Technologies for Clean and Renewable Energy Production
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Lecture-10
Tutorial 2

Hi friends now we will be having one tutorial session and in this session we will solve some numerical problems based on the discussions of last 4 classes.

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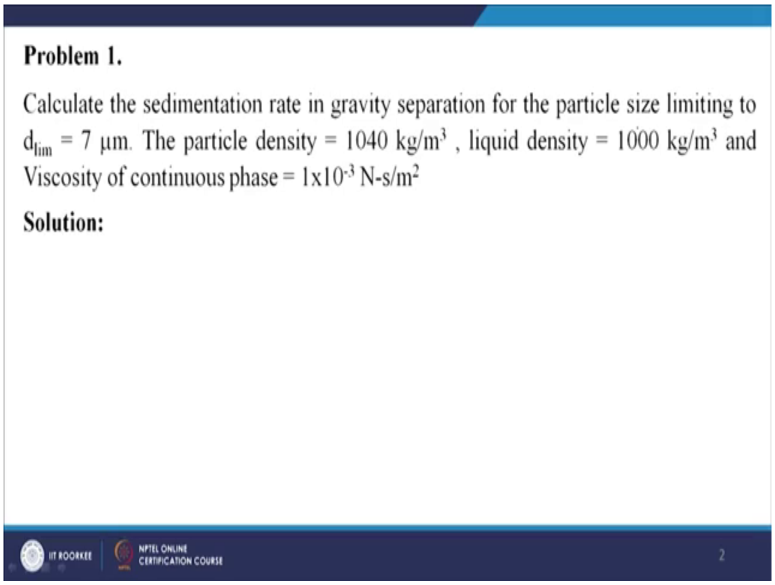

So, problem number one says that calculate the sedimentation rate in gravity separation for the particle size limiting to d limiting 7 micrometer, the particle density equal to 1040 kg per meter cube, liquid density is 1000 kg per meter cube and viscosity of continuous phase 1 into 10 to the power -3 Newton second per meter square. So, this is the problem we have to solve and in the previous class we have discussed on a coal cleaning part that the size and terminal settling velocity is used for the separation of particles in case of classification.

So, here we will see if a particle size of coal particle is known then what will be the terminal settling velocity there is very fundamental aspect we have provided here and we will discuss on it. So, what we will do if we assume the laminar flow conditions then Stokes law is applicable and in that case we can find out the terminal settling velocity.

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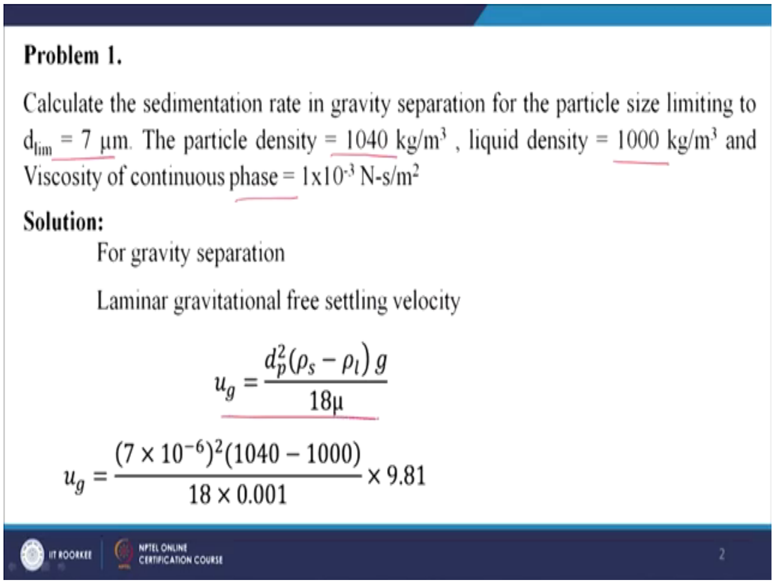

As for this formula that is terminal settling velocity is equal to dp square into ρ_s minus ρ_l into g divided by 18 into µ when dp is the diameter of the particle, ρ s is the density of the solid particle ρ_l is the density of the fluid under which the particle is falling g is the acceleration due to gravity gravitational acceleration and then µ is the viscosity of the media. So, we have to calculate u_g.

Now we will see what is the value of dp? dp is given here that is 7 micro meter so you have to convert it into meter unit so 7 into 10 to the power -6 dp you are getting and then ρ_s is given 1040 kg per meter cube and ρ_l is given as 1000 kg per meter cube and g we know that 9.81 meter per second square and then µ value is given also 1 into 10 to the -3 Newton second per meter square. So, in this case we will be getting the u_g value as 7 into 10 the -6 square as dp square then 1040 - 10000 into 9.81 divided by 18 into this is .001.

So, this is equal to 1.068 into 10 to the -6 meter per second. So, this is the terminal settling velocity of the coal particle.

