Technologies for Clean and Renewable Energy Production
Prof. Prasenjit Mondal
Department of Chemical Engineering
Indian Institute of Technology-Roorkee

Lecture-05
Tutorial 1

Hi friends. Now, we will have a tutorial class and in this class we will solve some numerical problems based on the topics discussed in the last 4 classes.

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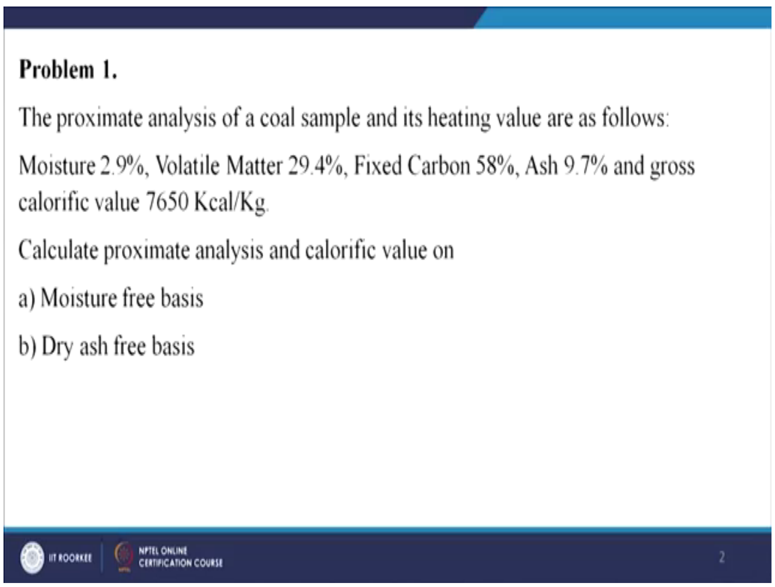

Our first problem statement is; the proximate analysis of the coal sample and its heating value are as follows. Moisture 2.9%, volatile matter 29.4%, fixed carbon 58%, ash 9.7% and gross calorific value 7650 kilo calorie per kg. Calculate approximate analysis and calorific value on moisture free basis and dry ash free basis. So, this is the problem statement. So you have to calculate approximate analysis and calorific value under 2 conditions. One is moisture free and dry ash free basis. It is given the moisture, volatile, fixed carbon, so all the proximate analysis values are provided on as received basis. So you have to convert it to moisture free basis and dry ash free basis and accordingly the calorific value also, you have to convert.

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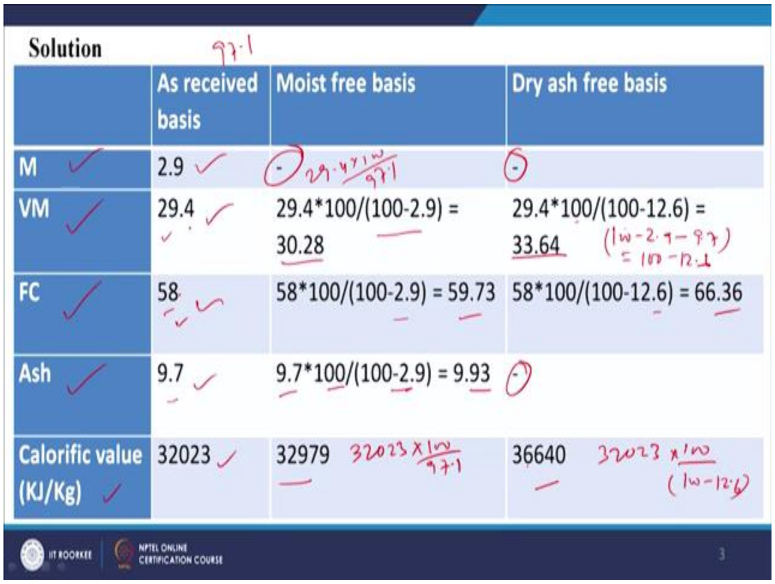

Solution

	As received basis	Moist free basis	Dry ash free basis
M	2.9		
VM	29.4	29.4*100/(100-2.9) = 30.28	29.4*100/(100-12.6) = 33.64
FC	58	58*100/(100-2.9) = 59.73	58*100/(100-12.6) = 66.36
Ash	9.7	9.7*100/(100-2.9) = 9.93	
Calorific value (KJ/Kg)	32023	32979	36640

Let us see, we have different compositions; moisture, volatile matter, fixed carbon ash and calorific value as received basis. It is given in the statement. Now if I want to convert these values in moisture free basis that means we are excluding the moisture. So, this moisture will not be available in this case. So, how much we are having total mass will be this one; out of a 100 we will be having a 100 - 2.9 so 97.1.

