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IACPE **No 19, Jalan Bilal Mahmood** **80100 Johor Bahru** **Malaysia**	**Separator Vessel Selection and Sizing** **CPE LEVEL TWO TRAINING MODULE**	

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INTRODUCTION

Scope

The process engineer should have some knowledge of the mechanical design of vessels. For example, the process engineer may have to make a preliminary design of vessels for a cost estimate. Reactors, fractionators, absorbers, heat exchangers, and some phase separators are classified as vessels. A vessel consists of a cylindrical shell and end caps, called heads. For safety, vessel design is governed by codes. An example is the ASME (American Society of Mechanical Engineers) Boiler and Pressure Vessel Code. Engineers who agreed on what is a safe procedure for designing vessels formulated this code.

Vessels in chemical processing service are of two kinds: those substantially without internals and those with internals. The main functions of the first kinds, called drums or tanks, are intermediate storage or surge of a process stream for a limited or extended period or to provide a phase separation by settling. Their sizes may be established by definite process calculations or by general rules based on experience. The second category comprises the equipment such as heat exchangers, reactors, mixers, fractionators, and other equipment whose housing can be designed and constructed largely independently of whatever internals are necessary.

Separator vessels are commonly used in petrochemical plants to separate the vapor-liquid mixtures, and three phase mixtures. The performance is determined by the characteristics of the fluid being separated, the size of the vessel and the type of internals installed. This guideline will provide a review of the important parameters in separator vessel sizing and selection.

Heterogeneous Separation

Heterogeneous mixtures consist of two or more parts (phases), which have different compositions. These mixtures have visible boundaries of separation between the different constituents which can be seen with the naked eye and consist of substances that do not react chemically. These substances can be elements or compounds. Components of a mixture can be separated using one or more appropriate techniques.

The separation can be done physically by exploiting the differences in density between the phases. The phase separations likely to be carried out are [1]:

- Gas–liquid (or vapor–liquid)
- Gas–solid (or vapor–solid)
- Liquid–liquid (immiscible)
- Liquid–solid
- Solid–solid

The principal methods for the separation of heterogeneous mixtures could be classified as:

1. Settling and sedimentation

   Sedimentation or settling can be used to separate any particle from any fluid, whether it is a liquid from a gas, a solid from a liquid, or a liquid from a liquid (with different densities). In settling processes, particles with higher density are separated from a fluid by gravitational forces acting on the particles.

   The separation of suspended solid particles from a liquid by gravity settling into a clear fluid and a slurry of higher solids content is called sedimentation.

2. Inertial and centrifugal separation

   This method is similar to sedimentation, but some forces are added in order to get a better separation. Inertial separation is done by giving the particles downward momentum, in addition to the gravitational force. In a centrifugal device, the centrifugal force is generated to increase the force acting on the particles. Particles that do not settle readily in gravity settlers often can be separated from fluids by centrifugal force.

   Centrifugal separation results a much shorter period of time than could be accomplished solely by gravity. It has mainly been used to separate fluids in static state, i.e. specific volumes, which needed to be separated.

3. Electrostatic precipitation

   It is generally used to separate particulate matter that is easily ionized from a gas stream by using an electric charge. The principal actions are the charging of particles and forcing them to the collector plates. The amount of charged particulate matter affects the electrical operating point of the electrostatic precipitator.

4. Filtration

Filtration is commonly the mechanical or physical operation which is used for the separation of solids from fluids (liquids or gases) by interposing a medium (a permeable fabric or porous bed of materials) through which only the fluid can pass. The solid can be retained on the surface of the filter medium, which is *cake filtration*, or captured within the filter medium, which is *depth filtration*.

5. Scrubbing

This method is commonly used to separate gas-solid mixtures. Very high particles collection efficiencies are possible with venturi scrubbers. The main problem with venturi scrubbers is the high pressure loss across the device.

6. Flotation

Flotation is a gravity separation process that exploits the differences in the surface properties of particles. The separation process is based on the use of very fine gas bubbles that attach themselves to the solid particles in suspension to make them buoyant and drive them toward the free surface of the liquid.

Flotation is especially useful to separate very small particles or light particles with low settling velocities. A number of chemicals can be added to the flotation medium to meet the various requirements of the flotation process.

Flotation requires the generation of small bubbles which can be produced by:

a. *dispersion*, in which the bubbles are injected directly by some form of sparging system

b. *dissolution* in the liquid under pressure and then liberation in the flotation cell by reducing the pressure

c. *electrolysis* of the liquid

7. Drying

   Drying is the removal of water moisture or moisture from another substance, by a whole range of processes, including distillation, evaporation and even physical separations such as centrifuges.

Separator Vessel

Generally, there are two types of vessel in chemical processing service: those substantially without internals and those with internals. The first types are commonly used as an intermediate storage or surge of a process stream for a limited or extended period, or to provide a phase separation by settling. The second category includes the shells of equipment such as heat exchangers, reactors, mixers, fractionators, and other equipment whose housing can be designed and constructed largely independently of whatever internals are necessary.

