# Tikrit University

# College of Petroleum Processes Engineering

# Department of Petroleum Refining Engineering


# Specialized Petroleum Processes

## Fourth Class

## Lecture 8


**By**

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# Crude Oil Processing from Refinery to Market

## 1. Crude Distillation

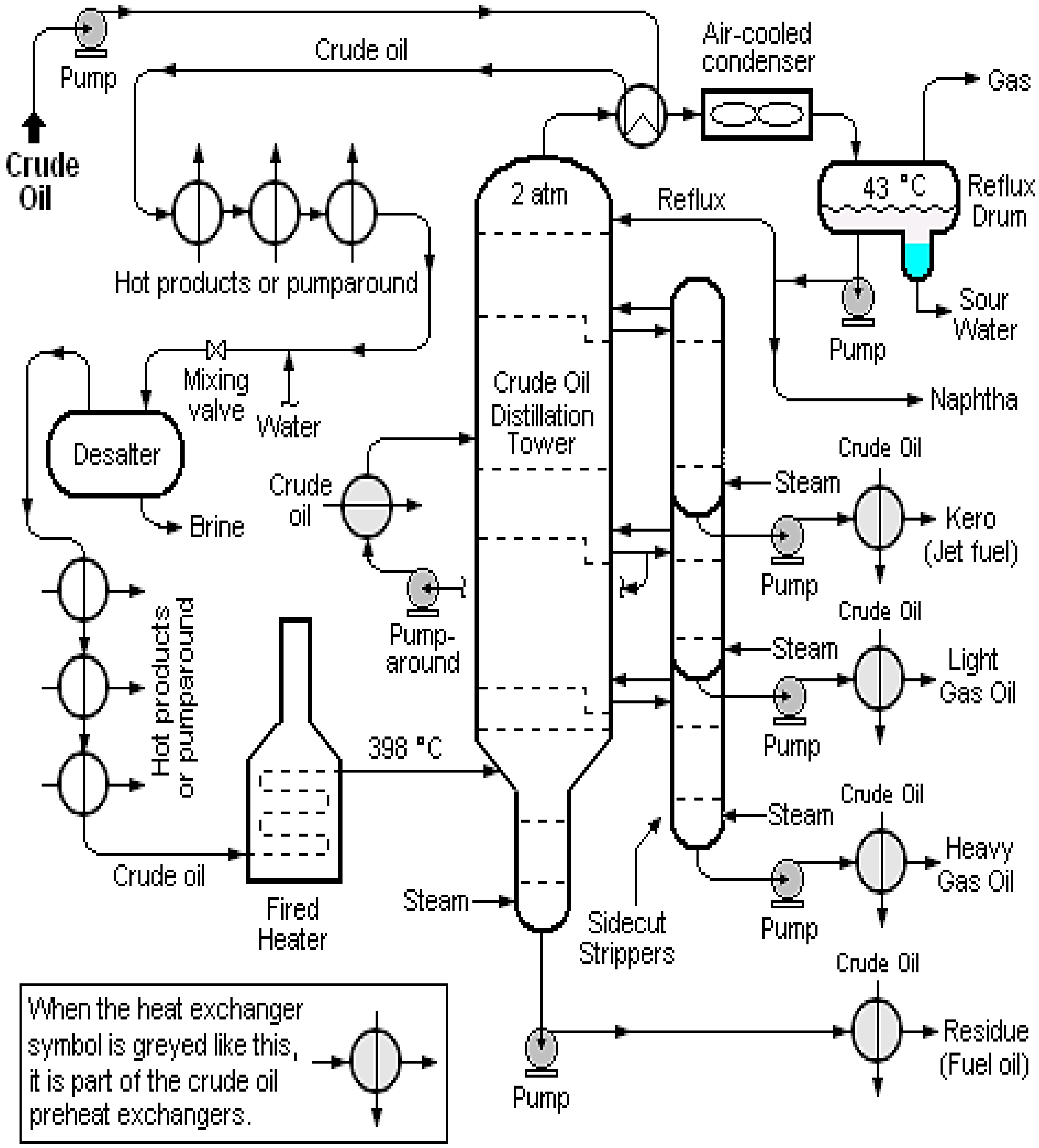


**Figure 1:** A schematic Process Flow Diagram of an atmospheric CDU.

## Main equipment in CDU

- Crude storage tanks and battery limit
- Feed pumps
- Desalter
- Preheat exchangers system
- Crude heater (Direct Fired Heater)
- Atmospheric Crude Distillation Tower
- Pump around system
- Products splitters or stabilizers
- Overhead condensers and reflux drum

## Crude Oil Desalting

It has already been studied.

## Preheating Exchangers System

- Crude oil is heated from storage temperature (45ºC) to about 350ºC before it is introduced to the fractionator column.
- The crude oil is pumped from storage tanks (battery limit area) and preheated in an exchangers train by recovering heat from the pump-around and products to a temperature of between 120-160°C.
- The crude is first heated using the fractionator overhead (ovhd) vapor (naphtha fraction) and top pumparound (TPA).
- This is followed by the kerosene product to insure a crude temperature of 150ºC which is the temperature required for the desalting process.
- After the Desalter, crude is heated by LGO then middle pumparound (MPA) and HGO products respectively to the temperature of 210ºC.

- The hot crude is then further heated by atmospheric residue and the bottom pumparound (BPA) and to a temperature of 260ºC.
- In most cases (but not all!) the crude probably flows through the tube side of these exchangers. The crude would be easier to clean from the tubes than the shell.

