Thermal Engineering: Basic and Applied
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Lecture - 41
Cooling Tower: Types and Analysis

I welcome you all to the session of thermal engineering basic and applied. Today we shall discuss about the cooling tower. In the last class, we have talked about the condenser. In fact the role of a condenser in a stream power plant and we have seen from the discussion that in a condenser we need to circulate coolant. And in most of the cases coolant is water, if we use water as a coolant and that coolant is circulated through the tubes which are placed in a condenser and that cold water will receive heat from the stream which flows over the tube. And then certainly at the outlet of the condenser that coolant which will come out will be having high temperature. Now, question is that coolant can be taken from the nearby lake, pond or river but it is not always a case that there will be a river or a pond or a lake adjacent to a stream power plant so we need to have a special arrangement. So, that we can reuse the coolant in a cyclic process and that too even if a lake pond or river is there, the water temperature at the exit or that coolant temperature at the exit of the condenser will be so high that environmental constraint will not allow to discharge that water directly into the pond, river or lake.

So, even if the water is available in plenty because of these environmental factors we need to think for recycling the coolant. So, that in the condenser itself it will take some heat from the flowing stream, upon receiving heat, temperature of the coolant will increase. In another circuit that coolant will again release heat to another stream. And the device in which heated coolant or, hot water will release heat to another stream is known as cooling tower. So, if we draw the schematic depiction.

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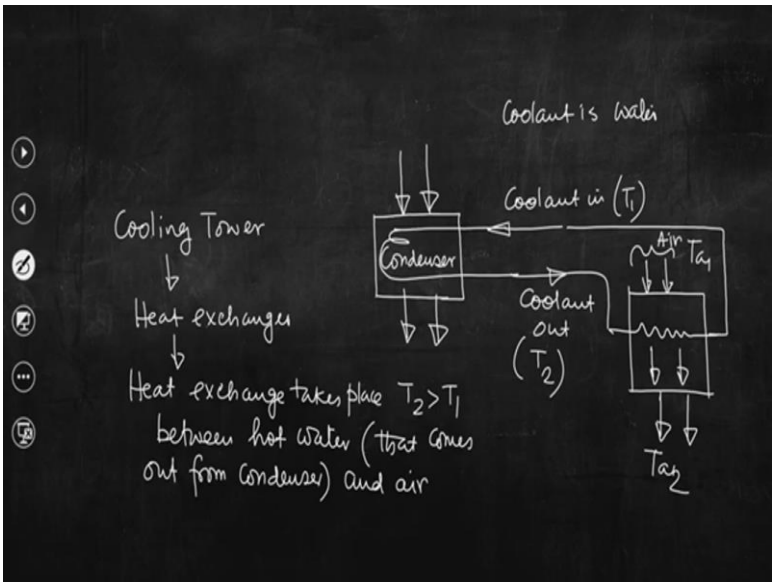

So, just if we draw this is the condenser and so this is coolant in and this is coolant out. So here stream is flowing over the tubes through which that coolant is circulated and coolant is water. Now since the temperature of water at the exit here is T_2 and certainly T_2 is greater than T_1. And that was the purpose to reduce this temperature of stream so that stream will be condensed.

And we had seen in the last class that condensed stream is collected in a basin and that condensate is pumped back to the boiler via a feed pump. So, now this coolant is again recirculated as I said you that we really cannot directly discharge this hot water into the nearby lake, pond or river even if cooling water is readily available and available in plenty.

So, what is done here we need to have another one circuit through which this coolant will be allowed to pass through a special type of heat exchanger. And this coolant temperature is further reduced by circulating air. This air stream is Ta2 and this air temperature is Ta1. So air which is allowed to flow over the tubes through which this hot water is circulated will take away heat.

And the coolant temperature will reduce and that coolant can be further taken into the condenser and process will continue. We can see this is the device in which this heat exchange takes place that means heat transfer from the heated coolant into the air stream and that is done in a cooling tower.

So, cooling tower is basically a heat exchanger in which heat exchanger in which heat exchange takes place between hot water that comes out from the condenser and air ambient air that is taken. Now we have understood that in a cooling tower essentially we are trying to reduce the temperature of the coolant which has already taken heat from the flowing stream.

And the sole purpose is to reuse the coolant instead of discharging directly that hot water into the nearby water source.