Separator vessel thus simply means as a vessel or tank without internals to provide a phase separation. This separator vessel furthermore can be classified into several categories based on their function. However, generally the classification in this guideline as pictured on Figure 1 below.

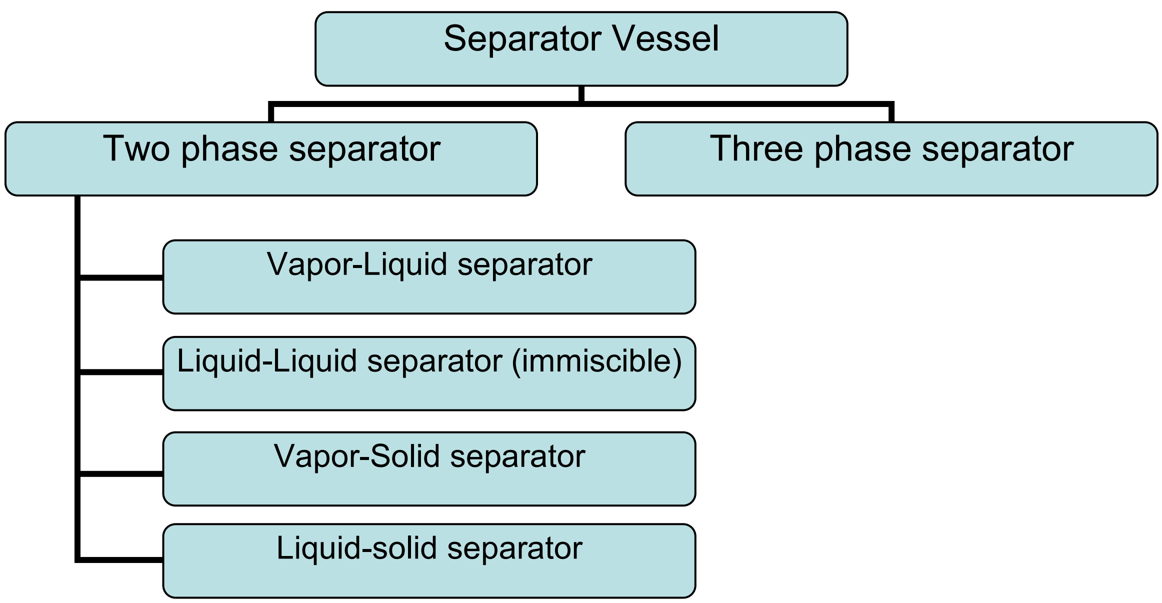

Figure 1. General types of separator vessel

Solid-solid separator is not included here since the separation process mostly takes part on a sieve, not in a vessel as the other phases separation. Separator vessels usually contain as follow:

1. Primary section.
2. Secondary section (gravity settling).
3. Coalescing section.
4. Sump or liquid collecting section.

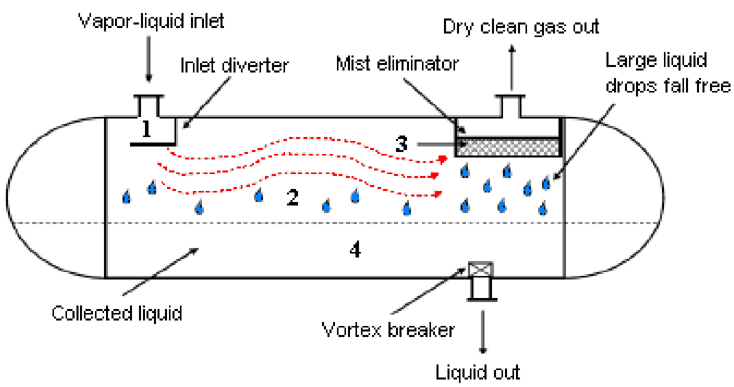

Figure 2. Major components of horizontal separator

Geometrically, all process vessels might be horizontal, vertical, or spherical. The horizontal and vertical types are commonly used, while the spherical separators are occasionally used for high pressure service where compact size is desired and liquid volumes are small.

Two Phase Separator

<u>Vapor-Liquid Separator</u>

The reasons for using vapor-liquid separators are to recover valuable products, improve product purity, reduce emissions, and protect downstream equipment. Gas-liquid separators are used after flashing a hot liquid across a valve. In this case the separator is called a flash drum.

A vapor-liquid separator is a vessel into which a liquid and vapor mixture is enters the separator about midway where a splash plate deflects the stream downward, wherein the liquid is separated by gravity, falls to the bottom of the vessel, and is withdrawn. The vapor travels upward at a design velocity which minimizes the entrainment of any liquid droplets in the vapor as it exits the top of the vessel.

