Heat Exchangers: Fundamentals and Design Analysis

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Lecture - 60
Direct Contact Heat Exchanger

Hello friends, today we are going to start a very interesting type of heat exchangers; very special type heat exchanger they are called Direct Contact Heat Exchanger. So, for the heat exchangers we have studied and discussed in this particular course, where two fluids they do not come into direct contact, they exchange heat across a solid wall, on either side of the heat exchange the solid wall there are 1 fluid ok.

But, in case of direct contact heat exchanger as the name suggests that there will be direct mixing of the two fluids. So; obviously, these are special kind of heat exchangers, their constructions are different, their design is different and applications are different.

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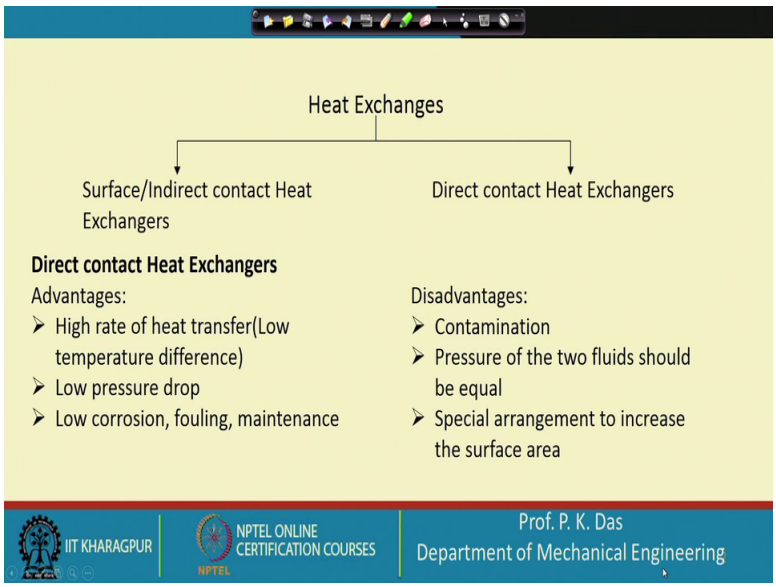

So, let us go to the next slide, heat exchanger we can have surface or indirect contact heat exchangers and direct contact heat exchanger. Direct contact heat exchanger have got several advantages like high rate of heat transfer, low temperature difference because, the thermal resistance offered by the solid wall is no longer there.

So, the temperature difference will be low and then low pressure drop because, again generally we will find that the fluid has not to pass through some sort of a conduit; the way we think that it has to pass through a pipe, a tubular passage or fin passage like that. So, narrow passage it has not to pass through a narrow passage so, there will not will be a lower pressure drop.

Then low corrosion fouling maintenance because we do not have a solid wall. So, or we do not have many solid walls of course, the heat exchanger has to be some sort of a containment structure should be there. So, as those features are not there so, you will have low corrosion fouling maintenance etcetera. What are the disadvantages? Disadvantages are contamination, two fluids are mixing together so, one may contaminate the other.

Then pressure of the two fluid should be equal, when they are missing together one should not be very high pressure one should not be low pressure. What does it mean? That pressure of the one fluid has to be brought either by increasing the pressure or by decreasing the pressure to the pressure of the other fluid. Then, special arrangement to increase the surface area; heat transfer is a surface phenomenon. So, here between the two fluid there will be some sort of an interface and the interface has to be large to have large heat transfer. So, some sort of a special arrangement like we have to form a spray or small bubbles etcetera, to have the heat exchange I mean good amount of heat exchange.

And what I have not written that for direct contact heat exchanger the fluids are to be immiscible or there should be two different phases of the same fluid like steam and water. So, if ultimately steam mixes with water and forms water there is no problem or it should be two immiscible fluid like air and water. So, we will have heat exchange, but we will not have any kind of mixing with one, I mean of one fluid with another.

But, let us say somehow we want to have heat exchange between alcohol and water we cannot mix them together because, they are not immiscible they are miscible fluid. So, ultimately we will get a mixture of alcohol and water. Or let us say there is oil and water we also cannot have heat exchange between them by direct contact because, that though they are immiscible it will be very difficult one they mix it will be very difficult to

separate them. So, these are the limitation or disadvantage of your direct contact heat exchanger.

