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Revision Memo

- 12/01** Highlights of this revision are:
- (1) Included discussion of Merichem FIBER-FILM Contactor (FFC) bundles.
 - (2) Expanded discussion of Cascade Weir Tray Towers and included Figure 7, "Double Pass Cascade Weir Tray".
 - (3) Referenced proprietary sieve tray designs, such as those offered by UOP.


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SCOPE

This subsection provides a general overview of the liquid-liquid extraction process, design issues and extractor types. In addition, it includes guidelines for selecting the appropriate extractor for specific applications.

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DEFINITIONS

Coalescence. Coalescence is the process by which the dispersed phase droplets merge to form larger drops or a liquid layer, and thereby separate from the continuous phase.

Continuous Phase. The continuous phase is one of the two immiscible phases in an extraction tower. The continuous phase flows through the extractor as a continuum, rather than as dispersed droplets.

Dispersed Phase. The dispersed phase is one of the two immiscible phases which are contacted in an extraction tower. It flows through the extractor as droplets purposely dispersed in the second (continuous) phase by the tower internals. The mixture of dispersed phase droplets in the continuous phase is called a dispersion.

Entrainment. Entrainment refers to the presence of droplets of one of the liquid phases in the other phase after a separation zone in the tower. Two critical separation zones are the top and the bottom of the tower, where the two phases disengage before leaving the tower.

Extract. The extract is the stream leaving an extraction tower which consists of the solvent and the compounds extracted from the feed by the solvent. It is also known as the rich solvent. It may also be referred to as the "extract solution" to differentiate it from the "extract product" which is produced by separating the solvent from the extracted components in a secondary separation step.

Interfacial Tension. Interfacial tension is the free energy loss due to molecular interactions at an interface between two liquid phases. It is a measure of the work required to disperse one phase in the other and is analogous to surface tension in vapor-liquid systems.

Raffinate. The raffinate is the stream leaving an extraction tower which consists of the feed components not extracted by the solvent.

Theoretical Stage. A theoretical stage is the equivalent of a single contacting zone in which the concentrations in the liquid phases leaving the zone are in equilibrium.

Tray. A tray is a perforated plate mounted inside an extraction tower which is used to disperse one of the phases and promote contacting between the phases.

Turndown Ratio. Turndown ratio is the ratio of the minimum dispersed phase flow rate to the design dispersed phase flow rate. Since the hydrocarbon feed stream is normally the dispersed phase, turndown ratio typically refers to the range of feed stream flow rates which will be encountered. It is sometimes expressed as a percent.

BASIC EXTRACTION PROCESS

Liquid-liquid extraction is a separation process in which a feed stream containing dissolved components (B) is contacted with an immiscible solvent which forms a second liquid phase and selectively extracts the dissolved components from the feed. This is shown in **Figure 1**. Two product streams are generated, the raffinate, which is the feed stream with components B removed, and the extract, which consists of components B dissolved in the solvent. Since the solvent and the feedstock are immiscible, two liquid phases are present in the extraction vessel. The solvent phase may, however, be partially soluble in the raffinate phase leaving the extractor.

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BASIC EXTRACTION PROCESS (Cont)

The extraction vessel is a tower with internals such as trays or packing. The light phase (shown as the feed stream in **Figure 1**) is fed at the bottom and rises up through the tower, while the heavy phase (solvent) flows downward through the tower, countercurrent to the rising light phase stream. In the flow configuration shown in **Figure 1**, the raffinate stream is removed at the top and the extract at the bottom of the tower. Either of the two phases present in the extractor can be the continuous or the dispersed phase. The droplets of the dispersed phase generally coalesce and are redispersed by the internals several times as they pass through the tower. (In **Figure 1**, the less dense feed phase is dispersed and the controlled interface is at the top of the tower.)

Liquid-liquid extraction is used primarily for those separations where distillation is not practical. This includes cases where the components to be separated have some of the following properties:

- Small relative volatility differences
- Temperature sensitivity at distillation conditions
- Removal of minor component required
- Readily separable by an immiscible extractive solvent
- Part of a similar class, such as aromatics, to be removed from a mixture of classes

Countercurrent flow of the immiscible phases in the extraction tower causes a staging effect which allows more complete extraction than could be achieved in a single theoretical stage. Extraction towers are generally designed with sieve tray internals to provide at least three theoretical stages. The number of actual trays installed in a tower to achieve the desired number of theoretical stages depends on the rate at which the extractable components are transferred from the feed to the solvent. The transfer rates are in turn dependent on the intimacy of contact between the two immiscible phases in the tower. Tower internals, such as packing or mechanical agitators, are sometimes used instead of trays to provide intimate contact between the phases.