Vapor-liquid separators are very widely used in a great many industries and applications such as:

- Oil refineries
- Natural gas processing plants
- Petrochemical and chemical plants
- Refrigeration systems
- Air conditioning
- Compressor systems for air or gases
- Gas pipelines
- Steam condensate flash drums

A vapor-liquid separator might consist simply of an empty vessel, which causes the fluid velocities in the entering pipe to be reduced by enlarging the cross-sectional area of flow. 95 % separation of liquid from vapor is normal. If greater than 95 % liquid separation is required, then use a wire-mesh mist eliminator, installed near the vapor outlet. Very small drops are separated by impaction using a wiremesh pad located at the top of the separator.

Usually, however the separator includes internal parts, to promote separation of the process, such as [2]:

1. Primary separation section (entrance): for separating the bulk of the liquid from the gas. It is desirable to remove the liquid slugs and large droplets of liquid quickly from the gas stream, and to remove gas from the liquid.

2. Secondary separation section: for removing smaller particles of liquid by gravity settling depends to a large extent on the decreased gas velocity and reducing the turbulence of gas.

3. Liquid separation section (or the liquid accumulation section): for removing gas bubbles which may be occluded with the liquid, and for sufficient storage of the liquid to handle the slugs of liquid anticipated in routine operation.

4. Mist extractor or eliminator section: for removing from the gas entrained drops of liquid, which did not separate in the secondary separation section. Mist extractor might be used to decrease the amount of entrained liquid in the gas and to reduce diameter of the vessel.

5. Vortex breaker (in the bottom of the vessel): prevents potential pump suction problems if a pump is used to remove collected liquids.

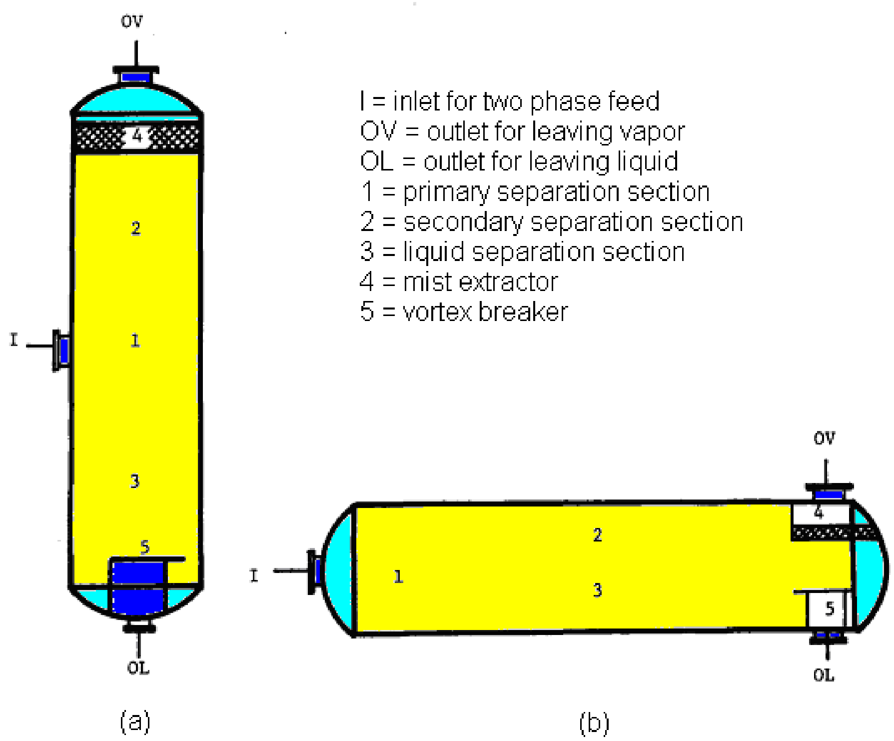

Figure 3. Internal parts of (a) vertical separator and (b) horizontal vapor-liquid separator

The major objective in sizing a gas-liquid separator is to lower the gas velocity sufficiently to reduce the number of liquid droplets from being entrained in the gas. Thus, the separator diameter must be determined. The separator is also designed as an accumulator for the liquid portion of the stream. Thus, the liquid height is calculated by allowing sufficient surge time to dampen flow-rate variations of the liquid stream, as was discussed earlier for accumulators. Presumably, this liquid height will also be sufficient to allow vapor bubbles to rise to the top of the liquid before being trapped in the outlet stream at the bottom of the vessel. This can be achieved by reducing the outlet liquid velocity by increasing the diameter of the outlet nozzle.

Separators may be designed with or without mist eliminator pads and may also have inlet diverters. Some separators may also have proprietary impingement or settling internals.

