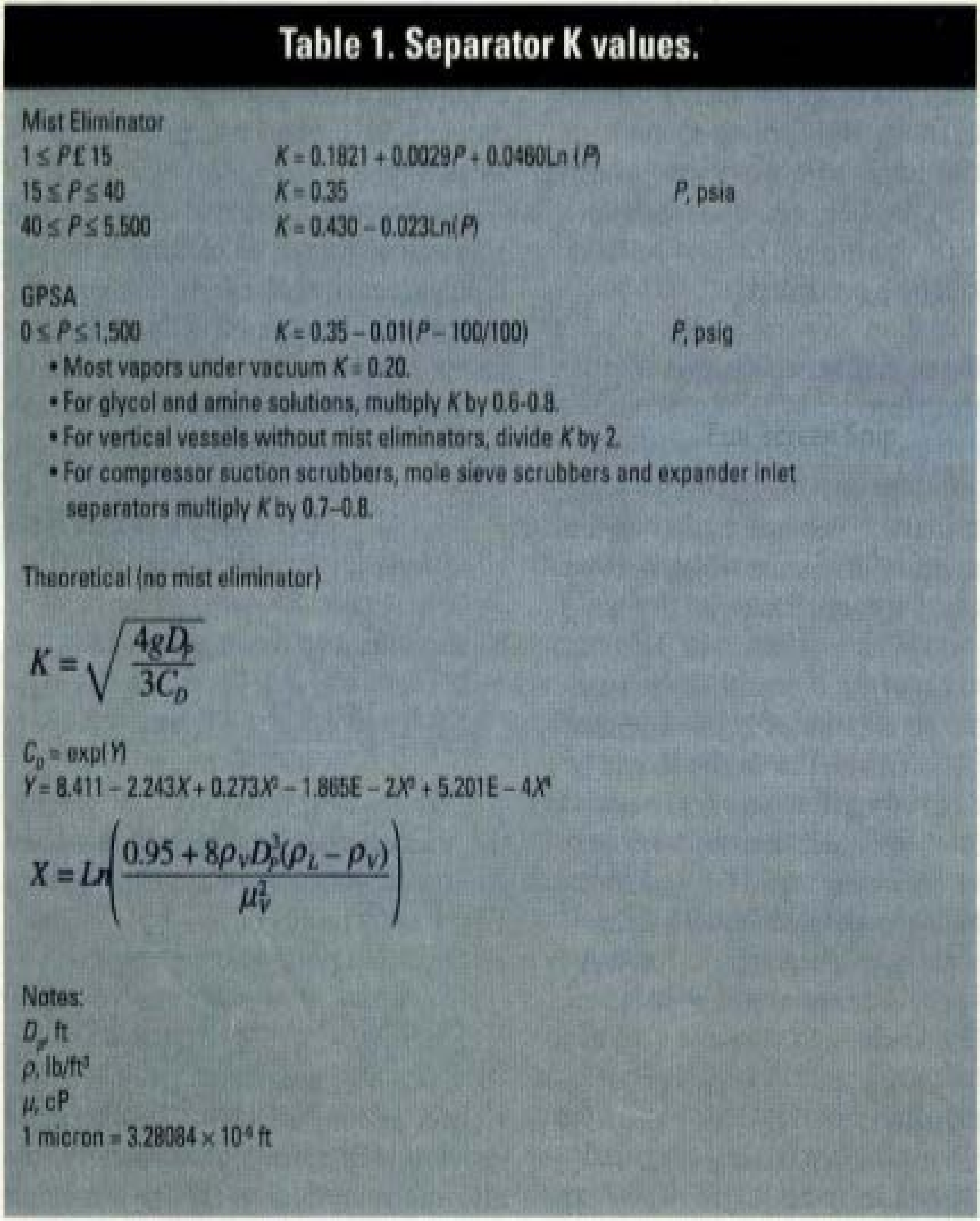


Table 1. Separator K values.

Mist Eliminator

$1 \le P \pounds 15$	$K = 0.1821 + 0.0029P + 0.0460\mathrm{Ln}(P)$	
$15 \le P \le 40$	$K = 0.35$	P, psia
$40 \le P \le 5.500$	$K = 0.430 - 0.023\mathrm{Ln}(P)$	

GPSA

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

- Most vapors under vacuum $K = 0.20$.
- For glycol and amine solutions, multiply K by 0.6-0.8.
- For vertical vessels without mist eliminators, divide K by 2.
- For compressor suction scrubbers, mole sieve scrubbers and expander inlet seperators multiply K by 0.7–0.8.

Theoretical (no mist eliminator)

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

$C_D = \exp(Y)$

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

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

Notes:

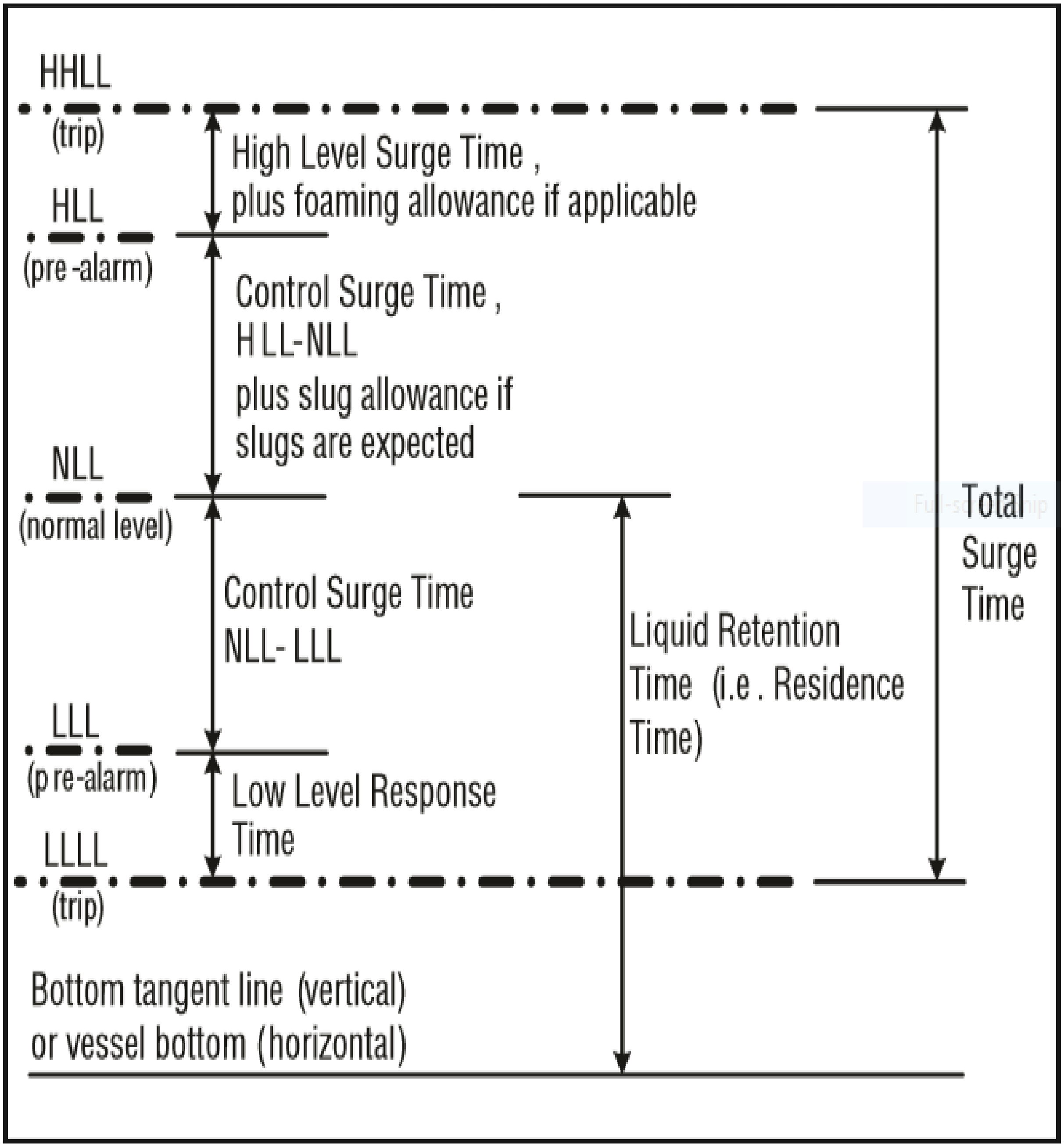
D_p, ft

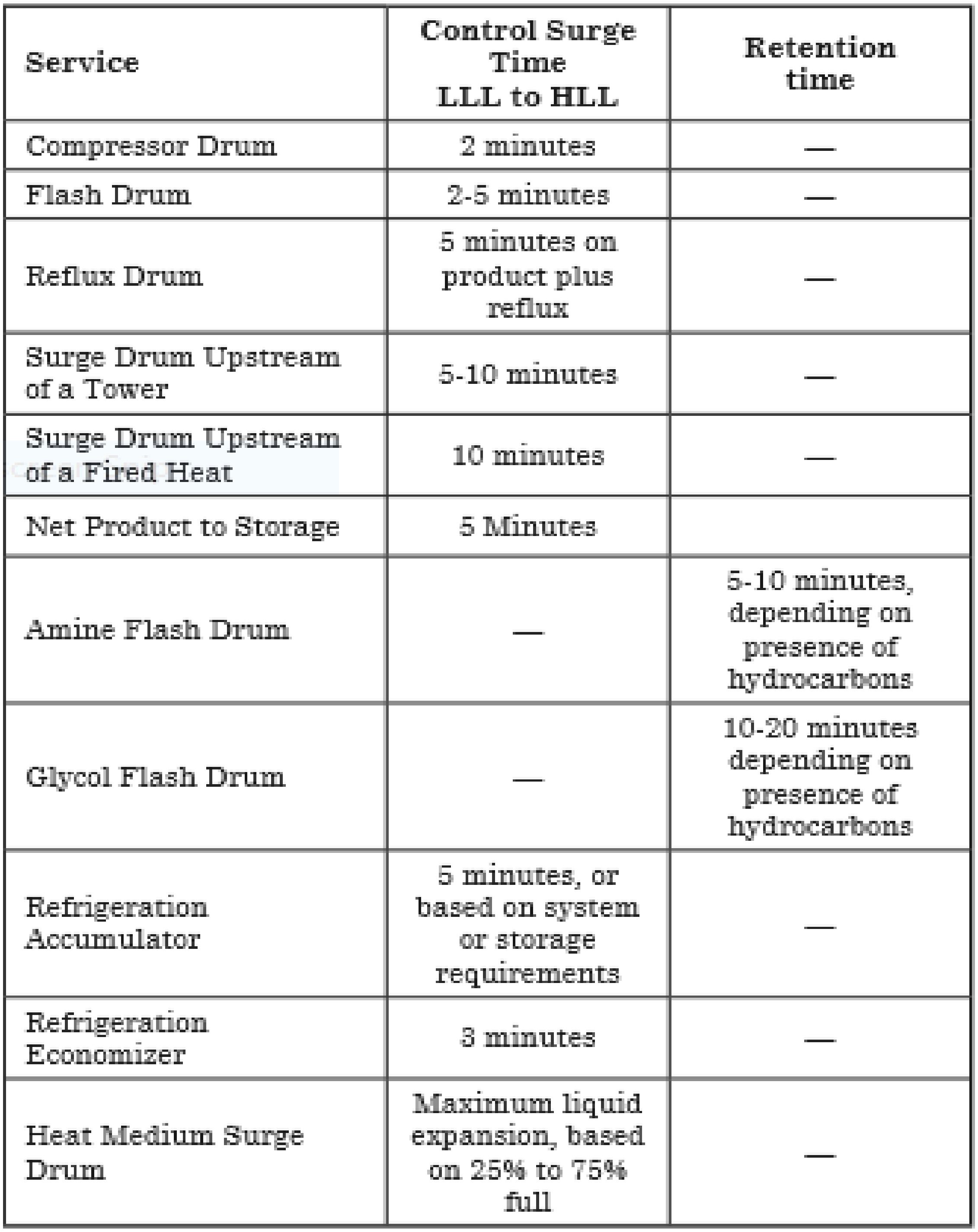
ρ, lb/ft^3

μ, cP

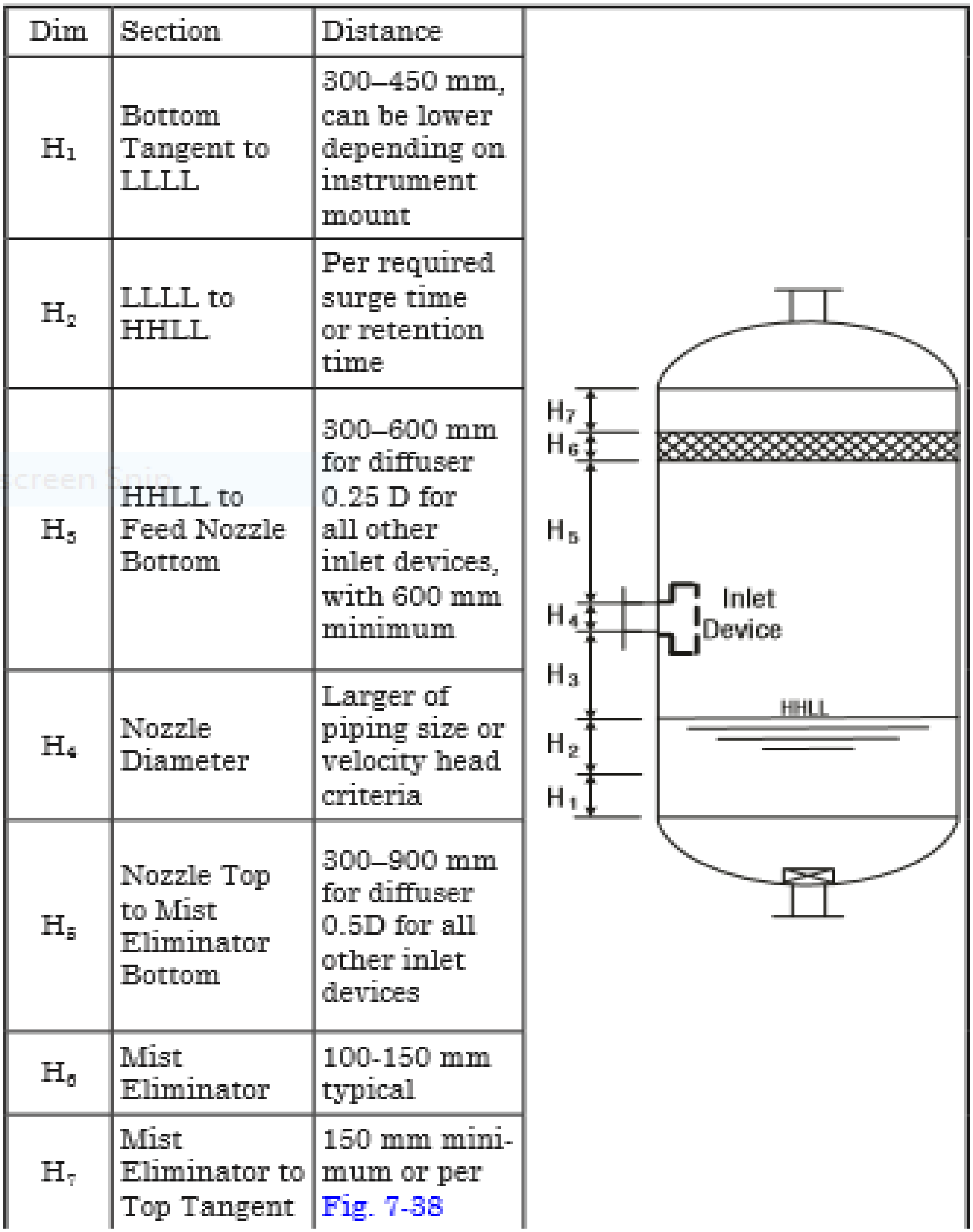
1 micron = 3.28084×10^{4} ft

Height Calculation





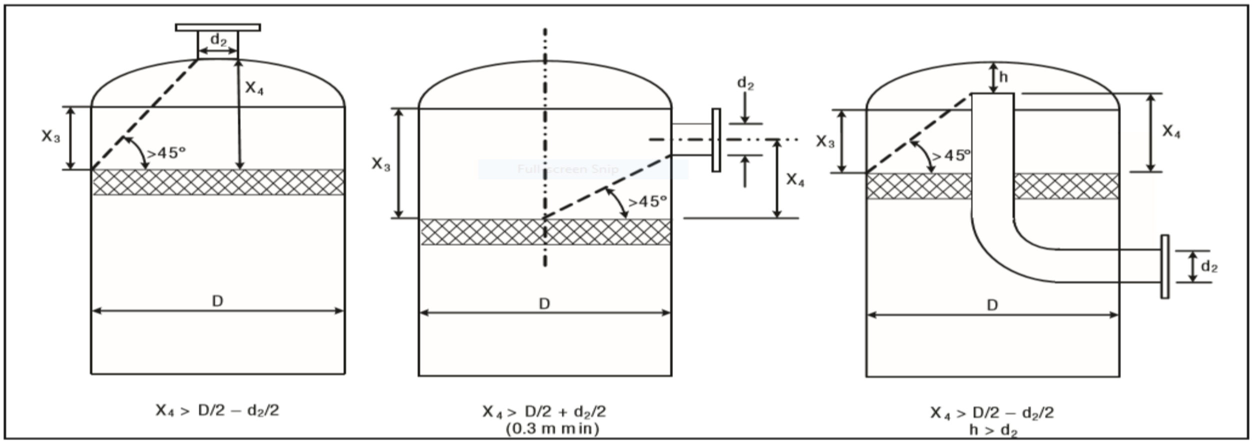
Service	Control Surge Time LLL to HLL	Retention time
Compressor Drum	2 minutes	—
Flash Drum	2-5 minutes	—
Reflux Drum	5 minutes on product plus reflux	—
Surge Drum Upstream of a Tower	5-10 minutes	—
Surge Drum Upstream of a Fired Heat	10 minutes	—
Net Product to Storage	5 Minutes	
Amine Flash Drum	—	5-10 minutes, depending on presence of hydrocarbons
Glycol Flash Drum	—	10-20 minutes depending on presence of hydrocarbons
Refrigeration Accumulator	5 minutes, or based on system or storage requirements	—
Refrigeration Economizer	3 minutes	—
Heat Medium Surge Drum	Maximum liquid expansion, based on 25% to 75% full	—



Dim	Section	Distance
H_1	Bottom Tangent to LLLL	300–450 mm, can be lower depending on instrument mount
H_2	LLLL to HHLL	Per required surge time or retention time
H_3	HHLL to Feed Nozzle Bottom	300–600 mm for diffuser 0.25 D for all other inlet devices, with 600 mm minimum
H_4	Nozzle Diameter	Larger of piping size or velocity head criteria
