Technologies for Clean and Renewable
Energy Production
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Lecture-20
Tutorial 4

Hi friends, now we will have a tutorial session and in this session we will solve some numerical problems based on our discussion in the last 4 classes.

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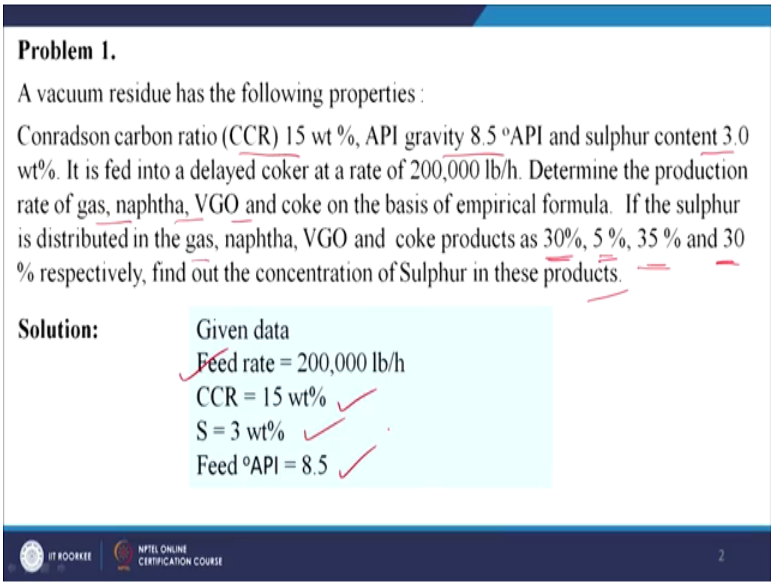

The first problem states, a vacuum residue has the following properties that Conradson carbon ratio CCR is 15 weight percent API gravity 8.5 degree API and sulphur content 3.0 weight percent. It is fed into delayed coker, delayed coker at rate of 2 lakhs pound per hour determine the production rate of gas, Naphtha, VGO and coke on the basis of empirical formula. If the sulphur is distributed in the gas, naphtha, VGO and coke products as 30% 5% 35% and 30% respectively, find out the concentration of sulphur in these products.

So, this is a problem based on delayed coking. And it is the properties of the feedstock given that is CCR API. Both are given and sulphur content is also given. Now after the delayed cooking, we will be getting different products that gas products will get, will get naphtha, will get VGO, we will get coke. So, these are the major products of the delayed coking process. And then we have to find out the sulphur content in this and relative amount of different products is already given.

So, 30% for gas, 5% for naphtha, 35% for VGO and 30% for coke so, we have to solve the problem. So now we will see what data is given we have feed rate 2 lakhs pound per hour and then CCR is 15% and sulphur is 3% in the feed and API is 8.5 for the feed. So then what we will do? We will use the empirical relationship to determine different products. As you have discussed in our previous classes that using some empirical formula, we can predict what will be the product distribution for a delayed coking process.

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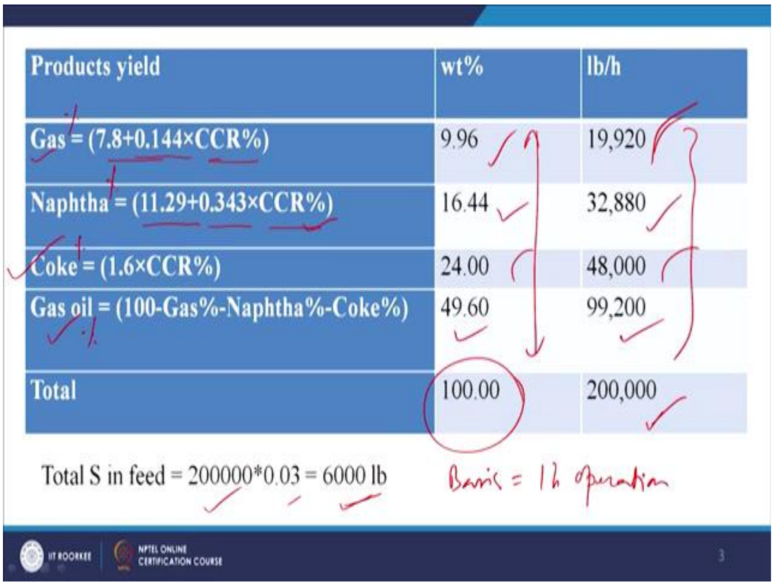

Products yield	wt%	lb/h
Gas = (7.8+0.144×CCR%)	9.96	19,920
Naphtha = (11.29+0.343×CCR%)	16.44	32,880
Coke = (1.6×CCR%)	24.00	48,000
Gas oil = (100-Gas%-Naphtha%-Coke%)	49.60	99,200
Total	100.00	200,000

Total S in feed = 200000*0.03 = 6000 lb

So here we had this expression gas = 7.8 + 0.144 x CCR % is the weight percentage of CCR. If we put here then we will get by using this formula we can get the gas weight percent. How much gas it will be produced, and accordingly we can get the production date also how many pounds per hour. So in this case, what is the CCR in our case we have 15%. So, 15, if we would 15 x0.144 x 7.8 = 9.96 and then 9.96 this is in percent gas in percent.

