

 DESIGN PRACTICES	DRUMS LIQUID-LIQUID AND VAPOR-LIQUID-LIQUID SEPARATORS PROPRIETARY INFORMATION - For Authorized Company Use Only	Section V-B	Page 1 of 23
		December, 2003	

Changes shown by ↕

CONTENTS

Section	Page
Scope	3
References	3
DESIGN PRACTICES	3
ENVIRONMENTAL DESIGN PRACTICES	3
GLOBAL PRACTICES	3
OTHER REFERENCES	3
DEFINITIONS	4
APPLICATION	4
BASIC DESIGN CONSIDERATIONS	5
INLET NOZZLES	5
LIQUID HOLDUP FOR PROCESS, CONTROL, AND SAFETY REQUIREMENTS	5
DROPLET SETTLING	5
DROPLET SETTLING VELOCITY	5
VAPOR SPACE	6
PREVENTION OF LIQUID REENTRAINMENT	6
SETTLING POTS	7
SETTLING BAFFLES	7
DUAL- MEDIA CRINKLE WIRE MESH SCREEN (DM-CWMS)	8
DRAWING NOTES	8
DESIGN PROCEDURE	8
DESIGN OF HORIZONTAL SETTLERS (WITH OR WITHOUT SETTLING BAFFLES)	8
DESIGN OF THREE COMPARTMENT HORIZONTAL SETTLERS	9
DESIGN CONSIDERATIONS FOR SELECTED SERVICES	9
FEED SEPARATOR DRUMS FOR SOUR WATER STRIPPERS AND AMINE REGENERATORS	9
SAMPLE PROBLEM	10
DESIGN BASIS	10
SOLUTION	11
NOMENCLATURE	16
COMPUTER PROGRAMS	16
APPENDIX	17

**Documents**

Document Sharing Hub

Section	Page	DRUMS	ExxonMobil
V-B	2 of 23	LIQUID-LIQUID AND VAPOR-LIQUID-LIQUID SEPARATORS	
December, 2003		PROPRIETARY INFORMATION - For Authorized Company Use Only	DESIGN PRACTICES

Section**Page****TABLE**

Table 1	Settling Drum Design Criteria	17
Table 2	Coalescence Media Application And Design Considerations	17

FIGURES

Figure 1	Typical Liquid-Liquid Settling Drum ⁽¹⁾	18
Figure 2	Drum With Horizontal Settling Baffles (Layout Of Typical Settling Baffle When Heavy Phase Drops Limit Settler Capacity) ⁽¹⁾⁽²⁾	19
Figure 3	Feed Drum For Sour Water Stripper Or Amine Regenerator ⁽¹⁾⁽²⁾	20
Figure 4	Horizontal Setting Drum With Two Stage Dm-Cwms Coalescence Media	21
Figure 5	Sample Problem - Atmospheric Pipestill Distillate Drum	22

Revision Memo

12/03 Highlights of this revision are:

1. Added additional design guidelines for separators in vapor-liquid-liquid service.
2. Revised required amine holdup time in the settling compartment of amine regenerator feed drums.
3. Revised the recommended difference in heights between oil and water overflow baffles in Eq. (6).
4. Added design considerations for alkylation settlers.
5. Provided additional design guidelines for Figure 2.
6. Corrected Figure 3 (Oil Overflow Baffle) and added note regarding location of vent nozzle.



 DESIGN PRACTICES	DRUMS LIQUID-LIQUID AND VAPOR-LIQUID-LIQUID SEPARATORS PROPRIETARY INFORMATION - For Authorized Company Use Only	Section V-B	Page 3 of 23
		December, 2003	

SCOPE

This subsection covers the design of both liquid-liquid and vapor-liquid-liquid separator drums (settlers). Guidelines are provided for sizing horizontal gravity settlers including settlers for feed drums to sour water strippers and amine regenerators. Also included are design guidelines for sizing separator drum internals such as inlet distributors, settling baffles, anti-vortex baffles, and dual-media crinkle wire mesh screen. Design of vapor-liquid separators where only one liquid phase is present is covered in [Section V-A](#).

For liquid-liquid systems that form stable emulsions, special design criteria are needed. Special criteria are used for acid settlers in alkylation plants, as well as caustic and water wash drums in the reactor product stream of sulfuric acid alkylation units.

