Thermal Engineering Basic and Applied

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Lecture – 42
Cooling Tower Performance

I welcome you all to the session of thermal engineering basic and applied and today we shall discuss about the cooling tower performance. In the last class we have talked about the classification of cooling towers and also, we have discussed about the analysis, the heat transfer process considering different types of cooling towers. Now whenever any mechanical device or any other device works, we need to know the performance of that particular device both qualitatively as well as quantitatively.

Now there are many parameters which are used to measure the quantitative performance of any mechanical component or device. Similarly, if we need to know the performance qualitatively, we also can measure a few parameters. Now whenever a designer is designing a cooling tower and that cooling tower is installed in a power plant, we also need to know what would be the performance of that cooling tower.

If the performance deteriorates with time, then eventually the performance of the plant will deteriorate. So today we shall discuss a few parameters which are directly related to the cooling tower performance. So what are those parameters?

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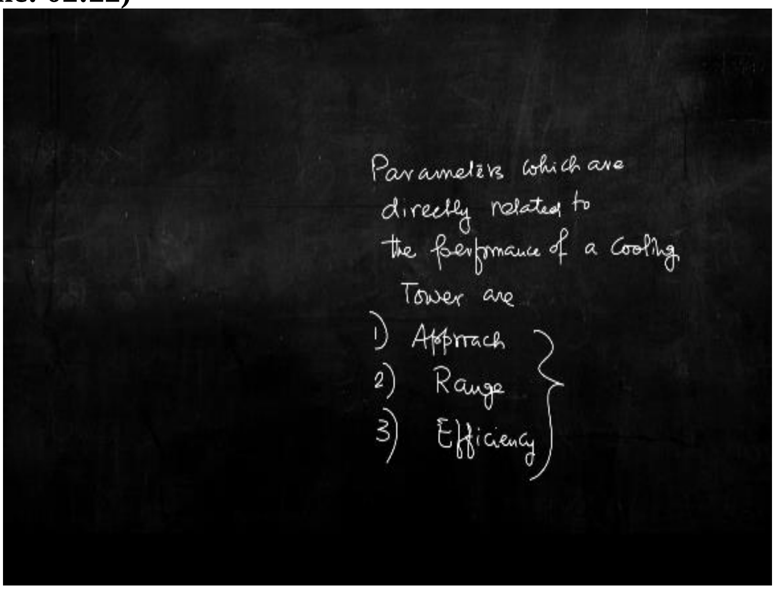

If we can write here the parameters which are 1) approach, 2) range, 3) efficiency; so if we can estimate or measure these 3 parameters, we can predict about the performance of a cooling tower. Now we all know that efficiency is one of the most important parameters typically used to quantify the performance of any mechanical component or device.

Now today we shall discuss about what is approach, what is range and what is efficiency of course in the context of the operation of a cooling tower? Now before going to discuss or define all these 3 parameters let us briefly recall the heat transfer mechanism inside the cooling tower. We have discussed that cooling tower is a heat exchanger in which water that comes out from the condenser which is having high temperature and that water will be again pumped back to the condenser, so the water that comes out from the condenser needs to be cooldown and that process is occurring in a cooling tower and the main purpose of using a cooling tower is to save the water or coolant. So that the same coolant can be recycled back for the heat transfer from this flowing steam.

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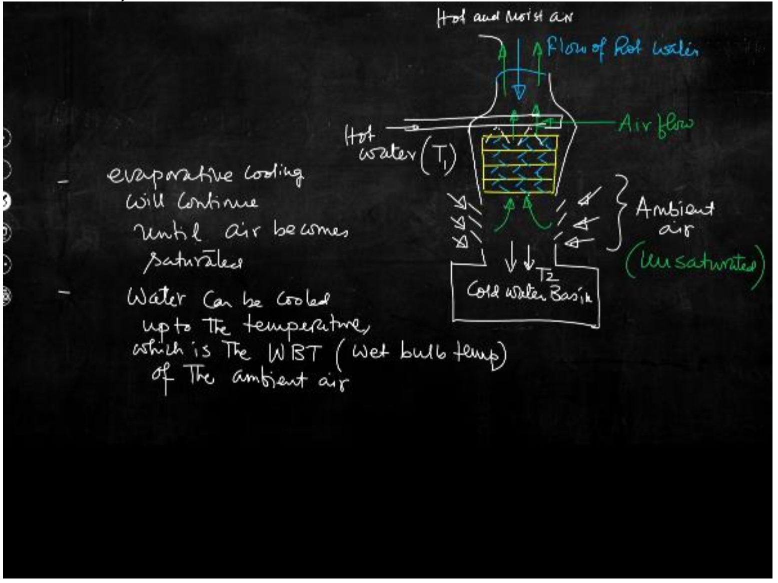

