Power Plant Engineering
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Lecture - 10
Problem Solving – I

Hello I welcome you all in this course on Power Plant Engineering. Today, we will solve a few numericals to have clear insight of the phenomena; whatever I have told you or whatever I have explained you in the previous lectures.

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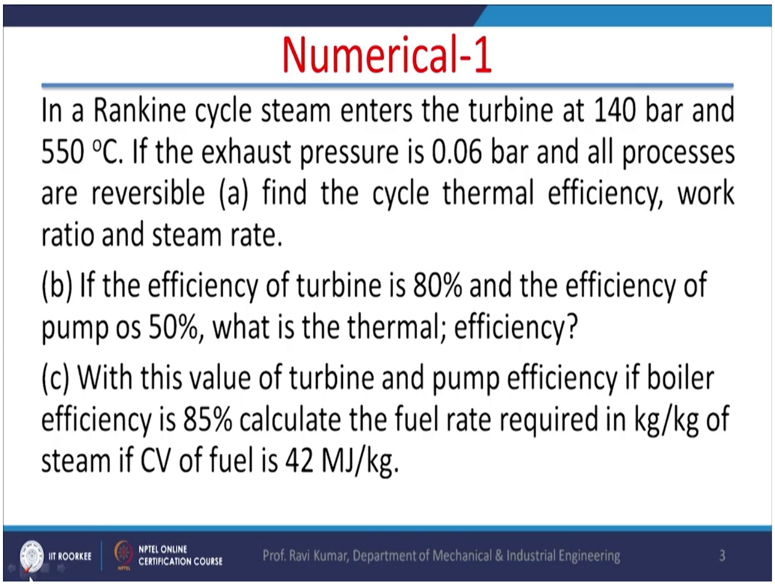

So, we will be today we will be solving some numericals based on the theory which I have explained you earlier.

Now, numerical number 1 it is based on the Rankine cycle. So, in a Rankine cycle the steam enters the turbine at 140 bar and 550 degree centigrade; so obviously, this steam is super heated steam. If the exhaust pressure is 0.06 bar or 6 kilo Pascal; so the vacuum order of the vacuum is very high and all processes are reversible, it is an ideal cycle, find the cycle thermal efficiency, work ratio and steam rate.

Then there is another part if the efficiency of the turbine is 80 percent; so this is not an ideal case; this is a case where efficiency of the turbine is 80 percent and the efficiency of the pump is only 50 percent, what is the thermal efficiency in this case?

Now, third one is with this value of turbine and pump efficiency, if the boiler efficiency is also 85 percent, calculate the fuel rate required in kg per kg of a steam if Calorific Value of the fuel is 42 Mega Joules per kg. So, 42 Mega Joules per kg is typically the calorific value of diesel. So, it is the boiler is oil based the furnace oil based boiler.

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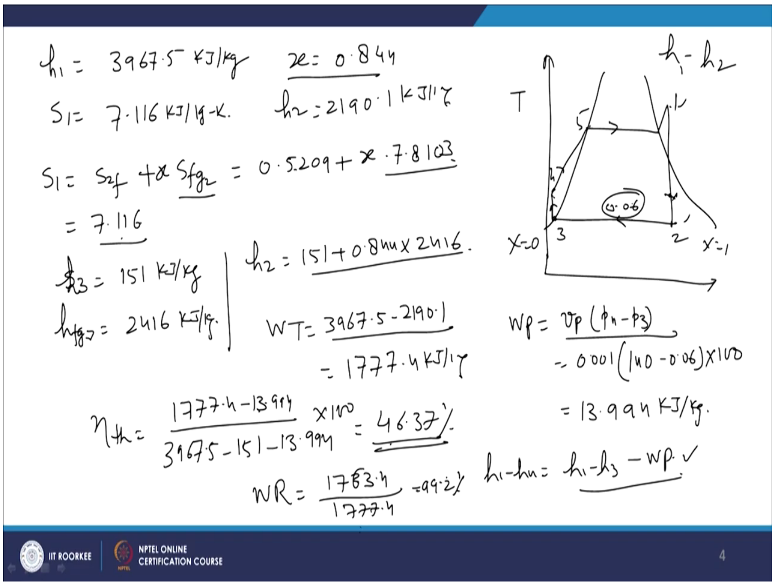

We will start with this, so first of all we will draw the Rankine cycle, ideal Rankine cycle or here in this Rankine cycle the steam is obviously, superheated. If you look at the steam table at this pressure of 140 bar and 550 degree centigrade, you will find that the steam is superheated. So, if you draw the Rankine cycle on temperature entropy diagram; this is X is equal to 1; the diagram is going to be like this. So, 1, 2, 3, 4 and this is 5 and the direction of the process is like this.

Now, first of all we will because we need for in order to find the output of the turbine; we need h 1 minus h 2. Now h 1, we can comfortably take from this steam table; if you look at the steam table at 140 bar, 140 bar and 550 degree centigrade temperature, in that case you will get 3967.5 Kilo Joules per kg; this is the value of h 1. Now, we have to find the value of h 2 and we do not know the quality of steam at state 2 right but one thing we know for sure that entropy at state 1 is equal to entropy at state 2.

