



DESIGN PRACTICES

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Revision Memo

- 12/99** Highlights of this revision are:
- Figure 1** and Reference 2 added: *Vertical Drum Debottlenecking for Vapor / Liquid Services*, EE.43E.99.
 - Experience limits added.
 - References made to PEGASYS computer programs.
 - Updated vendor-designed separators.
 - Conservation reduced in **Eq. (9)**.



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SCOPE

This section covers the design of vapor-liquid separator drums, including internals (such as distributors, anti-vortex baffles and crinkled wire mesh screens). Information is also given on the influence of the flow characteristics in the inlet piping on separator drum performance.

- ✦ This section does not include information pertaining to the design of drums for Environmental or Safety purposes. For blowdown drums and flare seal drums, see **Design Practice Sections XV-D** and **XV-E**, respectively. For FCCU wet gas scrubber venturi separators, see **Environmental Design Practice Section XVIII-A5**.

In addition, this section does not discuss how to debottleneck existing drums when poor performance is observed or increased rates are planned. Techniques to evaluate vertical drums in debottlenecking situations are discussed in Reference 2. Debottlenecking considerations from that report are shown in **Figure 1**. That report rates vertical drums using drop sizes, a more fundamentally sound basis than critical velocity, which is used in this subsection. The report also provides guidance on estimating the drop size distribution to a separator, and the drop size effectively removed by drum internals including crinkled wire mesh screens, vane-type mist eliminators, packing and grid. There is not yet an equivalent report or rating approach for horizontal drums. For debottlenecking of drums for critical separations, engineers are advised to contact the Fractionation and Thermodynamics Section at ER&E.

REFERENCES

DESIGN PRACTICES

Section III	Fractionating Towers
Section XI	Compressors
Section XII	Instrumentation
Section XIV	Fluid Flow
Section XV	Safety in Plant Design

OFFSITE DESIGN PRACTICES

Section XXV	Fuel Systems
Section XXVI	Steam Facilities

INTERNATIONAL PRACTICES

IP 5-1-1,	Pressure Vessels
IP 5-1-2,	Additional Requirements for Heavy-Wall Pressure Vessels, Thickness Over 2 Inches
IP 5-2-1,	Internals for Towers, Drums and Fixed Bed Reactors
IP 7-2-1,	Industrial Boilers

OTHER REFERENCES

1. Harleman, D. R., *Selective Withdrawal from a Vertically Stratified Fluid*, Intern Assoc. Hydro. Research, 8th Congress, August, 1959.
- ✦ 2. Maloney, D. P., Pagendarm, S. M., and Peruyero, J. M. A., *Vertical Drum Debottlenecking for Vapor / Liquid Services*, EE.43E.99, January 1999.
3. Marut, T. P., *Design Criteria for Flash Drums in Crude Preheat Service*, EE.79E.85, December, 1985.
4. Patterson, F. M., *Experimental Investigation of Critical Submergence for Vortexing in a Vertical Cylindrical Tank*, M.S. Thesis, University of Southern California, 1967.
5. Peruyero, J. M. A., *Design Criteria for Liquid/Gas Vertical Separator Drums*, EE.34E.73, April, 1973.
6. Peruyero, J. M. A., *Performance of Horizontal Liquid/Gas Separator Drums*, EE.71E.75, August, 1975.
7. Stober, B. K., *Carryover Reduction from Refinery and Chemical Plant Steam Drums*, EE.91E.79, August, 1979.

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DEFINITIONS

General definitions applicable to the design of separator drums are presented below:

Crinkled Wire Mesh Screen (CWMS) - Crinkled wire mesh screens are porous blankets of wire or plastic knitted mesh, which are used for removing entrained liquid drops from a vapor stream. CWMS is available in a wide variety of densities and wire diameters. Recommended CWMS densities and wire diameters are given in [IP 5-2-1, Internals for Towers, Drums and Fixed Bed Reactors](#). When vapor and entrained liquid drops pass through a CWMS, the vapor moves freely through the mesh pad, but the drops, because of their greater inertia, cannot follow the gas stream and are collected on the screen wires. The liquid collected on the wires runs down to the bottom surface and drops off the screen. If the liquid rate entrained to the CWMS is too high or if the vapor rate is too high, however, CWMS flooding will occur. To prevent this, the drum and the CWMS should be sized using the criteria given in this section.

▶ **Critical Velocity** - Critical velocity is an empirically calculated vapor velocity used to specify the maximum superficial vapor velocity through the separator drum. It is not related to sonic velocity, and at superficial velocities above the critical velocity there is no step change in liquid entrainment. Critical velocity is defined by **Eq. (1)**.

$$V_C = C_1 \left(\frac{\rho_L - \rho_G}{\rho_G} \right)^{0.5} \quad \text{Eq. (1)}$$

where: V_C = Critical velocity, ft/s (m/s)
 C_1 = Empirical constant = 0.157 ft/s (0.048 m/s)
 ρ_L = Liquid density at conditions, lb/ft³ (kg/m³)
 ρ_G = Vapor density at conditions, lb/ft³ (kg/m³)

The area used for calculating vapor velocity in a horizontal drum is the vertical cross-sectional area above high liquid level (or emergency liquid level, if applicable); for a vertical drum, it is either the horizontal cross-sectional area of the drum or that of the CWMS if a CWMS is used.

Liquid Separation Efficiency - Liquid Separation Efficiency is defined by **Eq. (2)**.

$$E = 100 \left(\frac{F - C}{F} \right) \quad \text{Eq. (2)}$$

where: E = Separation efficiency, %
 F = Liquid feed rate to the drum, lb/h (kg/s)
 C = Liquid carryover in the drum overhead, lb/h (kg/s)

Normal Gas Flow - Normal gas flow is the design gas rate fed to a separator drum at typical operating conditions (i.e., in the absence of upsets such as surges due to process instabilities or to the loss of upstream condensing capacity). CWMS in drums sized for 100% of critical velocity and horizontal drums with both vertical CWMS and horizontal CWMS will be highly effective at gas throughputs of 150% of normal gas flow, and therefore, no surge allowance is typically required for sizing these drums. If surges larger than 150% are anticipated for these drums, the Fractionation/Thermodynamics section of ER&E should be consulted.

