

PROCESS EQUIPMENT DESIGN COURSE

SEPARATORS

Prepared and Presented by :

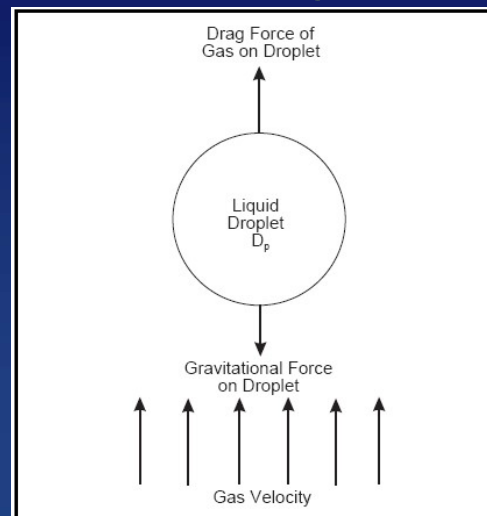
A. Kiashemshaki

Session Overview

- ✦ Introduction & Theory
- ✦ Separator Design & Construction
- ✦ Gas-Liquid Separator Design
- ✦ Gas-Liquid-Liquid Separator Design
- ✦ Mechanical Design
- ✦ Standards & References
- ✦ Exercises

Introduction & Theory

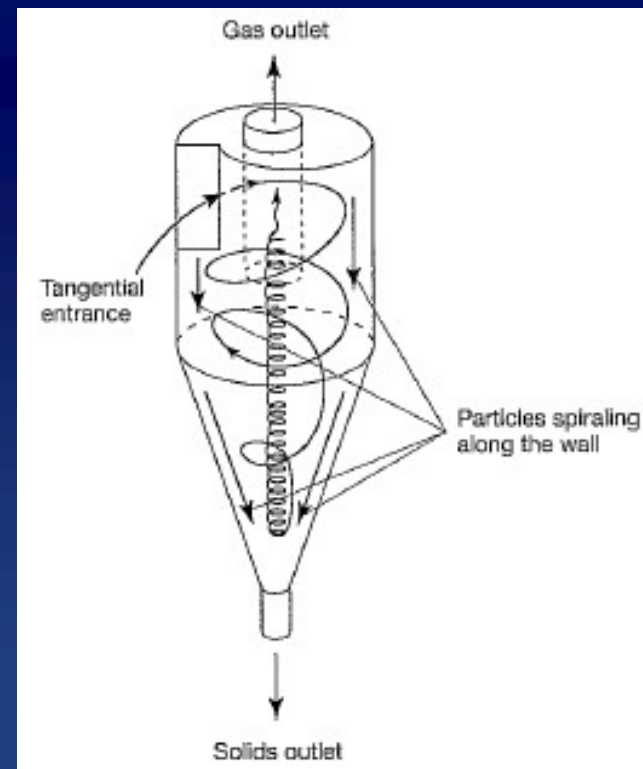
- ☀ Three principles used to achieve physical separation of gas and liquids or solids : *momentum*, *gravity settling*, and *coalescing*.
- ☀ **Separator** : a pressure vessel designed to **divide a combined liquid–gas system into individual components** that are relatively free of each other for subsequent disposition or processing.
- ☀ **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**.



Introduction & Theory

- ☀ Momentum:

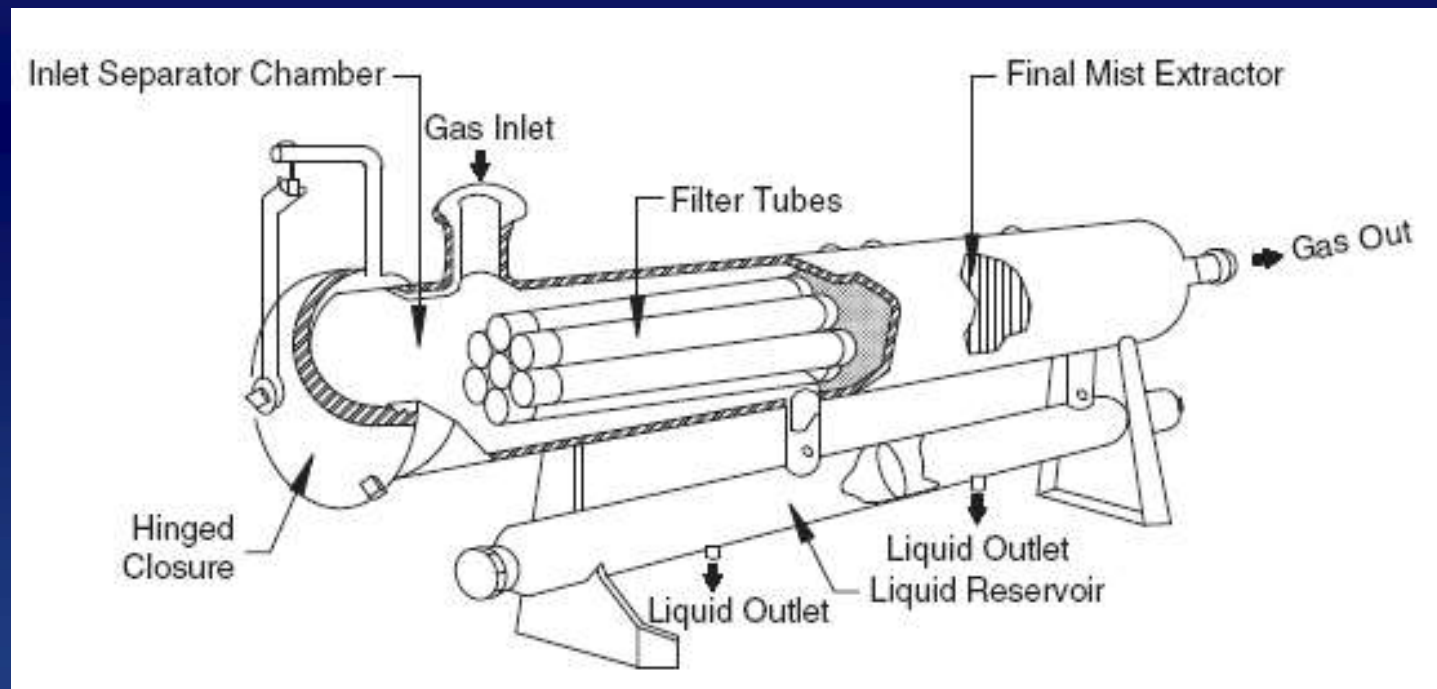
Fluid phases with **different densities** will have **different momentum**. If a two phase stream **changes direction sharply**, greater momentum will not allow the particles of heavier phase to turn as rapidly as the lighter fluid, so separation occurs.



Introduction & Theory

- ☀ Coalescing:

These are used in applications where conventional separators employing gravitational or centrifugal force are ineffective.



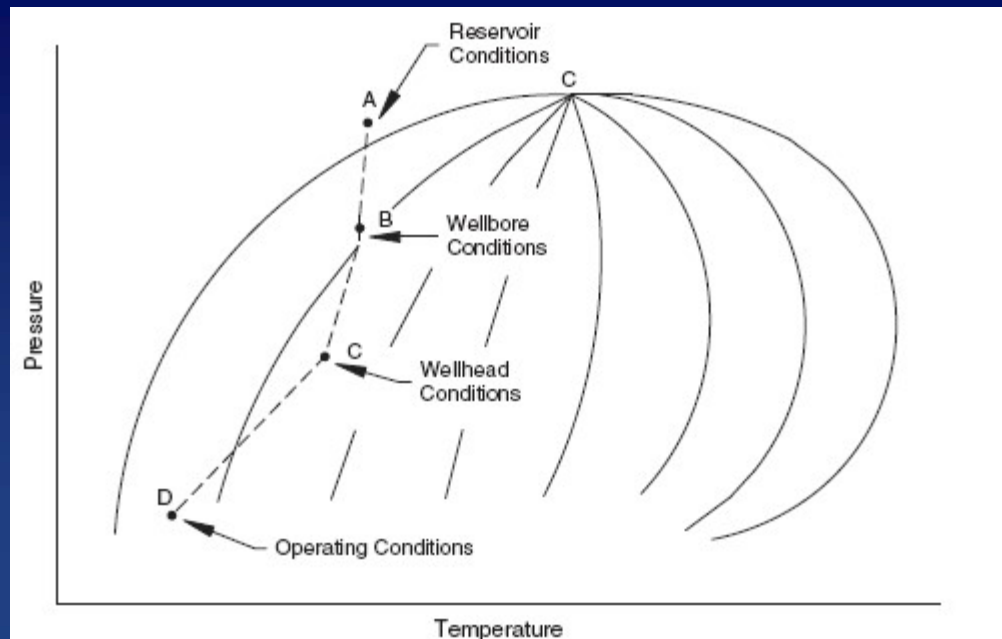
Introduction & Theory

WHY Separation is needed ?

☀ Downstream equipment cannot handle gas–liquid mixtures, for example:

- Pumps require gas-free liquid;
- Compressor and dehydration equipment require liquid-free gas;
- Product specification set limits on impurities
- Measurement devices for gases or liquids are highly inaccurate when another phase is present.

☀ Phase behavior :



Introduction & Theory

- ☀ The following factors must be determined before separator design:
 - gas and liquid flow rates (minimum, average, and peak),
 - operating and design pressures and temperatures,
 - surging or slugging tendencies of the feed streams,
 - physical properties of the fluids such as density, viscosity and compressibility factor,
 - designed degree of separation (e.g., removing 100% of particles greater than 10 mm),
 - presence of impurities (paraffin, sand, scale, etc.),
 - foaming tendencies of the crude oil, and
 - corrosive tendencies of the liquids or gas.

Introduction & Theory

★ Souders-Brown Equation for Gravity Settling:

$$V_t = K \cdot \sqrt{\frac{(\rho_l - \rho_g)}{\rho_g}}$$

$$K = \sqrt{\frac{4gD_p}{3C'}}$$

V_t = critical or terminal gas velocity necessary for particles of size D_p to drop or settle out of gas, m/s

M_p = mass of droplet or particle, kg

ρ_g = gas phase density, kg/m³

ρ_l = liquid phase density, droplet or particle, kg/m³

A_p = particle or droplet cross sectional area, m²

C' = drag coefficient of particle, dimensionless

μ = viscosity of continuous phase, mPa · s

$$Re = \frac{1,000 D_p V_t \rho_g}{\mu}$$

Introduction & Theory

☀ Gravity Settling:

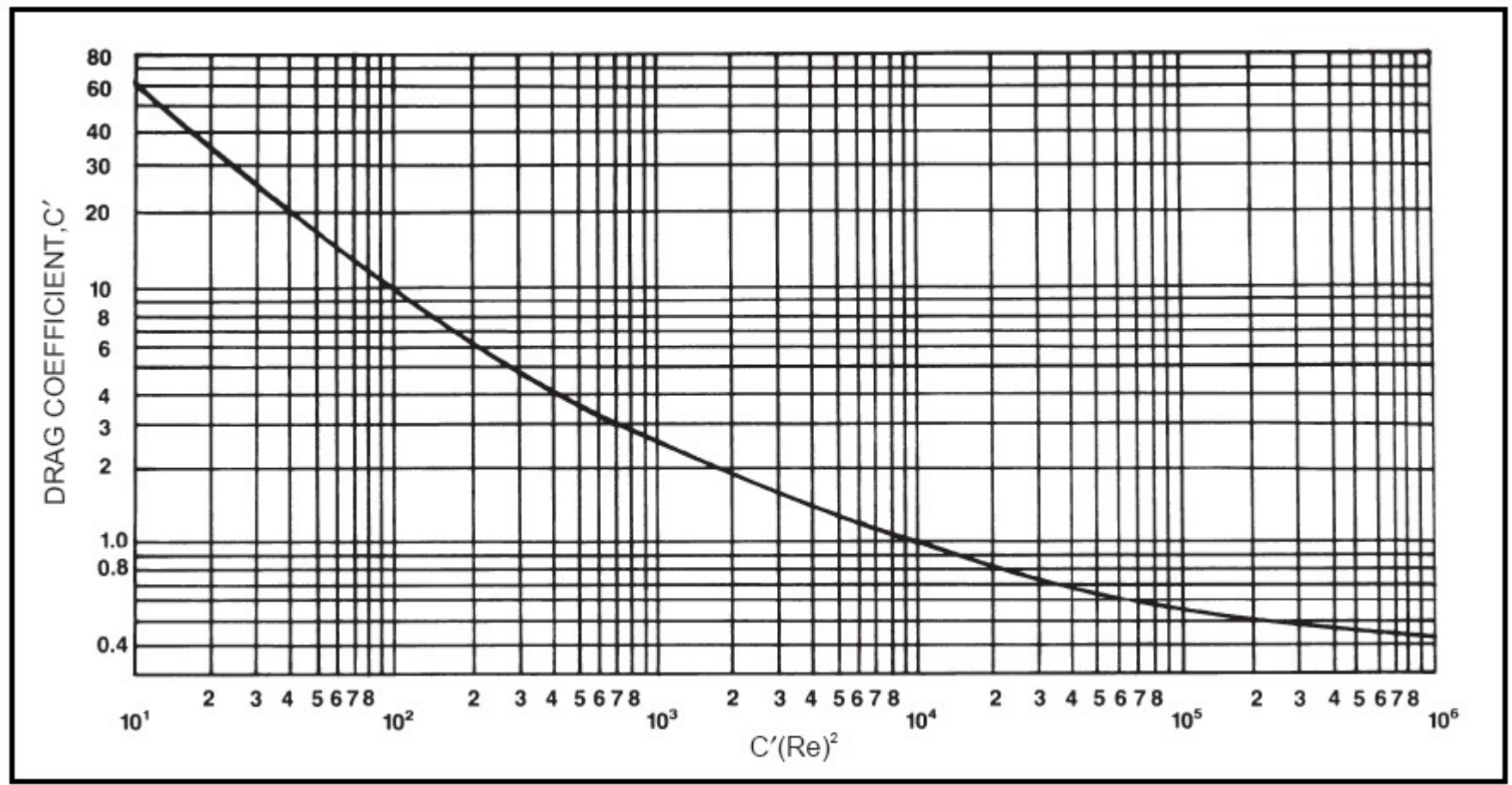
SI :

$$C' (\text{Re})^2 = \frac{(1.31) (10^7) \rho_g D_p^3 (\rho_1 - \rho_g)}{\mu^2}$$

FPS :

$$C' (\text{Re})^2 = \frac{(0.95) (10^8) \rho_g D_p^3 (\rho_1 - \rho_g)}{\mu^2}$$

Drag Coefficient of Rigid Spheres¹³



Introduction & Theory

- ☀ Gravity Settling:

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 can be expressed as:

$$V_t = \frac{1,488 \text{ g } D_p^2 (\rho_l - \rho_g)}{18 \mu}$$

- ☀ The droplet diameter corresponding to a Reynolds number of 2 can be found using a value of 0.025 for KCR in:

$$D_p = K_{CR} \left[\frac{\mu^2}{\text{g } \rho_g (\rho_l - \rho_g)} \right]^{0.33}$$

- ☀ Stoke's law is typically applicable for small droplet sizes and/or relatively high viscosity liquid phases.