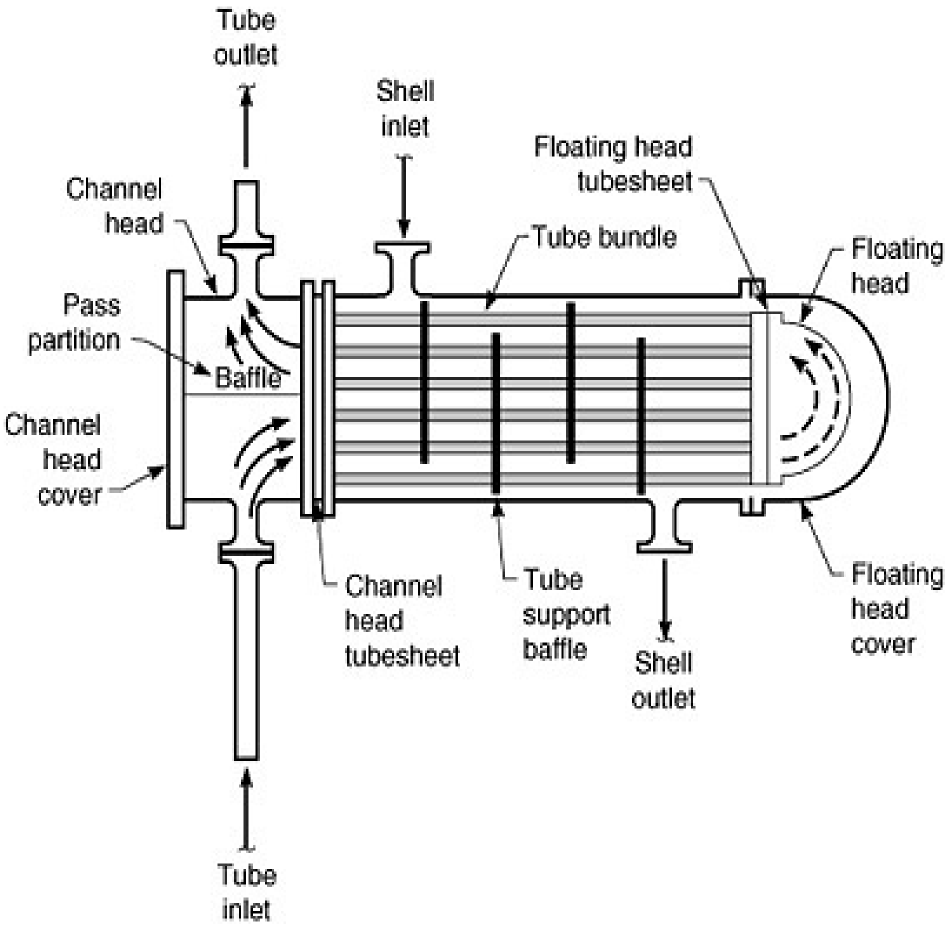


**Figure 2:** Typical shell and tube preheat exchanger.

## Pumparounds

- Liquid is removed from the tower, (all or portion of the side stream) is cooled by heat exchangers (exchanging heat with the crude oil feed), and returned to the tower.
- The top pumparound (TPA) is withdrawn from tray X and returned after heat exchange to tray above tray X.
- The middle pumparound (MPA) is withdrawn from tray X and returned after heat exchange to tray above tray X.

- The bottom pumparound (BPA) is withdrawn from tray X and returned after heat exchange to tray above tray X.

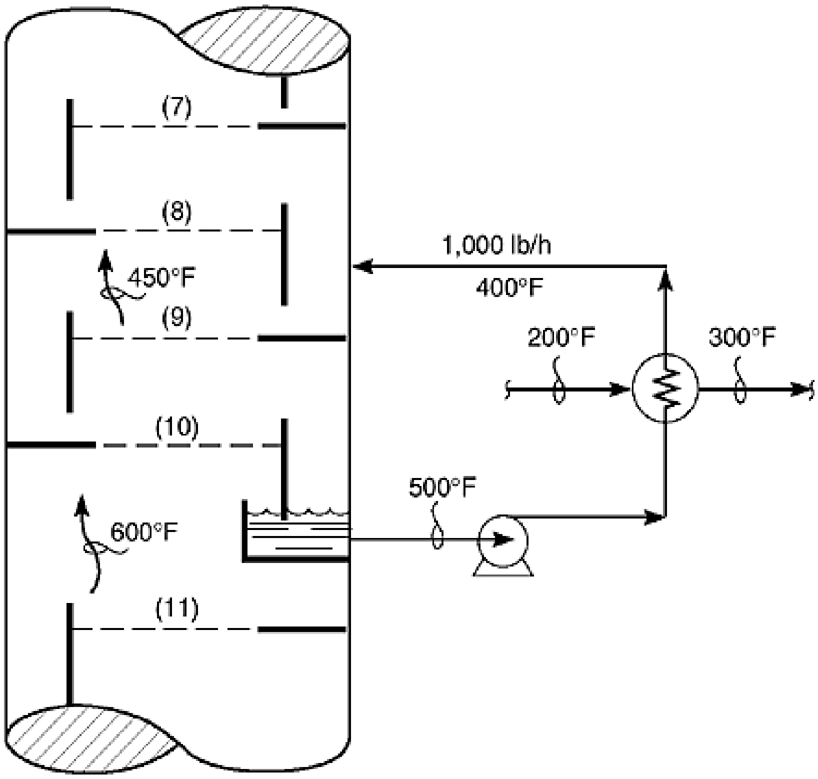


**Figure 3:** Example for pumparound work.

## Advantages of Pumparound

- **Better heat recovery** (at higher temperature) and better energy efficiency (143ºC, 215ºC and 315ºC for the top, middle, and bottom pumparounds, respectively) can be recovered by preheating the feed.
- **Better fractionation between product cuts.** When a portion of the liquid flowing down through the column is removed, cooled, and routed back to the column, this cooled streams condenses more of the vapor coming up through the tower (especially the heavy material in the vapor) allowing only the light material to rise up the tower in the vapor phase, thus, fractionation (separation) is enhanced.

- **Better tower design (more proportionate diameter and smaller height)** If all the heat in the tower is to be removed in overhead condensers, the amount of liquid reflux to the tower will be huge. This would result in an inverted cone-type liquid loading which requires a very large diameter at the top of the tower.

  The tower diameter will have to be reduced below each side product draw-off point along the tower to correspond to the decrease in liquid flow to conserve materials of construction and maintain balanced V/L traffic through the tower. To reduce the top diameter of the tower and even the liquid loading over the length of the tower, intermediate heat-removal streams MPA (pumparounds) must be used.
- **Better vapor-liquid traffic along the tower**. Each side stream product withdrawal decreases the amount of internal liquid (reflux) flowing down below that point in the column. To generate uniform liquid-vapor load through the column a portion of liquid is removed, cooled, and routed back to the column, this cooled stream condenses more of the vapor coming up the tower and provides the reflux (liquid traffic) below the product draw-off point.