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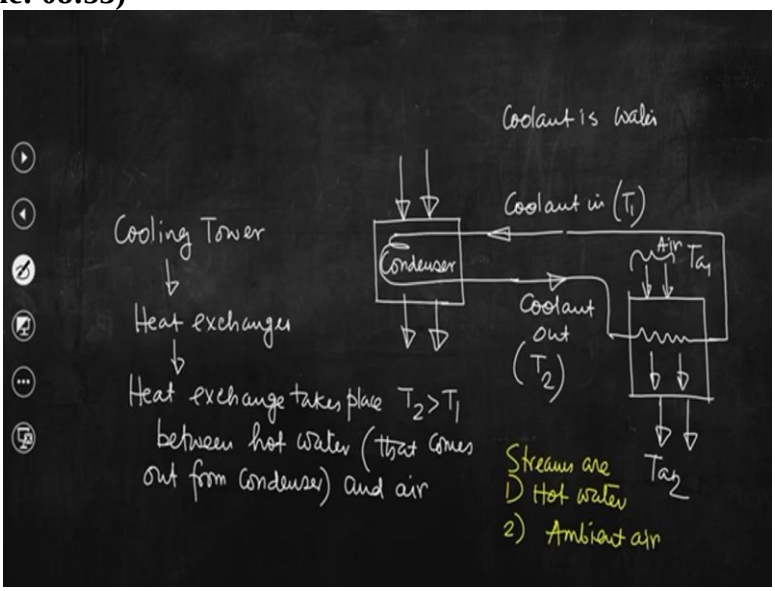

So, this cooling tower is very important even for the low capacity to high capacity power plants; so the sole purpose is to reduce the water demand. And we can reuse the water, so there are 2 broad classes of cooling tower, one is dry cooling tower and second category is wet cooling tower. So, if we can see from this particular circuit that there are 2 different streams one is hot water another is ambient air. Now if we allow these 2 different streams to mix while heat exchange is taking place. Then this type of cooling tower is known as wet cooling tower, so basically in a wet cooling tower you know 2 streams mix intensely.

So, as we have discussed in the context of a condenser that in a dry cooling tower also what is done is hot water will flow through the tubes while air stream will flow over the tubes. Now this airflow sometimes occurs because of the density difference, in most of the cases air is allowed to flow by an external agent like fan.

So whatever is the case, there are 2 different streams, in a dry cooling tower these 2 different streams do not mix together while they are exchanging heat. And now this wet cooling tower further can be sub classified.

Now we have understood whether it is dry cooling tower or wet cooling tower, we need to have a continuous flow of air and that air flow will reduce the temperature of the hot water. Now question is how can we have the flow of air through the cooling tower, as I said that air can flow

due to density difference that is due to pressure that is being developed due to the density difference. So we know that for any flow to occur there must be a pressure difference, driving force. Now the pressure difference is developed due to the density difference of the air. Of course the air which should be there inside the cooling tower will be having high temperature.

So density of the cold air that is the outside air and density of the hot air that is the inside air this two densities are not same. So it is because of this density difference, and that pressure difference is the driving force to make the flow of air occur through this particular device. So that means in one case we can have flow of air due to density difference and that is called natural draft cooling tower.

In another case we can have an arrangement so that a fan will you know allow air to flow over the tubes. So, in case as if we are allowing flow of air by making an arrangement so that external device that is fan will maintain the airflow and that type is known as mechanical draft wet cooling tower. So this is natural draft cooling tower and another one is mechanical draft cooling tower.

So you can understand that this half classification is based on the arrangement of airflow. Further this mechanical draft cooling tower also can be categorized into 2 classes. So you can understand that essentially you will be using an external source which will ensure that there will be a continuous flow of air through that cooling tower.

So now depending on the position of that particular device that external device that is fan this mechanical draft cooling tower can be further sub-classified into 2 categories. One is called force draft and second category is called induced draft. So essentially you can understand force draft like you know forcefully we are allowing air to flow through the cooling tower. And, induced draft that means air should be inducted into the cooling tower.

So essentially this particular sub classification is based on the positioning of that external device. So we shall be discussing this later in today's class. So now coming to the discussion of this special type that is wet cooling tower.