Introduction & Theory

- ☀ Gravity Settling:

Intermediate Law

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

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

- ☀ The droplet diameter corresponding to a Reynolds number of 500 can be found using a value of 0.334 for KCR in:

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

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

Introduction & Theory

- ☀ Gravity Settling:

Newton's Law

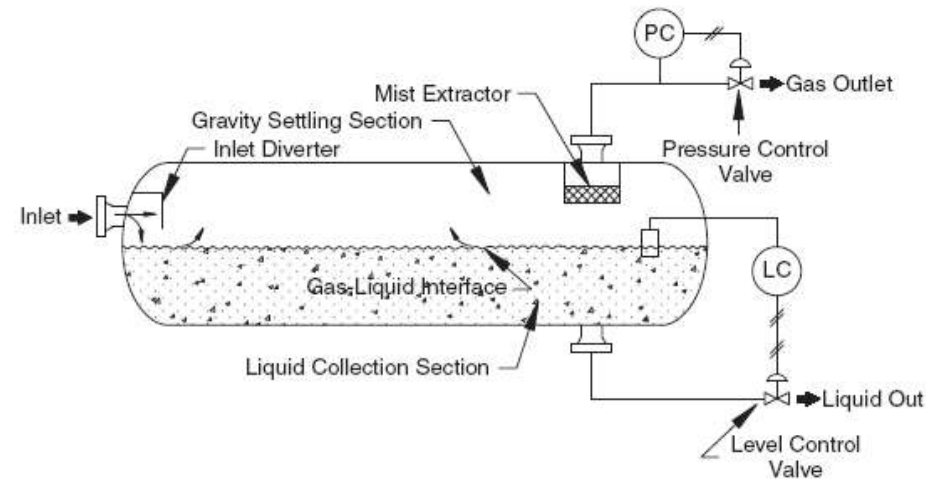
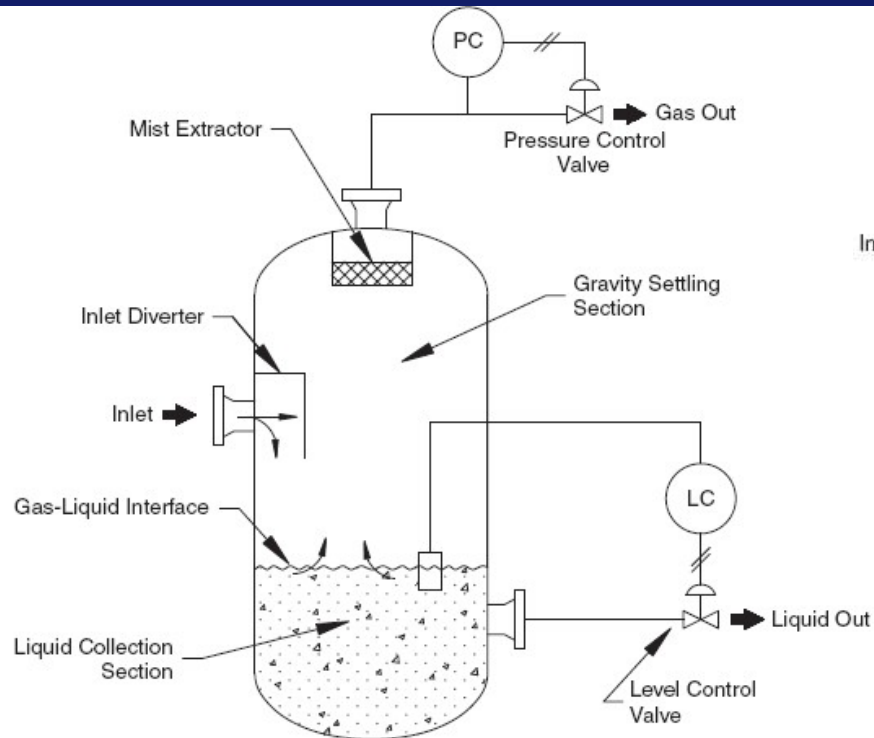
Newton's Law is applicable for a Reynold's number range of approximately 500 – 200,000, and finds applicability mainly for separation of large droplets or particles from a gas phase, e.g. flare knockout drum sizing. The limiting drag coefficient is approximately 0.44 at Reynolds numbers above about 500.

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

- ☀ 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 $KCR = 18.13$.

Separator Design & Construction

- Separators are usually characterized as **vertical**, **horizontal**, or **spherical**.



Separator Design & Construction

- ✦ **Inlet Devices:** Proper selection of the inlet device is critical in separator design. Inlet devices should reduce the momentum of the inlet stream, initiate gas-liquid separation with minimum creation of fine droplets, and distribute gas flow evenly throughout the inlet and gravity separation section of the vessel.
- ✦ It is necessary to maintain the inlet velocity head, J , within proper limits for the selected inlet device to insure good gas distribution and minimum liquid shattering

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

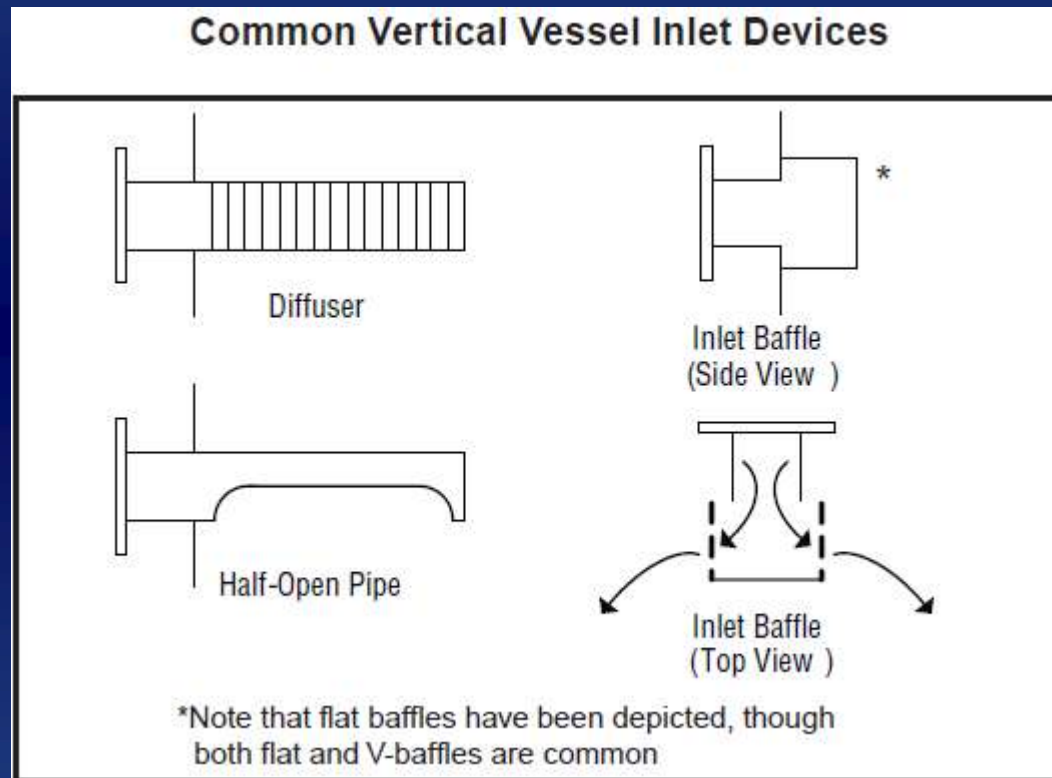
Separator Design & Construction

☀ Inlet Devices:

- ☀ The maximum mixed phase velocity head range used in the industry guidelines varies for the different inlet devices. Some typical maximums are:
 - 6000-9000 max. typ, up to 15 000 max $\text{kg/m} \cdot \text{s}^2$ for diffuser distributor
 - 975-2250 max $\text{kg/m} \cdot \text{s}^2$ for no inlet distributor
 - 1500-3750 max $\text{kg/m} \cdot \text{s}^2$ for inlet half pipe or elbow distributor
 - 1500-3750 max $\text{kg/m} \cdot \text{s}^2$ for v-baffle or other simple inlet diverter designs
- ☀ In addition, some users limit the inlet vapor phase velocity to 9 m/s or 18 m/s. The velocity should always be below the erosion velocity for the service.

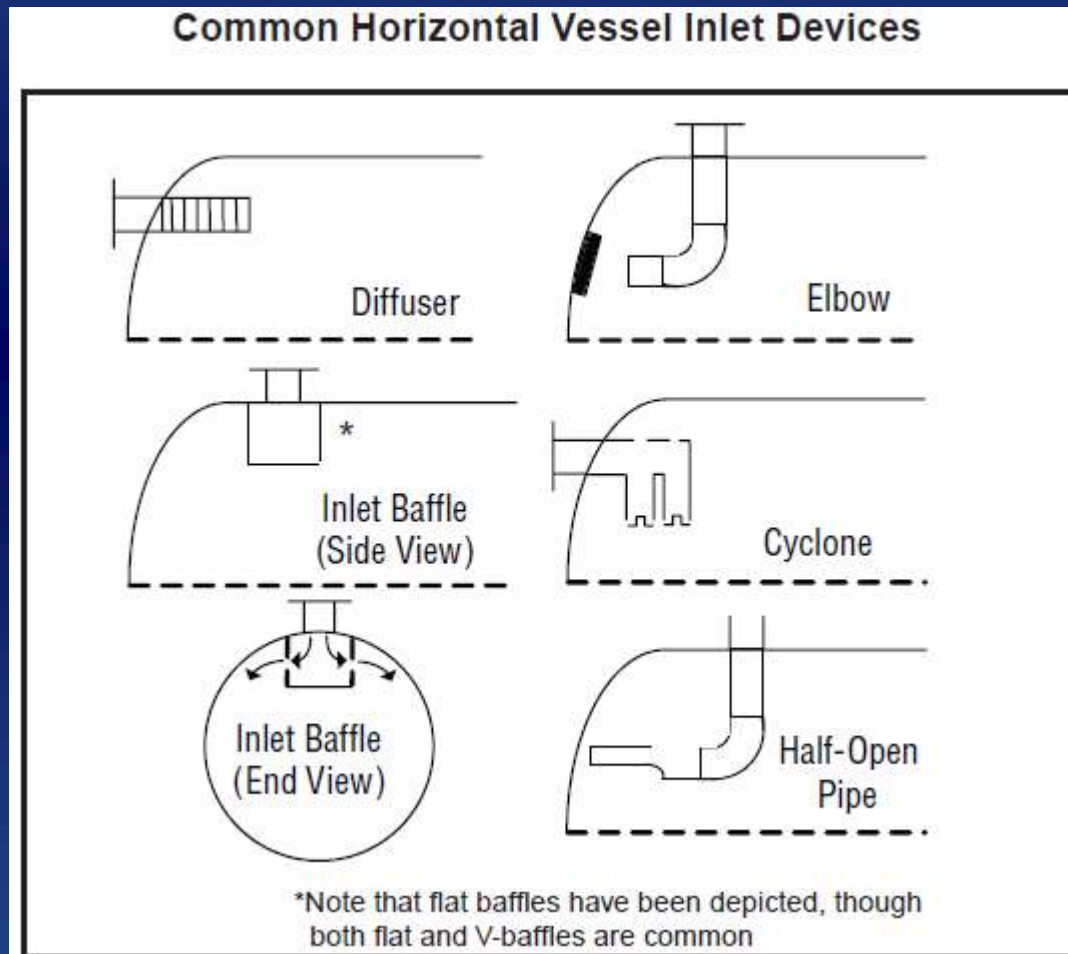
Separator Design & Construction

☀ Inlet Devices :



Separator Design & Construction

☀ Inlet Devices :



Separator Design & Construction

☀ Inlet Devices :

Typical Inlet Device Performance

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

1) Vessel orientation – (H) horizontal, (V) vertical, (T) three-phase

Separator Design & Construction

- ✦ **Gravity Settling Section:** The gravity separation section is the area where much of the liquid settles prior to entering the mist eliminator device.

