Chemical Process Utilities
Prof. Shishir Sinha
Department of Chemical Engineering
Indian Institute Technology - Roorkee

Module No # 09
Lecture No # 44
Concept of Heat Transfer in Cooling Tower and it's Components

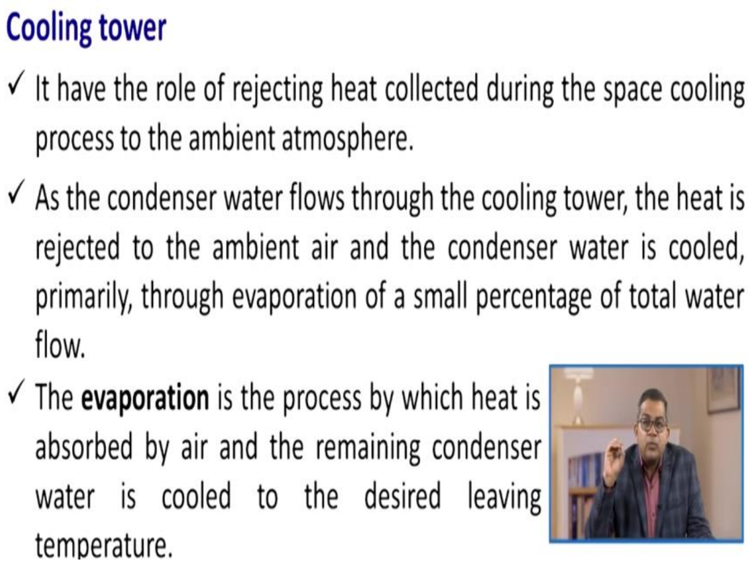
Welcome to the next lecture of cooling tower under the edges of chemical process utilities. Now, in this particular sector, we are going to discuss about the various concepts of heat transfer in cooling tower and different components. Now, before we go into have a broad discussion about this, let us have a brief outlook that what we discussed in the previous lecture.

So, in the previous lecture, we discussed about the theory, what is the theory of cooling tower? We perform some basic calculation, those related to the cooling tower these attributed to the moisture content that is pertinent to the absolute humidity, relative humidity mixing ratio. We discussed about the vapour pressure, we discussed about the dew point dry bulb temperature wet bulb temperature, we had one humidity calculation for reference.

Then we had a discussion about the total heat and enthalpy apart from the broad discussion about the psychometric chart. Now, in this particular lecture, he will discuss about the various concepts attributed to the heat transfer in cooling towers. We will discuss about the cooling tower, what are the different elements of cooling tower? Now, since as the name implies it may have some heat transfer aspects.

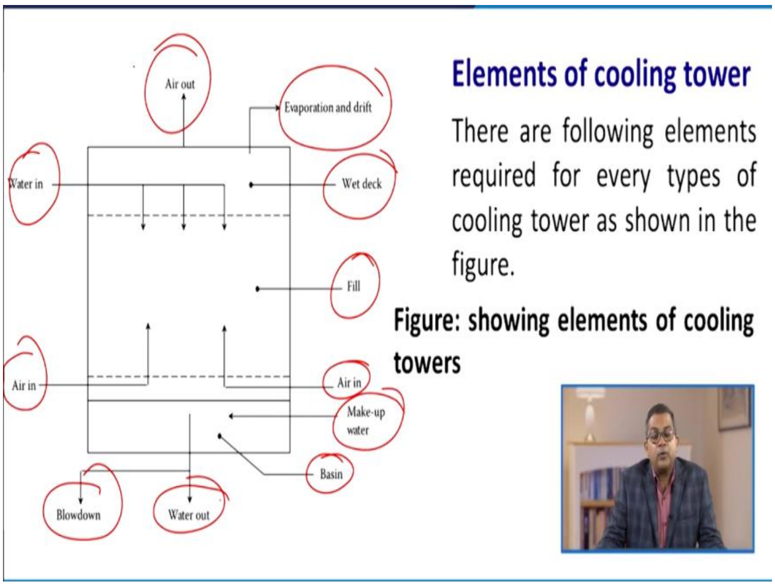
So, what is the heat transfer aspect in the cooling tower, we are going to discuss different modes of heat transfer. We will discuss about the heat transfer theory with respect to the overall heat transfer coefficient and Merkel's heat transfer theory. So, let us have a discussion about the cooling tower. Now, it has the role of rejecting heat collected during the space cooling process to the ambient atmosphere.

(Refer Slide Time: 02:23)



Now, as the condenser water flows through the cooling tower, the heat is rejected to the ambient air and the condenser water is good. Now primarily through evaporation of a small percentage of total water flow. Now, the evaporation is the process by which heat is absorbed by the air and remaining condenser water is cooled to the desired living temperature. So, by this way, it is a very important phenomenon in chemical engineering aspect.

(Refer Slide Time: 02.59)



Now, when we talk about the various elements of cooling tower, there are different elements required for every type of cooling tower. Now, in this particular figure like we must have evaporation and drift apart from this one must, have a wet deck feeling because it is duly supported by air. So, air inlet must be there. Similarly, the water inlet should be there, and because it is a phenomena of heat transfer between air and water.

So, you must have some makeup water then there is a basin and this water is coming out with the help of a blow down. And at the outset or at the upper part of this cooling tower we are having the outlet for the air.

(Refer Slide Time: 03:50)

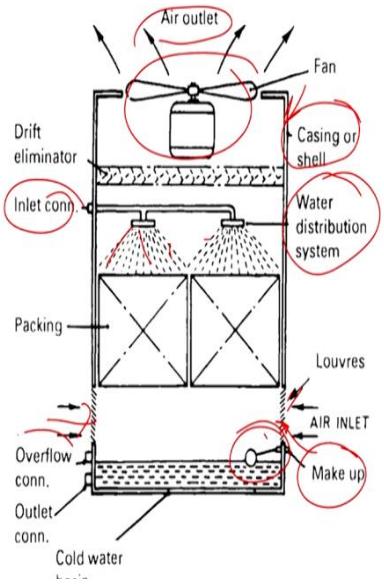


Figure: Schematic arrangement of typical mechanical draught cooling tower

Now, this is more you can say the schematic or a precise schematic arrangement of a typical mechanical draft of cooling tower here you see that it is supported by a fan to support the air outlet. We are having a proper casing and this if you recall that here we are having this water then water distribution system. This is through here you are distributing the water and there are certain packing’s for enhancing the overall heat transfer.

There are certain louvers through which you are supplying the inlet air and there is a port for this makeup water with the water sensor or water level indicator. Then there are certain overflows because sometimes this there may be over supply of water. So, there must be certain discharge port for the over overflow connection and this is the cold water basin.

(Refer Slide Time: 04:55)

Cont...

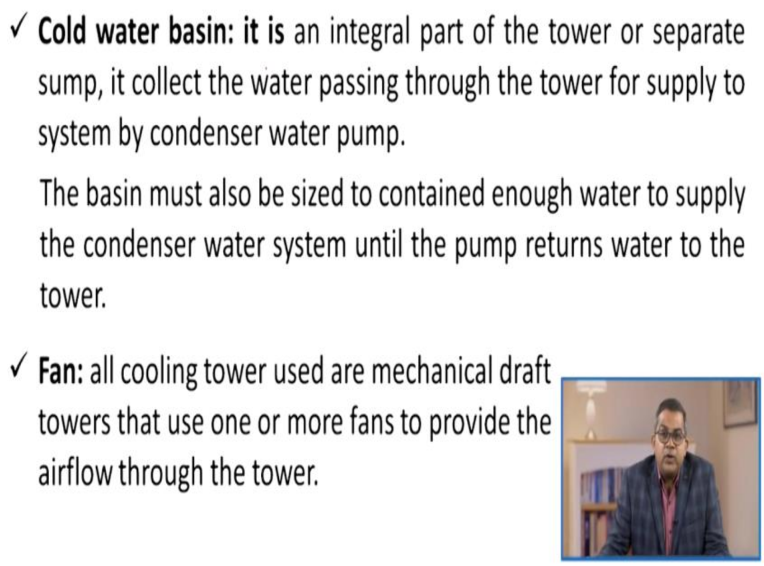
- ✓ **Fill or packing:** it is the heat transfer media in the cooling tower. The fill is designed to maximize the contact between the return condenser water and the ambient air. The better is the contact there are better the evaporation and heat transfer.
- ✓ **Wet Deck:** also known as hot water distribution, it is the pans or basins with metering outlets or spray nozzles designed to provide an even distribution of the return condenser water entering fill.

Now, when because we are discussing some elements of cooling tower. So, as you recall that we are having some packing over here. Now, this fill or packing, it is the heat transfer media in the cooling tower and these fields are designed to maximize the contact between the return condenser water and the ambient temperature. Now, the better is the contact, the better will be the evaporation and the heat transfer then there is a wet tech you see that here we are having this wet deck.

Now, this is also known as the hot water distribution, it is the pan or basin with metering outlet or spray nozzle. Now, here you see that these are the spray nozzle these spinners are designed to provide an even distribution of the return condenser water entering filling up operation. Then there is a cold water basin if you see that we here we are having the cold water basin.