## Crude Furnace or Crude Heater (Direct Fired Heater or Charge Heater)

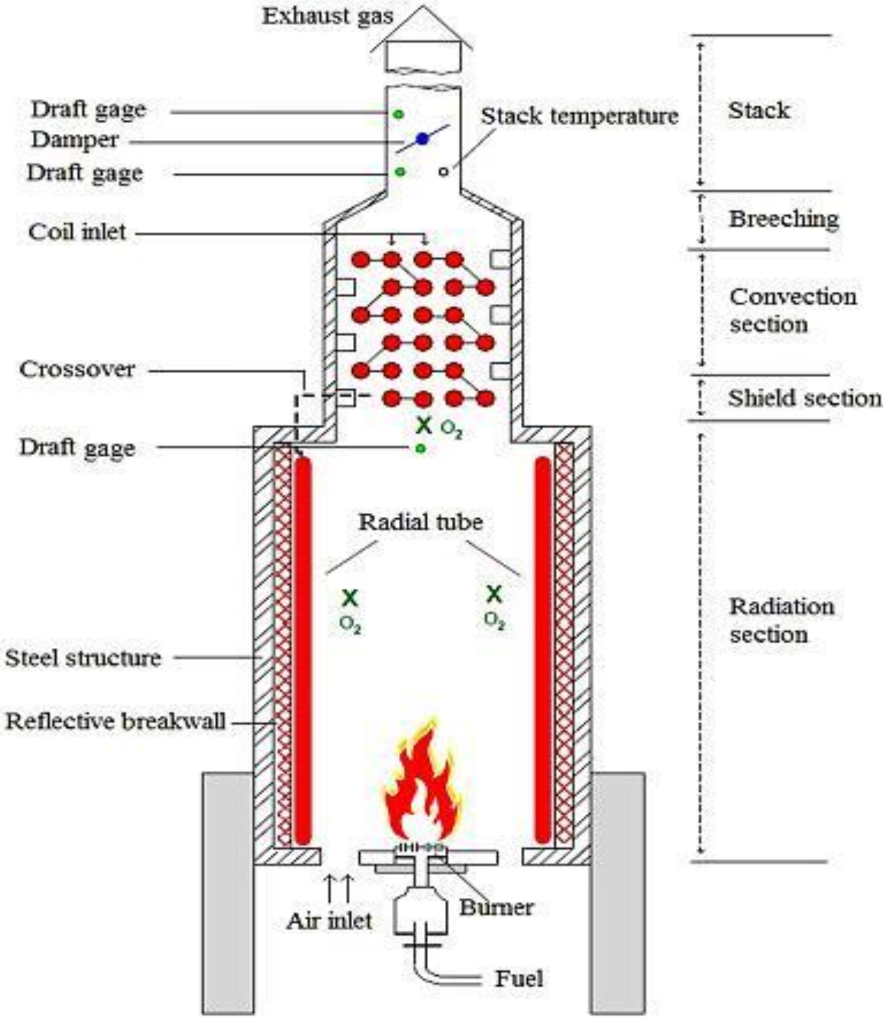


**Figure 4:** Typical fired heater or process furnace in CDU.

- The crude heater raises the temperature of the crude from 250 ºC to about 350 ºC to vaporize all the products withdrawn above the flash zone (total gas, naphtha, kerosene, diesel products) plus the over-flash (10 to 20% of the bottoms product).
- The crude enters the heater through four-six passes into the convection section where it is heated by the flue (combustion) gases, and then enters the radiation section for further heating.
- The passes join together at the heater outlet and enter the flash zone of the fractionator.

- The heater is equipped with an air preheat system to increase the efficiency (91.5%).
- The heater is both gas and oil fired (for flexibility).
- The skin temperature of each coil can be taken as an indication to the flow in each coil. If the skin temperature of one pass is much higher than the others, the flow in that pass is insufficient and must be increased.
- Heater outlet temperature is controlled by a temperature controller that regulates the amount of fuel (gas or oil) burned in the heater.
- This temperature should not exceed 350 ºC to prevent cracking of the feed or damage to the heater tubes. A process heater operating properly will have a zero, or slightly negative draft, at the shield section. The firebox will be slightly positive (+0.5 to +2.0) water column (mmH2O) and the stack will have a range of (-0.5 to -1.0 mmH2O).