So that is equal to 9.96% is so how much we had we had two lakhs, so 2 lakhs per hour, we had two lakhs pound per hour. So, 2 lakhs pound into this percent that is 0.0996 that is equal to 19,920 pound per hour. Then for the Naphtha this is equal to what will be the percentage of that the 11.29 + 0.343 x CCR weight %. So we will put 15 and will apply this formula for getting 16.44 weight percent.

And again we will multiply with the actual feed and then we will multiply this percent with it and are getting 32,880 pound per hour. Similarly, for Coke, we had the empirical relationship if that is equal to coke in % = 1.6 x CCR in weight%. So 1.6 x 15. So, we are getting 24 wt% = 48000 pound per hour. And gas oil, we can calculate by the difference.

So, 100% that it also in percentage so 100 minus gas percentage minus naphtha percent minus coke percentage. So we will be getting 100 - 9.96 - 16.44 - 24. So that is equal to 49.60. And that is equivalent to 99,200 pound per hour. So now we are getting by summing up we are getting 100% and this is our product distribution which is a pattern of the distribution of the products.

And then this is the total amount the product is formed that is equal to 2 lakhs pound per hour and this is in mass basis, the distribution of different products. Then, we have to find sulphur in these products. So, how much sulphur we had originally it is given the 3% in the feed. So, 2 lakhs x 0.03 = 6000 pound sulphur is present in it. So, here the basis is say one hour operation.

See the plant operates on one hour then it will consume 2 lakhs pound of feedstock and that will be having 6000 pound of sulphur. Then we will see, what is the Sulphur in gas?

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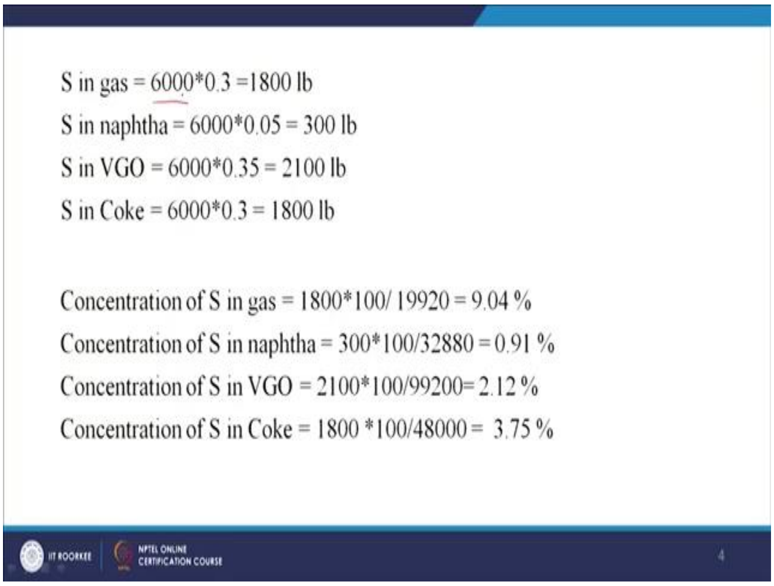

So, we have 6000 x 30% sulphur is coming as it is given totals sulphur which are in the feed 30% is coming to the gas and then 5% to naphtha, then 35% to VGO and again 30% to coke. So, this data will be using. So how much sulphur we had and how much what is the percentage of that sulphur transferred to a particular type of product that we will consider.

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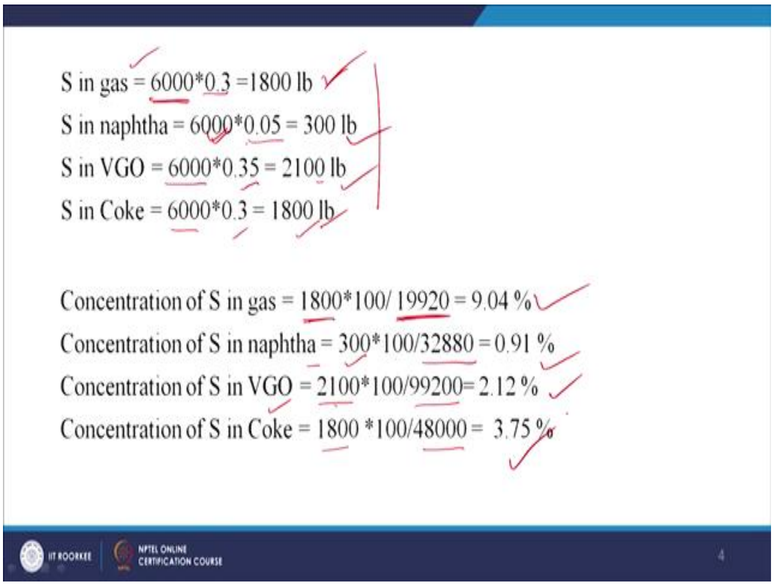

So in this case, we had 6000 pound of gas production per hour and 30% sulphur is coming here that is 30% of sulphur is converted. So we have 0.3. So, the 1800 pound we are getting here. And then sulphur in naphtha, that is equal to 6000 originally, 6000 pound sulphur was present in the feed. So 30% is converted to gas it is coming to the gas. So, that is the gas sulphur content is on it will be that is 6000 x 30% that is into 0.3.

