Course Name: PETROLEUM TECHNOLOGY

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Lecture 32: Purification processes (Contd.)

Hello and welcome to the 32nd lecture of Petroleum Technology. In this lecture, we will learn about various purification processes which are practiced in the refinery for various petroleum oil cuts. At the very beginning, we will talk about the hydro treatment. Hydro treatment is one of the most important operations which go on in the refinery and this hydro treatment is the refinery process which involves catalytic conversion and removal of sulphur, nitrogen, oxygen and metals from the petroleum crudes and petroleum fractions at high hydrogen pressures. So, at the very beginning, this hydro treatment talks about the separation or removal of the objectionable compounds which are there within the petroleum crudes as well as the petroleum fractions which are sulphur, nitrogen, oxygen compounds as well as the metal compounds which poses various problems to the operation or processing of these cuts.

So, hydro-treatment, first of all, we concentrate our discussion on the removal of these objectionable compounds. Next, it is not only the removal of these objectionable compounds; hydro-treatment also includes hydrogenation of unsaturated and hydrocracking of higher molecular weight compounds of petroleum fractions to lower molecular weight ones. So, within hydro-treatment, it is not only hydrodesulfurization, hydrodenitrification, or hydrodeoxygenation, as well as hydrodemetallation. All these are removal processes of all these unwanted substances, but also it take care of the saturation of the unsaturated compounds such as olefinic compounds, aromatic compounds, etc., which improves the quality of the end product and hydrocracking of higher molecular weight compounds of petroleum fractions, which may be a very long chain or polynuclear aromatic hydrocarbons.

These are cracked and, at the same time, saturated by the hydrocracking process to give us the lower molecular weight compounds. The increased application of hydro treating can be ascribed to the reason why we do the hydro treatment. This is because of the decreasing availability of light sweet crudes and thus, increasing the fraction of heavy sour crude that must be processed. People used to get the light and sweet crude for their needs because these light and sweet crudes are the most preferable crudes as they give us the high-quality fractions and mostly more profitable fractions, which are the lighter cuts such as gasoline, kerosene, diesel, jet fuel, etcetera. And as they are sweet crude, they do not pose a big problem in terms of sulfur compounds.

But as people continue to extract light and sweet crudes continuously throughout the world, we are depleting this high-quality crude. Whatever is left with us is the heavy and sour crude. It is not that we only start to get heavy and sour crude, but efforts are made to obtain light and sweet crudes through various exploration processes worldwide. In many cases, heavy and sour crudes are predominant. For instance, in India, some years ago, ONGC (Oil and Natural Gas Commission) and Oil India Limited discovered a significant reserve of petroleum crude in the Rajasthan basin. However, this crude is of poor quality, being highly thick, viscous, waxy, and bituminous, with a very high sulfur content.

So, these crudes need to undergo higher severity operations with multiple steps to produce distillates that meet Indian standard specifications. This processing is necessary to meet the specified standards for distillates obtained from sour and heavy crudes. It's worth noting that in recent years, ONGC has discovered a significant reserve of light and sweet crude near Kolkata in West Bengal. While there is a possibility of obtaining light and sweet crude, ongoing exploration efforts worldwide often reveal the predominance of heavy and sour crude reserves. Another reason for the increased application of hydrotreating is the trend to upgrade feedstocks for catalytic reforming and catalytic cracking. Both processes, catalytic reforming and catalytic cracking, are carried out through catalytic means.

So, catalysts used in these processes are prone to deactivation due to the deposition of unwanted substances coming from the feedstock. To prevent this deactivation, the feedstock that goes into catalytic reforming and catalytic cracking operations should undergo hydro treatment processes to remove these unwanted substances in advance. Furthermore, strict environmental regulations on sulfur content specifications of fuels play a crucial role. In today's world, countries are highly concerned about the environment. When fuels like transportation fuels or kerosene are burned, they emit sulfur oxide gases. If the sulfur content in these petroleum fractions is high, a significant amount of sulfur oxide gases will be produced, contributing to air pollution and degrading environmental air quality.

So, strict environmental regulations and standards are imposed on the sulfur content specifications of fuels by every country. The sulfur removal process in the refinery is one of the most important units, called hydrodesulfurization. Sulfur removal is a critical process associated with the environment, making the hydrodesulfurization unit crucial in the refinery among all processes. This process is used to meet the sulfur specifications of fuels. Major objectionable sulfur compounds present in petroleum fractions include sulfides, disulfides, mercaptans, thiophenes, and their higher derivatives. Sulfides, disulfides, and to some extent, mercaptans are the lower boiling sulfur compounds primarily found in the lower boiling hydrocarbon fractions, either naphtha or kerosene.