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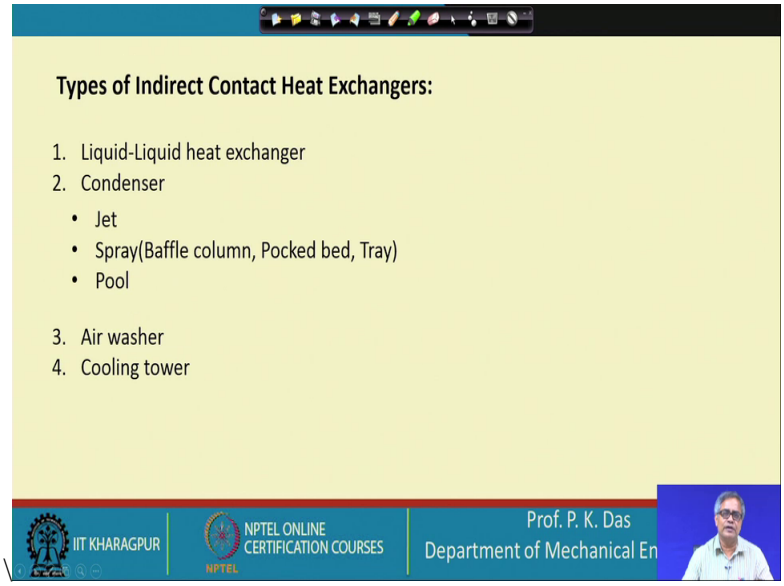

So, types of direct contact, sorry there is a mistake here it should be types of direct contact heat exchangers not indirect. So, types of direct contact heat exchanger it should be liquid-liquid heat exchanger. Condenser, condenser there are different condensers like; jet condenser, spray condenser baffle column, pocked bed, tray, etcetera, pool type condenser there could be air washer, cooling tower etcetera. I do not say that this is all the different type of heat exchangers have been listed over here. But main direct type, direct contact heat exchangers are listed over there.

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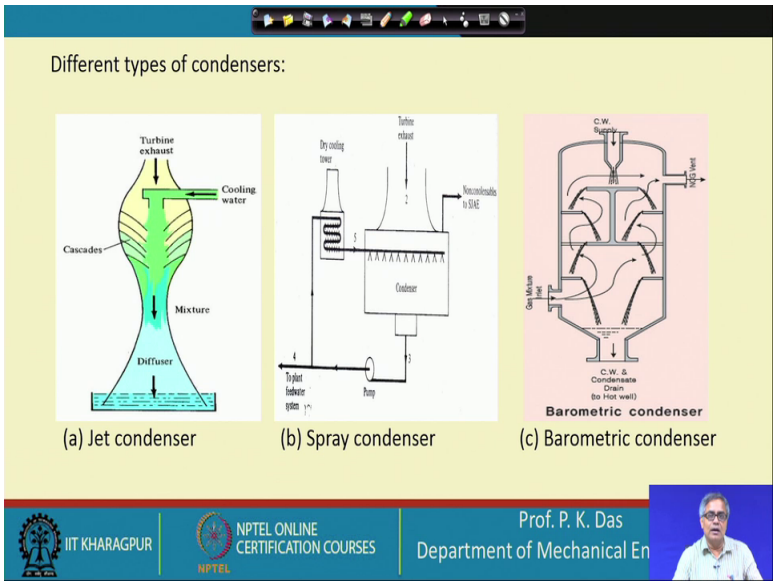

Different type of condensers; so, one is a jet condenser, jet condenser you see the how it is there that cooling water it is coming like a jet. And from the turbine steam is coming and the jet is made to pass through such a passage that some sort of a vacuum will be created. And the steam will be of course, the steam is coming at low pressure, but even then, steam will be induced and due to this induction of steam there will be mixture of steam and water, steam will condense and ultimately there will be condensate and one can collect this condensate.

So, it has got a typical shape so, this is like a convergent, divergent nozzle and this is the divergent part or diffuser part of the nozzle so, here the liquid can be collected. Spray condenser; so, here the water is being sprayed. So, let us say steam is coming from the top and water is being sprayed; obviously, this temperature should be lower than this steam temperature, for that what we can do whatever is getting condensed we take and in a heat exchanger we cool it further. So, that this is cooler compared to the outlet temperature of the condenser and it comes here and we get direct condenser.

There could be barometric condenser, what we are having that from the top the water is falling and steam is moving up. So, when the steam is passing through the water like this and we will have the condensation; there will be many trays like this so, ultimately only non condensable gas will be there which will go at the top. So, two things are very important in case of direct contact heat exchanger. The thorough mixing so, that there is

a very intimate contact between the two fluids and a good residence time. So, good residence time; obviously, when there is a jet we have got small droplets so, large amount of surface area, good mixing, etcetera and what we can have after this we can have different obstacle. So, that the flow is not in a straight path so, a good amount of time the both the liquid and the gas will be in contact so, that we can have.

Here you see the gas is passing like this then this, then this, then this so, there is a zigzag path and residence time is more and water is made to fall in thin film so, that the surface area is also large. So, this is one thing we have to do to have a good heat exchange between the two fluids. So, two fluids you see two fluids could be two very immiscible liquids, very very immiscible liquids, which can be separated easily.

