Lecture 15: Secondary Processing: Decomposition of Residues: Process description of FCC

Hello and welcome to the lecture number 15 of Petroleum Technology. In this lecture, we will discuss the process of FCC, and we will talk about the description of FCC processes. FCC process: whenever we try to describe it at the beginning we have to see that there are 4 major sections in the FCC plant. One is a converter, the next one is a flue gas train, then the main fractionator and the last one is a vapor recovery section. Again, the converter can be classified when we can be divided into 3 sections: one is the riser reactor, the next one is the catalyst stripper and the third one is the catalyst regenerator and cooler. In the FCC process, this is a very simplified flow diagram of FCC.

Here, this is the reactor, and the feedstock, along with the recycle, is heated and goes through the riser. This is the riser to the reactor where the catalyst is in the fluidized form, and whenever the feedstock is reached in the reactor in the very fine droplet modes, these droplets come in contact with the catalyst's very fine catalyst particles, and cracking reactions occur on the catalyst particle. As the cracking occurs, the products are formed, and those product vapors come out from the reactor overhead and go to the fractionator to get the various side-stream products. Now, after one batch of reaction when all the catalysts are coked, deactivated, and cannot operate more, cannot give the desired percentage of conversion, the catalyst is taken into a steam stripper. This is a steam stripper catalyst stripper where, by steam, any hydrocarbon vapor adhering to the catalyst is removed, and the catalyst is then sent to a regenerator where the catalyst particles are taken in the fluidized form on the top of the regenerator, and from the bottom, air is supplied to the regenerator where the coke is burnt in the countercurrent operation of the regeneration, and flue gas is generated. This flue gas is sent for steam generation to utilize its heat.

The decoked or regenerated catalyst is taken out from the bottom of the regenerator, and then, along with the fresh catalyst, it is sent through the riser to the reactor. The fractionator accepts the vapors after cooling, and the fractionator gives us the gas from the top and gasoline, light gas oil, heavy gas oil from the side stream, and from the bottom, the heavy products obtained. Some of the heavy products after exchanging heat are sent back to the fractionator for the reflux purpose to keep the fractionation running, and some part of these undecomposed or heavy bottoms is taken in the slurry settler where the catalyst fine sieve entrained into the product is separated, and clarified slurry is taken out as a product from the top, and from the bottom, the heavy residue is mixed with the fresh feed and sent to the reactor. This is a very simplified process description of FCC.

So, a cracking reaction occurs in the riser reactor, and preheated feedstock, along with the recycled feed, is atomized at the bottom of the reactor. This atomization is very important. The atomizer is actually a flat fan-shaped nozzle with a cone-like structure with multiple spray fan nozzles. The working purpose of this cone-like atomizer is that the feedstock is atomized into the reactor, and this atomization makes a uniform coverage of the feedstock globules throughout the reactor, preventing any bypassing of the catalyst and feedstock. That means maximum catalyst particles, or almost all the catalyst particles, can accept the feedstock tiny globules so that there is no loss.

The feed vapor carries the catalyst powder up the riser as a dilute suspension. As soon as the feedstock droplets come in contact with the tiny particles of the catalyst, heat transfer takes place between the catalyst particle and the feedstock, and a cracking reaction occurs. Products and vapors are formed, and vapors help to make a dilute suspension of the catalyst, making the catalyst in the fluidized form. Coke is formed in the cracking reaction as a solid deposit on the catalyst. As soon as the cracking reaction occurs, some amount of coke starts to form on the catalyst body, hence reducing its activity. As the coke is deposited on the catalyst, the catalyst's active sites are clogged by the coke particles, and the catalyst loses activity. Feedstock atomization, vaporization, and mixing with the catalyst are the key steps to influence the selectivity towards premium products. Feedstock atomization is highly important because the atomization should be uniform throughout the catalyst fluidized bed so that there should not be any loss of the feedstock, and each and every catalyst finds the globules. Vaporization is required to make the catalyst bed fluidized, and mixing with the catalyst is required because the hydrocarbon molecules should enter into the catalyst and react with the catalyst in a very close and intimate manner. Only then can complete conversion take place, and if complete conversion takes place, then only can we get premium products. This is the picture of the riser reactor along with the regenerator. The feed injection zone, as I have already said, is a very precise atomizer that atomizes the feed using flat fan-shaped nozzles. This fan-shaped nozzle ensures very uniform spraying of the feedstock throughout the reactor.