And naphtha 6000 total amount of sulphur present in the feed into the how many percentage converted into, transfered into Naphtha? That is 5% so 6000 x 0.05 = 300 pound and for VGO, it is again 6000 x 35% so 0.35 = 2100 pound and for coke 6,000 x 0.3 = 1800 pound. So, these are the mass of the sulphur present in different products stream.

Then what will be the percentage? So, then we can convert it into percentage because you have already calculated what will be the mass of different products we are getting through this process in one hour. So, then, concentration of sulphur in gas will be this is the sulphur in the gas and this is the total mass of the gas. So, the sulphur mass of sulphur into mass of gas in to 100. That is the percentage of sulphur in the gas stream.

Similarly, the concentration of sulphur in naphtha there is a mass of naphtha in the mass of sulphur in naphtha divided by mass of naphtha into 100, that is 0.91% and then concentration of sulphur in VGO, mass of sulphur in VGO divided by mass of VGO into 100. So, 2.12% and for coke again the sulphur in coke that is equal to 1800 divided by total Mass of coke, 48,000 into 100 so 3.75% (1800*100/48000=3.75%).

So, now we are able to determine that what will be the product distribution and how the sulphur will be distributed in different products.

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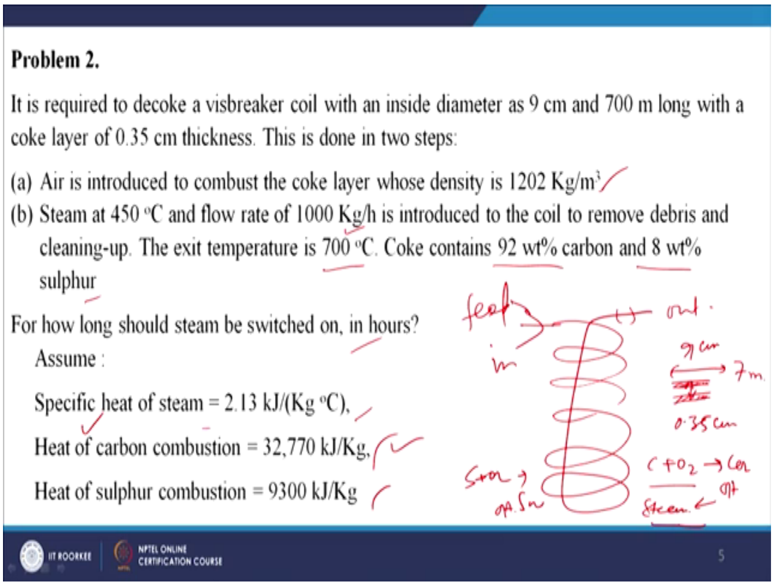

Now, we are coming to the next problem. So, problem 2, it states that it is it is required to decoke a visbreaker coil with an inside diameter as 9 centimetre and 700 metre long with a coke layer of 0.35 centimetre thickness. This is done in two steps. First step, AR introduced to combust the coke layer whose density is 1202 kg per metre square. In the second step, steam at 450 degrees centigrade and flow rate of 1000 kg per hour is introduced to the coil to remove the debris and cleaning up.

The exit temperature is 700 degrees centigrade. Coke contains 92% carbon and 8% weight sulphur. So, these are the data provided. Then for how long should steam be switched on in hours? We can assume the specific heat of steam is 2.13 kilo joules per kg degree centigrade. Heat of carbon combustion the combustion of carbon that is equal to 32,770 kilo joules per kg and then heat of sulphur combustion 9300 kilo joules per kg. So, this this information is given to us.

Then what we have to do? We have to calculate what is the time required to pass steam to the coil. So, this problem is a, is related on visbreaking. So, in visbreaking we have coil say so, we are we are giving feed in, this is product out. Say in and out. So, here the diameter of this we take some part of it this part. So, it will be like this. So it has diameter of 9 centimetre and inside these diameter there are some coke deposition during the visbreaking process, both sides there is some coke deposition process inside the tube.

So, these thickness is 0.35 centimetres and this length is equal to 7 metre. This is the problem statement. Now, once the visbreaking is completed the coke deposition has taken place. So, if we want to use this coil again so, we have to remove the coke from the inside of the coil. So, this can be done by providing air. So, what the air will do? That $C + O_2$ that will be CO_2, so, this reaction will take place and during this reaction heat will be generated.

