Power Plant Engineering

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Lecture – 07
Boiler Performance

Hello, I welcome you all in this course on Power Plant Engineering. We have amply discussed about the boilers normal boilers high pressure boilers their mountings and necessaries. Now today we will discuss about the performance of the boiler. Because performance of the boiler is a very important parameter to assess the efficiency of the power plant right and for example, if we if we take a car.

So, before we purchase a car, we assess the performance of the car and the performance of the car is assess how much mileage it is giving per liter how much kilometers it is covering ah. In similar way, the boiler performance is also assessed and there are different parameters to assess the performance of the boiler.

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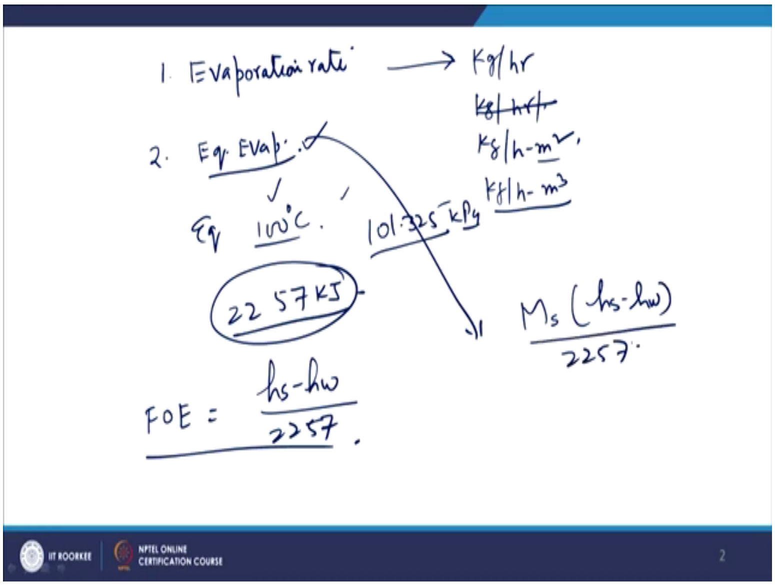

Now, the first parameter is evaporation rate. How much water is getting converted into this? So, there are certain units for evaporation rates for example, this is kg per hour. Now, kg per hour per meter square, kg per hour per meter square; because there are different boilers having different combustion area right. So, if the boiler is larger in size definitely it will producing more steam.

So, in order to neutralize the surface area, the unit is taken as kilograms per hour per meter square or kilograms per hour per meter cube. It is just to normalize the size of the boiler and compare their performance. So, that is one criteria that is known as evaporation rate. Another criteria is, equivalent evaporation equivalent evaporation. Now equivalent evaporation is a little different from evaporation rate. It says that it is how much water equivalent to water available at 100 degree centigrade converted into the 100 centigrade of a steam saturated steam.

How much kgs of water has been converted at 100 which is available at 100 degree centigrade into 100 degree centigrade saturated steam equivalent to that. So, now, this is known as a equivalent evaporation. The pressure will remain in this case 101.325; that is normal atmospheric pressure at the mean sea level. So, one equivalent evaporation is 22 57 kilo Joules.

So, how many equivalent of this is has been done by the boiler that is judged by this parameter equal equivalent evaporation rate. Now, another is factor of evaporation. Factor of evaporation is nothing, but equivalent equivalent evaporation of 1 kg of water. I mean, 1 kg of water it means hs minus hw divided by 22 57. This will give the factor of evaporation factor of evaporation. Now equivalent evaporation is multiplied by the mass of water which is converted into the steam hs minus hw divided by 22 57. Now next one is this is the most important one is boiler efficiency.