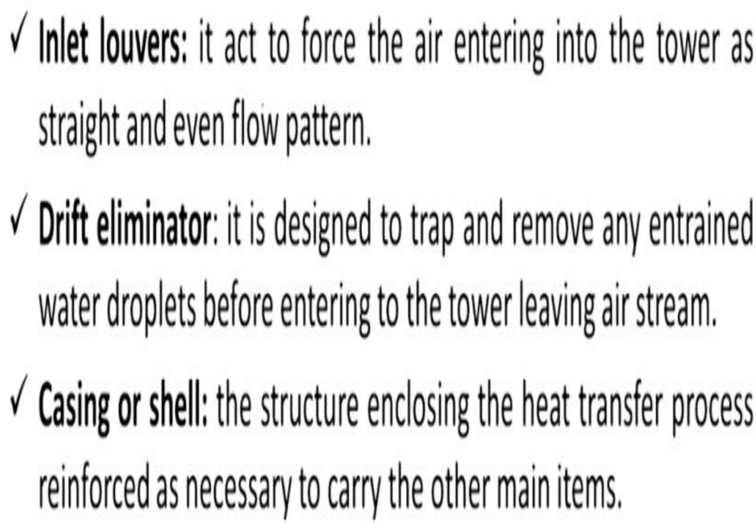
Now, it is an integral part of the tower or separate sump it collects the water passing through the tower for supply to system by condenser water pump. Now, this basin must also be sized to contain enough water to supply the condenser water system until the pump returns water to the tower then there must be fan here, we are having the fan.

(Refer Slide Time: 06:27)



Now, all cooling towers they use the mechanical draught tower that use one or more fans to provide the airflow through the tower then there are certain inlet louvers. Now, here you see that there are certain inlet louvers now.

(Refer Slide Time: 06:46)



It act to force the air entering into the tower as a straight or even flow pattern, then there are there is a drift eliminator. Now, it is designed to trap and remove any entrained water droplet before entering to the tower leaving air stream there. Then, obviously, all these things are there then we must have a casing or shell the structure enclosing the heat transfer process reinforced as necessary to carry the other main items.

(Refer Slide Time: 07:21)

- **Air inlet and outlet:** These are the positioned at which cooler air enters and warmed air leaves the tower. In natural draught towers the inlet is normally protected by drip-prof louvres and outlet by suitable grill. Whereas, in an induced draught fan is used the outlet as fan casing; with forced draught the fan casing provides the inlet.

Apart from this these cooling tower they are having some air inlet and outlet. Now, these are positioned at which the cooler air enters and warm air leaves the tower in natural draught tower. The inlet is normally protected by drip proof louvers and outlet by the suitable grills. Whereas in the induced draught fan is used the outlet as fan casing with forced drop the fan casing provide the inlet.

(Refer Slide Time: 07:56)

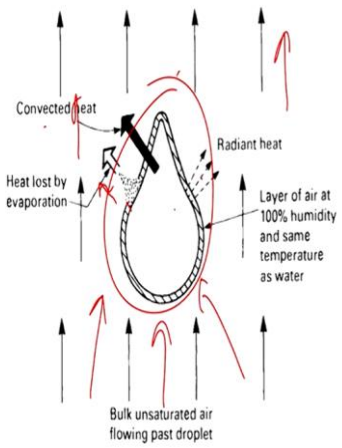


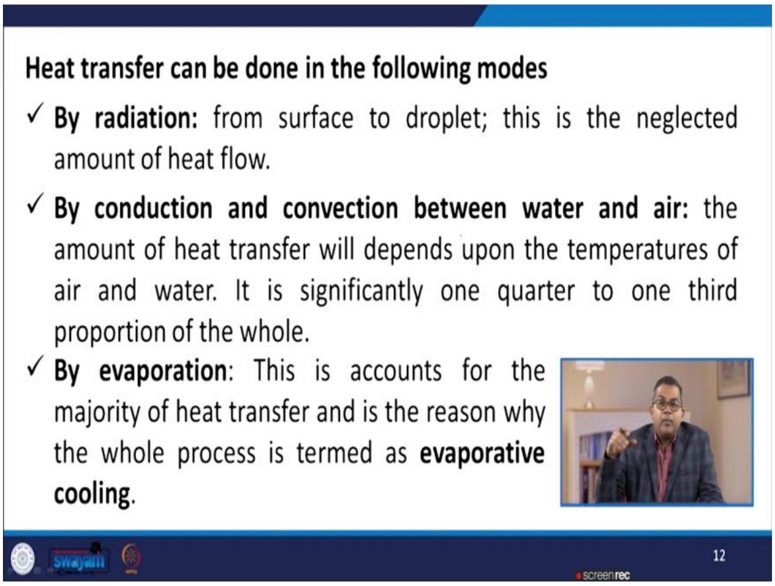
Figure: Showing various ways in which a water droplet loses heat.

Cooling Tower Heat Transfer

- The heat is transferred from a water droplet to the surrounding air by both the **sensible and latent heat transfer** processes.
- On considering a single droplet of water in the tower surrounded by the air.

Now, let us talk about the cooling tower heat transfer, the heat is transferred from water droplets to the surrounding air by both the sensible and latent heat transfer process. Now on if we consider a single drop of water here, you are having this single droplet of water in the tower and this is surrounded by the unsaturated air you see that here we are supplying some unsaturated air. Now, here you see that the heat is lost by the evaporation and this convicted heat is transferred to the surface and then this is the radiant heat.

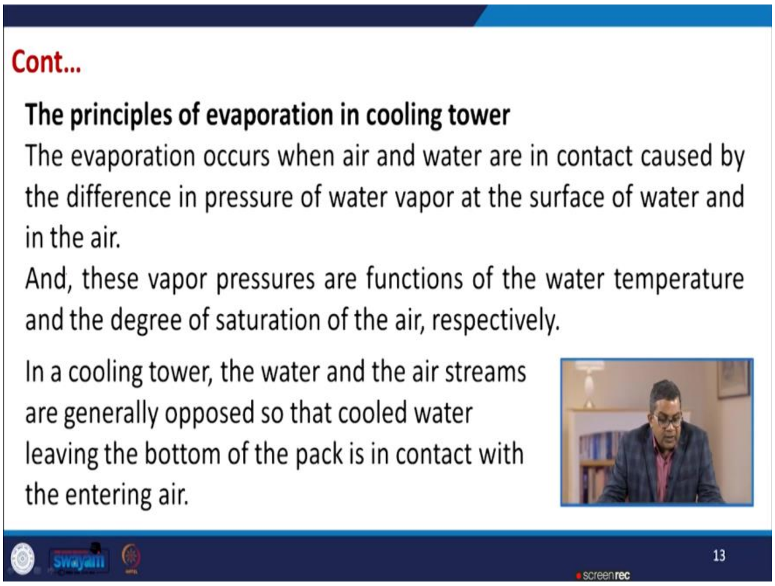
(Refer Slide Time: 08:41)



Now the heat transfer the question arises that how heat transfer can be done. Now the heat transfer can be done in various ways. One is by the radiation from surface to droplet and this is a neglected amount of heat flow. Now, here you see that now, by conduction and convection between water and air. The amount of heat transfer will depend upon the temperature of air and water.

It is significantly one quarter to one-third proportion of the whole another mode of heat transfer is by evaporation. This is accounts for majority of heat transfer and is the reason why the entire process is termed as evaporative cooling. Now, here you will see that the class by the evaporation

(Refer Slide Time: 09:33)

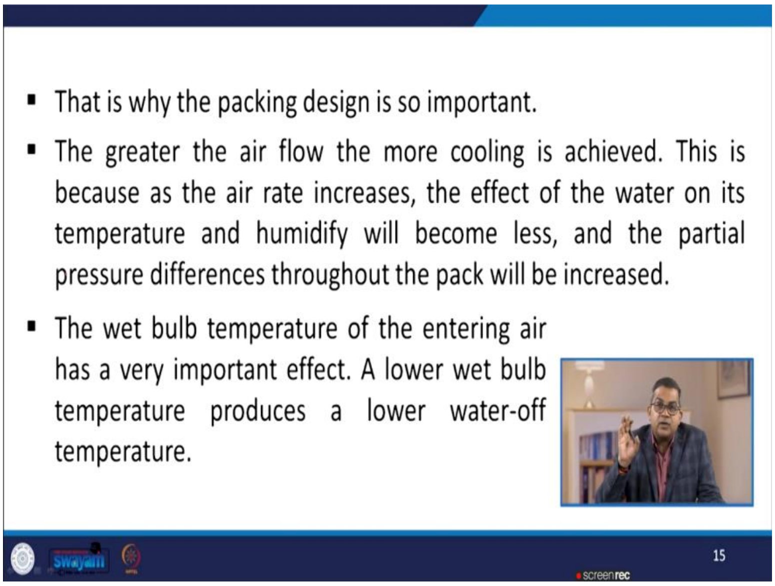


Now, the principle when we talk about the principles of evaporation in cooling tower, the evaporation occurs when air and water are in contact usually caused by the difference in pressure of water vapour at the surface of water and in the air. And these water these vapour pressures are function of the water temperature and the degree of such pollution of the air respectively.

Now, in a cooling tower, the water and air stream they are generally opposed. So that the cold water leaving the bottom of the pack. It is in contact with the entering air and that in other terms you can say they are in the counter currents manner they flowing the counter current manner. Similarly, how hot water entering the pack will be in contact with the warm air leaving the pack the evaporation usually will take place throughout the pack.