Now if we recall, this is cold water basin and through this opening area ambient air is drawn into the cooling tower and we have discussed for the mechanical draft cooling tower there are 2 different sub classifications. We can have one fan which is installed at the base of the tower and that is called force draft. So basically we can forcefully allow air to go inside the tower and here we are having special structure and in between this structure baffles are provided.

We shall discuss today the need of these baffles and this is the flow direction of water and airflow will be in the opposite direction. We have discussed about both natural draft and mechanical draft towers in the last class. What is happening, the ambient air that is drawn into the tower either by using an induced fan which will be located at the at the top of the tower or if we forcefully allow air to go inside the tower by using force draft fan the air is unsaturated. So air travels through the special structure that is filled and in between 2 fields baffles are placed. Baffles are placed only to alter the movement of the airflow; so had we not installed all these baffles over here airflow would have been more or less uniform. But by placing all these baffles we can alter the flow of air while that air passes through this particular structure.

These baffles are placed inside the field structure purposefully I will be discussing today. Now hot water is coming from top and this hot water distribution. Depending on the tower configuration, designer prefers to use this hot water distribution system to spray water otherwise water also can come from the top so that is up to the designer.

So this is the hot water and so basically these two steams mix intimately and that particular mixing will promote both heat and mass transfer and it is because of this mass transfer water will be cool down further, because this is evaporative cooling; so as water evaporates latent heat will be taken from the water and its temperature will reduce further and wewill be getting more cooling.

This air is traveling from the bottom part towards the top, when air will be in contact with the water at the bottom then evaporation will start, air will go up further and as water evaporates that water vapour moves along the air and eventually air will be moist. And that means eventually after traveling certain distance the air that was really unsaturated will be now saturated. If air becomes saturated then there will be no further evaporative cooling because that time air will not be having capacity to absorb any further water vapor. So basically, that also depends on the designer if the incoming air gets saturated in the midway of its travel towards up, then that saturated air will be again further in contact with hot air towards the upper part of the field.

And eventually will be getting hot and moist air that we have discussed in the last class, so this is hot and moist air. So the water can be cooled because of this evaporating cooling up to a temperature and that is the wet bulb temperature of the incoming ambient air, because if air becomes saturated no further cooling will be there due to evaporation. So that means as I said that intimate mixing of these two steams promotes both heat and mass transfers. Now though air is unsaturated, but in the course of the flow of air, air will be saturated and water molecule absorption by the air will not be possible and hence evaporative cooling will be reduced or evaporative cooling will be zero. So that means we can reduce the temperature of water or we can cool the water that is sprayed by this distribution system up to a temperature and that is the adiabatic temperature or wet bulb temperature of the incoming ambient air.

So this evaporative cooling will continue until air becomes saturated and that means water can be cooled up to the temperature which is the wet bulb temperature of the ambient air. Now from this discussion we shall define what is called approach, so now consider if the hot water temperature is T_1 and temperature that will be available at the cold water basin is T_2 then perhaps this is the range of the cooling tower, because we need to get cold water temperature T_2 when hot water having temperature T_1 is sprayed over the field structure in this cooling tower.