So, what we are going to do; we will take entropy at state entropy at state 1 can be calculated, can be taken from the steam table because it is superheated steam. So, if you go to the superheated zone properties of steam; you will find the; entropy of the steam at state 1. So, entropy of the steam at state 1 is 7.116 Kilo Joules per kg Kelvin that is entry of entropy of the state but what about of entropy of state 2?.

State 2 quality; we do not know right, but entropy of state 2 is known to us. So, S 1 is equal to S 2 f; it means entropy of at this pressure 0.06 bar of liquid plus x S f g of state 2 right; at this pressure 0.06. So, for 0.60 bar as saturated properties, we look for the entropy of the liquid and the entropy of the saturated vapour or change in the entropy; change in the entropy from liquid to saturated vapour. So, these values we have taken from steam table and they are coming as 0.5209 Kilo Joules per kg Kelvin plus x 7.8103 Kilo Joules per kg.

Now, from this because this is equal to S 1; S 1 is 7.116; 7.116 is equal to 0.5209, this is entropy of the liquid at 0.06 and multiplied by the quality of vapour and change in entropy from liquid to vapour phase. From here, we get the value of x as 0.844 right; this is the quality of vapour at state 2. We have properties of energy also enthalpy of liquid at this pressure 0.06 pressure, enthalpy of a saturated vapour also; we have 0.06 bar pressure and derived heat is also known that can be taken from the steam table.

So, at S 3 or enthalpy of the liquid at this pressure that is S 3 it is 151 Kilo Joules per kg and this is not S, this is h 3; not S; h 3, it is h 3 enthalpy at 3. And latent heat h f g at 3 is 2416 Kilo Joules per kg. Now, using these values we can find the value of h 2 as 151 plus 0.844 multiplied by 2416 and there we get the value of h 2 as 2190.1 Kilo Joules per kg. So, now we have the value of h 1 and we have value of h 2.

So, steam turbine is an open type of system right; if you apply for slow of thermo dynamics, you will find that the output of the turbine is h 1 minus h 2; that is h 1 minus h 2 that is the output of the turbine. The part of the output of the turbine is also used for pumping the liquid at state 3 to state 4 or in; in increasing the pressure of condensate. The part of the that work has been used, so work of the pump is specific volume at state 3 v d p; delta p and delta p is p 4 minus p 3 right.

And if you look at the work of the pump is equal to specific volume at 30.01. So, it is 0.001 meter cube per kg; it is taken from the steam table p 4 is 140, this is 0.06 they are in bar. So, it is converted into the kilo Pascal so that we get output in kilowatts; uniformity of the unit has to be maintained. So, it is coming is equal to 13.994 Kilo Joules per kg, this is the work of the pump. Now, this is the output; work of the turbine is 3967.5 minus 2190.1 and if you take difference of these two, then we get 1777.4 Kilo Joules per k g.

Now, this turbine or part of this turbine output is used for the pumping. So, net output is difference of these two and then we have to find the efficiency of the; thermal efficiency of the plant. So, thermal efficiency of the plant is net output that is 1777.4 minus 13.994 divided by net heat supplied in the cycle.

Net heat supplied in the cycle is h 1 minus h 4; h 1 is with us; h 1 minus h 4, h 1 with us, h 3 is with us, but h 4 is not with us right. So, in order to find h 1 minus h 4; we will take h 1 minus h 3 plus work of the pump; sorry this not plus, this is minus; not plus, this is minus right. So, this minus pump work. So, this will give us the value as 3967.5 and h 3 is 151 minus pump work is 13.994 because as the point is shifted from 3 to 4; the heat added in the boiler is reduced right.

So, pump work on the one side; the high grade energy is being used for increasing the pressure, on the same side it has reduced the requirement of low grade energy. So, if you solve this; we get a thermal efficiency of the order of 46.37 percent; this is multiplied by 100, so we will 46.37 percent.

Another term is work ratio and the work ratio is the network divided by the work output of the turbine. Now, let us understand what is the meaning and what is the significance of work ratio. Thermal efficiency is 46.37 percent of low graded energy has been converted into the high grade energy; this is the net output, this is the efficiency of the cycle. Now, when we talk about the work ratio work ratios is net output divided by the output of the turbine. So, here the net output is 1777.4 by the 13.999 right. So, net output is if you want to have work ratio; then net output is 1763.4 and turbine output is 1777.4; it is 99.2 percent; it is, it is quite high.

Now, work the concept of work ratio has coming to the picture, if you look at the Carnot cycle; Carnot cycle has very high efficiency, but at the same time; it has very low work ratio.