And that heat will be taken up by the steam as the steam inlet temperature is equal to 450 degrees centigrade and then when it is going out then the temperature is coming out it is 700 degrees centigrade. So, heat released by this reaction by the coke will be taken up by the steam and then its temperature will increase. So, if we do the energy balance, then we can be able to calculate the energy transferred from this reaction to the steam.

And accordingly we can calculate the time required to flow the steam as we have we have steam flow rate, it is given and specific heat is also given. And combustion for this reaction is also given. And again if sulphur is present, so sulphur will also be react with oxygen and it will give us SO_2. So that details is also given. So this is an energy balance problem. So, we will solve it now.

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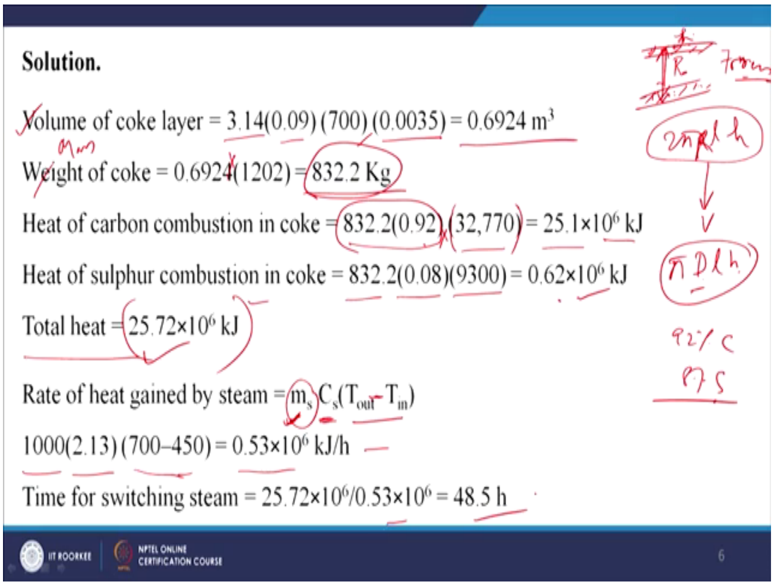

So, volume of the coke layer, we can calculate as we have told that this is the case. We have layer. So, what will be the volume of this layer, we can calculate. So, we have this is diameter and this is equal to say thickness D and there the thickness is small, and we can approximate and this is equal to 700 metre L so 2πrlh, so, this is equal to h. So 2πrlh, this will be the volume or πDlh, D is the diameter and r is the radius.

These are same so radius here we are having diameter. So, πDlh, so, this formula π 3.14 into 9 centimetres, so converted 0.09 metres. So D Now we're having L is also given 700 metre long. So, this equal to 700 and this is not 7, this is 700 metre, so 700 metre. And then this is equal to the thickness this thickness h to this thickness. So, this is a volume of this coke layer. So, how much coke was deposited in volume this h.

Then what will be the weight of this? that is equal to we must say mass of this. We can say mass of this Coke is equal to volume into its density. Density is given. That is equal to 1202 kg per metre cube that was given. So, multiply this x 1202 x 0.6924 = 832.2 kg. So, this amount of Coke is deposited inside the coil then heat of combustion of coke. What will be the heat of combustion of coke?

Because this coke has carbon and sulphur 92% carbon and 8% sulphur it is given. So, what is the mass of coke we are getting 0.92 of that will be the mass of carbon and that will be combusted to CO_2. So, for that ΔH value = 32,770 kilojoules per kg. So, now we are having the total mass in kg so, multiply it by this. So, you are getting 25.1×10^6 kilojoule by approximation it is and then heat of sulphur composition in coke.

So, how much sulphur is present in coke here 8% So, total mass of the Coke into 0.08 that is the mass of the sulphur then the heat released due to the combustion of Sulphur to sulphur dioxide. So, that is multiplied 9300 that is equal to 0.62×10^6 kilojoule. So, what is a total heat released by these two reactions? This plus this one so are getting 25.72×10^6 kilojoule.

So, this is heat released by the combustion reaction now this is taken up by the steam. So, so if we consider that m, m is given. So m is mass of the flow rate of steam m is mass flow rate of steam, then m Cp dT, ΔT that is T_{out} - T_{in}, temperature difference into mass of steam into Cp average specific heat of steam. Then we will be having this C_s and if we can use this formula and put the value of this we can get the rate of heat gained by steam, because this mass is related to the mass flow rate.

So, that it will be heat flow rate, it will be in a m_s C_s and T_{out} - T_{in}. So, in this case what is our m_s it is given 1000 kg per hour 1000 kg per hour steam it is given. So, 1000 we are putting then C_s it is given how much it is 2.13 kilojoule per kg per degree centigrade. So, we will put this value here and then temperature difference how much 700 output and input 450 so 700 - 450. So, then we are getting 0.53 x 10^6 kilojoule per hour.

So, this is the heat taken up by the steam per hour. But how much steam, how much heat has to be taken up by the steam this much. So, what will be the time required to transfer the total heat generated during oxidation process to the steam that will be 25.72 x 10^6 / 0.53 x 10^6 = 48.5 hour. So, 48.5 hour the steam switch has to be kept on.