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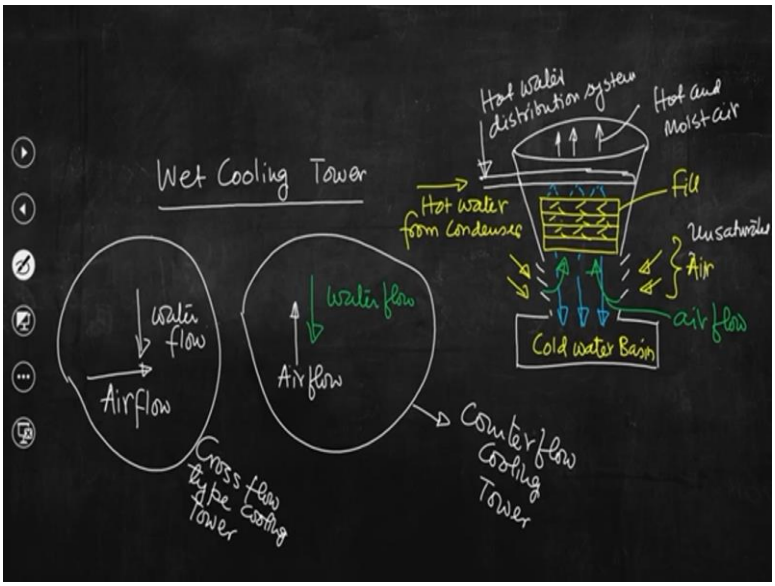

So, wet type cooling tower type, 2 different streams that is hot water and ambient air will mix together, let us now draw the schematic depiction of this particular type. Then we shall discuss about the internal arrangement and also the flow processes.

So this is hot water distribution system that sprays water over this particular arrangement. And in this particular arrangement we can see a few bars are layered horizontally and between 2 consecutive bars there is a gap and these bars are known as fill.

Now since this hot water distribution sprays water over this special arrangement that is called fill structure or bars. Then the water flows over that structure and due to gravity water comes down. Now you can see that there are another type of arrangements through which ambient air is allowed to flow into the cooling tower.

So, what we can understand this special arrangement is known as lowers. So, there is a gap through which air comes in to this cooling tower and air will be allowed to flow in the opposite direction to the water flow. Because water will be spread by this hot water distribution system and this particular arrangement is provided only to ensure that the distribution of the water should be more or less uniform.

So, as the water splashes from one fill to another fill by gravity that water flow intensely or intimately mixed with the airflow which is going in the opposite direction. So, as if water is coming down so this is water flow and that air is going up, so this is airflow. So this is counter flow type arrangement and when these 2 streams mix together heat and mass transfer takes

place, so basically the air which is at ambient temperature, now that air will take heat from the water that is coming down from the top fill to the bottom fill. And the heat transfer will be there as well as mass transfer will be there, ultimately we will be getting the air from the top of the tower; so this air is hot and moist air. So, basically that air will receive or absorb heat from the incoming water stream and when air will be coming out from the cooling tower that air is now having high temperature also having moisture content.

And that is why it is known as hot and moist air, I have mentioned that heat transfer will be there as well as mass transfer will be there. So kind of evaporative cooling when that air will be in contact with the incoming water stream water will evaporate. And it is because of this evaporation, latent heat will be taken by the from the water itself and the cooling effect will be more.

So basically that air which is coming out from the ambience is unsaturated air. So that unsaturated air when comes in contact with the water, water will evaporate and for this evaporation latent heat will be taken from the water itself. Water temperature will reduce so water evaporates that leaves along with the air stream in the form of water vapor. So, as if the air which is coming out eventually at the exit of the tower will be having moisture content. Now for example the unsaturated air is coming in and when unsaturated air will be at the middle in this particular structure that time air will be saturated upon absorbing water vapor.

So, now saturated air again when will be in contact with the hot air as it moves further up, then air temperature will be more. So eventually we are getting saturated air that has already absorbed water vapor. And again that saturated air is going up and up, further in contact with the hot water. So its temperature will increase and eventually will be getting hot and moist here.

So, this is basically the mechanism so you can understand that this heat transfer as well as mass transfer will be there. And as a result of which water temperature will reduce and air temperature will increase. As I said you that unsaturated air will be allowed to flow into the tower, so in this particular arrangement you can see that these 2 streams are having flow direction which are exactly opposite, water flow is in opposite to the airflow direction.

It is also possible that depending on the design that water flow is always vertically downward due to the gravity. Now if we allow air to flow in this direction, instead of having lowers over

here, we also can have lowers in this particular section and air will come into the cooling tower which is perpendicular to the direction of the water flow.