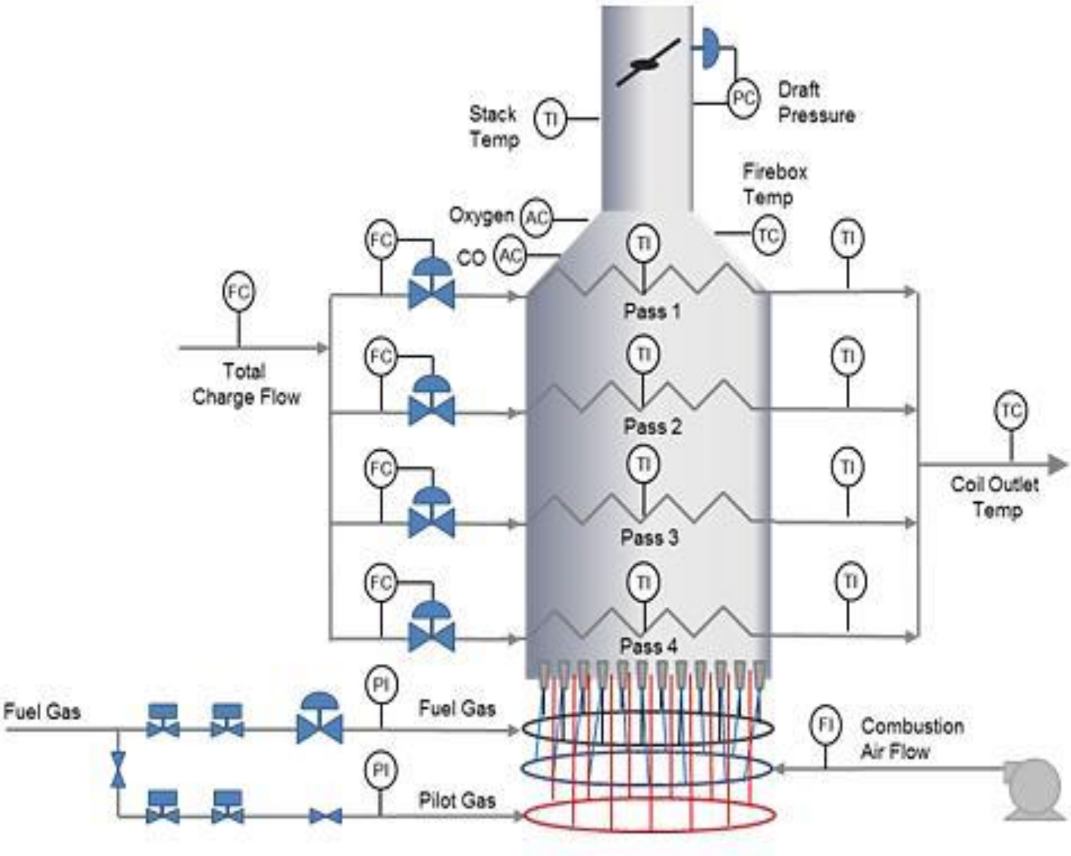


**Figure 5:** A schematic flow diagram for feed dividing to fired heater in CDU

## Atmospheric Crude Distillation Tower (design and internals)

Distillation is a physical process for the separation of liquid mixtures which is based on difference in the volatilities of the components of mixture. Main sections you should know:

- **Column overhead section:** condenser (to cool and condense the vapour leaving the top of the column), receiver (reflux drum hold condensed vapour), reflux/product pump recycle back liquid to the column, pressure control.
- **Rectification section:** side reflux, side draw, side stripper.
- **Zone flash section:** feed inlet
- **Stripping section:** wash section (steam stripping addition).
- **Bottom section:** bottom product pump.
- **Separation Trays:** 30-50 trays, which are used to enhance component separations.
- **Vertical shell:** where the separation of liquid components is carried out.
- **Reboiler** to provide the necessary vaporization for the distillation process. The above components are used either to transfer heat energy or enhance mass transfer.

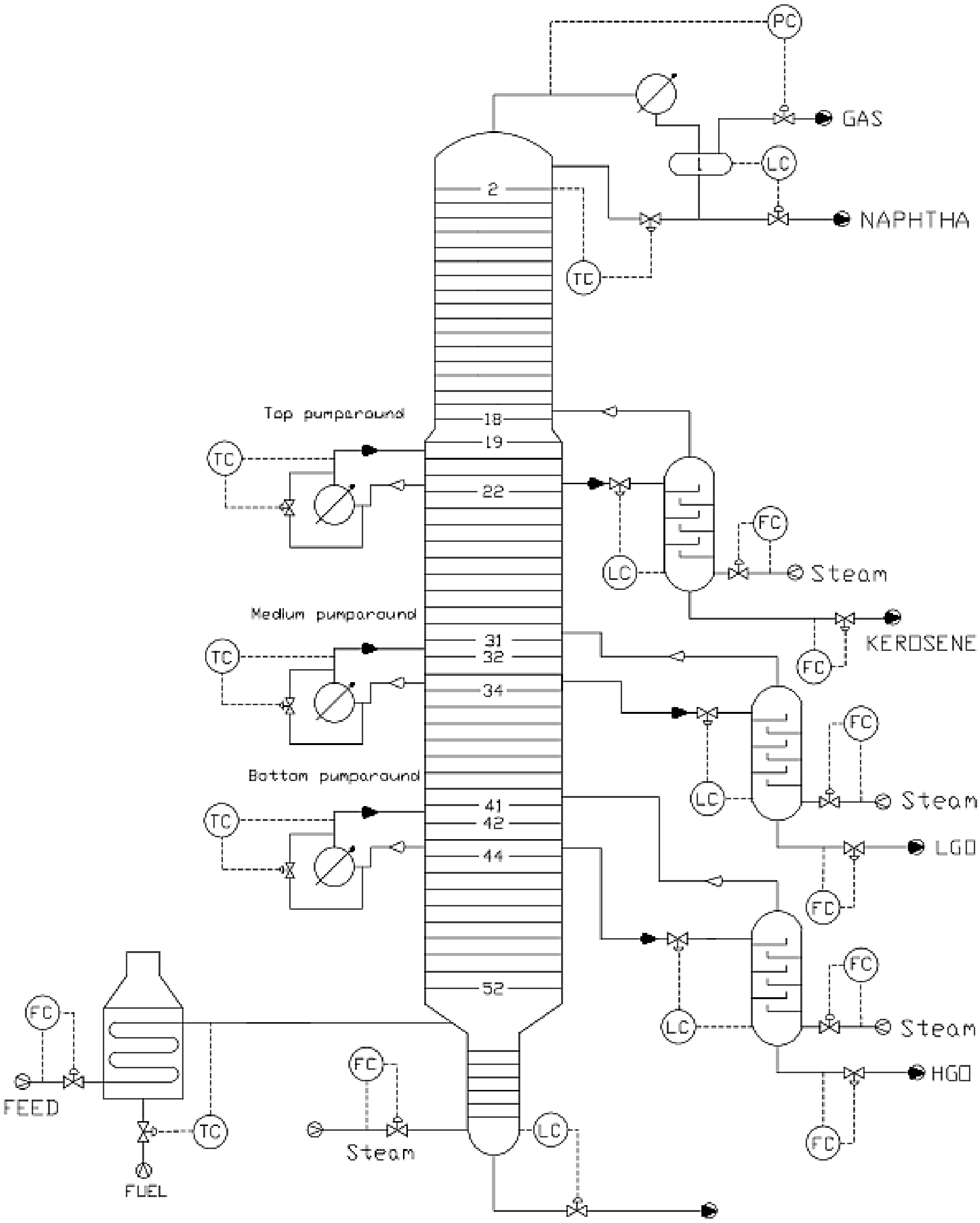


**Figure 6:** CDU tower

## Tray Design

- A tray acts as a mini-column, each accomplishing a fraction of the separation task
- The more trays there are, the better the degree of separation and that overall separation efficiency will depend significantly on the design of the tray.
- Trays are designed to maximize vapour-liquid contact by considering the liquid distribution and vapour distribution on the tray.