Maximum Gas Flow - Maximum gas flow is equal to the sum of the design gas rate fed to a separator drum at typical operating conditions plus the gas rate due to upsets such as surges due to process instabilities or the loss of upstream condensing capacity. Maximum gas flow should be used for sizing CWMS in vertical drums via **Eq. (4)** when maximum separation efficiency should be maintained during upsets such as in reciprocating compressor services.

Vane-Type Mist Eliminator - Vane-Type Mist Eliminators are zig-zag baffles which are used for removing entrained liquid drops from a vapor stream. Spacing between the baffles, turning angles and number of passes are designed to satisfy specific removal requirements. When the vapor and the entrained liquid drops pass through a vane-type mist eliminator, the vapor moves freely through the baffles, but the drops, because of their greater inertia, impinge upon the walls of the baffles. The liquid collected on the baffles runs down to the bottom surface and drops off the mist eliminator. Typically a vane-type mist eliminator is more resistant to fouling than a CWMS due to larger physical openings. Design and sizing of vane-type mist eliminators are carried out by the vendor. Typical vendors include Koch-Glitsch, Munters, and Peerless Manufacturing Co.

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APPLICATION

Ordinary vapor-liquid separator drums use gravity to separate liquid from vapor. Such drums are effective for removal of drops larger than about 200 to 400 micrometers (microns) (μm). Use of crinkled wire mesh screen increases the separation effectiveness so that drops down to about 5 to 10 μm can be removed. The liquid separation efficiency of ordinary drums without CWMS is typically 95 to 99.5%. Installation of a horizontal CWMS in the drum vapor space typically increases the liquid separation efficiency to perhaps 99.9% or more.

Where plugging of the CWMS may occur, such as in RESIDFINER and slurry services, other devices are available for the 5 to 10 μm drop size range; e.g., proprietary cyclone type separators, filter/separators and tailor designed vertical drums with tangential inlet nozzles and annular rings. For sizing the latter drums for these services, the Fractionation/Thermodynamics Section of ER&E should be consulted. When extremely fine droplets are to be removed, e.g., fogs due to rapid condensation from saturated gas or due to a chemical reaction, more efficient proprietary equipment is available. Two-stage filter/separators can be effective on drops down to about 2 μm , while Venturi scrubbers and electrostatic precipitators separate drops significantly smaller than 1 μm . Brownian diffusion can be utilized to separate smaller drops, e.g., Peerless Manufacturing Company's absolute separators which consist of minicyclones followed by a coalescer.

In selecting the proper separation device, the designer must consider both the desired degree of liquid removal from the gas stream and the acceptable droplet size. In some cases a fine mist may not be detrimental to downstream equipment, whereas large drops of liquid could be. On the other hand, even a fine mist may be a highly undesirable contaminant because of corrosiveness or catalyst poisoning.

For foaming services, consultation with the Fractionation and Thermodynamics Section of ER&E is recommended. Drum designs for these services tend to be service specific. Porta-Test International manufactures centrifugal separators that have been applied in debottlenecking non-Exxon drums, and ER&E is currently evaluating their technology.

In a few situations, it may be justified to install an inline separator to collect entrained liquid. Inline separators operate by centrifugal force and have low liquid holdup. "T-type" separators, installed in horizontal pipe runs, are preferred because of their higher efficiency, especially at moderate and high liquid rates. In general, inline separators are capable of removing droplets larger than approximately 10 μm in diameter; however, specific cut-point information should be obtained from the particular vendor. Vendors include: (1) Hayward Industrial Products (Wright Austin Division) of Elizabeth, New Jersey, and (2) Pennsylvania Separator Corp. of Brookville, Pennsylvania. Proposals for inline separators should be reviewed by an ER&E Separation Specialist.

Other technology is available from vendors that can be utilized in unique situations; for example, to remove solid particles as well as liquid droplets from feed to hydrogen reciprocating compressors. These include filter/separators or filter coalescers from Peco, King Tool and Pall. Each of these devices utilizes a filter coalescer in front to increase the size of the drops and to remove solid particles either to protect downstream processes, or to increase the run length of the mist eliminating element contained in the vendor's package. An ER&E Separation Specialist should be consulted if any of these devices are being considered.

EXPERIENCE LIMITS FOR VAPOR-LIQUID SEPARATORS

Experience limits for the design of vapor-liquid separators are provided in the following table. If an application is outside these bands, contact an ER&E Separation Specialist.

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	

BASIC DESIGN CONSIDERATIONS

The considerations discussed below are the basis for the design procedures given later in this section for designing drums except for those listed in **Table 1** or for drums in foaming services. The Fractionation/Thermodynamics Section of ER&E should be consulted for setting the design criteria for separator drums in foaming services. The design procedures for drums listed in **Table 1** are covered in **DESIGN PROCEDURES** under GUIDELINES FOR SPECIFIC SERVICES.

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BASIC DESIGN CONSIDERATIONS (Cont)

FLOW REGIME IN THE INLET PIPING

Different flow regimes may be present in the inlet piping of process separator drums. These flow regimes are defined in [Section XIV-D, Two-Phase \(Vapor-Liquid\) Flow](#).

Separator drums are normally designed with annular/spray or spray flow in the inlet piping. With this type of flow, liquid carryover increases with increasing gas velocity in the inlet piping. The presence of stratified flow, annular flow below onset of liquid entrainment, or wavy flow in the inlet piping of separator drums would increase the liquid separation efficiency of the drum to perhaps 99.8%. However, these types of flow are not usually encountered in process operations, because relatively large pipe diameters would be required. Nevertheless, the design of inlet piping to achieve these flow regimes should be considered for special services in which low entrainment rates are essential but a CWMS or other internals are not permitted; e.g., because it is a severely fouling service. Conservative estimates of the mixture velocities in the inlet piping for which drops are not entrained in annular pipe flow are given in **DESIGN PROCEDURES**, under *Maximum Permissible Velocity in Annular Flow Without Drop Formation*.

