

Distillation



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Q. How can I design an optimized distillation column?

The first step is to establish the optimum design procedure for a standard distillation column. Tailor that design to optimize column operation for flexibility, low capital cost, energy efficiency or handling difficult feeds. In this article, we assume that the feed is a mixture of hydrocarbon components with near-ideal behavior.

For a standard design, set the tower pressure such that it will lead to the design of an economical condensing exchanger. The cooling water or air-approach temperature usually sets the condensing temperature. If the pressure is set too low, a large and costly condenser will be required. However, the higher the pressure, the lower the relative volatility between the light and heavy keys. In other words, separation of lighter components requires higher column pressures in order to operate at reasonable condenser temperatures. Separation of heavier components can be accomplished with lower column pressures. UOP commonly uses a 30°F cold-end approach on air coolers. Typically, air condenser outlets will be designed at 130–145°F. Water condensers usually cool to 100°F.

The minimum number of stages and reflux required can be calculated using the Fenske and Underwood equations, respectively, while the Gilliland correlation may be used to determine the number stages vs. reflux rates. Set the reflux rate to 10% above the minimum reflux value to find the initial (or minimum) number of stages. Run several rigorous column simulations to establish the appropriate number of stages. Start with the minimum number of stages for the first run and add 5% for the second run.

Stage efficiency may be determined by experimentation, correlations, consulting literature or drawing on the knowledge of other skilled engineers. Different sections of the column may operate at different tray efficiencies. Many towers designed at UOP have stage efficiencies of 75–80%. Most of the vacuum system designs have efficiencies of 15–20%. The drying section of a benzene tower has an efficiency of 15%.

To determine the ratio of the light key to the heavy key, identify the stage in the tower where this ratio occurs in the liquid phase. This should be the optimum feed point.

Flexible columns

If the feed composition and heat content are variable, such as with naphtha or kerosene systems, stages may be added to the column to achieve the desired separation. Additional trays should be added to the tower section that needs more flexibility. Kerosene towers often have extra trays (2 or 3 stages) in each column section. Columns that are designed to handle feed variations are not optimized for any one feed.

The feed-variability challenge can also be addressed with additional reflux. Kerosene systems have a few additional trays

and a small additional capacity (~15%) in the reflux.

If the product specifications are variable, the tower must be capable of achieving the most difficult specification. The cost to build this capability into a column is high, and should be justified. High-purity products can require a large number of trays (e.g., 205 for a polypropylene (PP) splitter) and large reflux ratios (e.g., in the PP splitter, R/D = 12:1).

Lowest capital cost vs. minimum energy design

There is a tradeoff between the amount of reflux and the number of stages needed to achieve a desired separation. A higher reflux means that fewer stages are required. However, more reboiler duty is required, meaning that the column diameter is larger, and greater surface area is required in the condenser and reboiler. There is an economic tradeoff between energy requirements due to reflux changes and the capital cost. Usually, the condenser and the reboiler are the most costly components in a conventional fractionator, followed by the tower shell and trays. High-efficiency trays (or packing) and close tray spacing allow the tower diameter and tangent length to be minimized.

On the other hand, a tower with a lower energy requirement is designed at or near minimum reflux. Rigorous column simulations can be used to determine the minimum reflux requirement. The column should then be designed with a small margin (typically 10%) for operational variability. Reducing the operating pressure will minimize the reflux requirement.

Advanced options

In some cases, a better design can result by using the advanced options, described below:

Dividing wall — UOP has commercialized several dividing wall columns for the separation of kerosene and naphtha products (*CEP*, May 2002, p. 64). Energy savings of up to 30% and capital savings of up to 25% have been obtained.

Heat-pumped — Most of UOP's heat-pumped towers are propylene/propane splitters, which achieve difficult propylene purity and recovery specifications. The current design uses a two-stage heat-pump compressor with high-flux tubing, promoting better heat transfer, and a reduction in heat-exchange area.

Pressure-staged — Pressure-staged fractionation columns improve the energy efficiency of petrochemical complexes. One application is to use one high pressure column in a complex to provide the reboiler heat to the rest of the columns in the complex. Another application is to split a large vacuum fractionation tower into two small towers, one operating at 20 psia and the other at 3 psia. All of the condenser duty in the high pressure column is recovered in the reboiler of the second tower. The 2004 AIChE Spring National Meeting's (New Orleans, LA; Apr. 25–29) Seventh Topical Conference on refinery processing will contain a session on energy efficiency, one of which will detail the advanced distillation methods.

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