One thing could be there that if two liquids are having large density difference or one gas another liquid or vapor of the same liquid and the liquid; that means, liquid and vapor phase. So, generally in direct contact heat exchanger we have this kind of things.

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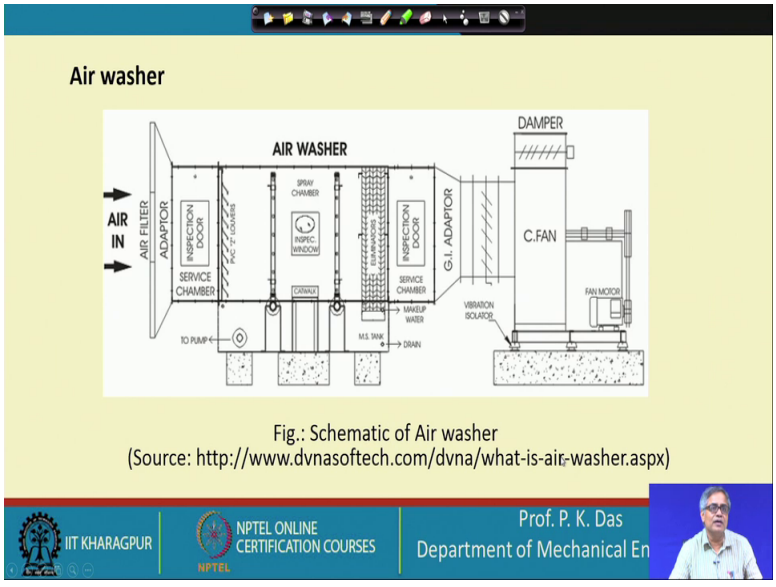

Fig.: Schematic of Air washer
(Source: http://www.dvnasoftech.com/dvna/what-is-air-washer.aspx)

Now go to the next slide, here I am showing one air washer, air washer is a device which is used for air conditioning purpose. Now, in air washer what we are having? Air is coming in and then it is passing through some sort of a louver and here we are spraying water in the air. So, it washes quote unquote washes the air and then the washed air quote, unquote washed air is passed may be through a demister where the water droplet

will be taken I mean separated out and then it will go to the room with the help of a fan, there could be additional heating.

Now, this water which is being sprayed its temperature is to be controlled and then we can get different air at different temperature and humidity in the conditioned space. As I have told it is for air conditioning purpose and with the air we are cooling and controlling the humidity of the air, sorry with the water we are cooling and controlling the humidity of the air. So, the water temperature has to be controlled very precisely.

Now, two devices are very important as direct contact heat exchanger. One of them is air washer and another is cooling tower both of them facilitate air water contact, contact of ambient air with water. And in both of them evaporation is a very important parameter of course, other than evaporation something else could be there; now and we are having something called moist air; that means, air with water vapor we are getting. So, it is very important to know the physics of air and water vapour mixture and that is called psychrometrics.

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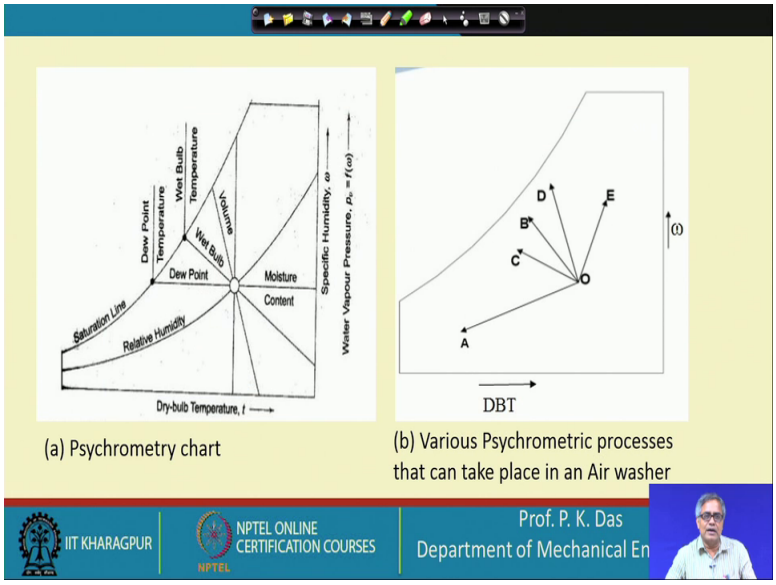

In the next slide we will see very quickly we will recapitulate psychrometric, this is not a class of either thermodynamics or refrigeration air conditioning; I will not go into details of psychrometrics. But I will tell you certain thing psychrometric chart looks like this, this is a psychrometric chart that which gives the properties of moist air and it gives this

properties of moist air at a particular pressure and this commonly used psychrometric chart are for atmospheric pressure.