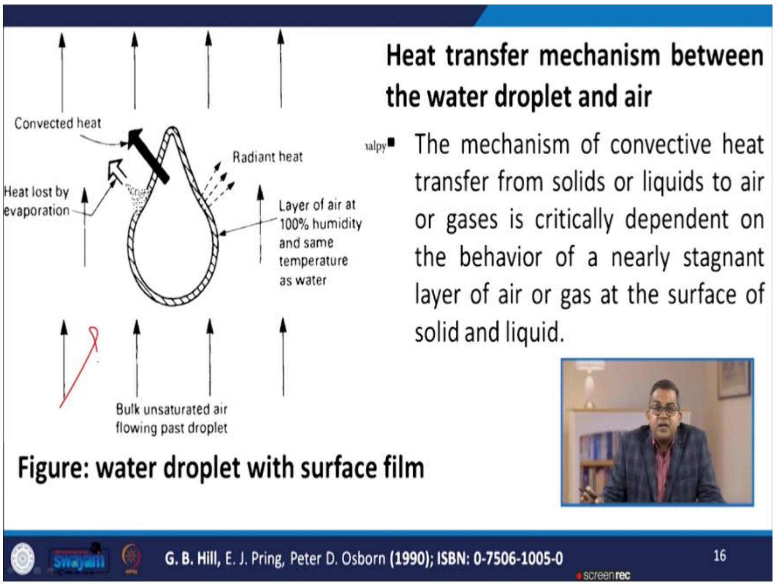
And it should be remarkably noted that at the top of the pack the air is nearly saturated and usually compensated for by the high water temperature and consequently high vapour pressure. The amount of evaporation which take place depends on a number of factors including the total surface area of the water present to the air and the amount of air flowing.

(Refer Slide Time: 11:05)



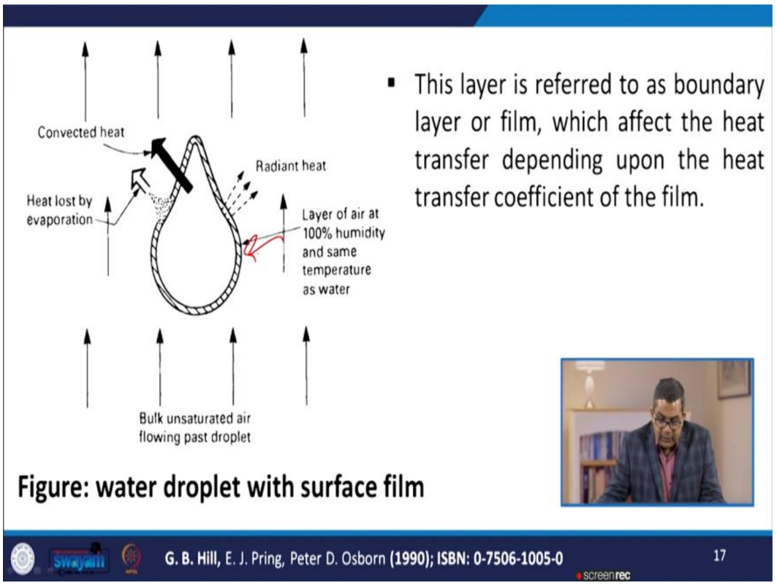
And that is why the packing design is so important the greater the air flow, the more cooling is achieved and this is because as the air rate increases the effect of water on its temperature and humidity situation will become less. And the partial pressure differences throughout the pack will be increased. The wet bulb temperature of the entering air has a very important effect. The lower the wet bulb temperature produces a lower water of temperature.

(Refer Slide Time: 11:43)



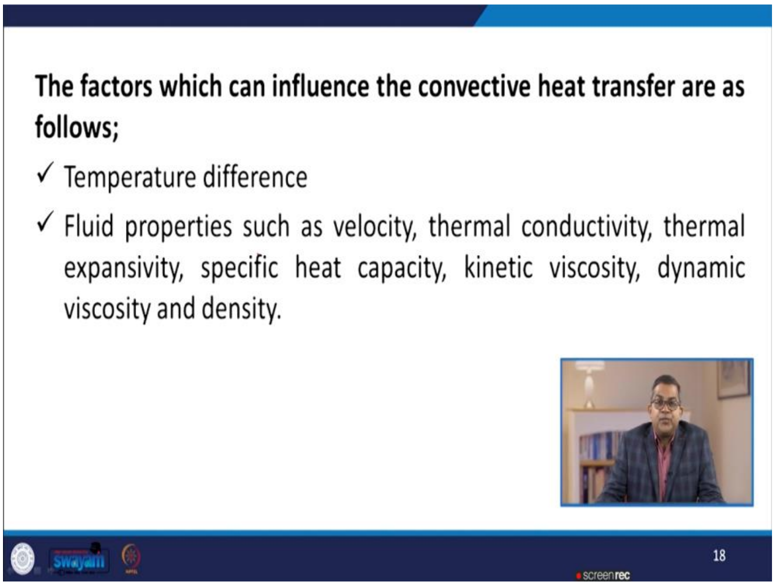
Come back to this figure again the heat transfer mechanism here now, we are discussing the heat transfer mechanism between the water droplet and air. The mechanism of convective heat transfer from solid or liquid to air or gases is critically dependent on the behaviour of a nearly stagnant layer of air or gas at the surface of the solid and liquid.

(Refer Slide Time: 12:08)



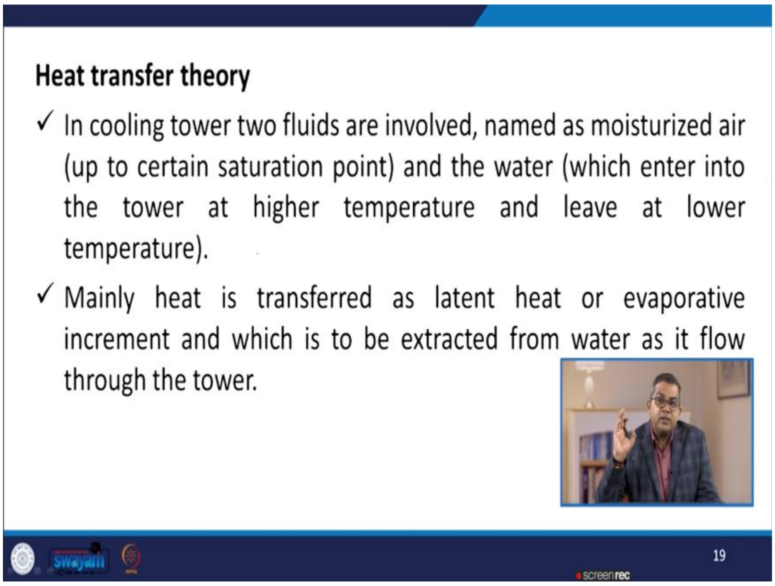
Now, this layer is referred as the boundary layer of film, which usually affects the heat transfer depending on the heat transfer coefficient of the film. So, we are talking about this particular layer not there are a couple of factors which can influence the convective heat transfer.

(Refer Slide Time: 12:34)



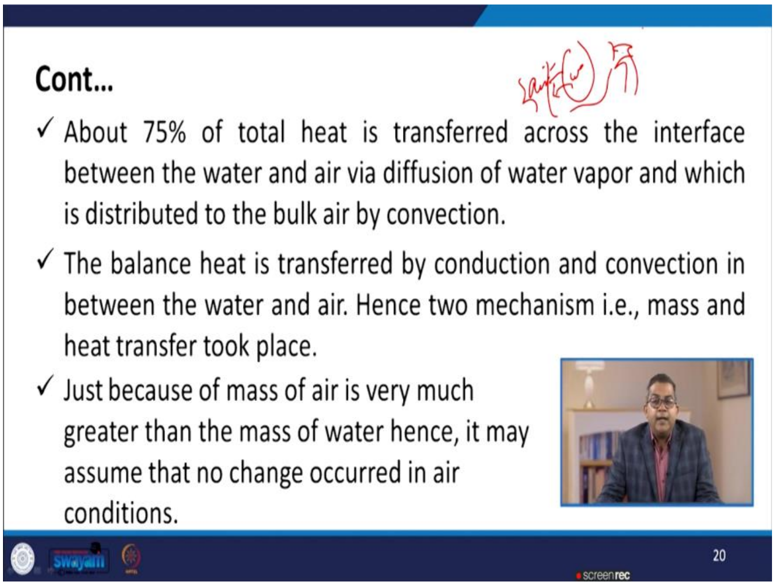
Now, those are one is the temperature difference and second is the fluid properties such as velocity thermal conductivity, thermal expansivity, specific heat capacity, kinetic viscosity, dynamic viscosity and density. Now, let us talk about the heat transfer theory.

(Refer Slide Time: 13:00)



Now, in cooling tower 2 fluids are involved one is moisturized air that is up to a certain saturation point and the water which enters into the tower at higher temperature and leaves the tower at lower temperature. Now, mainly heat is transferred as latent heat or evaporative increment and which is to be extracted from water as it flows through the tower.

