**Refrigeration and Air-conditioning**
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**Lecture No. # 35**
**Psychrometric processes**

Welcome back in the last lecture. I introduced psychrometry and there we discussed important psychrometry properties. We also introduced the concept of thermodynamic wet bulb temperature. And also discussed psychrometric chart it is seen that fortunately for air-water mixtures. The thermodynamic wet bulb temperature can be measured with sufficient accuracy using wet bulb thermometer provided certain precautions are taken. And I have also mentioned what are the precautions to be taken and I have also mentioned in the last lecture that a psychrometer is an instrument using which one can measure the dry bulb and wet bulb temperatures of moist air simultaneously. And there are two, basically two types of psychrometer one is what is called as steam steam type of psychrometer the other one is called as aspiration psychrometer one of the important requirements. While measuring wet bulb thermometer wet bulb temperature is that there must be a relative motion between the wet bulb and the surrounding air.

That means either the bulb should be moving or the air should be moving there must be some relative velocity okay. In a steam type psychrometer which consist of a dry bulb thermometer and a wet bulb thermometer. The thermometers are rotated which creates the motion okay. The rotation of thermometers creates the motion and this will give the correct reading of the wet bulb temperature. In aspiration psychrometer a small fan is used this fan drops the moist air from the surroundings. And blows the air over the wet bulb thermometer. Thereby one can measure the wet bulb temperature accurately. So it is very important to keep in mind that while measuring wet bulb temperature one has to take certain precautions only when the temperature indicated by the thermometer will be close to the thermodynamic wet bulb temperature. Now having measured wet bulb and dry bulb temperatures next task is to find the other psychrometric properties such as enthalpy humidity ratio etcetera okay. So for this we have to use certain empirical relations which will relate the wet bulb and dry bulb temperatures to the vapour pressure of water okay. So I will show these equations in this lecture and also discuss important psychrometric processes in this lecture.

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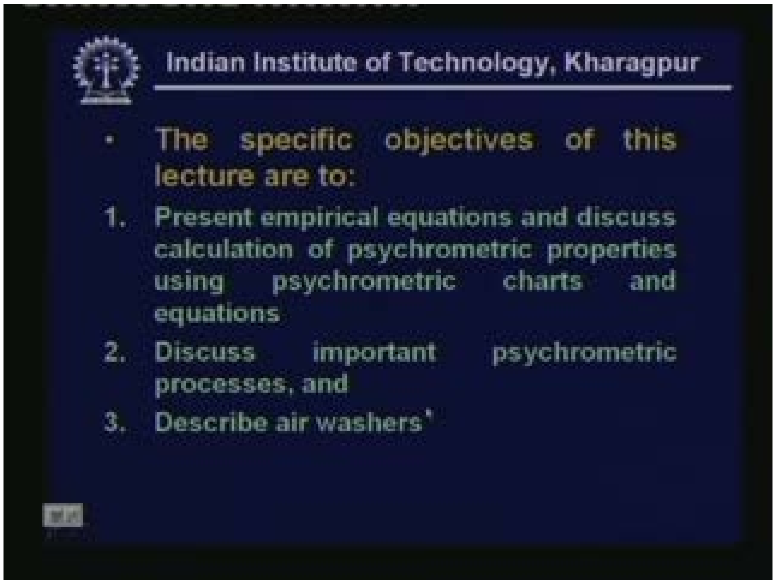


So the specific objectives of this particular lecture are to present empirical equations and discuss calculation of psychrometric properties using psychrometric charts and equations discuss important psychrometric processes and finally describe air-washers.

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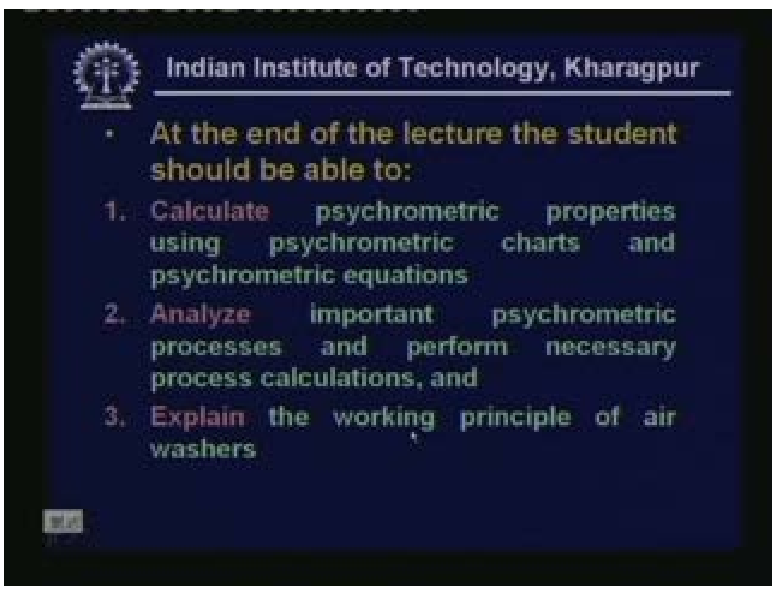


At the end of the lecture you should be able to calculate psychrometric properties using either psychrometric charts or psychrometric equations analyze important psychrometric processes and perform necessary process calculations and explain the working principle of air washers.

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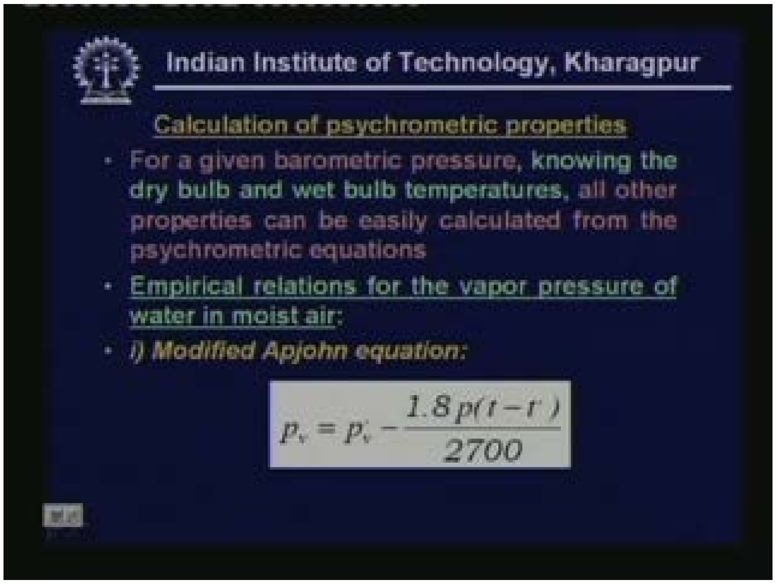


So first let us look at calculation of psychrometric properties. As I have already mentioned using psychrometer one can measure both the dry bulb and wet bulb temperatures and one can also measure the barometric pressure for example using the barometer okay. So once we know the barometric pressure and the dry bulb and wet bulb temperatures how do we find the rest of the properties first task is to find out the vapour pressure. So vapour pressure can be obtained by using any of the empirical relations shown below okay. For example one can use a relation called Modified Apjohn equation it is shown here where Pv is equal to P dash v minus one point one eight p into t minus t dash divided by two thousand seven hundred. In this equation Pv is the vapour pressure of vapour pressure of air P dash v is the saturated vapour pressure at wet bulb temperature p is the total pressure or barometric pressure t and t dash are dry bulb and wet bulb temperatures respectively.