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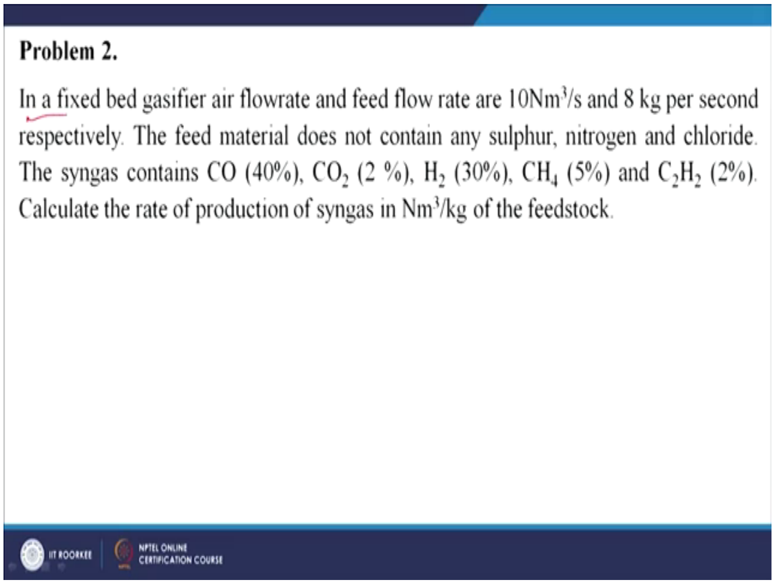

Our next problem statement says in a fixed bed gasifier air flow rate and feed flow rate are 10 normal meter cube per second and 8 kg per second respectively. The feed material does not contain any sulphur, nitrogen and chlorine. The syngas contains carbon monoxide 40%, CO_2 2% H_2 30% CH_4 5% and C_2H_2 2%. Calculate the rate of production of syngas in normal meter cube per kg of the feedstock. So, this is the problem statement we have to calculate the production of syngas normal meter cube per kg.

So, 1 kg of material will produce some amount of syngas, that amount we have to measure in terms of in the unit of normal meter cube. So, how we can do it? We can solve this problem by nitrogen balance.

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Solution:

We know that under the above condition the rate of syngas production can be computed by the following equation

$$Fuel\ gas\ production(Nm^3.kg^{-1}) = \frac{air\ flow\ rate\ (Nm^3.s^{-1}) \times 0.79}{\left[1 - \frac{CO + CO_2 + H_2 + CH_4 + C_2H_2}{100}\right] \times feeding\ rate(kg.s^{-1})}$$

Therefore,

Syngas production = [(10*(0.79)]/[(1-(0.4 + 0.02 + 0.3 + 0.05 + 0.02)]*8

= 7.9/ (0.21*8) = 4.702 Nm^3/kg feedstock

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As we have discussed in the previous classes that fuel gas production normal meter cube per kg of feedstock that is equal to air flow rate normal meter cube per second into .79 divided by 1 minus the CO + CO_2 + H_2 + CH_4 + C_2H_2 there is the composition of the flue gas by 100 into feeding rate of the feedstock. So, feeding rate of feedstock this is the total amount we are using per unit time and then 1 – this.

This term is giving us the nitrogen available in the flue gas, this part is giving us the nitrogen available in the flue gas 100 minus this whole term. So, flue gas production then what was the nitrogen in the air which was used in this case we are assuming that 21% oxygen so 79% nitrogen is there so that is what this term is 0.79, so air flow how much into .79 that is the nitrogen available in the air and then there is a nitrogen coming.

And what is the nitrogen available in the flue gas? That is flue gas production rate into this one and this is divided by the amount of material used. So, this formula is used to calculate the flue gas production that is in the unit of normal meter cube per kg. So, this we have discussed in the previous class. Now we have to put the value of these things, so what are the value of CO? It is given CO 40% CO_2 2% H_2 30% CH_4 5% and C_2H_2 2% so this value will put there.

And it was also given the 10 normal meter cube per second this is the air flow rate and 8 kg per second was the feed flow rate. So, though all the terms are given in the problem and we will be putting those things. so 10 the air flow rate into 2.79 divided by 1 - that is equal to CO 40% so 0.4 as 100 is divided here so this equal to .02, 2% CO_2 and then 30% hydrogen so 0.3 and then CH_4 was 5% so .05 and then C_2H_2 was again 2% so 0.02 we are getting this term and then this feed rate that was 8 kg per second so multiplied by 8.

So, this is the syngas production rate and now we are getting by calculation 7.9 by 0.21 into 8 that is equal to 4.702 normal meter cube per kg of the feedstock. So, now we are able to find out what will be the production of syngas per kg of feedstock.

