Lecture 6

Distillation of binary mixtures

The fundamentals of distillation are best understood by the study of binaq distillation, the separation of a two-component mixture.

A representative binary distillation operation is shown in Figure 1 for the separation of 620 lbmol/h of a binary mixture of 46 mol% benzene (the more volatile component) and 54 mol% toluene. The purpose of the 25-sieve-tray (equivalent to 20 theoretical stages plus a partial reboiler that acts as an additional theoretical stage.

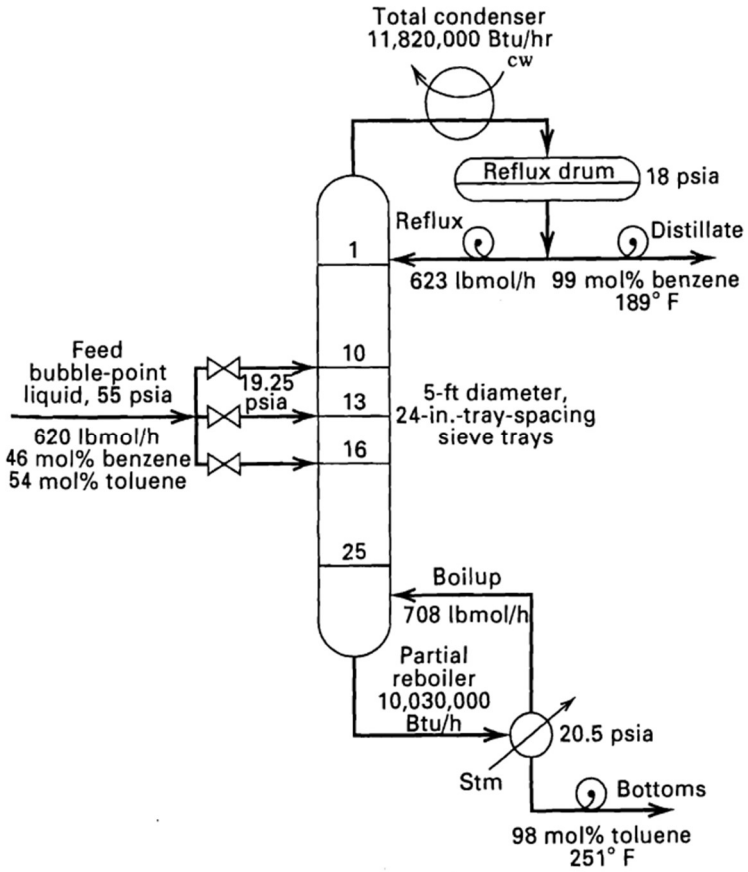

Figure 1 - Distillation of a binary mixture of benzene and toluene

The feed to the separation operation of Figure 1 is a saturated liquid at 55 psia (379 kPa). A bubble-point calculation gives a temperature of 294°F (419 K). When this feed is flashed adiabatically across the feed valve to the feed tray pressure of 19.25 psia (133 kPa), the feed temperature drops to 220°F (378 K), causing 23.4 mol% of the feed to be vaporized. A total condenser is used to obtain saturated liquid reflux and liquid distillate at a bubble-point temperature of 189°F (360 K) at 18 psia (124 kPa). The duty of the condenser is 11,820,000 Btu/h (3.46 MW). At the bottom of the column, a partial reboiler is used to produce vapor boilup and a liquid bottoms product. Assuming that the boilup and bottoms are in physical equilibrium, the partial reboiler functions as an additional theoretical stage, giving a total of 21 theoretical stages. Because the bottoms product is a saturated liquid, its temperature

of 25 1°F (395 K) corresponds to the bubble point of the bottoms at 20.5 psia (141 kPa). The duty of the reboiler is 10,030,000 Btu/h (2.94 MW), which is within 15% of the condenser duty.

The inside diameter of the distillation column in Figure 1 is a constant 5 ft (1.53 m). At the top tray this diameter corresponds to 84% of flooding, while at the bottom tray the percent flooding is 8 1 %. As shown, the column can be fed at any one of three trays. For the design conditions, the optimal feed entry is between trays 12 and 13. However, should the feed composition or product specifications change, one of the other two feed trays could become optimal.

Distillation columns similar to that of Figure 1 have been built for diameters up to at least 30 ft (9.14 m). With a 24.-in. (0.61-m) tray spacing, the maximum number of trays included in a single column is usually no greater than 150. In general, for the sharp separation of a binary mixture with a relative volatility less than 1.05, distillation can require many hundreds of trays, so a more efficient separation technique should be sought.

Technically, distillation is the most mature separation operation. Design and operation procedures are well established. Only when vapor-liquid equilibrium or other data are uncertain is a laboratory and/or pilot-plant study necessary prior to the design of a commercial unit.

Factors that influence the design or analysis of a binary distillation operation include:

1. Feed flow rate, composition, temperature, pressure, and phase condition
2. Desired degree separation between two components
3. Operating pressure
4. Vapor pressure drop, particularly for vacuum operation
5. Minimum reflux ratio and actual reflux ratio
6. Minimum number of equilibrium stages and actual number of equilibrium stages (stage efficiency)
7. Type of condenser (total, partial, or mixed)
8. Degrees of subcooling, if any, of the liquid reflux
9. Type of reboiler (partial or total)
10. Type of contacting (trays or packing or both)
11. Height of the column
12. Feed-entry stage
13. Diameter of the column
14. Column internals.