Here units are important dry bulb and wet bulb temperatures should be in degree centigrade and the pressure units should be consistent. So this is one of the empirical relations using which one can find out the vapour pressure. For example here we know the dry bulb and wet bulb temperatures from the psychrometer reading then we can find out P dash v which is nothing but the saturated vapour pressures using steam tables or equations for saturated steam then barometric pressure is anyway known okay. So next.

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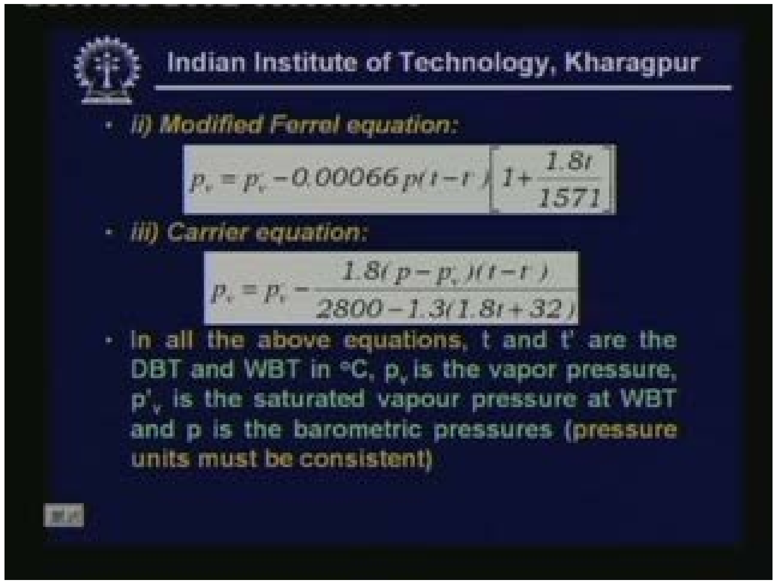


Empirical relation is what is known as Modified Ferrel equation. This equation is given by Pv is P dash v minus zero point zero zero zero six six p into t minus t dash multiplied by one plus one point eight t by fifteen seventy-one. Again here t and t dash are dry bulb and wet bulb temperatures p is the barometric pressure P dash v is the saturated vapour pressure at wet bulb temperature. One can also use what is known as the Carrier equation suggested by Williams Carrier this equation is shown here. Pv is equal to P dash v minus one point eight into P minus P dash v into t minus t dash divided by two thousand eight hundred minus one point three into one point eight t plus thirty-two.

As I have already mentioned in all the above equations t and t dash are the dry bulb and wet bulb temperatures. And the units must be in degree centigrade Pv is the vapour pressure P dash v is the saturated vapour pressure at wet bulb temperature and P is the barometric pressure. And as I said all the pressure units must be consistent okay. So these empirical equations can be used and using these empirical equations one can find the vapour pressure okay.

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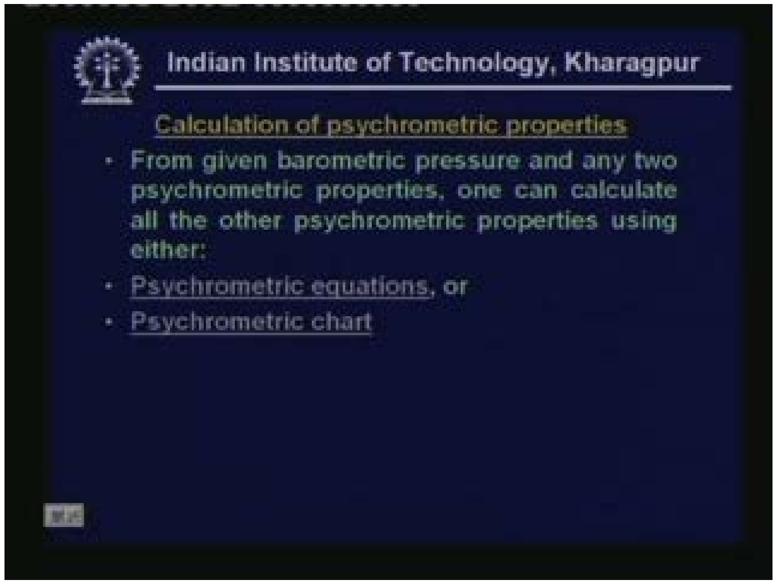


Now let us look at calculation of psychrometric properties from given barometric pressure and any two psychrometric properties one can calculate all the other psychrometric properties using either psychrometric equations or psychrometric charts. For example using Psychrometric equations how can we calculate the properties let me give some examples here.

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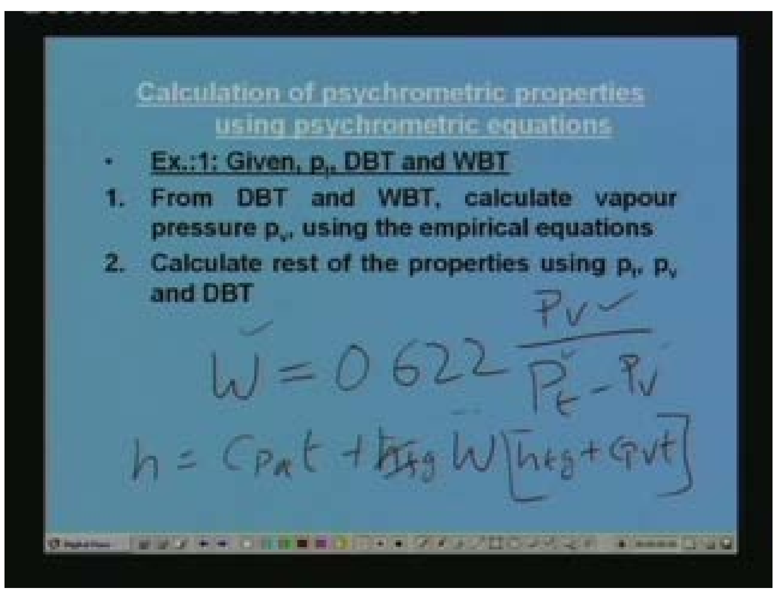


So calculation of psychrometric properties using psychrometric equations. For example let us say we know the total pressure dry bulb temperature and wet bulb temperature. These three are the independant properties and using these three properties we must find the other psychrometric properties. So step one is from dry bulb temperature and wet bulb temperature calculate vapour pressure Pv using any of the the empirical equations discussed just now. That means Carrier equation or Apjohn Ferrell equations okay. Then calculate rest of the properties using Pt Pv and DBT. For example what do you mean by rest of the properties. Let us say once we know the vapour pressure all other properties can be easily obtained. For example I want to find out lets say the humidity ratio W okay. Assuming the moisture to behave as a perfect gas we have derived the equations for the humidity ratio to be point six two two Pv divided by Pt minus Pv okay.

So Pv is known from the empirical relations Pt is the barometric pressure Pv is the vapour pressure of air. So we can find out what is humidity ratio similarly if you want to find out the enthalpy. Enthalpy also we have obtained equations like this Cpa into t plus hfg sorry plus W into hfg plus Cpv into t okay. So here hfg not there so here as you know Cpa is the specific heat of dry air Cpv is the specific heat of water vapour t is the dry bulb temperature which is known to us and hfg is the latent heat of vaporization which can be obtained from properties of steam and W is the humidity ratio. So you have found the humidity ratio from the pressure so substitute this W value here you can find out the enthalpy similarly one can find the other properties okay.