So, this particular arrangement is known as counter flow type cooling tower and this particular type of arrangement is known as cross flow type wet cooling tower. So basically it is up to the designer, depending on the design or placing of the lowers, it is possible that these 2 streams direction can be changed. So, this particular airflow as I said may be due to the pressure difference which is due to the density difference created. So basically the, pressure difference that will be developed due to density difference may be the driving force for the air to flow from ambience into the tower. And it will go up or sometimes maybe because of the requirement we need to have special device that is fan and that fan will allow air to flow through the cooling tower.

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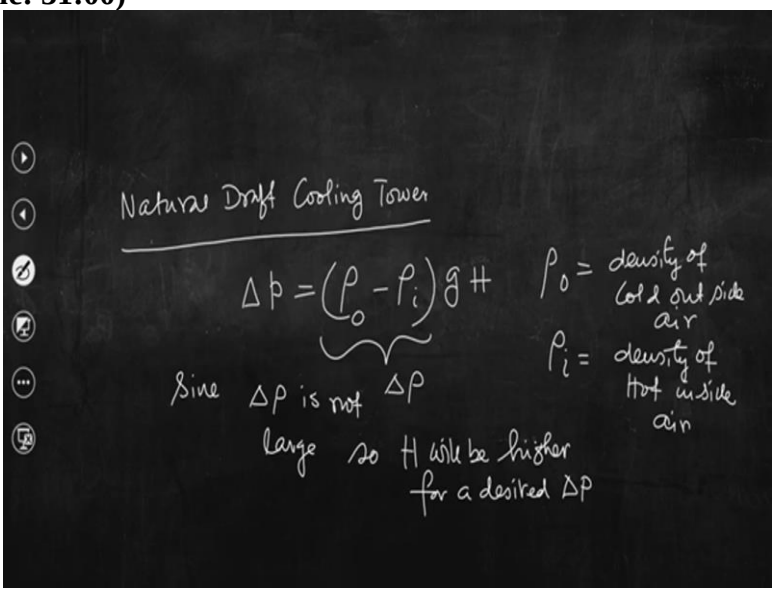

So in this particular classification natural draft cooling tower as I said you that the pressure difference is needed to make the flow occur; so, that pressure difference is due to the density difference.

$$\Delta p = (\rho_0 - \rho_i) g H$$

So, you can understand that when air will be in contact with water that air temperature will increase. So, that is the density of the hot air, now if we look at this expression, we can understand that still we need to have substantial pressure difference otherwise there will not be any flow of air why? Because you can understand that air has to flow over this particular arrangement or section wherein that airflow will experience substantial resistance because of

this arrangement. So if we need to overcome that resistance together with you need to maintain a certain flow rate of air, then this pressure difference will be up to a particular limit. Now since density difference of the hot and cold air is not very much, to get a sufficient value of Δp, height has to be very large and that is why the natural draft cooling towers are very tall, so this is the natural draft cooling tower.

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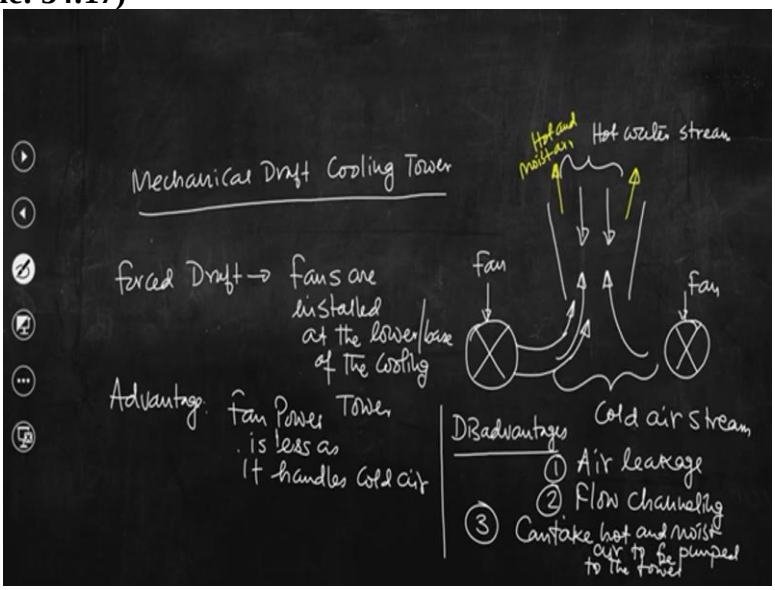

Now let us we discuss about the mechanical draft cooling tower. As I had discussed that to maintain the flow of air through the cooling tower, we need to have an external device and the device will ensure that the flow of air should be continuous. So, the device is basically a fan, so if this is the cooling tower and this is the hot water stream and we need to have cold air stream. Now we can have one fan here, we can have another one fan over here. So now the purpose of having these 2 fans is to provide adequate airflow through the tower and then heat exchange will occur and the water temperature will reduce and will be collecting water at the cold water basin and that water will be pumped back to the condenser. So this is the circuit. We can understand that in a force draft cooling tower as the name implies we are forcefully allowing air to flow through the tower.

