Lecture 08: Primary Processing of Crude Oil: Reflux Systems, Vacuum Distillation Unit (VDU)

Hello and welcome to the 8th lecture on petroleum technology. In this lecture, I will cover the primary processing of crude oil under which we will learn about different types of reflux systems and the vacuum distillation unit. Here actually in the refinery in the distillation apparatus, we use various kinds of reflux systems. Among those, the first one is tower top reflux or pump around reflux system and another one is overhead reflux system. Tower top reflux system is also called the side reflux system or circulating reflux system. Here part of the ascending vapor to the top section of the atmospheric tower is condensed by contacting the cooled pump around the reflux liquid and flows down as internal reflux.

Here the ascending vapor from the tower top is drawn out of a tray and it is then cooled by exchanging heat with a cold stream and then the condensed liquid is sent back again to the tower in a tray above the drawn tray. This liquid comes down as the internal reflux which comes in contact with the ascending vapors and mass transfer occurs for a good fractionation. For this tower top reflux system, pump around reflux system as the tower top has to take a lot of liquid to handle. So, the tower top diameter becomes more.

Now coming to the overhead reflux system, it can be divided into a cold reflux system and hot reflux system. In the overhead reflux system, what is done? The overhead vapor is taken out from the overhead trays, it is condensed, cooled, and then sent back to the top of the atmospheric distillation tower as a reflux. In the cold reflux system, it is a simple operation where the whole of the overhead vapor is condensed in one stage. The overhead vapor is drawn from the top plate of the distillation tower, it is then condensed and cooled in a condenser and then taken in a reflux drum. In the reflux drum, we get the non-condensable gases which are taken out as the off-gas or refinery off gas or refinery gases and the hydrocarbon liquid is taken out as the naphtha.

This naphtha is split into two parts, one is sent to the top of the distillation tower as the cold reflux and the other part is taken as the product naphtha. Finally, we will get some sour water which is mixed with the crude oil. This is the simplest operation and it is the tower, is the overhead tower is also narrow, it is not required to be broader in diameter. The next one is another overhead reflux system which is said to be a hot reflux system. In the hot reflux system, two stages of condensation operation are processed.

One is in the first stage, the heavier fraction is condensed and returns to the column as reflux and in the second stage, the lighter fraction is condensed and obtained as full range naphtha fraction. The vapor from the overhead of the tower is taken out, it is condensed halfway to some hydrocarbon liquids which are heavier, heavier fractions that are

condensed at a moderate temperature and we can get some gases that are not condensed at that temperature of the condenser. The hydrocarbon liquid which is obtained after condensation is sent back to the tower top as the reflux. Next is the other vapor, other part of the vapor which is not condensed in this first stage, is taken to the second stage of the condensation and cooling and then it is taken in a second reflux drum and the whole fraction is cooled here and the liquid part we get. Some non-condensable gases are obviously obtained which are taken out as the refinery off gas and we get the full range naphtha.

The temperature of the reflux sent to the top of the atmospheric tower as the reflux is more than the cold reflux system. So, this system is said to be a hot reflux system. Now let us talk about vacuum distillation. The atmospheric residue that we obtain from the bottom of the atmospheric distillation tower contains lots of valuable cuts and fractions that we cannot get at atmospheric pressure. If we want to get the valuable cuts out of the atmospheric residue by processing the atmospheric residue at the atmospheric tower condition then obviously we have to raise the temperature above the gas oil cut temperature and that will cause the cracking or decomposition of the atmospheric residue and at that condition, the whole atmospheric tower will be full of fumes and it will be non-operable, no fractionation will be obtained.

So, we have to take the atmospheric residue to be processed under vacuum so that we can recover those valuable cuts from the distillation tower. Now atmospheric residue is distilled under sub-atmospheric pressure. The vacuum tower has a flash tray or feed tray whose pressure is maintained at around 25 to 40 millimeters of mercury pressure under the atmosphere. Now crude oil can be of two types, one is lube-bearing crude and the other one is nonlube-bearing crude. Lube-bearing crudes are those that contain the hydrocarbon components that construct the lubricating oil. Usually, the lubricating oil has the composition of long-chain paraffinic hydrocarbons.

If the crude oil contains those hydrocarbons in its composition then obviously by vacuum distillation of the atmospheric residue of the crude will give us the lubricating oil base stock as the side product of the vacuum distillation unit. But some crudes that do not contain those long-chain paraffinic hydrocarbons or the lubricating oil hydrocarbon containing the lubricating oil then those crudes are called nonlube-bearing crude. Non-lube-bearing crude can produce only vacuum gas oil after vacuum distillation. The vacuum distillation of the crude which has a lubricating oil composition in it that is lube-bearing crude, is called lube type vacuum distillation. Vacuum distillation which processes the non-lube bearing crude is said to be a fuel type of vacuum distillation.