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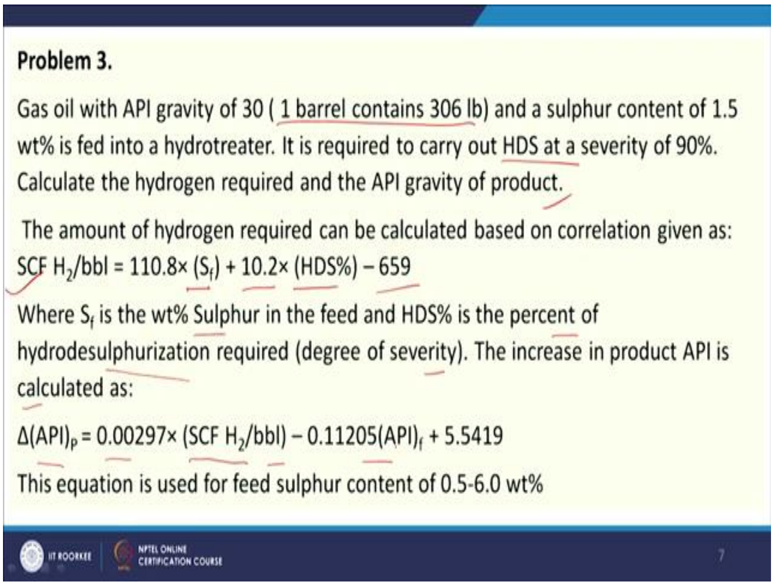

Next problem. So now we are coming to problem number 3. So, this problem says gas oil with API gravity of 30, 1 barrel container 306 pound and a sulphur content of 1.5 weight basis is fed into a hydrotreater. It is required to carry out hydro desulphurization at the severity of 90%. Calculate the hydrogen required and the API gravity of the product. The amount of hydrogen required can be calculated based on correlation given as:

SCF hydrogen per barrel is equal to 110.8 into Sf plus 10.2 into HDS% minus 659. So, this Sf is the weight percentage of sulphur in the feed and HDS is the percent of hydrodesulphurization required that is degree of severity. The increase in product API can be calculated as:ΔAPI_p = 0.00297 x (SCF H_2 / barrel) - 0.11205 $(API)_f$ + 5.5419.

So, this empirical relationship is given. We can use it to calculate the changes in API due to this process. So this equation is used for feed sulphur content of 0.5 to 6.0 weight percent. So, in our case, 1.5 wt% is provided. So, this formula we can use to calculate the API change due to this process. And what is the hydrogen requirement that can also be calculated by this empirical formula. So, we are going to do that. So, how will do it?

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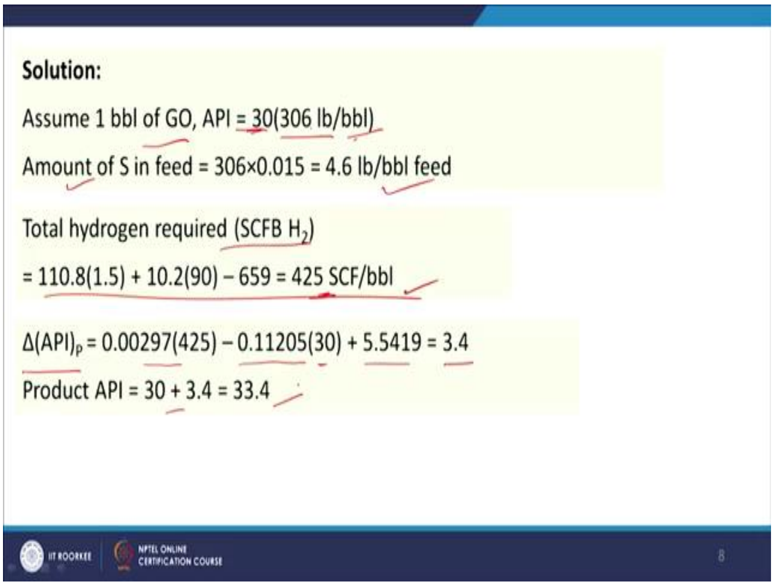

We are assuming that one barrel of gas oil so API is equal to 30 that means 306 pound per barrel, it is provided. What will be the sulphur in feed 15% it is, so we have to 306 pound into 0.15 so 4.6 pound per barrel feed we are having that sulphur. Then what will be the total hydrogen required? SCFB H_2, that is equal to it is given this formula is given. So 110.8 x S_F and S_F = 1.5 + 10.2 x degree of severity.

That is it is given 90%. So 90% severity is required so we will be putting here 90 - 659, it is coming to 425 SCF by per barrel. And ΔAPI for the product permission we are getting 0.00297 into this was given SCF and then 0.11205 into what is this this this 30 is equal to API. How much API feed had so this plus 5.5419 and it is given. So that is coming equal to 3.4. So 3.4 ΔAPI is changing.

So what will be the product so 30 + 3.4 = 33.4. Okay. So degree API is increasing. That means the product is becoming lighter through hydro processing the products become lighter.