Now it may be a force draft configuration in which fans are installed at the lower part of the cooling tower or base of the cooling tower. As if this blower or fan is allowing air to flow through the cooling tower. So now what are the advantages and disadvantages of this particular type.

Since this fans are located or installed at the base or at the lower part of the cooling tower essentially these fans are handling cold air, so the power consumption will be less.

But still there are a few drawbacks. Now since we are trying forcefully air to flow through the tower. So, that there will be a chance that air will leak from the tower into the ambience again.

So if we go back to this particular arrangements as if fans are located at the lower part of this or base of the cooling tower. And that fan is forcefully allowing air to flow through the tower. So air leakage will be there because all these are mechanical components there will be joints, flanges etcetera and that air will leak through those joints.

So as air is forcefully blown into this tower, there will be channelling of flow because the natural tendency of the air should be to follow a path having less resistance. And that is known as flow channelling, basically when air which is having high velocity will flow against the gravity and that too there is a special arrangement that is fill structure.

So air will try to follow a path which is having less resistance and that is known as flow channelling. 3) This particular fan is taking air from the ambience, so there might be a situation when that fan can still take the hot and moist air that is coming out from this tower outlet.

So this is hot and moist air, chance will be there that this fan will again try to capture this hot and moist air from the ambience. And will pass that hot and moist air again into this cooling tower, so performance will be deteriorated.

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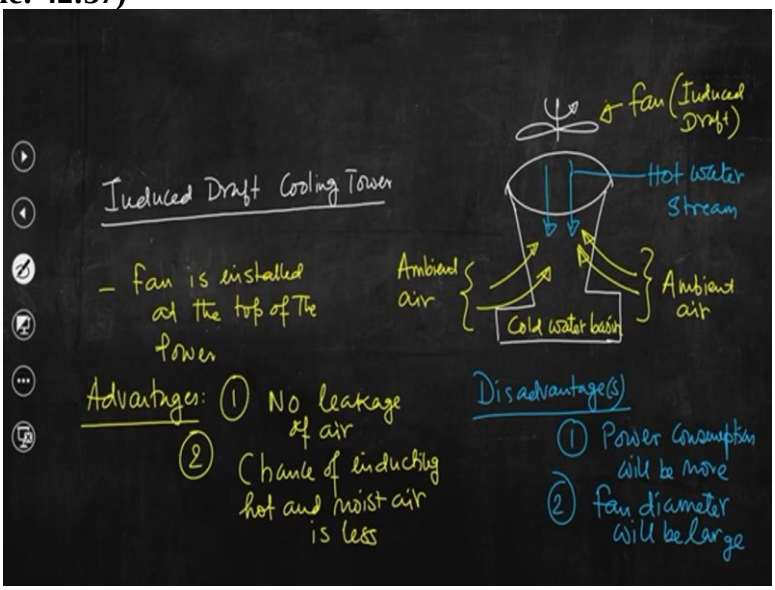

Now coming to the induced draft cooling tower, if we again try to draw the schematic, so this is hot water stream and ambient air and that is cold water basin. We can see this is the fan and

this is called induced draft. So what we can see in this case, instead of having fan at the lower part of the cooling tower fan, fan is located at the top of the tower depending on the requirement there might be more than 1 fans.

So this particular fan is inducting air through the lowers into the tower and this water stream is coming down. So this hot water will be distributed by this distribution system in the form of a spray that water will be allowed to flow over the fill structure and this fan will induct air by creating a negative pressure inside the cooling tower. So this fan is essentially creating a negative pressure inside the cooling tower.

And that negative pressure is responsible to create a pressure difference between this ambient air and the air which is there inside the cooling tower. Ambient air pressure is higher than the pressure inside the cooling tower that pressure difference is responsible to make this flow of air from outside into the tower and heat transfer will takes place.