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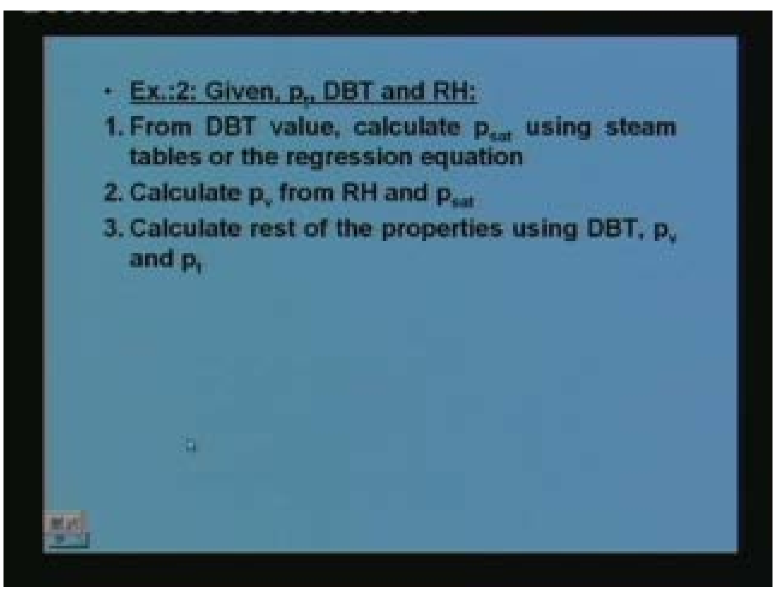


Suppose we know let us say the total pressure dry bulb temperature and relative humidity and we have to find out the rest of the properties first thing we do is from dry bulb temperature value we calculate the saturation pressure using steam tables or the regression equations. For example the ASHRAE equation which was mentioned in the last lecture. Okay so first find out the saturated pressure of water vapour at the dry bulb temperature then calculate vapour pressure from relative humidity and saturated pressure okay. Because we know that relative humidity we are assuming ideal gas behavior is simply given by RH is equal to Pv divided by Psat okay. So Psat is a function of dry bulb temperature only. So this we can obtain because we know the dry bulb temperature okay so Psat is known and relative humidity is mentioned okay. So then we can find out what is the vapour pressure Pv okay.

Once you know the vapour pressure Pv calculating other properties is very easy calculate rest of the properties using dry bulb temperature vapour pressure and total pressure okay. So like that using the simple equations mentioned in the last class. And some of the empirical equations given any three properties remember that you need three properties to fix the state of the moist air completely okay. So using any of these three properties we can find out the rest of the properties right. So this is the method of estimating psychrometric properties using psychrometric equations okay. Now the same thing can be done very easily using the psychrometric chart okay.

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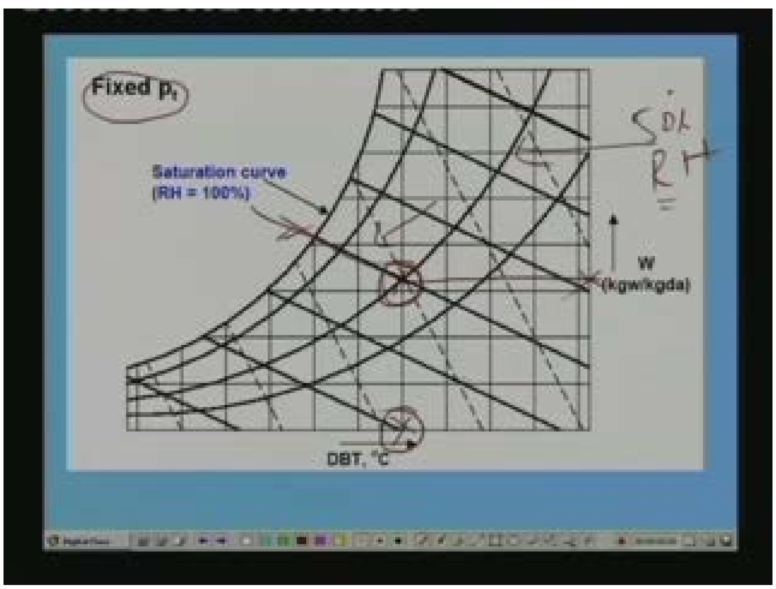


For example the psychrometric chart I have also already shown this psychrometric chart in the last lecture. And I have explained to you what are the different lines suppose we know dry bulb temperature. And let us say relative humidity okay. So for example it is given that this is the dry bulb temperature and this is the relative humidity okay. So these two are given and obviously the parametric pressure is also given. So one very important thing while using psychrometric chart is to make sure that you are using the right chart okay. That means you must use the chart given for that particular barometric pressure okay. So you must always look at the chart and see for what barometric pressure the chart is drawn and whether that barometric pressure matches with your barometric pressure or not okay.

So once you make sure of that it can be used easily right. So as I said once you know the dry bulb temperature and relative humidity lets say the relative humidity that of fifty percentage. That is this is fifty percent relative humidity line and this is some temperature. So we know these two values. So the intersection of constant relative humidity line of fifty percent and the constant dry bulb temperature line gives you the point okay. First you locate the point. So that point is this once you locate this point all other properties can be read from the chart. For example the humidity ratio can be directly read from here enthalpy can be read from this value. Because enthalpy line is like this specific volume is this. So once you put the point on the chart all other properties can be obtained okay. Or sometimes you may have, for example dry bulb temperature is given and humidity ratio is given okay. Let us say that dry bulb temperature is this and humidity ratio is this okay.

So you again you can fix the point by the intersection of the constant dry bulb temperature line and humidity ratio line will give you the psychrometric point or state of the air. Once you fix the state of the air other things can be easily obtained. For example relative humidity is something like this and enthalpy value is this and specific volume is between this value and this value. So you have to do of course some interpolation when you are using the psychrometric chart okay. So reading from the psychrometry chart even though it is easy, it can give rise to error. If you are not reading that values properly or if you are not doing the interpolation properly okay. So for calculation purposes it is best to use the psychrometric equations. Because it will give you the correct reading of course in the absence of psychrometric equations one can use the psychrometric chart okay. So this is how one can calculate the psychrometric properties. Now once we know the properties now next let us go to psychrometric processes.

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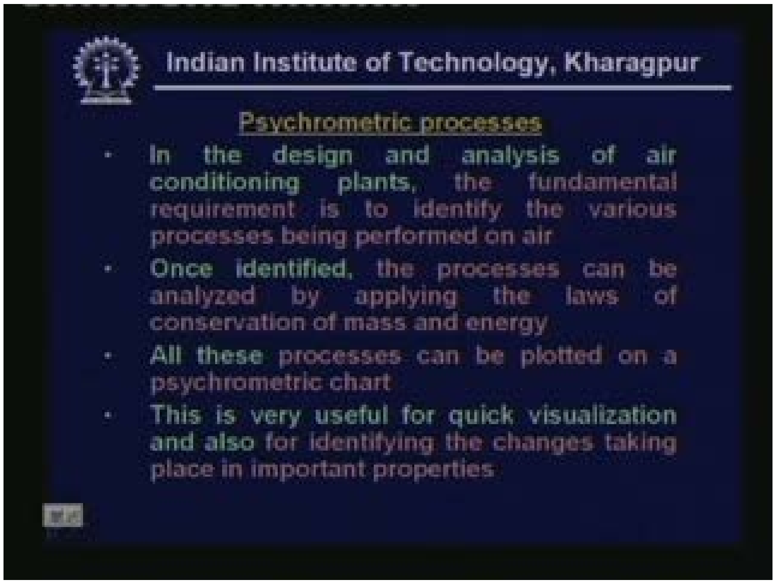


This is a very important topic psychrometric processes in the design and analysis of air conditioning plants or air conditioning systems. The fundamental requirement is to identify the various processes being performed on air once identified the processes can be analyzed by applying the laws of conservation of mass and energy. All these processes can be plotted on a psychrometric chart this is very useful for quick visualization and also for identifying the changes taking place in important properties. Okay, so the summary is you must be able to know what kind of processes are being performed on air and identify the process properly. And put the draw the process properly on psychrometric chart okay. So this will give you an idea of what is happening during the process what property changing how okay. And if you are reading the chart properly it will also give you the different changes taking place in the properties. So using the properties and then applying the conservation equation one can estimate what is the amount of mass transfer or what is the amount of heat transfer etcetera. During a given process okay. So understanding the processes is very important and what we will do is we will be showing all the processes on psychrometric chart okay. We will show the process path on the psychrometric chart okay. So let us begin with a simple process.