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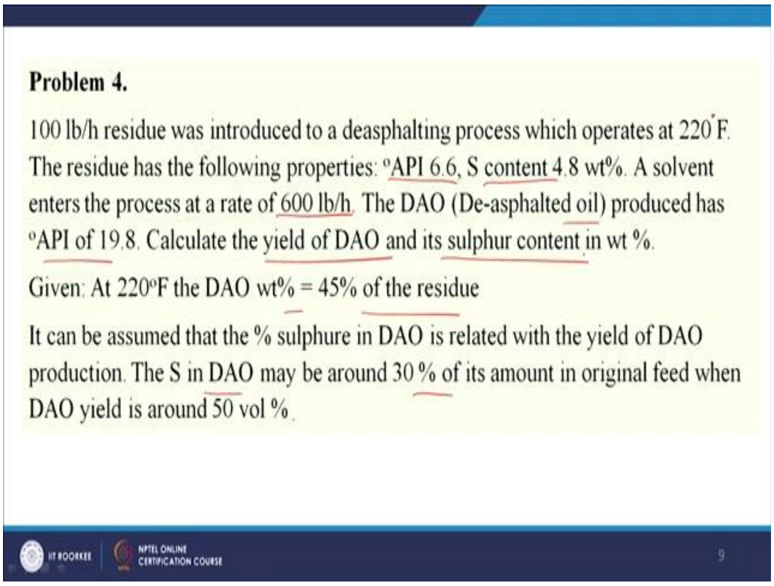

Next problem statement states, 100 pound per hour residue was introduced to a deasphalting process, which operates at 220 degree Fahrenheit. The residue has the following properties degree API 6.6 Degree API 6.6 sulphur content 4.8 weight % is solvent enters the process at a rate of 600 barrel per hour. The DAO that is deasphalted oil produced has degree API of 19.8. Calculate the yield of DAO and its sulphur content in weight %.

It is given at 220 degree Fahrenheit the DAO% is equal to 45% of the residue. It can be assumed that the percent sulphur in DAO is related with the yield of DAO production. The sulphur in DAO maybe around 30% of its amount, in original feed, when the DAO yield is around 50 volume percent, so, this is a problem statement. So, what we have to do? We have to calculate the yield of DAO and we have to calculate the sulphur content in it in weight basis or mass basis.

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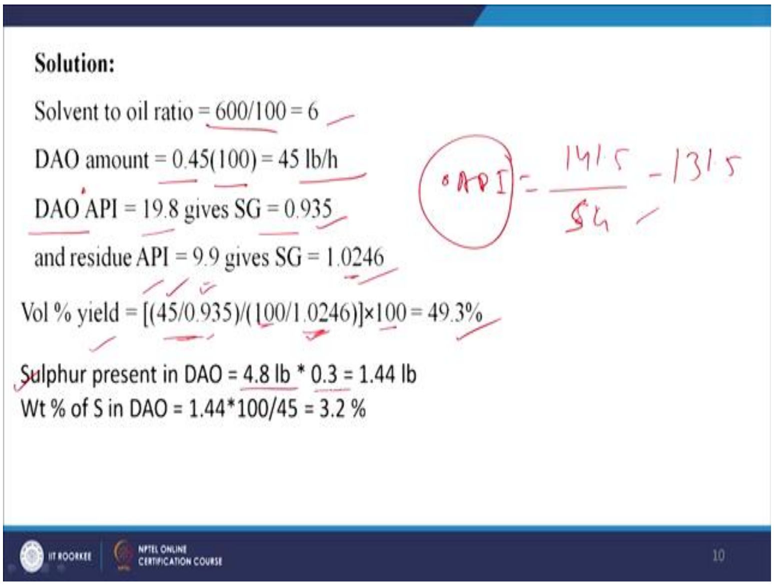

So, here, what is the solvent to oil ratio 600 pound per hour, we have 100 pound per hour residue and solvent is 600 pound per hour. So, what is the ratio 600 / 100, = 6. And then what is the DAO? How much DAO is produced that is equal to 45% its residual part is coming as DAO so, 0.45 x 100 = 45 pounds per hour. So, this is our DAO production the first part is done.

And then DAO which is produced what is the API, degree API? 19.8 gives SG so, that is equal to SG of 93.5. So what is this Degree API = 141.5 / specific gravity - 131.5 as you have discussed, so, here in this case API is available that is equal to 19.8. So, SG we can calculate by this expression and that is that is equal to 0.935 and residue API equal to 9.9 as already given.

So, in that case, we can get the SG also by the by using this formula here it is coming 1.0246 So, specific gravity of feed and specific gravity of product we are able to calculate. Then what will be the percentage yield. That is equal to 45 divided by specific gravity of it. That will be the volume. That will be the mass divided by this so, it is the volume of the DAO.