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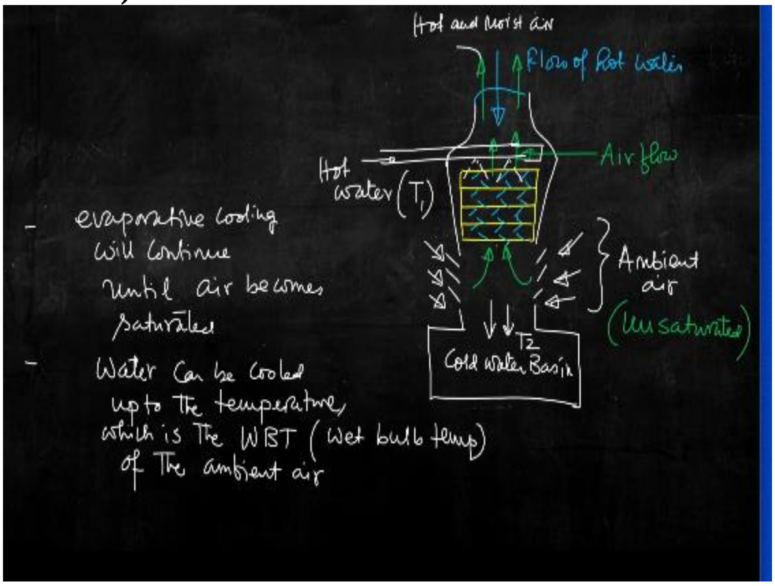

So, cooling tower range is the difference between the temperature of water that comes out from the condenser (inlet water temperature at the cooling tower) and cold water temperature at the cooling tower exit. So you can see this cooling tower range R is essentially $T_1 – T_2$ based on the configuration that we have discussed today.

Now question is what would be approach? though we are designing to get the temperature of cold water would be T_2 for the temperature which is having temperature T_1 at the inlet of this cooling tower but this is not possible to get T_2, because of this fact that incoming unsaturated air will be having certain capacity to absorb water molecules as it moves through the field structure.

Because as the incoming air start moving towards up that particular air will be saturated and once it becomes saturated no further evaporative cooling will be possible that means no matter if we design the cooling tower if we design several components of this cooling tower considering the fact that this would be the range that is T_1 - T_2.

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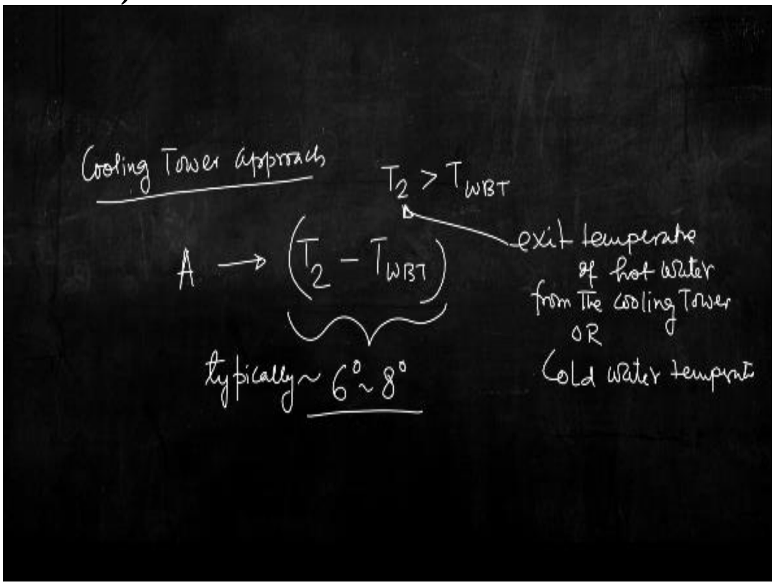

Cooling tower approach is T_C. So basically we are thinking to get temperature T_2 from this cooling tower but in reality will not the temperature T_2 at the cold water basin, this temperature T_1 of the hot water will reduce continuously.

It will reduce until the air becomes saturated and air will be saturated up to the temperature that is the wet bulb temperature of the unsaturated ambient air that means ideally if we use this ambient air to reduce the temperature of hot water which is having temperature T_1 we can bring the temperature of hot water up to the wet bulb temperature of the ambient air.