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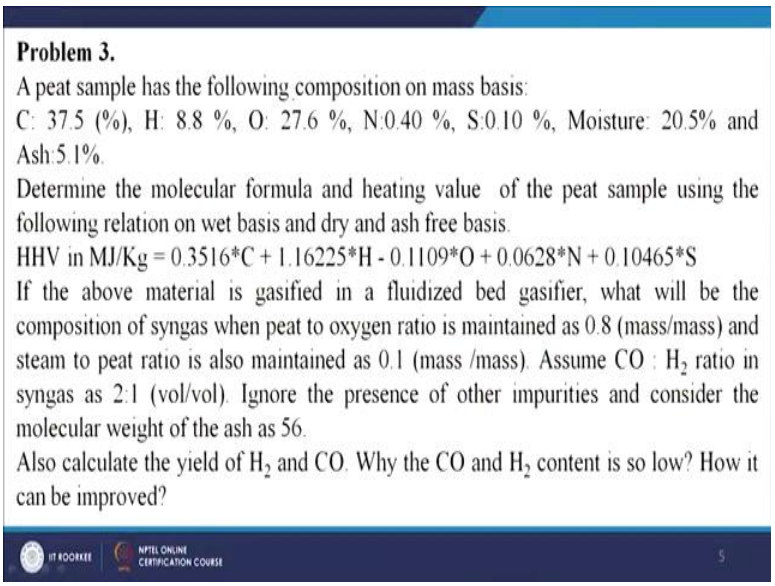

The next statement says a peat sample has the following composition on mass basis so carbon 37.5%, hydrogen 8.8%, oxygen 27.6%, N 0.40%, sulphur 0.10%, moisture 20.5%, and ash 5.1%. Determine the molecular formula and heating value of the peat sample using the following relation on wet basis and dry and ash free basis. So, the formula is given HHV, high heating value in mega Joule per kg is equal to 0.3516 into C + 1.16225 into H -0.1109 into O + 0.0628 into N + 0.10465 into S.

If the above material is gasified in a fluidized bed gasifier what will be the composition of syngas when peat to oxygen ratio is maintained at 0.8 mass by mass basis and steam to peat ratio is also maintained as 0.1 mass by mass basis? Assume CO and H_2 ratio in syngas as 2 is to 1 volume by volume and then ignore the presence of other impurities and consider the molecular weight of the ash as 56. Also calculate the yield of hydrogen and carbon monoxide and why the carbon monoxide and hydrogen content is so low? How it can be improved?

So, this is a problem statement see it has number of parts so we will be solving this problem step by step. So, this is a gasification problem and the composition of the sample feedstock is given and then we have to find out the molecular weight and molecular formula of the feedstock first of the peat sample. Then we will convert it into its percentage will convert it into dry basis then we will use this formula for the HHV calculation.

So, in two different basis, wet basis and dry and ash free basis we will be able to calculate the HHV. So, the first part will be done. Then we have to calculate the composition of syngas so composition of syngas means the feedstock will be reacting with gasifying region and it will be producing different syngas with different compositions. So, including different gas components and we have discussed in the previous class the gasification reactions can be presented by some generic expressions and we will be using that and then we will see how this mass balance is taking place.

And then what are the coefficients of the different elements available in the feedstock as well as how much moles of different gas components is produced from one mole of the feedstock that we will discuss. And we will ultimately get the concentration of different gas components.

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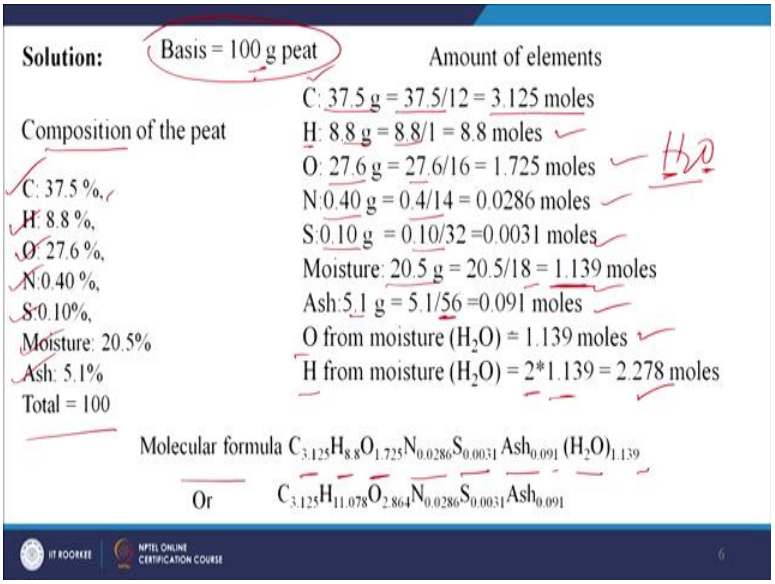

Now let us see, let us take a basis of 100 gram of peat so as for the statement we have composition of the peat that is carbon is 37.5%, hydrogen is 8.8%, oxygen is 27.6%, nitrogen 0.40%, sulphur 0.10%, moisture 20.5%, ash 5.1% so total we are getting 100%. So, what will be the amount of the elements present in 100 gram of peat. Carbon will be 37. 5 gram as it is percentage so hydrogen will be 8.8 gram then oxygen will be 27.6 gram, nitrogen will be 0.4 gram and sulphur 0.10 gram, moisture will be 20.5 gram, ash well be 5.1 gram.

Then what will be the moles present in this sample, 100 gram sample. So, we have to divide it 37.5 by 12 the molecular weight of carbon say 12 so that is equal 3.125 moles we are getting and then 8.8 by 1 for hydrogen say 8.8 moles we are getting. So, for oxygen 27.6 divided by 16 so we are getting 1.725 and then nitrogen .4 divided by 14 we are getting .0286 moles and for sulphur .10 divided by 32 so we are getting .0031 moles and for moisture 20.5 divided by 18 we are getting 1.139 moles and for ash 5.1 divided by 56 it is given the molecular weight of ash is 56 so we are getting 0.091 moles.

