Crude distillation

5.1 Introduction

In this section, we present a brief overview of the crude distillation process.

The first essential task for the crude oil consisting of more than 10^8 compounds is to separate its major components based on boiling point differences. This principle is exploited in the crude distillation unit which involves energy intensive operation. Since crude distillation involves the processing of the entire feed, it remains as the most significant operation in a refinery.

Process flowsheet

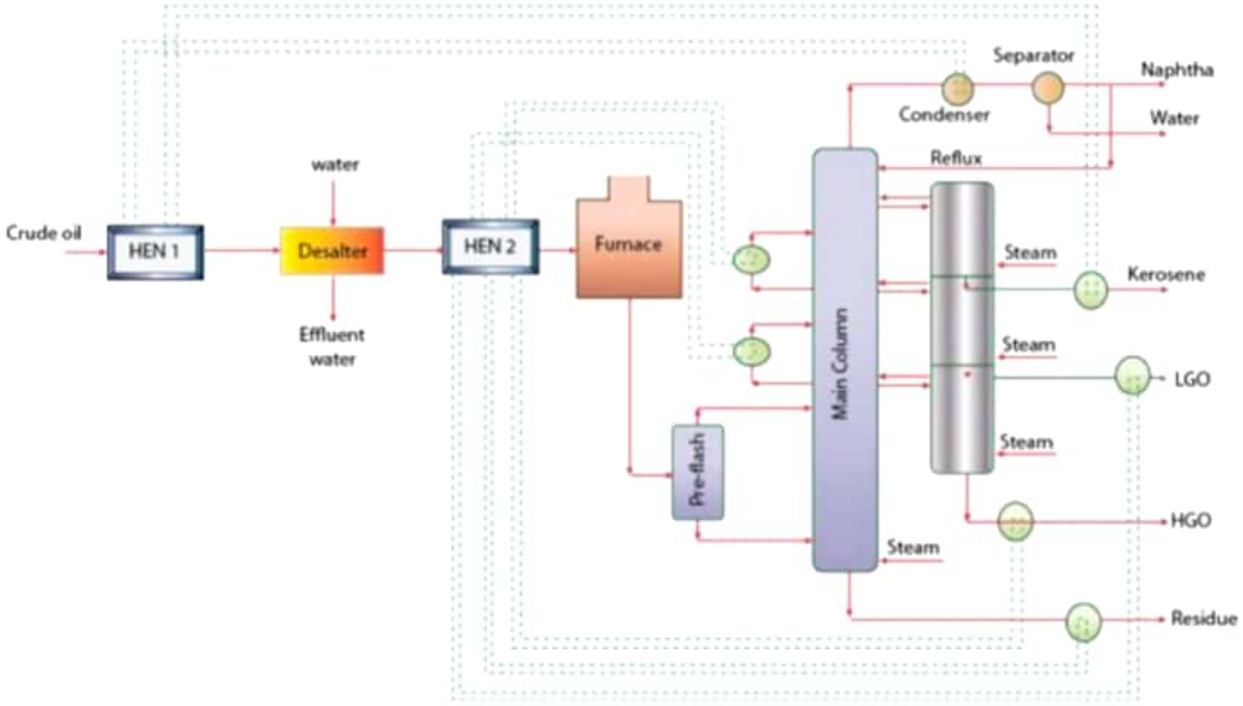

Figure.5.1: Process flowsheet - a conceptual diagram of the crude distillation unit (CDU) along with heat exchanger networks (HEN)

The conceptual process flowsheet for the petroleum refinery is shown in the Figure 5.1. It consists of the following important sub-processes:

- Crude desalter
- Furnace
- Pre-flash column
- Crude distillation column supplemented with side columns. These columns produce the desired products
- Pump around heat exchanger units
- Heat exchanger network that facilitates energy recovery from hot product and reflux streams to heat the crude oil.

We next present the functional role of various sub -processes in the crude distillation unit.