- Better vapour-liquid contact means better separation at each tray, translating to better column performance.
- At each tray partial vaporization of light components (heat transfer from heavy liquid to light liquid) and partial condensation takes place.

### Bubble cap trays

It is used above the flash zone (fractionation zone or enriching section). Despite their higher efficiency, bubble caps are avoided in the stripping zone of crude oil fractionators because of:

- High velocity of the steam tends to rip-off the caps.
- High viscosity of the residue negligent the role of caps.
- A bubble cap tray has riser fitted over each hole. The cap is mounted so that there is a space between riser and cap to allow the passage of vapour.
- Vapour rises through the chimney and is directed downward by the cap, finally discharging through slots in the cap, and finally bubbling through the liquid on the tray.

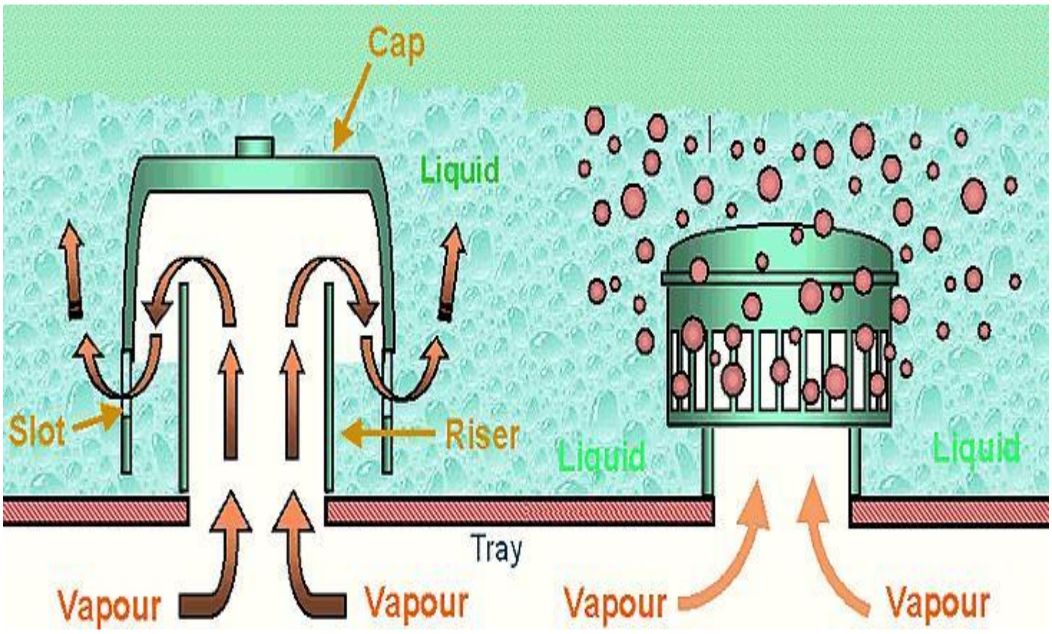


**Figure 7:** Bubble cup tray

## Sieve tray

Sieve trays below the flash zone (stripping zone or stripping section).

- Sieve trays are metal plates with holes in them.
- Vapour passes straight upward through the liquid on the plate.

Because of their efficiency, wide operating range, ease of maintenance and cost factors, sieve and valve trays have replaced the bubble cap trays in many applications.

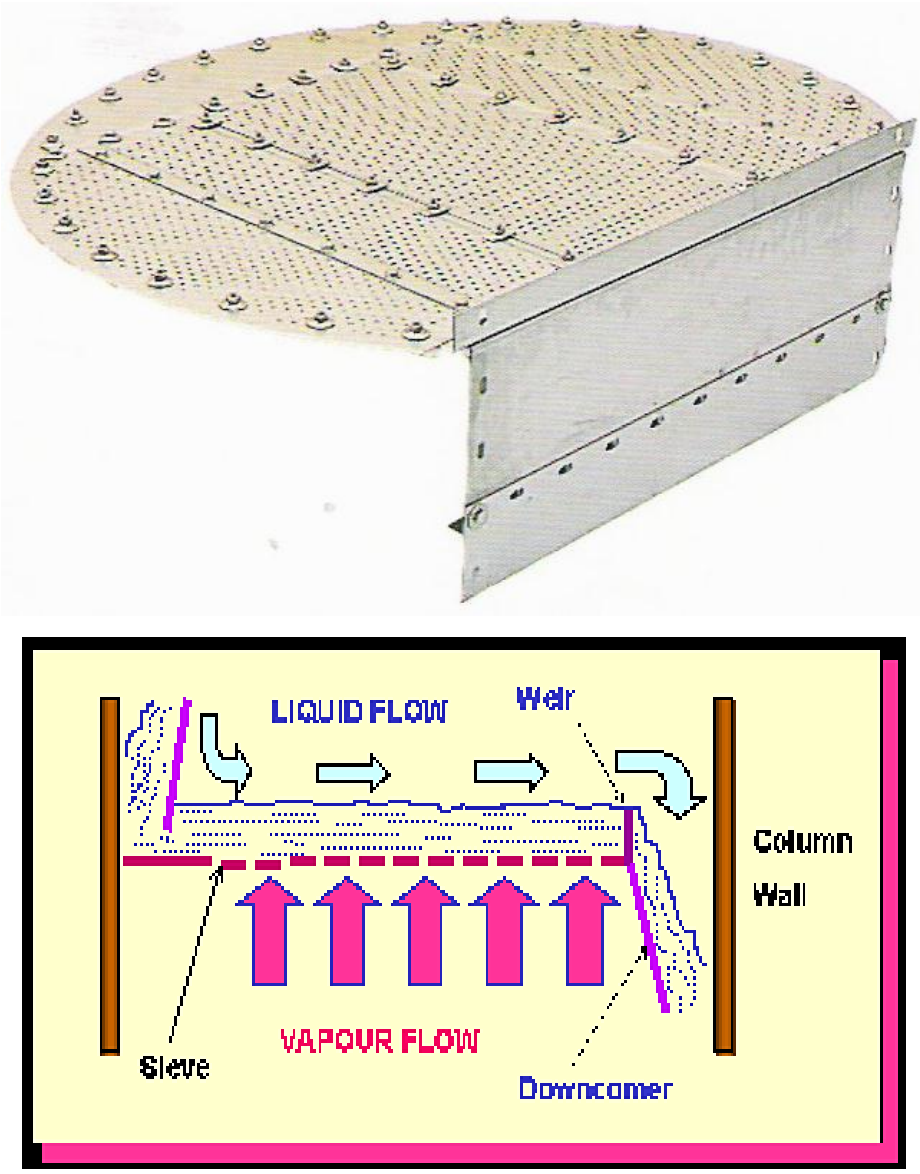



**Figure 8:** Sieve tray

## Valve tray

It is at the column overhead

- In valve trays, perforations are covered by lift-able caps.
- Vapour flows lifts the caps, thus self-creating a flow area for the passage of vapour.
- The lifting cap directs the vapour to flow horizontally into the liquid, thus providing better mixing than is possible in sieve trays.