So basically T_2 which we are getting in reality that should be wet bulb temperature of the ambient air, but this T_2 is greater than wet bulb temperature of the incoming air. So we are supposed to get T_1 as T_{WBT} wet bulb temperature. Now what will be getting is T_1 to T_2 that is in reality.

This T_2 is very critical if we design to get T_2 then this T_2 would be actually the wet bulb temperature of the ambient air. So when designer is designing the cooling tower he or she is designing keeping in mind that the temperature of hot water can be reduced up to the wet bulb temperature of the ambient air, but this only the case because this T_2 should be always greater than T wet bulb temperature because of several reason. So that depends on the air flow rate, condition of the air which is available.

Because when a designer is designing the cooling tower he or she is assuming that the wet bulb when the cooling tower is installed in that location may be wet bulb temperature has changed. So approach is the exit temperature which is slightly greater than the wet bulb temperature so exit temperature of hot water from the cooling tower or cold water temperature.

Now this T_2 should not be equal to T_{WBT}, if we need to ensure that for a given design condition cold water temperature will be equal to the wet bulb temperature, then you need to go for very tall cooling tower. So as I said you that it is not possible to have because of several factors like air flow rate, capacity of the cooling tower and when someone designed the cooling tower he or she has designed the cooling tower considering one particular wet bulb temperature.

But when the cooling tower has installed on that particular location may be because of this climatological factor, wet bulb temperature has changed. So cooling tower approach A. So, approach is the exit temperature of hot water from the cooling tower which is supposed to be wet bulb temperature of the incoming ambient air but in reality the exit temperature of the hot water from the cooling tower or cold water temperature is slightly higher than the wet bulb temperature of the ambient air.

$$A = T_2 - T_{WBT}$$

And this difference is known as approach and this is typically 6 degree to 8 degree, so basically if the difference is more than that means cooling tower is not working at its design condition.

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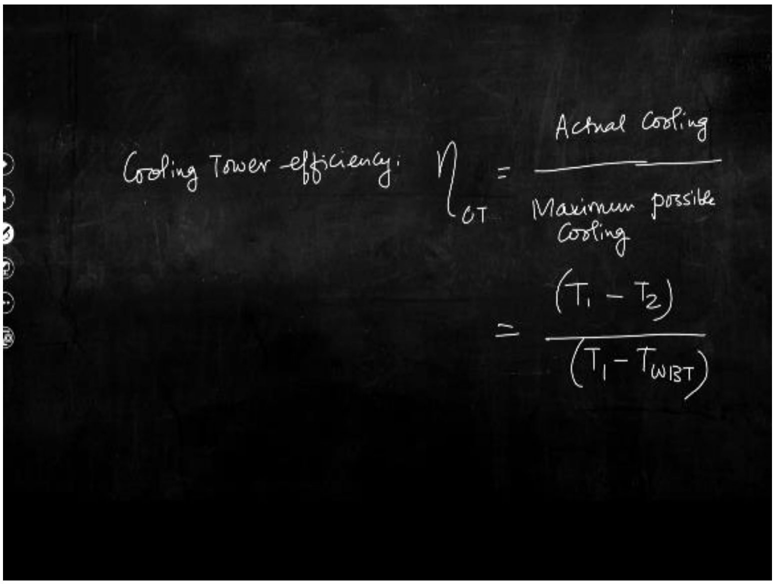

Next is cooling tower efficiency, like the efficiency of different other mechanical components devices like boiler, turbine, pump etc, we also can define the efficiency of the cooling tower because this is a very common parameter which is used to indicate the performance of the device. So what we have understood that though we are designing the cooling tower to get maximum possible heat transfer. But in reality you will be getting the actual heat transfer, so the cooling tower efficiency is defined as the actual cooling by the maximum possible cooling.

$$\eta_{CT} = \frac{\text{Actual Cooling}}{\text{Maximum Possible Cooling}} = \frac{T_1 - T_2}{T_1 - T_{WBT}}$$

So this is how the designer has designed the cooling tower to get the maximum possible cooling effect. But we are getting this, so the ratio is the cooling tower efficiency. Now with this I would like to discuss 2 important points those are again = indirectly related to the cooling tower efficiency =, what you have understood from today's lecture is that when these two steams are flowing through this field structure they are mixing intimately and as ambient air is in contact with the water steam, water vapor will evaporate.