And then what is the total volume of the residue? That is 100 by the mass and then divided by this specific gravity that is the volume. So, this volume of DAO divided by the volume of the residue or the feedstock into 100. So, 49.3% DAO yield. Now it is given that sulphur content is dependent on that DAO yield. And it is also given if DAO yield is around 50% the sulphur 30% of sulphur will be transferred to DAO.

So, we are having here sulphur present in DAO = 4.8 Lb x 0.3 because, we have 4.8% sulphur was originally present in feedstock So, 30% of it is being converted. So, that is equal to 1.44

pound is coming to that DAO. So, then what will be weight percentage of sulphur in DAO? That is this into this is divided by 45 into 100. The mass of sulphur divided the mass of DAO into 100. So, there is a percent of 3.2%. So, that was we are asked to calculate and were able to solve it.

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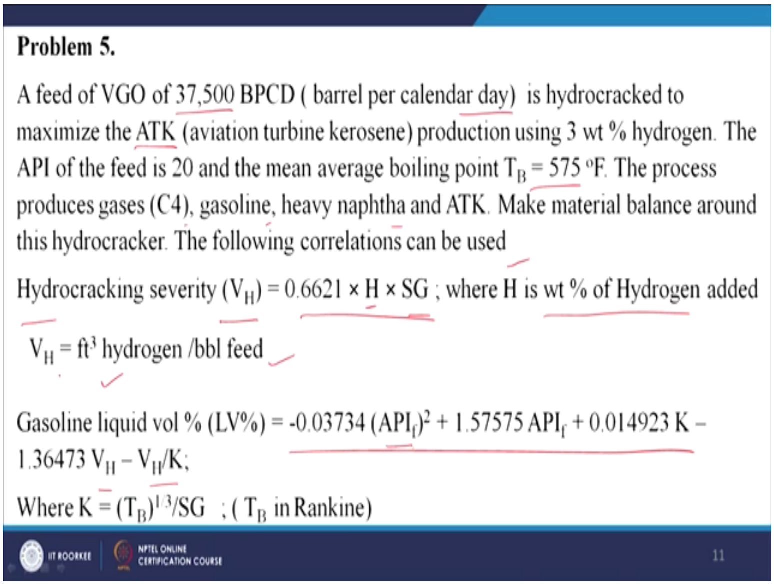

Our next problem is a feed of VGO of 37,500 BPCD that is barrel per calendar day is hydro cracked to maximise the ATK aviation turbine kerosene production using 3 weight % hydrogen. The API of the feed is 20 and the mean average boiling point that is T_B is equal to 575 degree Fahrenheit. The process produces gases gasoline, heavy naphtha and ATK. Make material balance around this hydro cracker the following correlations can be used.

So, hydro cracking severity we can calculate by using these correlations that is 0.6621 x H x SG where H is the weight percent of hydrogen added. And SG is a specific gravity and then V_H is the cubic feet of hydrogen produce per barrel of feed. And gasoline liquid yield can be calculated by this empirical relationship.

That is volume percent that is liquid volume percentage equal to this one - 0.03734 x API_f^2 + 1.57575 API_f + 0.014923 K - 1.36473 V_H -V_H / K. So, V_H already it is given and then can be calculated by $T_B^{1/3}$ / SG and this T_B in Rankine scale.

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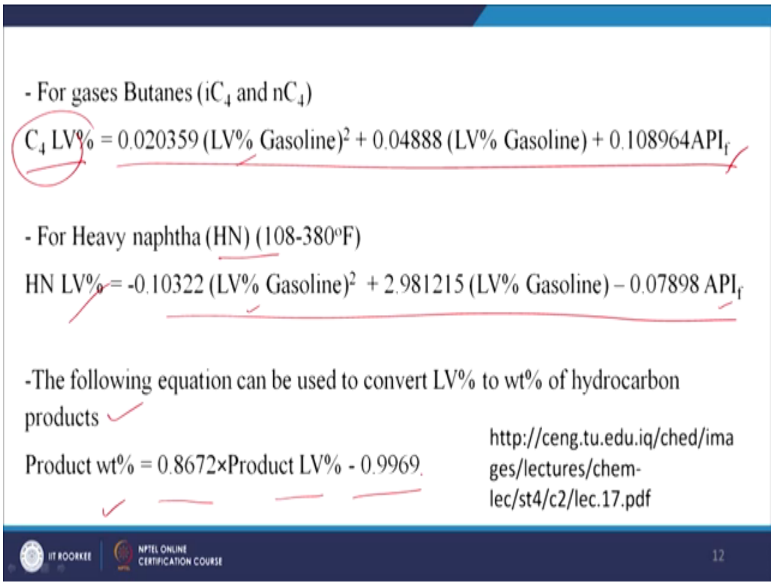

And Butane productions in volume percent, we can calculate by this empirical relationship. These productions will be dependent on the liquid volume percent of gasoline and API of the feed. Similarly heavy Naphtha can be the liquid volume of the heavy naphtha can be computed by this empirical relationship which is based on the gasoline percentage and API_f. API_f of the feed okay. The following equation can be used to convert liquid volume percent into weight percent for hydrocarbon products.