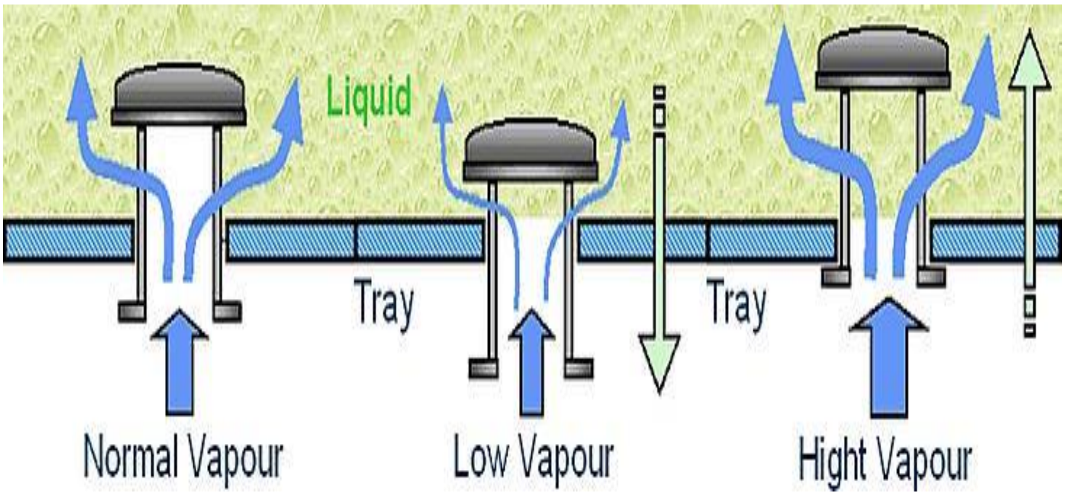


**Figure 9:** Valve tray

## Liquid vapour flow in a tray column

- Each tray has 2 conduits, one on each side, called 'downcomers'.
- Liquid falls through the downcomers by gravity from one tray to the one below it.
- A weir on the tray ensures that there is always some liquid (holdup) on the tray at a suitable height, e.g. such that the bubble caps are covered by liquid.
- Vapour flows up the column and is forced to pass through the liquid, via the openings on each tray.
- The area allowed for the passage of vapour on each tray is called the active tray area.

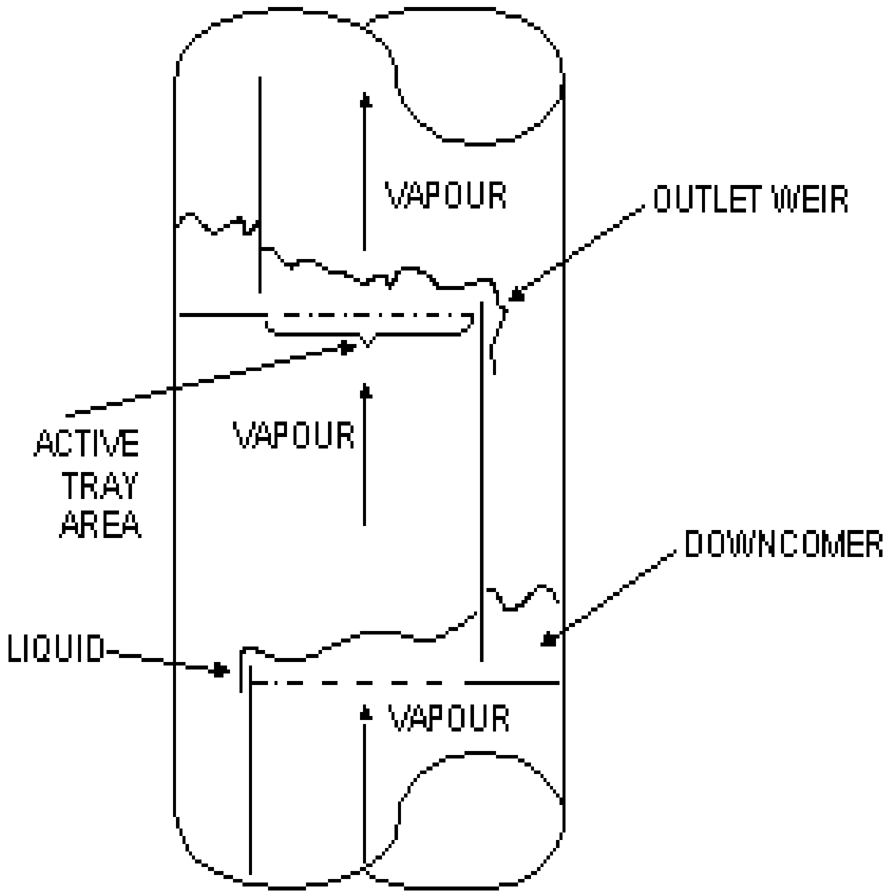


**Figure 10:** Liquid vapour flow in a tray column

## Reflux (heat removal) and its kinds

**Kinds of Reflux.** Ways of removing reflux heat are indicated in Fig. 16-3. With any of these types, regardless of the amount of liquid reflux, the same quantity of reflux heat is removed, except for slight changes in the top temperature. *Cold reflux* is defined as reflux that is supplied at some temperature below the temperature at the top of the tower. Each pound of this reflux removes a quantity of heat equal to the sum of its latent heat and the sensible heat required to raise its temperature from the storage tank temperature to the temperature at the top of the tower. A constant quantity of reflux is recirculated from the product storage tank into the top of the tower. It is vaporized and condensed and returns in like quantity to the product storage tank.