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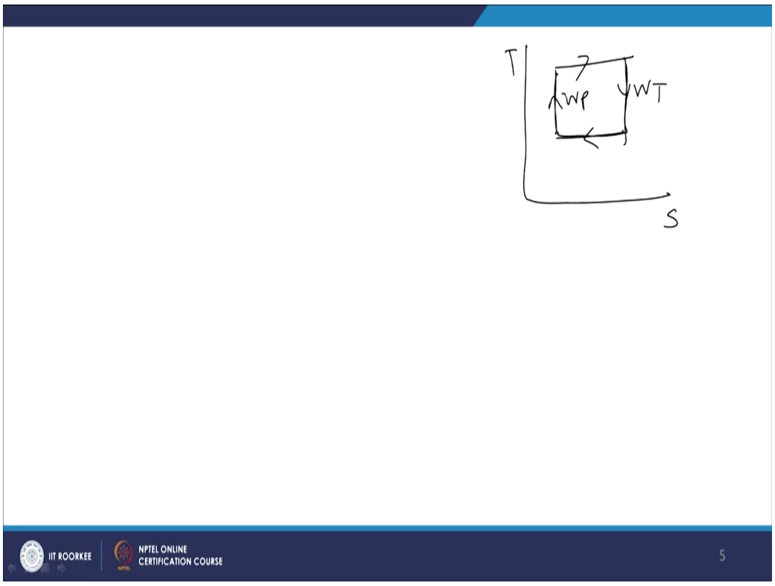

If you look at the Carnot cycle right; this is the turbine work and this is the work of the pump. So, work of the pump is also quite significant. So, efficiency is high no doubt Carnot cycle efficiency is high; at the same time it has got very low work ratio and it means for Carnot cycle, suppose I need an engine which is working on auto cycle or Rankine cycle, the size may be this much; for 1 kilo Watt engine.

For Carnot cycle based engine, size will be this much because work ratio is low. When the work ratio device is low; the size of the device will increase for the net output. So, next part of this is if the efficiency of the pump is 50 percent; efficiency of the pump is 50 percent and turbine efficiency is 80 percent.

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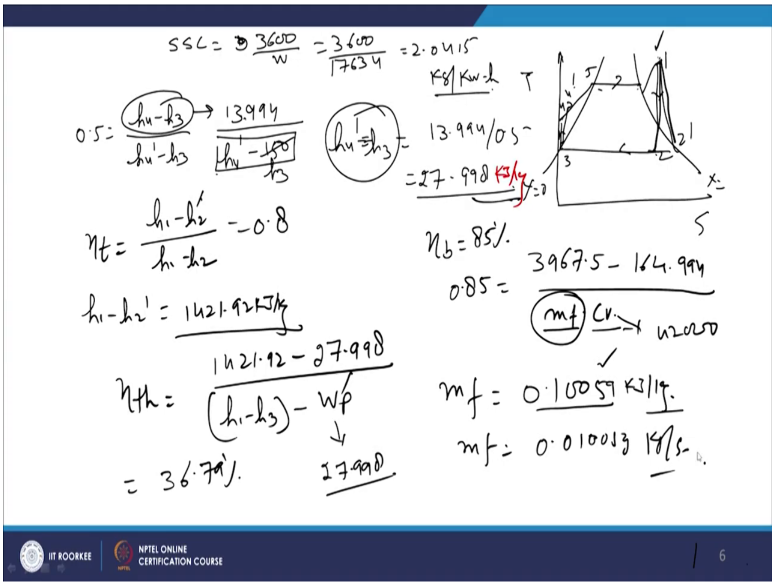

So, if you draw temperature entropy diagram here again; temperature entropy diagram here again right 1, 2, 3, 4, 5 right. Now, turbine efficiency is 80 percent; so no longer it is a vertical line, so it is 80 percent; so this is 2 dash and at the same time pump also is not a vertical; it is 4 dash here. So, if the efficiency of the pump is less, less amount of heat will be added in the boiler. At the same time if the turbine efficiency is 80 percent the output also be less from the turbine. So, now we will take this into the account.

And before going for this there was one thing more specific steam consumption. So, step in previous part; so specific steam consumption is 36 and sorry 3600 divided by net work output. And this will give 3600 net output was 1763.4 is equal to 2.0415 kg per kilo; kg per kilowatt hour; that is the specific steam consumption that was requirement of the part A.

Now, in part B; the pump efficiency is 50 percent, it means 0.5 is equal to h 4 minus h 3 divided by h 4 dash minus h 3. Now, here h 4 minus h 3 is known to us; that is 13.994, h 4 dash is not known to us; h 4 dash and h 3 is also know to us, that is 150 right. And from this we can get the value of h 4 dash and h 4 dash value is h 4 dash or we can take this; h 4 dash, this is h 3.

So, simply h 4 dash minus h 3, we can get from here that is 13.994 divided by 0.5; so we will always be using this h 4 dash minus h 3. So, it is coming around 27.998 kilowatt; sorry Kilo Joules per kg, not kilowatt; mass flow rate is not given. So, it is going to be Kilo Joules per kg; Kilo Joules per kg ok. So, now, the pump which was consuming 13.994 Kilo Joules per kg, now it is consuming just double of the power 27.998.

