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Sections 1-26

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by the

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Preface to the Twelfth Edition

The Gas Processors Suppliers Association is an organization of companies with specialized knowledge of the supply and service needs of the gas processing and related industries. A major service to them is embodied in the Engineering Data Book, which was first published in 1935. Over 150,000 copies of the Ninth, Tenth, and Eleventh Editions of the book were distributed for use throughout the world by engineers, operating personnel, and students.

The Twelfth Edition of the Engineering Data Book, available in two versions — FPS and SI — is an attempt to assemble, in a single compilation, basic design information together with data and procedures that can be used by field and plant engineers to determine operating and design parameters. It is also intended as an aid to design engineers who, in spite of increasing availability of computer routines and other sophisticated design methods, require a general reference work as a guide to accepted engineering practice for estimating, feasibility studies, preliminary design, and for making on-site operating decisions.

The loose-leaf format of the Data Book permits periodic updating to meet the changing technology of the process industries.

GPSA recognizes that the maintenance of the Data Book is a continuing task. Users' comments and suggestions are welcome. Any such comments should be made in writing to:

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A Brief History of the Engineering Data Book and Sponsoring Organizations

The GPSA Engineering Data Book was first published in 1935 as a booklet containing much advertising and a little technical information. In subsequent editions, technical information was expanded and the Data Book gradually became the accepted engineering reference work for the gas processing industry. In addition, the Data Book has found wide acceptance in the petroleum refining, gas transmission, and petrochemical industries.

The Gas Processors Suppliers Association (GPSA) was organized in 1928 as the Natural Gasoline Supply Men's Association (NGSMA). Its principal purpose was as a service organization to the parent Natural Gasoline Association of America (NGAA).

Both organizations underwent name changes in subsequent years in response to changing industry conditions. In 1961, the organizations became known as the Natural Gas Processors Association (NGPA) and the Natural Gas Processors Suppliers Association (NGPSA). In 1974 the names changed to the current Gas Processors Association (GPA) and Gas Processors Suppliers Association (GPSA).

Users of the manual should note that numerous references throughout the book may refer to publications of these organizations by the names in effect at the time of the publication.

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SECTION 7

Separation Equipment

PRINCIPLES OF SEPARATION

Three principles used to achieve physical separation of gas and liquids or solids are momentum, gravity settling, and coalescing. Any separator may employ one or more of these principles, but the fluid phases must be "immiscible" and have different densities for separation to occur.

FIG. 7-1

Nomenclature

A = area, ft^2
A_p = particle or droplet cross sectional area, ft^2
C = empirical constant for separator sizing, ft/hr
C* = empirical constant for liquid-liquid separators, (bbl • cp)/(ft^2 • day)
C′ = drag coefficient of particle, dimensionless (Fig. 7-3)
D_i = separator inlet nozzle diameter, in.
D_p = droplet diameter, ft
D_v = inside diameter of vessel, ft
G_m = maximum allowable gas mass-velocity necessary for particles of size D_p to drop or settle out of gas, lb/(hr • ft^2)
g = acceleration due to gravity, 32.2 ft/sec^2
H_l = width of liquid interface area, ft
J = gas momentum, lb/(ft • sec^2)
K = empirical constant for separator sizing, ft/sec
K_{CR} = proportionality constant from Fig. 7-5 for use in Eq 7-5, dimensionless
L = seam to seam length of vessel, ft
L_l = length of liquid interface area, ft
M = mass flow, lb/sec
M_p = mass of droplet or particle, lb
MW = molecular weight, lb/lb mole
P = system pressure, psia
Q = estimated gas flow capacity, MMscfd per ft^2 of filter area
Q_A = actual gas flow rate, ft^3/sec
R = gas constant, 10.73 (psia • ft^3)/(°R • lb mole)
Re = Reynolds number, dimensionless
S_{hl} = specific gravity of heavy liquid, water = 1.0
S_{ll} = specific gravity of light liquid, water = 1.0
T = system temperature, °R
t = retention time, minutes
U = volume of settling section, bbl
V_t = critical or terminal gas velocity necessary for particles of size D_p to drop or settle out of gas, ft/sec
W = total liquid flow rate, bbl/day
W_{cl} = flow rate of light condensate liquid, bbl/day
Z = compressibility factor, dimensionless

Greek:

ρ_g = gas phase density, lb/ft^3
ρ_l = liquid phase density, droplet or particle, lb/ft^3
μ = viscosity of continuous phase, cp

Filter Separators: A filter separator usually has two compartments. The first compartment contains filter-coalescing elements. As the gas flows through the elements, the liquid particles coalesce into larger droplets and when the droplets reach sufficient size, the gas flow causes them to flow out of the filter elements into the center core. The particles are then carried into the second compartment of the vessel (containing a vane-type or knitted wire mesh mist extractor) where the larger droplets are removed. A lower barrel or boot may be used for surge or storage of the removed liquid.

Flash Tank: A vessel used to separate the gas evolved from liquid flashed from a higher pressure to a lower pressure.

Line Drip: Typically used in pipelines with very high gas-to-liquid ratios to remove only free liquid from a gas stream, and not necessarily all the liquid. Line drips provide a place for free liquids to separate and accumulate.

Liquid-Liquid Separators: Two immiscible liquid phases can be separated using the same principles as for gas and liquid separators. Liquid-liquid separators are fundamentally the same as gas-liquid separators except that they must be designed for much lower velocities. Because the difference in density between two liquids is less than between gas and liquid, separation is more difficult.

Scrubber or Knockout: A vessel designed to handle streams with high gas-to-liquid ratios. The liquid is generally entrained as mist in the gas or is free-flowing along the pipe wall. These vessels usually have a small liquid collection section. The terms are often used interchangeably.

Separator: A vessel used to separate a mixed-phase stream into gas and liquid phases that are "relatively" free of each other. Other terms used are scrubbers, knockouts, line-drips, and decanters.

Slug Catcher: A particular separator design able to absorb sustained in-flow of large liquid volumes at irregular intervals. Usually found on gas gathering systems or other two-phase pipeline systems. A slug catcher may be a single large vessel or a manifolded system of pipes.

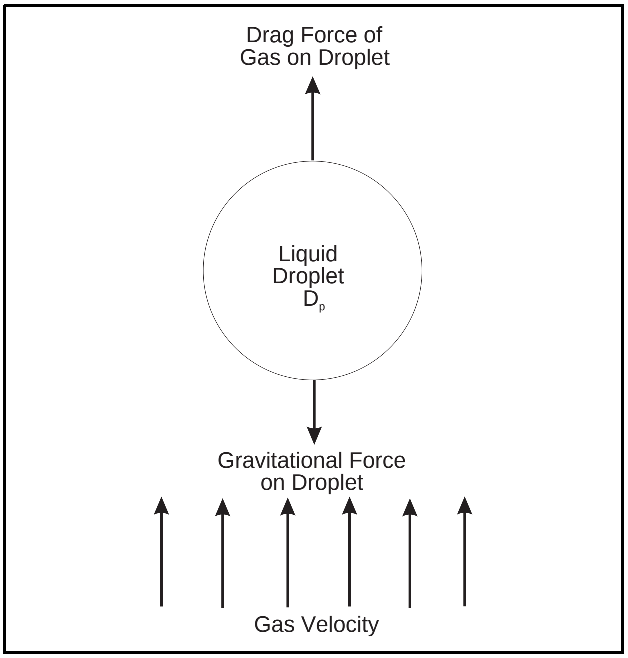
Three Phase Separator: A vessel used to separate gas and two immiscible liquids of different densities (e.g. gas, water, and oil).

Gravity Settling

Liquid droplets will settle out of a gas phase if the gravitational force acting on the droplet is greater than the drag force of the gas flowing around the droplet (see Fig. 7-2). These forces can be described mathematically using the terminal or finite-settling velocity calculation, Eq 7-1. The nomenclature for all equations in this section and terminology used are listed in Fig. 7-1.

FIG. 7-2

Forces on Liquid Droplet in Gas Stream



$$V_t = \sqrt{\frac{2\,g\,M_p\,(\rho_l - \rho_g)}{\rho_l\,\rho_g\,A_p\,C'}} = \sqrt{\frac{4\,g\,D_p\,(\rho_l - \rho_g)}{3\,\rho_g\,C'}} \qquad \textbf{Eq 7-1}$$

The drag coefficient has been found to be a function of the shape of the particle and the Reynolds number of the flowing gas. For the purpose of this equation, particle shape is considered to be a solid, rigid sphere. The Reynolds number is defined as:

$$Re = \frac{1{,}488\,D_p\,V_t\,\rho_g}{\mu} \qquad \textbf{Eq 7-2}$$

Fig. 7-3 shows the relationship between drag coefficient and particle Reynolds number for spherical particles.

In this form, a trial and error solution is required since both particle size (D_p) and terminal velocity (V_t) are involved. To avoid trial and error, values of the drag coefficient are presented in Fig. 7-4 as a function of the product of drag coefficient (C') times the Reynolds number squared; this technique eliminates velocity from the expression.[1] The abscissa of Fig. 7-4 is given by:

$$C'\,(Re)^2 = \frac{(0.95)\,(10^8)\,\rho_g\,D_p^3\,(\rho_l - \rho_g)}{\mu^2} \qquad \textbf{Eq 7-3}$$

As with other fluid flow phenomena, the gravity settling drag coefficient reaches a limiting value at high Reynolds numbers.

As an alternative to using Eq 7-3 and Fig. 7-4, the following approach is commonly used.

The curve shown in Fig. 7-3 can be simplified into three sections from which curve-fit approximations of the C′ vs Re curve can be derived. When these expressions for C′ vs Re are substituted into Eq 7-1, three settling laws are obtained as described below.