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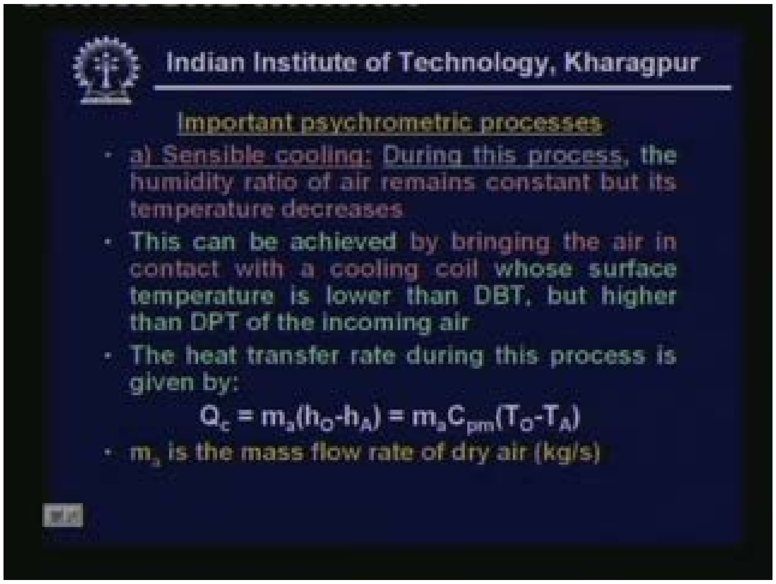


Let us look at some of the important psychrometric processes the first process is a very simple process that is sensible cooling it is as the name implies during this process the humidity ratio of air remains constant but its temperature decreases okay. That means there is no mass transfer only sensible heat transfer takes place okay. That is why you call it as sensible cooling process this can be achieved by bringing the air in contact with a cooling coil whose surface temperature is lower than the dry bulb temperature.

But higher than the due point temperature of the incoming air okay. Because you want to achieve only sensible cooling you do not want to add or remove moisture from the air okay. That means there should not be any moist air transfer okay. So when you are bringing moisture in contact with cold surface. For example and if the cold surface temperature is above the dew point temperature of air then air gets sensibly cool okay. That means no moisture transfer takes place okay. So that is what is required if you want only sensible cooling all right okay. Let me show this process how we can show this process on a psychrometric chart.

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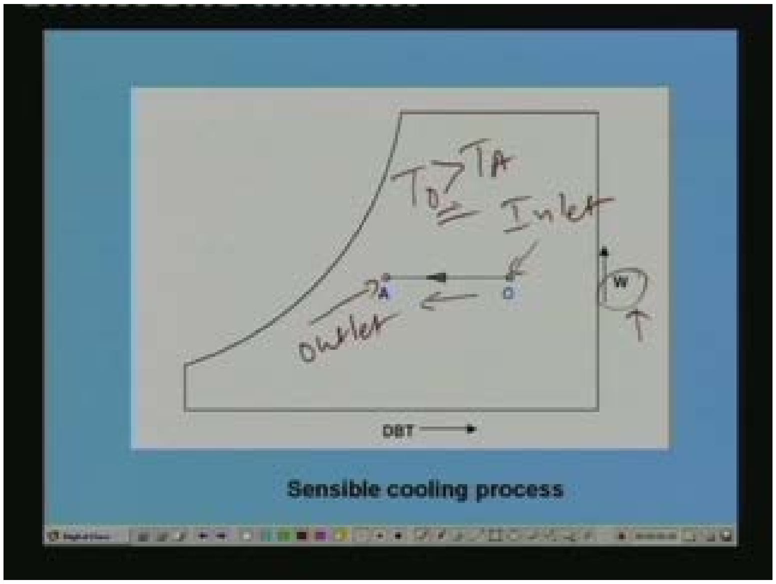


This is very easy because during this process as we have as I have already discussed the moist air content remains same. So it will be a horizontal line because this is the humidity ratio or moisture content ratio moist air content line. So moist air contented inlet let this, the inlet this is the outlet okay. So the moist air contented inlet and outlet remains same. So the line is a horizontal line and the lines move in this direction. Because the air is being cooled so the air temperature decreases okay. That means To is greater than TA obviously okay. This is the cooling process right. So you can very easily once you identify this state and once you then put this state then you can find out the rest of the properties if you are reading the psychrometric chart properly okay.

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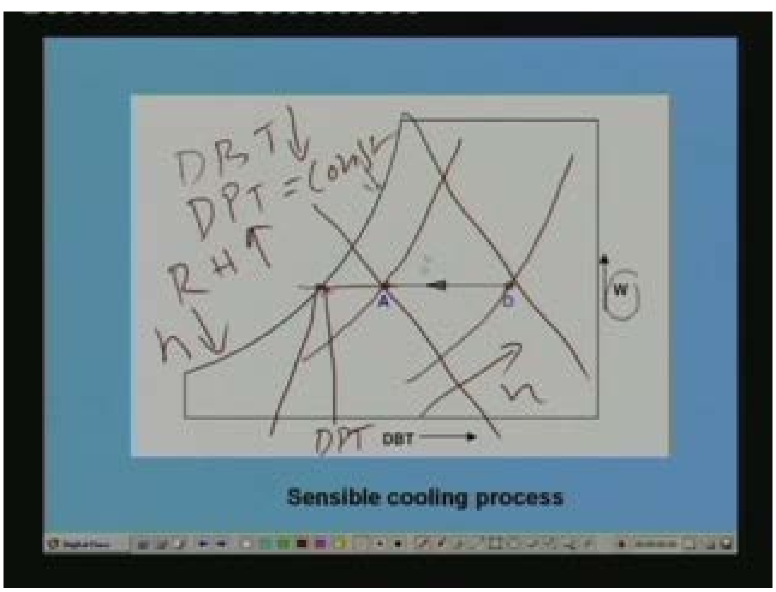

Now let us see what is happening during this process. As I said that the dry bulb temperature is reducing okay. Dry bulb temperature reduces dew point temperature remains constant. Because corresponding to this point or this point the dew point temperature is a, is this temperature. That means we have to draw this or extent this line. And where this line intersects this saturation curve that temperature will give you the dew point temperature okay. So this is your dew point temperature dew point temperature remains constant. Because moist air is not neither added nor removed okay. So DPT remains constant then you can see that relative humidity is increasing okay. At this point relative humidity is something like this at this point relative humidity is as increased okay. This is because we are keeping the moist air content same but we are reducing the dry bulb temperature okay.