Slug flow or bubble flow should be avoided in the inlet piping to vertical separator drums. These flow regimes result in excessive liquid carryover and vibration. If these flow regimes cannot be avoided at the drum inlet, liquid carryover can be minimized by use of a horizontal drum with two inlet nozzles and a central vapor outlet nozzle (preferred choice) or a vertical drum with a slotted distributor (second choice). If only slug flow is typically present in the inlet piping, a vertical drum with a tangential inlet nozzle and an annular ring will be more effective than one with a slotted distributor.

DRUM ORIENTATION

Separator drums are generally oriented with their axes horizontal or vertical. Vertical drums require less plot area, but horizontal drums typically are smaller in volume for high liquid loading service. Horizontal drums erected below other equipment such as condensers will reduce the structural material needed to support the entire circuit equipment. Because interfaces are more quiescent, horizontal drums are preferred where two liquid phases are separated and for services in which the flow regime in the inlet piping is slug flow or bubble flow.

Horizontal drums with one inlet nozzle will be more effective than vertical drums whenever the ratio of drum length to vapor space height is greater than one. Horizontal drums with two inlet nozzles will be more effective than vertical drums whenever the ratio of the drum length to vapor space height is two or greater. This improved effectiveness of horizontal drums results from the drops settling perpendicular to the gas flow, rather than countercurrent to gas flow as in vertical drums.

REENTRAINMENT AT THE LIQUID SURFACE

In many operations, especially at high pressure and temperature, liquid can be reentrained from the liquid surface and carried overhead. Reentrainment rate depends on the gas velocity in the inlet piping, the inlet nozzle type, the distance from the inlet nozzle to the liquid level or impinging surface, the surface tension of the liquid, and the densities and viscosities of the liquid and gas. Criteria for estimating the maximum mixture velocity leaving the inlet nozzle below which reentrainment will not occur are given in **DESIGN PROCEDURES** under *Preventing Entrainment from the Liquid Surface*.

NOZZLES

- ◆ **Size** - Inlet and outlet nozzles typically are line size. However, if reentrainment at the liquid surface might occur, the inlet nozzle diameter may be increased upstream of the drum (five line diameters in length). Generally the smallest instrument connection used for process vessels is 2 in. (50 mm) except for thermowells which are 1 1/2 in. (40 mm).

Inlet Nozzle Type and Orientation - Inlet nozzle type depends on the flow regime in the inlet piping, on the separator internals and the type of service. Recommended inlet nozzle types are given in [Table 3](#). Inlet nozzle orientations are shown in [Figures 2, 4, 5, 8](#) and [A](#) (under **SAMPLE PROBLEM**).

DISTRIBUTORS

- ◆ Distributors for vapor-liquid separators are not designed for good distribution. Instead they are designed for low slot (or hole) velocity to minimize the formation and entrainment of small bubbles or droplets, see [Eqs. \(3d\), \(3e\) and \(3f\)](#).

Perforated-pipe distributors should be T-shaped, with feed entering at the center and flowing toward both ends. For vertical drums, the distributor slots (or holes) should be located within a 120° included angle on the bottom portion of the header ([Figure 2](#)). For horizontal drums, the distributor slots (or holes) should point toward the near head of the drum, within 60° of the horizontal (see [Figure A](#) under **SAMPLE PROBLEM**). No openings should be placed directly opposite the entrance leg. For mechanical strength the minimum permissible distance between two adjacent slots (or holes) is equal to the distributor pipe thickness.

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BASIC DESIGN CONSIDERATIONS (Cont)

LIQUID HOLDUP

Design liquid holdup is usually determined by process, control or emergency requirements. Process requirements for various typical services are given in **Table 1**. Control and emergency requirements are covered in **Design Practices Sections XII, Instrumentation**, and **XV-D, Safety in Plant Design-Disposal Systems**, respectively. The Fractionation/ Thermodynamics Section of ER&E should be consulted for setting the minimum permissible liquid holdup time for new services, especially for potentially foaming services. Holdup in vertical and horizontal drums may be calculated using the values given in **Tables 2 and 5**, respectively.

ANTI-VORTEX BAFFLES

Anti-vortex baffles should be installed above all liquid outlets to minimize vortex formation with subsequent gas carryunder. Design criteria for anti-vortex baffles are given in **DESIGN PROCEDURES**, under *Design Criteria for Anti-Vortex Baffles*.

DESIGN CONSIDERATIONS FOR SELECTED SERVICES

LIQUID SURGE AND DISTILLATE DRUMS

Horizontal separator drums with CWMS are used for clean services; filter/separators or proprietary multiple cyclones are recommended for services in which solids or fouling materials are present.

COMPRESSOR SUCTION, COMPRESSOR INTERSTAGE, AND GAS TURBINE FUEL (GAS) SEPARATOR DRUMS

Vertical separator drums with CWMS are used for clean services; however, the CWMS should be composed of two 6-in. (150 mm) thick layers with 10 lb/ft³ (160 kg/m³) material on the top and 5 lb/ft³ (80 kg/m³) material on the bottom. The presence of solids, typically due to excessive corrosion problems, should be avoided by selecting adequate piping materials. When this is impractical, proprietary filter/separators (such as Peco filters) or gas scrubbers should be provided upstream of the compressor or gas turbine to mitigate compressor or fuel nozzle fouling problems.

The designer should also consider the installation of a vertical drum with a horizontal tangential inlet and an annular ring upstream of the filter/separator. This will significantly reduce the solids content in the feed to the filter/separator, thereby increasing the total gas volume that can be processed by the filter elements. The Machinery Engineering Section or the Fractionation/Thermodynamics Section of ER&E should be consulted for specific design criteria for separators in services containing solids.