This engager is situated at the top where two cyclones are located. After the reaction happens, the product vapors are taken out from the reactor overhead to the fractionator, and this separation occurs by the two-stage cyclones. Cyclones separate the catalyst and the product vapor and send the product vapor to the fractionator. In addition to this product vapor, which is taken out to the fractionator and separated by the two-stage cyclones, there may be some more vapors adhered to the catalyst, which are also separated by another closed cyclone separator. This closed cyclone separator is represented by Mobil. Mobil is another licensor, and they have patented this closed cyclone separator. It can separate the catalyst and vapor very quickly. Otherwise, if a closed cyclone separator is not situated in this disengager section, then, although there is no catalyst in the disengager, only product vapors are there, and thermal cracking may start in this area. If the product vapor is allowed to stay a little longer in the disengager part, this thermal cracking will produce dry gas, which is of low value. So, as soon as the catalyst is separated from the product vapor by two-stage cyclones in the disengager, the product vapor is sucked by this closed cyclone separator, and then and there, the product vapor is sent to the fractionator unit.

After the catalyst is exhausted, it is taken out from the reactor bed and sent to the regenerator. Now, before going to the regenerator, the catalyst is taken to the stripper section, and in the stripper section, steam is introduced to take out any hydrocarbon vapor that is there in and around every catalyst particle, to remove the adhered hydrocarbon from each and every catalyst particle. Steam takes out or strips out those hydrocarbon particles or hydrocarbon molecules, and this reduces the hydrocarbon carry-under to the regenerator. If steam stripping is not done, then the catalyst particles will carry a small amount of hydrocarbon with them. If those catalyst particles are taken into the regenerator along with the hydrocarbon, the regenerator temperature will increase, and at that high temperature, that hydrocarbon will produce extra coke on the catalyst particles, along with the coke that the catalyst particles are already carrying. So, the catalyst stripper is very important here, and a two-stage steam stripper is used, along with one standpipe through which the catalyst goes to the regenerator. The quantity of steam required to strip the oil vapors from the spaces between the catalyst particles is determined principally by the catalyst circulation rate and is generally about 1 to 2.5 kg per ton of circulated catalyst.

So, the amount of steam required for catalyst stripping depends on the catalyst circulation rate and the type of feedstock. When the catalyst reaches the regenerator, coke is removed from the spent catalyst, and activity is restored by combustion in the regenerator. The regeneration is done in an environment that allows the catalyst to restore its activity and selectivity after regeneration. Here, air is supplied to the regenerator by an air blower. This air blower is the largest compression unit in the FCC operation. It is actually an axial or centrifugal compressor run by a steam turbine or flue gas expander. This air blower delivers air at low pressure for regeneration.

In the beginning, the partial pressure of oxygen in the air is kept low to control the initial burning of coke so that the temperature will not suddenly rise to an uncontrollable range. If the temperature reaches a very high level because this burning is exothermic, then the catalyst may melt, sinter, and lose its activity. Here's what's done: the catalyst is taken to the top of the regenerator in a fluidized mode, and air is introduced from the bottom in a counter-current contact. The coke is removed or burnt, and flue gas is generated. Initially, when the partial pressure of oxygen is kept low, mostly carbon monoxide is produced, and the temperature is controlled. But as the regeneration process progresses, the percentage of oxygen is increased, and then 2 percent excess oxygen is used. This ensures that whatever carbon monoxide is produced can be converted into carbon dioxide because carbon monoxide is more poisonous than carbon dioxide. So, this flue gas should not contain any carbon monoxide. If any carbon monoxide is present in the flue gas, it is burnt with oxygen downstream in the carbon monoxide incinerator.