An inlet diverter produces the initial gross separation of liquid and vapor, as the sudden change in momentum occurs when the fluid enters the separator and hit it. Commonly, the inlet diverter contains a downcomer that directs the liquid flow below the oil or water interface. The inlet diverter assures that little gas is carried with the liquid. Some functions of inlet devices are:

- Reduces momentum of inlet stream
- Provides primary (bulk) separation of gas and liquid
- Enhances flow distribution of gas and liquid phases
- Prevents droplet shattering and re-entrainment of bulk liquid phases
- Stable liquid level control and reduced foaming

The impingement or settling internal might be added to optimized separation process. As the descriptive name suggests, the impingement separator allows the particle to be removed to strike some type of surfaces. There are basically three construction types for impingement separator: wire mesh, plates (curved, flat, or special shaped), and packed impingement beds.

The vapor-liquid separators which are generally used in industries might be classified into followings [3]:

1. Gravity separators

   The separation process in this gravity separator occurs by settling and sedimentation and depends on gravitational force. Liquid droplets or solid particles will settle out of a gas phase if the gravitational force acting on the droplet or particle is greater than the drag force of the gas flowing around the droplet or particle. The same phenomenon happens for solid particles in liquid phase and immiscible sphere of a liquid immersed in another liquid.

Gravitational forces control separation; the lower the gas velocity and the larger the vessel size, the more efficient the liquid/gas separation. Because of the large vessel size required to achieve settling, gravity separators are rarely designed to remove droplets smaller than 300 microns.

Gravity separators are not recommended as the soul source of removal if high separation efficiency is required.

Gravity separators are sometimes also called *scrubbers* when the ratio of gas rate to liquid rate is very high. These vessels have a small liquid collection section and are recommended only for the following items:

a. Secondary separation to remove carryover fluids from process equipment such as absorbers and liquid dust scrubbers.
b. Gas line separation downstream from a separator and where flow lines are not long.
c. Miscellaneous separation where the gas-liquid ratio is extremely high

2. Centrifugal vapor-liquid separators

Utilize centrifugal action for the separation of materials of different densities and phases, might be built in stationary and rotary types. In centrifugal separators, centrifugal forces act on droplets at forces several times greater than gravity as it enters a cylindrical separator. Generally, centrifugal separators are used for removing droplets greater than 100 μm in diameter, and a properly sized centrifugal separator can have a reasonable removal efficiency of droplet sizes as low as 10 μm.

Centrifugal separators generally might be divided into three types: stationary vane separator, cyclone separator, and inertial centrifugal separator. Cyclones and knock-out drums are recommended for waxy or coking materials. The efficiency of each of three types can be estimated using Table 1 below.

Table 1. Efficiency of centrifugal separator

Types	Efficiency Range
High velocity stationary vanes	99% or higher of entering liquid. Residual entrainment 1 mg/kg (ppm) or less.
Cyclone separator	70-85% for 10 micrometers, 99% for 40 micrometers, and larger. For high entrainment, efficiency increases with concentration.
Rotary	98% for agglomerating particles

3. Vapor-liquid filter separators

   They are used in separation of liquid and solid particles from gas stream. Gas filter separator has a higher separation efficiency than the centrifugal separator, but it uses filter elements which must periodically be replaced. Typical applications of gas filter separators are as follows:

   - Compressor stations to protect compressors from free liquid and prevent cylinder wear from solids.
   - Metering and pressure reduction stations at city gates: to remove liquid hydrocarbons, water, sand and pipe scale.
   - Protection of desiccant beds and collection of dust carry-over from beds.
   - Gas storage systems: to prevent injection or withdrawal of solids, dust, and small amounts of liquids.
   - Fuel lines to power plants and engines.

<u>Liquid-Liquid Separator</u> [4]

Vessels for the separation of two immiscible liquids usually are made horizontal and operate full, although some low rate operations are handled conveniently in vertical vessels with an overflow weir for the lighter phase. The latter mode also is used for particularly large flows at near atmospheric pressures. With the usual L/D ratio of three or more, the travel distance of droplets to the separated phase is appreciably shorter in horizontal vessels

Separating liquid-liquid dispersions can be difficult depending on the physical properties of the two liquid phases. The specific gravity, viscosity and interfacial tension (IFT) of the two liquid phases are important parameters in determining how easy two liquids can be separated.

Liquid-liquid separator might be divided into two broad categories based on their 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.

Differences in densities of the two liquids cause droplets to rise or fall by their buoyancy. The greater the difference in densities, the easier the separation becomes. Rising (or falling) droplets are slowed by frictional forces from viscous effects of the opposing liquid. Sufficient retention time must also be provided in the separator to allow for the gravity separation to take place.

Since the rise or fall of liquid droplets is interfered with by lateral flow of the liquid, the diameter of the drum should be made large enough to minimize this adverse effect. A rule based on the Reynolds number of the phase through which the movement of the liquid drops occurs is proposed by Hooper and Jacobs (1979). Liquid-liquid separation is hindered by turbulence. The separator diameter is calculated to minimize turbulence. Increasing the separator diameter reduces the Reynolds number and therefore turbulence.