To eliminate the presence of liquid in the feed to the compressor or gas turbine, the following steps should also be taken:

- The designer should ensure that the drum will operate satisfactorily under all process conditions, e.g., regeneration (if applicable), startup, normal operation, upsets, etc.
- Level High Alarms and Level High Cut Outs should be properly located in the drum.
- The distance from the drum to the compressor should be minimized. In addition, the suction line should be insulated and sloped away from the compressor. Heat tracing of the line should also be specified if calculations show that line insulation will not prevent condensation.
- In addition to the above, for reciprocating compressors, the compressor cylinder jacket inlet water temperature should be maintained between 10 to 15°F (6 to 8°C) above the gas inlet temperature to prevent condensation in the cylinder and valve areas.
- In addition to the above, for gas turbines, the fuel should be superheated 50°F (28°C) above its dew point.

It is sometimes economical to combine the compressor suction drum service with another drum service, such as in the distillate drum of a catalytic cracking unit primary fractionator. In such cases, the emergency liquid surge requirements for compressor suction service are added to the other service requirements. Horizontal drums with CWMS are common in this type of combination service.

LUBE OIL SEPARATORS FOR COMPRESSOR DISCHARGE

Lubricating oil from reciprocating and sliding-vane compressors can be carried into the compressor discharge gas stream as extremely fine droplets. Lube oil separators should be specified for instrument air and for processes which cannot tolerate the presence of this oil. **Section XI-O, Compressor Unit Piping and Process Train Equipment**, covers the types of lube oil separators commercially available, their estimated separation efficiency, pressure drop, and relative cost.

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DESIGN CONSIDERATIONS FOR SELECTED SERVICES (Cont)

FUEL GAS SEPARATOR DRUMS FOR FURNACES

Separator drums should be located on the fuel supply to the furnaces to collect slugs of condensate during upsets and to prevent excessive liquid entrainment to the furnace burners. For clean fuel gas service, a vertical separator drum with CWMS and sized for 100% of critical velocity at normal gas flow rate should be used. For sour and corrosive fuel gas services, the use of vertical drums with tangential inlet nozzles and annular rings or separator drums with proprietary multiple cyclones, such as Peerless dry scrubber or U.O.P. Multiclones or demonstrated equivalent, are recommended to minimize fouling and plugging of burners.

FUEL GAS SYSTEM CENTRAL COLLECTION DRUMS

A fuel gas system central collection drum (see **Offsite Design Practices Section XXV, Fuel Systems**) is designed to remove gross liquid entrainment. Either a vertical or a horizontal separator drum without CWMS is recommended for this service. The allowable vapor velocity through the drum is 100% of critical velocity at design gas flow rate. The allowable velocity through the vertical drum could be increased to 200% of critical velocity at maximum gas flow rate if a tangential inlet nozzle and an annular ring are used. Five minutes liquid holdup at the maximum liquid rate is provided. Other design criteria are given in **Offsite Design Practices Section XXV**.

STEAM DRUMS IN BOILER SERVICE

When steam is fed to a superheater, a steam turbine, or a reformer, steam drums should be designed as follows:

1. For **waste heat boilers** of the shell and tube or kettle reboiler type operating with steam pressures less than 700 psig (4820 kPa gage), vertical or horizontal separator drums with CWMS should be used.
 - a. For vertical separator drums, the CWMS and the drum vapor space are sized for 100% of critical velocity at design steam flow rate. The design shown in **Figure 2** is preferred; however, the CWMS should be composed of two 6-in. (150 mm) thick layers with 10 lb/ft³ (160 kg/m³) material on the top and 5 lb/ft³ (80 kg/m³) material on the bottom.
 - b. For horizontal separator drums, a combination of vertical and horizontal CWMS as shown in **Figure 5** is preferred. However, the vapor space and CWMS areas should be based on 100% of critical velocity at design steam rate. The density of the vertical and horizontal CWMS should be 5 lb/ft³ (80 kg/m³) and 10 lb/ft³ (160 kg/m³), respectively. Because of the potential foaming of the boiler water, the minimum permissible distance between CWMS bottom and the water is 18 in. (450 mm). When these criteria are satisfied in the absence of foaming, the liquid entrainment in the drum overhead should be less than 150 to 300 weight ppm (mg/kg).
 - c. For both horizontal and vertical separator drums, the maximum permissible velocity in the inlet piping depends on steam pressure as shown below:

STEAM PRESSURE		MIXTURE VELOCITY IN INLET PIPING	
psig	kPa gage	ft/s	m/s
100	690	30	9.1
200	1380	20	6.1
400	2760	15	4.6
600	4100	10	3.0
600+	4100+	(1)	

Note:

- (1) The Fractionation/Thermodynamics Section of ER&E should be consulted for sizing steam drums at pressures higher than 600 psig (4100 kPa gage).

2. Steam drums for **any other boiler type**, e.g., fired boilers, should be designed by the boiler vendor according to specifications given in **IP 7-2-1, Industrial Boilers**.

Impurities - The maximum permissible solids, alkalinity and silica content of the boiler water is a function of the boiler operating pressure as shown in **Offsite Design Practices Section XXVI-A, Boiler Feedwater Treating**.

WATER DISENGAGING DRUMS

Disengaging drums are provided to remove small amounts of hydrocarbon liquid and vapor contaminants from aqueous plant effluent streams to permit them to be safely discharged to the sewer. The design basis for these disengaging drums is described in **Section XV-D**.

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DESIGN CONSIDERATIONS FOR SELECTED SERVICES (Cont)

BLOWDOWN DRUMS

The main purpose of a blowdown drum is to disengage fluid streams from closed safety valve releases and from various drainage blowdowns, and to convert them into liquid and vapor streams which can be safely disposed of. Criteria for selection and design of blowdown drums are given in [Section XV-D](#).

FEED SEPARATOR DRUMS FOR AMINE SCRUBBERS

Hydrocarbon entrainment in the gas feed to amine scrubbers can result in foaming, with subsequent excessive carryover in the scrubber. In refineries, an integral separator drum in the bottom of the amine scrubber is used for the removal of most of the liquid entrainment due to condensation in the line. A schematic diagram of this drum is given in [Figure 6](#). This separator should contain a CWMS in its vapor space and the gas velocity through the drum and the CWMS should be 100% of critical velocity at design gas rate. In chemical plants (steam crackers), a superheater in lieu of a separator drum may be used to prevent condensation in the scrubber.