Now, this chart shows the regenerator process variables. Pressure is maintained at 1 to 2 atmospheres, and low pressure increases coke formation, while high pressure increases light hydrocarbon formation. So, the pressure should be optimized according to the process variables and the desired end product. Riser contact time is kept very low for the fresh catalyst at 2 seconds, and as time goes on, the contact time is increased up to 6 seconds as the catalyst loses its activity. The catalyst-to-oil ratio is maintained at 2 to 7, and slip velocity is a factor that determines how the process occurs, which is the vapor velocity divided by the catalyst velocity. A low slip velocity is desirable because an increase in slip velocity decreases the contact between vapor and catalyst particles.

Now, regarding the catalyst cooler, the catalyst cooler is situated just after the regeneration unit. The heat removal device in the regenerator is a feature that most readily distinguishes an RFCC from an FCC. So, whenever the catalyst particles come out from the regenerator after decoking, they carry a high amount of heat with them. So, the catalyst particles should be cooled to reduce the temperature to a level compatible with the reactor because the regenerated catalyst has to be fluidized into the reactor. If the catalyst particles carry the same heat as the regenerator, then at that high temperature, the feedstock will produce more coke. In an RFCC unit, metal contaminants, particularly nickel contained in the feedstock, produce coke on the surface of the catalyst because nickel will sit on the Y zeolite and encourage the dehydrogenation reaction. The dehydrogenation reaction is the precursor for coke formation. Moreover, asphaltenes form coke immediately upon contact with a catalyst, as asphaltenes have a very high carbon-to-hydrogen ratio. Their carbon content is very high compared to hydrogen, and as soon as they come in contact with the highly heated catalyst, they form coke by removing the hydrogen from it. Both types of coke are additive to the coke produced by the cracking reaction. While we are getting coke from the cracking reaction, whenever nickel and asphaltenes are present in the feedstock, they produce more coke on the highly heated catalyst.

So, a regenerator heat removal system is required, which consists of a variable-duty external catalyst cooler. This external catalyst cooler removes heat from the catalyst and makes it compatible with the temperature of the reactor. The excess heat taken out by the catalyst cooler is used to generate steam in the FCC unit. The flue gas train is the next unit of the FCC. Here, the energy from the regenerator flue gas is recovered in two forms. The flue gas obtained from the regenerator is utilized in two ways. One is for mechanical energy using a power recovery expander, and the other is for heat generation by producing steam in a flue gas cooler. Mechanical energy is obtained by utilizing this heat energy in the form of shaft work, and another utilization may be running the large air blower of the regenerator unit. Another utilization is the use of heat for steam generation in a flue gas cooler.

Next, coming to the main fractionator section, the fractionator produces various side cuts, and various light products. The vapors collected from the top of the reactor are taken to the main fractionator, which contains the superheated reactor reaction products from the disengager to produce liquid hydrocarbon products as side cuts. Fractionation is provided between liquid side-stream products to efficiently recover the heat available from condensing the superheated products. Heat exchange is done with other streams to utilize the heat of the superheated products coming from the disengager section.

Next, we will come to another section, which is the vapor recovery section. The vapor recovery section consists of a wet gas compressor, primary absorbers, stripper, secondary absorber, and de-butanizer. Various types of equipment are used for the vapor recovery section, where the purpose is to reject C2 and lighter components to the fuel gas system. Whatever gas or vapors are obtained from the disengager section, mostly C3 and C4 cuts are separated out, and C2 and lighter products, such as methane or any hydrogen produced, are rejected and sent to the flue gas system. The C3 and C4 fractions can be utilized as LPG, and C3 and C4 can be separated in a splitter, or propane and propylene can be separated in a propane-propylene separation unit. Butane and butylene can be separated in a butane-butylene separation unit, all of which are part of the cold separation process.

Another purpose of this section is to produce de-butanized gasoline. The gasoline obtained directly from the fractionator is unstabilized. So, the butane part should be removed from the gasoline because butane is not a component of gasoline. De-butanized gasoline is obtained with the required vapor pressure. If there is more butane present, the gasoline will have a higher vapor pressure, which is not acceptable. Sometimes, the total gasoline product can be split into light gasoline and heavy gasoline.

These are the references. Thank you for your attention.