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DISTILLATION SYSTEMS

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ABSTRACT

During the distillation process, a mixture is heated until it vaporizes, then is recondensed on the trays or at various stages of the column where it is drawn off and collected in a variety of overhead, sidestream, and bottom receivers. The condensate is referred to as the distillate. The liquid that does not vaporize in a column is called the residue.

Key words: *Tray columns-devices located on a tray in a column that allow vapors to come into contact with condensed liquids; three basic designs are bubble-cap, sieve, and valve.*

Valve trays-a small round metal disc with three or four legs called risers that allow the valve to lift as hot vapors push through the horizontal tray. Designed to enhance vapor-liquid contact in a plate column.

Tray columns-devices located on a tray in a column that allow vapors to come into contact with condensed liquids; three basic designs are bubble-cap, sieve, and valve.

INTRODUCTION TO DISTILLATION OPERATIONS

Separation operations achieve their objective by the creation of two or more coexisting zones which differ in temperature, pressure, composition, and/or phase state. Each molecular species in the mixture to be separated responds in a unique way to differing environments offered by these zones. Consequently, as the system moves toward equilibrium, each species establishes a different concentration in each zone, and this results in a separation between the species.

The separation operation called distillation utilizes vapor and liquid phases at essentially the same temperature and pressure for the coexisting zones. Various kinds of devices such as random or structured packings and plates or trays are used to bring

the two phases into intimate contact. Trays are stacked one above the other and enclosed in a cylindrical shell to form a column. Packings are also generally contained in a cylindrical shell between hold-down and support plates. The column may be operated continuously or in batch mode depending on a number of factors such as scale and flexibility of operations and solids content of feed. A typical tray-type continuous distillation column plus major external accessories is shown chematically in Fig. 1. The feed material, which is to be separated into fractions, is introduced at one or more points along the column shell. Because of the difference in density between vapor and liquid phases, liquid runs down the column, cascading from tray to tray, while vapor flows up the column, contacting liquid at each tray.

Liquid reaching the bottom of the column is partially vaporized in a heated reboiler to provide boil-up, which is sent back up the column. The remainder of the bottom liquid is withdrawn as bottoms, or bottom product. Vapor reaching the top of the column is cooled and condensed to liquid in the overhead condenser. Part of this liquid is returned to the column as reflux to provide liquid overflow. The remainder of the overhead stream is withdrawn as distillate, or overhead product. In some cases only part of the vapor is condensed so that a vapor distillate can be withdrawn.

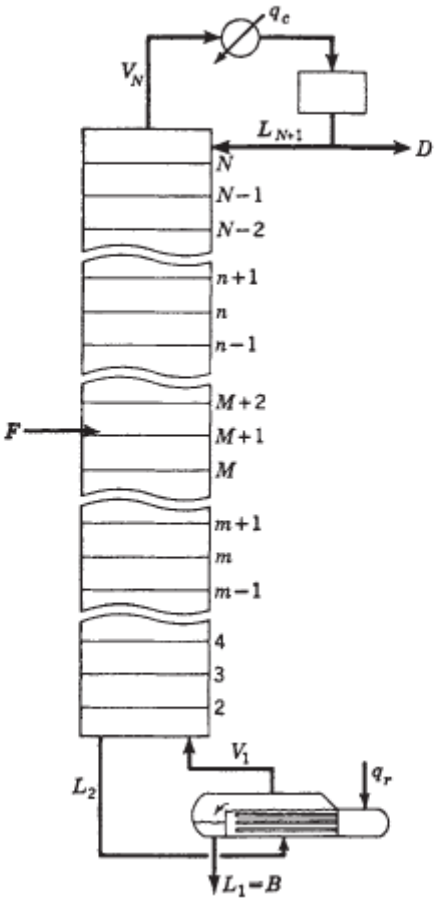
This overall flow pattern in a distillation column provides countercurrent contacting of vapor and liquid streams on all the trays through the column. Vapor and liquid phases on a given tray approach thermal, pressure, and composition equilibria to an extent dependent upon the efficiency of the contacting tray.

The lighter (lower-boiling temperature) components tend to concentrate in the vapor phase, while the heavier (higher-boiling temperature) components concentrate in the liquid phase. The result is a vapor phase that becomes richer in light components as it passes up the column and a liquid phase that becomes richer in heavy components as it cascades downward. The overall separation achieved between the distillate and the bottoms depends primarily on the relative volatilities of the components, the number of contacting trays in each column section, and the ratio of the liquid-phase flow rate to the vapor-phase flow rate in each section.

If the feed is introduced at one point along the column shell, the column is divided into an upper section, which is often called the *rectifying* section, and a lower section, which is often referred to as the *stripping* section. In *multiple-feed* columns and in columns from which a liquid or vapor sidestream is withdrawn, there are more than two column sections between the two end-product streams. The notion of a column section is a useful concept for finding alternative systems (or sequences) of columns for separating multicomponent mixtures, as described below in the subsection Distillation Systems. All separation operations require energy input in the

form of heat or work. In the conventional distillation operation, as typified in Fig. 1, energy required to separate the species is added in the form of heat to the reboiler at the bottom of the column, where the temperature is highest. Also heat is removed from a condenser at the top of the column, where the temperature is lowest. This frequently results in a large energy-input equirement and low overall thermodynamic efficiency, especially if the heat removed in the condenser is wasted.Complex distillation operations that offer higher thermodynamic efficiency and lower energy-input requirements have been developed and are also discussed below in the subsection Distillation Systems.