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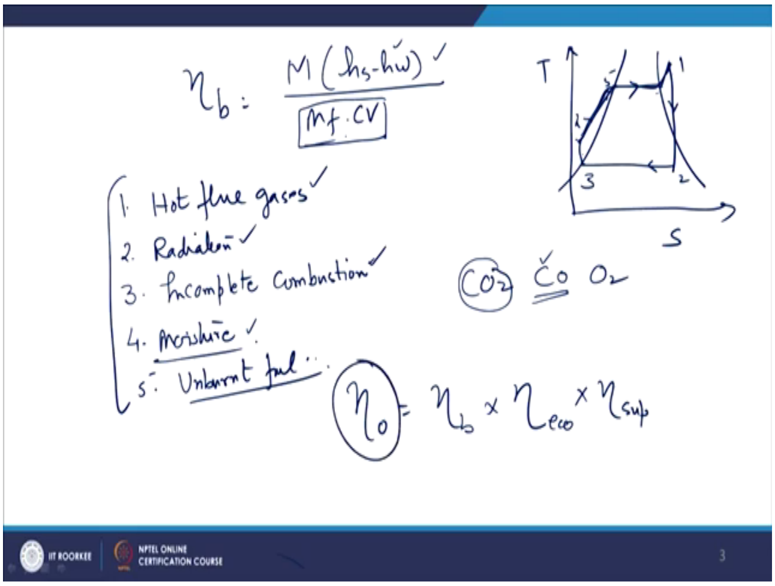

Now boiler efficiency is about how much heat is supplied to the boiler and what part of that heat has been converted into the useful steam. Suppose we are supplying 100 kilo Joules of heat to the boiler or how we are supplying heat we are burning fuel right. When we are burning fuel heat is liberated ideally all this heat should go into this steam I mean all I mean boiler should have a 100 percent efficiency, but ideally efficiency we cannot realize. So, part of the heat is lost, but almost the majority of the heat is it goes with the steam or it is converted into the steam.

So, boiler efficiency is mass of the steam generated; hs minus hw divided by mass of the fuel burn and the calorific value of the fuel. So, mass of the fuel burn means multiplied with the calorific value, if this gives the amount of heat which is liberated in the combustion chamber and this is the amount of heat which is going with the steam. If you look at the temperature entropy diagram for boiler let us take superheated steam. So, this part I mean 1 2 3 4 5.

So, 4 to 5 and 5 to 1. This process takes place inside the boiler. So, boiler get pressurized water that is why it is shown hw pressurize water; because if the condenser the pressure is of the order of 0.1 bar or 0.15 bar right. So, the pressure and the stage 3 is below atmospheric much below atmospheric pressure. It is approximately 0.1 or 0.2 absolute bar of absolute pressure then this water is pressurized up to the boiler pressure. The boiler pressure maybe 40 bar 50 bar and high pressure boiler it is 200 bars.

So, heavy duty pumps are used to increase the pressure of the water and this water when it enters the boiler the heat is added to this water is converted into the steam right. So, this so in order to define the efficiency of the boiler so, how much heat is going with the water and how much heat has been liberated while burning fuel inside the boiler. Now where the remaining heat goes the point is because for every boiler there is a boiler heat balance sheet where from the energy is coming and where to the energy is going right.

So, the heat going in the boiler is first of all it is going in hot flue gases; because when they when burning the boiler the flue gases are generated and the flue gases temperature of the flue gases is not at that atmospheric temperature. The temperature of the flue gases is quite high maybe 200, 300 or 400 degree centigrade. So, this heat which actually the flue gases are generated from the air. Air is used for burning the fuel and after the burning the fuel the flue gases are generated.

So, air which is taking a 25 degree centigrade the gas which is taken in at 25 degree centigrade for burning the fuel the temperature of this gas has increased to 300 or 200 degree centigrade. So, this heat is coming from the fuel. So, part of the heat is taken away by the hot flue gases. Second is radiation from the furnace; because when the furnace is heated 100 percent insulation is not possible though reflective material is used in the wall of the furnace, but 100 percent insulation is not possible right.

So, part of the heat is goes into the radiation. Now, regarding the combustion process also there is a phenomena which is known as incomplete combustion incomplete combustion. Though excess air is provided I mean when we burn the fuel stoichiometric calculations are done and excess air is provided so that no fuel remains unburned.