FIG. 7-3

Drag Coefficient and Reynolds Number for Spherical Particles[1]

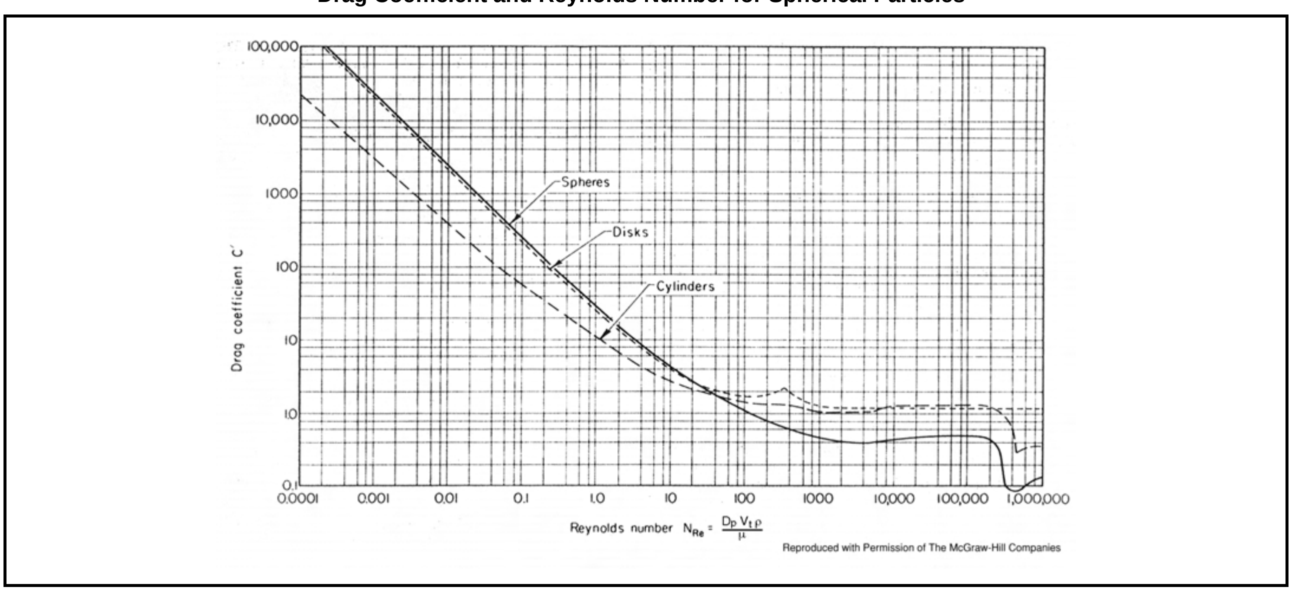
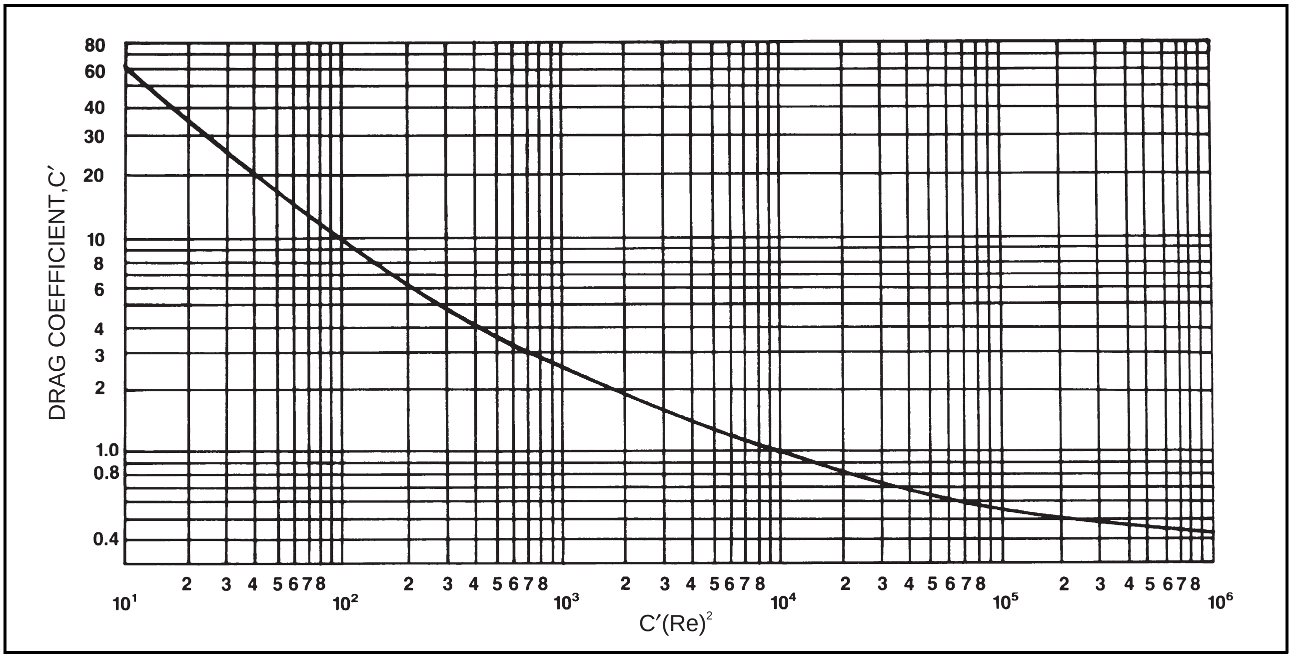


FIG. 7-4

Drag Coefficient of Rigid Spheres[2]



Stoke's Law

At low Reynolds numbers (less than 2), a linear relationship exists between the drag coefficient and the Reynolds number (corresponding to laminar flow). Stoke's Law applies in this case and Eq 7-1 can be expressed as:

$$V_t = \frac{1{,}488\ g\ D_p^2\ (\rho_l - \rho_g)}{18\ \mu} \qquad \textbf{Eq 7-4}$$

The droplet diameter corresponding to a Reynolds number of 2 can be found using a value of 0.025 for K_{CR} in Eq 7-5.

$$D_p = K_{CR}\left[\frac{\mu^2}{g\ \rho_g\ (\rho_l - \rho_g)}\right]^{0.33} \qquad \textbf{Eq 7-5}$$

A summary of these equations is presented in Fig. 7-5, which also provides general information regarding droplet sizes and collection equipment selection guidelines.

By inspection of the particle Reynolds number equation (Eq 7-2) it can be seen that Stoke's law is typically applicable for small droplet sizes and/or relatively high viscosity liquid phases.

Intermediate Law

For Reynold's numbers between 2 and 500, the Intermediate Law applies, and the terminal settling law can be expressed as:

$$V_t = \frac{3.49\ g^{0.71}\ D_p^{1.14}\ (\rho_l - \rho_g)^{0.71}}{\rho_g^{0.29}\ \mu^{0.43}} \qquad \textbf{Eq 7-6}$$

The droplet diameter corresponding to a Reynolds number of 500 can be found using a value of 0.334 for K_{CR} in Eq 7-5.

The intermediate law is usually valid for many of the gas-liquid and liquid-liquid droplet settling applications encountered in the gas business.

Newton's Law

Newton's Law is applicable for a Reynold's number range of approximately 500 – 200,000, and finds applicability mainly for separation of large droplets or particles from a gas phase, e.g. flare knockout drum sizing. The limiting drag coefficient is approximately 0.44 at Reynolds numbers above about 500. Substituting C′ = 0.44 in Eq 7-1 produces the Newton's Law equation expressed as:

$$V_t = 1.74\sqrt{\frac{g\ D_p\ (\rho_l - \rho_g)}{\rho_g}} \qquad \textbf{Eq 7-7}$$

An upper limit to Newton's Law is where the droplet size is so large that it requires a terminal velocity of such magnitude that excessive turbulence is created. For the Newton's Law region, the upper limit to the Reynolds number is 200,000 and K_{CR} = 18.13.

DROPLET SIZE DISTRIBUTIONS AND ENTRAINMENT LOADINGS

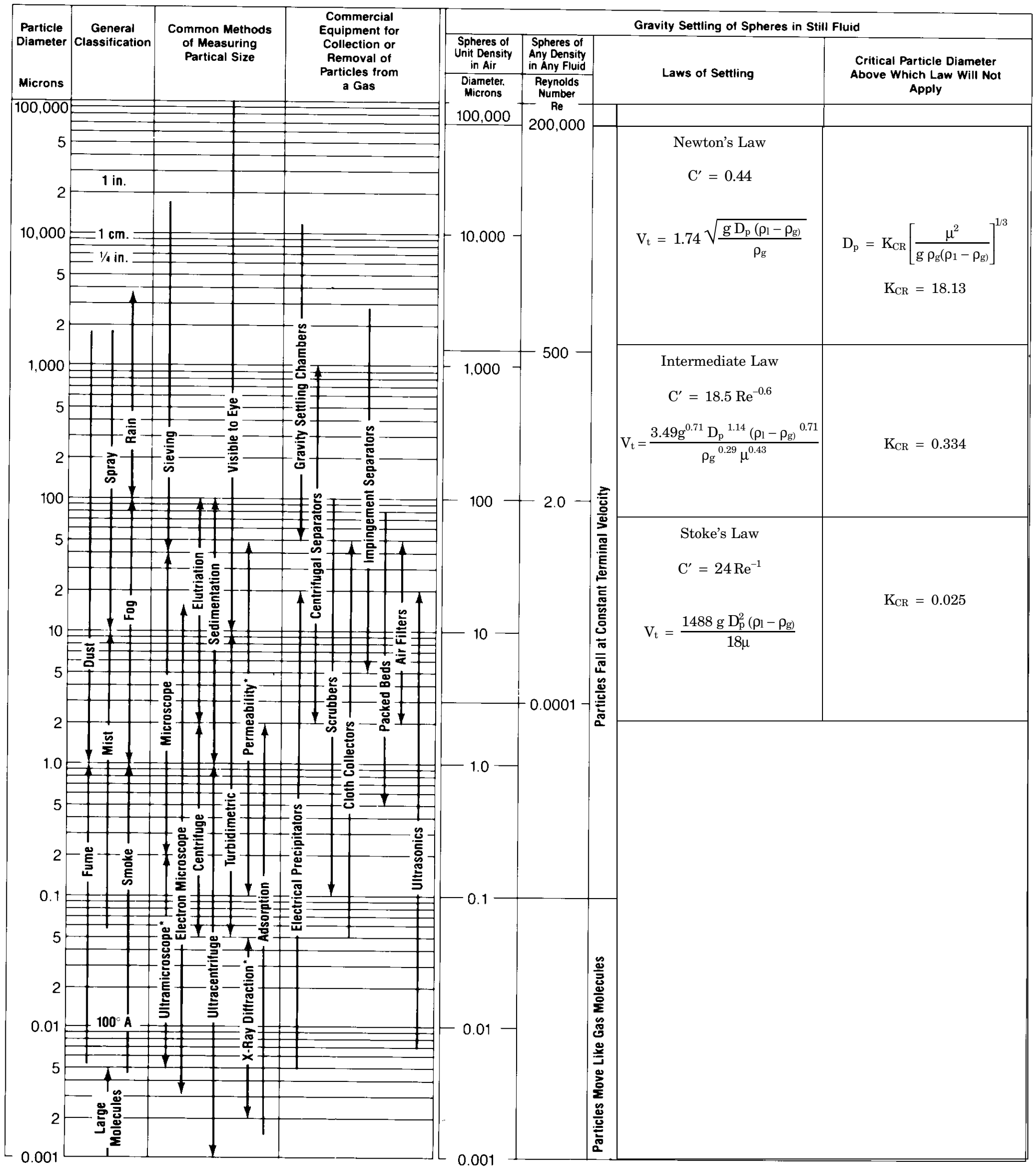
Liquid Drop Sizes in Gas-Liquid Systems

The gravity settling theory above provides valuable insight into the significance of certain physical properties and the physics that together influence the separation of dispersed droplets from a continuous phase, e.g. liquid droplets from a gas or liquid droplets of a specific density from a liquid phase of another density. However, a couple of problems remain:

- Determination of the actual droplet sizes that need to be dealt with.
- Determination of the amount of entrained liquid in droplet form.

FIG. 7-5

Gravity Settling Laws and Particle Characteristics



Adapted From Ref. 7-3

These issues apply to both gas-liquid and liquid-liquid separations.