Before going to the next slide let me tell you another thing. This lubricating oil base stock is taken out as the side draw products. Several types of lubricating oil base stocks are taken out from the vacuum distillation unit which have different properties in terms of

viscosity and carbon residue. So, those are blended together in different proportions to meet the industry standard, so that they can be used as lubricating oil for industry purposes. And vacuum gas oil is used as the feedstock for the hydrodesulfurization unit, fluid catalytic cracking unit as well as a hydrocracking unit. Now let us look at the scheme where atmospheric residue exchanges heat with different streams.

This is a simplified flow diagram of the heat-exchanging system. Atmospheric residue exchanges heat with the distillation products of the atmospheric column, then it exchanges heat with the vacuum residue to get preheated and then also the pump around the reflux stream. Afterward, it enters into the atmospheric residue furnace to get the required heat to produce the vapor and is then introduced into the feed tray of the vacuum distillation unit. Now let us talk about different types of vacuum distillation units depending on the type of furnace used in them. There are two types of vacuum distillation operation: one is wet type, and the other is dry type.

Depending on the steam injection to the furnace this classification is made. The wet type is where steam is injected into the furnace coils and the dry type is where steam is not used. So, furnace injection steam is required for the wet type of operation whereas, for dry type, it is not required. The operating pressure of the wet type is higher than the dry type because of the reason, that lots of steam is introduced and steam has having good effect on the process, in that the steam lowers the partial pressure of the hydrocarbon by one point. The next one is it imparts the velocity to the atmospheric residue which can flow through the tubes and another one is that it resists the coke formation in the tubes.

Now, ejector steam consumption is lower in the wet type because we are injecting steam into the furnace which is carried forward through the atmospheric column to the ejector steam system where the ejector operates in the vacuum system to produce the vacuum to create the vacuum in the distillation tower. And ejector steam consumption is higher in the case of dry type because we do not provide any steam at the beginning. A number of ejector stages are required of different types. One for the wet type, which is a two-stage operation, is sufficient for the ejector system whereas, for the dry type three-stage ejectors are required. And coking of the furnace tube is mild because steam inhibits the coke deposition on the furnace coils and the dry type is moderate. Now, let us discuss the fuel-type vacuum distillation operation.

In the fuels type, you understand that, we have only product from the top or side of the vacuum distillation unit, which is vacuum gas oil. And atmospheric residue is flashed at the required temperature in the vacuum tower feed plate. We can split the vacuum gas oil into two parts: one may be the light vacuum gas oil, LVGO and the other one will be heavy vacuum gas oil, depending on the boiling point of those two streams. And vacuum residue is withdrawn from the bottom of the tower. So, as a whole, there are two major

streams, one is vacuum gas oil as the side product and the bottom product is vacuum residue.

Vacuum gas oil is extracted from the side draw tray. It does not need very good fractionation because it is the only distillate product we obtain from the vacuum distillation unit of fuels type. And major properties to be controlled for vacuum gas oil are metal content and carbon residue content. So, we have to keep in mind that the vacuum gas oil should be in such a property, so, that it can maintain the specification of the metals content and carbon residue. Now, the next one is the lowering operating pressures because vacuum distillation unit operates at a far lower pressure than the atmospheric distillation tower.

And lowering operating pressure because significant increase in the volume of vapor per barrel vaporized. At lower pressure, lots of vapors are formed from the atmospheric residue introduced into the feed tray to the vacuum distillation unit. As a result, the vacuum distillation columns are much larger in diameter than atmospheric towers. If you go to the refinery you will see that the atmospheric tower is thinner, one thinner and long, whereas the vacuum distillation column is fat and smaller; this is the reason. Now, grid trays are used and side strippers are not used.

Here, we have the only distillate product, VGO vacuum gas oil. So, our main purpose is to get the proper heat transfer. Because of the need for proper heat transfer, we need grid trays. We do not need any bubble cap trays, as fractionation is not important here. Side strippers are not used because of the reason only one product is obtained from the side tray. Next, the internal designs of some vacuum towers are different from atmospheric towers, in that random packing is used instead of trays.

This is a specialized case where packing is used as the heat transfer and mass transfer area, not the trays. Now, let us talk about the fuel-style vacuum distillation unit. This is the flow diagram of a vacuum distillation unit where atmospheric residue exchanged heat with the side streams LVGO and HVGO and also the vacuum residue. And then sent to the atmospheric residue furnace where heat is provided to raise the vapor from the atmospheric residue. After it is heated, the atmospheric residue along with vapor and liquid stream, is introduced into the feed tray of the vacuum distillation unit.

Now, after introduction, the vapor flashes in the feed tray as in the rectifying section and the liquid from the feed tray comes down in the stripping section. While the liquid is coming down, it contains lots of valuable distillate fractions, which may be the component of vacuum gas oil. So, steam is introduced at the bottom of the vacuum distillation column to strip out the distillate fractions from this down-flowing liquid and steam along with this distillate vapor goes up. So, from the feed tray, this vapor and

steam, as well as the flashed vapor from the feed tray, all together ascend through the rectifying section and come to a wash oil section.