On the other side, when we are providing the excess air it is also it is got also getting heated up. So, too much excess air will also reduce the efficiency of the boiler. In any case this excess air is provided because the combustion is not homogeneous. In some of the places, excess oxygen will be available and some of the pockets there is the scarcity of the oxygen. So, when we do the I mean flue gases analysis. We get CO 2. We get CO at the same time we get oxygen also right.

So, incomplete combustion is there because CO all the carbon is not converted into the carbon dioxide right. So, some heat is or the some heat value is sacrifice. So, this incomplete combustion also affects performance of the boiler. Number 4 is moisture; moisture in the fuel moisture in the fuel also I mean because the moisture means presence of water in the in the fuel and when this fuel burns this water is converted into this steam and that is wastage of energy. And moisture contained can vary it can vary from 2 percent to 30 percent 3 percent to 30 percent. In fuel handling also a lot of energy spend it is apart from the boiler ok that we can discuss later on.

But regarding the combustion if the boiler also if there is a moisture in the fuel that also reduces the efficiency of the boiler. And next one is unburned fuel. All the fuel is not burnt some of the fuel remains unburned and this unburned fuel also reduces the efficiency of the boiler. So, there are several factors which affect the boiling efficiency of the boiler. So, 100 percent efficiency is not it, but nowadays if the efficiency goes up to 90 percent 85 to 90 percent efficiency has been realized for the boilers.

Now, there is a term for every machine there is a term overall efficiency. Now the boiler also has overall efficiency and overall efficiency is the efficiency of the boiler multiplied by efficiency of economizer. If you remember economizer is used for preheating the water. So, efficiency of the economizer is also important into efficiency of super heater. So, all these efficiencies are multiplied and then we get overall efficiency of the boiler. Now, regarding the performance of the boiler we will solve a numerical that will give us clear cut inside of the phenomena.

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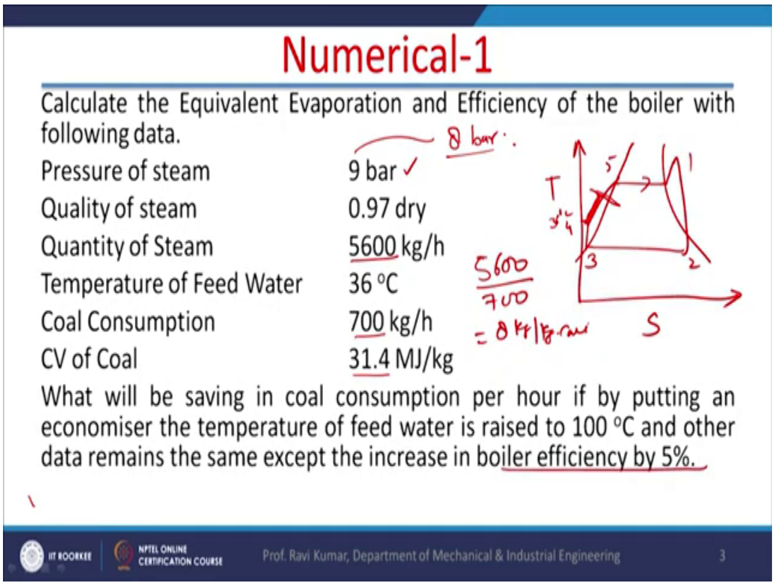

Now the calculate then I will read out the numerical the calculate the equivalent evaporation efficiency of the boiler with following data. Pressure of a steam 9 bar actually in boiler we the display is engaged. So, when we are saying pressure of the steam 9 bar, here it is because it is not mentioned we are considering it to be a absolute pressure otherwise it would have been 8 bar gauge if atmospheric pressure is 1 bar. Quality of the steam 0.97 dry quantity of the steam it is 5,600 kgs per hour.