For the moisture free basis, volatile matter will be 29.4 x 100 / (100- 2.9) = 97.1. So that is equal to 30.28 and similarly fixed carbon will be 58 x 100 / (100 - 2.9) = 97.1 that is equal to 59.72 we are getting here. Similarly ash content will be this into this divided by this, and what will be the calorific value? Calorific value is equal to 32023 into how much? 100 divided by 97.1.

So this is equal to 32979 kilo Joule per kg. This is for moisture free basis. Now for dry ash free basis, we will not be having moisture, will not be having ash, so you are getting this + this, so in this case, volatile will matter will be 29.4 into 100 divided by 100 minus, this is 100 – 2.9 – 9.7, so that is equal to 100 – 12.6, that were getting, so that value is converting to 33.64, for fixed carbon we are having 58 x 100/ (100 – 12.6) so 66.36.

In order with the calorific value obviously 32023 into 100 divided by 100 - 12.6, that we are getting? 36640 kilo Joule per kg.

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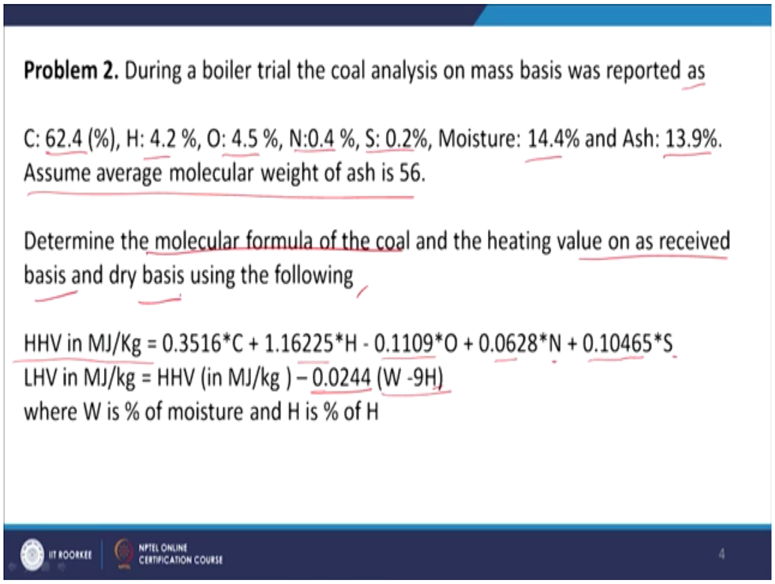

So, the problem is solved now our second problem. It says during a boiler trial the coal analysis on mass basis was reported as carbon 62.4%, hydrogen 4.2%, oxygen 4.5% nitrogen 0.4% sulphur 0.2% moisture 14.4% ash 13.9% and assume average molecular weight of ash is equal to 56 then determine the molecular formula of the coal and the heating value on as received basis and dry basis using the following.

So, these are the relationship, it is given for HHV, that is equal to 0.3516 into C, that is the percentage of carbon, +1.16225 into H, H is percentage of hydrogen and 0.1191 into O, percentage of oxygen, and 0.00628 into N, percentage of nitrogen, + 0.10465 into S, percentage of Sulphur. And LHV in mega Joule per kg is equal to HHV - 0.0244 into W – 9H, W is the percentage of moisture and H is percentage of hydrogen.

It is given, so we have to determine the molecular formula of the coal and the heating value as received basis as well as dry basis.

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Solution

	As received basis	Mass of element (g)	Mol. Wt. of element	Moles	Dry basis
% C	62.4	62.4	12	5.2	72.89
% H	4.2	4.2	1	4.2	4.91
% O	4.5	4.5	16	0.28	5.26
% N	0.4	0.4	14	0.028	0.47
% S	0.2	0.2	32	0.0062	0.23
% Ash	13.9	13.9	56	0.248	16.24
% Moisture	14.4	14.4	18	0.8	

Molecular formula $C_{5.2}H_{4.2}O_{0.28}N_{0.028}S_{0.0062}A_{0.248}(H_2O)_{0.8}$

Then what we will do? Obviously we will write the different parameters on as received basis. So as received basis is the percentage of carbon we are having as per the statement 62.4 then hydrogen 4.2, oxygen 4.5, nitrogen 0.4, sulphur 0.2, ash 13.9 and moisture 14.4 that is in percentage. So, if we assume that a 100 gram of material; so carbon is 62.4 gram, hydrogen is 44.2 gram, oxygen 4.5 gram nitrogen 0.4 gram, sulphur 0.2gram, ash 13.9 gram and moisture 14.4 gram.