Regarding turbine; efficiency of the turbine is again h 1 minus h 2 dash divided by h 1 minus h 2. Now, h 1 minus h 2 is already with us; so h 1 minus h 2 dash is going to be 1421.92 Kilo Joules per kg because h 1 minus h 2 dash is known and this is equal to 0.8 right; so h 1 minus h 2 sorry; this is h 2 dash; h 1 minus h 2; h 1 minus h 2; you are right. [FL]

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h 1 minus h 2 dash; it is h 1 minus h 2 dash divided by h 1 minus h 2. So, from here; we will get the h 1 minus h 2 dash, definitely it is going to be less than h 1 minus h 2 and it is going to be 1421.92 Kilo Joules per kg.

Now, thermal efficiency again; now we are calculating again thermal efficiency. Now, we will take h 1 minus h 2 dash minus pump work that is 27.998, now divided by again h 1 minus h 3; this is h 1 minus h 3, these values are with us minus work of the pump. Now, this is d work of the pump that is 27.998 Kilo Joules per kg; h 1 minus h 3 we have already calculated right. And this we will give us the thermal efficiency if you calculate the thermal efficiency out of this, it is going to be 36.79 percent.

So, because ideal cycle had efficiency approximately 46 percent, but because now the in the real cycle the efficiency of the turbine we have taken only 80 percent, we have taken efficiency of the pump only 50 percent of pump is consuming double of the power. Now, here the efficiency has reduced to 36.79 percent.

Now, efficiency of the boiler has to be considered now. Now, efficiency of the boiler in the last part is 85 percent right; now 85 percent means 0.85 is equal to h 1 minus h 4; h 4 dash. So, h 1 minus h 4 dash is means 3967.5 minus 164.994 divided by mass of the fuel and calorific value of the fuel.

Now, 3967.5 we have taken enthalpy at state 1, we have taken enthalpy at stage 4 dash; how we have done? We have done; we have just taken enthalpy at stage 3, enthalpy at stage 3 and pump work is added. So, pump work is when you add the pump work; you get the enthalpy of stage 4 right and mass of the fuel burnt and the calorific value of the fuel. Calorific value of the fuel is known to us that is 42000 Kilo Joules per kg; from here unknown is mass of the fuel.

So, mass of the fuel burnt can be taken here and it is 0.10059 Kilo Joules per kg. Now, this is the answer; this is the, this is the amount of fuel which is burning for; this is the amount of fuel which is burning for, so mass of the fuel is 0.010059 kg per second right. So, after this we will take another numerical which is the next numerical is the related with the boiler a use of economizer in the boiler.

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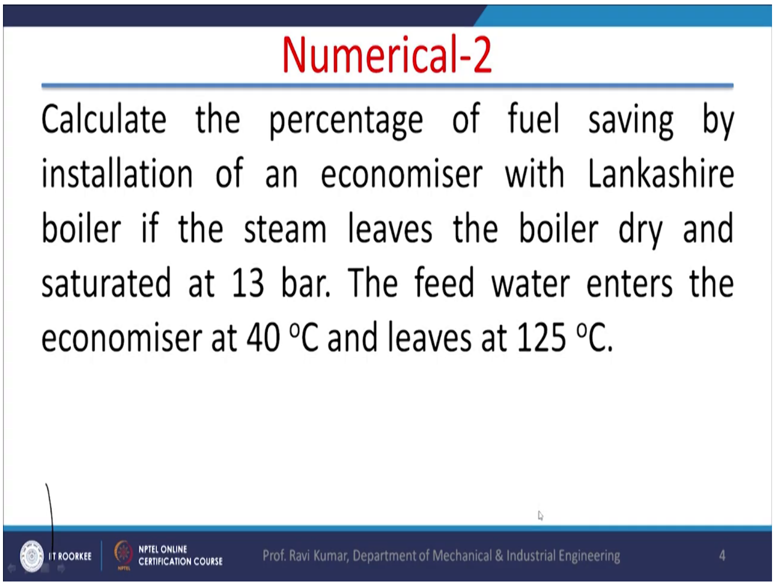

Calculate the percentage of fuel saving by installation of an economizer with Lancashire boiler; if the steam leaves boiler dry and saturated. So, now, in numerical 2; it is calculate the percentage of fuel saving by installation of an economizer with Lancashire boiler, if steam leaves the boiler dry and saturated at 13 bar pressure.

The feed water enters the economizer at 40 degree centigrade and leaves 125 centigrade. Now, the position of if you remember the position of economizer is that it comes into the contact with the flue gases; when the flue gases are leaving the boiler then economizer is fixed. So, feed water which is going to the boiler is heated in the economizer. So, feed water earlier which was going in the boiler at 40 degree centigrade; now it will be going at 125 centigrade and that is going to be the saving in energy in the boiler.