Reynolds number	Effect
Less than 5000	little problem
5000 - 20,000	some hindrance
20.000 - 50.000	major problem may exist
Above 50,000	expect poor separation

Figure 4 shows a design for a gravity settler. After the two-phase mixture enters the decanter at the feed nozzle, the liquid jet must be diffused to prevent mixing of the two phases and promote settling of the dispersed phase. One way to accomplish this is to insert two closely spaced, perforated parallel plates across the jet. The first plate drops the pressure of the jet, and the second plate decreases its velocity.

After flowing past the plates, the liquid-liquid mixture flows down the length of the decanter. Either the light or heavy phase could be dispersed, depending on the properties of both phases. The dispersed-phase drops will either move downward or upward toward the interface, depending on the specific gravity of the two liquids. Then, at the interface, drops will accumulate before coalescing with one of the phases. To prevent entraining either the light or heavy phase in the outlet streams, the liquid velocity in both outlet nozzles should be low. the liquid velocity in each outlet nozzle should not be any more than 10 times the average velocity of each phase in the decanter. This rule allows sizing the outlet nozzles. Even though settling and coalescing of drops occur simultaneously, it will be assumed that first the drops flow to the interface, and then the drops coalesce with the appropriate phase

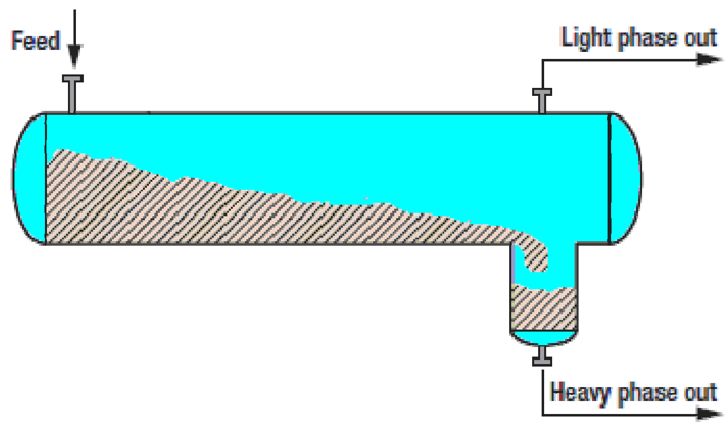

Figure 4. Typical arrangement of gravity settler

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. Liquid-Liquid coalescers are used to accelerate the merging of many droplets to form a lesser number of droplets, but with a greater diameter. Settling of the larger droplets downstream of the coalescer element then requires considerably less residence time. There are three-step methods of coalescing separation: collection of individual droplets; combining of several small droplets into larger ones; and rise (or fall) of the enlarged droplets by gravity.

This application is common in the quench section, compression section and hot fractionation section. The coalescers might be designed vertically or horizontally. The vertical design is used to separate water from hydrocarbons when the interfacial tension is greater than 3 dyne/cm. In the horizontal configuration, a settling zone achieves separation by gravity. This configuration is used when the interfacial tension is less than 3 dyne/cm or for the separation of oil from the water phase.

Here is a picture of vertical and horizontal coalescer.