So as a reason relative humidity increases obviously enthalpy reduces okay. Because enthalpy lines are constant enthalpy lines are like this okay. Enthalpy increases in this direction. So enthalpy reduces because we are taking energy from the air. So enthalpy of the air reduces okay so like that we can easily visualize what is happening to air during the process. And we can also read all these properties inlet and outlet properties from this psychrometric chart. Now the heat transfer rate during this process is given by Qc is equal to ma into H naught minus Ha. This is obtained by this is obtained by applying energy balance this is H o minus Ha can be written as Cpm into To minus Ta where Cpm is the moist air specific heat To and Ta are the inlet. And outlet temperature and here ma is the mass flow rate of dry air in terms of kg per second. Remember that these are repeatedly told in the last class also in all psychrometric calculation and all psychrometric properties are indicated on basis of dry air mass flow rate okay. I have already explained what are the advantages of using dry air as the basis okay. So ma is the mass flow rate of the dry air right.

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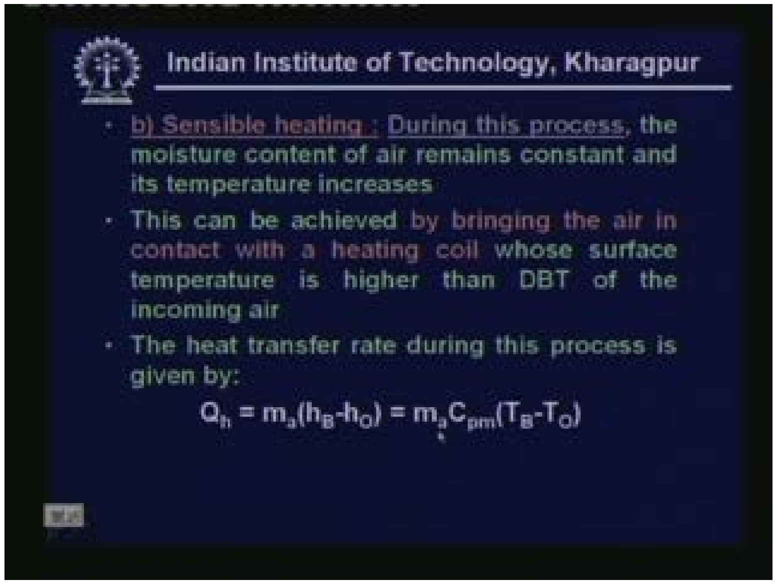


Now next, let us look at an another simple process that is sensible heating process. Of course this process is exactly opposite to the earlier sensible cooling process. So during this process the moist air content of air remains constant and its temperature increases obviously because you are heating the air. This can be achieved by bringing the air in contact with the heating coil whose surface temperature is higher than the dry bulb temperature of the incoming air. Obviously you have to have a surface or whose temperature is much higher than the dry bulb temperature. So that the air can get heated up and how do you show this process very easy.

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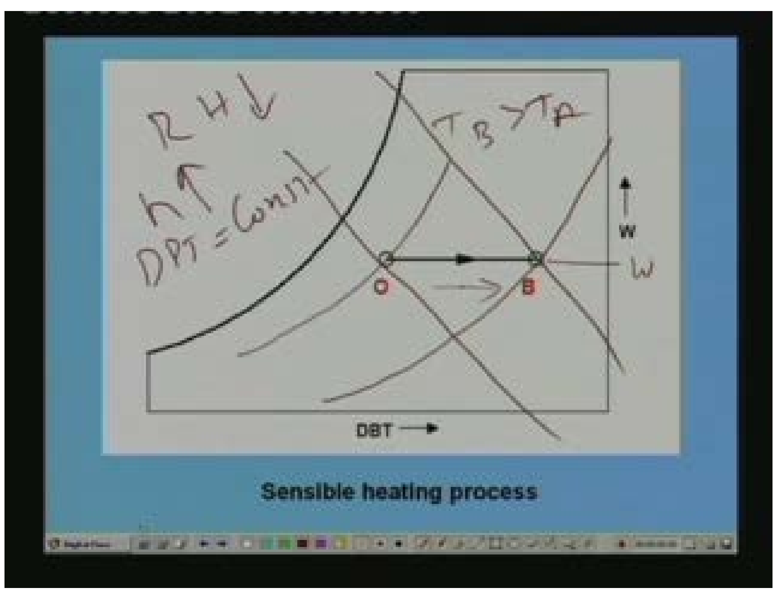

This is heating process. So the temperature of the air increases okay. So the process moves in this direction and humidity ratio remains constant. That means moist air content remains constant okay. Temperature is increasing obviously TB is greater than T A again you can see that during this process relative humidity reduces okay. Because moist air content is remaining constant relative humidity reduces okay. Enthalpy increases because we are adding energy to the, this thing. Enthalpy increases right again dew point temperature remains constant right like that you can find the other property.

And you can read the property values from the psychrometric chart and similar to sensible cooling the heat transfer rate. During sensible heating process can be obtained very easily by direct performing energy balance and Qh is the heat transfer rate that is equal to ma into hB minus hO where Hb and hO are the exit and inlet enthalpies of the moist air. And hB and hO can be written in terms of the specific heat and temperatures. That means finally you can write Qh as ma into Cpm into TB minus T naught where Cpm as I said is the specific heat of the moist air T B and t To are the exit and inlet temperatures of the air.

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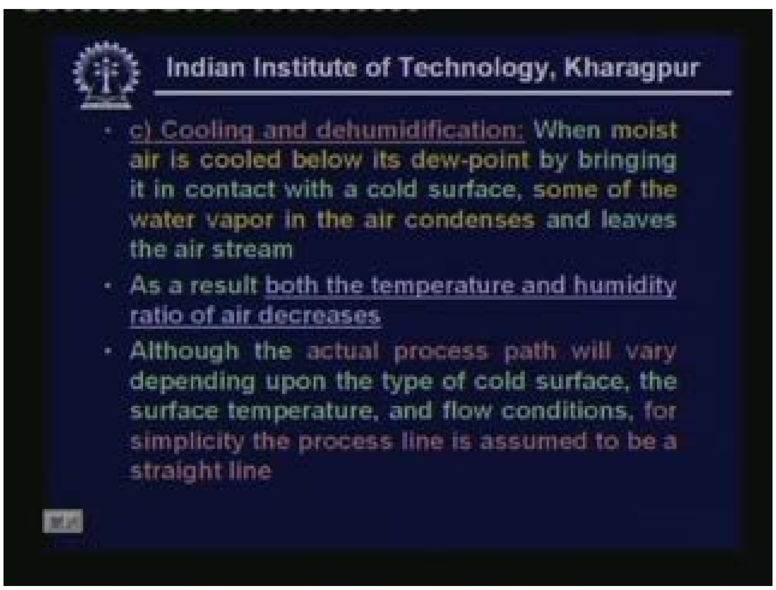


Now let us discuss a very important process this is called cooling and dehumidification. So as the name implies during this process air gets cooled and air also gets dehumidified. That means moist air content of the air reduces. And how do we do this what is the principle behind this when moist air is cooled below its dew point by bringing it in contact with a cold surface some of the water vapour in the air condenses and leaves the air stream. This we see from our day to day experience. For example if you leave a cool chilled cold drink bottle or chilled water glass of chill water on the table you find that on the outside of the surface of the bottle or in the glass water droplets appear okay. So where does the water appear from so obviously the water is appear from the surrounding air if the temperature of the cool water or the cold drink is less than the dew point temperature. When air comes in contact with the cold drink on the water moisture in the air condenses on the bottle or a, or the water okay. Because its temperature is lower than the dew point temperature.