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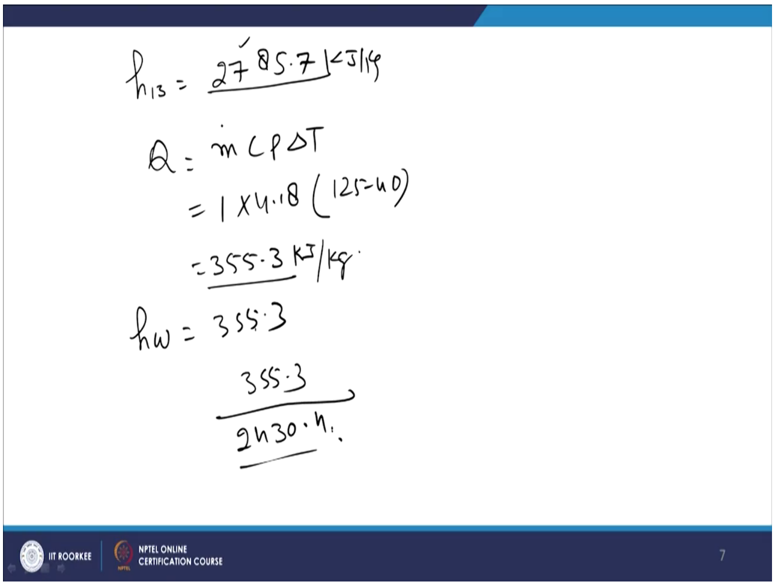

So, we will start with the enthalpy of steam at 13 bar; enthalpy of steam at 13 bar. So, that we can take from steam table that is 2785.7 Kilo Joules per kg; so this is the amount of steam saturated steam this is the enthalpy of saturated steam at 13 bar. Now, we are applying the economizer; in economizer the sensible heating takes place, the sensible heating of is taking place and the water is getting heat; the feed water is getting heated up. So, sensible heating is m C P delta T right.

We are taking 1 kg of water; we are analyzing for 1 kg of water. So, mass flow rate let us say is 1 kg or let us say 1 kg of water, mass flow rate is 1 kg C P is 4.18 and delta T is 125 minus 40 right. And this will give the value 5; 355.3 Kilo Joules; kilowatts the mass flow rate is 1 kg per second. If we take 1 kg of water, then it is Kilo Joules per kg; we are taking 1 kg of water or if mass flow rate is 1 kg per second, then it will be 1 kilowatt. So, Q is 355 point; per kg of water is 355.3 Kilo Joules per kg; now right.

Now, how much heat is reduced? How much heat is because h water is 355.3 right and usually it was required 2785.7; now this will be reduced from this right. So, net saving will be 355, it is saving divided by 2430.4. Now, solve the numerical; purpose of economizer boiler because economizer is provided, it is installed in the exhaust side of the boiler where the flue gases come into the contact with the economizer.

And this economizer takes heat from the; it is a sort of heat exchanger where transmission of heat takes places from the flue gases to the feed water and that feed water this heated feed water is supplied to the boiler. So, initially here where the boiler if I will read out the numerical; calculate the percentage of fuel saving by installation of an economizer with Lancashire boiler, if the steam leaves the boiler dry and saturated at 13 bar.

The feed water enters the economizer at 40 degree centigrade and leaves at 125 degree centigrade right. So, now in this case I; I have given you the physical value and this numerical, you can solve by yourself right. First of all, calculate the enthalpy at enthalpy initially without economizer.

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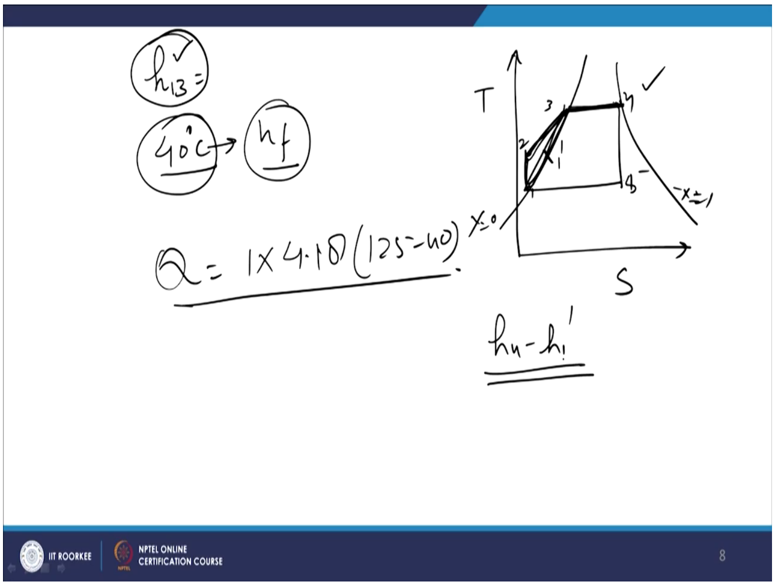

So, enthalpy first of all can calculate enthalpy at 13 bar; enthalpy of saturated vapour at 13 bar right.