Now this moisture will contribute hydrogen and oxygen H_2O so it will also having hydrogen and oxygen so if we want to know the hydrogen and oxygen content in moisture then we can say oxygen from the moisture is the same if one mole then oxygen is also one so that is equal to 1.139 moles. But hydrogen that is there are two moles of hydrogen in one mole of moisture. So, that will be 2 into 1.139 so 2.278 moles.

Now we are getting these are the number of moles present in this amount of feed so we can represent the molecular formula as $C_{3.125}$ $H_{8.8}$ $O_{1.725}$ $N_{0.0286}$ $S_{0.0031}$ ash is equal to 0.091 and H_2O 1.139 as you are getting here or if we use this, replace this moisture in terms of oxygen and hydrogen then we can get this formula where these are same only hydrogen and oxygen coefficients are changed.

So 8.8 so the 2+2 into 1.139 so 11.079 and for oxygen 1.725 + 1.139 so that is equal to 2.864. So, these are the molecular formula of the peat sample.

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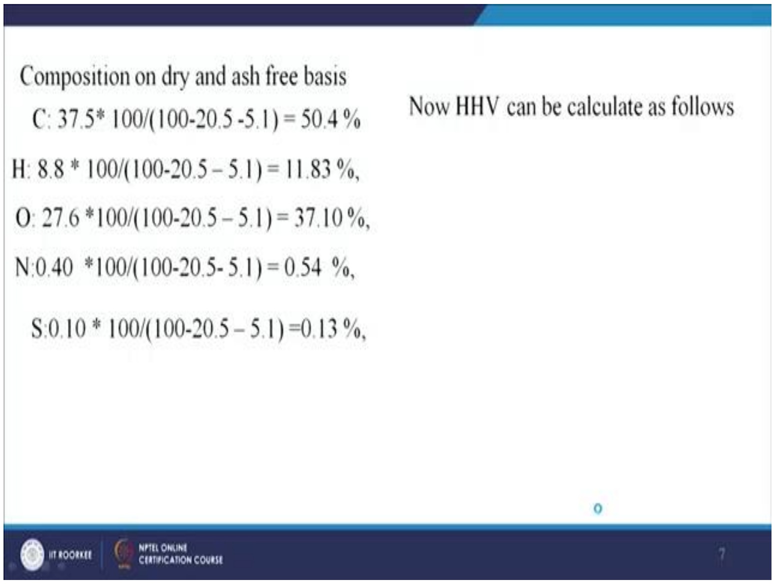

So, first part one part of the first question is done then we will see the heating value. So, if we want to see the heating value we have to in two different bases as such we can calculate the wet basis using the same composition provided in the statement otherwise you have to convert it into the dry and ash free basis then we will use the compositions of different elements in the HHV calculation expression.

So here we see compositions on dry and ash free basis, carbon we have 37.5 original sample so in dry and ash free basis that 37.5 into 100 divided by 100 - moisture – ash, so there is a 100 – 20.5 – 5.1 so this expression is giving us 50.4%. So, 50.4% carbon on dry and ash free basis. Similarly hydrogen we will be getting 8.8 into 100 by 100 – 20.5 – 5.1 that is equal to 11.83%.

So, similarly oxygen is 37.10% and nitrogen is 0.54% and sulphur is 0.13%. Now we are getting the composition of different elements in dry and ash free basis, then what will be the HHV?

If we want to calculate the HHV on dry and ash free basis this composition will use but if we want to calculate this on wet basis we will be using the composition of this which is originally available in this case. So, what will be the HHV in case of dry and ash free basis we will put this the expression is given this is the expression in this expression C is the percentage of carbon, H is the percentage of hydrogen, oxygen is the percentage of oxygen, N is percentage of nitrogen and S is percentage of sulphur.

So, HHV 0.3516 into 50.54 and then 1.16225 into 11.83 and then 0.1109 into oxygen that is 37.10 we are putting here and + 0.0628 into nitrogen that is 0.54 we are putting here and then 0.10465 into sulphur that is .13 so this much. So, we are getting by calculation HHV is equal to 27.40 mega Joule per kg dry and ash free basis. But if we want to get it on wet basis that will be 37.5 for carbon this is for hydrogen, this is for oxygen and this is for nitrogen and this is for sulphur.

So we are getting 20.387 mega Joule per kg so this is wet basis and this is dry and ash free basis. So, first part of the problem is solved now we have to see what will be the composition of the syngas. So, for that will be assuming the expression generalized expressions which is used to represent the gasification of some carbonaceous feedstock.