Batch distillation is preferred for small feed flows or seasonal production which is carried out intermittently in “batch campaigns.” In this mode the feed is charged to a still which provides vapor to a column where the separation occurs. Vapor leaving the top of the column is condensed to provide liquid reflux back to the column as well as a distillate stream containing the product. Under normal operation, this is the only stream leaving the device. In addition to the batch rectifier just described, other batch configurations are possible as discussed in the subsection Batch Distillation. Many of the concepts and methods discussed for continuous distillation are useful for developing models and design methods for batch distillation.

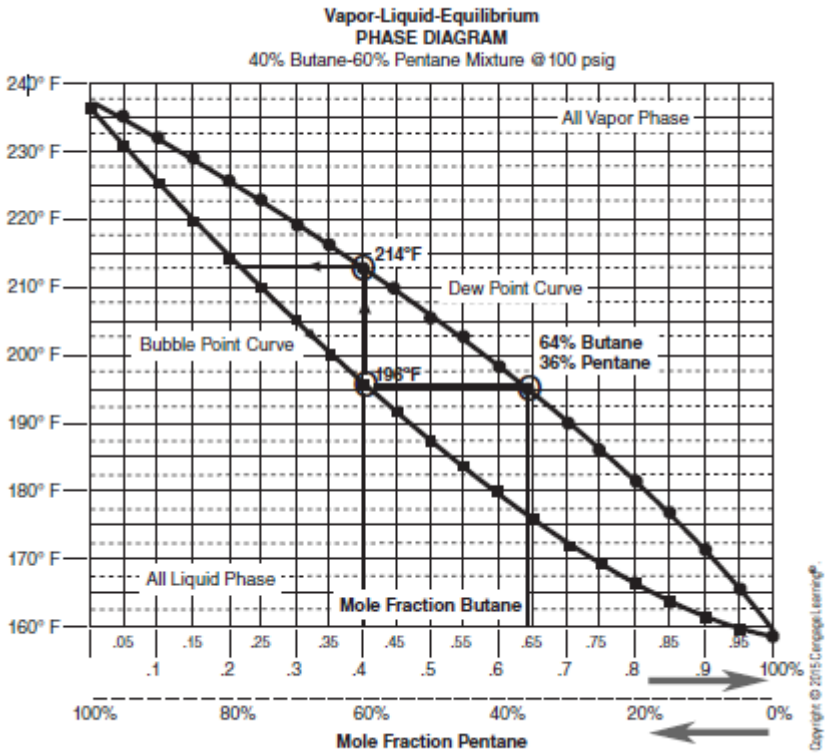


Petroleum compounds are composed of hydrocarbon molecules of varying sizes and shapes. Molecular weight determines how a chemical reacts during separation. For example, ethane has two carbon atoms and butane has four. During separation, butane remains in the lower section and ethane moves up the tower. The smallest or lightest components in a tower have the lowest boiling points. A distillation column is built on the principle that light and heavy molecules have different boiling points. Industry relies heavily upon this process to produce many of the chemicals we use today. For example, crude oil is a mixture of many of the chemicals used in modern manufacturing, including straight-run gasoline, naphtha, gas oil, various gases, salt, water, and clay. By knowing the temperature at which a chemical vaporizes, an operator can identify these specific components after they are heated, vaporized, and condensed on the different trays in a distillation column.

Distillation involves boiling liquids and condensing the vapors. When water boils, it turns into water vapor. The condensed water vapor is purer than he original mixture because most of the salts, minerals, and impurities do not vaporize at 212°F (100°C), the boiling point of water.

Principles of Distillation

The separation of components in a distillation column is based on the differences in volatility or boiling point. As the vapor rises up the tower andcontacts the liquid, the concentration of the lower boiling or more volatile components increase. As the liquid descends the tower, the concentration of the higher boiling or less volatile components increases. Increased pressure will result in increased temperatures in the tower. Each section in a trayed or packed column will have its own individual footprint or characteristics: pressure, temperature, composition, velocity, and performance. In the chemical processing industry, distillation and reactor technology are considered to be the two most complex operating areas. The basic principles of distillation include the study of phase behavior of a binary or two-component mixture, bubble point, dew point, boiling range, initial and final boiling points (IBP and FBP), mole fraction, the McCabe-Thiele method, and the concepts of entrainment, foaming, and weeping. Each of these areas is important for a technician to understand in order to work in and operate a distillation system. Figure 1 is often



referred to as **vapor-liquid-equilibrium (VLE) diagram** or phase diagram.

It provides a simple way for a technician to visualize the complex phase behaviors associated with distillation, boiling, and condensing of a two-or-more-component mixture. In this example 40% butane (C4), and 60% pentane (C5) will be used. The operating pressure will be controlled at 100 psig. The diagram can be used to show that the mole fraction of butane is 0.4 or 40%.