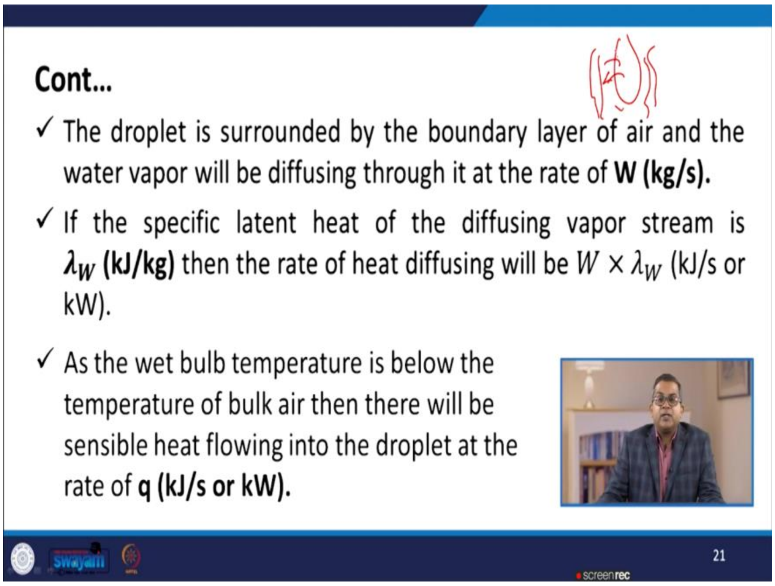
(Refer Slide Time: 13:22)



Now, roughly 75% or about 75% of total heat is transferred across the interface between the water and air. Now, this is a droplet and this is surrounded by air. So, this is the water droplet and this is air. So, this is the mode of this particular transfer is the diffusion or via diffusion of water vapour. Now, this is distributed to the bulk air by convection. So, first thing is that the diffusion and then it is the convection.

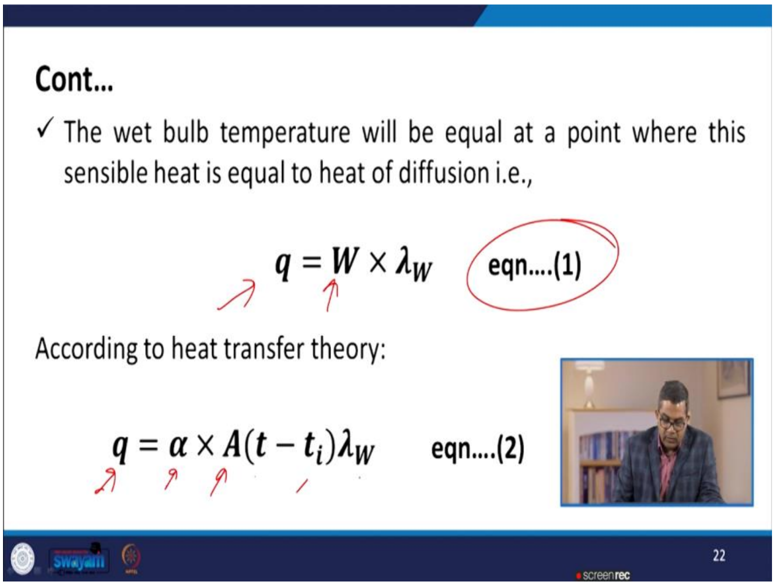
So, convective heat transfer applies the balance heat is transferred by conduction and convection in between the water and air. So, the 2 mechanisms that is mass and heat transfer usually take place. Now, just because of mass of air that is usually very much greater than the mass of water. Therefore, it may be assumed that no change occurred in the air condition. Now, that droplet is surrounded by the boundary layer of air and the water vapour will be diffusing through at its rate of say watt per kilogram second.

(Refer Slide Time: 14:47)



I mean this is the droplet and surrounded by this current of air. Now, if the specific latent heat of the diffusing vapour stream is lambda W and that is referred as kilogram per kilo joules per kilogram, then the rate of heat diffusing will be W into lambda W or kilo joule per second or kilo watt. Now, as the wet bulb temperature is below the temperature of bulk then there will be a sensible heat flowing into the droplet at the rate of q and that is that is having the unit of kilo joule per second or kilowatt.

(Refer Slide Time: 15.31)



Now, the wet bulb temperature will be equal at a point to where this particular sensible heat is equal to the heat of diffusion. And this is the mathematical representation that is q = W into delta lambda w and that is equation number 1. Now, if you recall the heat transfer theory now, it says that q = alpha into A into t – t_i into lambda w that is equation number 2.

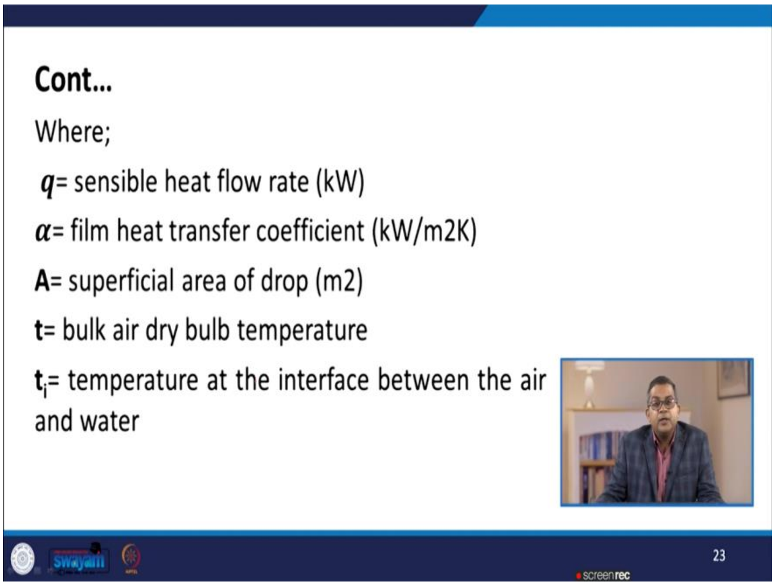
(Refer Slide Time: 16:10)

The wet bulb temperature will be equal at a point where this sensible heat is equal to heat of diffusion i.e.,

$$q = W \times \lambda_W \qquad \textbf{eqn....(1)}$$

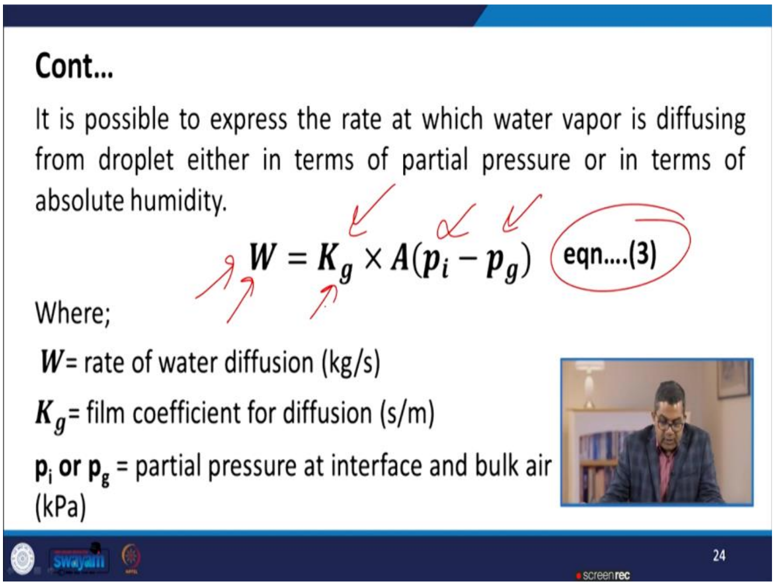
According to heat transfer theory:

$$q = \alpha \times A(t - t_i)\lambda_W \qquad \textbf{eqn....(2)}$$



Now, where the Q is the sensible heat flow rate in kilowatt alpha is the film heat transfer coefficient and it is having the unit of kilo watt per meter square Kelvin A is the superficial area of drop unit meters squared t is the bulk air dry bulb temperature and t I is the temperature at the interface between the air and water.

(Refer Slide Time: 16:48)



Now, it is possible to express the rate at which the water vapour is diffusing from droplet either in terms of partial pressure or in terms of absolute humidity. So, if we take that water this W = K_g into A into $p_i - p_g$ that is equation number 3. Where, w is the rate of water diffusion that is kilogram per second this K_g is the film coefficient of diffusion. Then p_i and p_g they are the partial pressure at the interface and the bulk and usually represented in the unit of kilo Pascal.

(Refer Slide Time: 17:38)

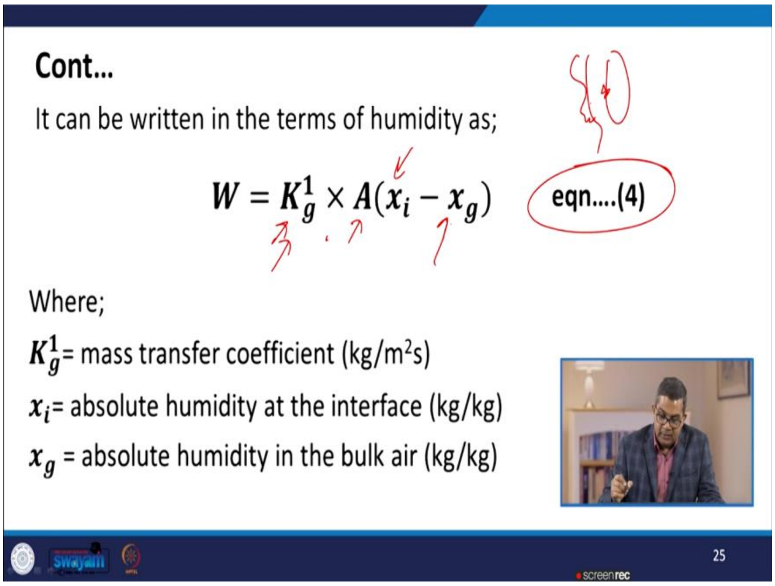
$$W = K_g \times A(p_i - p_g) \qquad \textbf{eqn....(3)}$$

Where;

W= rate of water diffusion (kg/s)

K_g= film coefficient for diffusion (s/m)

p_i or p_g = partial pressure at interface and bulk air (kPa)



Now one can write this equation in terms of humidity that is W = K^1_g into A into x_i - x_g we are this K^1_g is the mass transfer coefficient having the unit of kilogram per meters centimetre x_i is the absolute humidity at the interface. That is obviously, having the unit of kilogram per kilogram and the x_g is the absolute humidity in the bulk air and that is again the unit of a kilo gram per kilogram.