Enthalpy of liquid which is entering the boiler that is at is 40 degree centigrade. So, at 40 degree centigrade enthalpy of the fluid 13; 14 centigrade saturation temperature enthalpy of the liquid; enthalpy of vapour at that saturated vapour at 13 bar. If you calculate these two and take the difference that is the actual amount of heat which is being added in the boiler.

If you look at the Rankine cycle; so 1, 2, 3, 4; so 2 to 3 and 3 to 4; 2 to 3 and 3 to 4; this part is, this and this energy addition is taking inside the boiler right; here we are neglecting the pump work because pump work is not mentioned. So, we will say that starting from 1 to 3, starting from 1 to 3 and 3 to 4. So, heating is taking place; sensible heating from 1 to 3 and then 3 to 4; in this case pump work is neglected. So, we can take enthalpy at 4; that is the enthalpy at saturated vapour at 13 bar, enthalpy at 1; it means that 40 degree centigrade; enthalpy of the liquid. So, that is the amount of heat which is being added.

Now, we have put an economizer; so this economizer what it is going to do? It will add some heat; sensible heat to the feed water and that is going to be for 1 kg of water, it is going to be m C P delta T; so 4.18, delta T is 125 minus 40. Now, this heat addition will shift 0.1 to 0.1 dash.

And now actual amount of heat which is to be added is from state h 4 to h 1; h 4 sorry h 4 minus h 1 dash; h 4 minus h 1 dash, this is the actual amount heat which is going to be added in the case of economizer and when you solve the numerical, you will find that there is a 10 to 15 percent saving in heat in the boiler. So, 10 to 15 percent saving is a quite significant saving. So, these accessories which are used in the boilers; whether it is a super heater or an economizer or air free heater, these accessories definitely improve the efficiency of the system.

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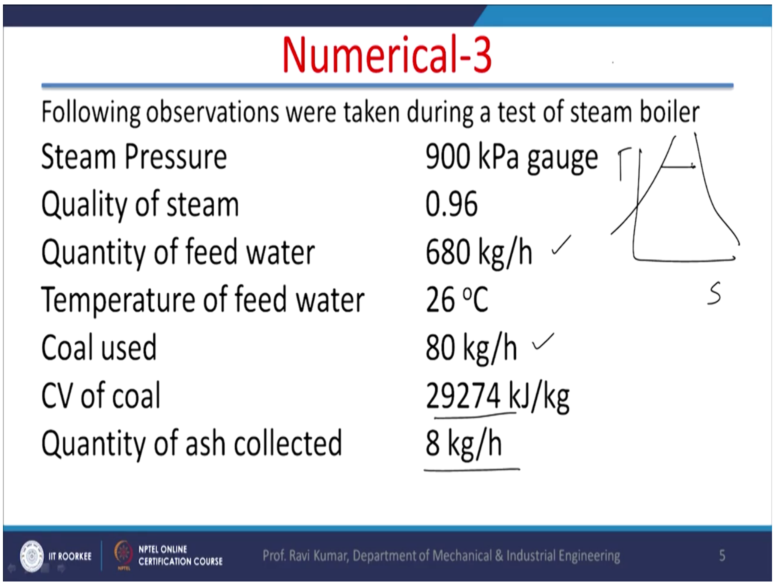

So, now after numerical 2; we will solve another numerical, this is the last one; following observations were taken during a test of a steam boiler. So, steam pressure 900 kilo Pascal gauge. So, atmospheric pressure has to be added before doing any calculation. Quality of steam 0.96. So, if you look at the Rankine cycle again here the, it is not fully saturated; it is 0.96 right.

Quantity of feed water is 680 kg per hour, temperature of feed water is 26 degree centigrade; this is the normal water which is fed to the boiler. Coal is 80 kg per hour, this is the amount of coal which is being used and calorific value of the coal is 29274 Kilo Joules per kg, quantity of ash collected is 8 kg per hour.

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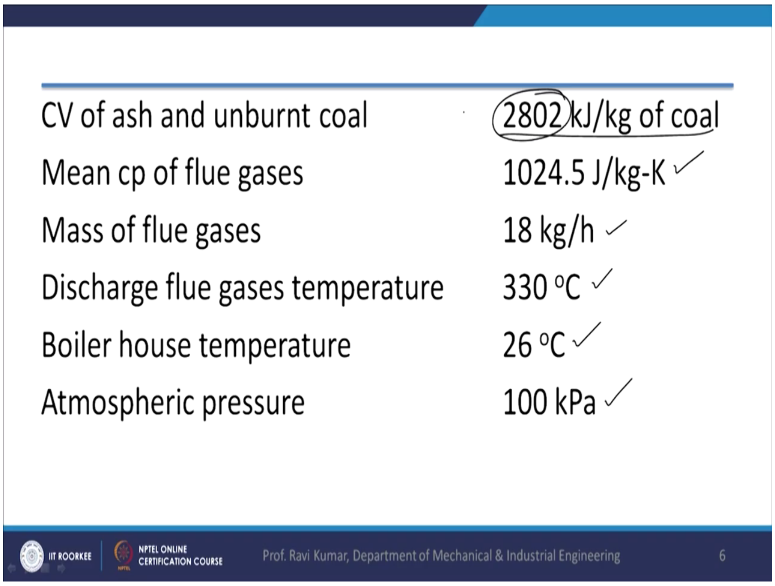

Then CV of ash and unburnt coal is calorific value is also given here, mean specific heat of flue gases is given 1024.5 Kilo Joules per kg Kelvin, mass of the flue gases 18 kg per hour, discharge flue gases temperature 330 degree centigrade, boiler house temperature 26 degree centigrade; at perhaps at the same temperature the water is supplied, atmospheric pressure 100 kilo Pascal.