HIGH-PRESSURE SEPARATORS

High-pressure separators, e.g., hot, high-pressure separators in hydrodesulfurization units, are designed to minimize both gas carryunder and liquid holdup volume, because of process debits of lost gas (H_2) and high drum costs, respectively.

A horizontal separator drum with either a horizontal CWMS or a combination of two vertical and one horizontal CWMS should be used for clean services (see [Figure 5](#)).

When entrainment should be reduced to a value equal to or less than 1 lb (1 kg) of liquid per 100 lb (100 kg) of gas and a CWMS cannot be used because of the possibility of plugging by coking, the mixture velocity in the inlet piping should not exceed 20 ft/s (6.1 m/s) to prevent forming very small drops. In addition, the vapor space should be sized for 100% of critical velocity at design gas rate, a slotted distributor inlet should be installed at each end of the drum, and the drum should have a single vapor outlet nozzle. Design criteria for preventing gas carryunder in the underflow of these drums are given in [Table 1](#) under *High-Pressure Separators*.

The following criteria, which allow for the foaming potential of liquids, are recommended for the design of separator drums in RESIDFINER service:

- A horizontal separator drum with two inlet nozzles and one vapor outlet nozzle should be used.
- The vapor space area should be sized for 100% of critical velocity at design gas rate.
- Reentrainment at the liquid surface should be prevented using appropriate equations given in **DESIGN PROCEDURES** under *Preventing Entrainment from the Liquid Surface*.
- The maximum mixture velocity in the inlet piping should be 16 ft/s (4.9 m/s).
- The minimum liquid residence time below low liquid level should be two minutes and the minimum vertical height below low liquid level should be 18 in. (450 mm).
- Facilities should be provided for the injection of anti-foaming agents into the feeds to the separator drums.
- Two or three gage glasses at various overlapping elevations should be installed to detect the presence of foam.

The Fractionation/Thermodynamics Section of ER&E should be consulted for design criteria for high pressure separators in synthetic fuels plants since they should be handled on a case by case basis.

CRUDE PREHEAT FLASH DRUMS

These drums can experience severe foaming, which can result in both vapor carryunder and overhead liquid entrainment. These phenomena can reduce refinery crude capacity by as much as 30% by such mechanisms as downstream pump cavitation, uneven furnace pass balancing, reduced APS flash zone temperature, and system upsets too severe to control.

To cope with foaming, crude flash drums require high liquid holdup, low superficial liquid and vapor velocities, as well as other design features. In most cases, the use of an antifoam agent cannot be economically justified or may have adverse process consequences. The design criteria detailed below are specific for refinery services, and therefore, are not applicable to crude oil production separators. The Fractionation / Thermodynamics Section of ER&E should be consulted on crude preheat flash drum design since emerging technology may result in drum size reduction.

Horizontal Crude Flash Drum Design Criteria - A horizontal separator with two inlet nozzles (see [Figure 12](#)) is recommended for this service since, compared to a vertical separator, it maximizes the surface area available for vapor/liquid separation, minimizes foam height, and provides a quiescent zone that enhances bubble disengagement. A horizontal CWMS or vane type mist eliminator is provided to remove small drops that would otherwise be entrained in the vapor leaving the drum.

Other key design criteria are summarized in [Figure 12](#) and its attached notes.

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DESIGN CONSIDERATIONS FOR SELECTED SERVICES (Cont)

Vertical Crude Flash Drum Design Criteria - Although a horizontal drum configuration is preferred for crude flash service, if plot space limitations do not allow a horizontal drum design, then a vertical drum design can be used (see **Figure 13**). However, a vertical drum will typically be larger, more expensive and less tolerant of upsets than a horizontal drum. The design criteria for vertical crude flash drums is basically the same as for horizontal drums with the following exceptions:

- A tangential inlet nozzle with an annular ring should be provided.
- A distance equivalent to 0.8 times the drum diameter should be provided between the bottom of the annular ring and the HLL.
- Four vertical anti-swirl baffles should be provided below the NLL. These baffles should extend from 6 in. (150 mm) below the NLL to the bottom tangent line. The baffle width should be about 10% of the drum diameter. Their purpose is to prevent vortex formation which may result in vapor carryunder.
- The horizontal CWMS or vane-type mist eliminator below the vapor outlet should occupy the entire drum cross sectional area.
- Minimum vertical height from the LLL to the **bottom tangent line** should be 3 ft (900 mm).

A complete list of design criteria for the vertical crude flash drum is given in **Figure 13** and its attached notes.

DESIGN PROCEDURES

GUIDELINES FOR SPECIFIC SERVICES

The procedure given below is recommended for designing a separator drum for any of the following services:

- Liquid surge and distillate drums.
- Compressor suction, compressor interstage, and gas turbine fuel (gas) separator drums.
- Lube oil separators for compressor discharge.
- Fuel gas separator drums for furnaces.
- Steam drums in boiler service.
- Feed separator drums for amine scrubbers.
- High-Pressure separators.
- Crude preheat flash drums.

Step 1 - Locate in **Table 1** the typical design criteria for the service. Additional design criteria are given in the main text under **DESIGN CONSIDERATIONS FOR SELECTED SERVICES**.

Step 2 - Based on the drum configuration selected in Step 1, use the corresponding drum drawing (**Figures 2, 4, 5, 8 and A** under **SAMPLE PROBLEM**) as a guide for drum design. In addition, see the specific design criteria given below for the type of drum selected, e.g., *Vertical Separator Drums With and Without CWMS*.

Step 3 - Size the drum vapor space using the area for calculating vapor velocity given under Definitions, Critical Velocity. For horizontal drums, use a length to diameter ratio of 3 to 4. Generally this results in minimum size and lowest cost. The diameter of a vertical drum is typically based on critical velocity criteria, other drum dimensions should be sized per **Figure 2. Table 2** shows areas and volumes of various size drums with 2:1 ellipsoidal heads.