(Refer Slide Time: 18:20)

It can be written in the terms of humidity as;

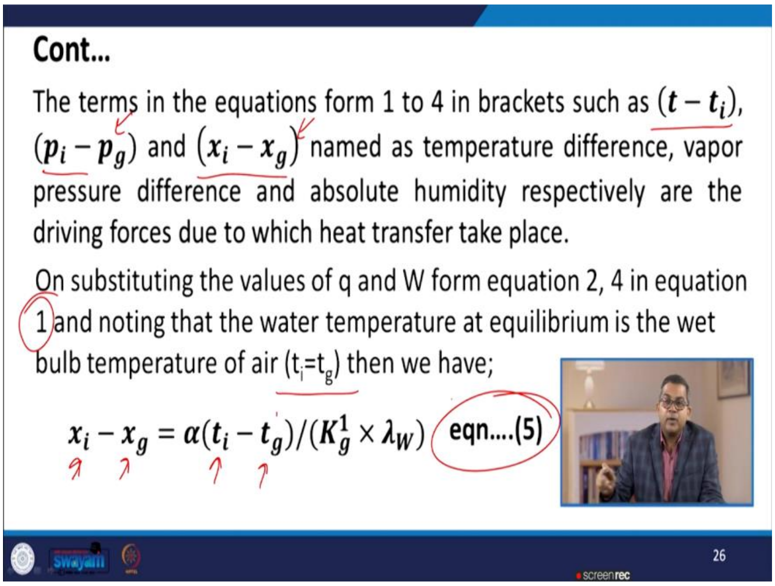
$$W = K_g^1 \times A(x_i - x_g) \qquad \textbf{eqn....(4)}$$

Where;

K_g^1= mass transfer coefficient (kg/m^2 s)

x_i= absolute humidity at the interface (kg/kg)

x_g = absolute humidity in the bulk air (kg/kg)

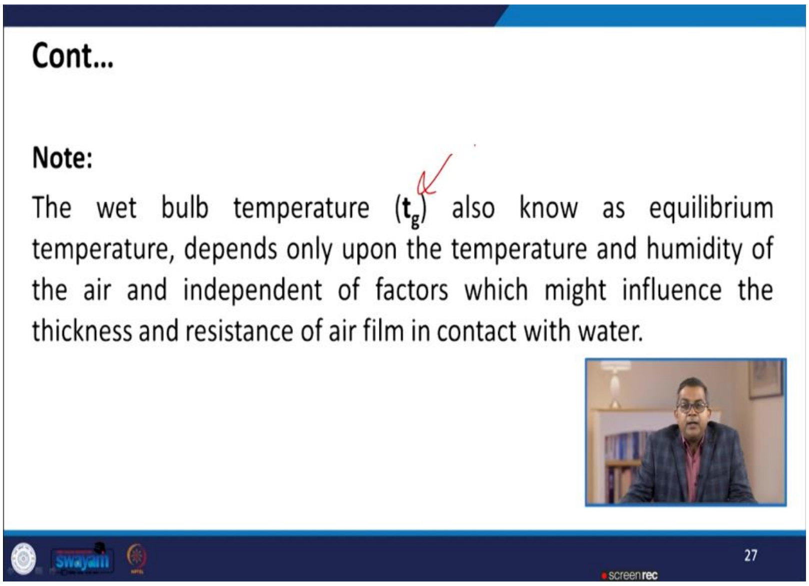


Now, the terms in the equation from all these equation from equation number 1 to 4 that is a t – t_i or $p_i - p_g$ or $x_i - x_g$ named as the temperature difference vapour pressure difference and absolutely absolute humidity respectively. And they are the driving force due to which heat transfer takes place now, obviously when we are looking for this heat transfer aspect. Then definitely there must be some driving force and this is the way through you which you can represent and you can analyse the scenario that how this heat transfers takes place?

Now, if we substitute the values of q and W from these previous 2, equation number 2 and equation number 4 an equation, very first equation and that assuming that the water temperature at equilibrium is the wet bulb temperature of air. In that case the t i would be equal to t g then we have $x_i - x_g$ = alpha $t_i - t_g$ over K^1_g into lambda and that is equation number 5.

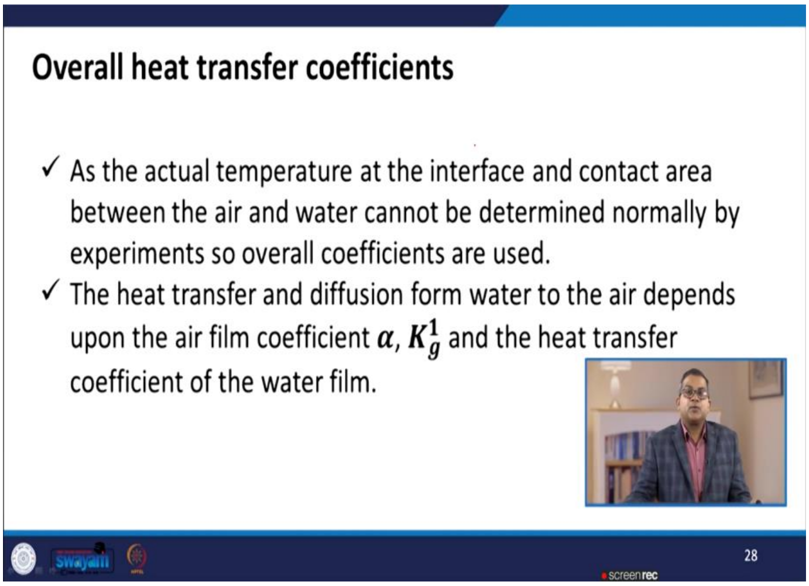
(Refer Slide Time: 19:40)

$$x_i - x_g = \alpha(t_i - t_g)/(K_g^1 \times \lambda_W) \qquad \text{eqn....(5)}$$



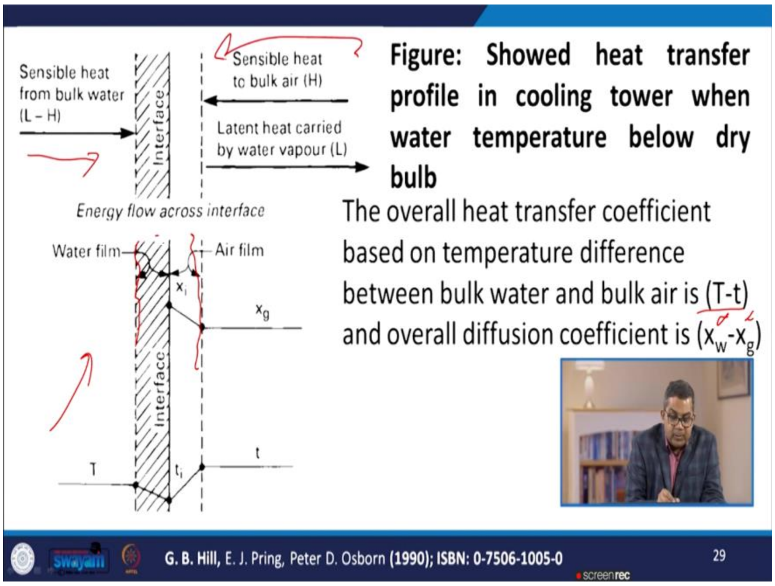
Now, the wet bulb temperature t g this also known as a equilibrium temperature, it depends only upon the temperature and humidity of the air. And it is usually independent of the factor which might influence the thickness and resistance of the air fit film in contact with water.

(Refer Slide Time: 20:03)



Now, let us talk about the overall heat transfer coefficient. Now as the actual temperature at the interface and contact area between the air and water cannot be determined normally by experiment. So, overall coefficients are used the heat transfer and diffusion from for water to air, it depends upon the air film coefficient and alpha and $K^1{}_g$ and the heat transfer coefficient of the water film

(Refer Slide Time: 20:40)



Now, this particular figure shows the heat transfer profile in cooling tower when water temperature below the dry bulb temperature. So, the overall heat transfer coefficient based on the temperature difference between the bulk water and bulk air is T - t and overall diffusion coefficient is $X_w – X_g$. So, here you see that we are having this air fill and this is we are having this water filled now, this we have to look at the sensible heat from bulk water.

And this is the sensible heat from bulk air and latent heat carried out by the vapour. Now, the overall heat transfer coefficient based on the temperature difference between the bulk water and the bulk is T - t.

(Refer Slide Time: 21:37)

Cont..

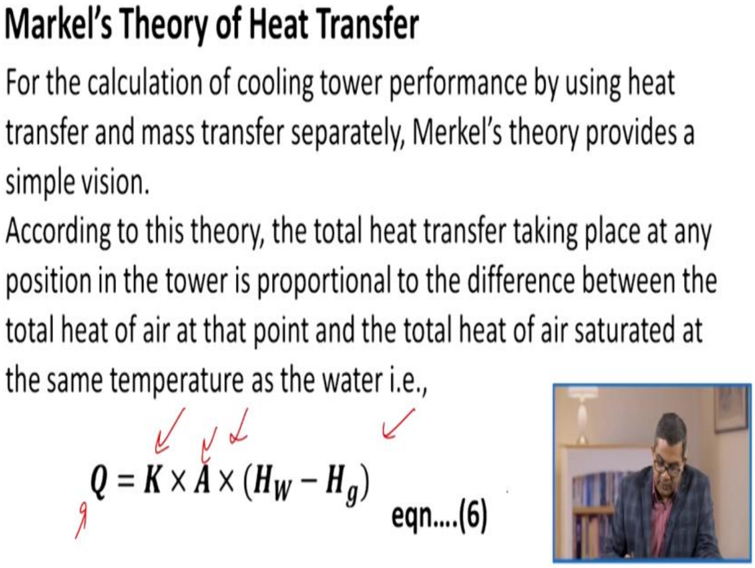
Note:

α is the thermal conductivity and K_g^1 is diffusion coefficient.