5.1.1 Crude desalter

- Crude oil consists of dissolved salts and they tend to cause fouling and corrosion in various process equipments. Therefore, dissolved salts need to be removed using a separation process.
- The crude desalting unit is a separation process. Here, water along with other trace chemicals such as caustic and acid are allowed to enter a mixing unit along with the crude oil.
- The mixture of crude oil and water is subsequently passed through an electrostatic precipitator cum gravity settler. The electrostatic field enables the agglomeration of water droplets and aids faster gravity settling.
- An essential issue for the good performance of crude desalter is the temperature of the operation. Usually, high efficiency of salt removal is possible between 100 – 300 ^{o}F.
- Therefore, the crude oil is heated to about 250 ^{o}F before it enters the desalter unit.
- The clean desalted crude oil flows from the top of the gravity settler and the water along with other dissolved impurities is removed as a bottom product

5.1.3 Pre-flash column

- The crude oil enters the pre-flash column after leaving the furnace
- The pre-flash tower separates the lighter fractions of the already heated crude oil.
- The heavier fractions of the crude oil leave from the bottom section of the pre-flash tower.
- Both lighter and heavier streams emanating from the pre-flash tower are fed to the main crude distillation column at various sections
- Pre-flash column enables better refluxes in the main column by distributing the streams effectively between various processing zones of the crude oil.
- Pre-flash column may or may not be included i.e., it is optional. In other words, the pre-flash column can be avoided and the heated crude oil from the furnace can be fed to the main column directly.

5.1.4 Main and Secondary distillation columns

- The distillation columns consisting of both main and secondary crude distillation columns are one of the most complex circuitries in distillation.
- The complex arrangement of distillation columns is based on research carried out with pilot plants and simulation software.
- The crude distillation columns (both main and primary) are regarded to an indirect sequence of thermally coupled distillation sequences to obtain the desired products.
- Effective distribution of vapor and reflux in the main column is a serious issue.
- The effective distribution of vapor and reflux is aided through pump around heat exchanger units.
- Live steam is also used in the recent designs. The live steam is usually at about 50 psig.
- The basic principle of using live steam stems out from several facts. Firstly, upon condensation, oil and water are very easy to separate. Secondly, steam can take significant amount of heat in terms of enthalpy. Thirdly, steam enables enhancement in relative volatility, a principle that is used in steam distillation laboratory experimental set ups. These principles together are anticipated to provide good dividends technically.
- Live steam cannot be just fed at one section of the CDU. It needs to be fed at various sections to ensure both good heat distribution and reduce relative volatilities of the hydrocarbons at various sections of the main and secondary towers.

- Therefore, live steam will enable good product quality as lighter hydrocarbons with higher relative volatilities in the bottom heavy product liquid streams will be easily stripped and carried along with the vapor.
- The only condenser in the main column is a partial condenser to facilitate the production of both gas and naptha+water stream.
- The circuitry totally avoided the existence of reboilers by introducing live steam. Therefore, much fixed costs of the column have been reduced. However, higher operating costs due to higher steam utilization rates are evident.

5.1.5 Pump-around units

- Pump around units are most essential units in the crude distillation column.
- They are used to maintain good reflux conditions in the main column and therefore the desired product quality.
- They also provide a good heat source as the liquid streams are at higher temperatures. Therefore, they are also important units in the heat exchanger network.
- The cooled liquid is sent back to a section above.
- Usually two pump arounds are used in conventional designs. However, there are crude distillation units with even three pump around units.

The circuitry connections between primary and secondary towers along with relevant pump around units are presented in Figure5. 2. It can be seen that very complex interactions exists between the main and secondary columns.