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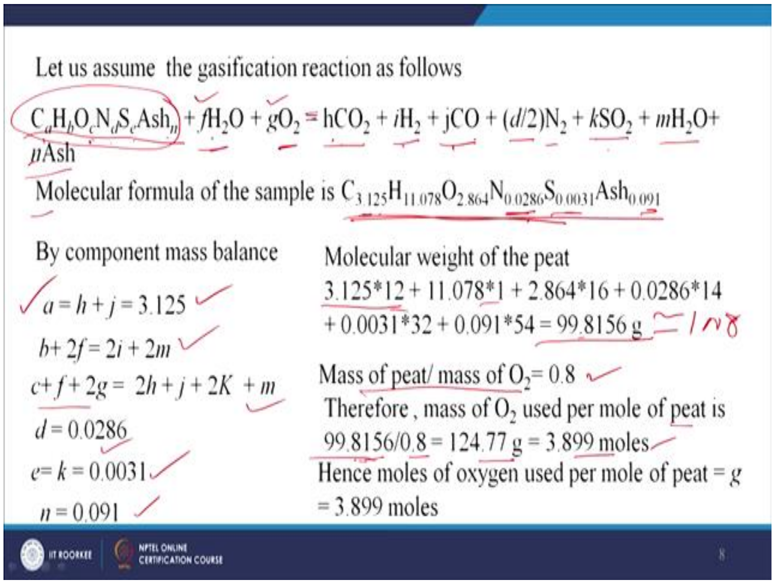

Here we see $C_aH_bO_cN_dS_eA_sh_n$ this is the general formula of the peat sample then it will be reacting it gasifying agents one is oxygen another is steam. So, we are assuming that one mole reacts with g mole of oxygen and f mole of H_2O. So, this is the expressions we are resuming and it will give us h mole CO_2, i mole H_2, j mole of CO, d by 2 mole of N_2, k mole of SO_2 and m mole of H_2O and n mole of ash.

Now we have molecular formula we have just derived let us see this one now if we compare this and this then we can get the value of a, b, c, d, e and n and from this we are getting h, i, j, d by 2, k, m, n and we also using g and f so there is some relationship we will be trying to find out the relationship by mass balance individual component balance and then we will try to get the value of h, i, j, d, k, m, n, f, g etcetera and we will be able to know one mole of feedstock will produce how many mole of this gas composition.

So, it will be easy to determine the individual gas components the moles of individual gas components and total gas components will give total moles then we will get the percentage of individual gas component on mole basis so this is the approach. Now let us see so if we compare this so what we are getting, a, carbon balance here a is equal to h + j so a is equal to h + j again this a is equal to 3.125.

So this a equal to h + j equal to 3.125 now hydrogen balance if we see so left side is b so b + 2f left side expression b + 2f and this is equal to 2i + 2m so 2i + 2m so this is equal to the expression by hydrogen balance. Then for oxygen balance here we are getting c + f + 2g left hand side, right hand side 2 h + j + 2 k + m this we are getting and for nitrogen balance here left side is d and right side is d by 2 into 2 that is d so both side matching and this d value is equal to this one.

So 0.0286 and then e is equal to sulphur balance so left side is e right side is k so e is equal to k and that value we can get from the sulphur .0031 and then here we are getting left hand side n for ash and here also getting n for ash so both will be same so n we are getting the value is equal to 0.091. Now some of the coefficients value we have come to know, the rest we have to know, for that let us see the molecular weight of this so we will put the molecular mass of this and we will be getting 99.81 that is equal to say 100 gram we assumed that previously that 100 gram samples we are getting now.

Now mass of peat by mass of oxygen it is given that is equal to 0.8 the problem statement says and if this then mass of oxygen used per mole of peat is equal to 99.8156 divided by 0.8 so this gram there is equal to 124.77 divided by 32 so it will come 3.899 moles, so mass of oxygen used per mole of peat is equal to this much hence moles of oxygen use per mole of peat that is equal to 3.899 moles that you can calculate.

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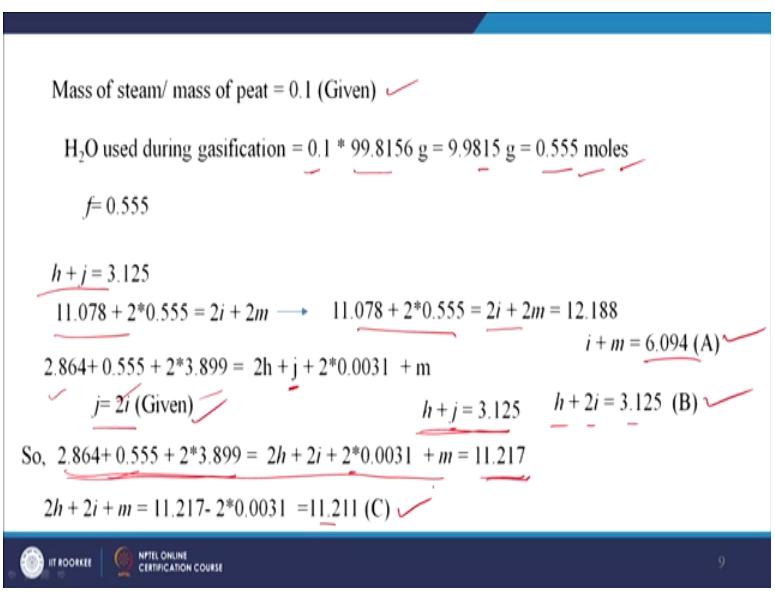

Then another information is also given in the problem statement that we will consider here that is mass of steam by mass of peat 0.1 it is given so H_2O use during gasification equal to how much? H_2O is giving the steam so that is equal to 0.1 into how much peat we have used 99.8156 so that is giving us this gram and 0.555 moles divided by 18 so it will be this gram to moles conversion. Then this steam was used for the reactions so we had some expression there f so this f was used for the gasification.