This includes thiophene and its higher derivatives, which are higher-boiling sulfur compounds and are mostly present in heavier distillates. For the removal of all these compounds, one of the important processes is hydrodesulfurization. In hydrodesulfurization, the feedstock is mixed with the required amount of hydrogen and sent to the reactor at high temperature and high pressure in the presence of a suitable catalyst. The sulfur compounds are converted to H_2S gas, and this hydrogen sulfide gas is evolved, leaving the fraction free of sulfur compounds. The sulfur is then removed in the form of H_2S. Sulfur reduction in petroleum fuel is gaining importance due to increasing awareness of the serious consequences of burning sulfur-bearing fuels.

So, everybody is concerned about sulfur. Sulfur reduction is gaining importance day by day, and hence, stricter regulations are being imposed regularly. The Ministry of Road Transport and Highways of India proposed Bharat Stage 6 emission standards, equivalent to Euro 6. Euro 6 has already been implemented in European countries, and Bharat Stage 6 is applicable in India from 2020 onward. As per these proposed notifications, the maximum limit of sulfur content in gasoline or diesel should be 10 ppm maximum. 10 ppm is equivalent to 10 milligrams per 1000 ml, which applies to all light and heavy-duty vehicles, including 2 or 3-wheelers.

So, this is a very strict regulation. Previously, the maximum sulfur limit was 50 ppm, and before that, it was 500 ppm in BS 4 (Bharat Stage 4). As time progresses, people are becoming more concerned about pollution, leading to more stringent regulations. This strict regulation poses a significant challenge for existing hydro desulphurization units in refineries. These units are not readily equipped to handle very poor-quality cuts, especially with the need to reduce sulfur levels to very low levels.

Hence, it is said that operating those Hydro Desulphurization (HDS) units in the refinery requires very high hydrogen pressure to achieve such low sulfur levels. If the design of the equipment allows, the catalyst loading should be increased along with the hydrogen partial pressure. Dealing with cracked gas oil or cracked gasoline as feedstock poses even more challenges since they are difficult to hydro-desulphurize and demand higher hydrogen pressure. At low hydrogen pressure, cracked gas oil, being aromatic-rich, tends to form polymers that lead to coke deposition on the catalyst surface. This coke deposition results in catalyst deactivation. To avoid these issues, high hydrogen partial pressure is essential for the effective hydro desulphurization of cracked gas oil or cracked naphtha. Elevated hydrogen pressure helps prevent unwanted reactions and deactivation of the catalyst.

In the refinery, hydrodesulfurization (HDS) is primarily carried out on gasoline and gas oil fractions to meet sulfur specifications. The catalyst used for this process can either be cobalt molybdenum oxide on alumina or nickel molybdenum oxide on alumina. When the objective is to reduce sulfur content and simultaneously saturate olefinic compounds, cobalt molybdenum oxide on alumina is employed. This catalyst serves a dual purpose of desulphurization and olefin saturation. On the other hand, if the goal is to improve the cetane number through aromatic saturation and enhance the color and color stability of diesel fuel, then nickel molybdenum oxide catalyst on alumina is utilized for that purpose. The hydrogen partial pressure is a crucial parameter in this process, ranging from 20 to 40 bars, sometimes even higher, depending on the characteristics of the feedstock.

Indeed, the hydrogen pressure requirement in hydro desulphurization (HDS) depends on the nature of the feedstock. For straight run cuts, lower hydrogen pressure may suffice, but for cracked fractions, higher partial pressure is often necessary. Achieving a uniform fluid distribution in the hydro-treating reactor is critical to prevent local over-hydrogenation or under-hydrogenation, and maintaining a specific residence time is essential. The operating temperature during hydro desulphurization typically ranges between 340 degrees Celsius at the beginning of the run and 370 degrees Celsius at the end of the run. As the reaction is exothermic and generates heat, makeup hydrogen is injected into the catalyst bed (quench hydrogen) to control and maintain the desired temperature in the reactor. In addition to desulphurization, diesel fuel processing in the HDS process must meet other diesel fuel specifications, including cetane number, oxidation stability, and color throughout the entire process cycle.