Step 4 - Select the type of inlet nozzle using criteria given in **Tables 1 and 3**, and herein for specific types of separator drums.

Step 5 - Calculate the inlet nozzle diameter using criteria given below under *Preventing Entrainment from the Liquid Surface*.

Step 6 - For drums with CWMS, estimate the minimum permissible distance between the top of the CWMS and the gas outlet nozzle, based on criteria given below under *Distance from Top of CWMS to Gas Outlet Nozzle*. For corrosive services, the CWMS should be made of suitable materials of construction. Suitable grating supports should be provided at the top and bottom of horizontal CWMS, and at the sides of vertical CWMS. Grids recommended for these services are described in **IP 5-2-1, Internals for Towers, Drums and Fixed Bed Reactors**.

Step 7 - Size the anti-vortex baffles and estimate the minimum permissible distance from LLL (low liquid level) to liquid outlet nozzle, using criteria given under *Design Criteria for Anti-Vortex Baffles*.

For services not covered in **Table 1** select the type of separator drum using the criteria given in **BASIC DESIGN CONSIDERATIONS**. However, the Fractionation/Thermodynamics Section of ER&E should be consulted for setting the minimum permissible liquid holdup time, especially for potentially foaming services. Then proceed with the drum design following Steps 2 to 7, above.

For critical services in which entrainment must be minimized and/or plugging of CWMS due to solids or fouling may occur, the Fractionation/Thermodynamics Section of ER&E should be consulted.

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DESIGN PROCEDURES (Cont)

DESIGN METHODS FOR ALL DRUMS

The following design methods, equations, and guidelines must be used for all drum designs.

Preventing Entrainment from the Liquid Surface

Criteria for estimating the maximum mixture velocity leaving the inlet nozzle, such that entrainment will not occur at the liquid surface, are given below:

1. Vertical Drums

a. Flush Inlet Nozzles

$$V_E = \frac{(C_2) \sigma}{f \mu_G \left(\frac{\rho_G}{\rho_L} \right)^{0.5}} \quad \text{for } h \leq 2.5 d_p \quad \text{Eq. (3a)}$$

and

$$V_E = \frac{(C_3) \sigma}{f \mu_G \left(\frac{\rho_G}{\rho_L} \right)^{0.5} \left(\frac{d_p}{h - 0.5 d_p} \right)^{0.5}} \quad \text{for } h > 2.5 d_p \quad \text{Eq. (3b)}$$

b. 90° Elbow Inlet Nozzles

$$V_E = \frac{(C_4) \sigma}{f \mu_G \left(\frac{\rho_G}{\rho_L} \right)^{0.5}} \quad \text{Eq. (3c)}$$

c. Slotted Distributors

$$V_E = \frac{(C_5) \sigma}{\mu_G \left(\frac{\rho_G}{\rho_L} \right)^{0.5}} \quad \text{for } \frac{x}{s_{\text{slot}}} \leq 5 \quad \text{Eq. (3d)}$$

and

$$V_E = \frac{(C_6) \sigma}{\mu_G \left(\frac{\rho_G}{\rho_L} \right)^{0.5} \left(\frac{s_{\text{slot}}}{x} \right)^{0.5}} \quad \text{for } \frac{x}{s_{\text{slot}}} > 5 \quad \text{Eq. (3e)}$$

d. Holed Distributors

Use **Eq. (3d)** for $\frac{x}{d_h} \leq 5$

and

$$V_E = \frac{(C_7) \sigma}{\mu_G \left(\frac{\rho_G}{\rho_L} \right)^{0.5} \left(\frac{d_h}{x} \right)} \quad \text{for } \frac{x}{d_h} > 5 \quad \text{Eq. (3f)}$$

e. Tangential Inlet Nozzle with Annular Ring.

DESIGN PROCEDURES (Cont)

The mixture velocity in the inlet piping should not exceed 220 ft/s (67m/s) or the value given by **Eq. (3g)** below, whichever is smaller.

$$V_E = \frac{C_8 \sigma \left(\frac{\rho_L}{\rho_G} \right)^{0.5}}{\mu_G} \quad \text{Eq. (3g)}$$

The nomenclature for **Eqs. (3a) to (3g)** is:

- V_E = Maximum mixture velocity at the exit of the inlet nozzle, such that entrainment will not occur at the liquid surface, ft/s (m/s)
- f = Jet velocity dissipation factor. As shown in **Figure 7**, f is a function of the distance x from the inlet nozzle to the impinging surface and the inlet nozzle diameter, d_p . [f is not used in **Eqs. (3d), (3e), and (3f).**]
- h = Distance from bottom of inlet nozzle to high liquid level (HLL), in. (mm)
- d_p = Inlet nozzle diameter, in. (mm)
- d_h = Hole diameter, in. (mm)
- s_{slot} = Slot height, in. (mm). Typically, slots are long and narrow. Slot height is the narrow dimension.
- x = Distance from the inlet nozzle to the impinging surface, in. (mm) (see **Figure 7**). For vertical drums with flush inlets, x is the drum diameter. x is equal to h for vertical drums with either slotted (or holed) distributors or 90° elbows.
- μ_G = Vapor viscosity at conditions, cP (mPa•s)
- ρ_G = Vapor density at conditions, lb/ft³ (kg/m³)
- ρ_L = Liquid density at conditions, lb/ft³ (kg/m³)
- σ = Liquid surface tension at conditions, dynes/cm (mN/m)

EMPIRICAL CONSTANTS	CUSTOMARY UNITS	METRIC UNITS
C_2	6.8×10^{-4}	2.1×10^{-4}
C_3	4.6×10^{-4}	1.4×10^{-4}
C_4	5.3×10^{-4}	1.6×10^{-4}
C_5	5.3×10^{-4}	1.6×10^{-4}
C_6	2.3×10^{-4}	7.0×10^{-5}
C_7	1.0×10^{-4}	3.1×10^{-5}
C_8	6.3×10^{-3}	1.9×10^{-3}

2. Horizontal Drums

- a. **90° Elbow Inlet Nozzles** - Use **Eq. (3c)**. However, for this case, x (in **Figure 7**) is the distance from the nozzle to the near head of the drum.
 With a combination of vertical and horizontal CWMS, the maximum permissible mixture velocity is five times the value calculated using **Eq. (3c)**.
 Without vertical CWMS (with or without horizontal CWMS), the maximum permissible mixture velocity is twice the value calculated using **Eq. (3c)**.
- b. **Slotted or Holed Distributors** - Use **Eqs. (3d), (3e) or (3f)**, whichever is applicable. However, in this case, x is the distance from the distributor to the near head of the drum.
 With a combination of vertical and horizontal CWMS, the maximum permissible mixture velocity is five times the value calculated using the appropriate equation.
 Without vertical CWMS (with or without horizontal CWMS), the maximum permissible mixture velocity is twice the value calculated using the appropriate equation.