So, this much of water is converted into the steam per hour. Temperature of feed water is 36 degree centigrade is quite high; coal consumption 700 kgs per hour and calorific value of coal is 31.4 mega Joules per kg. Now it is asked what will be the saving in coal consumption per hour if by putting an economizer the temperature of the feed water is raised to 100 degree centigrade. Now if we look at the temperature entropy diagram again a for Carnot cycle. Now as I mentioned earlier.

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Ok, if you look at this Rankine cycle, in the Rankine cycle the temperature entropy diagram the water is supplied to the boiler at this temperature. So, this temperature is 36 degree centigrade, but here the temperature is raised to 100 degree centigrade. So, it must be somewhere here because 9 bar saturation temperature will be quite high it will not be 100 degree centigrade. So, in economizer the preheating is there. So, this much heat has been saved in economizer right. Now the water is entering in the boiler at this point and heat is added to the water.

So, how much so, then the data remains the same except the increasing boiler efficiency by 5 percent. So, how much fuel is saved, that we have to judge from here.

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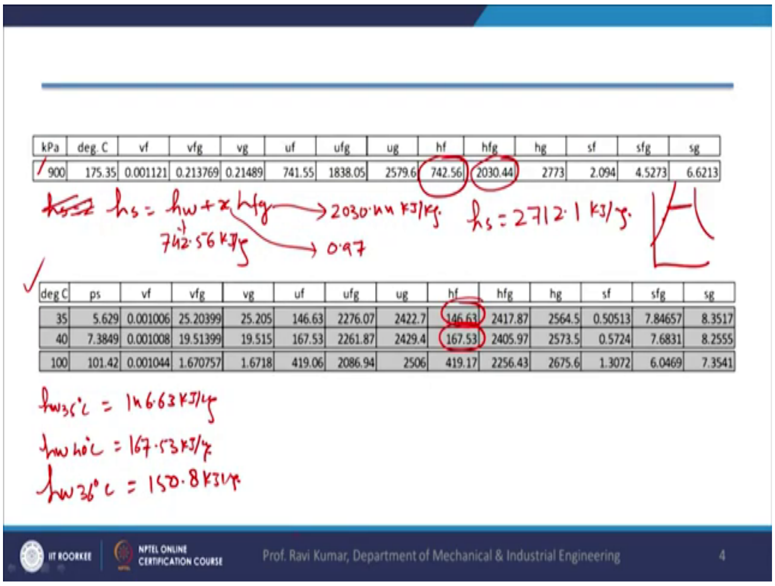

So, now here we will look at the properties of a steam will take the steam table. So, hs that is enthalpy of saturated water enthalpy of saturated water at 9 bar and that 9 bar because here the vapor is not superheated right it is 0.97 dry. So, if we draw the temperature entropy diagram so, the heating is terminated here. It does not go up to the saturation level.

So, heating is terminated here. So, hs is 2030 9 bar 20. This is hfg sorry because the vapor is 0.97 dry. So, h steam is going to be hw plus x hfg. Now hw is hw is this one 742. So, hw is 742.56 kilo Joules per kg this is hw. hfg is 2030.44 kilo Joules per kg. x is already with us 0.97. If you put all these values, we will get the value of hs as 2712.1 kilo Joules per kg.

Now, at 36 degree centigrade at 35 because in the steam table we have this is saturation steam table temperature based. So, the water temperature this is hw 1 is this one. So, at 35 at 35 degree centigrade it is 146.63 kilo Joules per kg; hw 40 degree centigrade is equal to 167

167.53 kilo Joules per kg. By linear interpolation we will get hw 36 degree centigrade as 150.8 kilo Joules per kg.

Now, if you look at the yes if you look at the steam generation level quantity of the steam is 5,600 kg per hour and coal consumption is 7 kg per hour. It means 8 kg of the steam is produced by 1 kg of coal; because if you divide this 5,600 divided by 700 you will get 8 kg per kg of coal right.