This is called the wash oil section. In this section, an internal reflux liquid, which is called wash oil, is introduced and it is the purpose of the introduction of this wash oil is to wash out if some of the vacuum residue mist, if at all, present in the ascending vapors. So, this wash oil is produced by taking out some of the ascending vapors from the side tray and then condensing it to make it an internal reflux liquid as well. Now, after the vapors are washed by the wash oil, the vapor goes up and after it reaches the heavy vacuum gas oil tray, heavy vacuum gas oil liquid-vapor is withdrawn from the tray. It exchanges heat with the feed and then we get the liquid HVGO heavy vacuum gas oil. And some part of this liquid is sent back to the column as the internal reflux. Similar is the case for the LVGO. The LVGO side draw tray is used to draw out the LVGO vapors, which exchange heat with the feed and we get the liquid HVGO again. Some liquid cold HVGO is sent back to the tower top to get it as reflux.

These internal reflux are very much required to run the distillation. Without reflux, fractionation is not possible because there will not be any mass transfer. Hence, internal reflux keeps the distillation alive. Now, from the bottom of the vacuum distillation tower, vacuum residue is withdrawn and it exchanges heat and gets cooled down. This vacuum residue is some part of this vacuum residue that is sent back to the bottom of the vacuum residue column to resist the coke formation at the bottom of the column because at the bottom of the column, obviously, the temperature is high and this is called quench oil. This is a quenching operation that, in fact, prevents coke formation at the bottom of the column.

A stream from the wash oil section, which is called heater recycle, contains an appreciable amount of vacuum residue content that is taken out and mixed with the atmospheric residue stream well ahead of the furnace and introduced together into the feed tray of the vacuum distillation unit. Now, the overhead vapor of the vacuum distillation unit contains the oil and steam as well as some non-condensable gases taken out and sent to a pre-condenser where the oil vapors are condensed and some steam is also condensed and some non-condensable gases are produced. That non-condensable gases are sent to an ejector system. It is the vacuum forming system that ejectors are used to create the vacuum in the vacuum distillation unit. Those gases, along with the steam in two-stage or three-stage operation, create the vacuum in the vacuum distillation unit. After that, the non-condensable gases are taken in a surface condenser and several surface condensers are provided to condense the gases as well as steam collected in a drum from where we get the refinery off gases as well as slop oil and sour water.

This is the overall simplified operation of vacuum distillation unit, fuels type. Now, coming to the lube-type vacuum distillation. Here, the major product is the lubricating

oil. There are several lubricating oil-based stock that is light stock, medium stock and heavy stock and depending on the market demand and the country's need as well as the specification, the side draw liquids may be of different types. In the atmospheric distillation tower, the vacuum distillation tower lube type, the atmospheric residue is introduced into the furnace.

Similarly, the ascending vapor and liquids are formed, which are taken out as the vacuum residue and some part as heater recycle is also taken out and mixed with the feed of atmospheric residue and side draw liquids, which are different lubricating oils. These side draw liquids are steam-stripped to maintain the viscosity and carbon residue content of those lubricating oil fractions. In the fuels type, we did not see any side stripper, but in the lube type, this side stripper is required. Except for the lubricating oil-based stock, we also get a light vacuum gas oil as a lighter product and we also introduce some condensed light vacuum gas oil as the pump around the reflux system to the column to run the distillation. Let us come to some major points of lube-type vacuum distillation units.

I already said the lubricating oil should be, the properties of the lubricating oil should be controlled which are viscosity and carbon residue. Accordingly, we have to do this steam stripping and a vacuum tower is installed with bubble cap trays for better fractionation. Here fractionation is required, so we need the bubble cap trays instead of grid trays and side stripper columns are provided to maintain the properties of the lubricating oil, so that steam can strip off the lighter fraction of the liquids. The maximum allowable feed temperature depends on the type of the feedstock. Obviously, if the atmospheric residue contains a lighter composition, then we have to go for a lesser temperature.

As for the lube-type vacuum distillation unit, we handle the atmospheric residue, which contains lots of lubricating oil fraction, which means the paraffinic hydrocarbons. So obviously, the temperature may be lower than the atmospheric residue, which does not contain any lubricating oil fraction from where we get the vacuum gas oil. Now, the operating temperature, maximum allowable pipe still heater coil outlet temperature is 400 to 430 degrees centigrade. It is obviously very high and it is required to maintain the vapor formed in the feed tray of the vacuum distillation unit. Another thing is the distance between the heater outlet and the feed tray of the vacuum distillation unit, it should be very small so that we can avoid cracking in that path.

The pressure of the vacuum tower top is 1.3 to 20 kilo Pascal. This pressure is maintained at the tower top and the optimum pressure varies with the type of the furnace operation, whether it is wet type or dry type. Also, feed temperature and cut temperature between VGO and VR at which temperature, up to which temperature will take VGO and where is the cut point of VGO and VR? Which part we will consider as VGO and which part we will consider as VR is also dependent on the market demand and specification as well as the selling price. These are the references. Thank you for your attention.