Neither of these are subject to precise calculation and yet equipment separation performance is dependent on both. As a result, the sizing of separation equipment, vapor-liquid and liquid-liquid, is still largely based on empirical methods. While progress is being made in this area, there is some way to go before droplet size distribution and entrainment loading prediction will be fully incorporated into separation equipment sizing procedures. Fig. 7-6 provides an indication of typical drop size distributions for various gas-liquid systems.

TYPES OF SEPARATORS

Separators are usually characterized by orientation as vertical or horizontal. They may be further classified as two-phase (gas-liquid) or three-phase (gas-liquid-liquid). Horizontal separators can be single- or double-barrel and can be equipped with sumps or boots.

Parts of a Separator

Regardless of shape, separation vessels usually contain four major sections plus the necessary controls. These sections are shown for horizontal and vertical vessels in Fig. 7-7. The inlet device (A) is used to reduce the momentum of the inlet flow stream, perform an initial bulk separation of the gas and liquid phases, and enhance gas flow distribution. There are a variety of inlet devices available and these are discussed in more detail in a later section.

The gas gravity separation section (B) is designed to utilize the force of gravity to separate entrained liquid droplets from the gas phase, preconditioning the gas for final polishing by the mist extractor. It consists of a portion of the vessel through which the gas moves at a relatively low velocity with little turbulence. In some horizontal designs, straightening vanes are used to reduce turbulence. The vanes also act as droplet coalescers, which reduces the horizontal length required for droplet removal from the gas stream.

The liquid gravity separation section (C) acts as a receiver for all liquid removed from the gas in the inlet, gas gravity, and mist extraction sections. In two-phase separation applications, the liquid gravity separation section provides residence time for degassing the liquid. In three-phase separation applications the liquid gravity section also provides residence time to allow for separation of water droplets from a lighter hydrocarbon liquid phase and vice-versa. Depending on the inlet flow characteristics, the liquid section should have a certain amount of surge volume, or slug catching capacity, in order to smooth out the flow passed on to downstream equipment or processes. Efficient degassing may require a horizontal separator while emulsion separation may also require higher temperature, use of electrostatic fields, and/or the addition of a demulsifier. Coalescing packs are sometimes used to promote hydrocarbon liquid – water separation, though they should not be used in applications that are prone to plugging, e.g. wax, sand, etc.

FIG. 7-6

Typical Partical Size Distribution Ranges From Entrainment Caused By Various Mechanisms

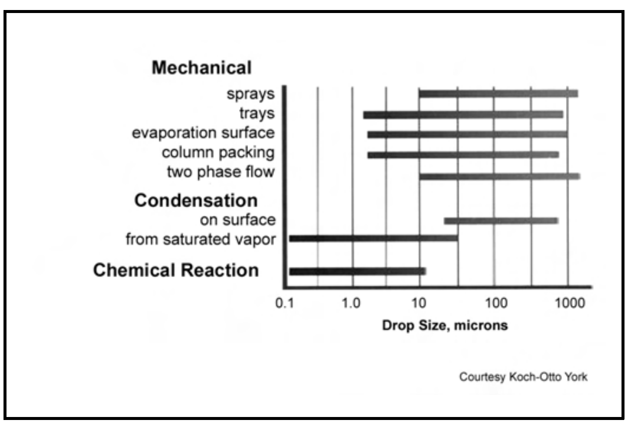
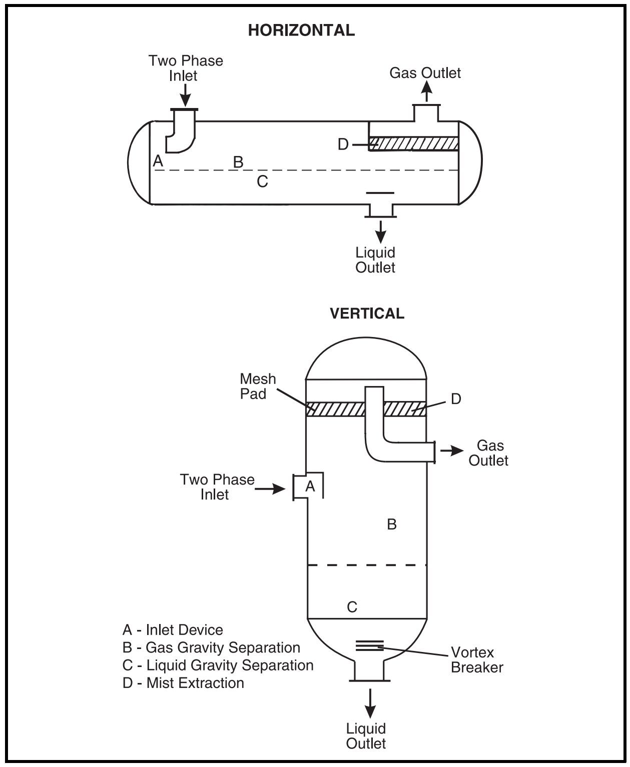


FIG. 7-7

Gas-Liquid Separators



The mist extraction section (D) utilizes a mist extractor that can consist of a knitted wire mesh pad, a series of vanes, or cyclone tubes. This section removes the very small droplets of liquid from the gas by impingement on a surface where they coalesce into larger droplets or liquid films, enabling separation from the gas phase. Quoted liquid carryover from the various types of mist extraction devices are usually in the range of 0.1 - 1 gal/MMscf.

Separator Configurations

Factors to be considered for separator configuration selection include:

- What separation quality is required by downstream equipment and processes?
- How well will extraneous material (e.g. sand, mud, corrosion products) be handled?

- How much plot space will be required?
- Will the separator be too tall for transport if skidded?
- Is there enough interface surface for 3-phase separation (e.g. gas/hydrocarbon/glycol liquid)?
- Can heating coils or sand jets be incorporated if required?
- How much surface area is available for degassing of separated liquid?
- Must surges in liquid flow be handled without large changes in level?
- Is large liquid retention volume necessary?
- What are the heat retention requirements (e.g. freeze protection)?

Vertical Separators

Vertical separators, shown in Fig. 7-8, are usually selected when the gas-liquid ratio is high or total gas volumes are low. In a vertical separator, the fluids enter the vessel through an inlet device whose primary objectives are to achieve efficient bulk separation of liquid from the gas and to improve flow distribution of both phases through the separator. Liquid removed by the inlet device is directed to the bottom of the vessel. The gas moves upward, usually passing through a mist extractor to remove any small entrained liquid droplets, and then the vapor phase flows out of the vessel. Liquid removed by the mist extractor is coalesced into larger droplets that then fall through the gas to the liquid reservoir in the bottom. The ability to handle liquid slugs is typically obtained by increasing vessel height to accommodate additional surge volume. Level control is normally not highly critical and liquid level can fluctuate several inches without affecting the separation performance or capacity of the vessel. Except for knockout drum applications, mist extractors are normally used to achieve a low liquid content in the separated gas in vessels of reasonable diameter.

Typical vertical separator L/D ratios are normally in the 2–4 range.

As an example of a vertical separator, consider a compressor suction scrubber. In this service the vertical separator:

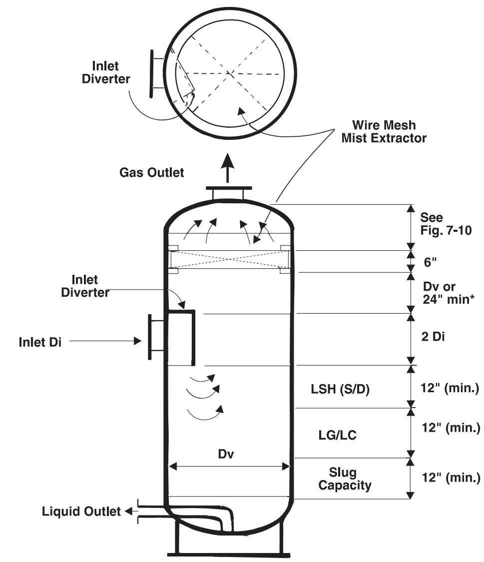
- Does not need significant liquid retention volume
- A properly designed liquid level control loop responds quickly to any liquid that enters, thus avoiding tripping an alarm or shutdown
- The separator occupies a small amount of plot space

Horizontal Separators

Horizontal separators are most efficient when large volumes of liquid are involved. They are also generally preferred for three-phase separation applications. In a horizontal separator, shown in Fig. 7-9, the liquid that has been separated from the gas moves along the bottom of the vessel to the liquid outlet. The gas and liquid occupy their proportionate shares of the shell cross-section. Increased slug capacity is obtained through shortened retention time and increased liquid level. Fig. 7-9 also illustrates the separation of two liquid phases (glycol and hydrocarbon). The denser glycol settles to the bottom and is withdrawn through the boot. The glycol level is controlled by an interface level control instrument.

FIG. 7-8

Vertical Separator with Wire Mesh Mist Extractor



LSH (S/D) Level Switch High (Shutdown)
LG/LC Level Gauge/Level Controller

- Dimensions may be influenced by instrument connection requirements.
- For small diameter separators ($\leq$ 48 inch ID.) with high L/G inlet flow ratios this dimension should be increased by as much as 50%.
- May use syphon type drain to:
  A. reduce vortex possibility
  B. reduce external piping that requires heating (freeze protection)

Horizontal separators have certain advantages with respect to gravity separation performance in that the liquid droplets or gas bubbles are moving perpendicular to the bulk phase velocity, rather than directly against it as in vertical flow, which makes separation easier.

In a double-barrel separator, the liquids fall through connecting flow pipes into the external liquid reservoir below. Slightly smaller vessels may be possible with the double-barrel horizontal separator, where surge capacity establishes the size of the lower liquid collection chamber.