The thickness of the film is primarily a function of the mass velocity of the air passing in the film.

Now, alpha is the thermal conductivity and K^1_g as I just told you is the diffusion coefficient. Now, the thickness of the film is primarily a function of mass velocity of the air passing in the film.

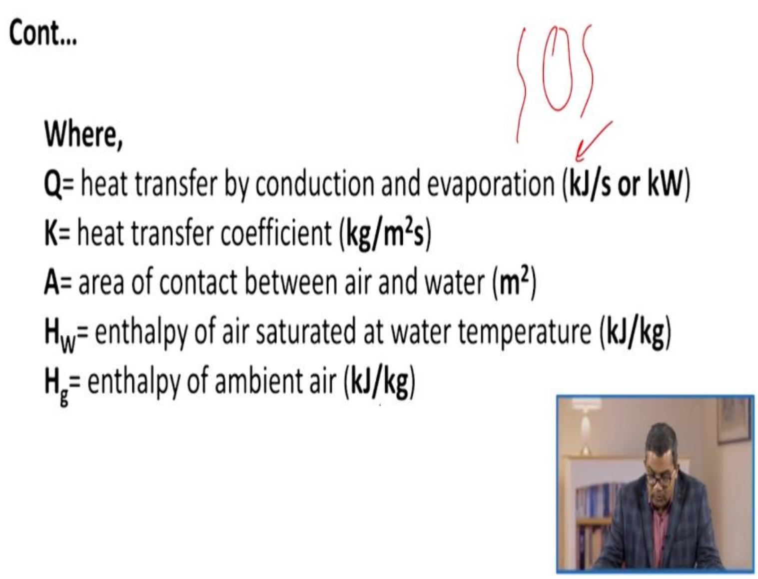
(Refer Slide Time: 21:59)



Now, let us talk about the Marcus theory of heat transfer for calculation of cooling tower performance by using heat transfer and mass transfer separately, the Markel's theory provides a simple version. According to this particular theory the total heat transfer taking place at any position in the tower is proportional to the difference between the total heat of air at that particular point and the total heat of air saturated at the same temperature as the water and that is Q = K into A into $H_w – H_g$ and that is equation number 6.

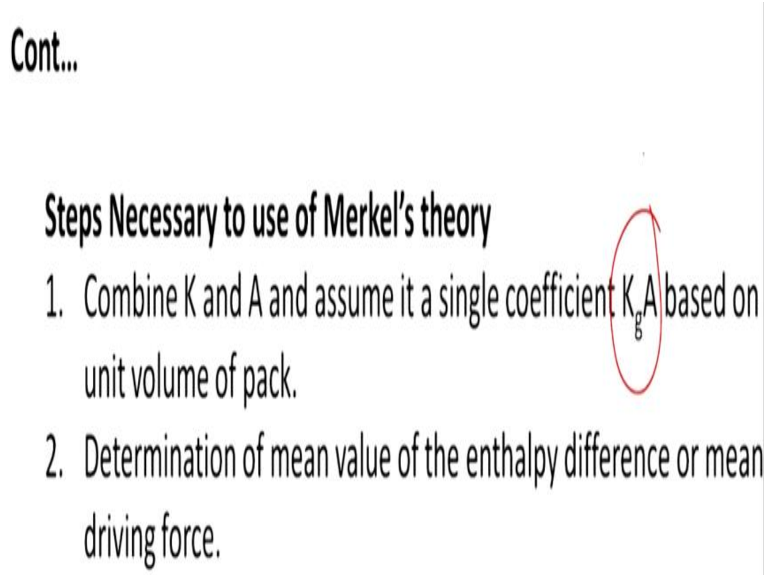
(Refer Slide Time: 22:44)

$$\boldsymbol{Q = K \times A \times (H_W - H_g)} \qquad \textbf{eqn....(6)}$$



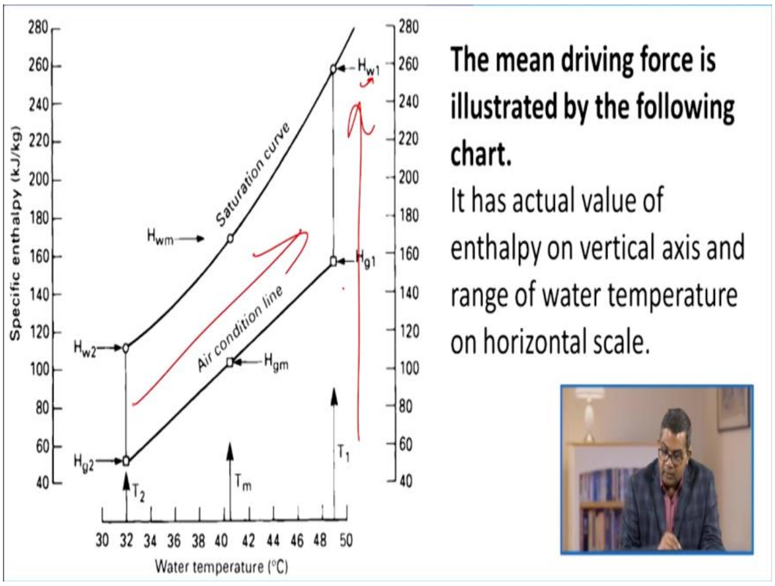
Now, here q is equal to the heat transfer by conduction and evaporation and referred as kilo joule per second or kilowatt. Now, K is the heat transfer coefficient having the unit of kilogram per meter square second. A is the area of contact between the air and water that is meters squared. H_w is the enthalpy of air saturated at water temperature that is having the unit of kilojoules per kilogram and H_g is the enthalpy of ambient air and again having the unit of kilojoules per kilogram.

(Refer Slide Time: 23:33)



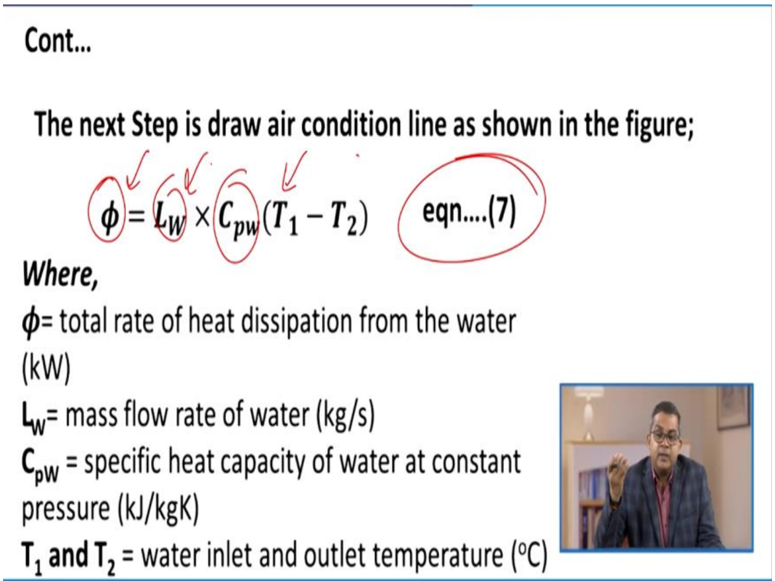
Now, there are various steps which are necessary if you use the Merkel's theory. Now, you need to combine K and A and assume it to a single coefficient of K_gA that is based on the unit volume of pack then determination of a mean value of the enthalpy difference or main driving force.

(Refer Slide Time: 23:59)



So, mean driving force is usually the illustrated by this particular chart. Now, it has the actual value of enthalpy on vertical axis, here you see that H g m and H w m and the range of water temperature on horizontal scale.

(Refer Slide Time: 24:21)



Now, another step which we need to look into is that to drop the air condition line. Now, here you see that this air conditioned line. Now, this is equal to the phi = L_w into C_{pw} into $T_1 – T_2$ and that is equation number 7. Now, what, is phi? The phi is that total rate of heat dissipation from the water and that is represented in kilowatt. L_w is the mass flow rate of water that is in kilograms per Second.

And C_{pw} is the specific heat capacity of water at constant pressure that is kilojoules per kilogram Kelvin and T_1 and T_2 are water inlet and outlet temperature obviously, they are represent that in terms of the unit of degree Celsius.