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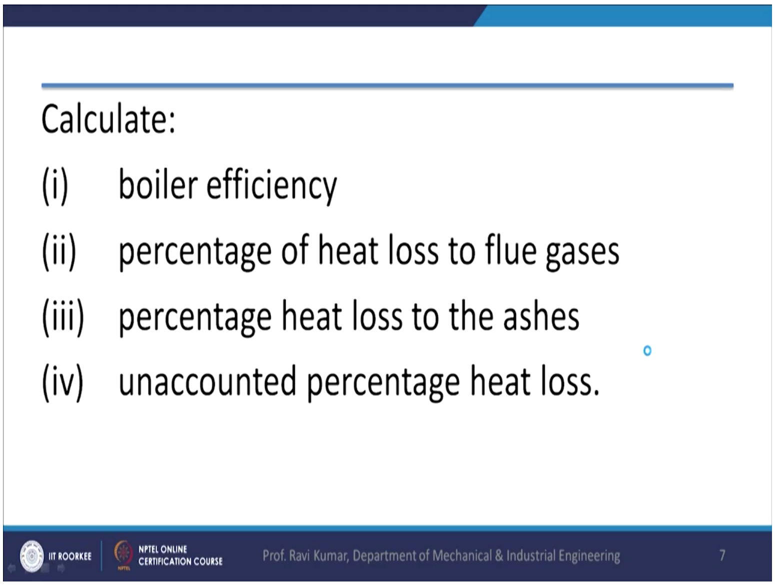

So, 9 kilo Pascal gauge uh; so absolute pressure is 10 bar 1000 kilo Pascal and then we have to calculate boiler efficiency, percentage of heat loss to flue gases, percentage of heat loss to ashes and so it is a sort of preparation of the balance sheet of a boiler; a balance sheet of a boiler is also prepared right. So say fuel is burnt in the boiler that is 100 percent, then what part of fuel is this heat released by burning fuel is this heat is used for converting water into the steam that is useful I mean meaningful use of the heat because boiler is for that purpose only.

How much heat is going out with the flue gases, how much heat is dissipated to the surroundings or going with the ash or the unburnt fuel. So, all this balance sheet has to be prepared for each boiler it is; so it is part of the boiler trial.

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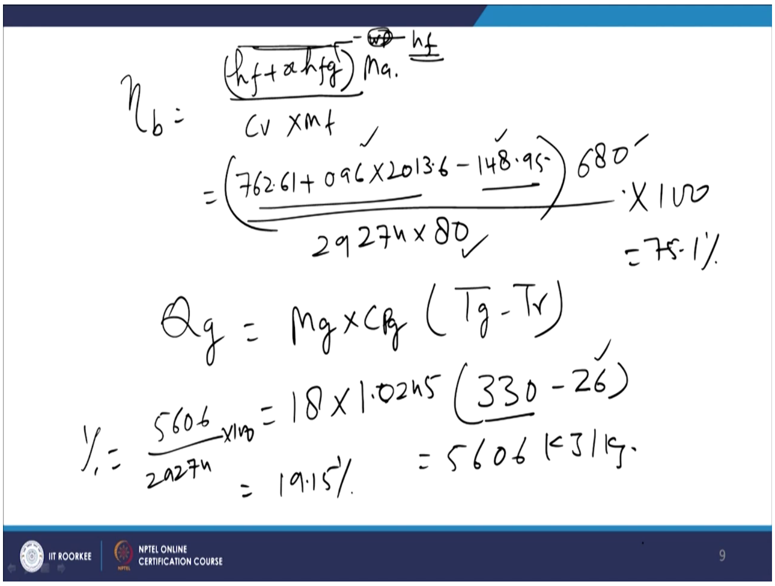

So, we will start with the efficiency of the boiler. So, efficiency of the boiler is enthalpy or heat added to the water divided by amount of the coal burns. So, it is h f plus x h f g divided by calorific value of the coal; mass of the fuel burnt multiplied by mass right. So, it is h f is 762; I have taken this value from the steam table plus quality of the steam it is given 0.96 into 2013.6 minus 148.95; this is the pump work, pump work has to be calculated pump work has to be calculated.