Now we are able to get the value of f so the value of f is given here that is 0.555 and also you have seen that h + j is equal to 3.125 and h and j value now we will use this formula b + 2f equal to 2i + 2m so if we put the value of b, b is equal to how much we are having 11.078 and then f we have calculated and then we will put here we will get the value of 2i + 2m so that that is done here h + j is equal to this much so b and this equal to 2i + 2m.

So this equal to this much 2i + 2m if we add this so 12.188 so i + m is coming 6.094 we are marking it as expression A. Then another expressions we had this one c + f + 2g is equal to 2h + j + 2k + m we will use this formula now we have get the value of c, f and then we have get the value of h we have got the value of c, f and now we will try to get the other values so, here this c f and this one and this equal to this. So, this other values are known.

Again we see here h + j this one and j value is also here i and j that relationship is also given that is j is equal to 2i CO and H2 ratio is 2 so j is equal to 2i it is given in the syngas. So, in this expression h + j equal to 3.125 can be this j can be replaced by i so h + 2i equal to 3.125 so this expression we are giving as B and which we have got here this expression that is equal to 11.217 by this time left hand side we are getting by addition of this 11.217.

So, we can get 2h + 2i + m is equal to 11.217 - this one 2 into 0.0031 so that is equal to coming equal to 11. 211 so we are marking it as C so we are getting some new expressions.

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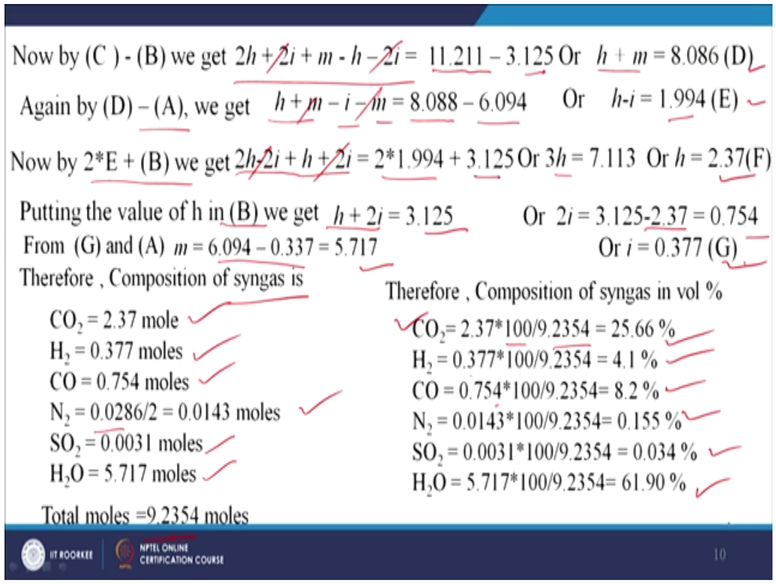

Then by C - B we can get this expression 2h + 2i + m - h – 2i so we will be putting the value of this expression so then the right-hand side of C and B so this is equal to this, so h this i, i is cancelled so h + m is equal to 8.086 is another expression we are getting. Again another operation if we do D minus A then we can get h + m - i - m that is equal 8.088 – 6.094 so this divided this - this is equal to this one and here again m cuts so h + h - i is equal to this one another expression we are giving that E.

Another step if we follow the 2 into E + B then we get this + this equal to this + this or 2i 2i cancel 3h equal to this one h is equal to 2.37. So, another expression you are getting that is equal to F. So, putting the value of h the value of h in B we get h + 2i equal to this one or 2i equal to this minus the value of h that is 2.37 that is equal to 0.754 so i is equal to divided by 2, so 3.77 that is another expression we are giving at G.

Now from G and A we can get m is equal to this minus this equal to this one. So, now we have got the value of all the coefficients. So, on the basis of those coefficients we are getting the composition of syngas that is CO_2 is equal to 2.37 mol and H_2 is equal to 0.377 moles CO is equal to 0.754 mole nitrogen is equal to this divided by 2 so 0.0143 moles SO_2 is 0.0031 moles H_2O 5.717 moles so total moles if we get that even 9.2354 moles.

So what will be the percentage? Percentage of CO_2 that is equal to 2.37 into 100 divided by

9.2354 so it is becoming 25.66%. Similarly for hydrogen it will be 0.377 into 100 divided by 9.2354 so it is coming 4.1% so for carbon monoxide 0.754 into 100 divided by 9.2354 that is equal to 8.2%. Similar way we can calculate the percentage of nitrogen as 0.155% and SO_2 as 0.034% and H_2 as 61.90%. So these are the percentage of different components in the syngas.