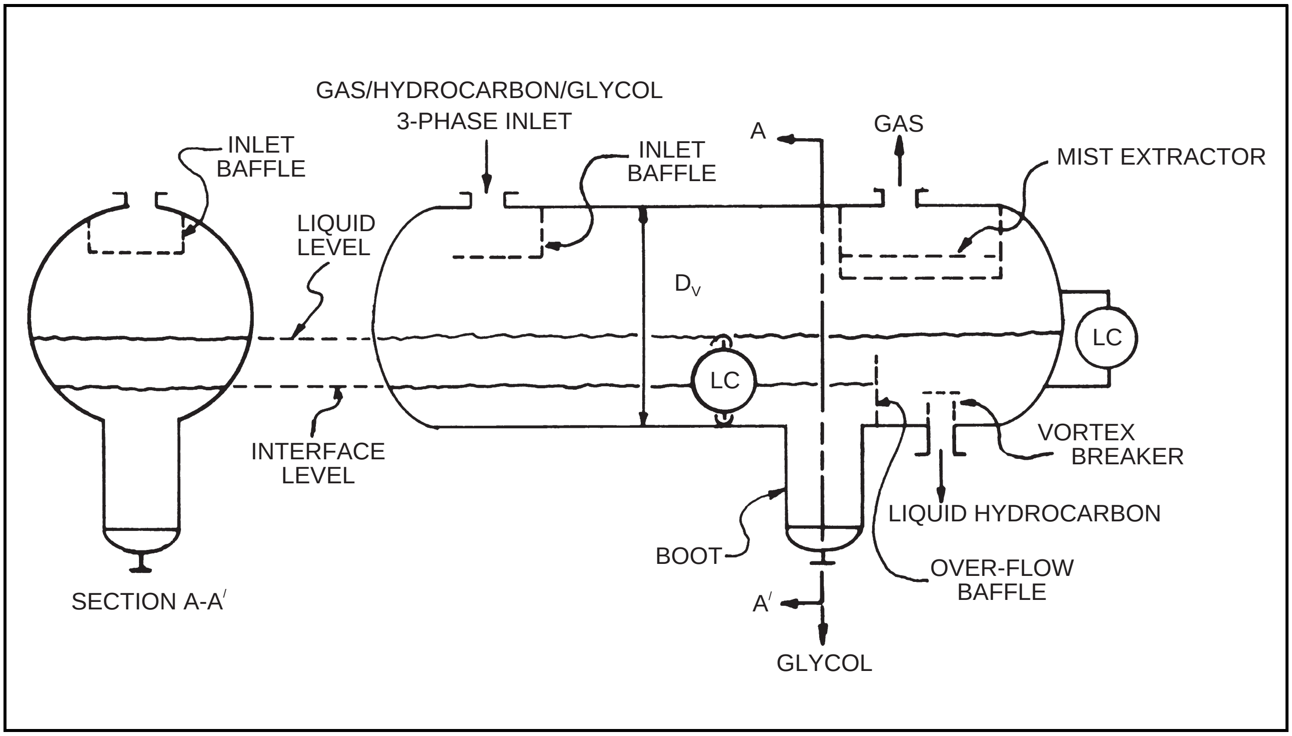
Typical L/D ratios for horizontal separators normally fall in the range of 2.5–5.

As an example of a horizontal separator, consider a rich amine flash tank. In this service:

- There is relatively large liquid surge volume required for longer retention time. This allows more complete release of the dissolved gas and, if necessary, surge volume for the circulating system.
- There is more surface area per liquid volume to aid in more complete degassing.
- The horizontal configuration handles a foaming liquid better than vertical.
- The liquid level responds slowly to changes in liquid inventory, providing steady flow to downstream equipment.

FIG. 7-9

Horizontal Three-Phase Separator with Wire Mesh Mist Extractor



VESSEL INTERNALS

Inlet Devices

The importance of the inlet device with respect to separation performance has been identified only relatively recently, mainly through the use of Computational Fluid Dynamics (CFD) modeling. The main functions of the inlet device are:

- Reduce the momentum of the inlet stream and enhance flow distribution of the gas and liquid phases.
- Efficient separation of the bulk liquid phase.
- Prevent droplet shattering and re-entrainment of bulk liquid phase.

There are several different types of separator inlet devices that are commonly used:

- no inlet device
- diverter plate
- half-pipe
- vane-type
- cyclonic

In addition to the inlet device itself, it has been determined that the inlet piping configuration is also important. The vane-type and cyclonic inlet devices generally provide improved separation performance compared to the others. The separator/inlet device manufacturer should be contacted for specific design/performance details.

Mist Extraction Equipment

Mist extractors are used to separate the small liquid droplets from the gas phase that were not removed by the inlet device or gas gravity settling section (main "body") of the separator. These droplets are typically less than 150–500 micron in size and usually much smaller. It is generally not economic to separate these droplets by gravity alone by making the separator larger. The different types of mist extractors use principles other than simple droplet settling by gravity to achieve efficient removal of small droplets.

Wire-Mesh

Wire-mesh mist extractors, or pads, are made by knitting wire, metal or plastic, into tightly packed layers which are then crimped and stacked to achieve the required pad thickness. If removal of very small droplets, i.e. less than 10 micron, is required, much finer fibers may be interwoven with the primary mesh to produce a co-knit pad. Mesh pads remove liquid droplets mainly by impingement of droplets onto the wires and/or co-knit fibers followed by coalescence into droplets large enough to disengage from the bottom of the pad and drop through the rising gas flow into the liquid holding part of the separator. Mesh pads are not recommended for dirty or fouling service as they tend to plug easily. Wire mesh pads are normally installed horizontally with gas flow vertically upwards through the pad. Performance is adversely affected if the pad is tilted more than 30 degrees from the horizontal.[4] Problems have been encountered where liquid flow through the pad to the sump is impaired due to dirt or sludge accumulation, causing a higher liquid level on one side. This provides the serious potential of the pad being dislodged from its mounting brackets, making it useless or forcing parts of it into the outlet pipe. Firmly secure the top and bottom of the pad so that it is not dislodged by high gas flows, such as when a pressure relief valve lifts or during an emergency blowdown situation. Figures 7-10 and 7-11 illustrate typical wire mesh installations in vertical and horizontal vessels.

Most installations will use a 6-inch thick pad with 9-12 lb/ft^3 bulk density. Minimum recommended pad thickness is 4 inches[4]. Manufacturers should be contacted for specific designs.

Separation Performance — There are two main aspects to mesh pad separation performance.

- droplet removal efficiency
- gas handling capacity

Droplet removal efficiency is typically given by the manufacturer as a curve showing % removal as a function of droplet size at design flow and a nominal liquid loading. These curves are usually based on tests of an air-water system at atmospheric pressure.

The gas capacity of mesh pads is almost universally specified by a load or sizing factor, K, as utilized in the Souders and Brown[5] equation given below:

$$V_t = K\sqrt{\frac{\rho_l - \rho_g}{\rho_g}} \qquad \textbf{Eq 7-8}$$

The required mist extractor area is obtained from

$$A = \frac{Q_A}{V_t} \qquad \textbf{Eq 7-9}$$

The design K value provides a certain degree of margin before liquid entrainment/carryover becomes excessive. Efficiency and capacity are normally inversely related, i.e. as droplet removal efficiency increases, allowable gas throughput decreases.

Because normal pressure drops across mesh pads are so low (less than 1 inch of water) this is not typically a major area of concern in gas processing operations. Fig. 7-12 provides a summary of performance parameters.

The K capacity factor for mesh pads is often derated for higher pressure operation, Fig. 7-13. All factors being equal, this is normally due to the reduction in surface tension of the liquid phase that occurs with increasing pressure.

Mesh pads normally operate efficiently over a range of 30–110% of the design gas rate.

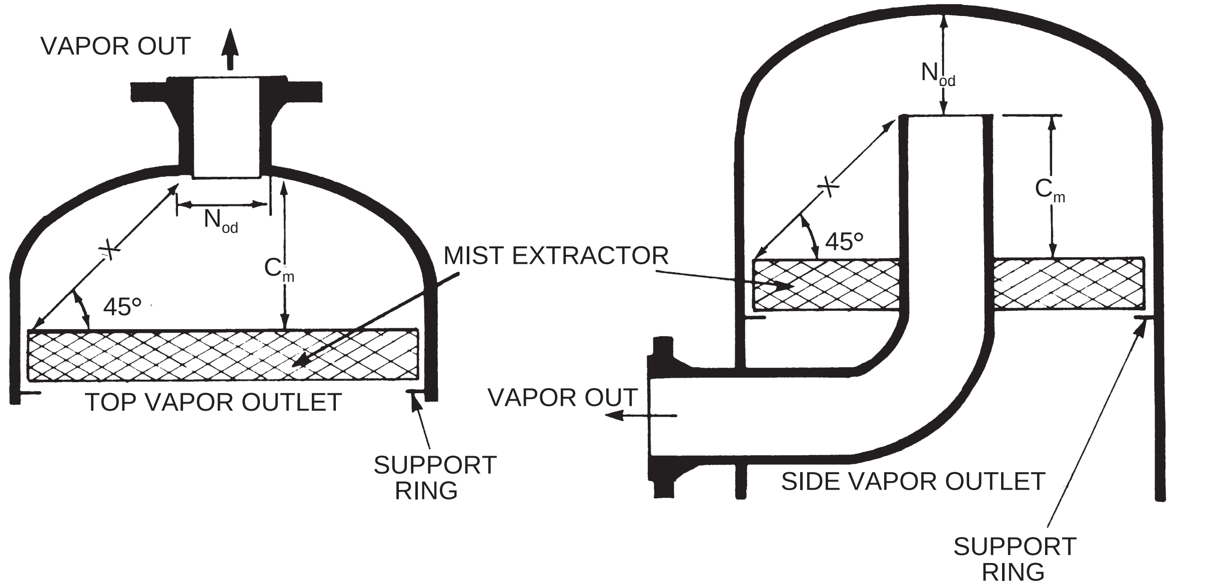
The gas capacity of a wire-mesh pad is typically defined in terms of a K "constant" as given in Fig. 7-12. This is an oversimplification. Among other things, K is also a function of the amount of entrained liquid reaching the mesh pad. As would be expected, K decreases with increasing inlet liquid loading. For typical mesh pad designs, liquid loads greater than 1 gpm/ft^2 are considered high and will require deration of the standard K factor, to prevent excessive entrainment carryover. However, per the earlier discussion on droplet size distributions, it is difficult to predict what the inlet liquid loading reaching the mist extractor will be for a given separator application.

Vane

Vane or chevron-type mist extractors (vane-pack) use relatively closely spaced blades arranged to provide sinusoidal or zig-zag gas flow paths. The changes in gas flow direction com-

FIG. 7-10

Minimum Clearance — Mesh Type Mist Eliminators



MINIMUM EXTRACTOR CLEARANCE, C_m:

$$C_m = 0.707 X \text{ or } \frac{M_{od} - N_{od}}{2}$$

WHERE:
M_{od} = MIST EXTRACTOR OUTSIDE DIAMETER
N_{od} = NOZZLE OUTSIDE DIAMETER

FIG. 7-11

Horizontal Separator with Knitted Wire Mesh Pad Mist Extractor and Lower Liquid Barrel

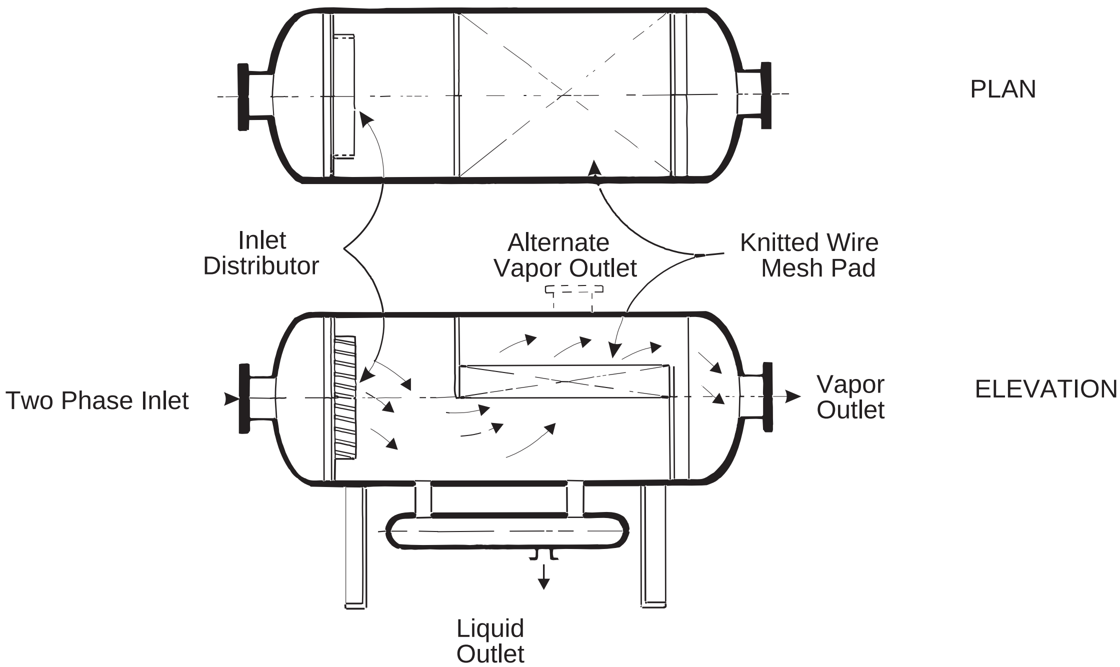


FIG. 7-12

Mesh Pad Separation Performance

Droplet removal efficiency:	99–99.5% removal of 3–10 micron droplets. Higher removal efficiency is for denser, thicker pads and/or smaller wire/co-knit fiber diameter.
Gas capacity, K, ft/sec	0.22–0.39. Generally, the lower capacities correspond to the mesh pad designs with the highest droplet removal efficiencies.

