Lecture 07: Primary Processing of Crude Oil: Atmospheric Distillation Unit (ADU)

Hello and welcome to the 7th lecture on Petroleum Technology. Today, we will discuss the primary processing of crude oil, under which we will talk about the atmospheric distillation unit. The atmospheric distillation unit is such that it processes the whole crude oil coming to the refinery. So, the amount of crude oil that a prior atmospheric distillation handles is called the capacity of the refinery. Here, you see the crude oil is first preheated by exchanging heat with several pumps around reflux systems and then it exchanges heat, goes to the desalter drum, where the salts and solids from the crude oil are removed. After desalting, the crude oil is preheated by exchanging heat with atmospheric residue as well as different side cuts obtained from the atmospheric distillation unit, and again, heat is exchanged with another pump around reflux system. It goes straight to the crude oil furnace.

Here in the crude oil furnace, the crude oil is heated at a required temperature to produce the required amount of vapor to be introduced into the feed tray of the atmospheric distillation column. Here, after the crude oil is introduced into the atmospheric distillation column, the vapor that is formed ascends upward and the liquid that is there, is coming down. So, here, the vapors are going towards the rectifying section and the liquid is coming down to the stripping section. The liquid that is coming down is obviously a heavier fraction. The steam is introduced from the bottom of the distillation tower.

This steam takes away some of the lighter boiling cuts, lighter boiling distillates from this liquid and goes up. So, after some time, we see that the vapor ascending from the feed tray, along with the steam and its distillate fractions taken out from the liquid stream, go towards the rectifying section. While going through the rectifying section, this vapor comes in contact with the liquid coming down from the trays, of the upper trays of the distillation column. Hence, there is a good contact between this vapor phase and liquid phase and mass transfer occurs and it is the requirement for a good fractionation of the cuts. Now, after this mass transfer, the vapor goes upward and from the top part of the distillation tower, the overhead vapors are taken out, condensed in the condenser and then cooler and then the off gases, which are non-condensable gases, are taken out from the top of the cooler drum and the hydrocarbon liquid which is called the full range naphtha is taken out from the bottom of the drum and sent to a debutanizer-splitter.

In the debutanizer-splitter, the non-condensable off gases are taken out from the full-range naphtha and we get two liquid cuts: one is light naphtha and the other one is heavy naphtha. Now, other liquid cuts taken out from different side draw trays are kerosene, light gas oil and heavy gas oil. These side draw liquids taken out at the required, from the required trays are sent to three steam strippers: kerosene stripper, LGO

stripper and HGO stripper. LGO is light gas oil and HGO is heavy gas oil. Steam is introduced into the stripper from the bottom and the liquid cut is introduced from the top. So, this is a counter-current contact between the steam and the liquid petroleum cut and steam carries the lighter boiling part from these liquid streams, takes it out from the top of the stripper, and introduces it back to the distillation column in a tray which is upper than the draw tray.

This same thing happens for light gas oil and heavy gas oil and after this, the side draw liquid hydrocarbon streams exchange heat with the cold crude oil and then send it to the storage. These are called straight run cuts, which means, these cuts are not processed in any other secondary processing, not processed, directly coming from the distillation tower from the atmospheric distillation tower. And at the end, we get the atmospheric residue, which is also exchanged heat with the crude oil and it is stored for the next step of processing. Now, look at this figure. This one, left, shows a part of the refinery to give you a life touch of the refinery. The right one shows a distillation tower that combines both atmospheric and vacuum columns.

Here, the distillates coming out from these two columns are arranged according to their carbon numbers. So, from the top, we get C1 to C4 gases that are methane to butane-butylene cut and after that, this is gas cut, and next we start to get the liquid cuts. C5 to C9 is the naphtha, or it is called light naphtha. And after that, we start to get C5 to C10, which is total gasoline. This one can be divided into light naphtha and heavy naphtha.

The next cut is C10 to C16, which is a kerosene cut. C14 to C20 is the diesel or gas oil cut. This cut is also called gas oil in the language of the refinery, like we do not use the term petrol for gasoline. Gasoline is the refinery term and petrol is the commercial term. The same goes for the case of diesel, diesel is the commercial term that the common people use. And next comes the lubricating oil.

Before we come to the lubricating oil, see these cuts coming from the atmospheric distillation column. After that, after the gas oil, we get actual atmospheric residue which is treated in the vacuum distillation column. Here from the vacuum distillation column, we may get lubricating oil. Lubricating oil will be from that type of crude oil which contains the lubricating oil composition. That means the hydrocarbons that construct the lubricating oil cut should be there in that crude oil.