Gas-Liquid Gravity Separation Section For Vertical Separators with Downstream Mist Eliminators —

- ✦ The gravity separation section for a vertical separator should be designed to allow a majority of the liquid to drop out upstream of the mist eliminator, to provide an even distribution of the gas to the gas polishing section, and to minimize re-entrainment from the liquid surface below the feed.
- ✦ This can be accomplished without over sizing the vessel diameter, if adequate space is provided above and below the feed nozzle, and the Inlet Section is properly specified (appropriate inlet piping configuration/ size, and inlet device).

Separator Design & Construction

☀ Gravity Settling Section:

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

- ☀ The goal of the gravity separation section for a horizontal separator is to remove a majority of the liquid droplets from the gas prior to the mist eliminator, to minimize surface re-entrainment due to waves and droplet shear at the gas liquid interface, and to promote an even gas flow distribution to the mist eliminator.
- ☀ To accomplish this, it is necessary to limit the gas velocity through the vapor space. For most applications, an approach of applying Stokes' Law to establish a vertical terminal vertical velocity, and then designing for the gas flow velocity and length to drop out say a 250-500 micron droplet would result in high horizontal velocity (greater than that typically used commercially).

Separator Design & Construction

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

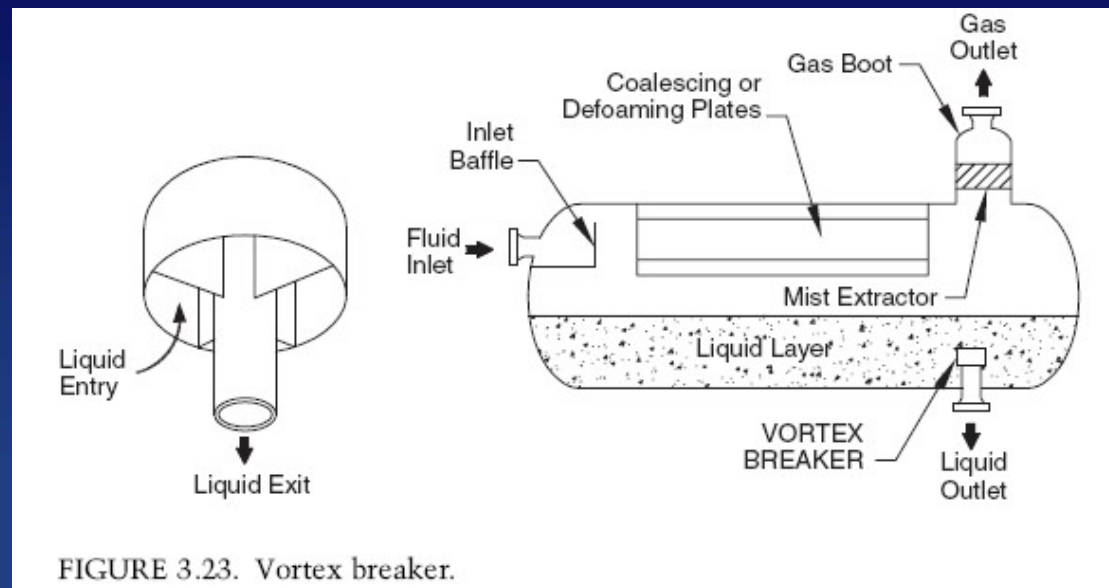
Separation Efficiency and Sizing Considerations For Wire Mesh Mist Eliminators

- ☀ Mist eliminator supplier can provide the d_{95} (droplet size for 95% removal efficiency), and for a given an estimated inlet droplet size distribution, an overall separation efficiency.
- ☀ Sizing for wire mesh mist eliminators is based on operating the mist eliminator at a maximum flow rate which is a safe distance from the flood point at the operating conditions.
- ☀ A conventional, 192 kg/m³, 0.3 mm filament, crimped wire mesh mist eliminator, will typically have a design K value of 0.11 m/s, for vertical flow to the mist eliminator, at low pressure.
- ☀ In horizontal gas flow, a design K value of 0.13 is typical for these conditions.

Separator Design & Construction

Vortex Breakers:

- ★ Liquid leaving a separator may form vortices or whirlpools, which can pull gas down into the liquid outlet.
- ★ Therefore, separators are often equipped with vortex breakers, which prevent a vortex from developing when the liquid control valve is open. A vortex could suck some gas out of the vapor space and re-entrain it in the liquid outlet.



Separator Design & Construction

Mist Extractors:

- ✦ Before a selection can be made, one must evaluate the following factors:
 - Size of droplets the separator must remove.
 - Pressure drop that can be tolerated in achieving the required level of removal.
 - Susceptibility of the separator to plugging by solids, if solids are present.
 - Liquid handling capability of the separator.
 - Whether the mist extractor/eliminator can be installed inside existing equipment, or if it requires a standalone vessel instead.
 - Availability of the materials of construction that are comparable with the process.
 - Cost of the mist extractor/eliminator itself and required vessels, piping, instrumentation, and utilities.

Separator Design & Construction

Mist Extractors:

Mesh Mist Eliminators

- ✦ Mesh mist eliminators 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.
- ✦ Mesh pads remove liquid droplets by impingement of droplets onto the wires, 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.
- ✦ The most common style of mesh mist eliminator used in gas processing is a 100 mm to 150 mm thick crimped wire mesh pad with 144 to 192 kg/m³ bulk density.
- ✦ High droplet removal efficiency for droplets 10 microns and larger is common for the above design.

Separator Design & Construction

Mist Extractors:

Vane Mist Eliminators

- ✦ Vane or chevron-type mist eliminators (vane-pack) use relatively closely spaced blades arranged to provide sinusoidal or zig-zag gas flow paths.
- ✦ Vane packs may be installed in either horizontal or vertical orientations.
- ✦ Vane capacity is reduced for vertical up flow applications relative to horizontal flow.
- ✦ Key performance parameters for vanes are droplet removal efficiency and gas handling capacity.
- ✦ Simple vanes with no pockets are typically capable of capturing 40 microns droplets,
- ✦ Pocketed vanes are capable of 20 microns,
- ✦ Highly complex vanes of 10-20 microns at favorable operating conditions

Separator Design & Construction

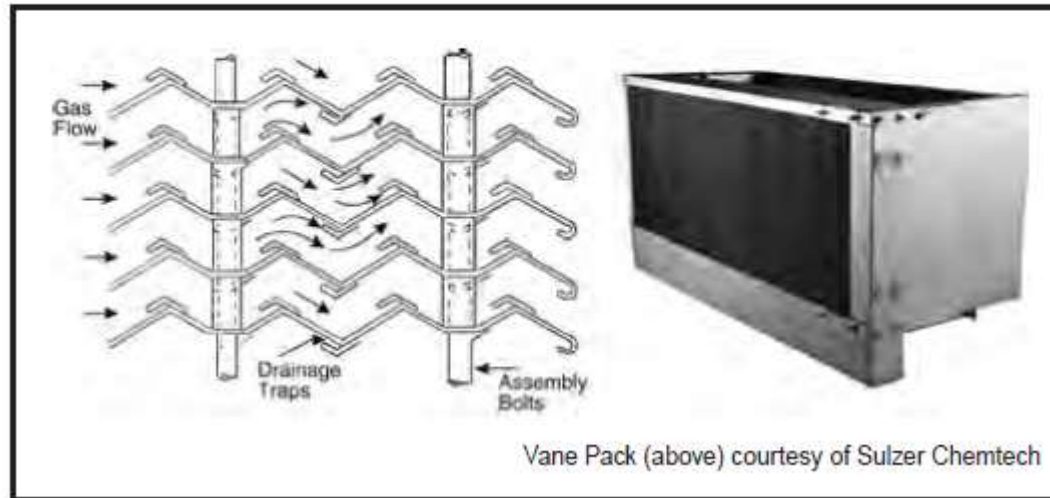
Mist Extractors:

Wire Mesh Mist Eliminator



Courtesy of ACS Separations and Mass Transfer Products

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



Vane Pack (above) courtesy of Sulzer Chemtech

Separator Design & Construction

Mist Extractors:

**Typical Souder's-Brown K Values for
Mist Eliminator Devices**

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

*Values for comparison purposes only

Separator Design & Construction

✦ Separator Configurations :

Factors to be considered for separator configuration selection include:

- 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 three-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?

Separator Design & Construction

Table 3.3.6 Performance comparison of vapor-liquid separators

	KO Drum		Wire Mesh Mist Eliminator		Vane Separator (2 stage)	Cyclone	Multi cyclone	Filter Separator
	Vertical	Horizontal	Vertical	Horizontal	Vertical		Vertical	
Installation								
Gas Handling								
max. capacity (*1)	Low	Low	Moderate	Moderate	High	Very High	Very High	Low
operating range(%) (*2)	0-100	0-100	30-110	30-110	30-110	50-110	50-110	0-100
Liquid removal efficiency								
overall(%)	80-90	80-90	>96	>96	>96	>96	>93	>99
for fine particle	Very Low	Very Low	High	High	High	Low	Low	Very High
Liquid Handling capacity								
for bulk (*3)	High	Very High	High	Very High	High	High	Low	Low
for entrainment (*4)	High	High	High	High	Moderate	Moderate	Moderate	Low
Fouling tolerance								
	High	High	Low	Low	Low	High	High	Low
Approximate pressure drop (*5)								
	Nil.	Nil.	2 mmHg	2 mmHg	10 mmHg	1% of Operating pressure	0.15 kg/cm ²	1.5 kg/cm ²

(*1) Based on separator with same diameter

(*2) Based on design flow rate of each separator type

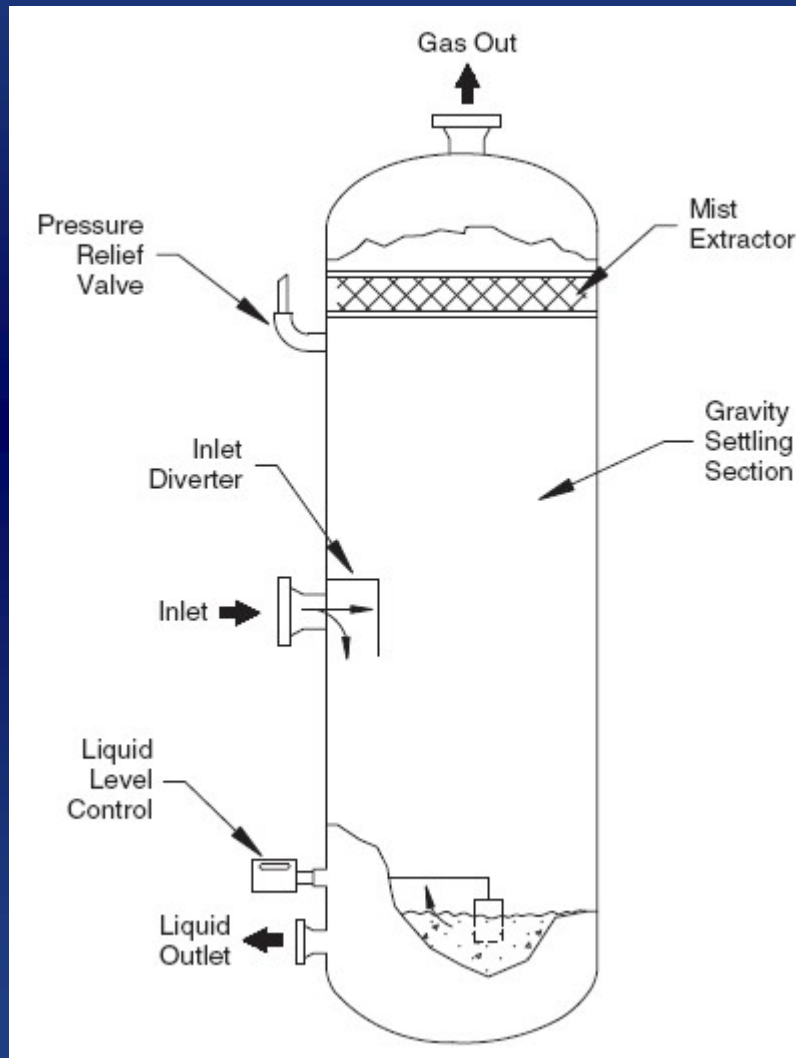
(*3) Liquid load for inlet of separator

(*4) Liquid load for inlet of separator element

(*5) Pressure drop for internal element.

Separator Design & Construction

☀ Vertical Separators:



- usually selected when the **gas-liquid ratio is high** or total gas volumes are low.