FIG. 7-13

Adjustment of K Factor for Pressure[6]

Pressure, psig	Percent of Design Value
Atmospheric	100
150	90
300	85
600	80
1,150	75

bined 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. Fig. 7-14 shows a typical vane-type mist extractor. Vane packs may be installed in either horizontal or vertical orientations, though capacity is typically reduced significantly for vertical upflow applications. Recently developed hollow vane designs with interconnected liquid drainage passages are capable of high gas handling capacities in a vertical upflow orientation. Vanes differ from wire mesh pads in that they typically do not drain the separated liquid back through the rising gas stream. Rather, the liquid can be routed into a downcomer that carries the fluid directly to the liquid holding section of the separator. Vane packs are better suited to dirty or fouling service as they are less likely to plug due to their relatively large flow passages. A vertical separator with a typical vane mist extractor is shown in Fig. 7-15.

A number of different vane pack designs are available. Pack thicknesses are generally in the range of 6–12 inches. Vanes are usually arranged in a zig-zag or sinusoidal pattern, with vane spacings of 1–1.5 inches typical. Vane types include no-pocket, single-pocket and double-pocket styles.

Separation Performance— As for mesh pads, the key performance parameters are droplet removal efficiency and gas handling capacity. Eq 7-8 and the load/sizing factor K, can also be utilized for calculating the capacity of vane-type mist extractors. Fig. 7-16 provides a summary of performance parameters.

Vane packs typically have pressure drops in the range of 0.5–3.5 inches of water.

FIG. 7-14

Cross-Section of Vane Element Mist Extractor Showing Corrugated Plates with Liquid Drainage Traps

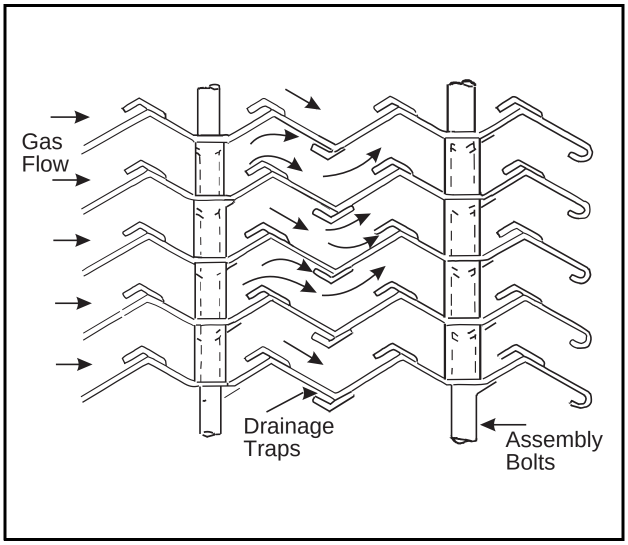
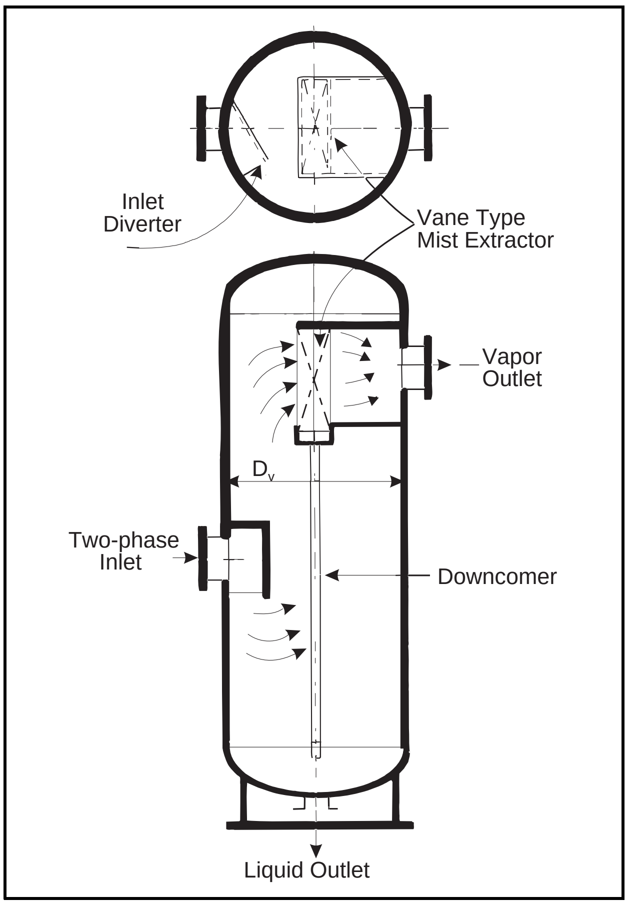


FIG. 7-15

Vertical Separator with Vane-Type Mist Extractor



As for wire mesh extractors, the droplet removal efficiencies quoted above for vane-type units are typically based on tests performed on air-water systems at atmospheric pressure. Testing has shown that for mesh type extractors, the low pressure air-water droplet removal efficiency results correlate reasonably well to higher pressure gas-hydrocarbon liquid systems. Vane packs on the other hand show a drop-off of removal efficiency as pressure increases. This is primarily a result of the decreasing allowable gas velocity with increasing pressure caused mainly by increased gas density. As gas velocity decreases, droplet inertia decreases and the droplets tend to follow the gas streamlines more easily through the vane passages, and exit the vane pack without being captured. Mesh pads also rely on velocity/droplet inertia to remove liquid droplets via impingement but they are less susceptible to capture efficiency reduction than vane packs because mesh pads have far more collection "targets", i.e. wire/fiber filaments.

Turndown is generally more of an issue with vane-packs, with droplet removal efficiency decreasing measurably as velocity decreases from design.

Vane-type mist extractors are also impacted by inlet liquid loading, but generally have considerably more tolerance towards liquids than mesh-pads. The manufacturer should be contacted for specific designs and applications.

FIG. 7-16

Typical Vane Pack Separation Performance

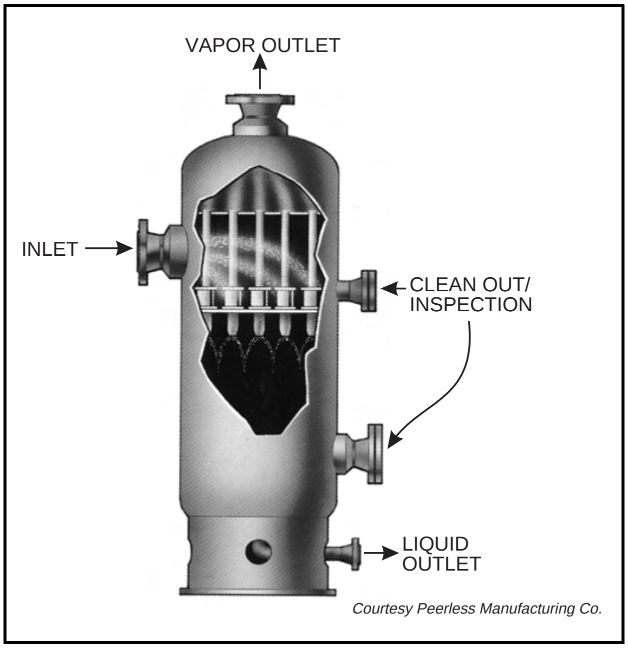
Droplet removal efficiency:	99% removal of droplets greater than 10–40 microns. Higher removal efficiency is for thicker packs, with closer vane spacings and more passes (bends).
Gas capacity, K, ft/sec	Horizontal flow: 0.9–1.0 Vertical up-flow: 0.4–0.5 The higher capacities are generally associated with pocketed vane designs.

Cyclonic

There are several types of centrifugal separators that serve to separate entrained liquids, and solids if present, from a gas stream. For mist extraction applications, reverse-flow, axial-flow and recycling axial-flow cyclones are typically used in multi-cyclone "bundles." Cyclonic mist extractors use centrifugal force to separate solids and liquid droplets from the gas phase based on density difference. Very high G forces are achieved which allows for efficient removal of small droplet sizes. The main advantage of cyclonic mist extractors is that they provide good removal efficiency at very high gas capacity. This generally allows for the smallest possible vessel diameter for a given gas flow. Cyclonic mist extractors are often used in low liquid load gas scrubbing applications, and for high pressure gas-liquid separation. These devices are proprietary and cannot be readily sized without detailed knowledge of the characteristics of the specific internals. The manufacturer of such devices should be consulted for assistance in sizing these types of separators. A typical centrifugal separator is shown in Fig. 7-17. Disadvantages of centrifugal separators are:

FIG. 7-17

Vertical Separator with Centrifugal Elements



- Some designs do not handles slugs well
- Pressure drop tends to be significantly higher than for vane or clean-knitted mesh mist extractors
- They have a relatively narrow operating flow range for highest efficiency

Separation Performance — As stated, the selection and design of de-misting cyclone bundles should be left to the manufacturers. While not a correct representation of the separation physics employed by cyclonic devices, the familiar K factor as used in Eq 7-8 can be used to provide indicative gas capacity for a multicyclone mist extractor. K factors will tend to range from 1 ft/sec for reverse flow multicyclones to 3 ft/sec or higher for the newest recycling axial-flow multicyclones. The liquid handling capacity of a multicyclone bundle is typically somewhat higher than that for vane-type mist extractors. The gas capacity factor, K, is based on the multicyclone bundle cross-sectional area, assuming 2 inch cyclone tubes and typical cyclone–cyclone pitch dimensions and layout arrangement.

GAS-LIQUID SEPARATOR SIZING

Specifying Separators

Separator designers need to know pressure, temperature, flow rates, and physical properties of the streams as well as the degree of separation required. It is also prudent to define if these conditions all occur at the same time or if there are only certain combinations that can exist at any time. If known, the type and amount of liquid should also be given, and whether it is mist, free liquid, or slugs.