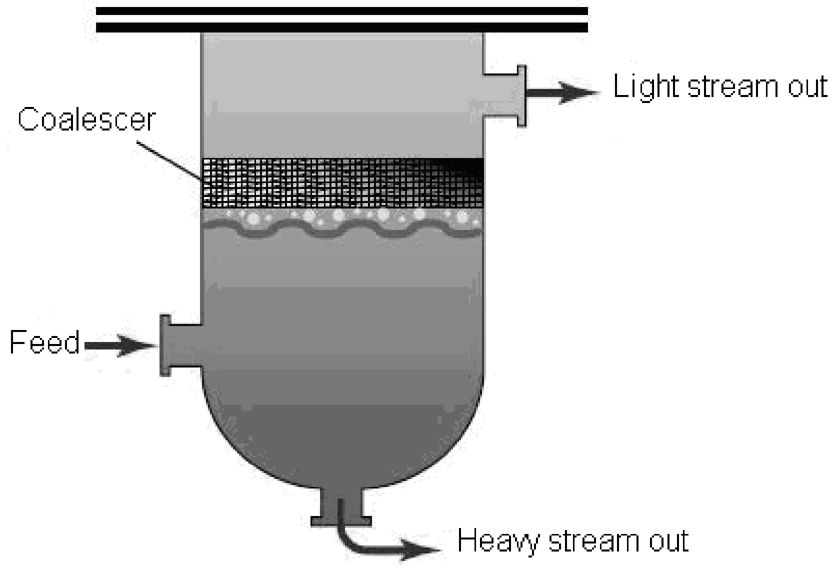

Figure 5. Vertical coalescer

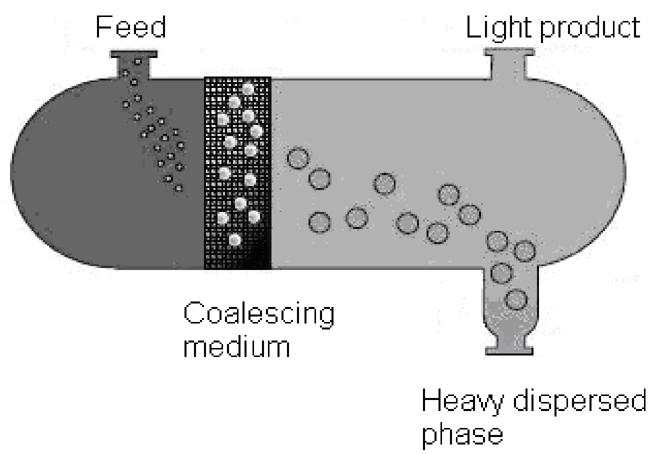

Figure 6. Horizontal coalesce

Different coalescing materials have been found suitable for different applications. Commercially, fiberglass seems to be the most popular medium due to its availability and low cost. Table 3 below shows different coalescing medias with their different surface properties, cost and fouling properties.

Table 2. Coalescing media

Media	Surface Characteristic	Porosity	Size	Fouling/Cost
Metal/plastic corrugated sheets	hydophilicity, oleophilicty	98-99%	9,5-25,4 mm Spacing/Crimps	Low/Low
Wire/plastic mesh	hydophilicity, oleophilicty	95-99%	0,05-0,279 mm	↓
Wire wool	hydophilicity	95-99%	0,05-0,279 mm	↓
Wire/polymer co-knits	oleophilicty	94-98%	21-35 µm	↓
Wire/fiberglass co-knits, glass mat	hydophilicity	92-96%	9-10 µm	High/High

In addition to the numerous coalescing media, Table 4 presents some coalescing media and their industrial applications with regard to the nature of emulsions they separate (emulsion source), flowrate and maximum droplet diameter.

Table 3. Coalescing media and their applications

Media	Source	Max. Droplet Diameter (µm)	Flow Range (gpm/ft^2)
Corrugated sheets	Separators with coarse emulsions and static mixers.	40-1000	15-75 (35-180 m^3/hr/m^2)
Wire mesh, wire wool	Extraction columns, Distillation tower feeds, impeller mixers.	20-300	7,5-45 (35-180 m^3/hr/m^2)
Co-knits of wire and polymer	Steam stripper bottoms, Caustic wash drums, High pressure drop mixing valves.	10-200	7,5-45 (35-180 m^3/hr/m^2)
Glass mat, co-knits of	Haze from cooling in	1-25	7,5-45

wire and fiberglass	bulk liquid phase, Surfactants giving, Emulsions with very low interfacial tension.	(35-180 $m^3/hr/m^2$)

Vapor-solid separator [5]

The most commonly encountered two phase vapor-solid separator in process industry is the decoking drum. A Decoking drum is provided for decoking of furnace tubes. Inlet stream to decoking drum may consist of steam, air and coke particles. Separation of coke particles from gases is essential to prevent coke particles being discharged to atmosphere or heater stack.

Separation of solid particles from vapor phase occurs under the influence of gravity. Forces which affect the rate of settling of solid particles are:

(i) gravity force

(ii) drag force due to relative motions

(iii) buoyancy force

Liquid-solid separator [6]

Solid-liquid separation processes are generally based on either one or a combination of gravity settling, filtration, and centrifugation principles. In gravity settling separation, solid particles will settle out of a liquid phase if the gravitational force acting on the droplet or particle is greater than the drag force of the fluid flowing around the particle (sedimentation).

Mechanical separation by filtration involves passage of most of the fluid through a porous barrier which retains most of the solid particulates or liquid contained in the mixture. Centrifugal separation occurs by changing the direction of two phase stream sharply, thus the greater momentum will not allow the particles of heavier phase to turn as rapidly as the lighter fluid and separation occurs.

Some commonly used liquid-solid separators are filters, centrifuges, hydrocyclones, and gravity settlers.

Three Phase Separator

Vapor-liquid-liquid separator [7]

Three phase separation is commonly applied when there are water, liquid hydrocarbon and hydrocarbon gases in the process stream. As with two phase design, three phase units can be either vertical or horizontal.

Vertical vessel is mainly applied when there is a large amount of vapor to be separated from a small amount of the light and heavy fluid (less than 10-20% by weight). Horizontal vessels are most efficient where large volumes of total fluid and large amounts of dissolved gas are present with the liquid. An example for vertical vessels is the compressor suction drums while good representative of horizontal vessel is the spent caustic deoiling drum.