H_5	Nozzle Top to Mist Eliminator Bottom	300–900 mm for diffuser 0.5D for all other inlet devices
H_6	Mist Eliminator	100-150 mm typical
H_7	Mist Eliminator to Top Tangent	150 mm minimum or per Fig. 7-38

Vapor Outlet Section

The sizing of the vapor outlet nozzle should be such that given the above placement of the mesh pad, the velocity is not high enough to cause channeling of the gas through the mesh pad. The nozzle outlet size is typically based on the lesser of that required for piping pressure drop, or a maximum velocity head criterion. Typical ranges for the maximum velocity head allowed for the vapor outlet are 4500–5400 kg/m • s2. In addition, some users limit the absolute velocity to 18 m/s. The pipe size can be decreased to the appropriate size based on pressure drop considerations, 5-10 pipe diameters downstream of the separator, as required.



$X_4 > D/2 - d_2/2$

$X_4 > D/2 + d_2/2$
(0.3 m min)

$X_4 > D/2 - d_2/2$
$h > d_2$

Liquid Outlet Nozzle

Many users limit the liquid outlet nozzle velocity based on pump suction line criteria (i.e. 11 kPa/100 m for fluid at or near boil, 22 kPa/100 m otherwise) or other line sizing criteria. For three phase separators, the velocity may be further reduced. Other users set a maximum outlet nozzle velocity (i.e., 0.9–1.5 m/sec) regardless of the service.

The liquid accumulation section collects liquid from the inlet, gravity separation and the gas polishing sections. This liquid accumulation section allows gas trapped in the liquid to escape by providing sufficient liquid residence time. This is particularly important if the system is foaming or highly viscous. The liquid accumulation section also provides sufficient volume to allow for fluctuations in the liquid flow rate or to accommodate slugs of liquid in the inlet flow

Additional Notes

Liquid Carry-Over Specification for Gas-Liquid Separators

•0.0134 m3 / MMSm3 (absolute reference)

•Supplier guarantee based on % removal for a specified droplet size, (i.e. d95, or 99% removal efficiency at 10 microns)

•98% overall liquid recovery

Gas Carry-Under Specification

A typical requirement for light hydrocarbons is minimal carry-under for gas bubbles 200 micron and larger. This is particularly important when the liquid is being pumped downstream of the separator, since pumps are only tolerant of dispersed dissolved gas to a limited extent. Gas volumes above 2% should be checked by the pump manufacturer.