And the water that evaporates will move along the air in the form of a water vapor that we have discussed. So basically the amount of water that is coming in and the amount of water that we are getting at the exit of the cooling tower will not be the same because certain amount of water in the form of water vapour will be carried away by the airstream. So as the water molecules are getting absorbed into the airstream and that water vapor will be carried away by the airstream.

So certain amount of loss will be there, there are several losses and all these losses will directly influence the cooling tower performance. So let us now talk about what are the losses, the first one is evaporation loss because as I said you that air which is in contact with the water that water will evaporate and that water that evaporates will be taken away by the airstream in the form of water vapor.

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Second one is called drift loss. See this hot water distribution system sprays hot water over this field structure. Now this hot water is supplied by a pump and the hot water is spread over the field structure. Now when hot water is getting sprayed by this distribution system, we may get water molecules of different sizes. Now a tiny volume or tiny water droplet that water droplet will be again carried away by the airstream. So this is called drift loss so relatively larger volume of water droplets will come in through this field structure due to gravity and airstream will go up.

But a tiny water volume due to this spray mechanism will be taken away by the airstream because we have seen that either a force draft or induced of fan will be there. Now if it is a force draft fan then we need to maintain certain velocity of air and that velocity of air will be good enough to carry away tiny volume of water droplet along with the airstream and that is called drift loss.

Now as I said you few minutes back this baffle structures are provided only to provide additional resistance to the airflow, because when air is flowing through this field structure certainly because of the field there will be a resistance, now over and above that resistance this baffle structures are provided with this field structure and the sole purpose of providing these baffle structures is to have a change in the direction of airflow.

And if that is the case as I said you that the airstream will try to carry a tiny volume of water droplet because water droplet is still heavier so when there is a direction change that water droplets separate out by the gravity so baffle structures are given here with the objective of getting heavier water molecules those otherwise will move with the air further up, those water molecules will be separated by the gravity due to this alteration in the airflow movement.

So we have understood about the drift loss as well as the purpose of providing this baffle structure. Finally another important loss that is the blow down loss, if we go back to the schematic depiction, when air is coming from ambient air that air may have some suspended solid now air is now having intimate mixing with the incoming water steam and water will be eventually collected at the basin.

So because of all this reason chances will be there that water will be contaminated. Now to maintain certain level of this concentration of different foreign particles or contamination, typically blow down is taken, so it is because of this reason that loss of water will be there. So we have understood that 3 major losses one is the loss due to evaporation, drift loss and blow down loss.

So if you need to replenish all these losses we need to supply makeup water and hence in cooling tower always we need to supply certain makeup water otherwise the cold water which will be going back to the condenser that flow rate will reduce and condenser efficiency will be reduced and eventually that will affect the total power plant efficiency. Now typically this evaporation loss is 1 to 1.5 percent, blow down loss is also 1 to 1. 5 percent, drift loss is really very minimum. So to do replenish all these losses, as I said makeup water is supplied so with this now let us solve one numerical problem today.

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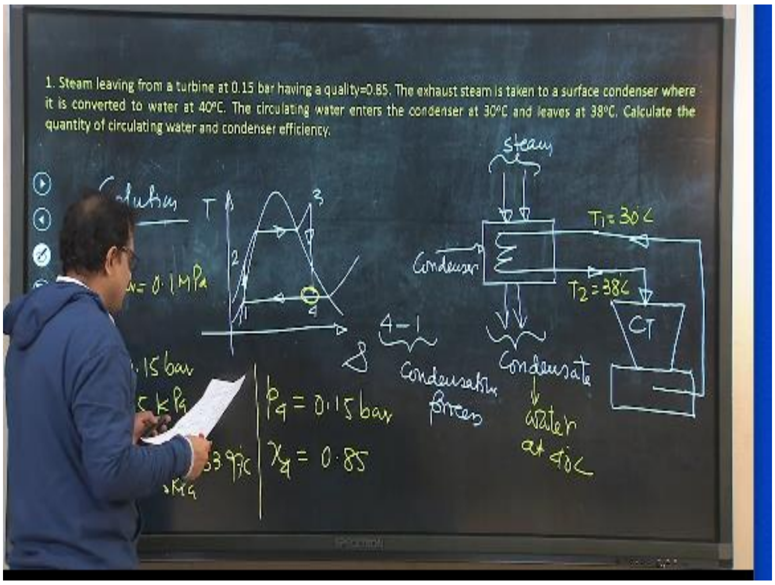