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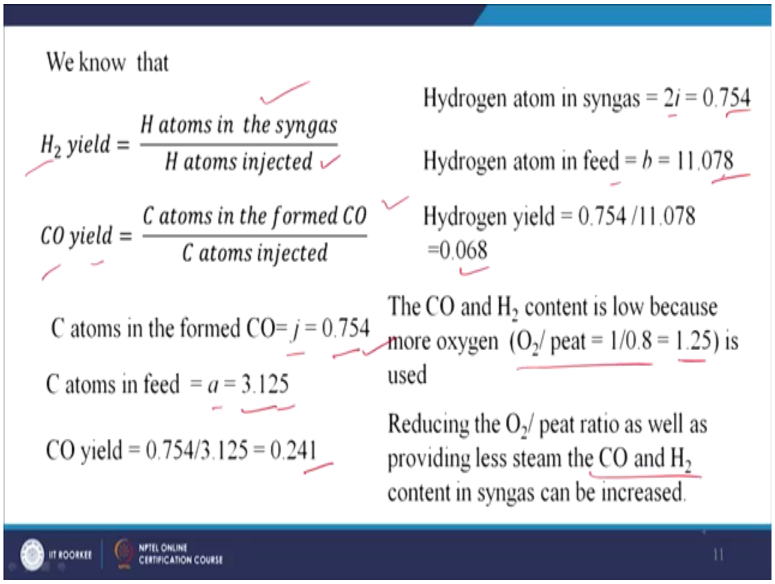

Then the third part we have to solve that is the hydrogen yield and carbon monoxide yield so what is the definition of hydrogen yield? Hydrogen yield we know that amount of hydrogen present there are hydrogen atoms in the syngas divided by hydrogen atoms injected in the feed. So, carbon monoxide yield is equal to carbon atoms in the formed CO divided by carbon atoms injected. See in this case what is the carbon atoms formed that is CO the moles of CO that is equal to j that is equal to 0.754 we have got.

And then carbon atoms in feed equal to how much it was given a that is 3.125 so what is the CO yield that is this divided by this so 0.241 and for hydrogen what is the hydrogen atom in syngas equal to 2i that is 0.754 and hydrogen atom in feed equal to b that was 11.078 we have calculated and then hydrogen yield equal to this divided by this so it is coming is equal to 0.068 but this yield are not very high.

The CO and H_2 content is low because more oxygen you see in this case the oxygen by peat was 1.25 or peat by oxygen was .8. So, it is in the higher range .68 it is a typical value we had discussed in case of coal or gasification here it is .8 so more oxygen is provided so CO is converted to CO_2 that is why we are getting here less CO and H_2 and then reducing the oxygen by peat ratio as well as providing less steam the CO and H_2 content in syngas can be increased. So, now the whole problem is solved.

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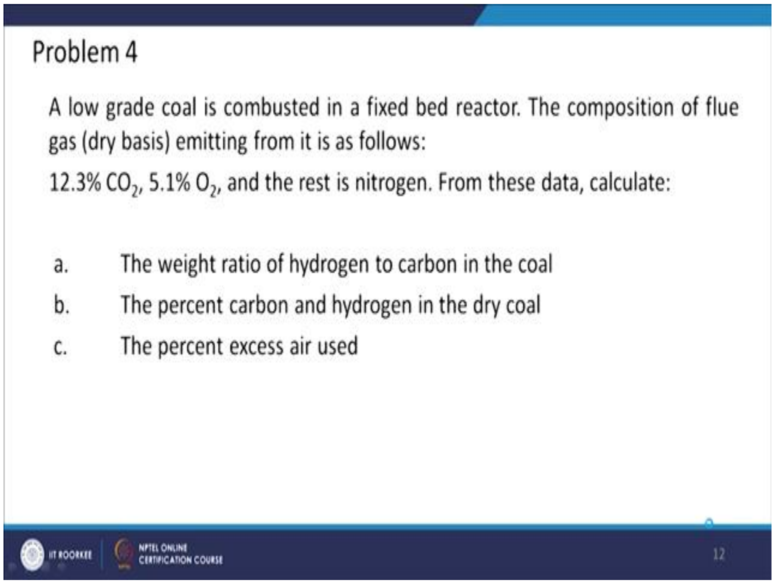

Now problem number 4 the statement says that a low grade coal is combusted in a fixed bed reactor. The composition of the flue gas on dry basis emitting from it is as follows: So, 12.3% CO_2, 5.1% O_2 and the rest is nitrogen, so from this data calculate the wet ratio of hydrogen to carbon in the coal, the percent carbon and hydrogen in the dry coal and the percent excess air used. So, here the flue gas composition is given.

So what happens in case of combustion the steam is produced and which is also available with the flue gas. So, that flue gas after cooling, the moisture is reduced that is that is present in dry basis. So, dry basis that composition is given here basically CO_2 and oxygen and rest is nitrogen. So, these are a simplification case we have it is given here other impurities are not considered. So, on the basis of this information you have to calculate how much CO and hydrogen ratio was present in the original feedstock? And what percentage of excess air was used?