Vertical Vessel Diameter and Height Sizing Procedure

1. Calculate the volumetric flow in m3/s
2. Select a proper K-value and de-rate it according to its pressure by using the table
3. Calculate U_T and U_v. For U_v calculation, multiply U_T by a correction factor between 0.75-1.
4. Calculate D by using .

$$D_{VD} = \sqrt{\frac{4\,Q_V}{\pi\,U_V}}$$

The reported D should be the calculated D + 150 mm

5. Calculate vessel Height according to Height Calculation

Vertical Separator Without Internals Sizing Procedure

A vertical separator without mist eliminating internals can be sized in a similar manner to that used for separators with internals. For applications that are gas controlled, the diameter is based on a maximum allowable terminal gas velocity. The K value used should be selected to insure massive entrainment does not occur, and a reasonable separation efficiency is achieved. The design terminal velocity can be based on the appropriate Stokes' Law, and is based on a droplet size of 250-500 micron, the gas and liquid properties, and the calculated drag coefficient, plus a safety factor. An alternative approach which is common in the industry is to base the design on a K value of approximately 0.046 m/s. For fluids with low surface tension at high pressure, or in other circumstances where small droplets are expected, either the target droplet size, or the design K, depending on the approach used, should be further reduced.

Horizontal Separator Without Internals Sizing Procedure

1. Calculate the vapor volumetric flow rate.
2. Calculate the liquid volumetric flow rate.
3. Calculate the vertical terminal velocity.
4. Calculate the Hold-up volume, VH
5. Calculate the Surge volume, VS
6. Obtain an estimation of L/D ratio, using following table and subsequently calculate D by following equation.

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

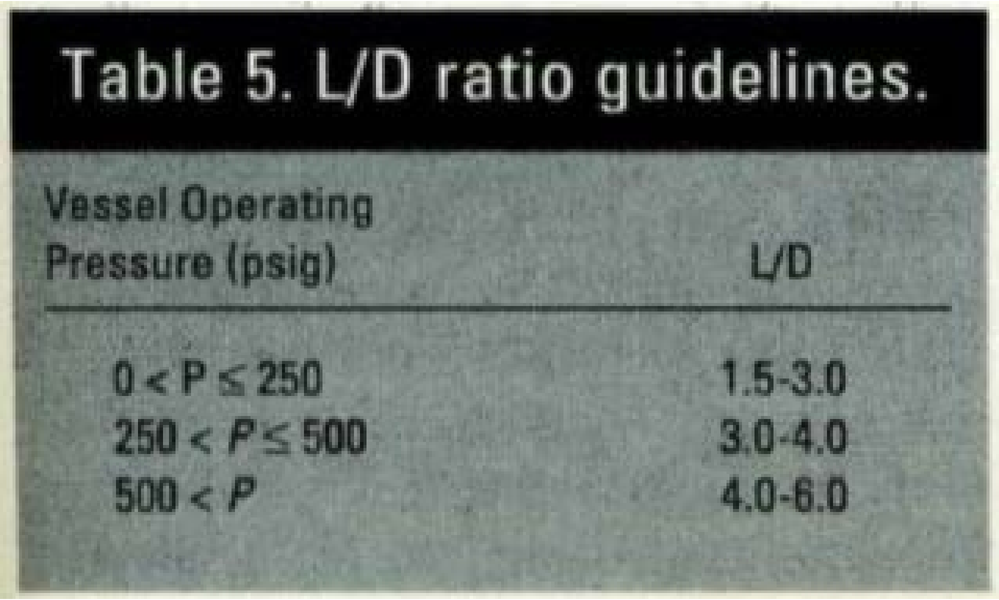


Table 5. L/D ratio guidelines.

Vessel Operating Pressure (psig)	L/D
$0 < P \leq 250$	1.5-3.0
$250 < P \leq 500$	3.0-4.0
$500 < P$	4.0-6.0