That is product weight % = 0.8672 x product LV% - 0.9969. So, this is the problem statement. Now, we have to do a mass balance of this.

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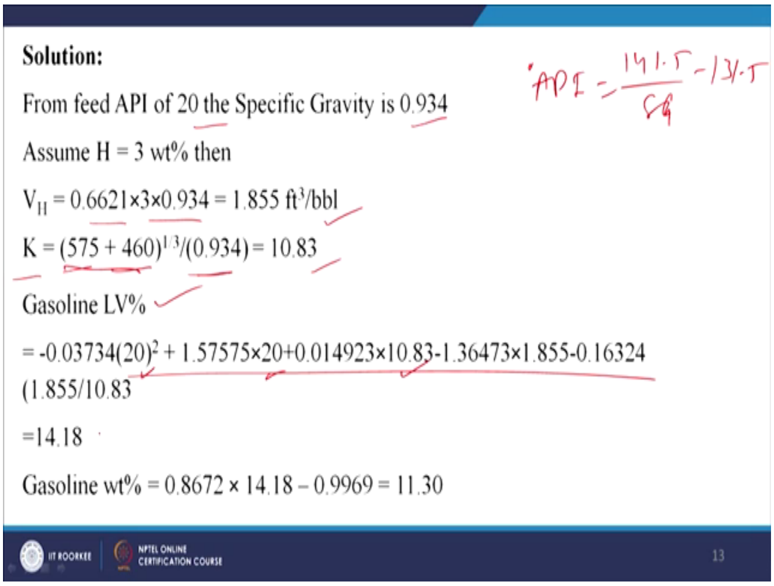

So, from feed API of 20 the specific gravity we can calculate 0.934. The same expressions Specific gravity = 141.5 /specific gravity. So, API = 141.5 /specific gravity - 131.5. The same formula we can use. And then hydrogen we have 3% we are adding in this case, then V_H will be how much 0.6621 x 3 x 0.934 because this x sulphur content S_F x Specific Gravity.

So we are getting 1.855 feet cube per barrel and then K, $K = T_B^{1/3} / SG$ so T_B in Rankine. So, this was 575 Fahrenheit, so + 460 there is an Rankine to the for one third by this so, that is equal to 10.83. Then what will be the gasoline liquid volume, this empirical formula we will put. So, this is API of the feed and then this is feed and this empirical formula we are already given.

This is equal to K value. So, we are putting the empirical formula and we are getting the value of 14.18 liquid volume percent. And gasoline wt% equal to how much? We will put that relationship which is given to convert vol% to wt% that is .8672 x 14.18 that is 14.18 is the liquid volume percent - 0.9969, so it is coming 11.30%.

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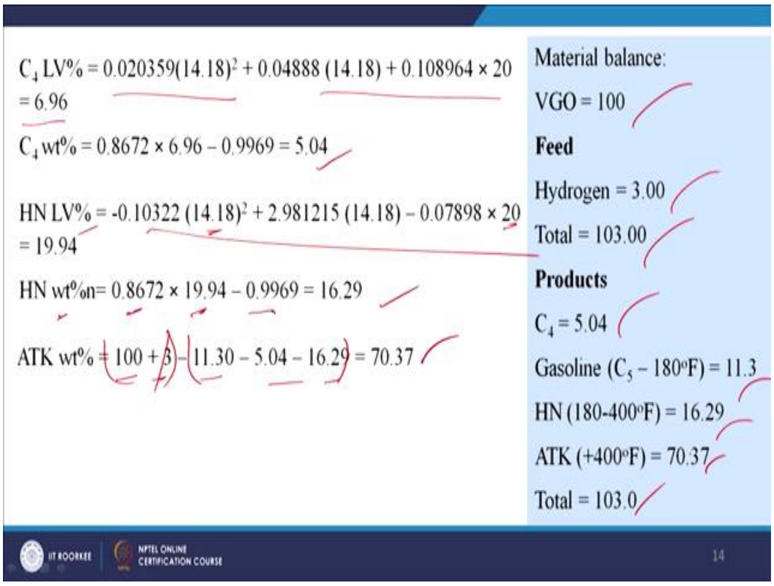

Similarly, for gas what will be the liquid volume percent? So, this one we will be putting the same expressions as provided. So, we are getting value of 5.04% and for heavy naphtha LV% equal to this expressions we had that is the gasoline production and then degree of feed API_f so, then you are getting 19.94%. And the weight percent if we want to convert, then these volume percent into this minus this already the expression is given.

So we get in 16.29% for heavy naphtha after for ATK we are getting 100 we have the feed plus 3 hydrogen we are adding then we are getting the difference of this, this is the difference of other masses. This is our input. This is our mass of the feedstock. This is our mass of other products. So remaining is the mass of the ATK weight percent that you can calculate.

And this is a summary of the material balance which we have, hydrogen we are adding and 103 we are getting and then we are getting the products this, this one gasoline and this one and this one are 1,2,3 so mass balance we are getting so upto this in this class, thank you very much for your patience.