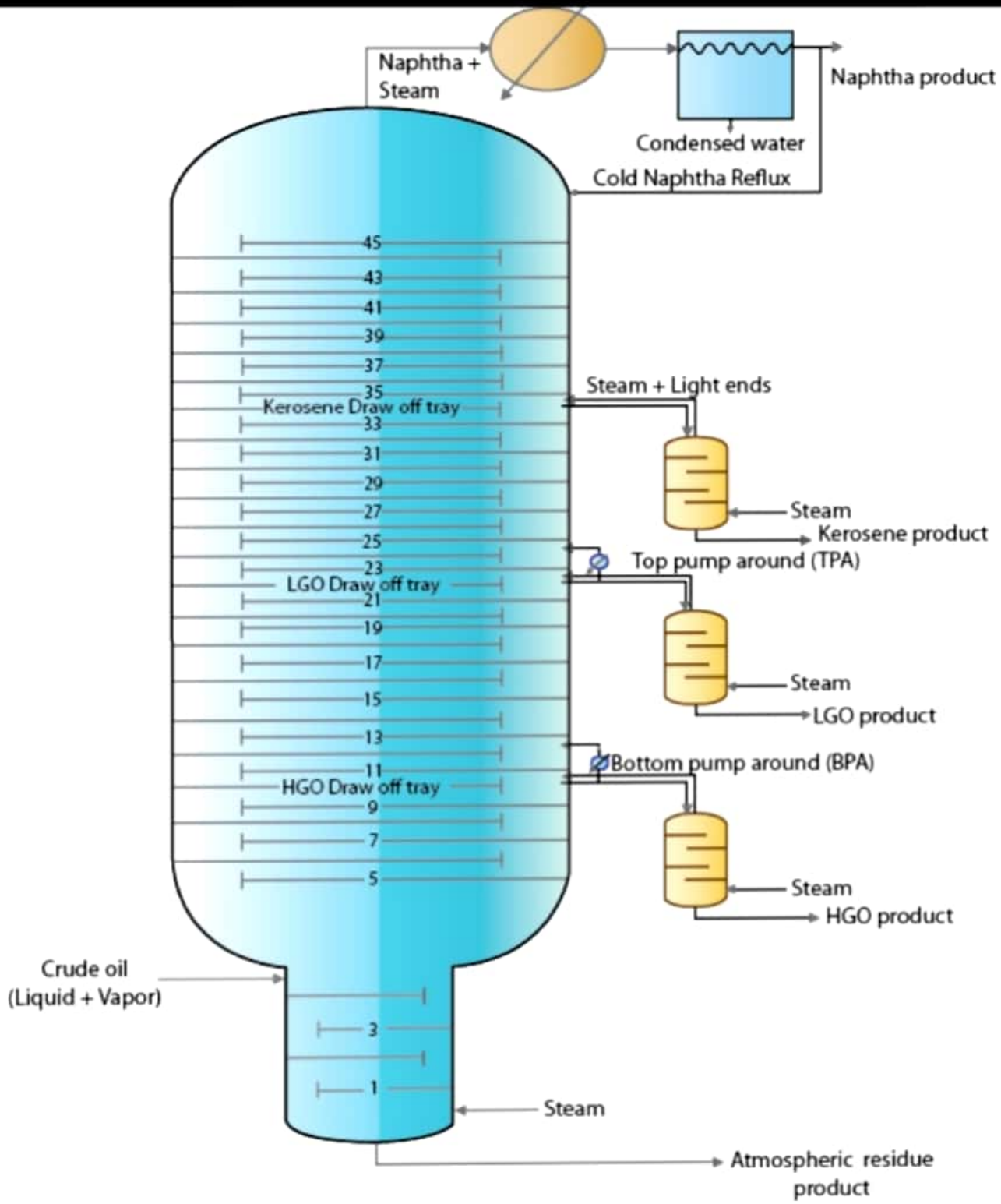

Figure 5.2: Design architecture of main and secondary columns of the CDU.

a) The main column consists of 45 trays and the secondary columns (side strippers) consist of 4 trays each. Three side strippers are used to strip the light ends from kerosene, LGO and HGO products.

b) The main column has two sections that are distinguished with respect to a flash zone. The flash zone is where the crude oil partially vaporized is fed to the main column. There are about 4 trays below the flash zone and 41 trays above the flash zone of the main column. The bottom most tray (residue

stripping tray) is numbered as 1 and the top tower tray is numbered as 45. Trays 1 to 4 process the atmospheric residue portion of the crude in the section below the flash zone.