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

- **Level control is not critical** and liquid level can fluctuate several inches without affecting operating Efficiency

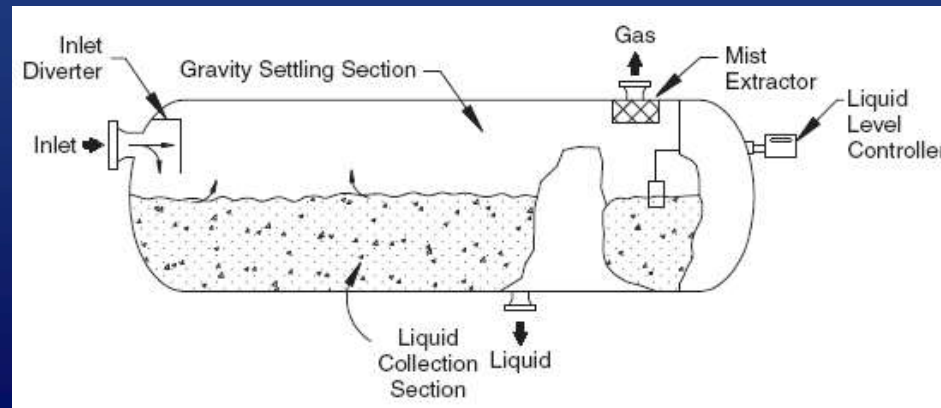
- **Mist extractors** can significantly **reduce** the required **diameter** of vertical separators.

- The separator occupies a **small amount of plot space**.

- The **liquid level responds quickly** to any liquid that enters thus tripping an alarm or shutdown.

Separator Design & Construction

☀ Horizontal Separators :



- ☀ most efficient where **large volumes of total fluids and large amounts of dissolved gas** are present with the liquid.
- ☀ Typical **L/D ratios** for horizontal separators normally fall in the range of **2.5–5**.
- ☀ The **greater liquid surface area** in this configuration provides optimum conditions for releasing entrapped gas.
- ☀ The horizontal configuration would handle a **foaming liquid better than a vertical**.
- ☀ Increased **slug capacity** is obtained through **shortened retention time and increased liquid level**.

Gas-Liquid Separator Design

Slenderness Ratio (Length/Diameter):

- ✦ For each vessel design, a combination of L and D exists that will minimize the cost of the vessel.
- ✦ It can be shown that the smaller the diameter, the less the vessel will weigh and thus the lower its cost.
- ✦ The L/D ratio for all process vessels should be within the range:
 $1.5 \leq L/D \leq 6$, except in the case of surge vessels operating at atmospheric conditions; in such cases, it is cheaper to use smaller L/D ratios.
- ✦ If $L/D > 4$ or $5 \rightarrow$ re-entrainment could become a problem. This should be checked for $L/D > 4$.

$$2 \leq L/D \leq 3 \quad \text{for} \quad P \leq 4 \text{ bara}$$

$$3 < L/D \leq 5 \quad \text{for} \quad P > 4 \text{ bara}$$

Gas-Liquid Separator Design

Selecting proper Diameter and Length :

- ✦ When making a final selection, it is always more economical to select a standard vessel size. (Refer to API-12J)
- ✦ Vessels with outside diameters up through 24 in. (600 mm) have nominal pipe dimensions.
- ✦ Vessels with outside diameters larger than 24 in. (600 mm) are typically rolled from plate with diameter increments of 6 in. (150 mm).
- ✦ The shell seam-to-seam length is expanded in 2.5-ft (750-mm) segments and is usually from 5 ft to 10 ft (1500–3000 mm).

Gas-Liquid Separator Design

Separators Without Mist Eliminator :

- ✦ 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 **150 to 2,000 microns**.
- ✦ Separators without mist extractors are designed for gravity settling using basic gravity settling equations.

Horizontal Vessels Length (without liquid retention):

$$L = \frac{4 Q_A}{\pi V_t D_v}$$

Gas-Liquid Separator Design

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.
- ★ Liquid capacity is typically specified in terms of residence time, which must be translated into vessel layout requirements for

$$U = \frac{W (t)}{1440}$$

U = volume of settling section, bbl

W = total liquid flow rate, bbl/day

FIG. 7-20

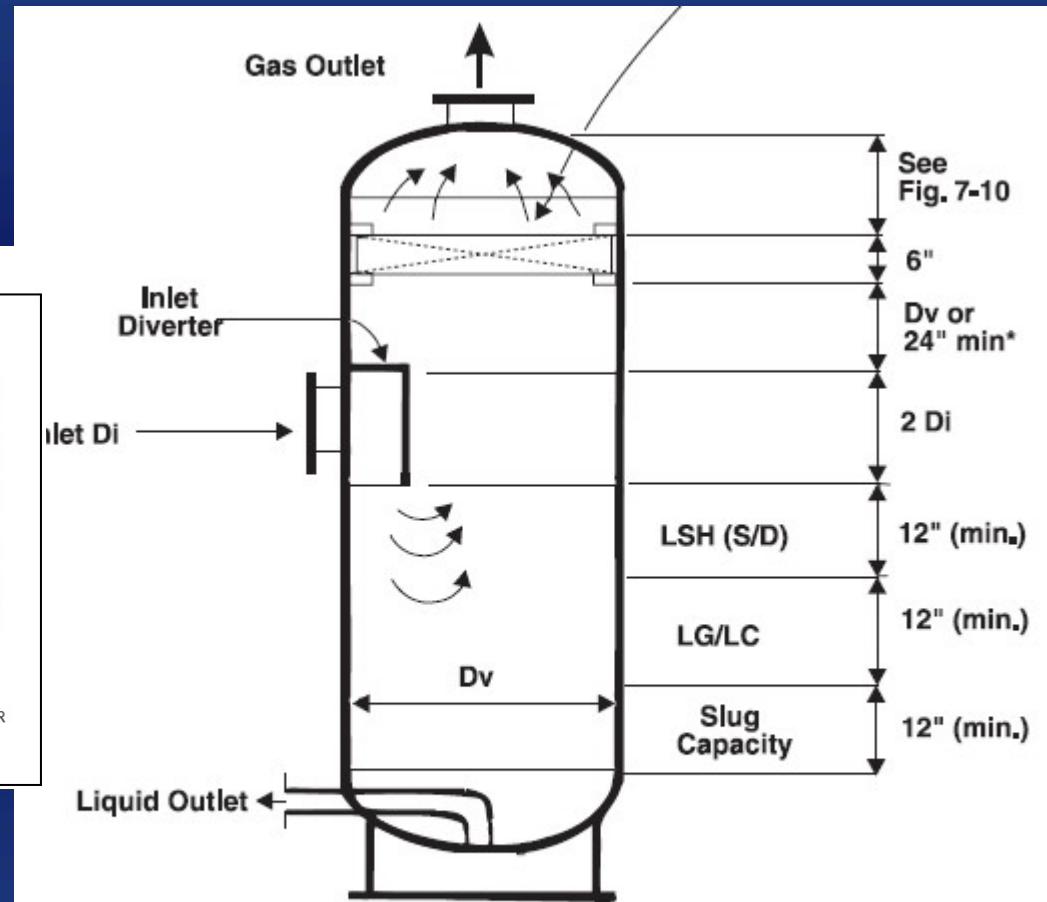
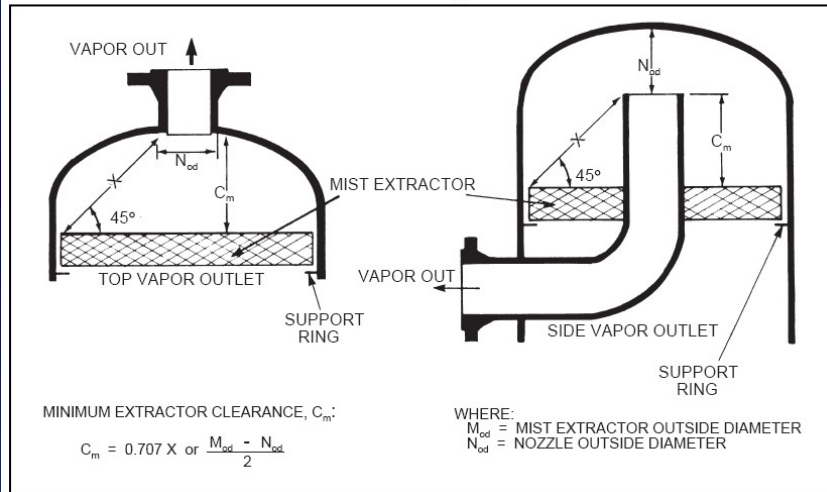
Typical Retention Times for Gas/Liquid Separator

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

Gas-Liquid Separator Design

FIG. 7-10

Minimum Clearance — Mesh Type Mist Eliminators

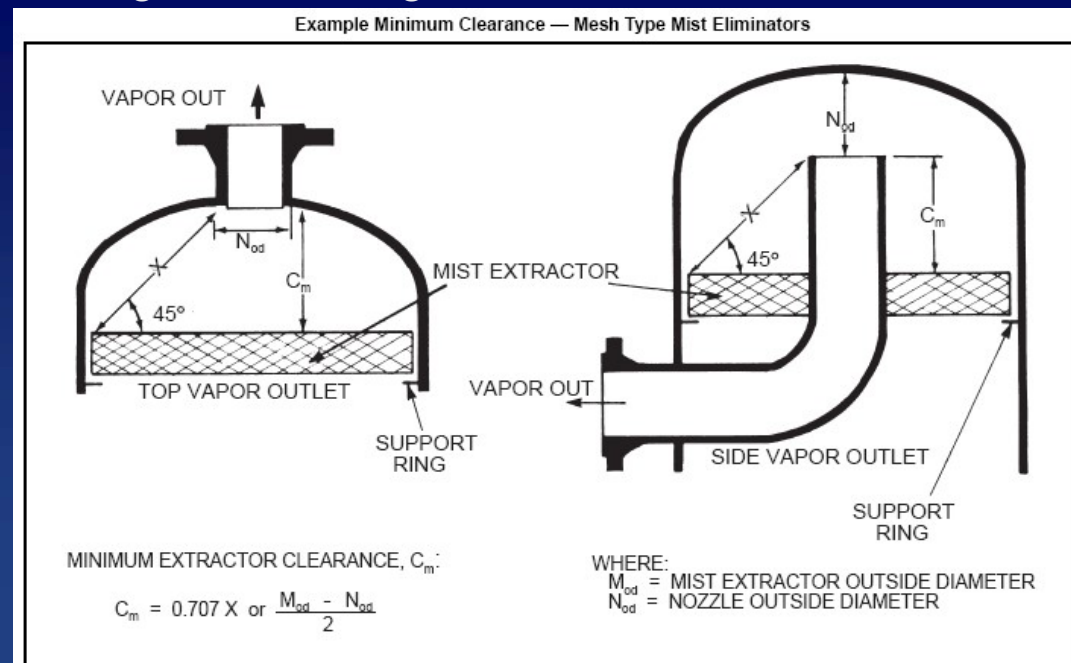


LSH (S/D) Level Switch High (Shutdown)
 LG/LC Level Gauge/Level Controller

Gas-Liquid Separator Design

Separators With Mist Eliminator :

- ☀ Removal of droplets down to **10 microns or smaller** may be possible with these pads.
- ☀ In plants where fouling or hydrate formation is possible or expected, mesh pads are typically not used. In these services vane or centrifugal type separators are generally more appropriate.
- ☀ Most installations will use a **150 mm thick pad** with 144-192 kg/m³ bulk density. **Minimum recommended pad thickness is 100 mm.**
- ☀ Quoted liquid carryover from the various types of mist extraction devices are usually in the range of 0.1 - 1 gal/MMscf.



Gas-Liquid Separator Design

Separators With Mist Eliminator (GPSA) :

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

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.

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.

Typical K & C Factors for Sizing Woven Wire Demisters

Separator Type	K Factor (m/s)	C Factor (m/h)
Horizontal	0.12 to 0.15	430 to 540
Vertical	0.05 to 0.11	200 to 400
Spherical	0.05 to 0.11	220 to 400
Wet Steam	0.076	270
Most vapors under vacuum	0.061	220
Salt & Caustic Evaporators	0.046	160
Adjustment of K & C Factor for Pressure - % of design value ¹⁵		
Atmospheric		100
1000 kPa		90
2000 kPa		85
4000 kPa		80
8000 kPa		75

- For glycol and amine solutions, multiply K by 0.6 - 0.8.
- Typically use one-half of the above K or C values for approximate sizing of vertical separators without wire demisters.
- For compressor suction scrubbers and expander inlet separators multiply K by 0.7 - 0.8.

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

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

Gas-Liquid Separator Design

Separators With Mist Eliminator :

Technip :

Critical velocity:

$$U_G^* = 0.381 \times K_V \sqrt{\frac{(\rho_L - \rho_G)}{\rho_G}} \quad (\text{m/s})$$

$$\log(K_V) = -0.876 - 0.837 \times \log(B) - 0.324 \times [\log(B)]^2 \quad (0.006 \leq B \leq 6)$$

with:

$$B = \frac{W_L}{W_G} \sqrt{\frac{\rho_G}{\rho_L}} \quad (\text{dimensionless})$$

if $B < 0.006$ use $K_V = 0.2$

if $B > 6$ use $K_V = 0.02$

W_L and W_G are the liquid and gas mass flow rates.