Now, what are the molecular weights of the elements? Carbon has 12, hydrogen is 1, Oxygen 16, nitrogen-14, Sulphur 32, ash 56 and H_2O 18. So how many moles are present in this amount of material? Then you can get 62.4 divided by 12 that is equal to 5.2 for carbon. Similarly 4.2 divided by 1 for hydrogen that is 4.2 and for oxygen we are getting 4.5 divided by 16 that is 0.28, for nitrogen we are getting 0.4 divided by 14, 0.028.

And for sulphur we are getting 0.2divided by 32 that is 0.0062 and for ash we are getting 13.9 divided by 56 so 0.248 and for moisture we are getting 14.4 divided by 18 that is equal to 0.8. So these are the moles present in this total 100 gram of the sample. So we can write the molecular formula C 5.2, H 4.2, oxygen 0.28, nitrogen 0.028, sulphur 0.0062 and ash 0.248 and is H_2O 0.8.

Now one part we are getting the molecular formula. Then we have to calculate the heating value both in as received basis as well as in dry basis. So, we have to convert these values, percentage values, from as received basis to dry basis. So, how can you do it? So dry basis means it will not be having any moisture. So here we are getting 62.4 into 100 divided by 100 - this moisture that is 14.4. See it is coming to 72.89 similarly we are getting hydrogen it is 4.2 into 100 divided by 100 – 14.4, so 4.91.

Similarly oxygen will be 5.26 that is equal to 4.5 into 100 divided by 100 - 14.4 and here also will get 0.4 divided by 14.4 and here also sulphur 0.2 into 100 divided by 100 – 14.4 and here will be getting 13.9 into 100 by 100 – 14.4. So these are the dry basis compositions we are getting for different elements.

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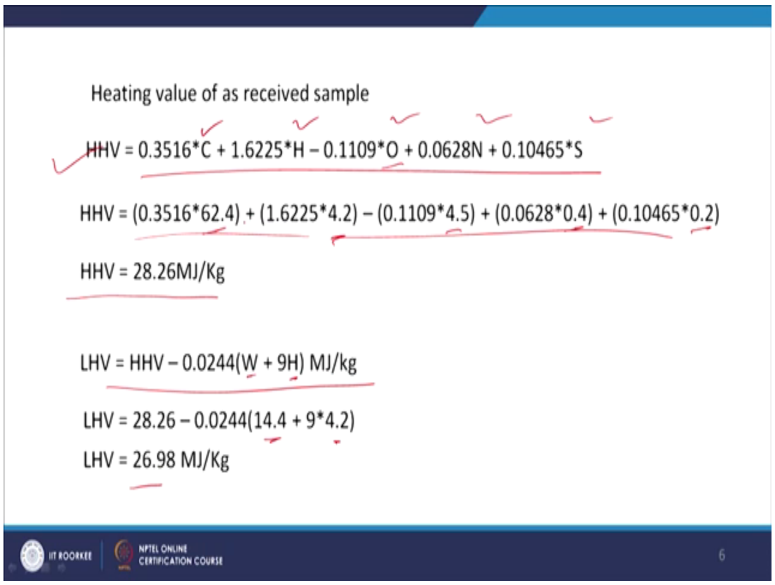

Then what we will do? Heating value we have to calculate so heating value formula is given which is equal to this, formula is given, now we have got the value of C H O N S. So we will put those values C is equal to 62.41 as received basis, hydrogen is 4.2, oxygen is 4.5, nitrogen is 0.4, Sulphur is 0.2. So by this formula, we are getting the HHV is equal to 28.26 Mega Joule per kg and LHV this formula is also given, which is LHV equal to this 28.26 -0.0244 into W, is the moisture content 14.4 and 9 into H equal to 4.2.

So, that we are getting 26.98 Mega Joule per Kg, on which basis as received basis. But if I use this formula on dry basis, this value will change percentage of C, percent of O, percentage of nitrogen, and percentage of Sulphur. So, accordingly our HHV value will also change.