So, in this psychrometric chart dry bulb temperature varies in this direction ok, low dry bulb temperature high dry bulb temperature and in this direction specific humidity varies. So, specific humidity it is given by the small w this is kg of water per kg of dry air and it is proportional to water vapor pressure also. So, that is there sometimes it is called humidity ratio, let us say we have got a point within this psychrometric chart so, it is dry bulb temperature can be obtained like this.

This is a constant dry bulb temperature in this direction we will get the moisture content from here and in this direction we will get the wet bulb temperature of this sample. From here wet bulb temperature and sorry enthalpy they are very close lines I mean with a very small angle between them.

So, enthalpy of the moist air that also can be obtained from here then, volume of the moist air along this line I will get. Another line, which is very important that is relative humidity line along this line I will get the relative humidity constant relative humidity so, this is the relative humidity line. Now, you see if I move in this direction; that means, what I am doing keeping the moisture content or specific humidity constant what I am doing I am reducing the dry bulb temperature and already pressure is constant.

So, at one point I will reach the 100 percent relative humidity or saturation curve so, this is called the dew point temperature, this is the dew point temperature. Now, if I put more humidity, but enthalpy more or less I try to keep it constant. So, I will get the constant wet bulb line and this way also I can reach the 100 percent saturation line. So, these are the few things regarding psychrometric chart, various psychrometric processes we can see in the other diagram and most of these processes can be realised with the help of our air washer.

So, in this direction what I am getting? I am getting cooling and dehumidification, which is very important for your summer air conditioning, in this direction I am getting heating bar plus humidification. So, sometimes this is important for winter air conditioning in between different paths and many of these processes by controlling the temperature of the water which is to be sprayed in, which is to be sprayed in a air washer, we can get many of these psychrometric processes.

I will not elaborate it, only one kind of heat exchanger I will spend some time because, that is very important and only one type of direct contact heat exchanger I like to give some details because of the constraint of time that is cooling tower. So, with this we will end our discussion on air washer let us go to cooling tower.

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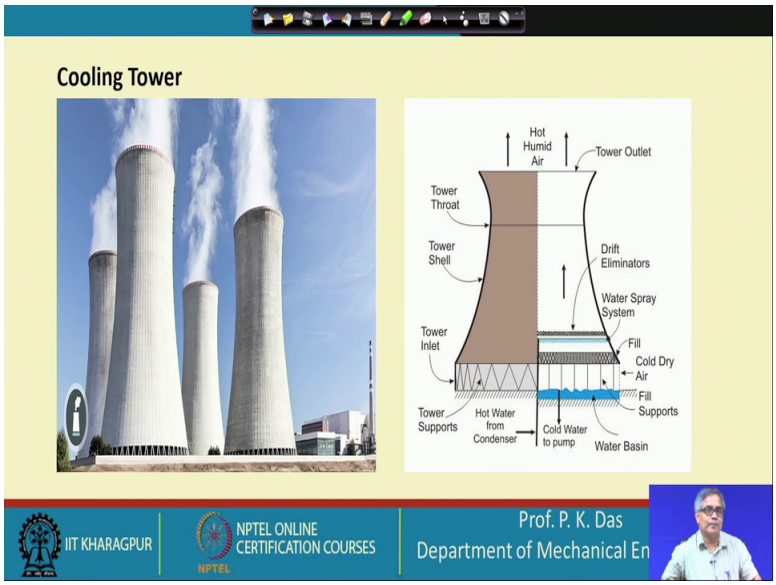

So, cooling tower is a device like this there are many similarities between air washer and cooling tower. In cooling tower we are cooling the circulating water, the circulating water may come from a very large power plant fossil fuel power plant or nuclear power plant or it may come from a chemical plant or it may come from a refrigeration plant.

Now, these are natural draft cooling tower very large cooling tower either it is connect with the size one can say that either it is connected to some nuclear power plant or some this thing or some fossil fuel coal based power plant, of course in case of oil refinery etcetera also one can get cooling tower. If I see that the part of the cooling tower it is like this ok, I have shown the cut view also.

So, what we will have? What we will have is like this there will be somewhere hot water will be injected, water spray system here hot water will be injected. So, hot water will pass through some sort of element heat transfer element which is called fill and this cooling tower has got a chimney like structure. So, that will create some sort of a natural draft by which ambient air will pass through like this so, hot water is falling like this and ambient is air is passing in the from the lower side to the higher upper side in this

opposite direction. So, it is a counter current flow kind of an arrangement and we will have good amount of mixing and the hot water will evaporate.