Foster-Wheeler :

$$V_c = 4.57 \sqrt{\frac{\rho_l}{\rho_g} - 1}$$

where V_c = critical entrainment velocity, cm/sec

Shell :

The vessel diameter shall satisfy

1. the primary separation criterion (i.e. separation by Schoepentoeter):

$$\lambda_{\max} = Q_{\max}^* / (\pi D_{\min}^2 / 4) = 0.1 + 0.008 \rho_G^{-0.14} \phi_{\text{feed}}^{-0.76}$$

giving $D \geq 1.13 \sqrt{Q_{\max}^* / \lambda_{\max}}$

If no slugs are expected, the above criterion shall not exceed

$$\lambda_{\max} = 0.20 \quad \text{m/s}$$

If slugs are expected:

$$\lambda_{\max} = 0.10 \quad \text{m/s (to prevent overloading of the vane pack)}$$

Gas-Liquid Separator Design

Separators With or Without Mist Eliminator :

Total :

$$V_s = K \left[\frac{\rho_L - \rho_v}{\rho_v} \right]^{1/2}$$

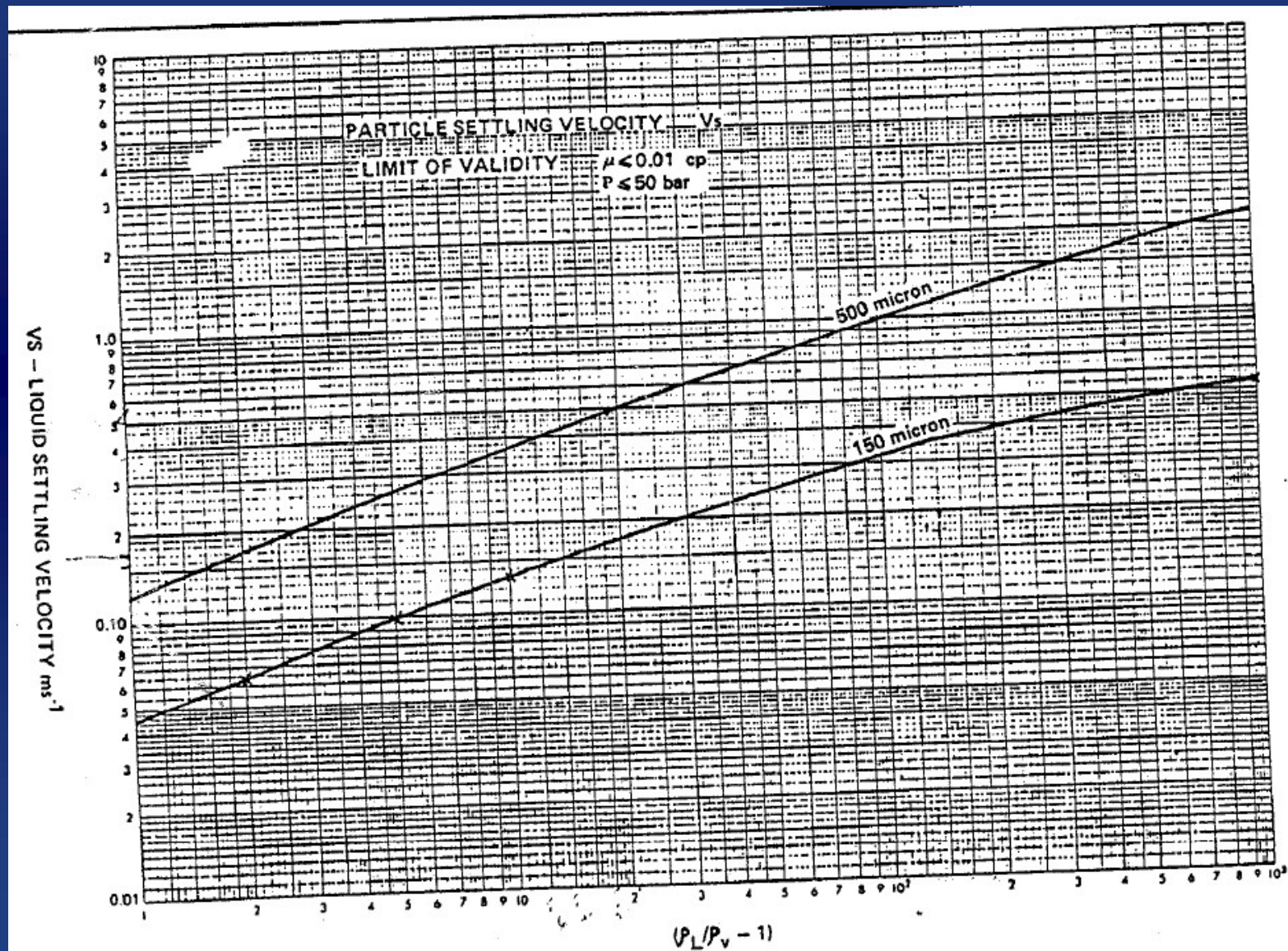
$$K = 0.003616 \left(\frac{D}{C} \right)^{1/2}$$

$\rho_{L,v}$ - liquid or vapour density kg/m³
 V_s - settling velocity m/s
 K = correlating parameter m/s
 D - particle diameter -microns
 C - drag coefficient
 μ - vapour viscosity - centipoise

- For medium and low pressure with gases of viscosity less than 0.01 cp Figure 1 can be used to estimate V_s .
- For higher pressures (> 50 bar) or viscosities in excess of 0.01 cp it is necessary to calculate V_s . The drag coefficient C is calculated using Figure in slide 9.

Gas-Liquid Separator Design

Figure 1



Gas-Liquid Separator Design

Vessel Volumes:

Horizontal Cylinder:

$$V_c = A1 \times L$$

- Partial volumes and areas of a horizontal vessel can be calculated using the estimated using the following equations:

$$A1 = \left[\frac{D^2}{4} \text{Arccos} \left(\frac{D-2h}{D} \right) \right] - \left[\left(\frac{D}{2} - h \right) (Dh - h^2)^{1/2} \right] \text{ in } m^2$$

D = inside diameter of the vessel, (m),

h = distance between the cylinder bottom and the liquid level, (m),

Arccos in radians

2 Dished Heads

$$V_{dh} = 0.21543 \times h^2 \times (1.5 \times D - h) \quad \text{in } m^3$$

2 Elliptical Heads

$$V_{eh} = 0.52194 \times h^2 \times (1.5 \times D - h) \quad \text{in } m^3$$

2 Hemispherical Heads

$$V_{hh} = 1.047 \times h^2 \times (1.5 \times D - h) \quad \text{in } m^3$$

Gas-Liquid Separator Design

Vessel Volumes:

Horizontal Cylinder:

$$V_c = A_1 \times L$$

- Partial volumes and areas of a horizontal vessel can be calculated using the following equations:

$$A_1/A_T = (\theta - \sin \theta)/(2 \pi)$$

$$\theta = 2 \arccos(1 - 2h/D), \theta \text{ in radians}$$

D = inside diameter of the vessel, (m),

h = distance between the cylinder bottom and the liquid level, (m),

2 Dished Heads

$$V_{dh} = 0.21543 \times h^2 \times (1.5 \times D - h) \quad \text{in m}^3$$

2 Elliptical Heads

$$V_{eh} = 0.52194 \times h^2 \times (1.5 \times D - h) \quad \text{in m}^3$$

2 Hemispherical Heads

$$V_{hh} = 1.047 \times h^2 \times (1.5 \times D - h) \quad \text{in m}^3$$

Volume up to Baffle

for depth

(elliptical heads)

$$= \frac{0.52194h^2(1.5D - h)}{2} + (A_1 \times B)$$

Gas-Liquid Separator Design

Vertical Separators with mist extractor sizing procedure:

1. Select a proper K factor and de-rate it, calculate settling velocity
2. Calculate allowable gas velocity based on 85% of settling velocity (TOTAL procedure) to allow sufficient margin (conservative) or take 100% of settling velocity based on proper inlet devices (GPSA).
3. Calculate drum diameter and select a diameter according to API12J recommendations (slide 23) (Add 3 to 6 in. to drum diameter to accommodate a support ring and round up to the next 6 in).
4. Calculate height as follows : (Let h be the height of vessel required for liquid

$$H = h + d_n + t + X + Y + 0.15 D_v$$

d_n = diameter of inlet nozzle

t = thickness of demister mat, usually 0.1 m

$X = 0.3 D_v$ with a minimum of 0.3 m

$Y = 0.45 D_v$ with a minimum of 0.9 m

} for a vessel equipped with half-open pipe inlet device

X : distance between HHLL to bottom inlet nozzle

Y : distance between top inlet nozzle to demister bottom

Gas-Liquid Separator Design

Vertical Separators with mist extractor sizing procedure (cont.):

- ☀ Calculate h (hold-up length) based on design criteria in slide 24 or use the following minimum requirement between LA(L) and LA(H) which shall be applied in the absence of other overriding process considerations :

Automatic control

4 minutes for product to storage

5 minutes for feed to a furnace

4 minutes for other applications

Manual control

20 minutes.

5. For vessel diameters of 0.8 m and greater, a vane-type inlet device is recommended. The diameter of the nozzle, may be taken equal to that of the feed pipe, but the following two criteria shall also be satisfied:

$$\rho_m V^2 \leq 6000 \text{ kg / m.s}^2$$

$$\rho_g V_{g,in}^2 \leq 3750 \text{ kg / m.s}^2$$

Gas-Liquid Separator Design

Vertical Separators with mist extractor sizing procedure (cont.):

6. When the vessel diameter is less than 0.8 m the feed nozzle should be fitted with a half-open pipe inlet device. The nozzle diameter may be taken equal to that of the feed pipe but the product $\rho_g \times V_g^2$ shall not exceed 1500 kg/m.s².
7. The diameter of the gas outlet nozzle should normally be taken equal to that of the outlet pipe, but the product $\rho_g \times V_g^2$,out shall not exceed 3750 kg/m.s².
The diameter of the liquid outlet nozzle shall be chosen such that the velocity in it does not exceed 1 m/s, but should preferably be lower. The nozzle shall be equipped with a vortex breaker.
8. Check the slenderness ratio to be between 2 and 4, if not change diameter and redo calculations.

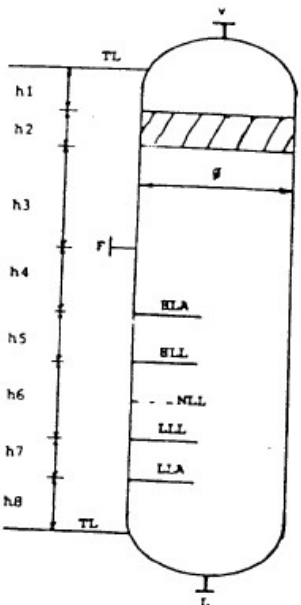
Example

Operating data :			
Pressure (operating)	bara	=	1.04
Temperature (operating)	°C	=	34
Gas MW		=	51.4
Gas flow rate	kg/h	=	7290
Gas density (T,P)	kg/m ³	=	2.1
Actual volume flow Q _g	m ³ /s	=	0.97
Liquid description : CRUDE OIL			
Liquid flow rate	kg/h	=	10390
Liquid density (T,P)	kg/m ³	=	210
Actual volume flow	m ³ /min	=	0.23
Particle size	microns	=	150

Gas-Liquid Separator Design

Vertical Separators with mist extractor sizing procedure (cont.):

☀ TOTAL procedure for height calculation :



$h1$: max (15 % of ϕ or 400 mm)

$h2$: 100 mm if mesh selected
 150 mm for compressor KO

$h3$: max (50 % of ϕ or 600 mm)

If no mesh use $h1 + h2 + h3 = 60 \% \phi$ or 800 mm

$h4$: $400 \text{ mm} + d/2$; $d = \text{inlet nozzle } \phi$

$h5$: calculate based on 1-2 minutes residence time at maximum liquid inflow (min 200 mm)

$h6$: base on following hold up times : (min 350)

- reflux drums	4 min	
- product drums	5 min	with pump
	3 min	no pump
- heater feed	8 min	
- HP sep. to LP sep.	4 min	

$h7$: 1-2 min residence time (minimum 150 mm)

$h8$: 150 mm for bottom connected LC
 300 mm for side connected LC

Note : For compressor suction drums that are normally dry set HLL at 450 mm above tan line and use bottom connected LC. This will reduce vessel height if required. No specific HLL-LLL hold up time required.

Gas-Liquid Separator Design

Vertical Separators without mist extractor sizing procedure:

1. Calculate settling velocity based on settling equations in slide 8,9 (use 150micron particles typically).
2. Calculate allowable gas velocity based on 85% of settling velocity (TOTAL procedure) to allow sufficient margin (conservative) or take 100% of settling velocity based on proper inlet devices (GPSA).
3. Calculate drum diameter and select a diameter according to API12J recommendations (slide 23).
4. Calculate height as follows : (Let h be the height of vessel required for liquid hold-up)

$$H = h + d_n + X + Y$$

Where:

- | | |
|-------|---------------------------------------|
| d_n | is Inlet nozzle diameter, in m; |
| X | is 0.3 D_v with a minimum of 0.3 m; |
| Y | is 0.9 D_v with a minimum of 0.9 m. |

Gas-Liquid Separator Design

Vertical Separators without mist extractor sizing procedure (cont.):

5. The feed nozzle shall be fitted with a half open pipe or a flow diverting box inlet device. The nozzle diameter, d_n , may be taken equal to that of the feed pipe but the product $\rho_g \times V_g^2$ shall not exceed 1500 kg/m.s^2 .
The diameter of the gas outlet nozzle should normally be taken equal to that of the outlet pipe, but the product $\rho_g \times V_g^2$,out shall not exceed 3750 kg/m.s^2 .
The diameter of the liquid outlet nozzle shall be chosen such that the velocity in it does not exceed 1 m/s , but should preferably be lower. The nozzle shall be equipped with a vortex breaker.
6. Check the slenderness ratio to be between 2 and 4 , if not change diameter and redo calculations.