For example, a compressor suction scrubber designed for 70-150 MMscfd gas at 400-600 psig and 65-105°F would require a unit sized for the worse conditions, i.e. 150 MMscfd at 400 psig and 105°F. But if the real throughput of the compressor varies from 150 MMscfd at 600 psig, 105°F to 70 MMscfd at 400 psig, 65°F then a smaller separator is acceptable because the high volume only occurs at the high pressure.

An improperly sized separator is one of the leading causes of process and equipment problems. Inlet separation problems upstream of absorption systems (e.g. amine and glycol) can lead to foaming problems, and upstream of adsorption systems (e.g. molecular sieve, activated alumina, and silica gel) can cause fouling, coking, and other damage to the bed. Equipment such as compressors and turbo-expanders tolerate little or no liquid in the inlet gas steam, while pumps and control valves may have significant erosion and/or cavitation when vapors are present due to improper separation. In addition, direct-fired reboilers in amine and glycol service may experience tube failures due to hot spots caused by salt deposits caused by produced water carryover into the feed gas.

Design Approach

There is as much art as there is science to properly design a separator. Three main factors should be considered in separator sizing: 1) vapor capacity, 2) liquid capacity, and 3) operability. The vapor capacity will determine the cross-sectional area necessary for gravitational forces to remove the liquid from the vapor. The liquid capacity is typically set by determining the volume required to provide adequate residence time to "de-gas" the liquid or allow immiscible liquid phases to separate. Operability issues include the separator's ability to deal with solids if present, unsteady flow/liquid slugs, turndown, etc. Finally, the optimal design will usually result in an aspect ratio that satisfies these requirements in a vessel of reasonable cost. These factors often result in an iterative approach to the calculations.

VAPOR HANDLING

Separators without Mist Extractors

Separators without mist extractors are not frequently utilized. The most common application of a vapor-liquid separator that does not use a mist extractor is a flare knockout drum. Mist extractors are rarely used in flare knockout drums because of the potential for plugging and the serious implications this would have for pressure relief. is typically a horizontal vessel that utilizes gravity as the sole mechanism for separating the liquid and gas phases. Gas and liquid enter through the inlet nozzle and are slowed to a velocity such that the liquid droplets can fall out of the gas phase. The dry gas passes into the outlet nozzle and the liquid is drained from the lower section of the vessel.

To design a separator without a mist extractor, the minimum size diameter droplet to be removed must be set. Typically this diameter is in the range of 300 to 2,000 microns (1 micron = 10^{-4} cm or 0.00003937 inch).

The length of the vessel required can then be calculated by assuming that the time for the gas flow from inlet to outlet is the same as the time for the liquid droplet of size D_p to fall from the top of the vessel to the liquid surface. Eq 7-10 then relates the length of the separator to its diameter as a function of this settling velocity (assuming no liquid retention):

$$L = \frac{4\,Q_A}{\pi\, V_t\, D_v} \qquad \textbf{Eq 7-10}$$

If the separator is to be additionally used for liquid storage, this must also be considered in sizing the vessel.

Example 7-1—A horizontal gravity separator (without mist extractor) is required to handle 60 MMscfd of 0.75 specific gravity gas (MW = 21.72) at a pressure of 500 psig and a temperature of 100°F. Compressibility is 0.9, viscosity is 0.012 cp, and liquid specific gravity is 0.5. It is desired to remove all entrainment greater than 150 microns in diameter. No liquid surge is required.

Gas density, $\rho_g = \frac{P\,(MW)}{RTZ} = \frac{(514.7)\,(21.72)}{(10.73)\,(560)\,(0.90)}$

$= 2.07\ \text{lb/ft}^3$

Liquid density, $\rho_l = 0.5\,(62.4) = 31.2\ \text{lb/ft}^3$

Mass flow, $M = \frac{(60)\,(10^6)\,(21.72)}{(379)\,(24)\,(3600)} = 39.8\ \text{lb/sec}$

Particle diameter, $D_p = \frac{(150)\,(0.00003937)}{12} = 0.000492\ \text{ft}$

From Eq 7-3,

$$C'\,(Re)^2 = \frac{(0.95)\,(10^8)\,\rho_g\,D_p^3\,(\rho_l - \rho_g)}{\mu^2}$$

$$= \frac{(0.95)\,(10^8)\,(2.07)\,(0.000492)^3\,(31.2 - 2.07)}{(0.012)^2}$$

$$= 4738$$

From Fig. 7-4, Drag coefficient, $C' = 1.40$

Terminal velocity, $V_t = \sqrt{\frac{4\,g\,D_p\,(\rho_l - \rho_g)}{3\,\rho_g\,C'}}$

$$= \sqrt{\frac{4\,(32.2)\,(0.000492)\,(29.13)}{3\,(2.07)\,1.40}}$$

$$= \sqrt{0.212} = 0.46\ \text{ft/sec}$$

Gas flow, $Q_A = \frac{M}{\rho_g} = \frac{39.80}{2.07} = 19.2\ \text{ft}^3/\text{sec}$

Assume a diameter, $D_v = 3.5$ ft

Vessel length, $L = \frac{4\,Q_A}{\pi\,V_t\,D_V} = \frac{4\,(19.2)}{\pi\,(0.46)\,(3.5)}$

$= 15.2$ ft

Other reasonable solutions are as follows:

Diameter, feet	Length, feet
3.5	15.2
4.0	13.3
4.5	11.8
5.0	10.6

Example 7-2—What size vertical separator without a mist extractor is required to meet the conditions used in Example 7-1?

$$A = \frac{Q_A}{V_t} = \frac{19.2}{0.46} = 41.7\ \text{ft}^2$$

$D_v = 7.29$ ft minimum

Use a 90-inch ID vertical separator.

Separators with Mist Extractors

Of the four major components of a separator that were discussed in a previous section, the mist extractor has the most impact on separated gas quality with respect to carried over liquid content. The sizing equations and parameters provided in the mist extraction section size the mist extractor itself, not the actual separation vessel. The gas capacities of the various types of mist extractors is generally inversely related to the amount of entrained liquid that the mist extractor is required to remove.

- the amount of liquid in the separator feed gas.
- the inlet flow condition of the feed, i.e. multiphase flow pattern, .
- the type of inlet device used.
- the sizing/dimensions of the gas gravity separation section of the separator.

For lightly liquid loaded separation applications, e.g. less than 10-15 BBL/MMSCF (gas scrubbing application), the mist extractor performance will be controlling and will generally dictate the cross-sectional area requirements of the gas gravity separation section. For a vertical separator, this will determine the vessel diameter. A horizontal vessel would not typically be used in a lightly loaded gas-liquid separation application. Good flow distribution to the mist extractor is still required.

In more heavily liquid loaded separation applications, a vertical or horizontal separator configuration may be chosen depending on the specific conditions. In either case, some "pre-conditioning" of the gas phase, specifically reduction of the gas entrainment loading, may be required ahead of the final mist extraction element.

Vertical Separators

Historically, the gas handling capacity of conventional vertical separators that employ mist extractors has normally been calculated from the Souders and Brown equation, Eq 7-8, using "experience-based" K factors. Typical K values for vertical separators from API 12J[7] are presented in Fig. 7-18.

In qualitative terms, the ranges of K given above may be taken to reflect difficulty of the separation conditions, i.e. from non-ideal/difficult to ideal/easy. As indicated in Fig. 7-18, K is also a function of vessel height. This reflects the fact that a certain minimum distance is required to establish a relatively uniform velocity profile before the gas reaches the mist extractor. Theoretically, it is not simply the vessel height that is important with respect to velocity profile, but the vertical height between the inlet device and the mist extractor. As gas handling capacity is based on an allowable limit for liquid carryover into the separated gas stream, and the final liquid removal element is the mist extractor, the mist extractor has a significant influence on the K value used for separator sizing.

The vertical height of the vessel is also influenced by the liquid handling requirements and general vessel layout criteria as indicated in Fig. 7-8. Typically, the liquid phase will occupy the lower third of the vessel height.

A design that optimizes the inlet feed flow condition and utilizes an efficient inlet device, may provide enough feed gas

FIG. 7-18

Typical Values of K for Vertical Separators

Height, feet	K, ft/sec
5	0.12 – 0.24
10 or taller	0.18 – 0.35

* assumes vessel is equipped with a wire-mesh mist extractor

pre-conditioning to allow the vessel diameter to be sized equivalent to the mist extractor. However, traditionally the method typically used has been to "oversize" the gas gravity section, i.e. vessel diameter, relative to the mist extractor. This has generally been done in two ways:

- Derate the mist extractor K factor and use this reduced K value in Eq 7-8 to determine the vessel diameter. Guidelines as to determination of the appropriate deration factor are not well defined. A relatively low liquid loading application with steady flow, a low inlet velocity and a good inlet device should require minimal deration of the extractor K factor, i.e. deration factor approximately equal to 1. On the other hand, an application with significant liquid volumes, unsteady flow, high velocity inlet and a simple diverter plate inlet device may require a deration factor of 0.5. Normally, it would be more economic to improve the inlet flow condition/device than to significantly oversize the vessel relative to the mist extractor requirements.
- Select a separable droplet size and size for the vessel diameter using Eq 7-1. A droplet size of 150 microns has been typically specified. This may be overly conservative for vane pack and cyclonic mist extractors, which generally have higher gas and liquid capacities than mesh pads.

Comparison of Eq 7-8 & Eq 7-1, indicates that

$$K = \sqrt{\frac{4_g D_P}{3C'}} \qquad \textbf{Eq 7-11}$$

This shows the approximate equivalence of the empirical K and the more theoretical droplet separation sizing methods. However, the value of K in Eq 7-8 as used in practice depends on other factors besides droplet size, drag coefficient, and liquid entrainment loading, including: type of internals, unsteady flow, surface tension, liquid viscosity, foaming, gas velocity profile uniformity, degree of separation required, etc. Additional duration may be required to account for these factors.

Horizontal Separators

Eq 7-8 can also be used for calculating the gas capacity of horizontal separators. However, some modifications are required to reflect the fact that in the gas gravity separation section of a horizontal separator, the liquid droplets are falling perpendicular to the gas flow rather than in direct opposition as occurs in a vertical separator. This makes it easier to separate droplets in a horizontal vessel. Partially offsetting this advantage is the fact that in a horizontal separator, the liquid gravity separation section is occupying part of the vessel cross section, leaving reduced area for gas flow.

In calculating the gas capacity of horizontal separators, the cross-sectional area of that portion of the vessel occupied by liquid (at maximum level) is subtracted from the total vessel cross-sectional area. Typical horizontal separator designs will have the normal liquid level at the half-full point. Values of K for horizontal separators from API 12J are given in Fig. 7-19.

There is some disagreement as to how K should vary with separator length. The API 12J recommendation is shown in Fig. 7-19. Many separators are greater than 10 feet in length, with some reaching 50 feet or more. The relationship shown in Fig. 7-19 for adjusting for length will give K factors greater than 1 ft/sec for large separators. These higher values of K for large (long) horizontal separators are generally considered to be overly optimistic. In practice, K = 0.5 ft/sec is normally used as an upper limit for horizontal separators equipped with wire-mesh mist extractors. Separators equipped with vane-type or cyclonic mist extractors may utilize higher K values than those for mesh pads.