Whenever we go for the HDS for the diesel fuel, then along with the sulfur reduction, we have to keep it in mind that in one go, in one reaction process, we have to improve the cetane number. We have to improve the oxidation stability as well as color. What is required for all these specifications to improve is the aromatic saturation and nitrogen removal. These two processes are required to improve all these properties of the diesel fuel. When aromatics are saturated, which is an undesirable compound in the diesel fuel, and if the aromatic rings are disintegrated to give a long-chain paraffinic compound, and that is saturated because of this hydrogen, obviously, the cetane number will be improved. The oxidation stability is also related to the nitrogen compound removal as well as aromatic and olefinic compounds saturation and color.

Color also is given; the color, which is not specified according to the standard specifications, should be taken care of because of the reason that it has to be marketed in the diesel fuel has to market. So, color should be according to the specification, and for that aromatic saturation is needed. Deep HDS, deep hydro desulfurization, is operated at higher severity at higher temperature and higher hydrogen pressure. These units are employed to saturate and open aromatic rings to improve cetane number. To improve the cetane number, particularly for a cracked diesel fuel fraction, not all the time for the straight run diesel fuel, this high severity operation is needed.

This chart is showing some of the reactions of hydrotreatment. First one is desulfurization. Here, methyl thiophene is converted to a 5-membered ring, and also the sulfur is removed in the form of H_2S. Next one is a straight chain, this is a thiol or mercaptan, SH is the functional group, and by the reaction with hydrogen, the sulfur is removed in the form of H_2S, and we get another ring structure. Third one is a disulfide, 2 S-S bonds are there. This shows the disulfide compound, and in this hydrodesulfurization process with the reaction with hydrogen, this compound is cracked, broken down into a smaller chain compound, C_3H_8, which is propane, and we get H_2S gas; sulfur is removed as H_2S. Now, coming to denitrification, nitrogen removal, this is methyl pyridine. It is reacting with hydrogen to remove nitrogen in the form of ammonia.

Similarly, this one is quinoline. Quinoline reacts with hydrogen to give us benzene and propane, propane, and ammonia. The nitrogen is removed in the form of ammonia. The hydrocarbon saturation, this is one example; one olefinic compound is shown RCH double bond CH_2, which is saturated by hydrogen, RCH_2CH_3; this is a straight-chain paraffin. Oxygen removal, this one is an alcohol which reacts with hydrogen to remove oxygen in the form of water, and we get the paraffinic structure. This one is phenol; phenol is converted to benzene, and we get water, which takes out the oxygen from phenol. These are the reactions of hydrotreatment, and many more reactions are there, not only these are some of the examples.

Now, coming to the types of hydrotreater, it is quite common for a refinery to have multiple hydrotreaters because in the refinery, we have many distillation fractions, and those are to be processed properly by removing this sulfur, nitrogen, oxygen, and metal compounds, as well as we have to go for the saturation of some of the unwanted unsaturates. So, some of the more common are naphtha hydrotreater. Naphtha hydrotreater operates for the reason that heavy naphtha, which is the feedstock to the catalytic reformer unit, has to be hydrotreated to remove the sulfur and other unwanted compounds from it, so that we can resist the catalyst deactivation in the reformer. Another one is kerosene hydrotreater.

Kerosene is the illumination fuel which we use, and also fine grade of kerosene, the premium grade of kerosene, is used as a jet fuel. This has to be treated in the hydrotreater unit to remove the sulfur as well as to improve the smoke point properties for the jet fuel. Sulfur removal is done in the HDS of the hydrotreater section, as well as the smoke point, is improved by saturation of aromatics because aromatic compounds form smoke, black, sooty flame it gives. So, aromatics are saturated. So, this smoke point should be improved; smoke point is increased.

Distillation hydrotreater, hydrotreater is actually the metal distillate hydrotreater. Hydrotreats diesel blend stocks to remove the sulfur and nitrogen and raise the cetane number. So, for the diesel fuel, along with the sulfur and nitrogen removal at the same time, the cetane number is improved by saturating the aromatics and also the ring opening of the aromatic compounds. Vacuum gas oil hydrotreater, VGO hydrotreater, hydrotreats VGO before feeding into the FCC unit. Vacuum gas oil is the feedstock for FCC to get the lighter fractions after cracking, and as the VGO is a heavier fraction coming out from the vacuum distillation unit. So, there is obviously, a possibility of the VGO to have a good amount of objectionable compounds such as sulfur, nitrogen, oxygen, etcetera, and before VGO is fed to the FCC unit to protect the FCC catalyst, VGO has to be hydrotreated, and this reduces sulfur resulting in lower sulfur products.