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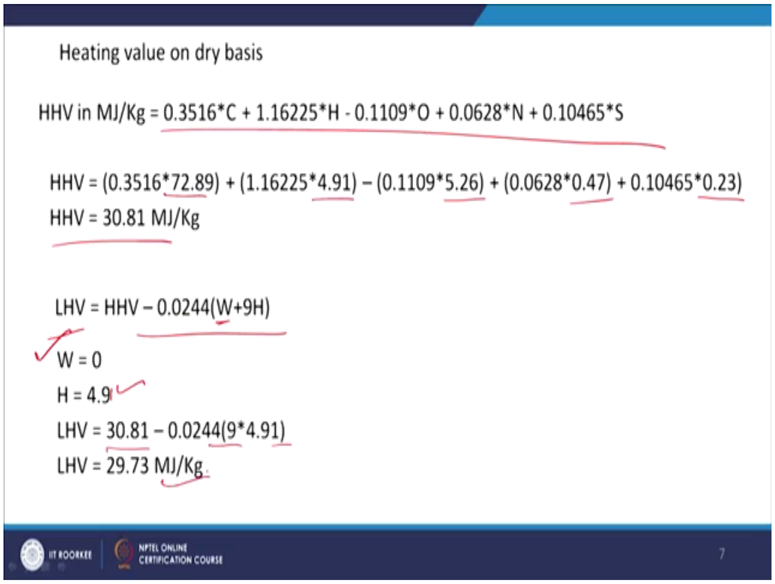

As seen here this is the formula so carbon content is changed to 72.89 so we will put it here hydrogen is 4.91 will put it here and oxygen is changed to 5.21, so we will put it here and hydrogen is 0.47, so we have put here and then sulphur is 0.23 and the value is coming 30.81 Mega Joule per kg and low heating value is equal to? Again we have formula but what is the moisture in this case? It is dry basis.

So we will not have any moisture. So the W equal to 0 and H is equal to 4.9 as it is converted that is 4.9 we can write then LHV is equal to this one, as this one, so it is coming 29.75 Mega Joule per kg. So now we are able to solve the problem. We have determined the molecular formula. We have determined the heating value low heating value and high heating value on the basis of as received basis and dry basis.

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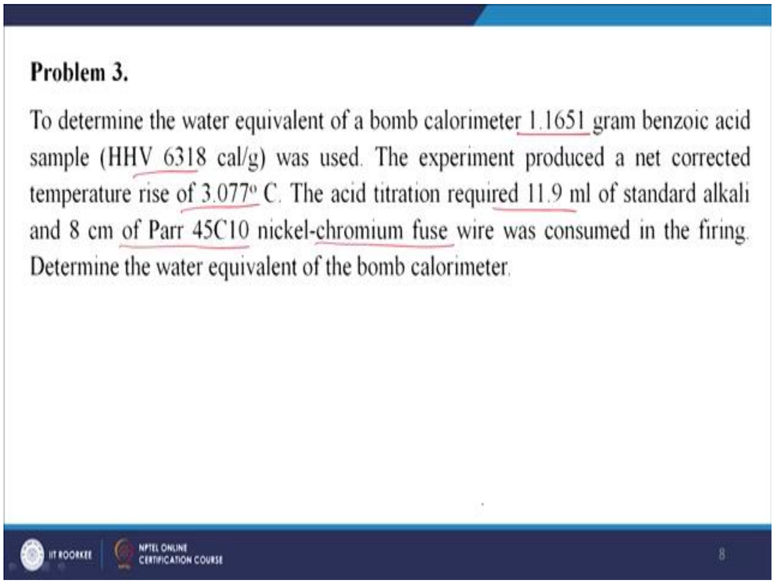

Now, we are coming to problem number three. The statement is; to determine the water equivalent of a bomb calorimeter 1.1651 gram benzoic acid sample high heating value 6318 calorie per gram was used. The experiment produced a net corrected temperature rise of 3.077 °C the acid titration required 11.9 ml of standard alkali and 8 centimetres of Parr 45C10 nickel-chromium fuse wire was consumed in firing. So determine the water equivalent of the bomb calorimeter.

This is our problem statement. So you have to determine the water equivalent of the bomb calorimeter.