The same general principles as discussed for vertical separators apply for horizontal separators with mist extractors in

FIG. 7-19

Values of K for Horizontal Separators

Length, ft	K, ft/sec
10	0.40 – 0.50
Other	$K_{10}\left(\frac{L}{10}\right)^{0.56}$

* assumes vessel is equipped with a wire-mesh mist extractor

high liquid loading applications. For a horizontal separator, mesh pad and cyclonic type mist extractors will normally be installed horizontally with vertical upflow, while vane pack may be installed horizontally, vertically, or sometimes in a vee-pattern. Additionally, in a horizontal separator, the liquid droplets are settling perpendicular to the gas flow which makes separation easier. For these reasons, the approach of derating the mist extractor K to calculate the cross-sectional area of the gas gravity section is not as straightforward as for a vertical vessel. Typically the required cross-sectional area of the gas gravity section of a horizontal separator is sized based on droplet settling theory. The procedure is similar to that discussed previously for separators without mist extractors. For vessels with mesh pad mist extractors a typical droplet size for design is 150 microns. For separators equipped with vane-type or cyclonic mist extractors, a larger drop size may be appropriate, which may allow for a smaller vessel. The vessel manufacturer should be consulted.

In calculating the gas capacity of horizontal separators, the cross-sectional area of that portion of the vessel occupied by liquid (at maximum level) is subtracted from the total vessel cross-sectional area

LIQUID HANDLING

The design criterion for separator liquid handling capacity is typically based on the following two main considerations:

- Liquid degassing requirements.
- Process control/stability requirements.

Generally, one or the other of these factors will dictate. Liquid capacity is typically specified in terms of residence time, which must be translated into vessel layout requirements for dimensioning purposes. Residence time establishes the separator volume required for the liquid as shown in Eq 7-12:

$$U = \frac{W\,(t)}{1440} \qquad \textbf{Eq 7-12}$$

Typical residence times are shown in Figures 7-20 and 7-21.

Note that except for the Natural gas – condensate application, the residence times specified in Fig. 7-20 are primarily based on process control stability/operability.

These values are primarily intended to reflect liquid degassing requirements. In practice, process control stability and operability requirements will often override the degassing requirements.

Vessel layout recommendations, including liquid handling requirements, are given in Fig. 7-8 and 7-9 for vertical and horizontal separators, respectively.

The retention time requirements given in Figures 7-20 and 7-21 are not specific to vessel orientation. However, the liquid degassing process actually involves the separation of gas bubbles from the liquid phase, which under ideal conditions can be described by the gravity settling equation, Eq 7-1. Similar to liquid droplet settling out of the gas phase, it is easier for a gas bubble to rise perpendicularly through the moving liquid in a horizontal separator than directly against the downflowing liquid in a vertical vessel. Theoretically, for equal liquid residence times, the horizontal separator should be slightly more efficient at degassing. However, this has not typically been an issue in practice. If it is deemed necessary to calculate vessel liquid handling requirements for a degassing constraint according to gravity settling theory, a gas bubble size of 150–200 microns has been suggested by several sources.

FIG. 7-20

Typical Retention Times for Gas/Liquid Separator

Application	Retention Time, minutes
Natural Gas – Condensate separation	2 – 4
Fractionator Feed Tank	10 – 15
Reflux Accumulator	5 – 10
Fractionation Column Sump	2
Amine Flash Tank	5 – 10
Refrigeration Surge Tank	5
Refrigeration Economizer	3
Heat Medium Oil Surge Tank	5 – 10

FIG. 7-21

API 12J Retention Times for Gas-Oil Separators

Oil Gravity	Liquid Retention Time, min
> 35	1
20 – 35	1 to 2
10 – 20	2 to 4

Three-Phase and Liquid-Liquid Separation

The gas handling requirements for three-phase separation are dealt with in a similar manner as discussed for two-phase separation. Traditionally, sizing for liquid-liquid separation has involved specification of liquid residence times.

Fig. 7-22 provides suggested residence times for various liquid-liquid separation applications. These figures generally assume equal residence times for both the light and heavy liquid phases.

While the residence time approach for liquid-liquid separation equipment design has been widely used in industry for years, it does have some limitations.

- the typical approach of assuming equal residence times for both liquid phases may not be optimum, e.g. It is generally much easier to separate oil droplets from water than vice-versa. Settling theory (Eq 7-1) explains this as being due to the lower viscosity of water compared to oil.
- Residence times do not take into account vessel geometry, i.e. 3 minutes residence time in the bottom of a tall, small diameter vertical vessel will not achieve the same separation performance as 3 minutes in a horizontal separator, again according to droplet settling theory.
- The residence time method does not provide any direct indication as to the quality of the separated liquids, e.g. amount of water in the hydrocarbon or the amount of hydrocarbon in the water. Droplet settling theory can not do this either in most cases, but there is some empirical data available which allows for approximate predictions in specific applications.

FIG. 7-22

Typical Retention Times for Liquid-Liquid Separation

Type of Separation	Retention Time, minutes
Hydrocarbon/Water Separators[7] Above 35° API hydrocarbon Below 35° API hydrocarbon 100°F and above 80°F 60°F	 3 – 5 5 – 10 10 – 20 20 – 30
Ethylene Glycol/Hydrocarbon[8] Separators (Cold Separators)	20 – 60
Amine/Hydrocarbon Separators[9]	20 – 30
Coalescer, Hydrocarbon/Water Separators[9] 100°F and above 80°F 60°F	 5 – 10 10 – 20 20 – 30
Caustic/Propane	30 – 45
Caustic/Heavy Gasoline	30 – 90

Removal of very small droplets may require the use of specialized internals or the application of electrostatic fields to promote coalescence.

Liquid-liquid separation may be divided into two broad categories of operation. The first is defined as "gravity separation," where the two immiscible liquid phases separate within the vessel by the differences in density of the liquids. Sufficient retention time must be provided in the separator to allow for the gravity separation to take place. The second category is defined as "coalescing separation." This is where small particles of one liquid phase must be separated or removed from a large quantity of another liquid phase. Different types of internal construction of separators much be provided for each type of liquid-liquid separators. The following principles of design for liquid-liquid separation apply equally for horizontal or vertical separators. Horizontal vessels have some advantage over verticals for liquid-liquid separation, due to the larger interface area available in the horizontal style, and the shorter distance particles must travel to coalesce.

There are two factors that may prevent two liquid phases from separating due to differences in specific gravity:

- If droplet particles are so small that they may be suspended by Brownian movement. This is defined as a random motion that is greater than directed movement due to gravity for particles less than 0.1 micron in diameter.
- The droplets may carry electric charges due to dissolved ions. These charges can cause the droplets to repel each other rather than coalesce into larger particles and settle by gravity.

Effects due to Brownian movement are usually small and proper chemical treatment will usually neutralize any electric charges. Then settling becomes a function of gravity and viscosity in accordance with Stoke's Law. The settling velocity of spheres through a fluid is directly proportional to the difference in densities of the sphere and the fluid, and inversely proportional to the viscosity of the fluid and the square of the diameter of the sphere (droplet), as noted in Eq 7-3. The liquid-liquid separation capacity of separators may be determined from Equations 7-13 and 7-14, which were derived from Equation 7-3.[9] Values of C* are found in Fig. 7-23.

Vertical vessels:

$$W_{cl} = C^{*}\left(\frac{S_{hl} - S_{ll}}{\mu}\right)(0.785)\, D_v^2 \qquad \textbf{Eq 7-13}$$

Horizontal vessel:

$$W_{cl} = C^{*}\left(\frac{S_{hl} - S_{ll}}{\mu}\right) L_l\, H_l \qquad \textbf{Eq 7-14}$$

Since the droplet size of one liquid phase dispersed in another is usually unknown, it is simpler to size liquid-liquid separation based on retention time of the liquid within the separator vessel. For gravity separation of two liquid phases, a large retention or quiet settling section is required in the vessel. Good separation requires sufficient time to obtain an equilibrium condition between the two liquid phases at the temperature and pressure of separation. The liquid capacity of a separator or the settling volume required can be determined from Eq 7-12 using the retention time given in Fig. 7-22.

The following example shows how to size a liquid-liquid separator.

FIG. 7-23

Values of C* Used in Equations 7-13 and 7-14

Emulsion Characteristic	Droplet Diameter, microns	Constant,[10] C*
Free Liquids	200	1,100
Loose Emulsion	150	619
Moderate Emulsion	100	275
Tight Emulsion	60	99

Example 7-3—Determine the size of a vertical separator to handle 600 bpd of 55° API condensate and 50 bpd of produced water. Assume the water particle size is 200 microns. Other operating conditions are as follows:

Operating temperature =	80°F
Operating pressure=	1,000 psig
Water specific gravity =	1.01
Condensate viscosity =	0.55 cp @ 80°F
Condensate specific gravity for 55° API =	0.76

From Eq 7-13, $W_{cl} = C^*[(S_{hl} - S_{ll}) / \ ] \times 0.785 \times D_v^2$

From Fig. 7-23 for free liquids with water particle diameter = 200 microns, C* = 1,100

600 bbl/day = $1{,}100 \times [1.01 - 0.76) / 0.55] \times 0.785 \times D_v^2$

$D_v^2 = 660 / 392.5 = 1.53 \text{ ft}^2$

$D_v = 1.24$ feet

Using a manufacturer's standard size vessel might result in specifying a 20-inch OD separator.

Using the alternate method of design based on retention time as shown in Equation 7-12 should give:

$V_1 = ql(t) / 1440$

From Fig. 7-22, use 3 minutes retention time

$V_1 = 650 \times 3 / 1440 = 1.35$ bbl

$V_1 = 1.35 \times 42 = 56.7$ gallons

Assuming a 20-inch diameter and 1,480 psig working pressure, a vessel would be made from a 1.031-inch wall seamless pipe which holds 13.1 gal/ft. The small volume held in the bottom head can be discounted in this size vessel. The shell height required for the retention volume required would be:

Shell height = V_1 / vol/ft = 56.7 / 13.1 = 4.3 feet

This would require a 20 inch OD x 10 foot separator to give sufficient surge room above the liquid settling section for any vapor-liquid separation.

Another parameter that should be checked when separating amine or glycol from liquid hydrocarbons is the interface area between the two liquid layers. This area should be sized so the glycol or amine flow across the interface does not exceed approximately 2,000 gal/day/ft².

The above example indicates that a relatively small separator would be required for liquid-liquid separation. It should be remembered that the separator must also be designed for the vapor capacity to be handled. In most cases of high vapor-liquid loadings that are encountered in gas processing equipment design, the vapor capacity required will dictate a much larger vessel than would be required for the liquid load only. The properly designed vessel has to be able to handle both the vapor and liquid loads. Therefore, one or the other will control the size of the vessel used.