When the hot water will evaporate it will take the latent heat of evaporation from it is own body so, it will get cooled. Hot water may get sensibly cooled little bit with the help of air, but more than that it will evaporate and send the water to the to the dry air and by that way it will get cooled. So, that is the way water will get cooled, cold water will be collected at the bottom that can be taken again for the condenser cooling.

There is some sort of a drift eliminator here we can see some sort of a drift eliminator is there because, as the hot water is passing in the downward direction, air is passing in the upward direction there will be small droplet of water taken by that taken by the air that has to be separated so, drift eliminator will separate that.

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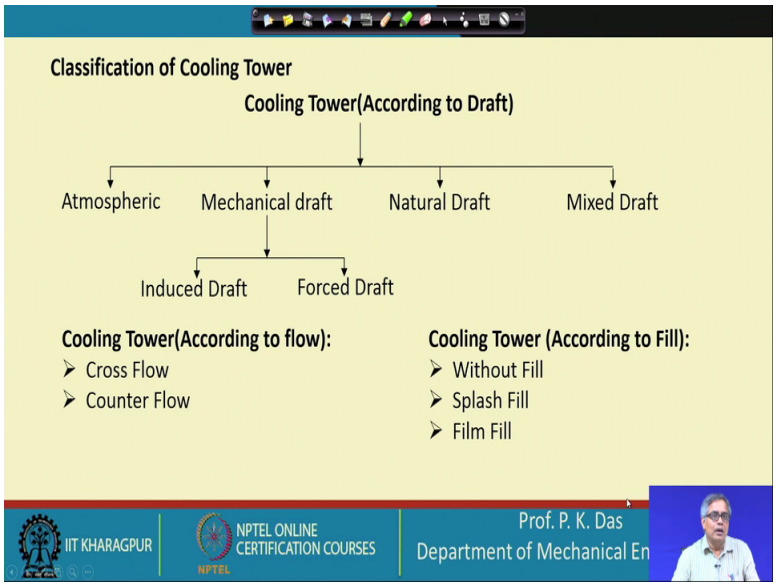

Well, let us go to some sort of a classification of cooling tower, cooling tower according to draft, it could be at atmospheric I mean neither we have got a chimney nor we have got a fan it is called atmospheric cooling tower. Then mechanical draft cooling tower it will have fan and either it could be induced draft or it could be forced draft if it is inducing air flow through the cooling tower then, it is induced draft, if it is forcing air flow through the cooling tower then, it is forced draft.

Then there could be natural draft that we can have some sort of a chimney that is creating the air flow rate it is called a natural draft cooling tower. And there could be mixed draft cooling tower some unique design where there will be natural draft plus there should be some there could be some sort of a fan. Then according to the flow it could be cross flow or counter flow and according to the fill the cooling tower could be without fill it may have some splash fill it may have some film fill.

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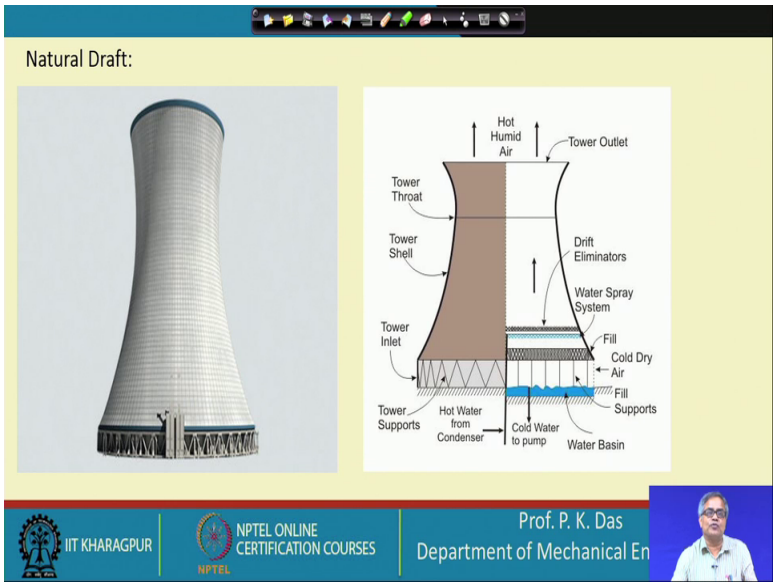

So, this is a natural draft cooling tower I will not explain it due to this chimney there is no fan the air will be drawn and this could be very large structure. And you see this is kind of a convergent divergent structure it has nothing to do with the nothing to do with the air flow, but this kind of structure gives better stability to the cooling tower. So, this is actually from the structural design, this is not from the fluid flow or heat transfer point of view that we have to give a convergent divergent kind of a design.