So, let me read out the problem statement. Steam leaving from a turbine at 0.15 bar having a quality 0.85, the exhaust steam is taken to a surface condenser where it is converted to water at 40 degree Celsius. The circulating water enters the condenser at 30 degree Celsius and leaves at 38 degree Celsius we need to calculate the quantity of circulating water and condenser efficiency.

So let me draw the schematic first, this is the condenser and this is cooling tower, so this is steam flow and this is condensate. So this is the circuit, exhaust steam is taken to this condenser wherein by circulating cooling water steam temperature is reduced, steam is converted to condensate and that hot water is taken to cooling tower and in the cooling tower again by circulating ambient air that temperature of that hot water is reduced and again pump back to the condenser, so this is the circuit.

Now basically it is given that steam leaving from a turbine at 0.15 bar, so if we try to draw the T-S diagram, at the inlet of the turbine, steam condition we really do not know, but we are assuming that this is the case. So 4 to 1 is the condensation process, steam leaving from the turbine at 0.15 bar having quality 0.85.

$$p_4 = 0.15\ bar = 15\ kPa; x_4 = 0.85; T_1 = 30^{\circ}C; T_2 = 38^{\circ}C$$

$$@15\ kPa, T_{sat} = 53.97^{\circ}C$$

So basically condensation starts at point 4 that is the exit steam quality and that process occurs at a constant pressure eventually you are getting water at state point 1 and that water is saturated liquid corresponding to that pressure at which condensation is occurring, now that condensation pressure is given 15 kilo pascal. So saturation temperature of that condensate at that pressure is 53.97 degree that we can take from the steam table.

Now what we have to calculate we need to know what is enthalpy, because essentially we have to apply energy balance, so cooling water is coming at 30 degree Celsius temperature leaving from the condenser at 38 degree Celsius temperature and that cooling water is taking some amount of heat and that water circulation will reduce the enthalpy of the steam. So the enthalpy change you need to calculate. So first we need to know what would be the enthalpy at state point 4 that is at the exit of the turbine.

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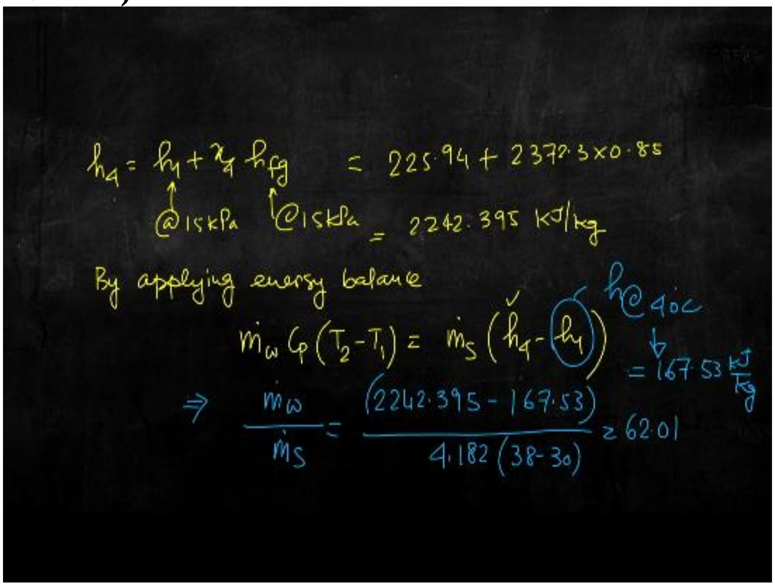

$$@\,15\,kPa \quad h_4 = h_f + x_4 h_{fg} = 225.94 + 2372.3 \times 0.85 = 2242.395\ kJ/kg$$

So this is the enthalpy of steam at the exit of the turbine or at the inlet of the condenser. Now it is given that it is converted to water at 40 degree Celsius temperature.