(Refer Slide Time: 25:19)

The next Step is draw air condition line as shown in the figure;

$$\phi = L_W \times C_{pw}(T_1 - T_2) \qquad \textbf{eqn....(7)}$$

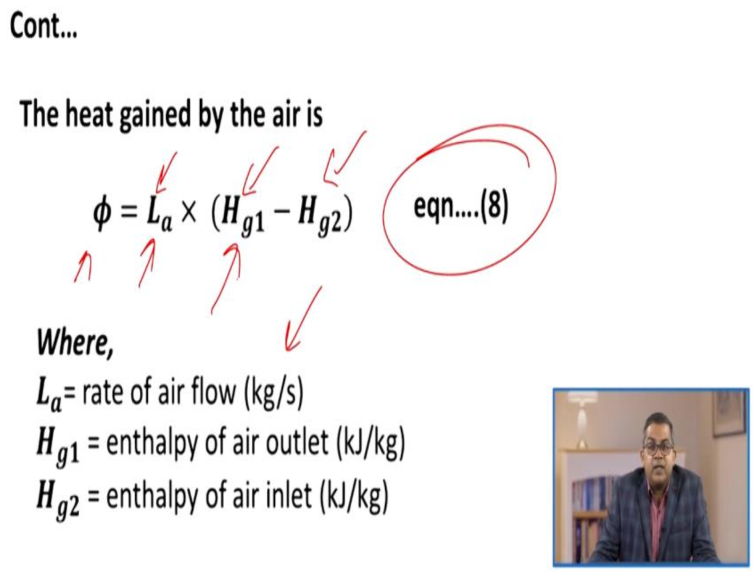
Where,

ϕ= total rate of heat dissipation from the water (kW)

L_W = mass flow rate of water (kg/s)

C_{pW} = specific heat capacity of water at constant pressure (kJ/kgK)

T_1 and T_2 = water inlet and outlet temperature (^oC)



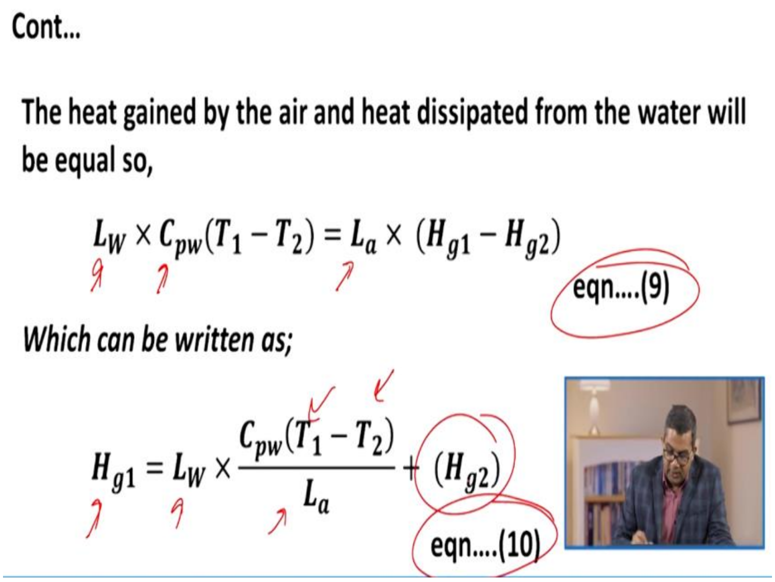
So, heat gained by the ear is phi = L_a into $H_{g1} - H_{g2}$ and that is equation number 8. Now, here L_a is the rate of air flow in kilogram per second, H_{g1} is the enthalpy of air outlet that is kilojoules per kilogram; H_{g2} is the enthalpy of air inlet in kilojoules per kilogram.

(Refer Slide Time: 25:49)

The heat gained by the air is

$$\phi = L_a \times (H_{g1} - H_{g2}) \qquad \textbf{eqn....(8)}$$

Where,
L_a= rate of air flow (kg/s)
H_{g1} = enthalpy of air outlet (kJ/kg)
H_{g2} = enthalpy of air inlet (kJ/kg)



So, if we see that the heat gained by the air and heat dissipated from the water will be equal. So, L_W into C_{pw} into T_1 -T_2 = L_a into H_{g1} – H_{g2}, and that is equation number 9. Now, one can write this particular equation, if we try to rearrange this equation, and that is H_{g1} = L_W into C_{pw} into T_1 – T_2 upon L_a + H_{g2} and that is equation number 10.

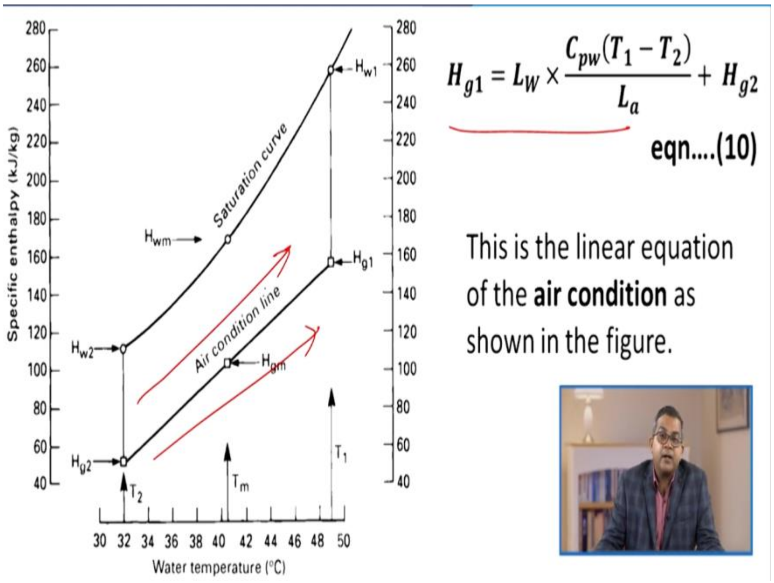
(Refer Slide Time: 26:30)

The heat gained by the air and heat dissipated from the water will be equal so,

$$L_W \times C_{pw}(T_1 - T_2) = L_a \times (H_{g1} - H_{g2}) \qquad \textbf{eqn....(9)}$$

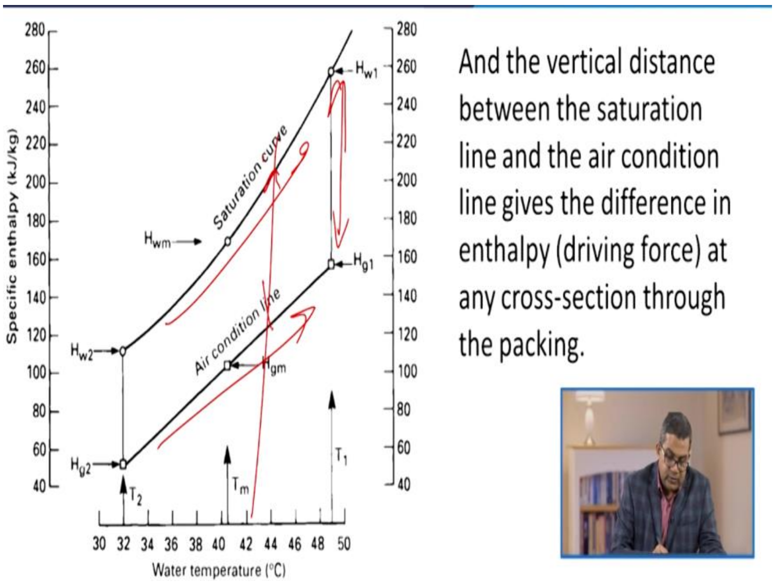
Which can be written as;

$$H_{g1} = L_W \times \frac{C_{pw}(T_1 - T_2)}{L_a} + (H_{g2}) \qquad \textbf{eqn....(10)}$$



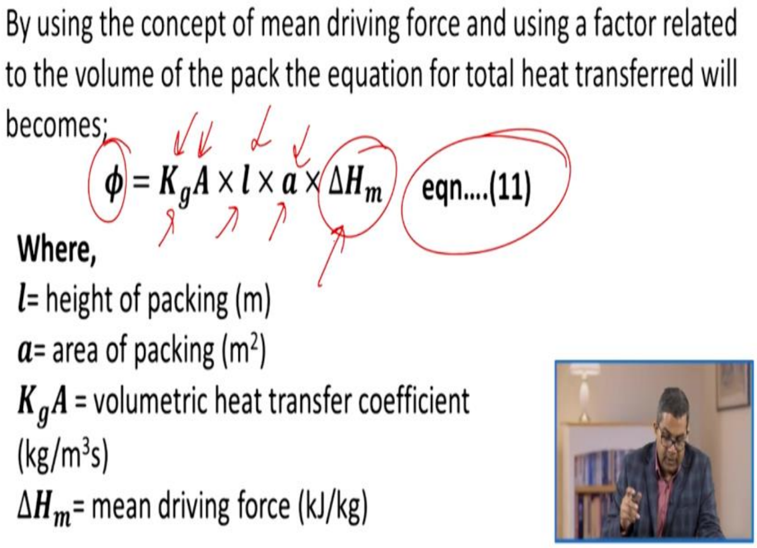
Now, this if we try to formulate in this particular figure, which is representing the water temperature versus a specific enthalpy. Then there is a linear equation of air condition and this particular line this shows the air conditioning line or air conditioned line.

(Refer Slide Time: 27:00)



Now, the vertical distance this one between the saturation line this is a saturation curve and air conditioning line. This gives the difference in the enthalpy that is the driving force at any cross section through the packing. So, if we take this cross section this gives you that particular useful information.