Gas-Liquid Separator Design

Horizontal Separators with mist extractor sizing procedure:

1. Calculate settling velocity based on settling equations in slide 8,9 (use 500micron particles if vane type mist extractor and 150micron for wire mesh).
2. Calculate allowable gas velocity based on 85% of settling velocity (TOTAL procedure) to allow sufficient margin (conservative) or take 100% of settling velocity based on proper inlet devices (GPSA).
3. Select a diameter according to API12J recommendations (slide 23).
4. Select a slenderness ratio based on recommendations in slide 22 and calculate preliminary L. ($A_t = \pi \cdot D^2 / 4$)
5. Calculate liquid area (Al) based on hold-up requirements :
$$Al = (\text{Total liquid vol. flowrate}) / \text{hold-up Time} / L$$
6. Calculate hl (liquid height) from this [figure](#).

Gas-Liquid Separator Design

Horizontal Separators with mist extractor sizing procedure (cont.):

7. Calculate vapor height : $h_v = D - h_l$
8. Calculate liquid drop-out time : $\theta = h_v / \text{settling velocity}$
9. Calculate vapor velocity : $U_v = Q_v / A_v$, $A_v = A_t - A_l$
10. Calculate minimum length : $L_{\min} = U_v * \theta$
11. If $L_{\min} \leq L$, the selected L is ok , if not change diameter and return to step 5.

Gas-Liquid Separator Design

Horizontal Separators without mist extractor sizing procedure:

1. Calculate settling velocity based on settling equations in slide 8,9 (use 150micron particle diameter, if it is a flare KO drum use 300-600microns).
2. Calculate allowable gas velocity based on 85% of settling velocity (TOTAL procedure) to allow sufficient margin (conservative) or take 100% of settling velocity based on proper inlet devices (GPSA).
3. Select a diameter according to API12J recommendations (slide 23).
4. Select a slenderness ratio based on recommendations in slide 22 and calculate preliminary L then calculate total area. ($A_t = \pi \cdot D^2 / 4$)
5. Calculate liquid area (A_l) based on hold-up requirements :
 $A_l = (\text{Total liquid vol. flowrate}) / \text{hold-up Time} / L$
6. Calculate h_l (liquid height) from this [figure](#).

Gas-Liquid Separator Design

Horizontal Separators without mist extractor sizing procedure (cont.):

7. Calculate vapor height : $h_v = D - h_l$
8. Calculate liquid drop-out time : $\theta = h_v / \text{settling velocity}$
9. Calculate vapor velocity : $U_v = Q_v / A_v$, $A_v = A_t - A_l$
10. Calculate minimum length : $L_{\min} = U_v * \theta$
11. If $L_{\min} \leq L$, the selected L is ok , if not change diameter and return to step 5.

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.

- a. A single contingency results in the flow of 200,000 pounds per hour (25.2 kilograms per second) of a fluid with a liquid density of 31 pounds per cubic foot (496.6 kilograms per cubic meter) and a vapor density of 0.18 pound per cubic foot (2.9 kilograms per cubic meter), both at flowing conditions.
- b. The pressure is 2 pounds per square inch gauge (13.8 kilopascals gauge), and the temperature is 300°F (149°C).
- c. The viscosity of the vapor is 0.01 centipoise.
- d. The fluid equilibrium results in 31,000 pounds per hour (3.9 kilograms per second) of liquid and 169,000 pounds per hour (21.3 kilograms per second) of vapor.

Gas-Liquid Separator Design

Horizontal Separators with or without mist extractor sizing procedure (Total):

1. Calculate settling velocity V_s .
2. Derate this by $F = 0.85$ and calculate required vapour velocity V_m m /s.
$$V_m = V_s \times 0.85 \times L/D$$
3. Evaluate required vapour cross sectional area, A_v .
4. Assume drum is 70 % full i.e $h/D = 0.7$ and evaluate drum diameter to give required A_v , (to nearest 50 mm). For "dry" vessels use $h/D = 0.35$.
5. For required (liquid surge volume) calculate volume at HLL, if insufficient adjust D or L (note if L/D changes significantly recheck A_v using new V_m).
6. Set position of LLL in drum and confirm required surge volume between HLL-LLL. If volume is insufficient increase D, L or h. Include volumes in heads.

Gas-Liquid Separator Design

Horizontal Separators with or without mist extractor sizing procedure (Total):

7. When setting LLL height take into account any LSSL, LSL alarms and vortex breakers which may set minimum value usable. Usually 300-350 mm..

Notes :

- ☀ L is designated as the flow path length i.e distance between inlet and outlet nozzle. L' is the tangent-tangent length. For 1st estimates

$$L' = L + 1.5 d_1 + 1.5 d_2$$

d_1 = inlet nozzle diameter

d_2 = outlet nozzle diameter

- ☀ For high volumetric flows of gas with small liquid volumes consider using split flow arrangement. Design is as above but with half vapour volume *flow*.

- ☀ Normal design is with top entry, exit nozzles. However if space is limiting (primarily offshore) head mounted nozzles can be used to increase flowpath

Gas-Liquid Separator Design

Vapor-Liquid Experience Limits:

VAPOR-LIQUID SEPARATOR EXPERIENCE LIMITS

PARAMETER	LOWER LIMIT	UPPER LIMIT
Drum Diameter, ft (m)	0.7 (0.2)	25 (7.6)
Vapor Density, lb/ft ³ (kg/m ³)	0.005 (0.08)	5 (80)
Liquid Density, lb/ft ³ (kg/m ³)	20 (320)	80 (1280)
Surface Tension, dynes/cm or mN/m	2	75
Liquid Viscosity, cP or mPa•s	0.05	2
CWMS Liquid Loading, gpm/ft ² (dm ³ /s•m ²)	0.0 (0.0)	20 (13.6)
Foaming Tendency	NONE, except for Crude Flash Drums	

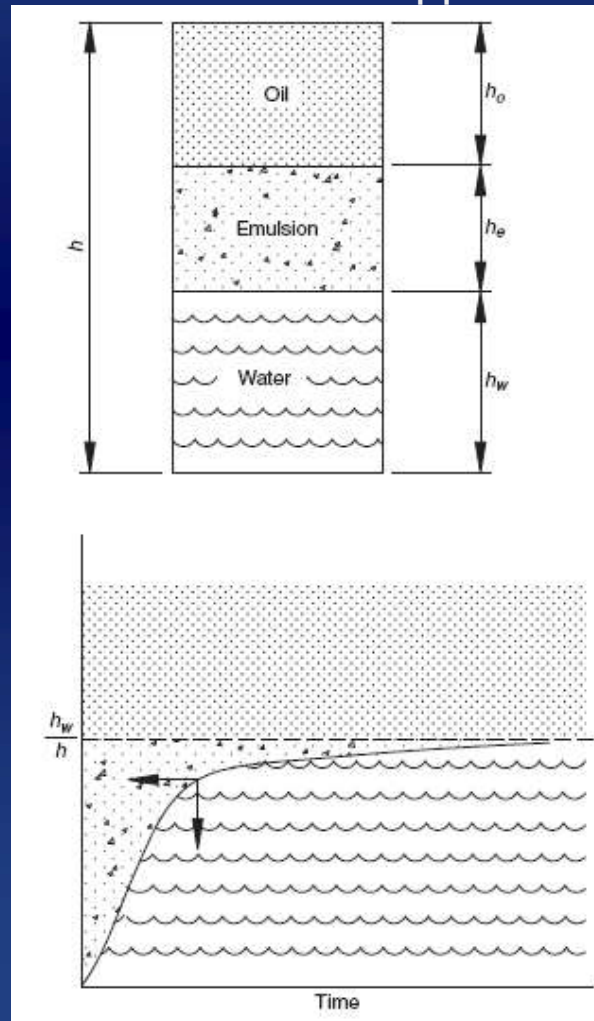
Gas-Liquid Separator Design

Selection between Horizontal and vertical separators:

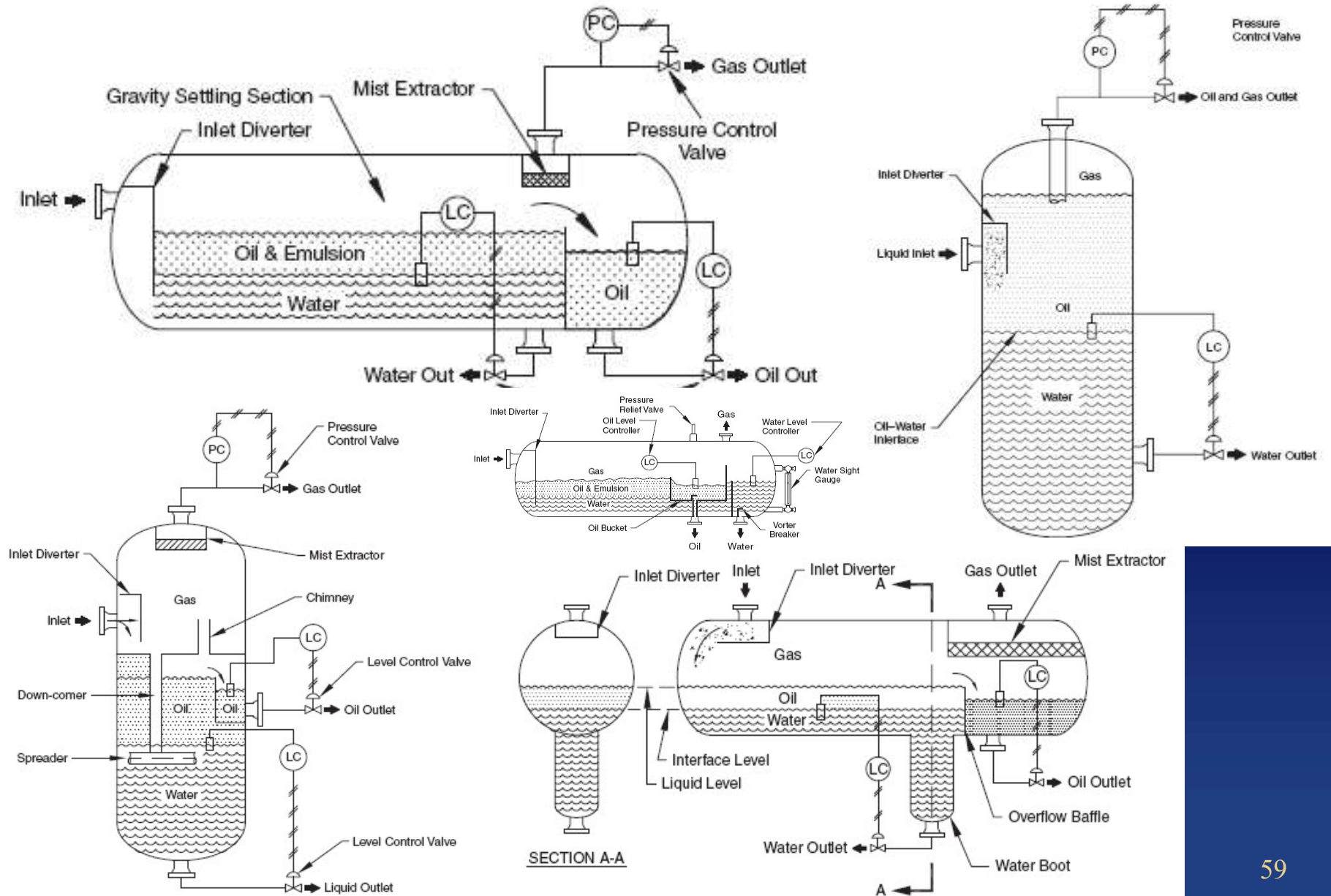
- ☀ Gravity separation is more efficient in horizontal vessels than in vertical vessels.
- ☀ Horizontal separators have greater interface areas, which enhances phase equilibrium. This is especially true if foam or emulsion collect at the gas–oil interface. Thus, from a process perspective, horizontal vessels are preferred.
- ☀ Horizontals do have several drawbacks, which could lead to a preference for a vertical vessel in certain situations:
 - Horizontal separators are not as good as vertical separators in handling solids.
 - Horizontal vessels require more plan area to perform the same separation as vertical vessels.
 - Small-diameter horizontal vessels [3-ft (1.5-m) diameter and smaller] have less liquid surge capacity than vertical vessels sized for the same steady-state flow rate.
- ☀ In summary, horizontal vessels are most economical for normal oil–water separation, particularly where there may be problems with emulsions, foam, or high gas–liquid ratios.

Gas-Liquid-Liquid Separator Design

- When oil and water are mixed with some intensity and then allowed to settle, a layer of relatively clean free water will appear at the bottom.