FILTER SEPARATORS AND COALESCING FILTERS

General

There are two main types of filtration equipment used in gas-liquid separation service in the gas processing industry: the filter separator or "filter sep" and the coalescing filter. Both equipment types are of proprietary design, and the manufacturer should be contacted for detailed selection and sizing.

Filter Separator

Filter separators are available in horizontal and vertical orientations, with horizontal the most common. Fig. 7-24 shows a horizontal filter separator. This type of separator is often used for solids and liquid removal in relatively low liquid loading applications. A filter separator is a two-stage device. Gas enters the inlet nozzle and passes through the filter section, where solid particles are filtered from the gas stream and liquid particles are coalesced into larger droplets. Any free liquids are also removed in the first section. The coalesced droplets pass through the filter riser tubes and are carried into the second section of the separator, where a final mist extraction element removes these droplets from the gas stream. Flow through the filter elements is from an outside-to-inside direction. A pressure drop of 1-2 psi is normal in a clean filter separator. If solids are present, it will normally be necessary to replace the filter elements at regular intervals. A 10 psi pressure drop criteria is often used for filter changeout. Removal of the filters is achieved via a quick-opening closure.

The second stage of a filter separator contains a mist extraction device. As for a conventional separator this may be a mesh pad, vane pack or multicyclone bundle. The same issues regarding mist extractor selection criteria, sizing, etc. apply as discussed previously. Mesh pads and vane pack are most commonly utilized.

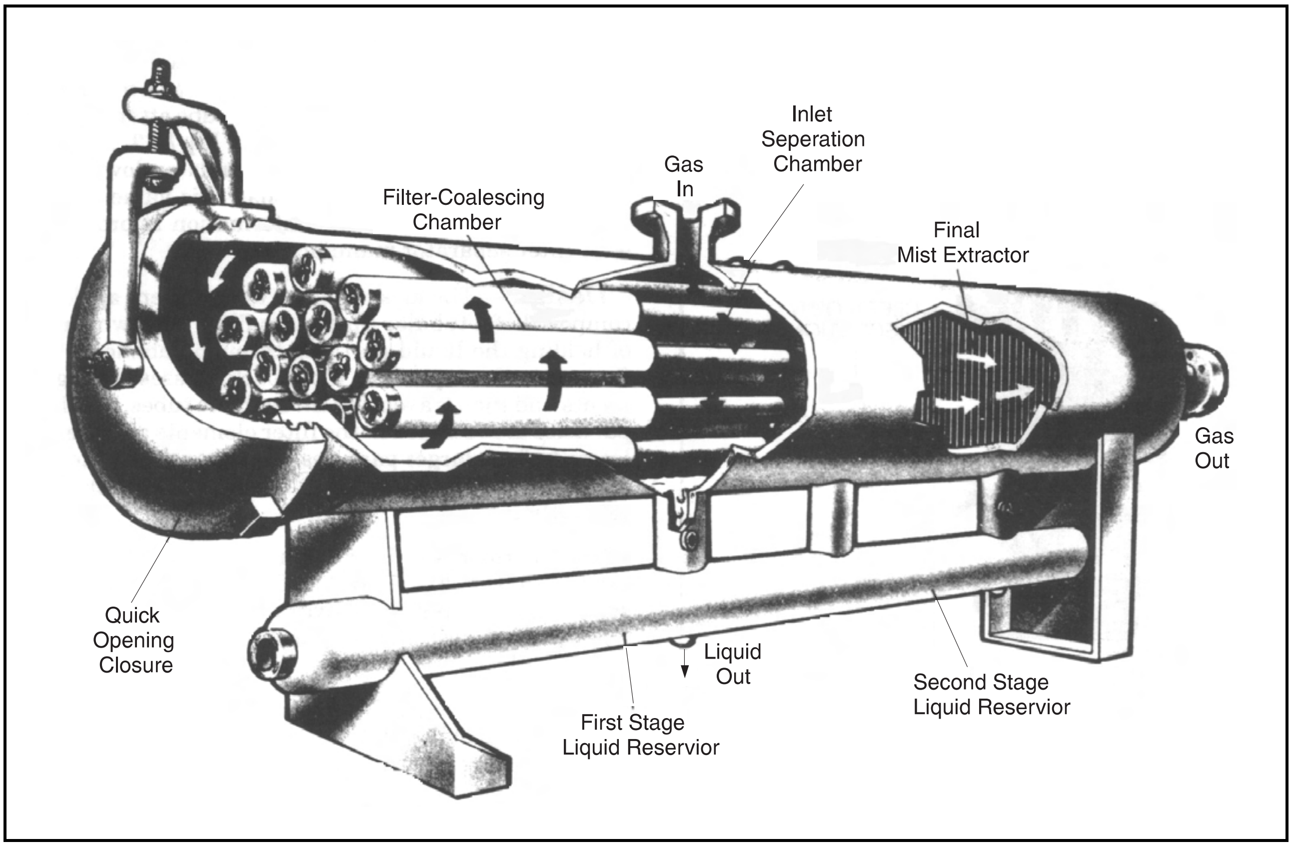
The design of filter separators is proprietary and a manufacturer should be consulted for specific sizing and recommendations.

Coalescing Filter

The coalescing filter is a more recent (early 1980s) piece of separation equipment designed for "gas polishing' service. Fig.

FIG. 7-24

Horizontal Filter-Separator



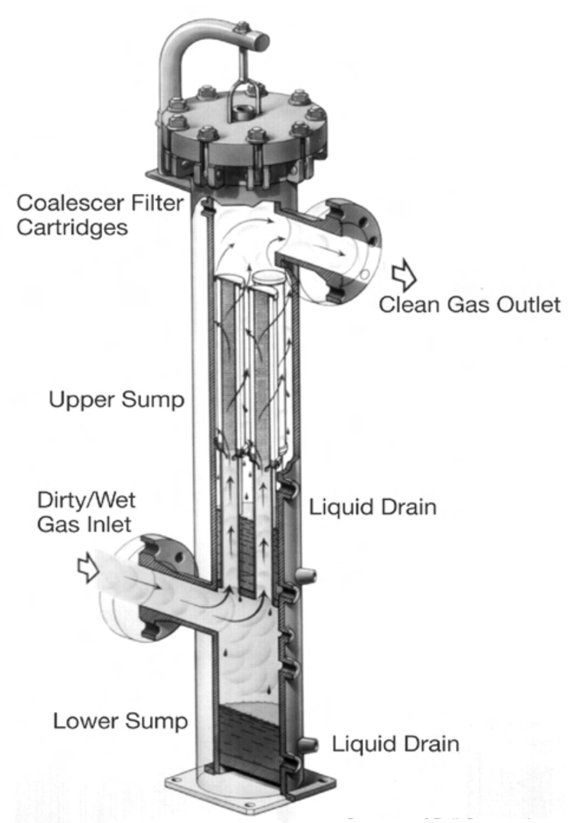
7-25 illustrates a typical coalescing filter. A coalescing filter is typically intended to remove fine liquid aerosols/mist from gas streams where entrained liquid loads are low. A typical filtration rating for coalescing filter elements is 0.3 microns absolute. This means that solid spherical particles larger than 0.3 micron are unable to pass through the filter element. Aerosol liquid coalescing performance is not as easily quantifiable and is subject to several factors. A coalescing filters are normally used to protect equipment/processes that are particularly sensitive to contamination. Two of the most common applications are upstream of mole sieve systems and amine contactors. The unit is typically intended to remove carryover from an upstream conventional separator and/or any liquids that may condense from the gas phase due to temperature or pressure reduction. Coalescing filters can experience short filter element life if the gas contains appreciable amounts of solids, e.g. corrosion products.

PARTICULATE REMOVAL — FILTRATION

Filtration, in the strictest sense, applies only to the separation of solid particles from a fluid by passage through a porous medium. However, in the gas processing industry, filtration

FIG. 7-25

Typical Coalescing Filter



Courtesy of Pall Corporation

commonly refers to the removal of solids and liquids from a gas stream.

The most commonly used pressure filter in the gas processing industry is a cartridge filter. Cartridge filters are constructed of either a self-supporting filter medium or a filter medium attached to a support core. Depending on the application, a number of filter elements are fitted into a filter vessel. Flow is normally from the outside, through the filter element, and out through a common discharge. When pores in the filter medium become blocked, or as the filter cake is developed, the higher differential pressure across the elements will indicate that the filter elements much be cleaned or replaced.

Cartridge filters are commonly used to remove solid contaminants from amines, glycols, and lube oils. Other uses include the filtration of solids and liquids from hydrocarbon vapors and the filtration of solids from air intakes of engines and tubing combustion chambers.

Two other types of pressure filters that also have applications in the gas processing industry include the edge and precoat filters. Edge filters consist of nested metallic discs enclosed in a pressure cylinder that are exposed to liquid flow. The spacing between metal discs determines the solids retention. Some edge filters feature a self-cleaning design in which the discs rotate against stationary cleaning blades. Applications for edge filters include lube oil and diesel fuel filtration as well as treating solvents.

Precoat filters find use in the gas processing industry; however, they are complicated and require considerable attention. Most frequent use is in larger amine plants where frequent replacement of cartridge elements is considerably more expensive than the additional attention required by precoat filters.

The precoat filter consists of a course filter medium over which a coating has been deposited. In many applications, the coating is one of the various grades of diatomaceous earth that is mixed in a slurry and deposited on the filter medium. During operation, additional coating material is often added continuously to the liquid feed. When the pressure drop across the filter reaches a specified maximum, the filter is taken offline and backwashed to remove the spent coating and accumulated solids. Applications for precoat filters include water treatment for water facilities as well as amine filtration to reduce foaming. Typical designs for amine plants use 1-2 gpm flow per square foot of filter surface area. Sizes range upward from 10-20% of the full stream rates.[11]

Filtration Equipment Removal Ratings[12]

The two main methods of specifying removal ratings for filters are 1) nominal rating, and 2) absolute rating. Nominal rating typically means that 90% (or sometimes 95%) by weight of the contaminants above a specified size (e.g. 10 μm) has been removed. The 2% (or potentially 5%) of the contaminant passing through the filter is not defined by the test. Therefore, it is possible to have particle much larger than the nominal size (e.g. 30 μm to 100 μm).

Absolute rating can be defined by one of two standards. The National Fluid Power Association's (NFPA's) standard of absolute rating states that the diameter of the largest hard spherical particle that will pass through a filter under specified test conditions is an indication of the largest opening in the filter. The Beta (β) Rating System determined by the Oklahoma State University, "OSU F-2 Filter Performance Test" determines the ratio of the number of particles of a given size in the influent divided by the number of particles of the same given size in the effluent. This results in the following equation for relating the β value to removal efficiency:

$$\% \text{ removal} = (\beta - 1) / \beta \times 100 \qquad \textbf{Eq 7-15}$$

Most "absolute" filters typically have a β of 10,000 (99.99% removal).

Special Applications – Slug Catcher Design[13]

Slug catcher design is a special application of gas-liquid separator design. Performing these calculations is a combination of pipeline multiphase hydraulics and separator sizing. There are two main types of slug catchers, vessel and pipe. Reference 13 provides design details and an example of slug catcher design.

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