So in, this case we can see that fan is installed at the top of the tower and so this is one important thing. 1) Since air is now inducted so always pressure inside the tower is negative. So there is no chance of having air leakage from inside the tower into the outside, 2) what we can see that there is no possibility of having hot air to be inducted. So if we go back to the previous slide this force draft fan may collect hot and moist air and again can supply that hot and moist air into the tower but in this case, since this would be always inducted, so chance of inducting hot and moist air into the tower will be reduced. So, now most important disadvantage is that this particular fan is located at the top of the tower. Essentially this fan is now handling with hot and moist air and hence the power consumption will be more because of this density reduction, the volume of air that will be handled by this particular fan is more. And hence electrical power consumption will be more. 2) Since more volume of air will be handled by this type of fan, the diameter of the fan would be more.

So we have discussed about wet cooling tower. We have discussed about both natural draft and mechanical draft cooling tower, we have also discussed about force draft and induced draft cooling tower.

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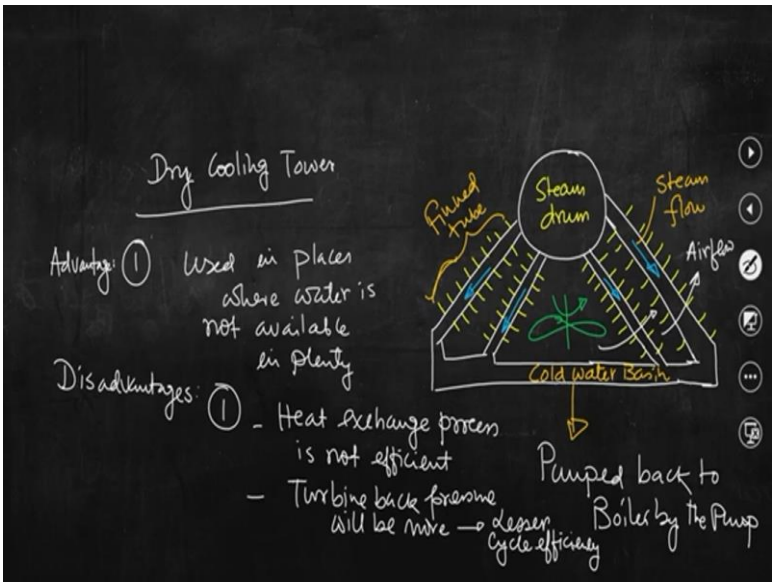

So now let us discuss about dry cooling tower as I said that in this particular type 2 different streams do not mix together instead heat transfer or heat exchange you will takes place while one stream is passing through the tube or tubes and another stream will pass over the tubes. So if we try to understand the mechanism of this heat transfer it would be you know convenient if we discuss it with a schematic.

So this is the schematic depiction of a dry type cooling tower, so what you can understand is that stream from is collected in the stream drum. So at the exit of the turbine that stream is in the condenser. Now that stream is allowed to flow through a number of tubes to be precise finned tubes. So this is basically fan, air is allowed to flow over this finned tube. And this flow is initiated by this fan, so basically what we can understand is from this particular arrangement is that flowing stream is cooled by the air blown over the tubes by this particular fan. This is a force draft fan, stream which is coming out from the stream drum into this finned tubes that stream is cooled by the air which is blown over the tubes by this fan, so this is the arrangement.

Now try to understand since these 2 streams are not getting mixed intensely, so mixing efficiency or heat transfer efficiency will be poor. And if the heat transfer efficiency is poor the temperature of the condensed team will be little high. So this condensate will be collected and pumped back to the boiler by the pump, now since the condensate that will be collected here because heat exchange efficiency is not that much efficient, the temperature of the condensate to be little more. And that will increase the turbine back pressure if the turbine back pressure is more, we have discussed in the last class that specific work output will be less and it will reduce the plant efficiency. So this particular cooling tower is promisingly used in places where water

quantity is less. So this is the advantage. Now disadvantage is heat exchange is not efficient so turbine back pressure will be more that means lesser cycle efficiency.

So that means the cycle or plant deficiency will be less because the temperature of the condensate would be little more which in turn will allow the turbine back pressure to be high. And if we recall the discussion that we had in the last class that specific work output of the plant or cycle will be less. So these are the advantage and disadvantages of the this particular type of cooling tower.

But still this particular type of cooling tower having all these disadvantages feature, has promising potential to be used in places where water is not available in plenty. So, now if we summarize, we have discussed about the cooling tower today we have tried to understand the role of cooling tower, then we have discussed about the classification of cooling tower.

And for each type we have analyzed the mechanism of the heat transfer together with we have discussed the merits and demerits associated with each type. So with this I stop here today and we shall, continue our discussion in the next class. Thank you.