Trays have three functions. The first is to form droplets of the dispersed phase as shown in **Figure 2**, to provide high interfacial area for mass transfer. Trays also direct the flow of the continuous phase to enhance contacting between the continuous phase and the dispersed droplets. The trays then separate the dispersed and continuous phases by permitting coalescence of the dispersed phase droplets. The coalesced dispersed phase is collected under (or over) the tray and redispersed by the sieve holes.

Packing, such as rings or saddles used in distillation towers, promotes contacting by forcing both phases to follow more tortuous flow paths through the tower, thereby maintaining the dispersion, bringing both phases into closer contact and preventing short circuiting of either phase. Alternatively, mechanical agitators, such as rotating discs and reciprocating plates, can be used to maintain droplet dispersion and promote contact between the phases.

The two phases must be separated near the tower outlets to prevent entrainment of the light phase at the bottom outlet and entrainment of the heavy phase at the top outlet. This can be done by maintaining low velocities near the outlets and allowing sufficient time for the dispersed phase to coalesce.

The extract is usually sent to a secondary separation where the solvent is recovered from the extracted feed components by distillation or stripping. The solvent is then recycled to the extractor. Solvent may also be recovered from the raffinate in some cases. One criterion for solvent selection is the ease of recovery in the secondary separation steps.

DESIGN ISSUES

The design of an extraction tower requires specification of a number of items. These items are listed and discussed briefly in the following paragraphs. Detailed descriptions are given in subsequent subsections.

CHOICE OF SOLVENT

The solvent to be used is specified in the design basis specification (DBS). The choice of solvent is based on a number of factors such as selectivity, capacity, initial and replacement costs, ease of recovery, stability, corrosivity, and toxicity.

SELECTION OF EXTRACTOR TYPE

The type of extractor to be used depends on the specific service. Guidelines on extractor selection are discussed in more detail later.

NUMBER OF TRAYS, HEIGHT OF PACKING OR THEORETICAL STAGES

Typically the number of trays or height of the packed section needed to meet separation requirements is specified based on previous operating information. If the number of theoretical stages is specified, it must be used together with an overall tray or packing efficiency to determine the number of trays or height of packing needed for the separation.

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DESIGN ISSUES (Cont)**SELECTION OF THE DISPERSED PHASE**

Selection of the phase to be dispersed in a liquid-liquid extraction tower is an important design consideration to assure satisfactory mass transfer efficiency and phase separation. Normally the phase with the higher volumetric flow rate is dispersed since this will provide the larger number of drops, i.e., maximize the interfacial contact area between the two phases. Other factors, such as the viscosity of each phase and the tendency to form stable emulsions, can affect phase separation, and therefore impact on selection of the dispersed phase in some cases. Guidelines on selection of the dispersed phase are discussed further in the subsections covering specific extraction tower designs for various services. For new services, your FRACTIONATION SPECIALIST should be consulted.

TOWER DESIGN

Design of the extraction tower includes specification of the following:

- Diameter** - The tower diameter is based on the throughput and maximum allowable velocities of the two phases.
- Tray Design** - Tray design includes specification of the tray layout and spacing.
- Packing Materials** - If a packed tower is chosen, the type and size of the packing material must be specified. Also, the need for re-distributors must be evaluated.
- Other Internals** - Tower inlets and outlets, top and bottom section details, and location of the interface control zone must be specified.

EXTRACTOR TYPES AND DESCRIPTIONS

A number of different extractor types are available for various extraction services. **Extractor types** are listed as follows and described briefly in this section:

Sieve Tray Towers

Packed Towers

Mechanically Agitated Extractors

- a. Rotating Disc Contactors
- b. Reciprocating Plate Extractors
- c. York-Scheibel Extractors

Other Extractor Types

- a. Mixer-Settlers
- b. Angle Iron (Shed Row) Towers
- c. Centrifugal Extractors
- d. Pulsed Extractors

1. Sieve Tray Towers

Sieve tray towers are the most widely used extractor type in extraction service within ExxonMobil. They are relatively inexpensive, can cover a wide range of services and operating conditions, and can be readily scaled up to large sizes. Applications include removal of contaminants from light hydrocarbons, lube oil treating and aromatics recovery.

A number of different tray designs can be specified depending on the application. Two common designs, described in detail in [Section IV-B](#), are listed below:

TRAY DESIGN	PRIMARY DESIGN FEATURE	PRIMARY ADVANTAGE
Single Dispersion Area	Flow of dispersed phase occurs at all times through all perforations (see Figure 2)	Simplicity
Dual Dispersion Area	Secondary set of perforations is used at high dispersed phase flow rates (see Section IV-B, Figure 3)	Greater operating flexibility