Since hydrocarbons from gravity settlers may have entrainment levels as high as 200 ppm, insufficient water is removed in gravity settlers to meet distillate product quality specifications. Therefore, more effective drying equipment, such as sand filters, salt driers, or vacuum driers, may be required. Cartridge coalescers may be competitive for deentrainment when plot space is limited or throughput is low. ExxonMobil has experience with FACET International coalescers for water removal from alkylation C₄ streams and Pall PhaseSep coalescers for caustic removal from cat naphtha streams. Separator design criteria for the removal of oil from refinery wastewater are given in the **ENVIRONMENTAL DESIGN PRACTICES, [Section XIX](#), Water Pollution Control**.

When special considerations require that a settler be installed vertically, a SEPARATIONS SPECIALIST should be consulted for specific recommendations.

REFERENCES

DESIGN PRACTICES

Section V-A	Vapor-Liquid Separators
Section XII	Instrumentation
Section XV	Safety in Plant Design

ENVIRONMENTAL DESIGN PRACTICES

Section XIX	Water Pollution Control
-------------	-------------------------

GLOBAL PRACTICES

GP 03-06-01	Piping for Instruments
GP 05-01-01	Pressure Vessels
GP 05-01-02	Additional Requirements for Special Criteria Pressure Vessels
GP 05-02-01	Internals for Towers, Drums, and Fixed Bed Reactors
GP 15-05-01	Level Instruments

OTHER REFERENCES

1. Ackerman, S., "Alkylation Reactor Products Treating Summary," 96FPD4 80 (September 26, 1996).
2. Baird, R. S. and R. J. Fiocco, "Guide for Applying Coalescing Media to Debottleneck Extractors, Liquid-Liquid Settlers and Sand Filters," ER&E Report EE.5E.93 (January 1993).
3. Bustin, W. M., "Anti-Vortex Baffles," ER&E Report EE.3R.54 (January 26, 1954).
4. Canevari, G. P., Fiocco R. J., and Shrier A. L., "Liquid-Liquid Separations," ER&E Report EE.10ER.66 (November 1, 1966).
5. Fiocco, R. J., "Distillate Drying Handbook," ER&E Report EE.96E.75 (December, 1975).
6. Rouse, H., "Seven Exploratory Studies in Hydraulics," Proc. ASCE 82. HY4 pp 1038 - 1 to 1038 - 34, (August, 1956).
7. EMRE Sulfuric Acid Alkylation Operating Manual, Section 4D - Settler, July 2001.



Section	Page	DRUMS LIQUID-LIQUID AND VAPOR-LIQUID-LIQUID SEPARATORS PROPRIETARY INFORMATION - For Authorized Company Use Only	 DESIGN PRACTICES
V-B	4 of 23		
December, 2003			

DEFINITIONS

Settling Pot. A relatively small collection pot located on the bottom of a horizontal settling drum used to provide settling space to collect the heavy liquid phase. When a relatively small amount of heavy liquid phase is present, a settling pot can be used to reduce the required drum size by eliminating the heavy phase layer in the bottom of the drum.

Dual Media Crinkle Wire Mesh Screen (DM-CWMS). The primary mechanism for separation of immiscible liquid-liquid mixtures is gravity settling. Since settling velocity increases with liquid droplet diameter, separation can be significantly enhanced by promoting the growth of droplets by coalescence. One method of promoting coalescence is by flowing droplet-containing liquid through a bed of solid media with high surface area, such as fine fibers, thin filaments, and small particles. DM-CWMS is a high surface area, coalescing medium which is manufactured by co-knitting plastic filaments or glass fibers with metallic wire mesh.

APPLICATION

For gravity settling of an immiscible liquid-liquid mixture to occur, two basic separation phenomenon must occur: (1) settling or rising of droplets from both liquid phases to the liquid-liquid interface level, and (2) coalescence of the droplets in the emulsion band at the interface between the two liquid phases. The design criteria in this subsection assume that coalescence of the emulsion band is rapid. If this assumption is not correct, contact a SEPARATIONS SPECIALIST.