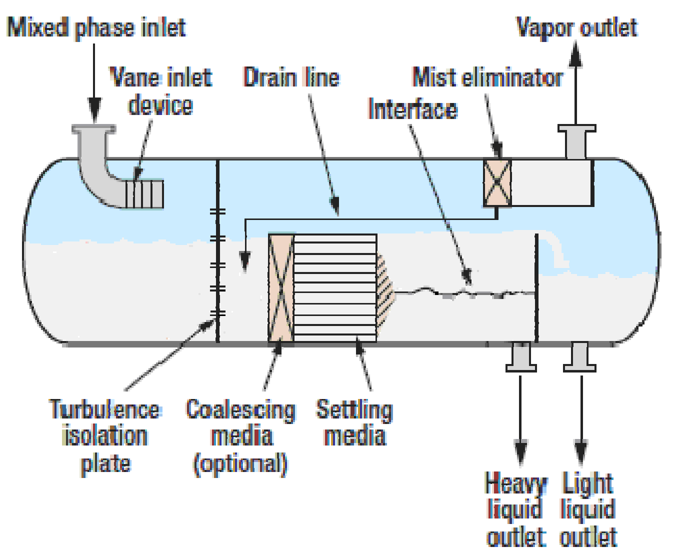

Figure 7. Horizontal 3-phase separator

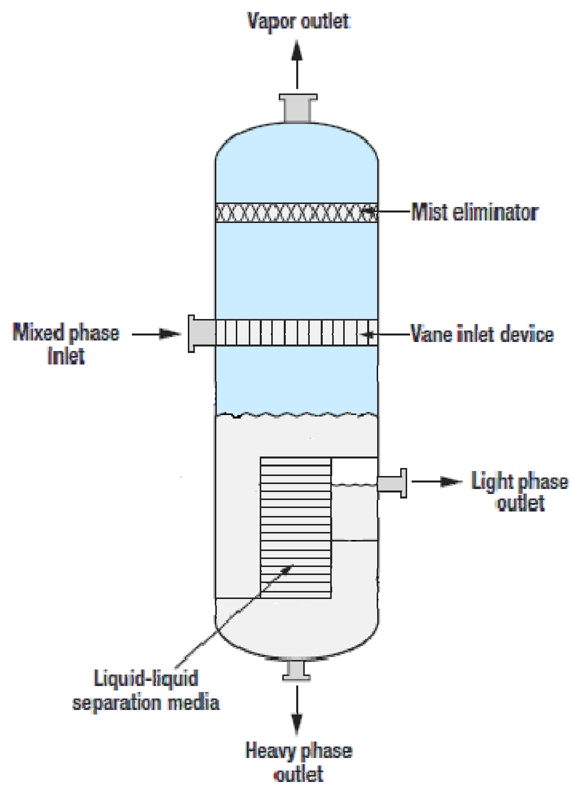

Figure 8. Vertical 3-phase separator

The three phase separation vessel commonly contains four major sections as listed below:

a. The primary separation section used to separate the main portion of free liquid in the inlet stream

b. The secondary or gravity section designed to utilize the force of gravity to enhance separation of entrained droplets.

c. The coalescing section utilizes a coalescer or mist extractor. Our normal application is using a knitted wire mesh pad on top of vessel.

d. The sump or liquid collection section acts as receiver for all liquid removed from gas in the primary, secondary, and coalescing section.

A vane-inlet device might be used in this separator to gradually reduce the inlet momentum and evenly distribute the gas phase across the vessel diameter. Such device can also act as the first-stage gas-liquid separation. In the gas-liquid portion of the vessel, a wire-mesh mist eliminator provides high separation efficiency.

For the liquid-liquid separation in the bottom of the drum, the first-stage is typically some type of enhanced-gravity separation media. If very high separation is required, adding a second “polishing” stage provides the ability to remove the last remnants of entrainment.

DEFINITIONS

Accumulators- These are storage tanks following distillation column condensers. For partial condensers, this flow may be a mixture of vapor and liquid. The outlet flow may be regulated by a level controller in order to avoid the tank either flooding (liquid out the top) or going dry (vapor out the bottom).

Coalescer- A mechanical process vessel with wettable, high-surface area packing on which liquid droplets consolidate for gravity separation from a second phase (for example gas or immiscible liquid).

Control Volume- A certain liquid volume necessary for control purposes and for maintaining the velocity limit requirement for degassing and to counter foam in separators.

Conventional Gas-Liquid Separator- Vertical or horizontal separators in which gas and liquid are separated by means of gravity settling with or without a mist eliminating device.

Critical Diameter- Diameter of particles larger than which will be eliminated in a sedimentation centrifuge.

Demister Mist Extractor- A device installed in the top of scrubbers, separators, tray or packed vessels, etc. to remove liquid droplets entrained in a flowing gas stream.

Disengaging Height- The height provided between bottom of the wire-mesh pad and liquid level of a vapor-liquid separator.

Fabric Filter- Commonly termed "bag filters" or "baghouses", are collectors in which dust is removed from the gas stream by passing the dust-laden gas through a fabric of some type.

Filter Separators- A piece of unit operation equipment by which filtration is performed. 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.