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Maximum Permissible Velocity in Annular Flow Without Drop Formation

A conservative estimate of this mixture velocity is given by **Eq. (3h)**:

$$V_I = \frac{(C_g) \sigma}{\mu_G \left(\frac{\rho_G}{\rho_L} \right)^{0.5}} \quad \text{Eq. (3h)}$$

where: V_I = Mixture velocity in the inlet piping, below which velocity liquid drops are not entrained in annular pipe flow, ft/s (m/s)
 C_g = Empirical constant = 5.9×10^{-4} Customary units (1.8×10^{-4} Metric units)
 Other terms are described in the nomenclature.

Vertical Separator Drums With and Without CWMS

For services in which a moderate liquid carryover of up to 5 lb (5 kg) of liquid per 100 lb (100 kg) of gas is permissible, CWMS are not required and the vapor space in the drum should be sized for 100% of critical velocity at design gas flow rate. For critical services in which liquid entrainment should be reduced to less than 1 lb (1 kg) of liquid per 100 lb (100 kg) of gas, a 5 lb/ft³, 6 in. (80 kg/m³, 150 mm) thick CWMS is recommended. For foaming services, both the drum and the CWMS horizontal cross-sectional area should be sized for 100% of critical velocity at design gas flow rate. Specific design criteria for sizing CWMS in vertical drums in selected services are detailed in **Table 1** and under **DESIGN CONSIDERATIONS FOR SELECTED SERVICES**. For all other services, the drum and the CWMS should be sized for either 100% of critical velocity at normal gas flow rate or the value given by **Eq. (4)** below, whichever is larger.

$$V_{C,MAX} (\%) = 225 K_{\sigma\mu} (C_{10})^{L_L} \left(\frac{(D-2W)^2}{D^2} \right) \quad \text{Eq. (4)}$$

where: $V_{C,MAX}(\%)$ = Maximum allowable percent of critical velocity at maximum gas flow rate, %
 $K_{\sigma\mu}$ = Surface tension - viscosity parameter, dimensionless, see **Figure 3**
 L_L = Maximum liquid loading which is the maximum liquid feed rate divided by the drum horizontal cross-sectional area, gpm/ft² (dm³/s•m²)
 D = Drum diameter, ft (mm)
 W = CWMS support ring width, ft (mm)
 C_{10} = Empirical constant = 0.953 Customary units (0.932 Metric units)

The last term in **Eq. (4)** accounts for the reduction in area for vapor flow at the bottom of the CWMS due to the presence of the CWMS support ring. A support ring 2 in. (50 mm) wide is typically recommended for these services.

The procedure for calculating both the vertical drum diameter and the CWMS diameter using **Eq. (4)** is detailed below.

1. Calculate the maximum vapor flow rate, ft³/s (dm³/s).
2. Calculate critical velocity, ft/s (m/s).
3. From **Figure 3** read $K_{\sigma\mu}$ at the viscosity of the liquid (μ_L) and surface tension (σ), or calculate $K_{\sigma\mu}$ using **Eqs. (5), (6), and (7)** below.

$$\sigma_{STD} = 10 \left[1.68 - \frac{0.276}{(\mu_L)^{0.45}} \right] \quad \text{Eq. (5)}$$

$$f_{(\sigma\mu)} = \frac{\sigma - \sigma_{STD}}{[\sigma \sigma_{STD}]^{0.5}} \quad \text{Eq. (6)}$$

$$K_{\sigma\mu} = 1.24 f_{(\sigma,\mu)} \quad \text{Eq. (7)}$$

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DESIGN PROCEDURES (Cont)

4. Assume a trial diameter (D) and calculate its corresponding cross-sectional area.
5. Calculate the maximum liquid loading, L_L .
6. Calculate the actual percent of critical velocity ($V_{C,ACTUAL}\%$) at the trial diameter.
7. Calculate the maximum allowable percent of critical velocity using **Eq. (4)**.
8. Calculate the ratio of the actual percent of critical velocity to the maximum allowable percent of critical velocity.
9. Approximate the next trial drum diameter using the ratio calculated in Step 8 as given below.

$$D_{NEW} = D \left(\frac{V_{C, ACTUAL} (\%)}{V_{C, MAX} (\%)} \right)^{0.5} \quad \text{Eq. (8)}$$

10. Repeat calculations starting from Step 5 until actual percent of critical velocity is in reasonably good agreement with the maximum permissible percent of critical velocity.

The above steps assume that the drum cross-sectional area is determined by the vapor loading. A larger drum diameter will be required if the liquid holdup requirement sets the drum cross-sectional area.

For cases in which the turndown ratio is between three and six, two CWMSs should be used in series. The cross-sectional area of the bottom CWMS should be based on 100% of critical velocity or the value calculated using **Eq. (4)**, whichever is larger. The cross-sectional area of the top CWMS should be one-third of the bottom CWMS cross-sectional area. The distance between the two CWMSs should be about 2 ft (600 mm).

Since the liquid loading which a CWMS can handle without flooding decreases with increasing density of the CWMS, the Fractionation/Thermodynamics Section of ER&E should be consulted for the design of separator drums with any other type of CWMS. Additional design criteria are given in **Figure 2**.