7. Calculate the total cross-sectional area

8. Calculate the low liquid level height using following table or HLLL = 0.5D + 7 in.

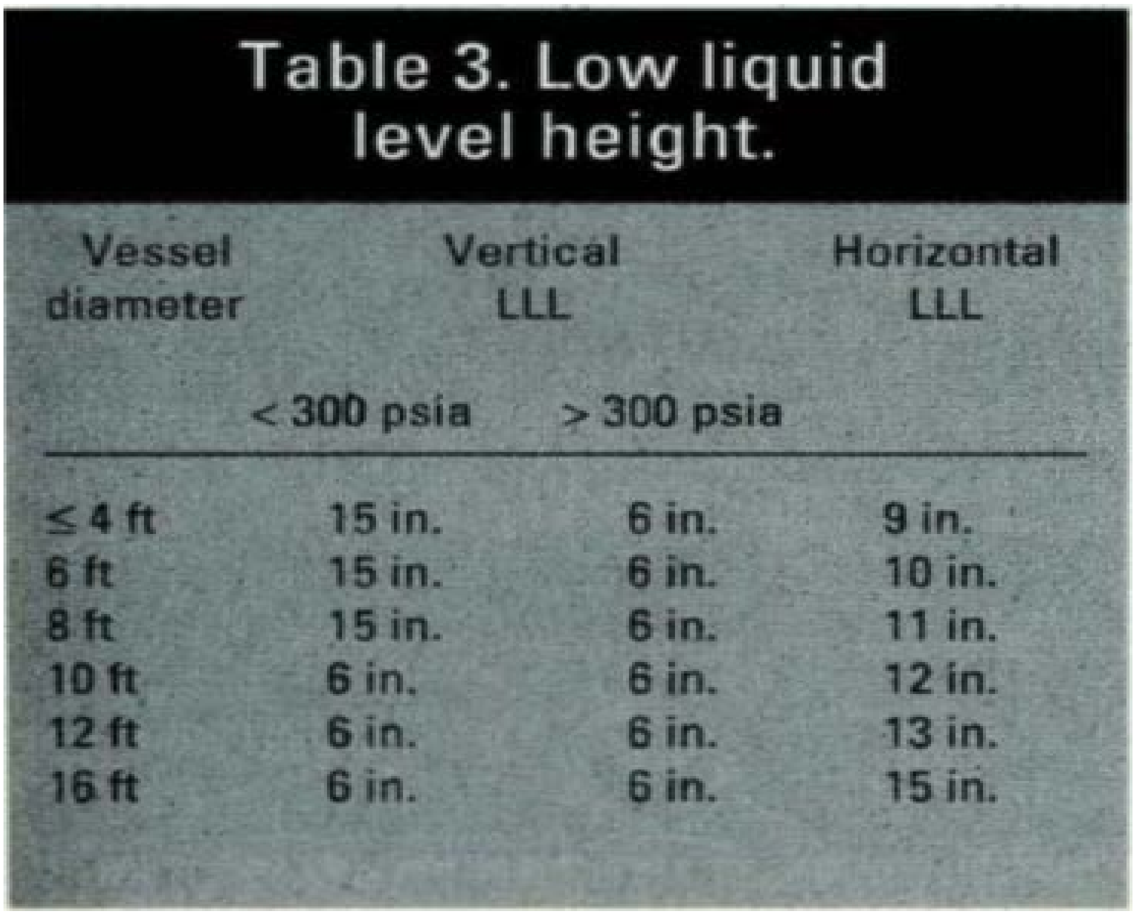


Table 3. Low liquid level height.

Vessel diameter	Vertical LLL		Horizontal LLL
	< 300 psia	> 300 psia	
≤ 4 ft	15 in.	6 in.	9 in.
6 ft	15 in.	6 in.	10 in.
8 ft	15 in.	6 in.	11 in.
10 ft	6 in.	6 in.	12 in.
12 ft	6 in.	6 in.	13 in.
16 ft	6 in.	6 in.	15 in.

9. Calculate H_{LLL}/D and use Goal-Seek function in Excel to find A_{LLL}/AT and subsequently A_{LLL}.

10. Set HV to 0.2D or 1 ft. if there is no mist pad eliminator and set it to 0.2D or 2 ft. if there is a mist pad eliminator. Then calculate HV/D and by using Goal-Seek function calculate AV/AT