Filter Medium- The "filter medium" or "septum" is the barrier that lets the liquid pass while retaining most of the solids; it may be a screen, cloth, paper, or bed of solids.

Filtrate- The liquid that passes through the filter medium is called the filtrate.

Flash drums- Vessels into which flow a mixture of liquid and vapor. The goal is to separate the vapor and liquid. For design calculations it is normally assumed that the vapor and liquid are in equilibrium with one another and that the vessel is adiabatic (no heat lost or gained). One must simultaneously satisfy a material balance, a heat balance, and equilibrium.

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

Hold-Up Time- A time period during which the amount of liquid separated in a gas-liquid separator is actually in the vessel for the purpose of control or vapor separation.

Knock-Out- A separator used for a bulk separation of gas and liquid. 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.

Line Drip- A device 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.

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.

Mesh- The "mesh count" (usually called "mesh"), is effectively the number of openings of a woven wire filter per 25 mm, measured linearly from the center of one wire to another 25 mm from it.

Open Area- A percentage of the whole area of a woven wire filter.

Overflow- The stream being discharged out of the top of a hydrocyclone, through a protruding pipe, is called "overflow". This stream consists of bulk of feed liquid together with the very fine solids.

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.

Scrubber- A type of separator which has been designed to handle flow streams with unusually high gas-to-liquid ratios.

Slug Catcher- A particular separator design able to absorb sustained in-flow of large liquid volumes at irregular intervals.

Surge tanks- These are storage tanks between units, and can serve a variety of purposes. They can dampen fluctuations in flow rate, composition or temperature. They can allow one unit to be shut down for maintenance without shutting down the entire plant.

Target Efficiency- The fraction of particles or droplets in the entraining fluid of a separator, moving past an object in the fluid, which impinge on the object.

Terminal Velocity or Drop-Out Velocity- The velocity at which a particle or droplet will fall under the action of gravity, when drag force just balances gravitational force and the particle (or droplet) continues to fall at constant velocity.

Underflow- The stream containing the remaining liquid and the coarser solids, which is discharged through a circular opening at the apex of the core of a hydrocyclone is referred to as "underflow".

Vapor Space- The volume of a vapor liquid separator above the liquid level.

NOMENCLATURE

A	Vessel cross-sectional area, ft^2 (m^2)
A_h	Head surface area, ft^2 (m^2)
A_{LLL}	Low liquid level area, ft^2 (m^2)
A_s	Shell surface area, ft^2 (m^2)
A_V	Vapor disengagement area, ft^2 (m^2)
D	Vessel diameter, ft (m)
D_p	Diameter of particle or droplet, ft (m)
D_{VD}	Vessel inside diameter, ft (m)
E	Joint efficiency, % (%)
G	Gravitational force, ft/s^2 (m/s^2)
H_D	Disengagement height, in (mm)
H_H	Hold-up height, ft (m)
H_{LLL}	Low liquid level height, in (mm)
H_{ME}	Mist eliminator height, ft (m)
H_s	Surge height, ft (m)
H_{UN}	H_{LLL} to the centerline of nozzle height, in (mm)
H_V	Height of vapor disengagement area, ft (m)
K	Sounders-Brown constant, ft/s (m/s)
L	Vessel Length, ft (m)
L_{min}	Minimum vessel length requirement, ft (m)
M	Fraction of vertical area filled with liquid
M_L	Liquid mass flow rate, lb/h (kg/h)
M_V	Vapor or gas mass flow rate, lb/h (kg/h)
P	Vessel design pressure, psia or psig (kg/cm^2)
P_{op}	Vessel operating pressure, psia (kg/cm^2)
Q_L	Liquid volumetric flow rate, ft^3/min (m^3/min)
Q_V	Vapor or gas volumetric flow rate, ft^3/s (m^3/s)
Q_o	Oil volumetric flow rate, ft^3/s (m^3/s)

Q_w	Water volumetric flow rate, ft^3/s (m^3/s)
S	Allowable stress, psig (kg/cm^2-g)
T	Vessel design temperature, °F (°C)
T_H	Hold-up time, min (min)
T_{op}	Vessel operating pressure, °F (°C)
T_S	Surge time, min (min)
t_c	Corrosion allowance, in (mm)
t	Shell thickness, in (mm)
t_h	Head thickness, in (mm)
t_r	Retention time, min (min)
t_{ro}	Oil retention time, min (min)
t_{rw}	Water retention time, min (min)
V_T	Terminal velocity, ft/s (m/s)
V_{max}	Maximum allowable gas velocity, ft/s (m/s)
V_V	Vapor velocity, ft/s (m/s)
W	Vessel weight, lb (kg)

Greek Letters

μ	Viscosity of flowing fluids, cp (cp)
ρ_m	Media (commonly vapor or gas) density, lb/ft^3 (kg/m^3)
ρ_p	Particle (commonly liquid or oil) density, lb/ft^3 (kg/m^3)
θ	Liquid drop out time, s (s)