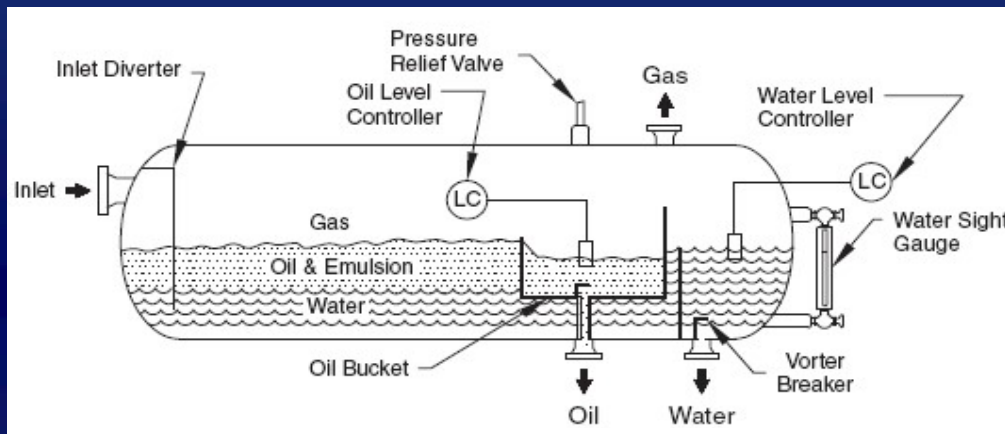


Gas-Liquid-Liquid Separator Design

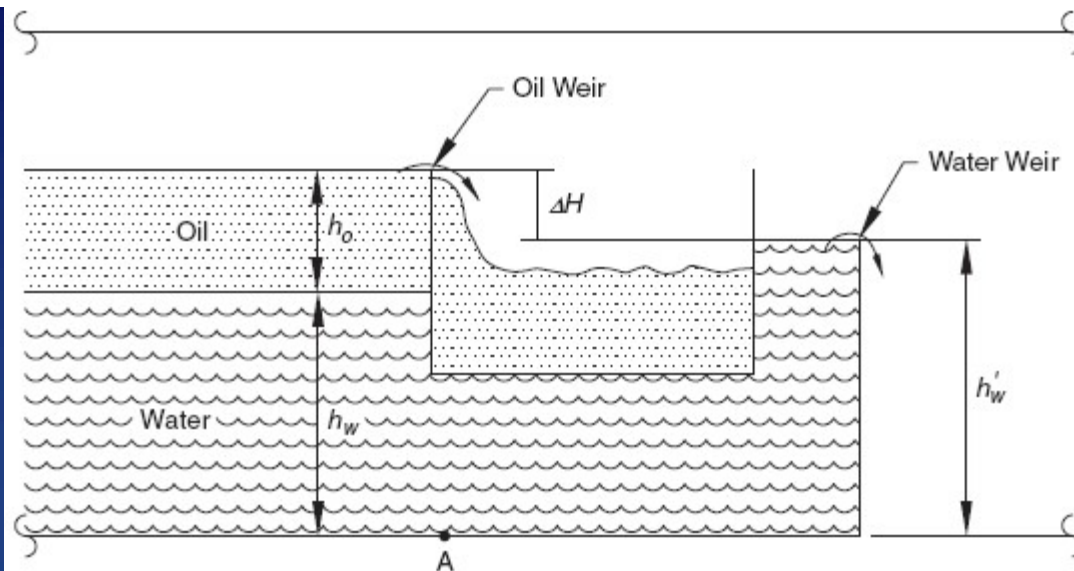


Gas-Liquid-Liquid Separator Design

- Three-phase separators with a bucket and weir design are most effective with high water-to-oil flow rates and/or small density differences.



$$\Delta h = h_o \left[1 - \left(\frac{\rho_o}{\rho_w} \right) \right]$$



Gas-Liquid-Liquid Separator Design

- ☀ 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.
- ☀ The gas capacity and retention time considerations establish certain acceptable combinations of diameter and length.

Typical Retention Times for Liquid-Liquid Separation

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

Gas-Liquid-Liquid Separator Design

Liquid-liquid Settling Velocity (Based On Stokes Law) :

- ★ The following equation can be used for calculating the settling velocity of water in oil or the upwards "settling" of oil in water. The important fact is to use the viscosity of the continuous phase i.e. : for oil settling upwards through water use the water viscosity, for water settling in oil use the oil viscosity.

$$U_t = \frac{g \times D^2 (\rho_H - \rho_l)}{18 \mu_c}$$

U_t	=	terminal velocity	m/s
g	=	gravitation acceleration	m/s ²
ρ_H	=	density heavy fluid	kg/m ³
ρ_l	=	density light fluid	kg/m ³
μ_c	=	viscosity (continuous phase)	kg/m.s
D	=	particle diameter	m

- ★ Setting the particle size to 125 microns and using more useful units gives :

$$U_t = 0.5108 \left(\frac{\rho_H - \rho_l}{\mu_c} \right)$$

U_t	in mm/min
μ_c	in centipoise
ρ	in kg/m ³

- ★ The above equation is valid for REYNOLDS number of 0.1 - 0.3.
- ★ If calculated settling velocity is > 250 mm/min use 250 max.

Gas-Liquid-Liquid Separator Design

Horizontal 3-phase Separators sizing procedure (Total):

Sufficient residence time to allow separation of the oil-water mixture as well as the oil surge and vapour flow areas must be provided.

1. Proceed with steps 1 to 4 as for a two phase separation. Use $L / D = 3$ (1st estimate) and evaluate L.
 2. Provision now has to be made to accommodate both oil and water surge volumes. Use Tan-Tan length L' and not nozzle-nozzle distance L.
 3. Calculate LLL required to give approximate 4 min oil surge capacity (minimum). Inspection will reveal whether sufficient height exists below LLL to include the interface levels. If not, adjust the vessel D or L to give sufficient room.
- ☀ Note: If the water cut is very small, consideration may be given water boot instead of a baffle arrangement see step 10.

Gas-Liquid-Liquid Separator Design

Horizontal 3-phase Separators sizing procedure (Total):

4. Having determined HLL and LLL now set both position and height of baffle. Calculate terminal settling velocity of water droplet and settling time at both HLL and LLL ($U_{t,W}$ and $U_{t,L}$). Volumetric flow of liquid is in both cases the oil plus the water. Calculate fall distance of a droplet across length of the drum. Baffle height and position can now be set noting:
 - the baffle should be at least 75 mm below the LLL.
 - the baffle should be at least 2/3 down the length of the drum from the Inlet.
 - in some cases the water droplets will settle to the floor in a short distance. The baffle should still be set at a minimum of 2/3 along the vessel.

Horizontal velocity at HLL: $V_{HLL} = (Q_W + Q_L) / A_{HLL}$

Vertical fall from HLL $= B \times U_{t,W} / V_{HLL}$

HLL - Vertical fall from HLL should be less than baffle height.

Gas-Liquid-Liquid Separator Design

Horizontal 3-phase Separators sizing procedure (Total):

Horizontal velocity at LLL: $V_{LLL} = (Q_W + Q_L) / A_{LLL}$

Vertical fall from LLL $= B \times U_{t,W} / V_{LLL}$

LLL - Vertical fall from LLL should be less than baffle height.

5. Set the HIL at baffle height - 75 mm. The LIL according to height determined by vortex breaker + LSL use a minimum of 300-350 mm.
6. Check If an oil droplet will rise through the water layer (from drum floor) to LLL before reaching water outlet. Use area at LLL with normal oil + water flowrates. (This criteria is very rarely governing but must be checked).

Horizontal velocity at LLL: $V_{LLL} = (Q_W + Q_L) / A_{LLL}$

Gas-Liquid-Liquid Separator Design

Horizontal 3-phase Separators sizing procedure (Total):

$$\text{Vertical rise within distance } B = B \times U_{t,L} / V_{LLL}$$

Vertical rise within distance B should be greater than baffle height.

7. Calculate water surge time between HIL and LIL, and residence time between NIL and outlet. Remember to use only one head volume, and length of drum up to baffle. Minimum acceptable times are 4-5 min. If calculated times are very long consider using a water boot arrangement.
8. Rationalise all dimensions and "tidy" levels to standard values if possible i.e: 150 mm, 200, 250, 300 etc. This allows use of standard displacers.
9. Recalculate all residence times based on "tidied" levels (if required).
Note: In calculating the final residence times make sure that the vessel tangent length is used and not the nozzle to nozzle distance L.

Gas-Liquid-Liquid Separator Design

Horizontal 3-phase Separators sizing procedure (Total):

10. Boot Calculation

If the water volumetric flow is so small as to not warrant a separate baffled settling compartment as detailed above a water boot should be used instead.

☀ To design proceed as follows:

1. Proceed as previous up to step 3.
2. Calculate settling distance of water droplet when vessel is operating at LLL. Water droplet should reach floor of drum before oil outlet. Remember that the oil exit nozzle will be raised above the floor as a standpipe. Adjust drum D or L to achieve settling.
3. Check that settling is also possible when operating at HLL. droplet to fall below drawoff nozzle level.

Gas-Liquid-Liquid Separator Design

Horizontal 3-phase Separators sizing procedure (Total):

4. Size water draw off boot diameter (*try to use standard pipe diameters*). Calculate rising velocity of the oil in water, set downward velocity of water in boot at 90% of this and evaluate boot diameter. Boot length by inspection (use standard displacers).

Note : Boot diameter must be less than 35% of vessel diameter.

Minimum diameter shall be 305 mm.

The height / diameter shall range from 2:1 to 5:1.

NOZZLE SIZING

- ☀ Inlet nozzle
 - Size based on normal volumetric flow + 10 % (liquid + vapour flow).
 - Limit inlet velocity to 7 - 13 m/s.
 - Round nozzle diameter up or down to nearest standard size.

Gas-Liquid-Liquid Separator Design

Horizontal 3-phase Separators sizing procedure (Total):

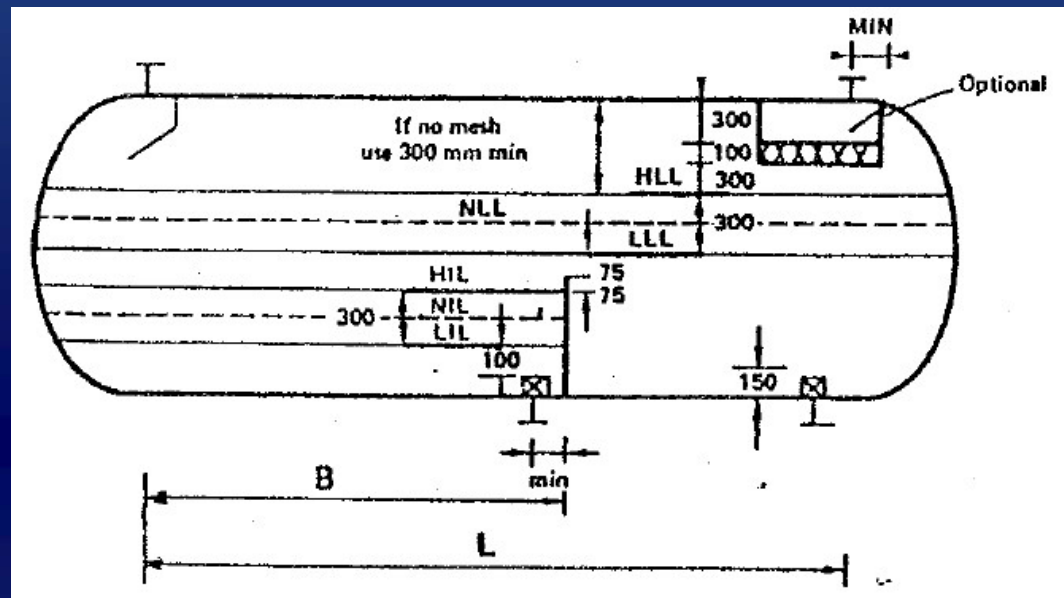
NOZZLE SIZING

- ✦ Gas outlet
 - Size on normal flow
 - Velocity limit 15-30 m/s

- ✦ Liquid outlet
 - Normal flow + 10%
 - Velocity limit 1-3 m/s HC
2-4 m/s water
 - Min. diameter = 2" (avoid plugging)

Gas-Liquid-Liquid Separator Design

Horizontal 3-phase Separators sizing procedure (Total):

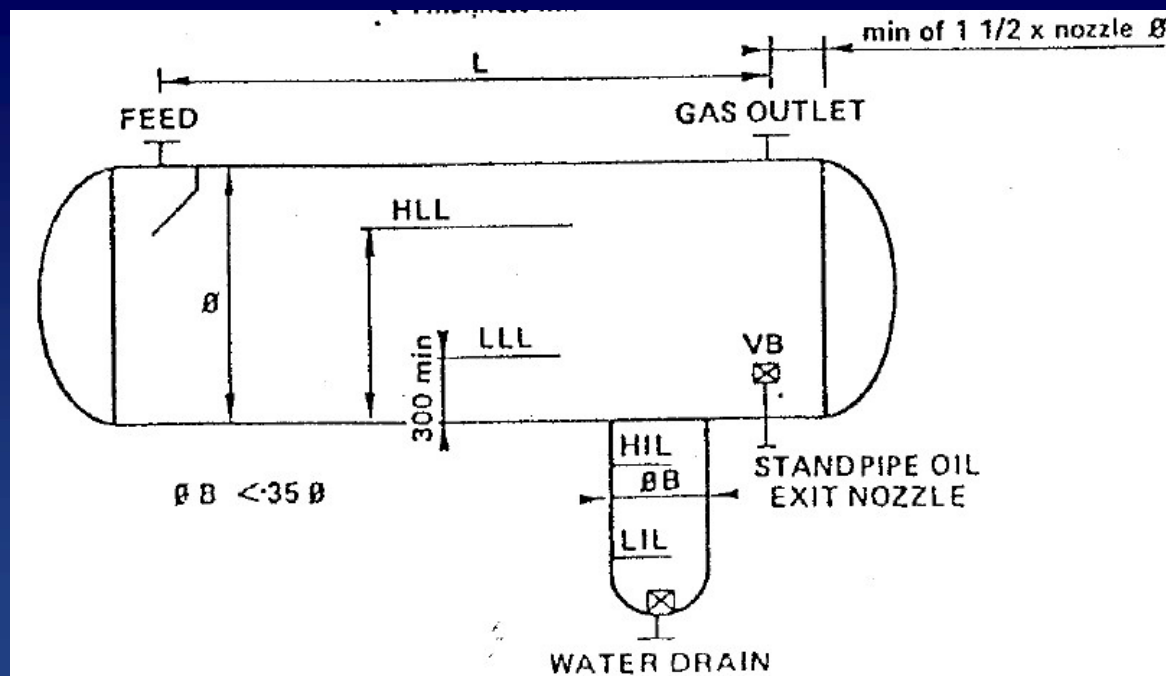


- ☀ OIL RESIDENCE TIME – Volume between NLL-NIL up to baffle only
use residence time of 3-6 minutes for design
- ☀ OIL SURGE TIME - Volume between HLL and LLL across full length of vessel
use 4-5 minutes if feeding to another column/vessel
5 minutes if pumping to storage
3 minutes if flowing to storage (no pump)
8 minutes if sole charge to fired heater