11. Calculate the minimum length to accommodate liquid holdup/surge, using following equation:

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

12. Calculate the liquid dropout time

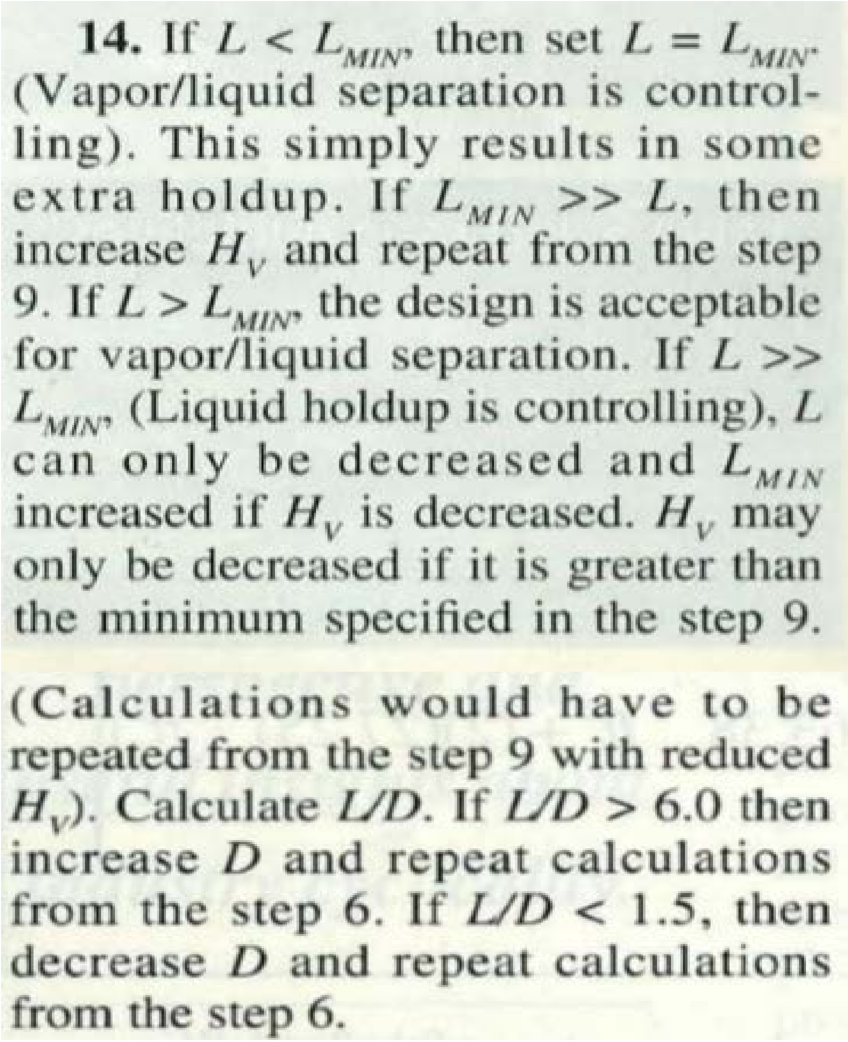
$$\phi = \frac{H_V}{U_V}, \ s$$

13. Calculate the actual vapor velocity

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

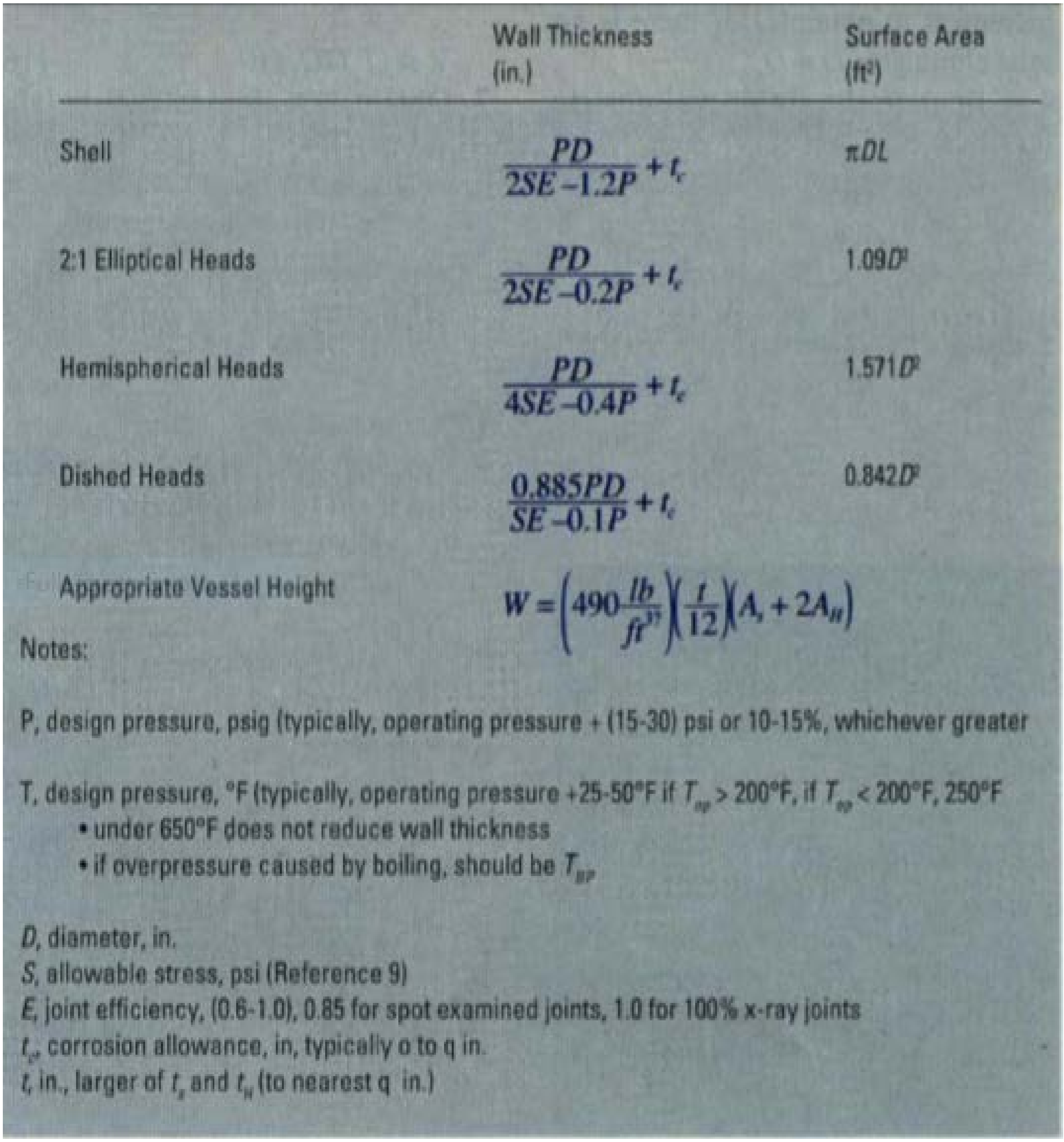
14. Calculate the minimum length required for vapor-liquid dis-engagement.

$$L_{MIN} = U_{VA}\phi, \ \text{ft}$$



14. If $L < L_{MIN}$, then set $L = L_{MIN}$. (Vapor/liquid separation is controlling). This simply results in some extra holdup. If $L_{MIN} >> L$, then increase H_V and repeat from the step 9. If $L > L_{MIN}$, the design is acceptable for vapor/liquid separation. If $L >> L_{MIN}$, (Liquid holdup is controlling), L can only be decreased and L_{MIN} increased if H_V is decreased. H_V may only be decreased if it is greater than the minimum specified in the step 9.