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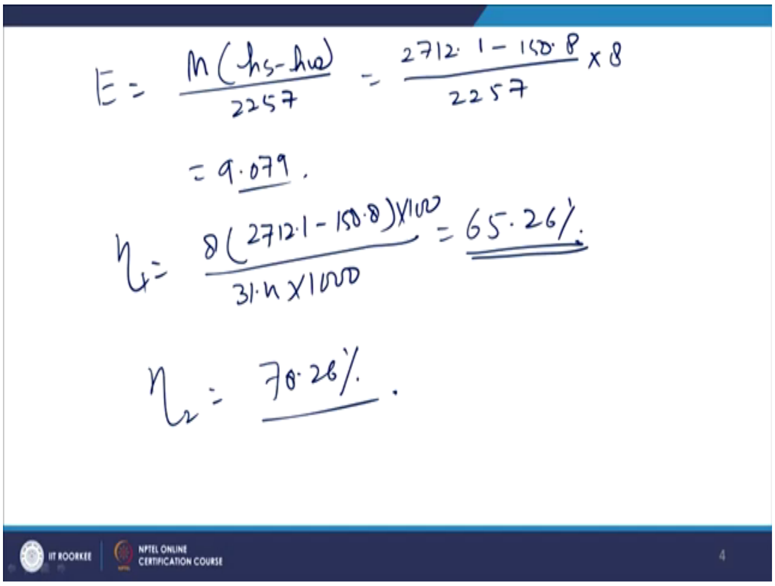

So, if you want to calculate the equivalent evaporation, equivalent evaporation. Equivalent evaporation is going to be mass of the steam produced per kg of coal hs minus hw divided by 22 57 it is going to be equal to 2712.1 minus 150.8 divided by 22 57 multiplied by 8 and it is going to be equal to 9.079. This is equivalent evaporation.

Now we are concerned with the efficiency because by putting economizer the efficiency is improved by 5 percent. So, efficiency can also be calculated as this will take the same terms m multiplied by hs minus hw. So, 8 multiplied by 2712.1 minus 150.8 divided by energy added 31.4 calorific value of coal per kg of coal. So, here 31.4 multiplied by 1,000 because it is a mega Joules per kg and when we solve this we get the efficiency at 65.26 percent just to multiply this by 100.

So, this is the efficiency of the boiler without economize right. Now we are putting economizer while a by through economizer the efficiency is improved by 5 percent. So, now, efficiency of this is the n1 let us say this is n 2; it is going to be 70.26 percent. This is the modified efficiency of the boiler. Now once we have modified efficiency of the boiler.

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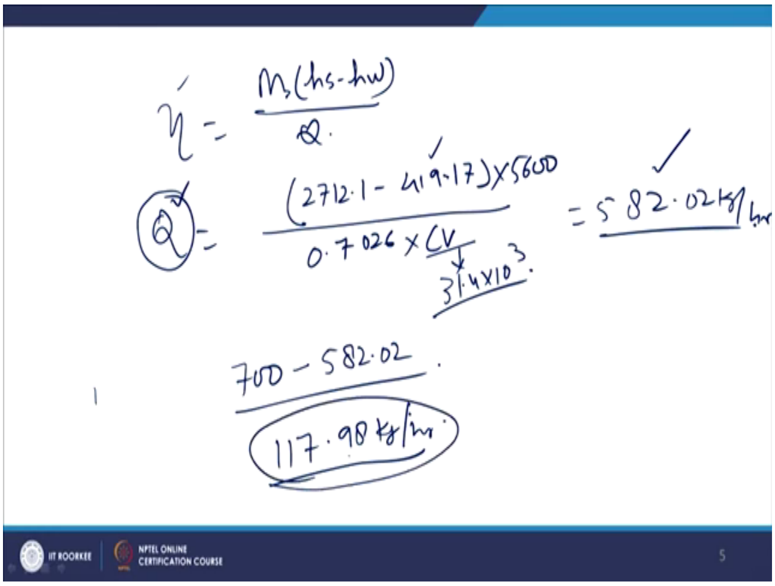

Now, efficiency is equal to mass steam hs minus hw divided by heat supplied. Now we have efficiency with us. We can always calculate the heat supplied.