So, if we do the hydrotreatment of VGO, then hydrotreated VGO has the lesser sulfur content which goes into the FCC unit, undergoes the cracking operation, and the gasoline and cycle oil, that is cycle oil in the form of metal distillate obtained after the cracking operation, should have a lower sulfur content. So, the products will have lower sulfur products. FCC gasoline hydrotreater, even if we remove the VGO sulfur, still it may be seen that the FCC gasoline obtained from the FCC unit may have some amount of sulfur which is not meeting the standard specifications. So, those gasoline FCC gasoline undergoes the hydrotreatment process, and sulfur is removed. Resid hydrotreater, that is the residue hydrotreater, treats residues, you know the atmospheric residue, vacuum residue which you get as the bottom product of the two distillation units, atmospheric distillation unit, and vacuum distillation unit.

So, resid hydrotreater hydrotreats atmospheric residue or vacuum residue to reduce sulfur, sometimes before sending it to an RFCC unit for upgrading. Obviously, most of the time you have seen that atmospheric residue, and in many cases, vacuum residue is sent to the RFCC unit, Resid Fluidized Cracking Unit, for upgradation or to get a lighter fraction out of them by cracking operation. So, as we always expect that residues contain more amount of sulfur which comes directly from the crude oil which is processed, and we get the residue. Then obviously, to protect the RFCC unit catalyst, this vacuum residue and atmospheric residue should be sent to the hydrotreatment unit to reduce the sulfur content. This is the flow diagram of a hydrotreater.

You see one is the reactor, two is the reactor heater or reactor furnace, three is the makeup compressor, makeup hydrogen compressor, four is the recycle compressor, five is the separation system, and six is the fractionator. Here, the fresh feed which is to be hydrotreated, along with the hydrogen coming from the recovery unit, makeup hydrogen, is sent to the heat exchanger where it exchanges heat with the product. Product coming out from the bottom of the reactor, which is the hydrotreated product, and then after gaining some heat from the product, it goes to the furnace to attain the required temperature. After that, the heated feedstock is introduced at the top of the reactor where catalyst beds are there, and catalyst beds are cooled by some quenched hydrogen, and after the reaction, the hydrotreated product comes out and exchanges heat with the cold feed, and then it is introduced into the separation system. Here, from the top of the separation vessel, we get the gaseous fractions, and from the bottom, we get the liquid fraction.

This gaseous product and liquid products. Now, this gaseous product contains a large amount of H_2S gas as well as some unreacted hydrogen units. So, that unreacted hydrogen is recovered in the unit and is recycled back to the system, and some amount of hydrocarbon vapor, which has come out with the gaseous product from the liquid product, is recovered and then sent to the fractionator. At the same time, the heavier liquid products obtained from the bottom of the separation system are again sent to the same fractionator where we get the fractionated products, those are naphtha and middle distillate and hydrotreated heavier products, and this sour gas, that is H_2S, is removed and sent to the sour gas processing system. This is, as a whole, the process operated in the refinery hydrotreatment process. Mostly, this is shown as the sulfur removal, but at the same time in the reactor, as I said along with the sulfur removal, other objectionable elements or objectionable compounds are removed at the same time, and it is not only H_2S; some little amount of ammonia and water vapor is also removed, as well as some of the other objectionable hydrocarbons, and here the saturation of olefins and aromatics also happens.

This is the process description, which I have already said: Hydrocarbon feedstock mixed with the recycle and makeup hydrogen is heated and charged to the reactor. The feedstock is desulfurized in the presence of a catalyst; the product is then stripped to remove excess hydrogen, which is unreacted hydrogen and hydrogen sulfide, prior to the fractionation; it should not enter into the fractionating unit. At the same time, I am saying that this hydrogen, which is recovered from the system, is again recycled back; it should be very pure, and it should not contain any H_2S gas in it, and as well as any hydrocarbon. Small amounts of light materials, then the feedstock, are generally produced by cracking; some are taken as products in the fractionation. As you see, these are the lighter fractions, and then the hydrotreated products, which are obtained as a result of the hydrocracking operation, which is also operated in this reactor. Now, coming to the importance of hydrogen in this process.