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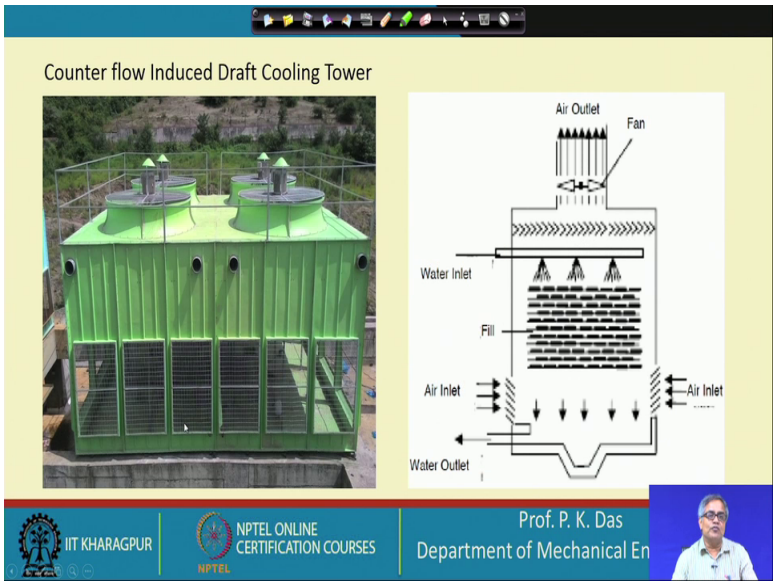

So, this is some sort of a cross flow, sorry this is counter flow heat exchanger, sorry counter flow cooling tower mechanical draft and induced draft. Induced draft there is a fan so, there is a fan so, it will induce the air flow through the cooling tower. And here there are fill sorry there are louvers through the louver air will come in and there is a fan so, the fan is inducing the flow, water is falling in the downward direction and the are fills so, this is your counter flow induced draft cooling tower.

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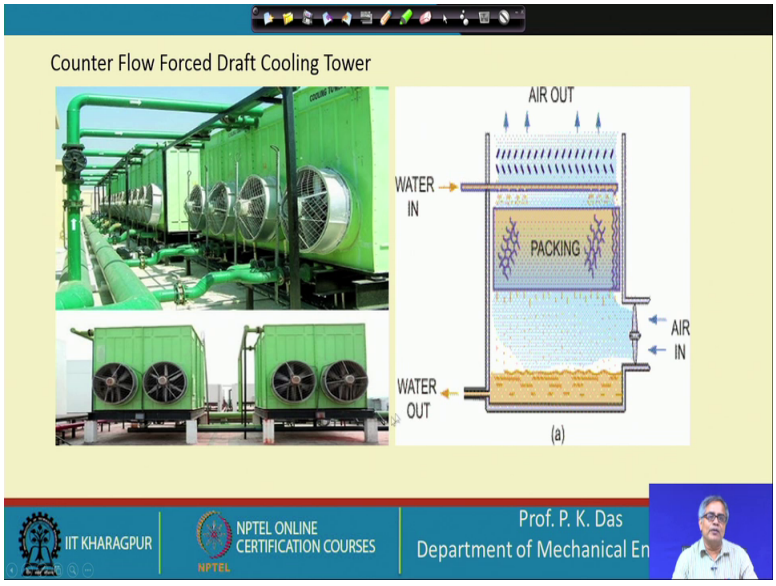

This is a forced draft cooling tower so; air will be forced through it ok. So, this is the forced draft cooling tower and there should be some packing of fill at the top we can find this is your drift eliminator.

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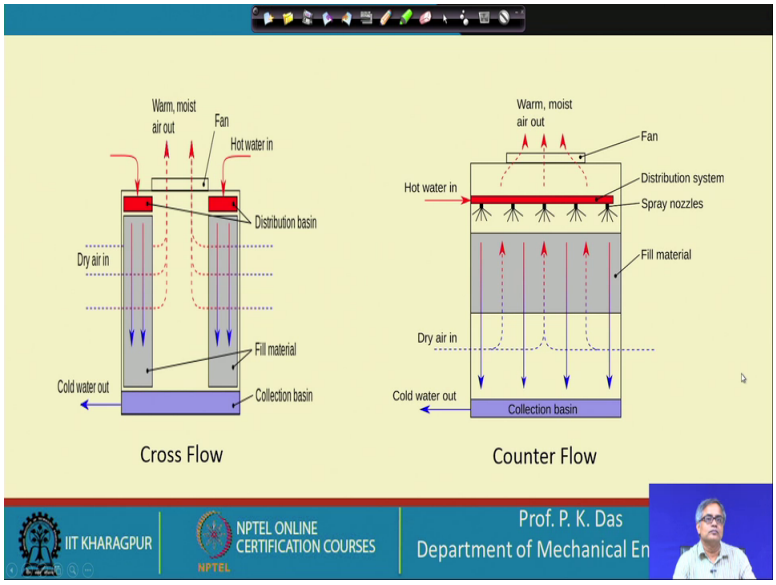

Now, this is a cross flow kind of cooling tower though the diagram is not very well representative of very good representative of a cross flow heat exchanger, sorry cross flow cooling tower. Because, cross flow cooling tower it is not vertical we will see some cross flow cooling towers later on probably and there is some sort of a slant surface, this surfaces should be little bit slant.