So, Q is equal to 8 2712.1 minus 419 point 419.17 divided by 0.7026. This is the efficiency multiplied by calorific value, calorific whatever the calorific value is there into 5,600 that is the amount of steam which is generated. So, we will remove this 8. 8 will remove. So, this is the amount of heat which is going with a steam per hour. This is enthalpy of steam and thus enthalpy of water I have taken 419.17.

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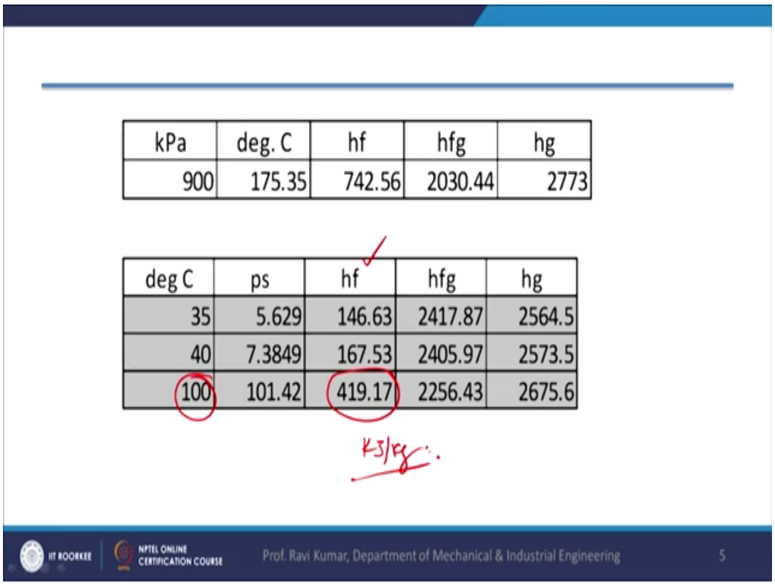

kPa	deg. C	hf	hfg	hg
900	175.35	742.56	2030.44	2773

deg C	ps	hf	hfg	hg
35	5.629	146.63	2417.87	2564.5
40	7.3849	167.53	2405.97	2573.5
100	101.42	419.17	2256.43	2675.6

This I have taken from here. 100 degree centigrade 4917 is the enthalpy of the liquid right.

So, 4197.17 this is kilo Joules per kg. So, this value I have taken because the water is heated it is no longer it is at 35 36 degree centigrade. Now it is at 100 degree centigrade. So, when the hot water is heated we will take the value this enthalpy value of the water which is entering the boiler. This is steam. This is how much steam is convert this is the total amount of heat which is going which is going away with a steam in the boiler. Now, I should I should divided by efficiency right divided by calorific value of the fuel will give you the amount of fuel which is burnt right.

So, calorific value of the fuel is again how much? 31.4. So, this is 31.4 into 10 to power 3; because it is in mega Joules and when we solve this we get 582.02 kg per hour. This is the amount of fuel which is required now. Earlier how much it was? It was 700. Now by improving efficiency of the boiler, it has gone down to 582.02. So, per hour we are saving 117.98 kg of fuel right.

So, here what we have done. First we have calculated the efficiency of the boiler in initial conditions. In modified conditions the feed water temperature has increased 200 degree centigrade and it is given that efficiency by this method efficiency is improved by 5 percent.

So, first we calculated in first case efficiency then added 5 percent and then in for second case we calculated how much amount of heat is added or how much coal is required to be burnt right. So, when we calculated the how much coal is required to be burned, but taking difference of initial requirement and the later requirement we got the saving in the coal.