(Calculations would have to be repeated from the step 9 with reduced H_V). Calculate L/D. If $L/D > 6.0$ then increase D and repeat calculations from the step 6. If $L/D < 1.5$, then decrease D and repeat calculations from the step 6.



	Wall Thickness (in.)	Surface Area (ft²)
Shell	$\frac{PD}{2SE-1.2P}+t_c$	πDL
2:1 Elliptical Heads	$\frac{PD}{2SE-0.2P}+t_c$	$1.09D^2$
Hemispherical Heads	$\frac{PD}{4SE-0.4P}+t_c$	$1.571D^2$
Dished Heads	$\frac{0.885PD}{SE-0.1P}+t_c$	$0.842D^2$
Appropriate Vessel Height	$W=\left(490\frac{lb}{ft^3}\right)\left(\frac{t}{12}\right)\left(A_s+2A_H\right)$	

Notes:

P, design pressure, psig (typically, operating pressure + (15-30) psi or 10-15%, whichever greater

T, design pressure, °F (typically, operating pressure +25-50°F if T_{op} > 200°F, if T_{op} < 200°F, 250°F

- under 650°F does not reduce wall thickness
- if overpressure caused by boiling, should be T_{BP}

D, diameter, in.
S, allowable stress, psi (Reference 9)
E, joint efficiency, (0.6-1.0), 0.85 for spot examined joints, 1.0 for 100% x-ray joints
t_c, corrosion allowance, in, typically o to q in.
t, in., larger of t_s and t_H (to nearest q in.)

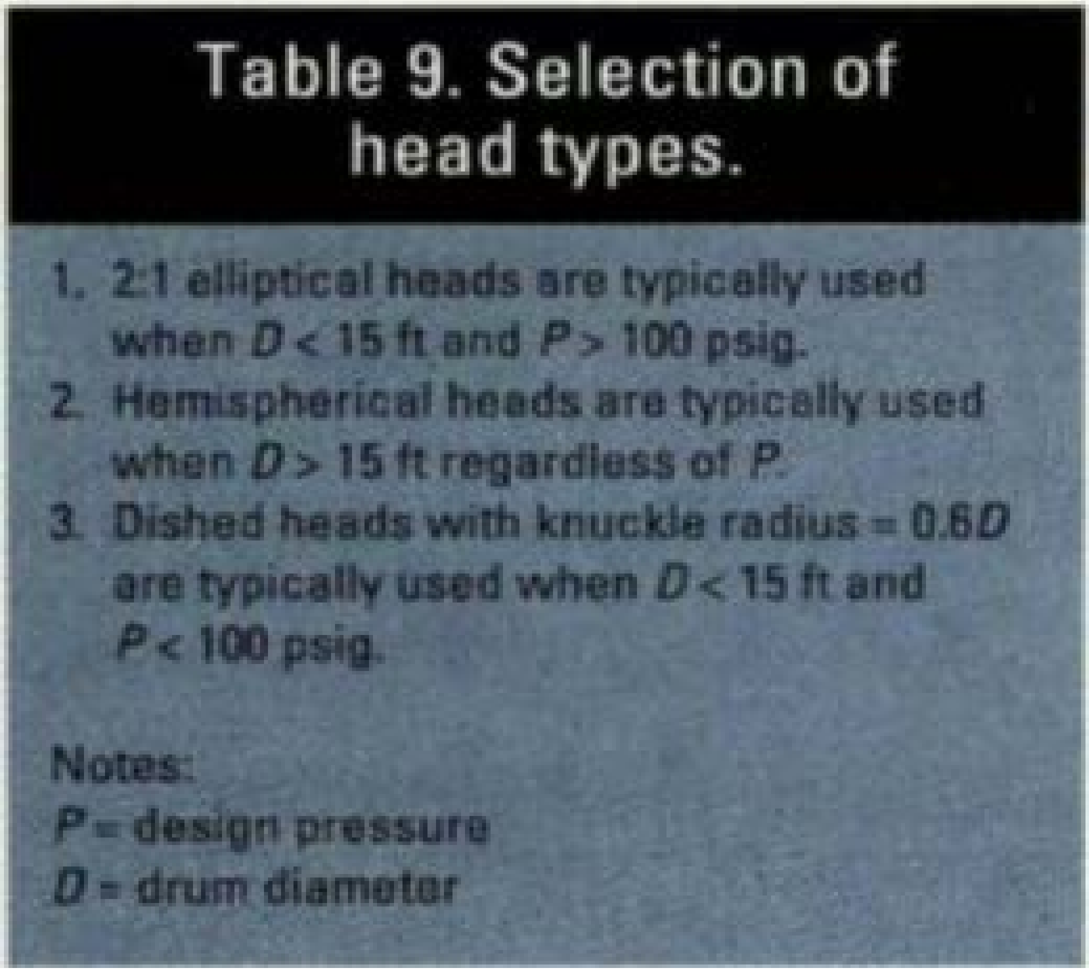


Table 9. Selection of head types.

1. 2:1 elliptical heads are typically used when $D < 15$ ft and $P > 100$ psig.
2. Hemispherical heads are typically used when $D > 15$ ft regardless of P.
3. Dished heads with knuckle radius = $0.6D$ are typically used when $D < 15$ ft and $P < 100$ psig.

Notes:
P = design pressure
D = drum diameter