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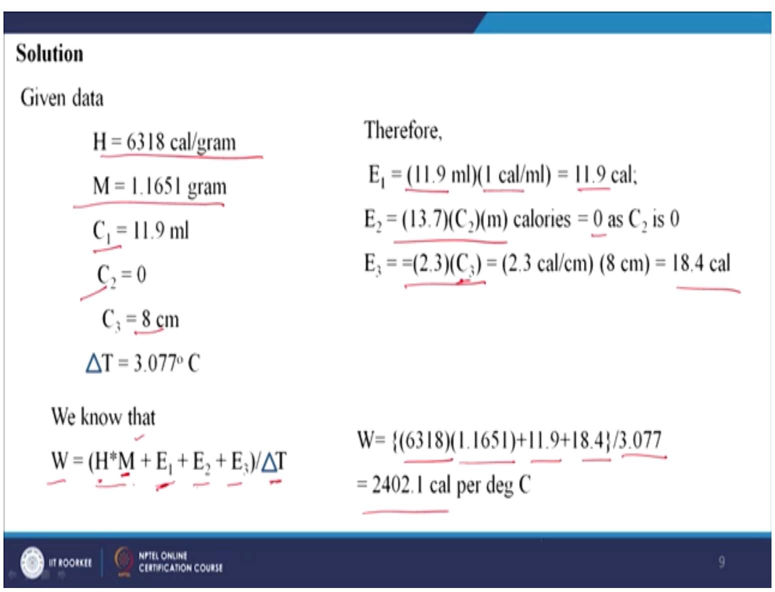

We have some formula that is equal to, water equivalent is equal to high heating value into M mass of sample taken then $E_1 + E_2 + E_3$ divided by ΔT. We have to identify the values of each term in this expression. So what is the H in this case H is given in the statement that is 6318 calorie per gram. What is this M? It is given 1.1651 Gram we have taken it. Then what is E_1? E_1 can be calculated on the basis of C_1. So what is C_1? Alkali, amount of alkali solution required in ml for acid titration, it is 11.9 ml.

So E_1 is equal to 11.9 per ml into one calorie per ml it is 11.9 calorie. Then what will be E_2? E_2 will come from C_2, we have C_2, there is no sulphur as the statement you see here in the statement, there is no sulphur as benzoic used there is no sulphur so that is a C_2 is equal to 0. And then E_2 is equal to 13.7 into C_2 into mass of this. So that is equal to 0 and E_3 is coming from C_3. So 2.3 into C_3 as it is say 45C, we are using 45C10 nickel chromium fuse wire. So for this, expression is applicable, 2.3 into 8 centimetre, it is used so 8 into this, 18.4 calorie.

Now, we have got all those values and ΔT value is also given so what will be the W? This into this one + this one + this one divided by ΔT, so I getting 2402.1 calorie per °C. So this is the water equivalent of the calorimeter.

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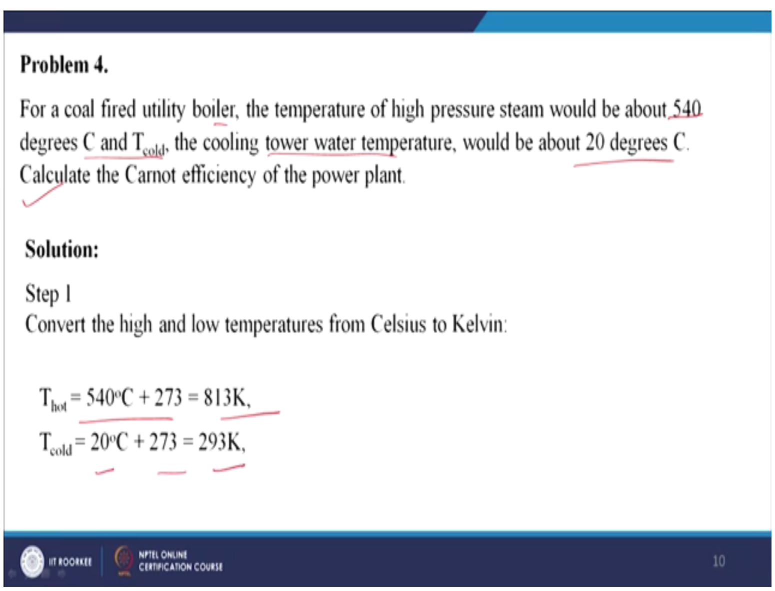

Now our problem statement is for a coal fired utility boiler; the temperature of high pressure steam would be about 540 °C and T cold the cooling water temperature. The cooling tower water temperature would be about 20 degrees Celsius then calculate the Carnot efficiency of the power plant. Very simple, if we see what we have to do, we have to convert this centigrade to Kelvin and then 540 °C converted to Kelvin and 813 and then T cold equal to 20 °C. It is equal to 293 Kelvin.