But, to understand the philosophy it can be this diagram is good. So, water will be falling in this direction, air will be moving in this direction at 90 degree to each other this is called cross flow, just like your cross flow heat exchanger. This is counter flow, in counter flow cooling tower water will be falling in the downward direction and air will be moving in the upward direction so, this is counter current flow as we have got in other heat exchanger also.

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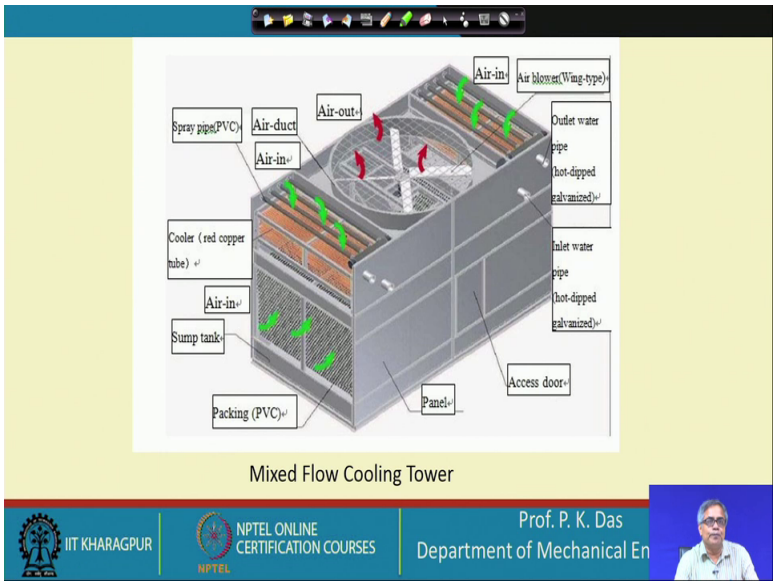

So, actually this is a mixed flow kind of cooling tower we can have some cooling tower where we can have some sort of a mixed flow that some flow is taking place like this and here also some flow is taking place. These are not very common design, but in some cases we can have mixed flow kind of cooling tower also.

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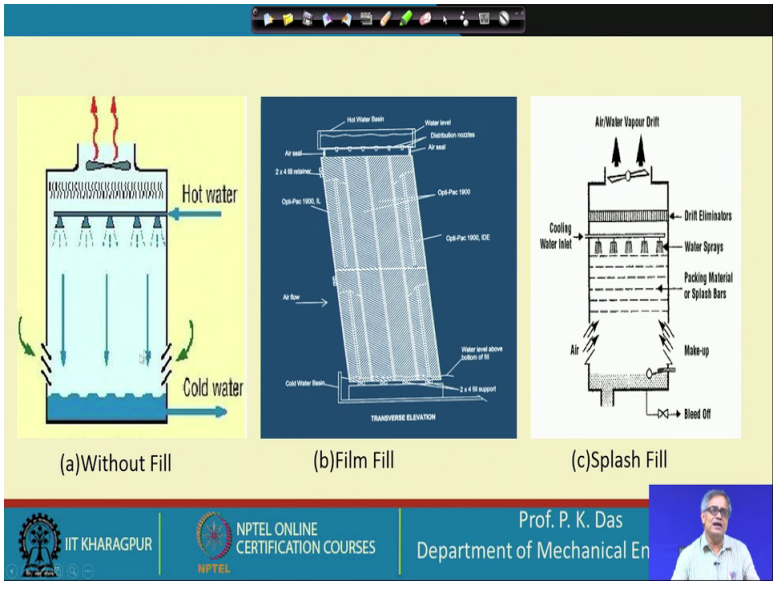

Different kind of fills have been explained over here so, this is without a fill atmospheric cooling tower in many cases we can find this atmospheric cooling tower, they are generally small and with small refrigeration or air conditioning unit we can have. This is

a cross flow heat exchange cross flow cooling tower. As I have told the wall should be slant so, wall is slant, air is moving like this and water is falling like this. So, it is a counter flow cooling tower sorry cross flow cooling tower and here we have got film fill, I think I have to explain what is film fill and here we have got splash fill so, this is also I will explain.