Rigorous gravity settler design requires information on feed drop size distribution. Since this information is usually not available, a simplified approach based on past experience is presented. Typical settlers designed with the criteria presented in this subsection will have less than 200 ppm entrainment in each liquid product. This entrainment level is usually acceptable for products going to heat exchangers and fractionators since this concentration is smaller than the amount of second phase present due to solubility. If reduced entrainment levels are required, process specific data may be needed to establish the applicability of gravity settling; perhaps a different separator device, such as a sand filter, may be needed.

Whenever possible, one should avoid subjecting the settler feed to high shear stresses, such as those produced in pumps and pressure letdown systems. High shear stresses may generate small drops which will not separate in gravity settlers. A common problem in poorly operating gravity settlers is too high an inlet velocity.

For settlers handling slow coalescing emulsions, separation of liquid droplets is not the controlling factor. In these settlers (such as acid settlers in sulfuric acid alkylation plants), additional residence time and/or interface area may be required for coalescence of the emulsion band at the interface. The use of settling baffles, DM-CWMS, or other coalescing devices may assist in these separations. Laboratory or plant data are typically required to guide these types of design since the liquid properties and presence of surfactants or solids will affect separation rates.

Settler designs for new services should be based on actual plant or laboratory data. A SEPARATIONS SPECIALIST should be consulted on the type of data to be collected or regarding the basis for past designs.

The following table gives experience limits for the design of liquid-liquid settlers. Designers should contact a SEPARATIONS SPECIALIST if the application is outside these experience limits.

LIQUID-LIQUID SETTLER DESIGN LIMITS

VARIABLE	LOWER LIMIT	UPPER LIMIT
Liquid Viscosity, cP (mPa•s)	0.05 (0.05)	10 (10)
Liquid Density, lb/ft ³ (kg/m ³)	20 (320)	80 (1300)
Density Difference, lb/ft ³ (kg/m ³)	6 (100)	62 (1000)
Settling Baffle Spacing, in. (mm)	9 (225)	-
Interfacial Surface Tension, dyne/cm (mN/m)	10 (10)	50 (50)
Method of Droplet Generation	-	Mild mechanical mixing, such as extractors and orifice mixers or control valves with pressure drops less than 20 psi (140 kPa)

 DESIGN PRACTICES	DRUMS LIQUID-LIQUID AND VAPOR-LIQUID-LIQUID SEPARATORS PROPRIETARY INFORMATION - For Authorized Company Use Only	Section	Page
		V-B	5 of 23
		December, 2003	

BASIC DESIGN CONSIDERATIONS

INLET NOZZLES

1. Separators Handling Liquids Only

For this service, the inlet nozzle should terminate in a tee distributor located at the normal interface ([Figures 1 or 2](#)). The distributor holes should be at least 0.5 in. (12.7 mm) in diameter and should point toward the near head of the drum. A sufficient number of holes should be provided to limit the liquid exit velocity to 1 ft/s (0.305 m/s) or less to avoid the formation of small droplets.

If a bottom settling pot is provided, the bottom of the inlet distributor pipe should be elevated about 4 in. (100 mm) from the vessel bottom.

2. Separators Handling Liquids and Vapors

For this service, the inlet nozzle should be a slotted tee distributor located in the vapor space and designed for vapor-liquid service as described in [Section V-A](#) (Vapor-Liquid Separators). For high vapor rate, non-fouling services (i.e., fractionator distillate drums), a 6-inch thick, 5 lb/ft³ density (150 mm thick, 80 kg/m³ density) vertical CWMS should be provided between each inlet nozzle and the 6 inch thick, 5 lb/ft³ density (150 mm, 80 kg/m³ density) horizontal CWMS. The vertical CWMS should cover the entire drum cross-sectional area for vapor flow and should extend to the low interface level (LIL). 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. For other critical services where high liquid-liquid separation efficiency is required, consult with a SEPARATIONS SPECIALIST.

LIQUID HOLDUP FOR PROCESS, CONTROL, AND SAFETY REQUIREMENTS

Design liquid holdup time is usually determined by process, control, or emergency requirements. Control and emergency requirements are covered in [Sections XII, Instrumentation](#), and [XV, Safety in Plant Design](#), respectively. Additional liquid holdup requirements for process reasons, such as caustic inventory for reasonable batch replacement intervals, need to be determined prior to settler design.

DROPLET SETTLING

Liquid-liquid separation in horizontal gravity settlers is based on the assumptions that: (1) each phase is dispersed in the other, and (2) separation will occur if the holdup time of each phase is equal to or larger than the time required for the drops to rise or settle to the interface.