Once the moist air condenses you are taking out the water vapour from the air in the liquid form. That means air becomes dried or air becomes dehumidified okay. So if you want to perform the process of cooling and dehumidification what is required is you must have a cooling coil or you must have a surface whose temperature is lower than the dew point temperature of the incoming air okay. So when air comes in contact with such a surface not only its temperature reduces. Because of the temperature difference but its moist air content also reduces. Because some of the water vapour in the air condenses and leaves the air as in the liquid form okay.

So as a result as I said both the temperature and humidity ratio of air decreases. So how do you show this process. So although actual process path will vary depending upon the type of cold surface the surface temperature and flow conditions for simplicity the process line is assumed to be a straight line actual process path line is quite complicated. And it depends upon several factors but we assume that the process is a straight line okay. So let me show the process.

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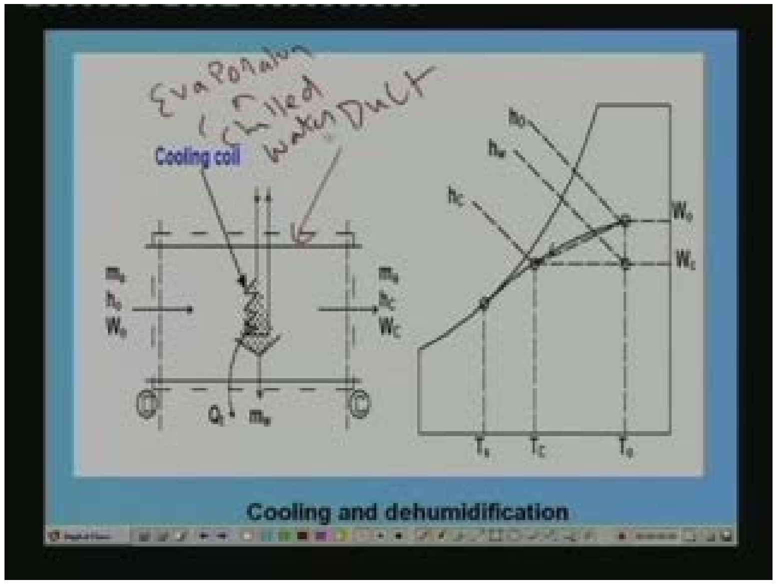


So this is how it is done for example you can see here. Let us say that we have a duct a cooling duct okay. This consists of a cooling coil here okay. For example this cooling coil could be the evaporator of a refrigeration system okay. That means refrigerant flow through this coil or it could be a chilled water coil. That means chilled water flows through this okay.

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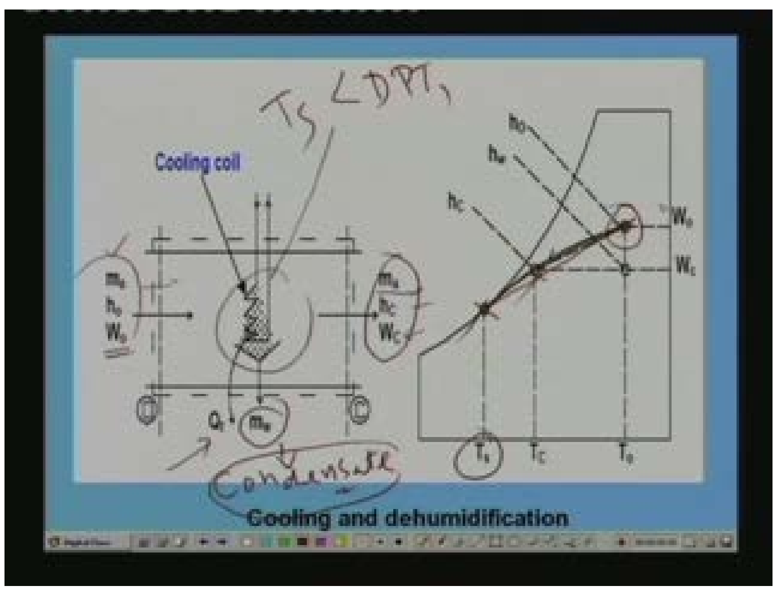


So when that means the coil surface and as I said the surface temperature of the coil is Ts okay. It is shown here Ts should be lower than the dew point temperature of air okay. When it is lower than dew point temperature of air and when this air comes in contact with the coil some of the water vapour condenses okay. And it leaves in liquid form. So this Mw is the, what is known as the condensate okay. Condensate is nothing but the liquid water that has condensed from the moist air okay. And once it condensates it leaves the air stream okay. So what is coming out from the duct is condensate and cooled and dehumidified air okay. So you can see that ma is the mass flow rate of dry air it remains constant. So ma enters the duct and ma leaves the duct h naught and W naught are the enthalpy and moist air content at the inlet to the duct or inlet to the control volume and hc and Wc are the enthalpy and humidity ratio at the outlet and Qt is the cooling load on the coil.

Okay, we have found an expression for this I will show you that. So this is how it can be this process can be achieved and if you are showing this repellent in this process on a psychrometric chart. As I said the actual process is complicated. Let us say that we know inlet condition okay. And we are able to locate the point on the psychrometric chart okay. We know that point right and suppose we also know the surface temperature of the coil okay. Let the surface temperature of the coil be Ts okay. And from the straight line law we know that the exit condition always lies on a straight line joining these two points Ts and inlet condition T naught okay. That means it will be lying on some other some line joining these two points okay. It could be somewhere from here right so exit condition lies between To and Ts on the straight line.

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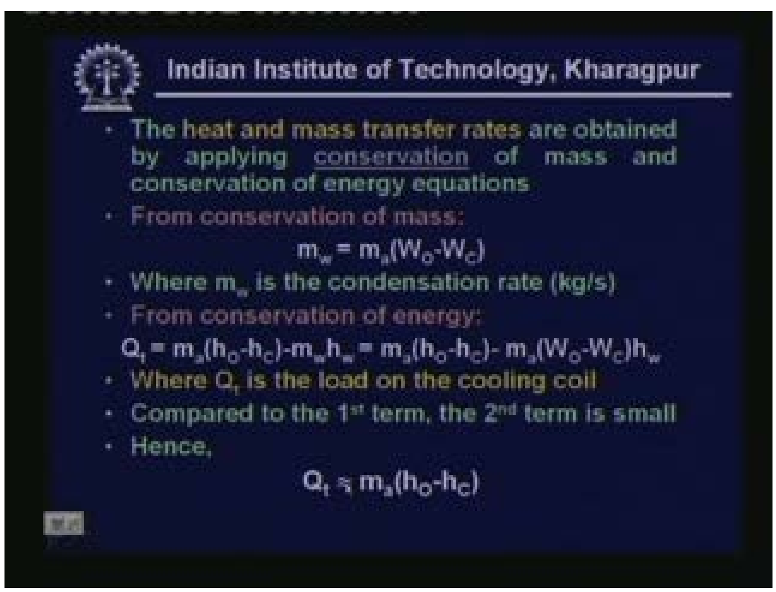

The heating and mass transfer rates are obtained by applying conservation of mass and conservation of energy equations. So we take the control volume okay.