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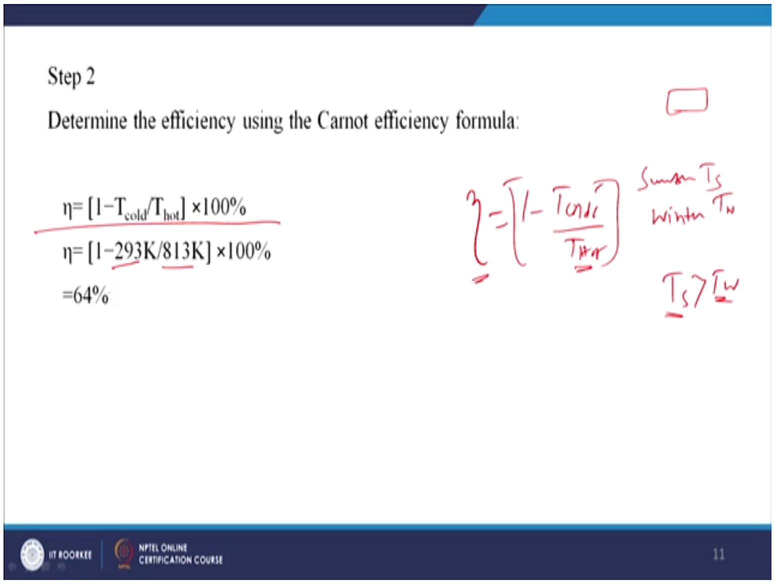

Then what is the Carnot cycle? We have some formula and epsilon equal to 1 – T cold by T hot into 100. So what is T cold? 293, what is T hot? That is a 13 so we will put this value and will getting the 64% efficiency. In this connection , one problem we may discuss here also, that thermal power plant is producing electricity throughout the year, so, in winter and in summer, in which case the thermal efficiency will be higher.

So if we use this equal to 1 - T cold T H hot so as the thermal power plant is the same, technology you are using say boilers a supercritical technology or subcritical whatever may be, T H is fixed. So, efficiency summer T S, T cold that is related to cold that is ambient temperature we are using for this. If it is so T summer and if it is for winter we are getting winter. So Ts is greater than Tw so when TS will put here obviously the efficiency will be lesser and we will put TW here we will get more efficiency then that when you put TS in case of T cold. So, that is why in winter the efficiency will be higher.

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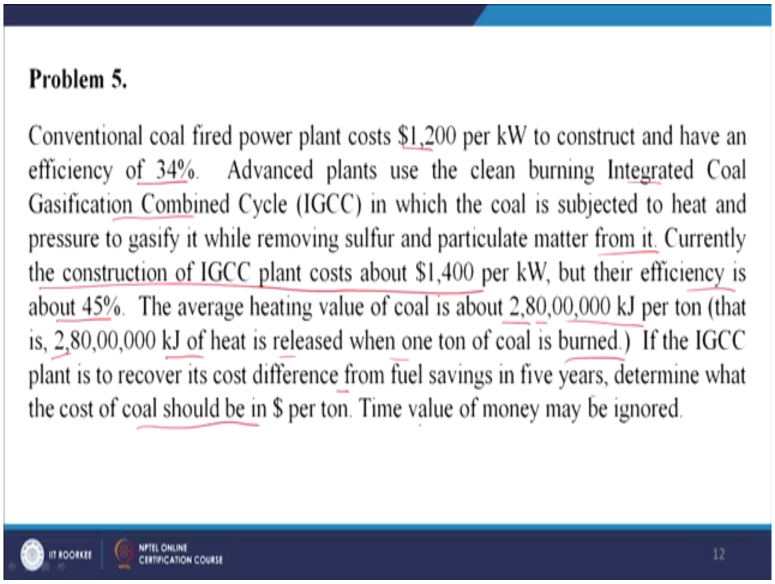

Now the problem statement number 5. Here we have to solve this problem. It is given that a conventional Coal Fired power plant cost dollar 1200 per kilowatt to construct and have an efficiency of 34% advanced plants use the clean-burning integrated coal gasification combined cycle that is called IGCC integrated gasification combined cycle in which the coal is subjected to heat and pressure to gasify it while removing Sulphur and particulate matter from it.

Currently the construction of IGCC plant cost about dollar 1,400 per kilowatt, but the efficiency is about 45%. The average heating value of coal is about 2 crores 80 lakhs kilo joule per ton that is 2 crores 80 lakhs kilo Joule of heat is released when one ton of coal is burned. If the IGCC plant is to recover its cost difference from fuel-saving in 5 years determine what the cost of coal should be in dollar per ton. The time value of the money may be ignored.