The starting mole fraction of pentane is 0.6 or 60%. This vapor-liquidequilibrium diagram is set up with the temperature on the left vertical axis and the mole fraction going across the bottom. The phase diagram also shows the **bubble point curve** and the **dew point curve**. It is important to remember that the **bubble point** is defined as the specific temperature where the mixture first produces vapor. The **dew point** is defined as the temperature where the first drop of liquid forms. Looking at the curve, we see that the bubble point for our mixture is 196°F at 100 psig. If we had a mixture that included a butane mole fraction of 0.6. or 60% and 40% for the pentane, the bubble point would be 180°F. We can also see that a 0.4 butane mole fraction would have a dew point of 214°F.

As this mixture of butane and pentane heats up, vaporization begins to occur.

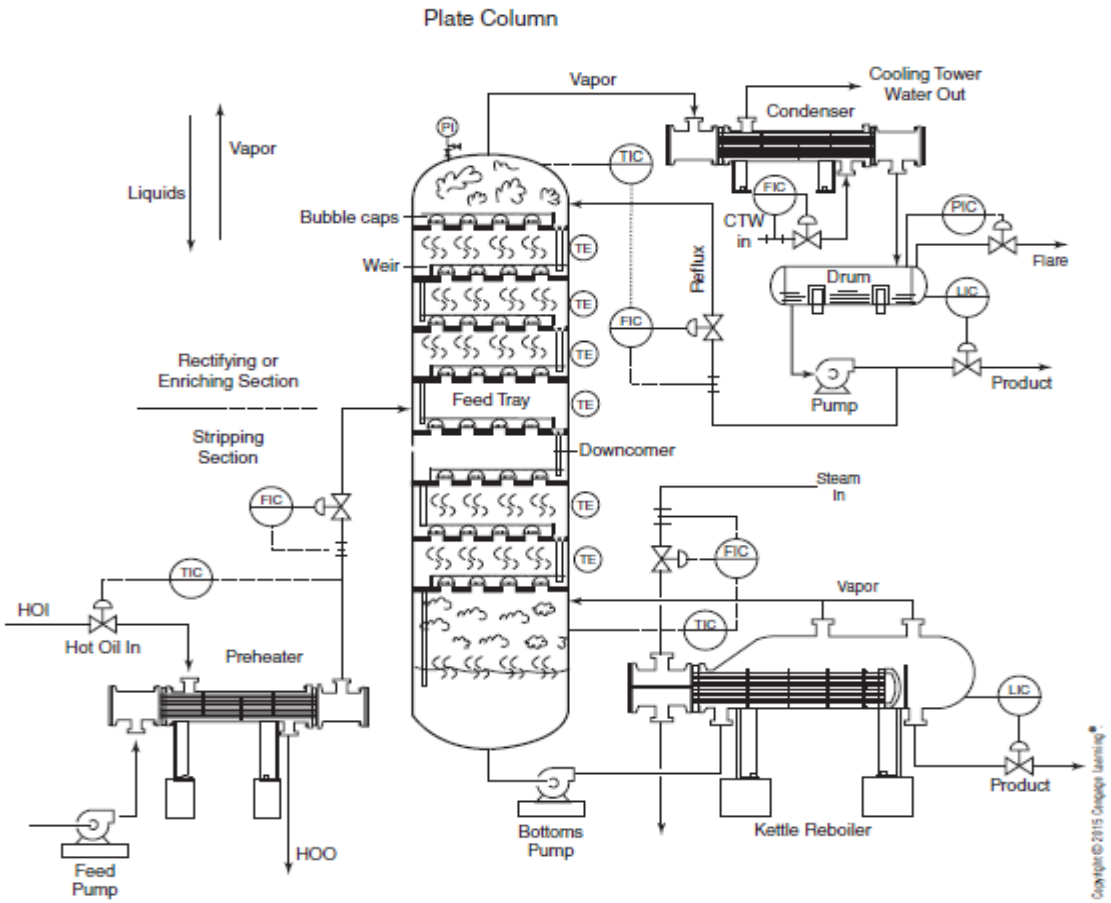
As more of the lighter component (butane) begins to boil off, a lower concentration of butane will remain until eventually all of the butane will be separated from the pentane. As this process occurs the bubble point will be shifted for the butane to the left on the phase diagram. It is also important to point out that everything below the bubble point curve will be in the liquid state while everything above the dew point curve will be in the vapor phase.

Plate Columns

Plate columns, sometimes called **tray columns**, come in three basic designs:

bubble-cap, sieve, and valve tray. The basic components of a plate column include the feed inlet, feed tray, rectifying or enriching section, **stripping section**, bottom outlet, overhead outlet, reflux line, reboiler, condenser, feed preheater, sidestream outlets, downcomer, weir, riser, control loops, pipes, pumps, valves, instrumentation, and computers (Figures 2 and 2.1).

The tray arrangement inside a plate distillation column will depend on the specific process for which it is being used. The tray in Figure 2.3 has all three types of components.



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