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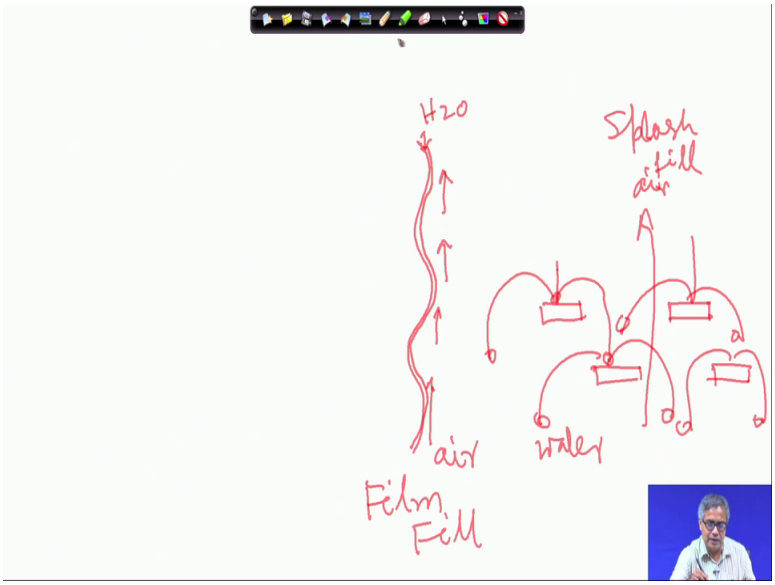

So, let me go to the so, film fill is like this, let us say we have got a surface and liquid water is forming a film over it like this. So, air is passing like this so, this is your film fill. And splash fill, so, this is film fill and splash fill is like this that we have got elements in the path of air and water.

So, water droplet is falling it is breaking into two droplets or more droplets, then falling then breaking into more droplets falling and here it is falling like this, falling like this from here it is falling. So, this is your water is basically splashing and air is moving in the upward direction, this is air and this is your water and here this is your water H2O and this is your air. So, this is the difference between splash fill and film fill.

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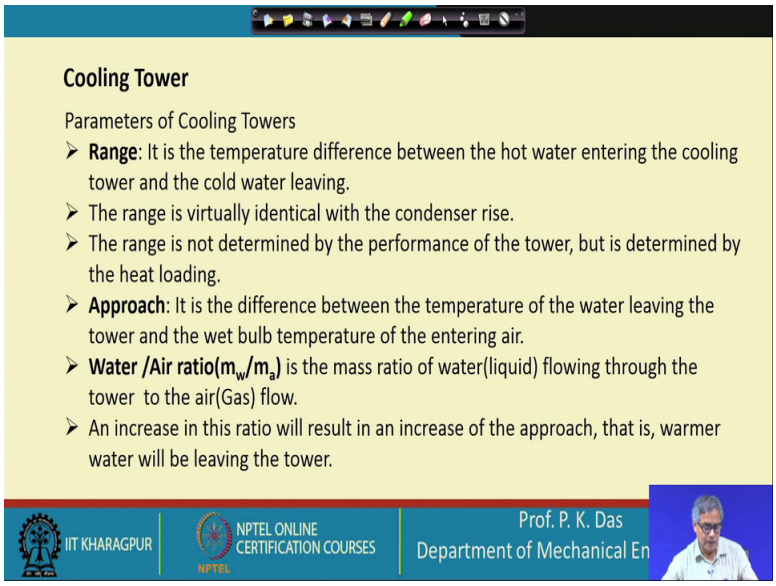

Now, two things are very important in case of cooling tower, one is range; it is the temperature difference between the hot water entering the cooling tower and the cold water leaving. The range is virtually identical with the condenser rise; that means, what is the temperature rise in the condenser then, there is another thing which is important that is your approach. It is the difference between the temperature of the water, leaving the tower and the wet bulb temperature of the entering air.

So, this is very important this point I like to stress upon that in a cooling tower the cold water temperature ideally should not ideally need not be the dry bulb temperature of the water, it could be even lower than that is the wet bulb temperature of water, sorry wet bulb temperature of the air.

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For this a small explanation is needed so, let us say this is your psychrometric chart, this is the ambient air condition, this is the DBT of the ambient air condition dry bulb temperature. If we put a thermometer in air we will find this, this is the wet bulb temperature of the ambient air, this is the wet bulb temperature. So; that means, WBT is less than DBT or it could be at best equal to DBT and if water is cooled ideally it can be cooled to WBT, ideally this can be cooled to WBT. So, water temperature could be in lower than the dry bulb temperature, but it will not be equal to the wet bulb temperature.

So, there is a difference between the wet bulb temperature and the cold water temperature. Let us say cold water temperature is denoted by, cold water temperature is denoted by your CWT so, CWT minus WBT is your approach; how closely it is approaching the wet bulb temperature. So, that is the approach ok. So, with this I will I would like to stop over here and then, we will see some more aspects of cooling tower in our next lecture.

Thank you.