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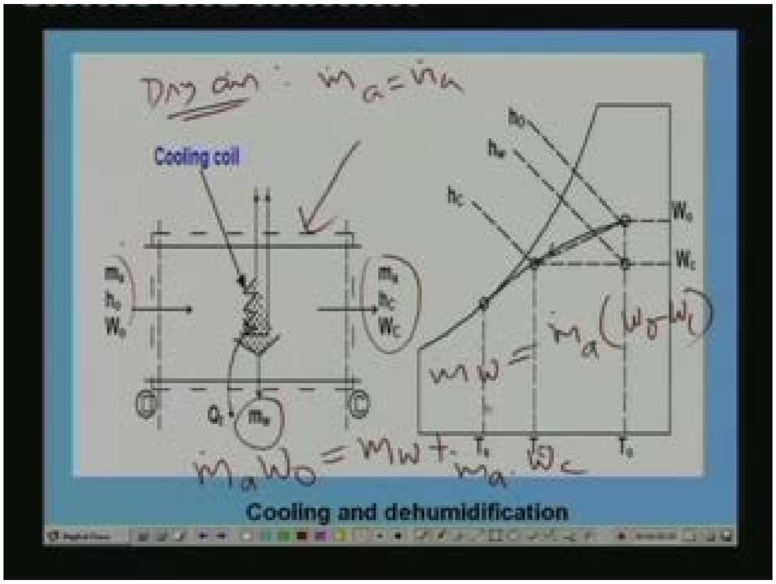


So this is the control volume let us say the dash line and we apply conservation of mass what is conservation of mass. For example we can derive conservation of mass for dry air which is very trivial here. For example because the dry air mass remains constant dry air mass transfer equation is m dot a equal to n dot a what are mass is entering the same mass is leaving and for water vapour also you can write the energy sorry mass balance. So water mass of water entering the same mass of water must leave okay. The water is entering here in the form of vapour is leaving in the form of vapour and also in the form of liquid okay. So if you write the energy balance for it the amount of water vapour entering is m dot a into W naught. This is the amount of water in the incoming stream this should be equal to water vapour leaving the control volume water vapour leaving the control volume is m dot W in the liquid form plus m dot a into Wc okay. So this is the mass balance for the water vapour. So from this equation we can easily show that m dot W that is the condensate rate is nothing but Ma into W o minus Wc okay. So this is the mass balance.

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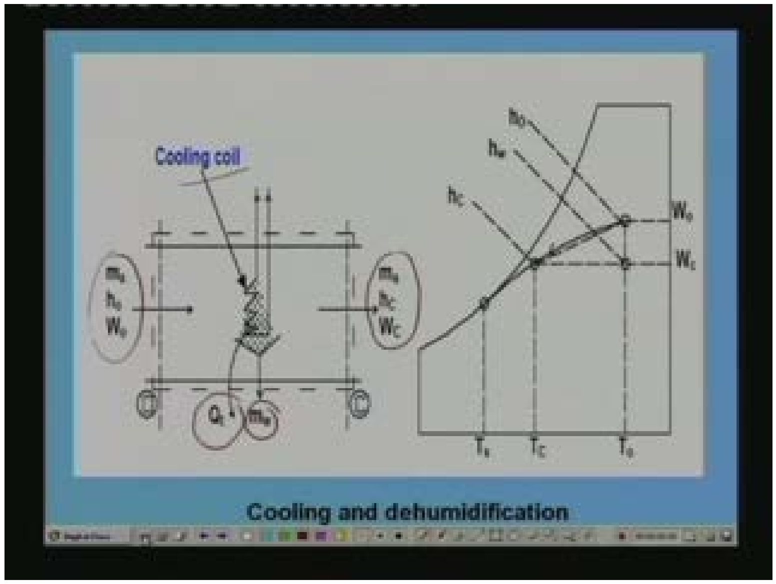


Similarly one can write the energy balance take the control volume and for steady state water energy is coming in must go out. And energy coming is in the form of enthalpy of the air and is leaving you also in the form of enthalpy of air. And also there is some energy leaving by enthalpy of condensate and some energy has to leave. Because that is nothing but the load on the cooling coil okay. So as I said from conservation of mass we can show that m dot W is equal to ma into Wo minus Wc where m dot W is the condensation rate in kg per second. So many kgs of water is being condensed per second. That is the meaning of this and from conservation of energy we can easily show that the load of the cooling coil Qt is equal to ma into h h naught minus hc minus mw hw and for Mw. We have to substitute using the conservation of mass. So finally we find that Qt is equal to ma into h naught minus hc minus ma into W naught minus Wc into hw here Qt is the load on the cooling coil. And as I said h naught and hc are the inlet and exit enthalpies of air and hw is the enthalpy of the condensate. That means enthalpy of the liquid water that is in the control volume okay.

Compared to the first term the second term is generally small. That means this term this term is relatively small compared to this term okay. So we can generally neglect this term ones you neglect this term you find that Qt is equal to m dot a into h naught minus hc okay. So that means total mass flow rate multiplied by the enthalpy difference.

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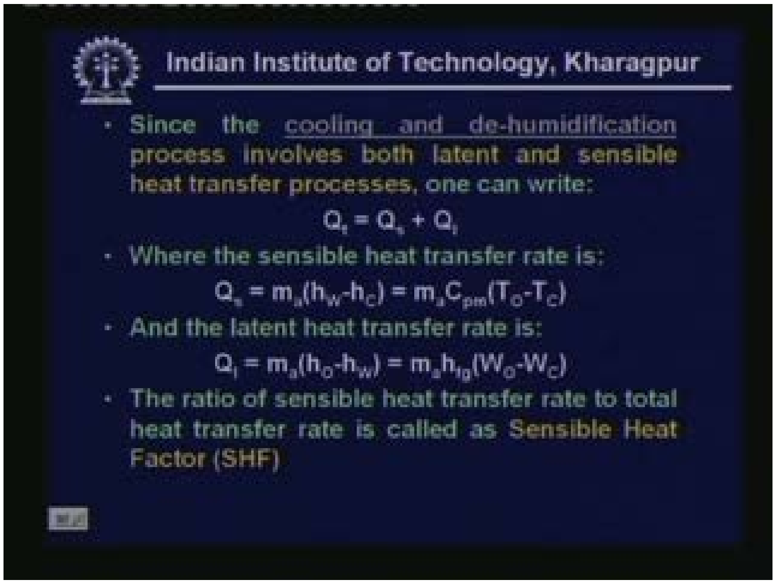


Since the cooling and de-humidification process involves both latent and sensible heat transfer processes. One can write Qt is equal to Qs plus Ql okay. Because we have seen that both sensible as well as latent heat transfer are taking place. So you can separate them out so total heat transfer rate is sensible heat transfer rate plus latent heat transfer rate where the sensible heat transfer rate is given by Qs is equal to ma into hw minus hc that is equal to ma into Cpm into T naught minus Tc okay. Let me show this in psychrometric chart.