(Refer Slide Time: 27:24)

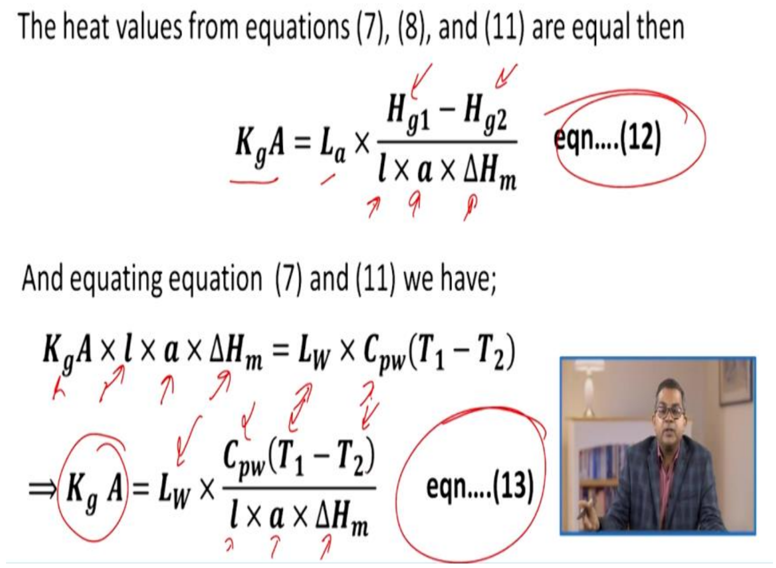


Now, by using the concept of mean driving force and using a factor that is related to the volume of the pack of the equation for total heat transfer, this becomes Phi =K_{gA} into L into a into delta H_m and that is equation number 11. Now, the L is the height of packing in meter this a, is the area of the packing the unit is meter squared. And this K_gA that is the volumetric heat transfer coefficient that is kilo gram per meter cube second.

And delta Hm is the main driving force which we have already discussed this is delta Hm and having the unit of kilojoules per kilogram.

(Refer Slide Time: 27:16)

$$\phi = K_g A \times l \times a \times \Delta H_m \qquad \text{eqn....(11)}$$



So, the heat values from the equation number seven in the previous slides' equation number 78 and 11 they are equal then K_gA = La into $H_{g1} - H_{g2}$ upon L into a into delta H_m that is equation number 12. Now, if we equate the equation 11 and equation 11 Then we have K_{gA} into L into a into delta H_m = L_W into C_{pw} $T_1 - T_2$ and if we try to rearrange this thing, then it becomes the K_gA = L_W into C_{pw} $T_1 - T_2$ upon L into a into delta H_m and that is equation number 30.

(Refer Slide Time: 29:05)

The heat values from equations (7), (8), and (11) are equal then

$$K_gA = L_a \times \frac{H_{g1} - H_{g2}}{l \times a \times \Delta H_m} \qquad \text{eqn....(12)}$$

And equating equation (7) and (11) we have;

$$K_gA \times l \times a \times \Delta H_m = L_W \times C_{pw}(T_1 - T_2)$$

$$\Rightarrow K_gA = L_W \times \frac{C_{pw}(T_1 - T_2)}{l \times a \times \Delta H_m} \qquad \text{eqn....(13)}$$

Note;

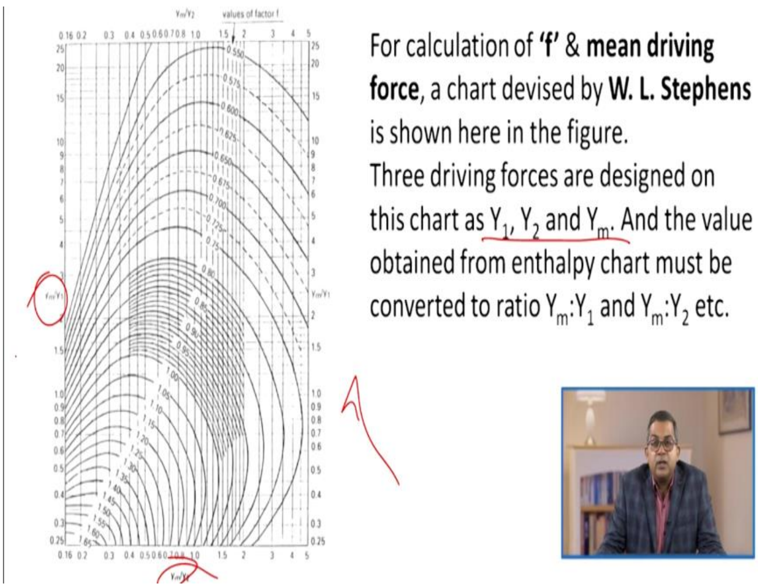
In the practical situation the values for the H_{g1}, H_{g2}, L_w, L_a, T_1 and T_2 are known.

The air condition line can be drawn by connecting the point H_{g1} and H_{g2}.

By using water temperature on the horizontal scale it is possible to mark off the driving force at the top and bottom of the tower and mean point.

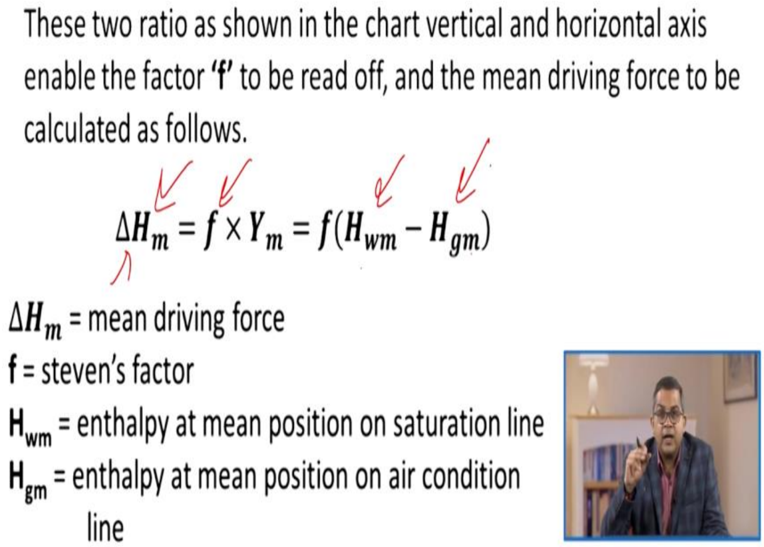
Now, in practical situation the values for H_{g1}, H_{g2}, L_W, L_a, T_1 and T_2 they are known, the air conditioning line or air-conditioned line can be drawn by connecting the point H_{g1} and H_{g2} if you see that this is the delta H which we will talking about. Now, by using the water temperature on the horizontal scale, it is possible to mark off the driving force at the top and a bottom of the tower and mean point.

(Refer Slide Time: 29:38)



Now for the calculation of fn the mean driving force a chart device by its Stephen is shown here. Not 3 driving force are designed on this chart and that is Y_1, Y_2 and Y_m and the values obtained from the enthalpy chart must converted into the to the ratio of Y_m is to Y_1 and Y_m is to Y_2

(Refer Slide Time: 30:09)



Now, these 2 ratios which we have represented in this chart, vertical and horizontal axis enable the factor f that to be read off and the mean driving force to be calculated as per this following mathematical equation. That is delta H_m = f into Y_m and that is equal to $H_{wm} – H_{gm}$ where delta H_m is the main driving force which we discussed about F is the Stephen factor, this one is the Stephen factor and H_{gm} that is the enthalpy at main position on saturated saturation line and H_{gm} is the enthalpy at main position on air-conditioned line.

(Refer Slide Time: 30:53)

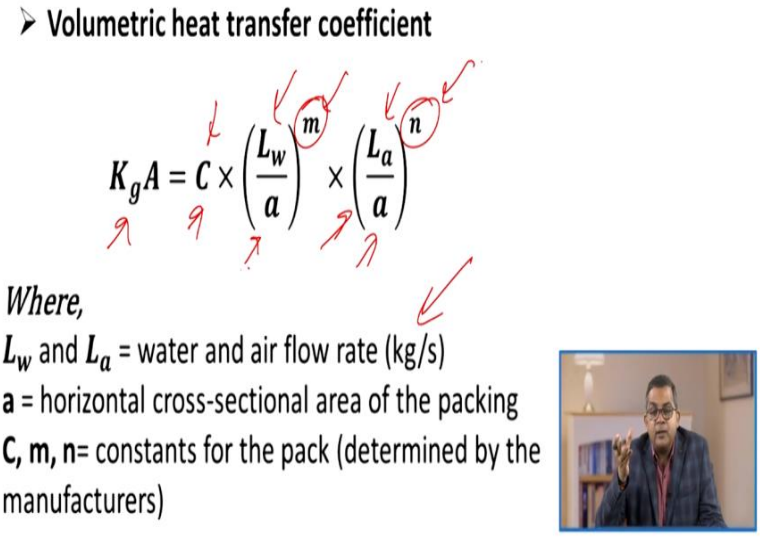
$$\Delta \boldsymbol{H_m} = \boldsymbol{f} \times \boldsymbol{Y_m} = \boldsymbol{f}(\boldsymbol{H_{wm}} - \boldsymbol{H_{gm}})$$

ΔH_m = mean driving force

f = steven's factor

H_{wm} = enthalpy at mean position on saturation line

H_{gm} = enthalpy at mean position on air condition line



Now, let us talk about the volumetric heat transfer coefficient and that is K_gA = C into L_w over a to the power m into L_a over A to the power n, where L_w and L_a, they are the water and air flow rate and that is the kilogram per second. And A is the horizontal cross sectional area of the packing and C, m, n and these are the constants for the pack and usually determined or given by the manufacturer.

So, in this particular lecture, we are discussed about the various design parameters and design aspects and equations for cooling tower design. Again, we have listed with a couple of references for your convenience thank you very much.

Volumetric heat transfer coefficient

$$K_gA = C \times \left(\frac{L_w}{a}\right)^m \times \left(\frac{L_a}{a}\right)^n$$

Where,
L_w and L_a = water and air flow rate (kg/s)
a = horizontal cross-sectional area of the packing
C, m, n= constants for the pack (determined by the manufacturers)