By applying energy balance we can write

$$\dot{m}_w C_p (T_2 - T_1) = \dot{m}_s (h_4 - h_1)$$

It is said that steam after releasing heat comes out from the condenser as a saturated liquid having temperature 40 degree Celsius. So while we will be calculating this h_1 instead we should write this is h at 40 degree Celsius because we are getting water.

$$\frac{\dot{m}_w}{\dot{m}_s} = \frac{2242.395 - 167.33}{4.182(38 - 30)} = 62.01\ \frac{\text{kg of water}}{\text{kg of steam}}$$

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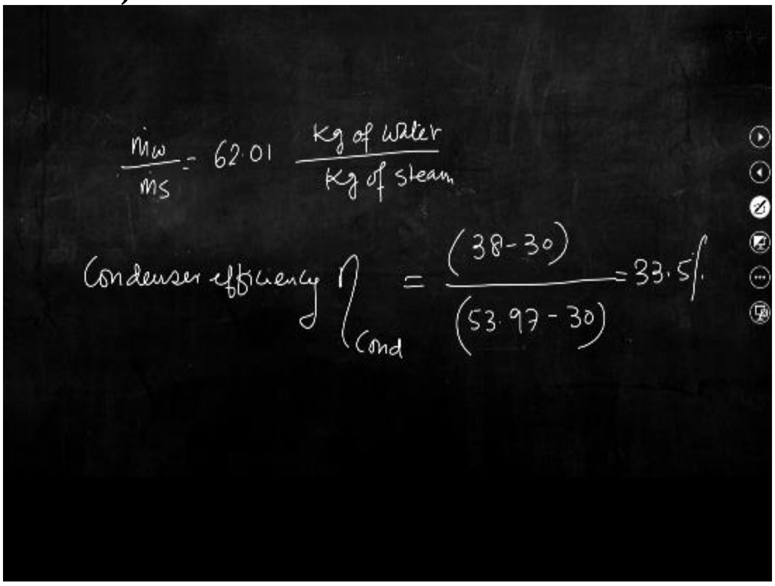

So if we need to circulate 1 kg of steam with 40 degree Celsius at the condenser outlet then you need to supply 62.01 kg of water. Now next is what is condenser efficiency.

We can understand that this condenser is provided to reduce the temperature of steam from this saturation temperature at the pressure at 4 to 30 degree because steam that is coming into the condenser having Tsat = 53.97 degree Celsius. So that is the temperature of incoming steam into the condenser and we are supplying water which is available at 30 degree at the exit of the cooling tower.

Now that means we are supposed to reduce the temperature of steam from this value to 30 degree so that would be the maximum possible reduction of temperature of the steam as it passes through the condenser. So the maximum possible reduction in temperature of the flowing steam that is 53.97 – 30. So this is the maximum possible reduction in temperature of the flowing steam but instead we could reduce from 38 – 30.

So essentially you know that water temperature has increased by 8 degrees so that means that 8 degrees the actual reduction of the steam temperature. $\eta_{cond} = \frac{38-30}{53.97-30} = 33.5\%$. So if you try to summarize today's you know discussion we have discussed about the performance of the cooling towers by defining 3 important parameters, we have seen the physical significance of these 3 parameters.

Then we have also discussed about that there are certain loss of water as it passes through the cooling tower and that loss of water is also indirectly related to the cooling tower performance. We have identified the possible source of those losses, also a typical value of total loss and then we have solved one problem from the condenser. So with this I stop here today and we shall continue our discussion in the next class thank you.