Hydrogen is one of the most important elements in the production of desulfurized fuel; without hydrogen, hydrodesulfurization is not at all possible. For hydrotreating, the hydrogen stream must be extremely pure, greater than 99 percent purity, and have no humidity and no moisture content. The stream should have a low hydrocarbon content as well as low mercaptan and hydrogen sulfide levels. So, what I said previously is that this makeup hydrogen or recycled hydrogen should go through some very strict purification process so that it should not contain any hydrocarbon gas, mercaptan vapor, or hydrogen sulfide gas; a very low content is specified.

Only about 15 to 30 percent of the hydrogen demand of a refinery is produced internally by the process, such as catalytic reforming of naphtha; the rest is supplied by external producers. It is observed that the catalytic reforming of naphtha produces gas, and then 90 volume percent is hydrogen. So, this catalytic reforming is a very good source of hydrogen within the refinery. Except for this catalytic reforming, FCC also produces lots of refinery gases which contain a little hydrogen, maybe 5 volume percent.

The rest is supplied by external producers. In fact, to get hydrogen outside the refinery, steam cracking of naphtha is practiced, where we get the synthesis gas, carbon monoxide, and hydrogen mixture, which is almost a 50-50 mixture. So, the amount of hydrogen is high, and that is a good source of hydrogen. Except for steam cracking, the partial oxidation process is another source of hydrogen. Even the gasification of petroleum cokes is another source of hydrogen from which we get an ample amount of hydrogen. As environmental restrictions become tighter, refiners will need to explore hydrogen sources with small carbon footprints. Whatever I have said till now, whether steam cracking or gasification or partial oxidation, all these are related to some carbon compounds such as carbon dioxide and carbon monoxide. So, carbon dioxide and carbon monoxide are not environmentally friendly.

Hence, nowadays, researchers are going to develop some processes that will give us the purest hydrogen without making any carbon content or any carbon compounds in it. So, smaller carbon footprints, maybe water electrolysis or some other processes. Hydrotreating severity under conventional operating conditions, hydrogen less than 35 bar HDS results in a density reduction with a modest cetane number improvement. For the usual hydrodesulfurization process with a distillate straight run distillate coming from the sweet crude, the hydrogen partial pressure may be kept less than 35 bar because the sulfur content is lesser. At the same time, after the HDS, it is observed that, as a whole, the density is reduced with a modest cetane number improvement for gas oil.

Density reduction occurs because of the hydrocracking to make the smaller chain molecules from the longer chain molecules with a modest cetane number improvement because of the reason that these aromatics are disintegrated, and they are getting saturated. So, as a whole, a little cetane number can be improved. During the HDS step, polycyclic aromatics are hydrogenated to mono and diaromatics, but the total aromatics concentration remains at about the same level. During this process, there is a moderate hydrogen pressure; the polycyclic aromatics, which have many aromatic rings together, joined together, are condensed ring aromatics; they form they are hydrogenated to form mono and diaromatics. For example, let us think about an aromatic compound having 4 or 5 rings condensed together; all are unsaturated; those are highly objectionable compounds for the improvement of the cetane number.

Among these 4 and 5 unsaturated rings, during this hydrotreatment process, it may happen that some 3 rings are saturated. So, we get diaromatics; if 4 rings are saturated, we get monoaromatics, but still, the total aromatic concentration remains at the same level. Consequently, the density and ASTM D 86 95 volume percent decrease, but the cetane gain is generally limited to around 3 points. So, as a whole, it is seen that although the density is reduced because of getting smaller, or in fact, for this polynuclear aromatic hydrocarbons, they may get disintegrated; they may get cracked to give smaller ring aromatic compounds. So, as a whole, density will be reduced ASTM distillation 95 volume percent temperature may decrease, but the cetane gain is not very good; cetane gain is not very appreciable.

With regard to diesel stabilization, the typical HDS operating conditions cannot produce enough hydro denitrification to stabilize cracked gas oil. For stabilization purposes, to maintain the oxidation stability of the diesel, it needs to undergo the hydro denitrification process; nitrogen compounds should be removed as well as aromatic content should be reduced. So, it is difficult for a cracked gas oil to pull the cetane number or the oxidation stability at a desired level, whatever hydrogen partial pressure you apply. For cetane improvement stability and stability of diesel, the hydrogen partial pressure should increase significantly. For nitrogen removal, it is difficult to remove nitrogenous compounds; it is not easy. It is a nitrogen compound for nitrogen compound removal and aromatic saturation. So, for the cetane number improvement, we have to go for the hydrogen partial pressure.