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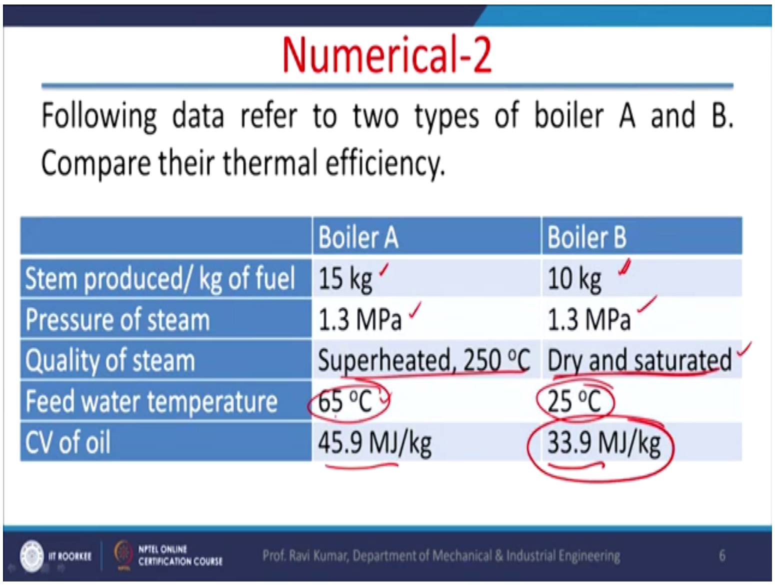

Now, in order to have more understanding of this, we have taken another example. They refer there are 2 type of boilers boiler A because here we are comparing the performance.

So, boiler A a steam produces a boiler A produces steam 15 kg B produces 10 kg. They are altogether different boilers and we have to compare their performance. Pressure of a steam 1.3 mega pressure is same. Now, quality of a steam first boiler is giving superheated steam at 250 degree centigrade right, second is giving dry and saturated steam; feed water temperature is also different here 65 degree 25 degree, calorific value of the fuel is also different. Now we have to compare the performance of these two boilers right and for comparing the performance we have to find the efficiency of the boiler what is the efficiency of the boilers?

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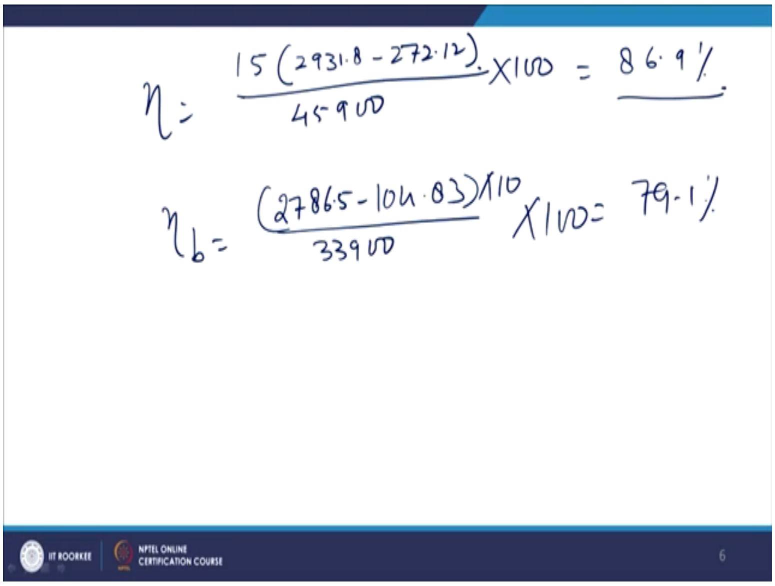

So, now for finding out the efficiency of the boilers again the same formula will be used 15 kg first we let us take boiler 1 it is 15 kg of a steam right and it is 1.3.