So what we have to calculate we have to calculate what will be the price of the coal so that the excess amount of money which is being invested in case of IGCC plant that can be recovered within 5 years period. So, this is the problem, but normally what happens, 5 years means there will be some changes in the value of the currency money also, so that part we know to consider time of value, time value of money may be ignored so that is told.

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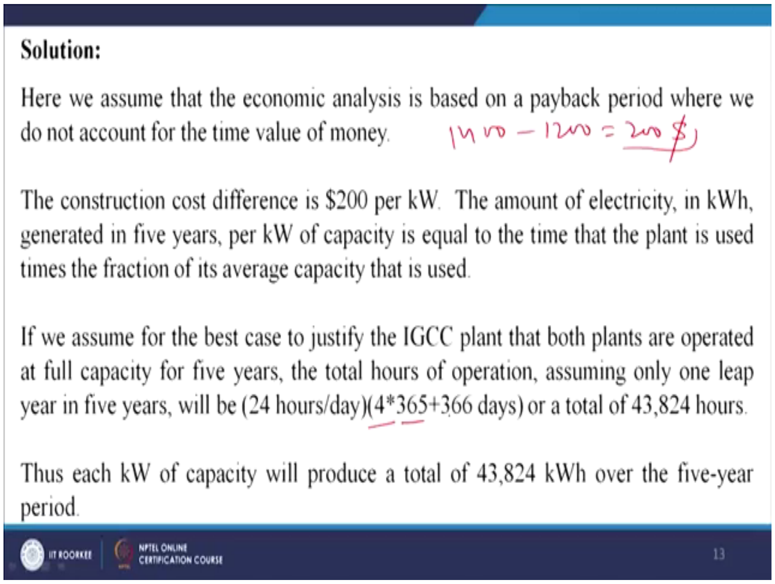

So, now let us see as it is given that we need not to consider the time value, so directly we will consider the time 5 years' time, it is provided. So, what is the construction cost difference the conventional power plant and IGCC that will? We will see as 1400 - 1200, that is dollar 200, dollar 200 costlier the IGCC than the conventional one for 1 kilowatt capacity. So, to 5 years, within 5 years how much electricity will be generated with the capacity of 1 kilowatt? That we can calculate.

Then that much of energy is required in terms of electricity, electric energy. So for that certain amount of heat energy is required that is related to efficiency of the power plant. And then we will calculate that, then that amount of energy is coming from the coal basically, heating value of coal is known. So how much coal is required for both the cases with having different efficiency that will calculate and then on that way that we have to see that the dollar 200 is recovered by the use of IGCC by saving of the power or the production of the more electricity.

So that, what we are going to do; so, what is our first objective? We have to determine how much amount of electricity can be generated with 1 kilowatt capacity for 5 years. So, for 5 years that will also depend in many factors may be the plant is operating with high load or say throughout the year or it may have some breakdown, anything may be, but we will be assuming the full load is there and headed 100% utilization is possible.

So in 5 years, we will be getting 365 days into 4 + 1 leap year so 366 days. So, this 4 into 365+ 366 days into 24 hours that is totally 43824 hours we are getting. So, one kilowatt is running for 43824 hours so total kilowatt hour we are getting 43824. So this is the energy which is produced if the plant is used in full capacity. Now this is the electrical energy which is produced but we have 2 different plants. So one plant is having less efficiency other is having higher efficiency.

So we will be finding out the coal requirement to produce this amount of electricity in 2 different routes to different plants and what will be the coal requirement? How much heat divided by heating value of the coal, how much heat present in the coal? What amount of energy we are using here? Kilowatt hour that is electric energy. So, that equivalent of heat energy you have to get it.