The holdup time required for separation in the light liquid phase is obtained by dividing the vertical distance between the top of the drum (or upper surface of the light liquid phase, if vapor is also present) and the interface level in question by the drop settling velocity of the heavy phase. Likewise, the time required for separation in the heavy liquid phase is obtained by dividing the vertical distance between the bottom of the drum and the interface in question by the drop settling (rising) velocity of the light liquid phase. Drop settling velocity is calculated from [Eq. \(1a\), \(1b\), or \(1c\)](#) and the appropriate drop size from [Table 1](#).

DROPLET SETTLING VELOCITY

Although liquid-liquid settling is not a single-drop phenomenon, settling rate equations based on rigid spheres have proved satisfactory for design purposes. The application of these equations, which are valid for vapor bubble diameters less than 0.0236 in. (0.6 mm) and liquid droplet diameters less than 0.0394 in. (1.0 mm), depends on the Reynolds number of the bubbles or drops.

RANGE OF APPLICABLE REYNOLDS NUMBERS, Re

Stokes' Law:	$V_S = (C_1) \left(\frac{d^2 \Delta S}{\mu} \right)$	Re < 2	Eq. (1a)
Intermediate Law:	$V_S = (C_2) \left[\frac{(d)^{1.143} (\Delta S)^{0.714}}{(\mu)^{0.429} (S_c)^{0.286}} \right]$	Re ≥ 2 ≤ 500	Eq. (1b)
Newton's Law:	$V_S = (C_3) \left(\frac{d \Delta S}{S_c} \right)^{0.5}$	Re > 500	Eq. (1c)

Section V-B	Page 6 of 23	DRUMS LIQUID-LIQUID AND VAPOR-LIQUID-LIQUID SEPARATORS PROPRIETARY INFORMATION - For Authorized Company Use Only	ExxonMobil DESIGN PRACTICES
December, 2003			

$$Re = (C_4) \frac{d V_S S_c}{\mu} \quad \text{Eq. (2)}$$

where: V_S = Settling velocity of dispersed phase droplets or bubbles, in./min (mm/s)

C_1 = Constant = 8.3×10^5 for Customary units (544 for Metric units)

C_2 = Constant = 1.03×10^4 for Customary units (108 for Metric units)

C_3 = Constant = 2.05×10^3 for Customary units (172 for Metric units)

C_4 = Constant = 10.74 for Customary units (0.999 for Metric units)

d = Diameter of dispersed phase droplet or bubble, in. (mm)

ΔS = Difference in specific gravities of continuous and dispersed phases (with respect to water at 60°F), dimensionless (absolute value)

S_c = Specific gravity of continuous phase at conditions, dimensionless

μ = Viscosity of continuous phase at conditions, cP (mPa·s)

Note that for design purposes, V_S is limited to a maximum value of 10 in./min (4.2 mm/s) to avoid situations where phenomenon such as turbulence could affect settling droplets. Also, since V_S must be known before Re can be calculated to determine which equation for V_S applies, a trial-and-error calculation using an assumed value for V_S is needed.

VAPOR SPACE

For vapor-liquid-liquid services, see [Section V-A](#) (Vapor-Liquid Separators) for criteria on sizing the vapor space.

PREVENTION OF LIQUID REENTRAINMENT

Anti-vortex baffles should be installed ahead of all liquid outlet nozzles to prevent reentrainment. The types used are subway grating baffles for bottom outlet nozzles, and square solid baffles for top liquid hydrocarbon outlet nozzles ([Figure 1](#) and [Section V-A, Figure 11](#)).

Heavy Liquid Phase Outlet - Subway grating baffles are designed using criteria ([Figure 11](#)) in [Section V-A](#); however, the minimum distance from the low interface level to the heavy liquid phase outlet nozzle is the larger of either 9 in. (230 mm) or the value calculated from Eq. (3):

$$h_{LI} = \frac{C_5 Q_h^{0.4}}{\left(1 - \frac{\rho_l}{\rho_h}\right)^{0.2}} \quad \text{Eq. (3)}$$

where: h_{LI} = Minimum height from low interface level to outlet nozzle for heavy liquid phase, in. (mm)

C_5 = Constant = 15 for Customary units (100 for Metric units)