That crude oil is called lube-bearing crude oil, lube-bearing crude which can produce lubricating oil. If the crude is not lube-bearing, it cannot produce lubricating oil. Next, it is shown the fuel oil. If the crude is non-lube bearing then we can get vacuum gas oil which can be divided into vacuum gas oil and fuel oil depending on the need of the market as well as the choice of refiner and for the country itself. In the end, we get

vacuum residue which is mostly asphaltic residue that is treated in some other processing units.

Now, this shows how we treat the naphtha coming out from the condenser of overhead vapors. We have already shown over here that the overhead vapor that is coming out is condensed and then cooled and stored in a drum, cooling drum. From the top of the drum we get, we collect the off gases which are also called refinery gases: refinery off gases. And the hydrocarbon, say, hydrocarbon liquids are collected from the bottom of the drum. Now, after we collect the hydrocarbon liquid it is introduced into a debutanizer.

Debutanizer removes the butane cut C4 paraffin and C4 olefin. C4 paraffin and C4 olefin cuts. After the gasoline is introduced into a splitter, the splitter splits the liquid product into light naphtha and heavy naphtha. Usually light naphtha has a composition of C5 to 90 degrees centigrade. Although this 90-degree centigrade is not fixed it, depends on the country's specification and heavy naphtha is usually which is common in a 90 to 140-degree centigrade cut.

Now, coming to the steam stripping in the atmospheric distillation unit. We have already talked about the steam stripping in the description of the atmospheric distillation unit. What is a steam stripper? The steam is introduced, one part of the steam is introduced at the bottom of the atmospheric main distillation column which carries the lighter boiling distillate fraction from the liquid coming down from the feed tray and carries the vapor along with the steam to the rectifying section of the column. That is one type of stripping in the atmospheric distillation column itself. Some side strippers are also described where the side stream liquid, side streams are steam stripped to remove their lighter ends.

So, light end removal is called in the refinery, which is called steam stripping. And as steam removes the lighter ends, so, it stabilizes the cut. That means the distillate cut will not produce unnecessary vapor at a moderate temperature. So, in this way, the flash point of the cut is standardized.

Usually, the steam strippers are small thin columns with bubble trays; usually, we see there are 4 bubble trays. Even some side-to-side pans are also seen in the stripping tower and the diameter, the common diameter is 20 inches. The rate of steam addition is usually in the range of 10 to 50 kg per meter cube in the atmospheric distillation unit as a whole in the bottom part of the major main atmospheric distillation unit as well as the side strippers. Next, it comes to the feed charge system. In the refinery, the feed crude oil can be charged to the atmospheric distillation column in various ways.

So, the first one is the simple pre-flash system. Here crude oil is directly sent to the atmospheric tower without being processed by any preliminary separation equipment, may be some pre-flash drum or some pre-fractionator unit. So, let us look at this picture here crude oil after desalting is sent to a heat exchanger and then to the crude oil furnace.

And crude oil furnace produces the required vapor and then a vapor and liquid mixture of the crude is sent to the feed tray of the atmospheric distillation column. And atmospheric distillation column produces whatever side streams required, all those they produce.

Now although it is a very simple type of operation, some problems are associated with it. What is in the crude oil furnace? Within the tubes of the crude oil furnace large amounts of vapors are produced and it causes the pressure drop. Pressure drop in the pipe still heater which is called the crude furnace. Also, maldistribution of vapor and liquid is observed in the tubes of the furnace which is not desirable. Next comes another type of crude charge system which is called the pre-flash system, where the picture is given here. What is done? Desalted hot crude is introduced to a pre-flash drum before being sent to the atmospheric distillation unit. Here crude is desalted and then heated in a heat exchanger, and then the whole crude is sent to a pre-flash drum.

What happens here? The lighter boiling fractions are flashed at a lower pressure taken out from the top of the pre-flash drum and sent directly to the atmospheric distillation unit. The heavier fractions are taken out from the bottom which exchanges heat and is then sent to a crude oil furnace. Then it is introduced into a tray lower than the tray where we have introduced the lighter boiling parts. Then, the atmospheric tower produces whatever sidecuts are required. In this way, we can divide the two streams and we divide the trays in which we put the two streams. Now this avoids the unnecessary pressure drop in the tubes of the crude oil because we have removed the lighter boiling parts from the crude oil.

And also it removes the possibility of the maldistribution of the vapor and liquid in the crude oil tubes of the furnace. Now let us come to the type of feed charge system that is called the fractionator system. Here a pre-fractionator is installed. This is the pre-fractionator to remove gas and a part of the naphtha fraction from the crude oil. Here crude oil is desalted, heated in a heat exchanger and then put into a pre-fractionator. Pre fractionator is a small distillation column having several trays in it which can distill out the lower fraction from the overhead.