In fact, whenever we work with only the straight-run diesel fraction, this problem is not very severe, but if, say, around 20 percent, even 20 percent, cracked gas oil is blended with the 80 percent straight-run gas oil, still, we do not get good benefit out of this HDS or hydrotreating operation with high hydrogen partial pressure. Deep HDS, deep hydro desulfurization, is high-severity HDS. The objective of deep HDS is to reach the desired sulfur specification while improving other properties such as specific gravity, ASTM D 86 distillation characteristics, and cetane number and nitrogen compound content. So, deep HDS removes sulfur; it maintains the sulfur specification, and at the same time, it improves the other qualities of diesel, such as specific gravity or diesel or gasoline. But, in most cases, we go for diesel hydro desulfurization because diesel contains more sulfur compared to gasoline. So, the objective of deep HDS is to reach the desired sulfur specification while improving the other properties such as specific gravity, ASTM D 86 distillation characteristics, cetane number, and nitrogen compound content; all these are improved as well along with the sulfur removal during the deep HDS. Hydro-desulfurized light gas oil can meet all the diesel fuel specifications. Light gas oil is not very difficult to hydro desulfurize and to attain the diesel fuel specification which is given in terms of sulfur and other properties, but as the gas oil becomes heavier, it is more difficult to meet all the specifications and to add it, instead of taking 100 percent straight run, if we mix, if we blend some cracked gas oil, this is more difficult.

Hydrodesulfurized heavy gas oil must be fractionated, and its cetane number must be improved using a cetane booster to meet tighter specifications. Instead of trying to meet the sulfur specification by only HDS, this heavy gas oil has to be fractionated to get the lighter fractions out of it, and its cetane number, the cetane number of those lighter fractions, should be improved by adding some cetane booster or cetane number improver to meet the tighter specifications of the standard. Refiners often blend cracked gas oils with straight-run gas oil followed by HDS to meet diesel demand. Diesel has great demand in the market, so to meet that demand, sometimes refiners blend the cracked gas oil with the straight-run gas oil. The problem is the percentage of cracked gas oil is limited by the economics of the HDS process because cracked gas oil does not allow the ultimate hydro-treated product to meet the sulfur specification.

So, the percentage of cracked gas oil, which is to be blended with straight-run gas oil, is limited, and that is limited by the economics criteria. Scientific saturation and cetane number improvement. If the cetane number specification cannot be met by simple HDS or stability improvement, the level of severity must be increased. It is seen that for gas oil, obviously, we cannot meet the sulfur specification by only simple HDS, or we cannot get the stability improvement by only HDS for a difficultly processed feedstock, specifically the cracked gas oil instead of this straight run and at the same time, the heavier gas oil. A nickel-molybdenum-type catalyst is usually employed to meet the processing objectives to get a higher cetane number as well as stability.

Nickel-molybdenum type of catalyst works fine because the application of nickel-molybdenum type catalyst is for the aim to get the aromatic saturation as well as nitrogen removal. The cetane number of straight run gas oils can be increased by 10 points, for example, from 53 to 63 when 65 bar hydrogen pressure is applied to pull the cetane number from 53 to 63. That is increased by 10 points; it is very difficult, but it can be done for the straight run gas oil if high hydrogen pressure, that is, 65 bars, is applied. The severity level is important as the amount of cracked gas oil blended with straight run gas oil is increased and hydrotreated to meet diesel specification, as you might have understood by now that cracked gas oil poses a problem in meeting the specification. So, as the amount of cracked gas oil blended to the straight run gas oil increases, the severity level has to increase more, and even then, we cannot meet the diesel fuel specification. For unblended cracked oil, when there is no straight run gas oil blended with the cracked oil, the cetane number is low. For unblended cracked gas oil, the cetane number is obviously low at the beginning itself and cannot be improved to the desired specifications with a single-stage hydrotreatment even at high hydrogen partial pressure.

Even if we take the hydrogen partial pressure up to 140 bars, it is a very high pressure and at the expense of very high hydrogen, as well as hydrogen being related to high safety concerns, we cannot reach this specification for the cracked gas oil, which is only the cracked gas oil without any blend. So, here a two-stage hydrotreatment is necessary to improve the cetane number. In this case, for the cracked gas oil, if we do not have any other way but to use the cracked gas oil as the feedstock for the hydrotreatment, in that case, a two-stage hydrotreatment is necessary to improve the cetane number to the desired specification.

These are the references which you can consult with. Thank you for your attention.