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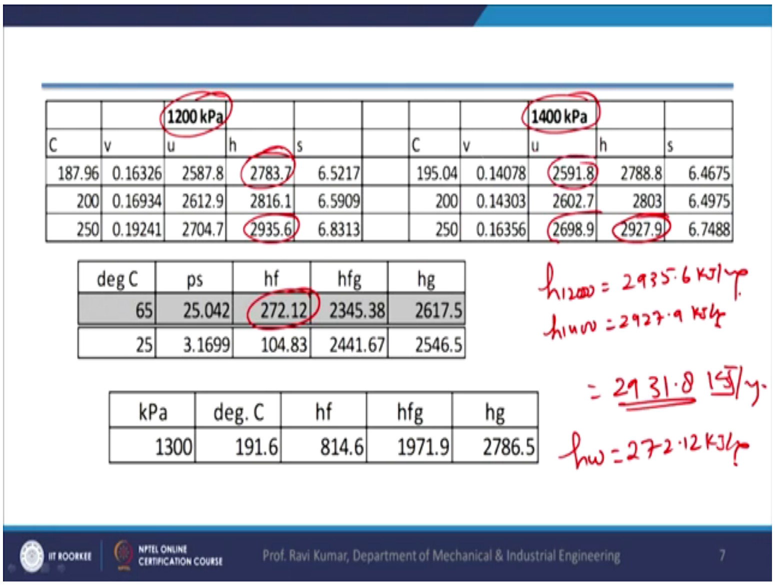

So,1.3 so, we have 1,200 k 12 kilo Pascal properties. We have 1,400 kilo Pascal properties by assuming linear variation we can get 1,300 kilo Pascal properties. And by doing this we get enthalpy of superheated steam for getting enthalpy of superheated steam.

So enthalpy it is 12250 it is 2935. So, h 1200 is equal to 2935.6 kilo Joules per kg 1,400 sorry this 1,400 is equal to 2927.9 kilo Joules per kg. So, if we take average of this because just 1,300 is lying middle of these two it is 2931.8 kilo Joules per kg. So, this is the enthalpy of a steam which is prepared in the boiler. Water is at water is at 65 degree centigrade.

So, 65 degree centigrade water, enthalpy of the water is 272.12 kilo Joules per kg. CO file is this much steam produced 15 kg ok. So, here efficiency of the boiler is going to be 15 multiplied by enthalpy of superheated steam it is 2931.8 and minus enthalpy of the water 272.12 multiplied by 15 divided by 45900. We have multiplied then the calorific value of the fuel by 1,000. This 15 kg of a steam is produced by burning 1 kg of coal right. And this gives the efficiency as usually multiply this by 100, the efficiency is going to be 86.9 percent.

So, this is the efficiency of first case. Now let us take second case. In second case, the steam produces 10 kg per kg of fuel, pressure of the steam is same 1.3 mega Pascal it is dry in saturated right. So, when it is dry and saturated rate at dry in saturated at 13 ok. So, we will take these enthalpies average of these right and water temperature is how much 25 degree centigrade. So, we will take water temperature at enthalpy of water at saturated water at 25 degree centigrade.

It is 104.8 kilo Joules per kg and now we will again calculate the boiler efficiency of the boiler. It will come around 2786.5 that is the enthalpy of saturated water because in second case it is dry and saturated steam not saturated steam; because in second case it is dry and saturated steam and multiply minus enthalpy of saturated water 104.83 divided by 33900. This is calorific value of the fuel right and steam produced is only 10 kg right and you multiply it by 100 you will get efficiency a 79.1 percent.

So, by just comparing the efficiency because here, in this case there are two different operating parameters. In one boiler we are getting superheated steam and another boiler we are getting saturated steam feed water temperature is also different, steam production rate is also different, calorific value of the fuel is also different. But if you want to compare the performance of these 2 boilers we have to take the efficiency of the boiler. So, if we are there other parameters also, but the efficiency is the most reliable and most required parameter to be known about the boiler.

So, we have calculated efficiency of boiler A that is coming around 86.9 percent. Then we calculated the efficiency of the boiler B by taking properties from the steam table and it is coming around 79.1 percent. So, definitely boiler a is better than boiler B as far as the efficiency is concerned, but is the requirement is 15 kg or 12 kg per hour we have no other option, but go for the boilering. That is all for today.

Thank you very much.