*Hot reflux* is reflux that is admitted to the tower at the same temperature as that maintained at the top of the tower. Obviously, the reflux or overflow from plate to plate in the tower is essentially hot reflux because it is always substantially at its boiling point. For convenience, the overflow reflux or reflux in the tower is referred to as *internal reflux*. Both hot and internal reflux are capable of removing only the latent heat, because no difference in temperature is involved.

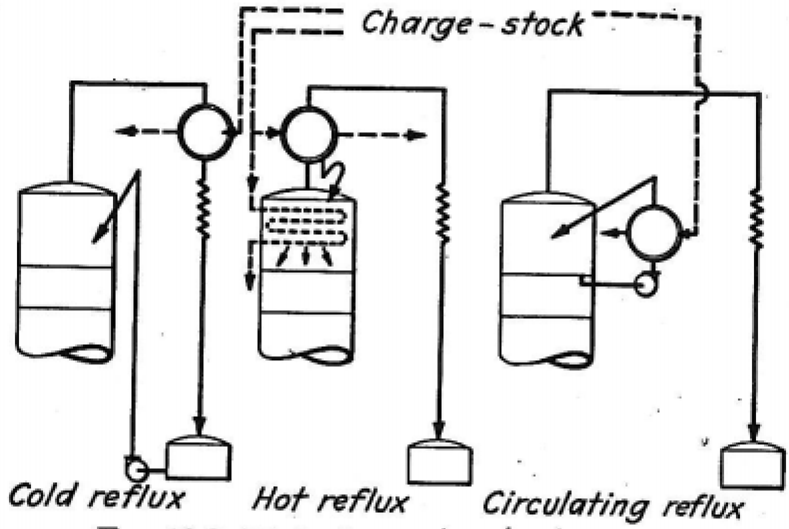


Fig. 16-3. Methods of removing reflux heat.

*Reflux ratio* is defined as the amount of internal reflux divided by the amount of top product. Since internal or hot reflux can be determined only by computation, plant operators usually obtain the reflux ratio by dividing actual reflux by top product. This is satisfactory, of course, but it should be properly labeled.

**Example 1: Quantity of reflux:** A tower fractionating system is such that 2000000 BTU/hr must be removed of reflux heat must be removed. The overhead product is 58 API gasoline (Latent heat = 123 BTU/Ib). How many pound and gallons are required of:

**1)** Hot reflux

**2)** Clod reflux (top temperature =300 $^0$F and storage tank at T = 100 $^0$F)

**3)** Circulating reflux (the reflux is cooled from 300 $^0$F to 300 $^0$F).

## Solution:

Basis: 1 hr.

The overhead product is assumed to be a 58 API gasoline (6.22 lb per gal). The temperature at the top of the tower is 300°F.

1. *Hot Reflux.* The latent heat of the gasoline is about 123.

$$\text{Lb of hot reflux} \ldots\ldots\ldots \frac{2{,}000{,}000}{123} = 16{,}250 \text{ lb per hr}$$

$$\text{Gal hot reflux} \ldots\ldots\ldots\ldots \frac{16{,}250}{6.22} = 2{,}615 \text{ gal per hr}$$

2. *Cold Reflux.* Assume storage tank at 100°F.

$$\text{Lb cold reflux} \ldots\ldots\ldots\ldots \frac{2{,}000{,}000}{123 + (300 - 100)0.575} = 8{,}400$$

$$\text{Gal cold reflux} \ldots\ldots\ldots\ldots \frac{8{,}400}{6.22} = 1{,}350$$

3. *Circulating Reflux.* Assume the reflux is cooled from 300 to 200°F.

$$\text{Lb circulating reflux} \ldots\ldots\ldots\ldots \frac{2{,}000{,}000}{(300 - 200)0.605} = 33{,}100$$

$$\text{Gal circulating reflux} \ldots\ldots\ldots \frac{33{,}100}{6.22} = 5{,}310$$

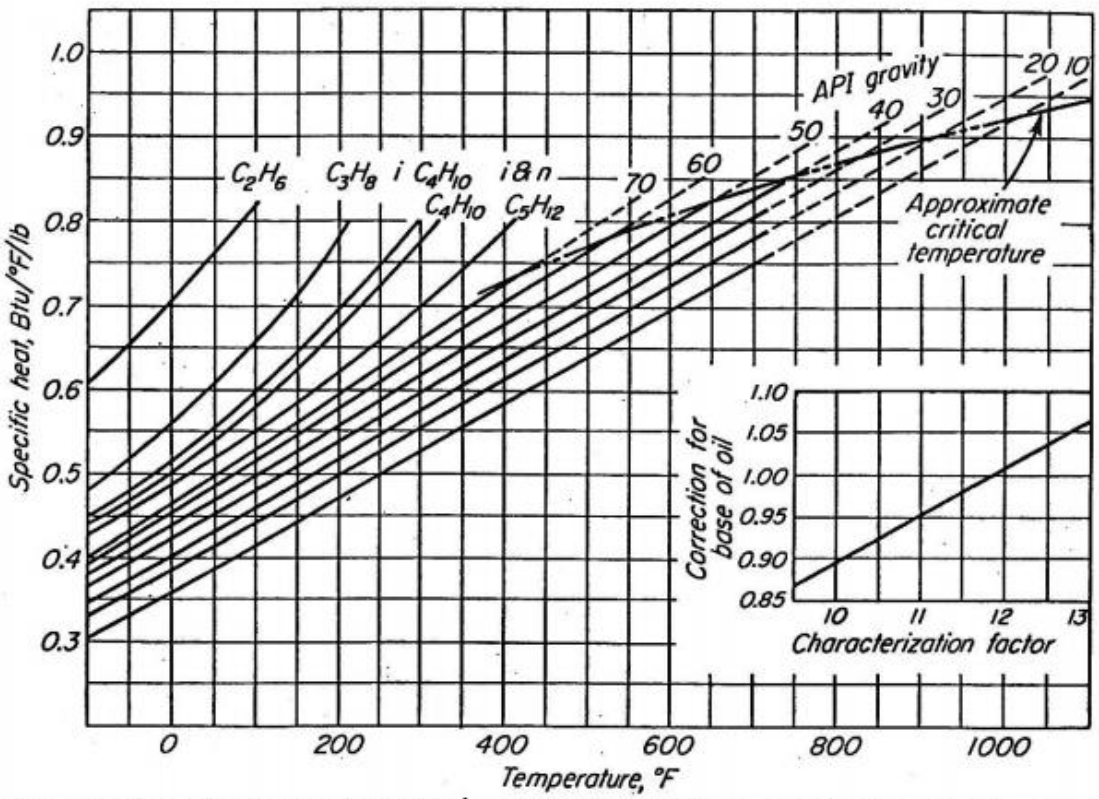


FIG. 5-1. Specific heats of Mid Continent liquid oils with a correction factor for other bases of oils.