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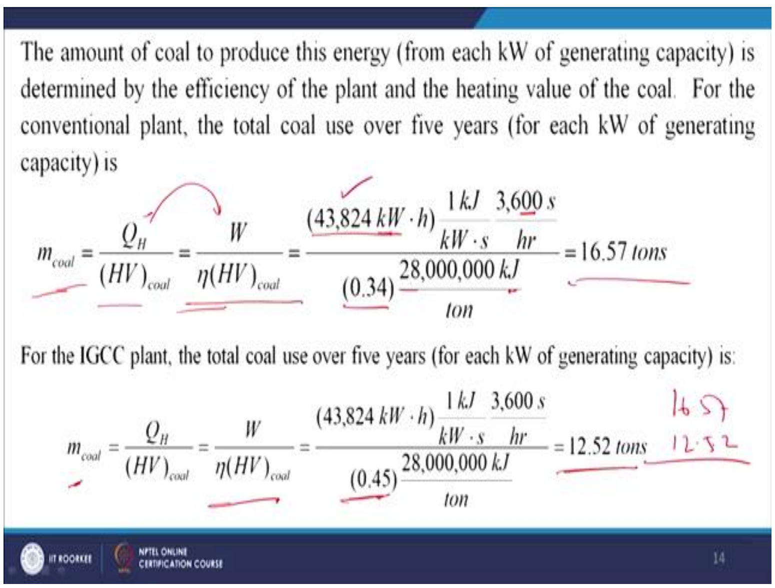

So, mass of coal there is equal to heat energy divided by heating value of the coal. But this Q w has to be correlated with the electrical energy that is related to the efficiency of the power plant so W by efficiency will be in place of Q H now M coal equal to this expression we are getting W by efficiency into H V Coal efficiency for the conventional method is .34 and H V is equal to given 2 crore 80 lakhs kilo joule per ton and then W is also given this much of electricity we produced we need the plant can produce with full load.

So, to produce this amount of electricity we need this amount of coal that is 16.57 tons of coal is required which are the conversion, why this 3600 second? Because you are having kilowatt and Joule it is given in kilo Joule. So watt has to be converted into Joule so that is a joule per second so that hour has been converted to second. So that is 3600 second has been put here? So this is our 16.57 tons we are getting.

But for the second case for IGCC plant. What will be the coal requirement? That is also same formula Q H by H V coal and then W by H into H V Coal, in this case efficiency is .45 other parameters are same so here because of this higher value of this, our coal requirement is less that is 12.52 tons. So, for 16.57 - 12.52 is equal to the coal saved. We are getting by the use of this IGCC plant. So this coal saved means we are using less amount of money that should be equivalent to how much investment we have made for the installation of the IGCC plant.

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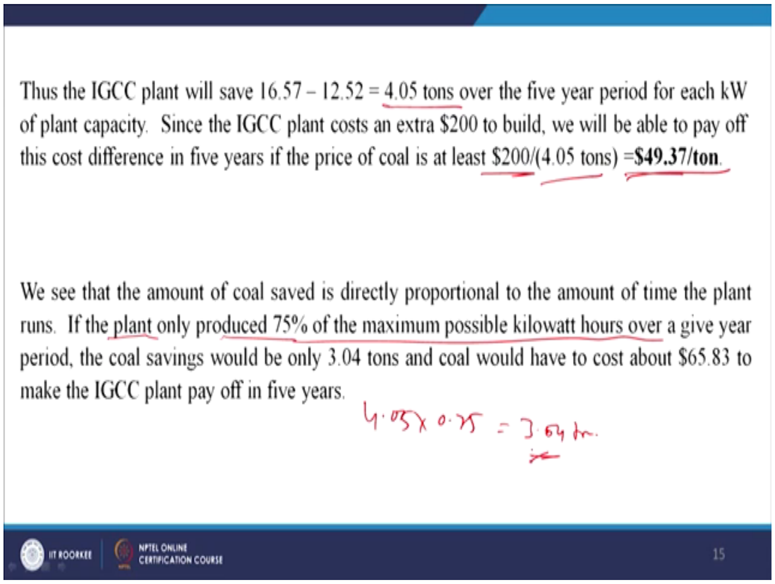

So that is equal to 4.05 tons, of coal can be saved over the 5 years for one kilowatt of plant capacity for one kilowatt of plant capacity. So what will be the cost of it? So, that will be 200 we have to save from this that is the 4.5, 4.05 tons. So, dollar 200 by 4.05 tons that is equal to 49.37 dollar per ton so that was the question which was asked so we have solved it now. Now it can be possible that plant is not running with full load.

So with the; how much efficiently it is running that will vary that will also influence this one. So one another case just I have shown you that is if it is a if the plan only produced 75% of the maximum possible kilowatt hours over a given 5 years then saving will be 4.05 into 0.75 that is equal to 3.04 ton. In this case the dollar 200 has to be recovered from this so 200 divided by 3.04. So price of the coal will be so the price will 65.83 dollar. Okay, so now we have solved all the problems. So thank you very much for your patience.