And in the overhead, there is a reflux drum, cooler, condenser and reflux drum. A reflux is there which goes back to the distillation column and the hydrocarbons are taken out from the top of the distillation reflux drum and it is a naphtha fraction lighter boiling. So, from the bottom of the pre-fractionator, we get the heavier fractions and then it is introduced into the crude furnace and then from the crude furnace this fraction goes to the atmospheric distillation unit to produce the cuts. Now here again the crude furnace does not have to handle lots of vapor in it. So, pressure drop and maldistribution of vapor-liquids all these problems are totally gone.

Another thing is, as the main atmospheric distillation unit does not have to take lots of vapor and lighter boiling material for processing into it, so, the diameter of this atmospheric distillation unit can be narrower. Next coming to the dual flash, dual flash system. Here this system is applied to the process, to process two or more kinds of crude oils, whose properties are very different. Say, we have two crudes, crude A and crude B whose properties are different, maybe in sulfur content, they have different sulfur content and their residues all the sulfurs are concentrated into the residues. So, their residues are having two different sulfur content and we do not want to mix those two residues, so that their properties will not get altered. So, in this system, crude oil A is desalted separately and crude oil B also then exchanges heat in a heat exchanger, then it is sent to a crude oil furnace and then to the atmospheric distillation tower. Crude oil B is desalted, then goes to the crude oil furnace then to a preflash drum where the distillate fractions are taken out from the top of the pre flash drum and introduced into the distillation, atmospheric distillation tower and the heavier fractions are taken out as the atmospheric residue of B. The bottom of the main atmospheric distillation column produces the atmospheric residue from A as well as the other distillate products, lighter products. So, these are the different types of feed charge system which are practiced in the refinery.

Now I have already said that we collect the refinery off gases from different points in the atmospheric distillation unit. All those gases are collected together they are mainly C1 to C4+ gases that means, methane to butane or more than butane. So, those gases are separated in the refinery. Several refineries do this which is called cold separation of gases. Usually this distillation is done at a low temperature and high pressure to distill off the gaseous fractions which are to be liquefied and then they are distilled. So, here look at this picture, the first one, first column is demethanizer. Here C1 and C4 plus gases are introduced after exchanging heat and then this distillation occurs where we get from the top, from the overhead, the methane C1 as the overhead product. If any hydrogen is mixed with the gas mixture then obviously, there is a possibility of getting hydrogen from the top along with the methane. Now the bottom part of this distillation unit is obviously, it contains C2 to C4 plus cut this is introduced into a second distillation unit which is called de-ethanizer.

So, de-ethanizer from the overhead removes all C2 cut and this C2 cut is having ethane ethylene and also acetylene. Acetylene is not required. So, the whole cut is taken and sent to a selective hydrogenation unit where hydrogen is introduced into it to convert this acetylene into either ethane or ethylene. And the bottom of this selective hydrogenation unit this is obviously, C2 cut having no acetylene in it, is sent to the ethane ethylene separation column. 4 is ethane ethylene separation column where from the top, we get the lighter product ethylene and from the bottom, we get the heavier product ethane.

Now, what about the bottom product of this deethanizer? The deethanizer bottom product is C3 to C4 plus cut. It is introduced into the depropanizer column. The depropanizer

column takes out the overhead vapor, which is C3 cut. In this C3 cut, we get propane propylene and methyl acetylene. Obviously, methyl acetylene is not a desirable component. So, it is selectively hydrogenated in a selective hydrogenation unit.

And we get all C3 cut from the bottom of the selective hydrogenation unit devoid of any methyl acetylene in it. This cut is sent to a propane-propylene separation column where there are two propane-propylene separation columns required for separating the propane and propylene. From the top of the second column, we get the lighter product propylene and from the bottom of the first column, we get the heavier product propane. Now, the bottom product of this depropanizer, the bottom product of depropanizer is C4 and C4 plus cut. It goes to the debutaniser column where from the top, we get C4 cut and from the bottom, we get a heavier fraction of C4 plus amount.

This is altogether the separation of the refinery gases. This is required to get the petrochemical feedstocks, which are, you know, the ethylene and propylene are the petrochemical feedstocks. As well as we need propane propylene and butane butylene for making our LPG. LPG is a gas that is usually used for domestic purposes, as well as LPG. Some industrial uses are also there.

LPG is liquefied petroleum gas. We are already familiar with this gas, a mixture of C3 and C4 hydrocarbons. This butylene is also required for the petrochemical unit. Methane is a very high calorific value gas used for some fuel purposes, which is also called natural gas or compressed natural gas and is used for many in industry use as well as for everyday use. These are the references and thank you for your attention.