## O/H Condensing System

- The fractionators O/H vapors (usually consisting of gas, un-stabilized naphtha and the stripping steam).
- The pentane and heavier fraction (C5+) is condensed in the overhead cooling system.
- The butane and lighter (C4-) remain in the gas phase.
- Ammonia solution is injected to crude column vapor line and on top tray to control acids formed by hydrolysis of the salt present (e.g. Na+Cl- + H2O → HCl + NaOH).
- Corrosion inhibitor is also added to prevent corrosion due to HCl and H2S present.

## Atmospheric Residue Section (bottom section)

Several trays are generally incorporated below the flash zone section and steam is introduced below the bottom tray to:

- Lower the partial pressure and, thus, the boiling point of the residue to avoid thermal cracking and degradation of the bottom product (Thermal cracking produces coke, which tends to block heat exchangers and other equipment resulting in poor heat transfer and lower efficiencies).
- Strip any remaining gas oil (more valuable) from the liquid in the flash zone (residue).
- Produce high-flash-point bottoms (by stripping the low boiling point material).

## Stripping Stream

- Crude towers do not normally use reboilers because of the tendency of the residue to crack at high temperatures clogging the heat exchanger.

- Superheated steam is used instead to reduce the partial pressure of the hydrocarbon and thus lower the required vaporization temperature.

## Side Draw Stripper (stripping the light ends)

- The liquid side stream withdrawn from the tower will contain low-boiling components, which lower the flash point of the product. (Because the lighter products in the vapor phase pass through the heavy products in the liquid phase and the two are in equilibrium on every tray).
- These ‘light ends’ are stripped from each side stream in a separate side-strippers.
- Side strippers is used to remove light ends from the product stream thus improving (increasing) their flash points & initial boiling point IBP.
- Side strippers could be either **separated nor mounted side strippers.**

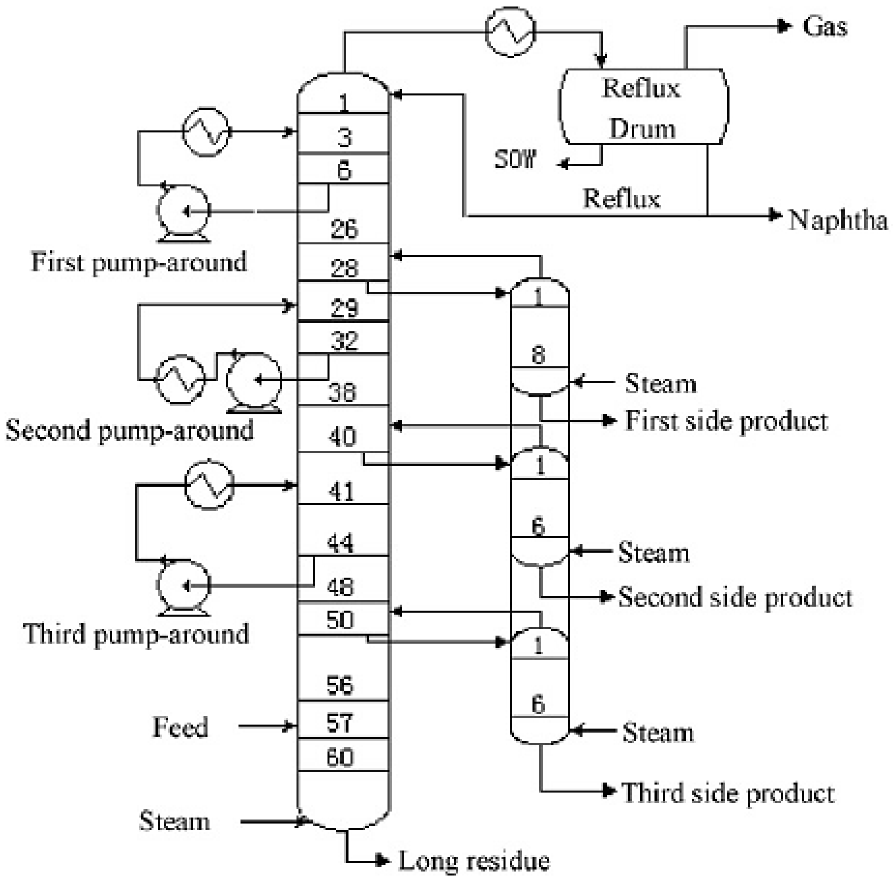


**Figure 11:** Three side strippers mounted on each other

- The strip-out /light ends (along with the stripping steam) leave the stripper at the top and enters the fractionator in the vapor zone directly above the tray of the side draw.
- The stripped products withdraw from the bottom of each stripper. Products Draw (side streams)
- Kerosene product is drawn from kerosene tray and is introduced to the top tray of Kerosene stripper.
- Diesel (light gasoil) product is drawn from light gasoil tray and is introduced to the top tray of diesel stripper.
- Each of the side stream products removed from the tower decrease the amount of liquid traffic below the point of draw-off.
- Increasing the amount of kerosene withdrawal, will result in a decrease in the amount of liquid going down through the tower.

This will lead to less condensation of vapors going up and more of the diesel cut will rise up and go into kerosene (↑FBP).

- The opposite is also true.
- The over flash is a liquid drawn from tray (above the flash zone) and returned to tray (below the flash zone).
- The over flash (which is 5 vol. % of the crude) helps to remove the heavy material from the diesel product and improves the fractionation (separation) between the diesel and the atmospheric residue cuts.