Gas-Liquid-Liquid Separator Design

Horizontal 3-phase Separators sizing procedure (Total):

- ☀ WATER RESIDENCE TIME - Volume between NIL and outlet
Use 4 minutes minimum
- ☀ WATER SURGE TIME - Volume between HIL and LIL
Use 4-5 minutes minimum



Mechanical Design

- ★ The following formulas are used in the ASME code Section VIII, Division 1 for determining wall thickness:

Wall Thickness—Cylindrical Shells

$$t = \frac{Pr}{SE - 0.6P},$$

Wall Thickness—2:1 Ellipsoidal Heads

$$t = \frac{Pd}{2SE - 0.2P},$$

Wall thickness—Hemispherical Heads

$$t = \frac{Pr}{2SE - 0.2P},$$

Wall Thickness—Cones

$$t = \frac{Pd}{2\cos \alpha (SE - 0.6P)}.$$

where S = maximum allowable stress value, psi (kPa), t = thickness, excluding corrosion allowance, in. (mm), P = maximum allowable working pressure, psig (kPa), r = inside radius before corrosion allowance is added, in. (mm), d = inside diameter before corrosion allowance is added, in. (mm), E = joint efficiency

Mechanical Design

Maximum allowable stress value for common steels (2007 Edition)					
<i>ASME Section VIII 2007 Edition</i>					
<hr/>					
<i>Div. 1</i> <i>Div. 2</i>					
<hr/>					
<i>Metal</i>	<i>Not Lower Than</i>		<i>-20 °F</i>	<i>-20 °F</i>	
<i>Temperature</i>	<i>Not Exceeding</i>		<i>650 °F</i>	<i>100 °F</i>	
<hr/>					
Carbon steel plates and sheets	SA-516	Grade 55	15,700	18,300	
		Grade 60	17,100	20,000	
		Grade 65	18,600	21,700	
		Grade 70	20,000	23,300	
	SA-285	Grade A	12,900	15,000	
		Grade B	14,300	16,700	
		Grade C	15,700	18,300	
	SA-36		16,600	16,900	
	Low-alloy steel plates	SA-387	Grade 2, cl.1	15,700	18,300
			Grade 12, cl.1	15,700	18,300
Grade 11, cl.1			17,100	20,000	
Grade 22, cl.1			17,100	20,000	
Grade 21, cl.1			17,100	20,000	
Grade 5, cl.1			17,100	20,000	
Grade 2, cl.2			20,000	23,300	
Grade 12, cl.2			18,600	21,700	
Grade 11, cl.2			21,400	25,000	
Grade 22, cl.2			21,400	25,000	
Grade 21, cl.2			21,400	25,000	
Grade 5, cl.2			21,400	25,000	
SA-203			Grade A	18,600	21,700
			Grade B	20,000	23,300
			Grade D	18,600	21,700
			Grade E	20,000	23,300
High-alloy steel plates	SA-240	Grade 304	20,000	20,000* *	
		Grade 304L	16,700	16,700	
		Grade 316	20,000	20,000	
		Grade 316L	16,700	16,700	

Austenitic stainless set at 2/3 yield/allowable stress, *not* 3.0 or 3.5 S.F due to low yield strength values relative to ultimate tensile strength, 304 UTS 75,000 Yield 30,000.
 Example: Hydrostatic testing $1.3 \times 20,000 = 26,000$ (Yield is 30,000) for 304.

Mechanical Design

- ☀ The shell weight can be estimated from (SI) :

$$W = 0.0254 dtL \quad (5.5b)$$

where W = weight, lb (kg), d = internal diameter, in. (mm), t = wall thickness, in. (mm), L = shell length, ft (m).

- ☀ The weight of one 2:1 ellipsoidal head is approximately (SI):

$$W \approx 9.42 \times 10^{-6}td^2 + 1.34 \times 10^{-3}td$$

- ☀ The weight of nozzles and internals can be estimated at 5–10% of the sum of the shell and head weights.
- ☀ The weight of pedestals for a horizontal vessel can be estimated as 10% of the total weight of the vessel.
- ☀ the weight of a skirt can be estimated as the same thickness as the shell (neglecting the corrosion allowance) with a length given by (SI) :

$$L = 2.5 \times 10^{-4}d + 0.61$$

where L = skirt length in ft (m)

References

- ✦ Engineering Data book , Gas Processors Suppliers Association (GPSA), 2004
- ✦ Specification for Oil and Gas Separators, API SPEC 12J
- ✦ ASME Section VIII Div 1
- ✦ Gas-Liquid and Liquid-Liquid Separators, K.Arnold, M.Stewart, Gulf pub. Company, 2008

Exercise

OFFSHORE TEST SEPARATOR

Operating data .

Operating pressure bara = 40

Operating temperature °C = 50

GAS MW

Mass flowrate kg/h = 4509

Density T,P kg/m³ = 35.0

Qg Vol flow m³/h = 129
 μ = 0.0103

Particle size microns = 150

CONDENSATE

ρ_c

Ql

μ_c

Flowrate kg/h = 31000

Density T,P kg/m³ = 725.4

Vol flow T,P m³/min = 0.71

Viscosity cp = 0.75

WATER CUT

ρ_w

Qw

μ_w

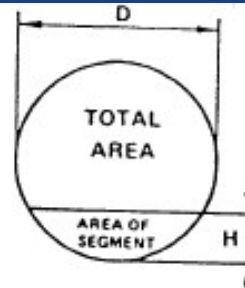
Flowrate kg/h = 9955

Density T,P kg/m³ = 988

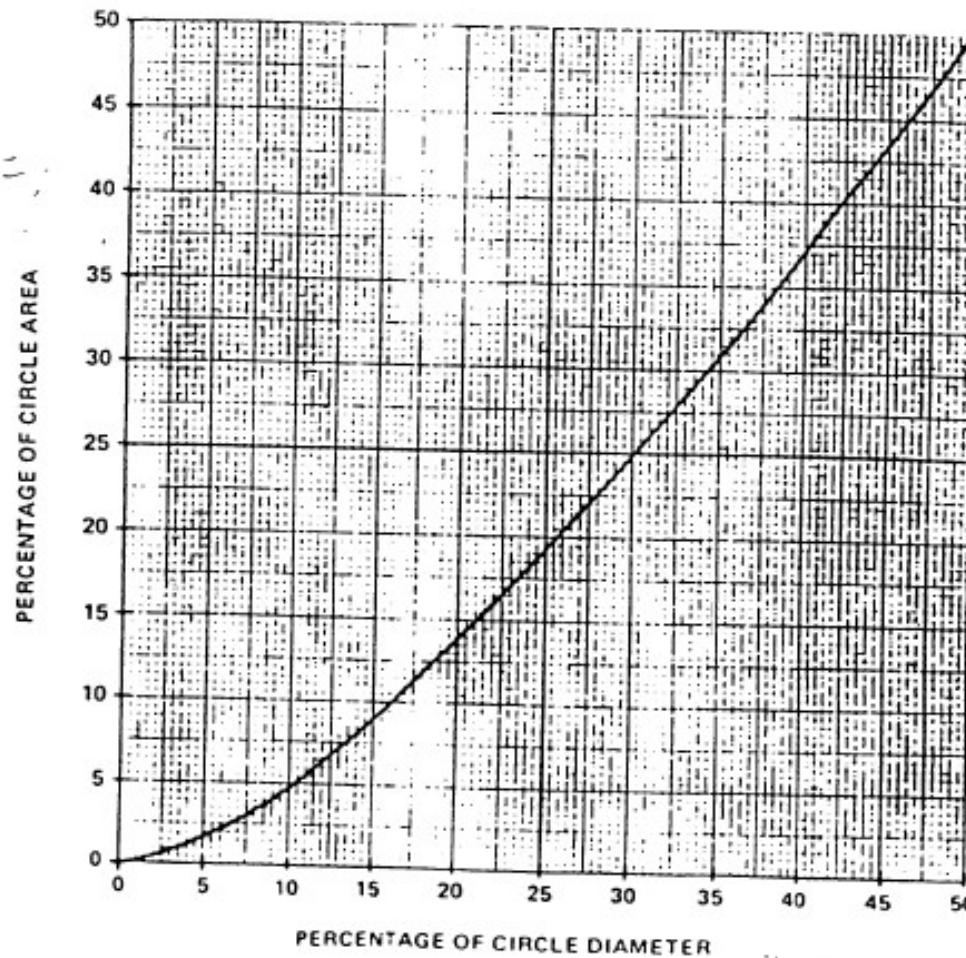
Vol flow T,P m³/min = 0.168

Viscosity cp = 0.54

Gas-Liquid Separator Design



$d = \frac{1}{2} D$
 $h = \dots$
 $g = \dots$



Gas-Liquid-Liquid Separator Design

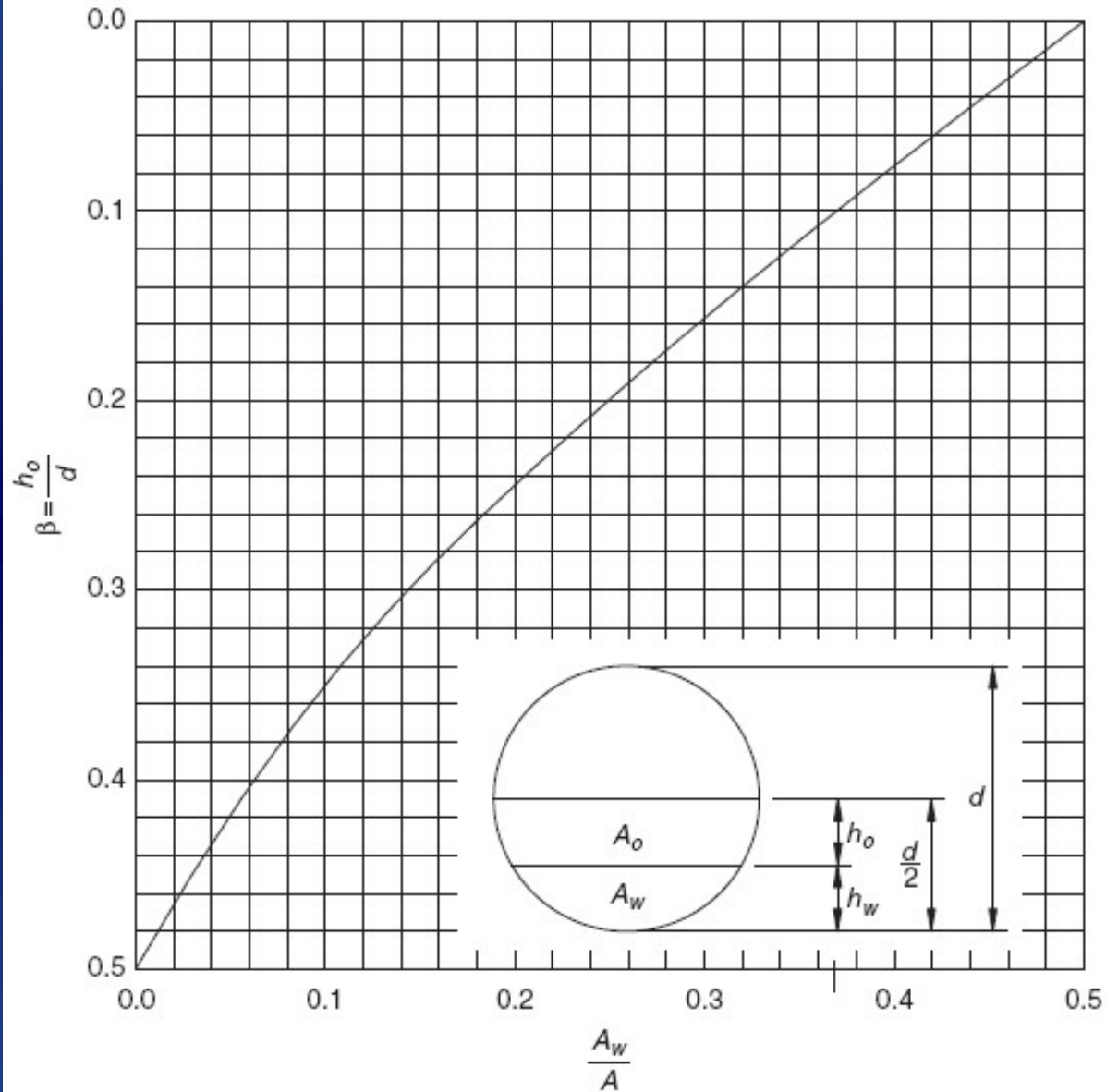


FIGURE 4.20. Coefficient “ β ” for a cylinder half filled with liquid.