c) Trays 5 to 10 (6 trays above the flash zone) process the HGO product portion of the crude. From tray 10, HGO draw off product is taken out (as liquid) and enters the HGO side stripper unit. From tray 10 as well, the liquid stream is drawn and sent to tray 12 via a bottom pump around unit that enables cooling of the liquid stream. The steam + light ends from the HGO side stripper enter tray 11 of the main column.

d) Trays 13 to 22 (10 trays above the HGO processing zone) process the LGO product portion of the crude. From tray 22, LGO draw off product is taken (as liquid) and sent to the LGO side stripper unit. Also, from tray 22, another liquid stream is taken out and sent to tray 24 via a top pump around unit (TPA) that enables cooling of the liquid stream. The steam + light ends from the LGO side stripper enter tray 23 of the main column.

e) Trays 24 to 34 (10 trays above the LGO processing zone) process the kerosene product portion of the crude. From tray 34, the kero draw off stream is taken and sent to the kerosene side stripper unit. The steam + light ends of the kerosene side stripper enter tray 35.

f) Trays 34 to 45 (12 trays above the Kerosene processing zone) process the naphtha product portion of the crude. **It is interesting to note that tray 34 is regarded as a tray processing both LGO as well as naphtha processing zone. This is because there is no pump around associated to the tray 34. Where pump around is associated, that tray is often ignored in counting, as it affects to a large extent the tray hydraulics and contributes less towards the separation of the components.**

g) It is interesting to note that steam enters main column at trays 1, 11, 23, 35 and therefore is present along with the vapor stream along with the hydrocarbons. Therefore, **steam balances throughout the column are very important.**

h) The cold naphtha stream obtained from the phase separator is sent back to the main column as reflux stream.

5.1.6 Heat exchanger networks

- Two heat exchanger networks exist in the crude distillation unit, one before the crude desalter and one after the crude desalter.
- The heat exchanger networks facilitate energy recovery from hot product, naphtha+steam vapor and reflux streams to heat the crude oil in an indirect heat transfer mode i.e, using heat exchangers.
- Therefore, the design and operation of a heat exchanger network is very important in the crude distillation unit.
- Further, it needs to be understood that the naphtha heat integrated condenser is a partial condenser where as all others are heat exchangers without any phase change streams.
- The heat exchanger networks enable to increase the crude oil stream temperature to about 200 – 230 ^{o}C which is significantly higher than the crude oil source temperature (about 20 – 30 ^{o}C).
- Crude distillation units without heat exchanger networks have higher furnace load targets. They also cause more pollution due to burning more fuel oil and fuel gas streams.

5.2 Technical questions

1. **What is the most important aspect of main column in the CDU?**

Ans: The column hydraulics with a good distribution of liquid and vapor in the CDU is the most important aspect. The entire concept of live steam at various sections, top and bottom pump arounds, over-flash is centered around this designed basic feature.

2. **What similarities are there for the CDU with vacuum distillation unit?**

Ans:: Both crude and vacuum distillation units have similar architecture of the main and secondary columns i.e., both have complex stream circuitries with pump arounds, heat exchanger networks and utilization of steam. Only basic difference is that while we operate the VDU at lower pressure (30 – 40 mm Hg), the operating temperatures will be lower than those in the CDU. Otherwise, the basic principles remain the same.

3. **What primary disadvantage exists by using live steam in the CDU columns?**

- Live steam once it enters the column does not condense anywhere, as we don't want any condensation to happen.

- When live steam is used, vapor load increases significantly in the column

- This increases the diameter of the column at various sections. There will be ofcourse a section that has maximum vapor load and this section will have the maximum diameter.

References:

5. Gary J.H., Handwerk G.E., Petroleum Refining: Technology and Economics, Taylor & Francis, 2005

6. Jones D.S.J., Elements of Petroleum Processing, John Wiley & Sons, 1995