Q_h = Discharge rate of heavy phase, ft³/s (dm³/s)

ρ_l = Density of light liquid phase at conditions, lb/ft³ (kg/m³)

ρ_h = Density of heavy liquid phase at conditions, lb/ft³ (kg/m³)

Light Liquid Phase Outlet - Design criteria for solid baffles used with light phase top outlet nozzles are given in [Figure 1](#). The minimum distance between the high interface level and the outlet nozzle is the larger of the two values calculated from [Eqs. \(4a\) and \(4b\)](#):

	DRUMS LIQUID-LIQUID AND VAPOR-LIQUID-LIQUID SEPARATORS PROPRIETARY INFORMATION - For Authorized Company Use Only	Section	Page
		V-B	7 of 23
		December, 2003	

DESIGN PRACTICES

$$h_{HI} = d_{\ell} + C_6 \quad \text{Eq. (4a)}$$

$$h_{HI} = \frac{C_7 (Q_L)^{0.5}}{\left(d_{\ell}\right)^{0.25} \left(1 - \frac{\rho_{\ell}}{\rho_h}\right)^{0.25}} \quad \text{Eq. (4b)}$$

where: h_{HI} = Minimum height from high interface level to outlet nozzle of light liquid phase, in. (mm)

C_6 = Constant = 4 for Customary units (100 for Metric units)

C_7 = Constant = 5.88 for Customary units (62.8 for Metric units)

Q_L = Discharge rate of light liquid phase, ft³/s (dm³/s)

d_{ℓ} = Diameter of outlet nozzle for light liquid phase, in. (mm)

Other terms are as defined for [Eq. \(3\)](#).

For vapor-liquid-liquid services, the light liquid phase is typically withdrawn through a bottom outlet nozzle with a straight extension (interior pipe extending up from the bottom nozzle) ([Figure 5A](#)). With these nozzles, subway grating anti-vortex baffles, designed according to criteria in [Section V-A](#), should be used. The minimum distance the nozzle should extend above the high liquid-liquid interface level is the larger of 4 in. (100 mm) or the larger of the two values calculated from [Eq. \(4a\)](#) and [Eq. \(4b\)](#). If the drum has a settling pot, the minimum extension above the bottom of the drum is 4 in. (100 mm).

SETTLING POTS

When a relatively small amount of heavy liquid phase is present, it is often withdrawn through a settling pot on the bottom of the drum. Settling pots permit a reduction in the drum size by eliminating the heavy phase layer on the bottom of the drum. To satisfy mechanical and economic considerations, settling pot diameters should not exceed the following:

Drum Diameter (D), in. (mm)	Pot Diameter, max.
$D \leq 40$ (1000)	D/2
40 (1000) $< D < 60$ (1500)	20 in. (500 mm)
$D \geq 60$ (1500)	D/3

SETTLING BAFFLES

Horizontal baffles may be used to reduce the distance which the drops must travel and thus reduce the required liquid holdup time for separation and subsequent drum size.

In drums with settling baffles, the liquid holdup time between adjacent baffles (or shell and adjacent baffle) should be equal to or larger than the time required for the drops to travel the vertical distance between the baffles (or shell and adjacent baffle). The vertical spacing between adjacent baffles for a given drum size depends on the horizontal velocity of the phase in which the baffles are to be installed, baffle length, and the drop settling velocity. Baffle spacing of 18 in. (450 mm) is required for access; however, spacings as low as 9 in. (230 mm) have been used for droplet settling. The calculation procedure is as follows:

Step 1: Calculate the horizontal velocity of the liquid phase in which the settling baffles are to be installed. The horizontal velocity is obtained by dividing the continuous phase volumetric flow rate by its vertical cross-sectional area for flow. This area is the area above the liquid-liquid interface when baffles are installed in the light liquid phase. This area is the area below the interface for baffles installed in the heavy liquid phase.

Step 2: Calculate the settling velocity of the dispersed phase droplets, using [Eq. \(1a\)](#), [\(1b\)](#), or [\(1c\)](#) and the appropriate drop size from [Table 1](#).

Step 3: Calculate the maximum permissible vertical distance between adjacent baffles using [Eq. \(5\)](#):

$$h = C_8 \left(\frac{V_s L_{sb}}{V_{hz}} \right) \quad \text{Eq. (5)}$$