Vertical Separator Drum with Horizontal Tangential Inlet and Annular Ring

This type of drum is currently recommended for the following services: 1) fouling and corrosive fuel gas services (see *Fuel Gas Separator Drums for Furnaces*), 2) central collection drum for fuel gas system, 3) services in which slug flow regime is present in the inlet piping (see **Table 3**); and 4) non-condensable blowdown services (see **Section XV-D, Safety in Plant Design - Disposal Systems**).

The designer should also consider the use of this drum upstream of a Peco filter for compressor services in which solids or fouling materials are present. It will significantly reduce the solids loading into the Peco filter, thereby increasing the total gas volume that can be processed by its filter elements which require replacement when fouled. Finally, tailor-designed vertical drums with tangential inlet nozzles and an annular ring are currently being used in slurry services such as Flexicoker Venturi separator drums. The Fractionation/Thermodynamics Section of ER&E should be consulted for developing specific design criteria for slurry services.

The following design criteria should be used for sizing a vertical drum with horizontal tangential inlet(s) and an annular ring:

- The horizontal cross-sectional area for vapor flow should not exceed 200% of critical velocity at maximum gas flow rate.
- The core area for upward vapor flow, i.e. the drum cross-sectional area minus the annular ring area, should not exceed 300% of critical velocity at maximum gas flow rate (see **Figure 8**).
- A distance equivalent to the drum diameter should be provided between the bottom of the annular ring and the solid circular baffle.
- To prevent reentrainment of the liquid film which collects on the separator wall, the mixture velocity in the inlet piping should not exceed 220 ft/s (67 m/s) or the value given by **Eq. (3g)**, whichever is smaller.

When the drops are formed by the interaction between the liquid and the vapor in the inlet piping, liquid separation efficiencies of 99.8% plus can be attained if the calculated value for the following expression exceeds C_{11} .

$$\frac{C_T \rho_L \sigma^2 (1+n)}{\mu_G D (\rho_G)^2 (V_s)^3} \geq C_{11} \quad \text{Eq. (9)}$$

where: C_T = Annular ring configuration factor, dimensionless
 n = Vortex exponent, dimensionless
 V_s = Mixture velocity in inlet piping, ft/s (m/s)
 C_{11} = Empirical constant = 500 Customary units (3.6 Metric units)



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DESIGN PROCEDURES (Cont)

When only one inlet nozzle is used, C_T is given by the following expression

$$C_T = 16 \left(2 + \frac{12D}{d_p} - \frac{3d_p}{12D} \right) \quad \text{Eq. (10)}$$

For two inlet nozzles, the value of C_T is 50% of the value calculated using **Eq. (10)**. The value of the vortex exponent, n , is given by the following expression:

$$n = C_{12} D^{0.14} \quad \text{Eq. (11)}$$

where: C_{12} = Empirical constant = 0.567 Customary units (0.255 Metric units)

Horizontal Separator Drums With and Without Horizontal CWMS

For services in which a moderate amount of entrainment is permissible [e.g., up to 5 lb (5 kg) of liquid per 100 lb (100 kg) of gas], CWMSs are not required and the vapor space in the drum should be sized for 100% of critical velocity at normal gas flow rate. The inlet nozzle(s) should terminate in either a 90° elbow or a slotted distributor, pointing toward the near head of the drum.

For clean, low entrainment services, a 6-in. thick, 5 lb/ft³ horizontal (150 mm thick, 80 kg/m³) CWMS should be installed in the vapor space, to reduce liquid carryover to less than 1 lb (1 kg) of liquid per 100 lb (100 kg) of gas. In addition, drums larger than 3 ft (1 m) in diameter should have an inlet nozzle at each end and a single central vapor outlet nozzle. The drum and the CWMS area for vapor flow should be sized for 100% of critical velocity at design gas flow rate. Additional design criteria are given in **Figure 4**.

Horizontal Separator Drums with Both Vertical and Horizontal CWMS

For clean services in which liquid carryover should be reduced to less than 1 lb (1 kg) of liquid per 100 lb (100 kg) of gas, the vapor velocity through the drum vapor space can be increased by 25% (to 125% of V_c) if two vertical and one horizontal CWMS are installed in the vapor space (see **Figure 5**). The drum should have an inlet nozzle at each end, terminating in either a 90° elbow or a slotted distributor, and a single central vapor outlet nozzle. A 6-in. thick, 5 lb/ft³ (150 mm thick, 80 kg/m³), vertical CWMS should be located between each inlet nozzle and the 6 in. thick, 5 lb/ft³ (150 mm thick, 80 kg/m³), horizontal CWMS. The vertical CWMS should cover the area for vapor flow and should extend at least 6 in. (150 mm) below the low liquid level. The area for vapor flow (in the drum and through the CWMS) should be sized for 125% of critical velocity at design gas flow rate.

Horizontal drums with both vertical CWMS and horizontal CWMS are smaller than horizontal drums with horizontal CWMS. However, with small low-pressure drums, the savings from the smaller diameter may be offset by the extra cost of the vertical CWMS.

Distance from Top of CWMS to Gas Outlet Nozzle

For both vertical and horizontal drums, the distance from the top of the CWMS to the gas outlet nozzle should be adequate to prevent flow maldistribution through the CWMS. The minimum distance for this purpose is given by **Eq. (12a)**:

$$h_o = \frac{C_{13} D_{CWMS} - d_o}{2} \quad \text{Eq. (12a)}$$

where: h_o = Minimum distance from top of CWMS to gas outlet nozzle, in. (mm)
 D_{CWMS} = Diameter of a round CWMS, or long side of a rectangular CWMS, ft (mm)
 d_o = Outlet nozzle diameter, in. (mm)
 C_{13} = Constant = 12 for Customary units (1 for Metric units)

If this distance is impractical, a slotted gas collector (preferred choice) or a solid circular baffle located between the CWMS and the gas outlet nozzle, should be used. If neither of these two alternatives is satisfactory, contact the Fractionation and Thermodynamics Section of ER&E for a perforated plate vapor distributor.