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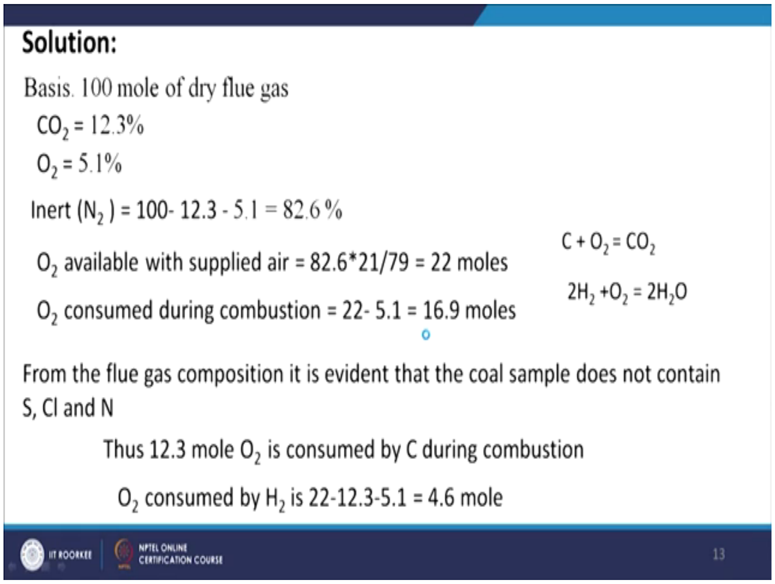

Now let us solve it so we are taking 100 mole of dry flue gas, this is our basis then what will be the CO_2 as it is 12.3% and O_2 5.1% so this 12.3 moles and 5.1 moles it will be an inert will be rest of it. So, 100 – 12.3 – 5.1 that is equal to 82.6% so 82.6 moles will be so oxygen available with supplied air that is equal to how much 82.6 so we are assuming that 21% oxygen rest is nitrogen so this into 21 divided by 79.

So 22 moles, so 22 moles of oxygen is supplied and that oxygen will react with carbon dioxide and that will react with that oxygen will react with carbon and for produce CO_2 and this will also react with hydrogen and from H_2O as per these expressions. So, oxygen consumed during combustion equal to how much where we had 22 moles and now we are having 5.1 moles so this difference the 16.9 moles were used during combustion through these two reactions.

Two types of reactions took place then from the flue gas composition it is evident that the coal sample does not contain sulphur, chloride and nitrogen. Thus 12.3 mole of O_2 is consumed by carbon during combustion as per this expressions so one mole one mole so 12.3 mole oxygen is consumed by carbon. Similarly oxygen consumed by hydrogen equal to 22 – 12.3 – 5.1 so 4.6 mole.

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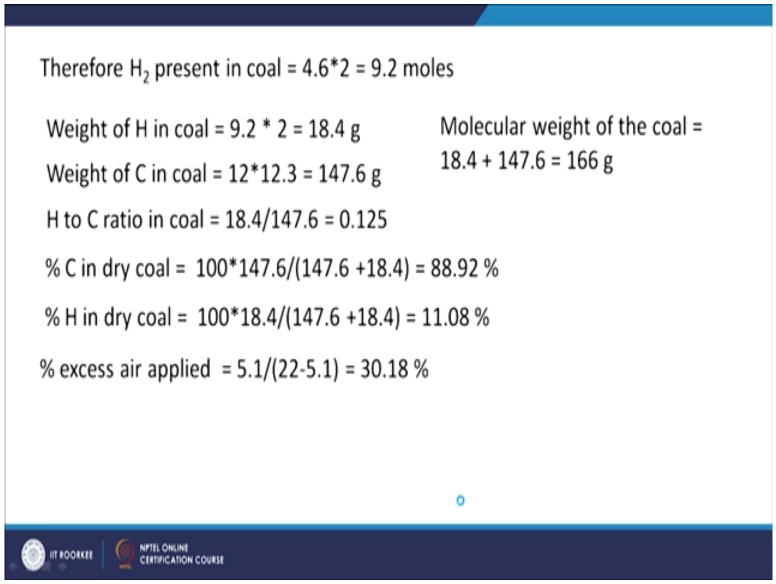

Now hydrogen present in coal equal to how much? Because this 1 mole of oxygen is consumed by 2 mole of hydrogen. So, 2 mole of hydrogen is present on each so 9.2 moles weight of hydrogen in coal equal to 9.2 into 2 molecular weight of hydrogen 18.4 gram weight of carbon in coal equal to how much 12 into 12.3 moles that is equal to 147.6 gram so weight hydrogen to carbon ratio in coal so 18.4 by 147.6 that is equal to 0.125 and the percentage carbon in dry coal that is equal to will just convert it this 147.6 divided by 147.6 + 0 + 18.4 into 100.

So, this is the percentage basis this much and hydrogen will be how much this is hydrogen18.4 divided by this into 100 so that is 11.08% and excess air supplied equal to how much we 5.1 moles and total how much we have supply it that is 22 and what was used 22 – 5.1 so that was the required amount. So, what is excess percentage 5.1 divided by this one is these will be 30.18% okay. So, now we have solved all the problems on this tutorial, so thank you very much for your patience.