Then, not pump work; this is the enthalpy of water sorry, not pump work; this is the enthalpy of water, this is the enthalpy of steam this is enthalpy of water. So, the change in and difference in enthalpy has to be taken right. So, this is the enthalpy of steam which is coming out of the boiler and this is the enthalpy of water which is supplied to the boiler. So, in order to find the net amount of heat added difference of these two enthalpy has to be taken and this is multiplied by 680; amount of steam generated, calorific value is 29274 into amount of coal burnt is 8 kg per hour.

If you look at the values; so quantity of feed water is 680; so that is why I have multiplied there by 680; coal use is 80 kg per hour. So, that is why I have divided there by 680 kg; 680 and 80 right and this will give the efficiency of the boiler. And once we have the efficiency of the boiler and that is coming around you multiplied by 100 and that is 75.1 percent, this is giving; this is the efficiency of the boiler.

Now, the second part is heat carried away by the flue gases; now in order to find heat carried away by the flue gases, that is Q g is equal to mass of the gas C P of the gas T g minus T r. So, mass of the gas is 18; if you remember it is 18, C P is 1.0245; I have taken in Kilo Joules per kg Kelvin, in data it is given joules per kg Kelvin; I have taken Kilo Joules per kg Kelvin. Gas temperature is 330 and water temperature is 26 degree centigrade or the air temperature or the room temperature is 26 degree centigrade.

So, air temperature is 26 degree centigrade; flue gases temperature air is taken from the room the room temperature is 26 degree centigrade that is why I have taken this as 26 and this gives the value 5606 Kilo Joules per kg, this is amount of heat which is carried away by the flue gases by burning 1 kg of coal.

So, therefore, percentage loss; if you look at the percentage loss percentage loss is 5606 divided by the calorific value; calorific value is 29274 multiplied by 100. So, percentage of heat which is going with the flue gases is 19.15 percent ok. So, this is the amount of flue gases which is; this is the amount of amount of heat which is going away with the flue gases.

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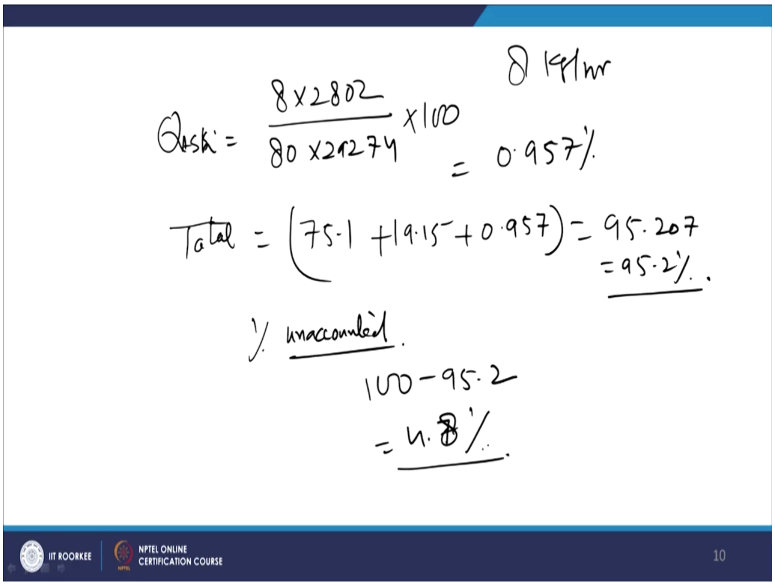

Now, mass of the air if you remember it is 8 kg per hour; this is the amount of ash which is being generated during the operation of the boiler. Therefore, percentage of heat because; calorific value of ash is given calorific value of ash is given 2802 Kilo Joules per kg and mass of the ash is 8 kg per hour right.

So, heat is going to be; the heat going with ash is 8 into 2802 divided by 80 into 29274 because 80 kg of fuel is burnt per hour and this will multiply this by 100; this will give 0.957 percent. So, 0.957; approximately 1 percent of heat which is generated is going with the ash, it is taken away by the ash.

So, total account of heat if you take; the total account of heat; so total, efficiency is 75.1. So, 75.1 is used for converting water into the steam; 19.15 percent of heat is going out with flue gases 0.957 percent of heat is going with the ash right. If you take sum of these; this is going to 95.207 or 95.2 percent.

So, percentage of unaccounted heat; so percentage of unaccounted, percentage of unaccounted heat is 100 minus 95.2 and it is going to be 4.7 or 4.8 percent. So, 4.8 percent of heat is unaccounted; it is I mean in boilers if the unaccounted rate is 4 percent, it is access because you cannot fully insulate the boiler. So, so the heat will be lost in the radiations from through conduction heat transfer, radiation heat transfer, convection heat transfer; some heat loses to be there. So, this is the amount of the unaccounted heat loss in a boiler.

So, today we have solved three numericals; we have done one numerical for I mean typical Rankine cycle with ideal; we have taken one ideal case, one real case. And another numerical we solve for the just to show the importance of economizer in a; in a boiler because economizer in a boiler can improve the efficiency significantly, save the energy and improve the efficiency of the boiler. And third one was about the sort of heat balance sheet of it boiler; that is all for today.

Thank you very much.