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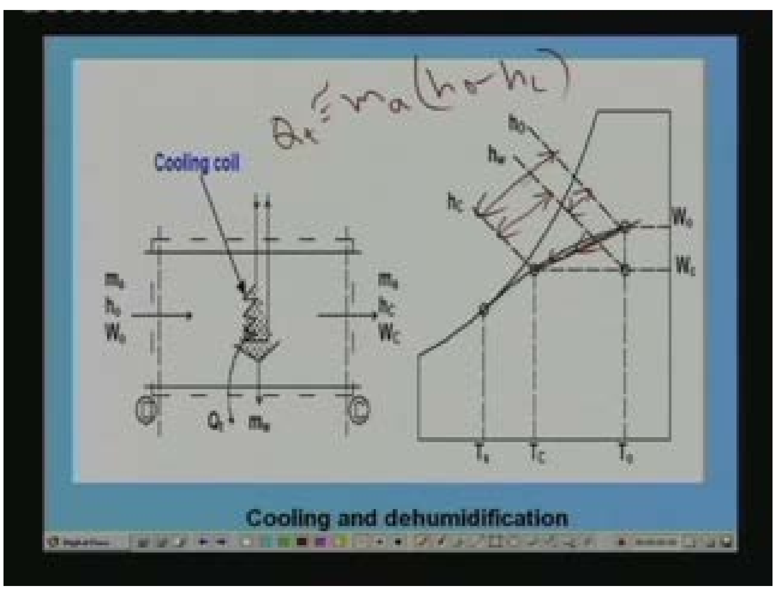


On the psychrometric chart if you see this is the, let us say that this is the process okay. So this is the process what we are doing is we are we have shown that Qt is equal to approximately equal to m dot a into h naught minus hc okay. h naught minus hc is nothing but this enthalpy difference okay. So this enthalpy difference is split into sensible as well as latent enthalpies. For example this is the enthalpy change during the sensible process and this is the enthalpy change due to latent heat transfer okay. And this plus this is obviously equal to the total enthalpy change.

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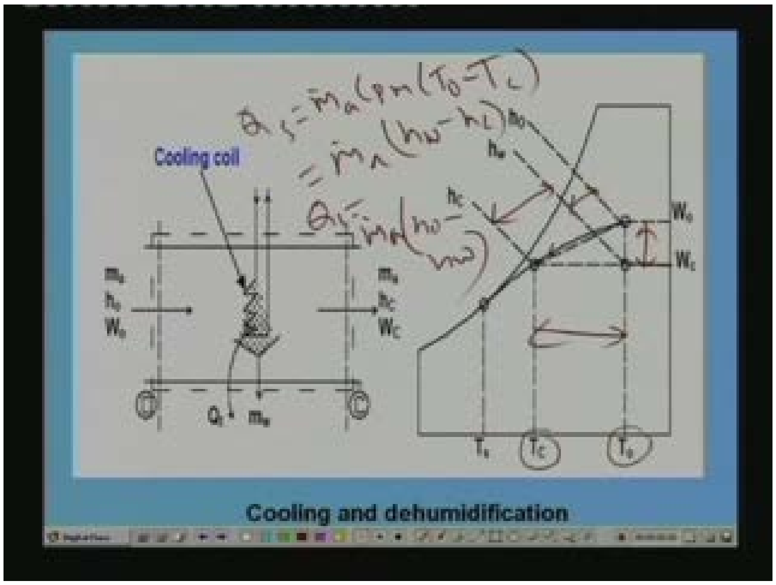


Okay, and in this process you can see that what is the sensible heat transfer rate sensible heat transfer rate is nothing but what is the temperature change temperature change is from T naught to Tc okay. So sensible heat transfer rate Qs is nothing but m dot a into Cpm into T naught minus Tc this is equal to m dot a into h w minus hc. That means this portion okay. That means this enthalpy difference is the mass flow rate.

Similarly latent heat transfer Ql is nothing but m dot a into this enthalpy difference okay. This is the process that is nothing but h naught minus hw okay so like that you can split the total heat transfer rate. And the latent heat transfer is as I said is Ql is ma into h naught minus hw h naught minus hmm. Now this term can also be written in terms of the humidity ratio and the latent heat of vaporization. That means latent heat transfer can also be written as ma into h fg where h fg is the latent heat of vaporization into Wo minus Wc. The ratio of sensible heat transfer why are we doing this. There is a purpose behind this. Let me explain this the ratio of sensible heat transfer rate to total heat transfer rate is called as sensible heat factor or abbreviated as SHF okay. Sometimes it is also called as sensible heat ratio okay.

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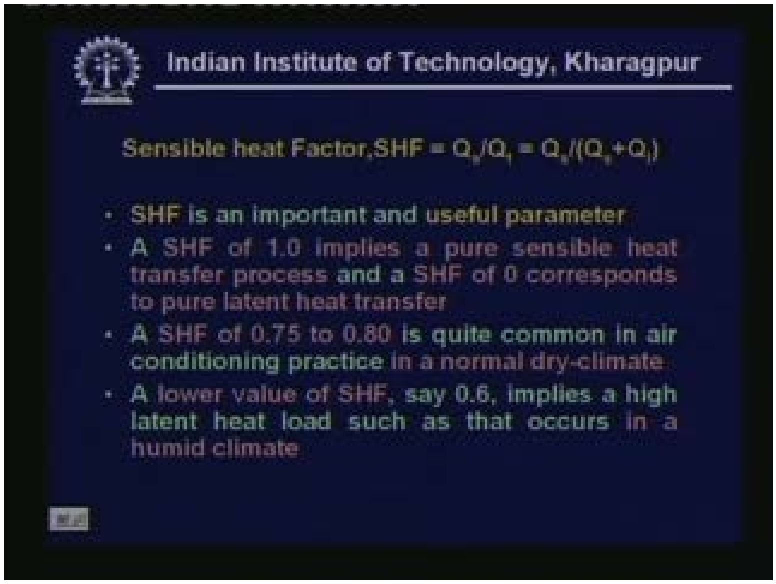


That means the sensible heat factor SHF is defined as Qs divided by Qt where Qs is the sensible heat transfer rate Qt is the total heat transfer rate. And Qt can be written as Qs plus Ql now what is the advantage of this we will see that the sensible heat factor is an important and very useful parameter in air conditioning systems calculations and a sensible heat factor of one implies a pure sensible heat transfer process. Because a sensible heat transfer factor is one means Qs is equal to Qt that means Ql is zero. That means it is a pure sensible heat transfer process. Similarly a sensible heat factor of zero means Qs is zero. That means it is a pure latent heat transfer process a SHF of point seven five to point eight is quite common in air conditioning practice in a normal dry climate okay. In normal air conditioning systems in normal dry climate we find that the latent heat to sensible heat is in the ratio of about one is to four okay. That means you get a sensible heat factor of both seven five to point eight. However a lower value of sensible heat factor say for example point six implies a high latent heat load such as that occurs in a humid climate. For example in coastal regions okay we shall use this factor later when we later do the load calculations okay.

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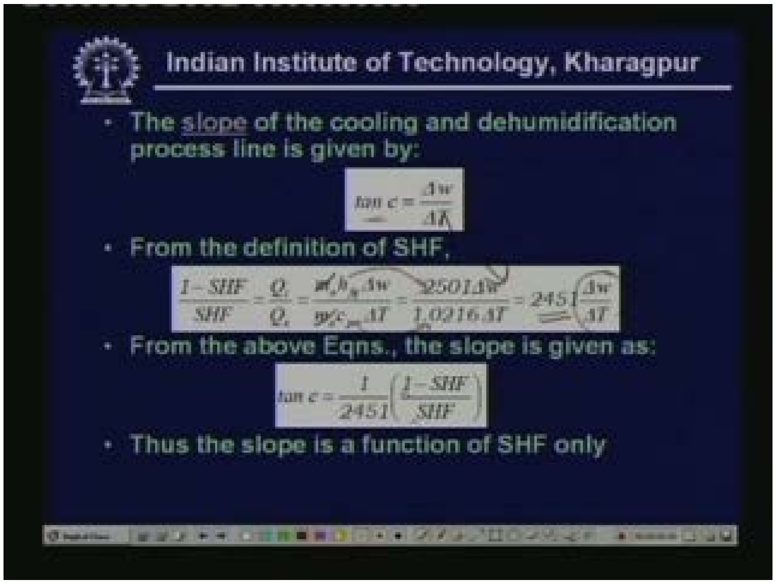


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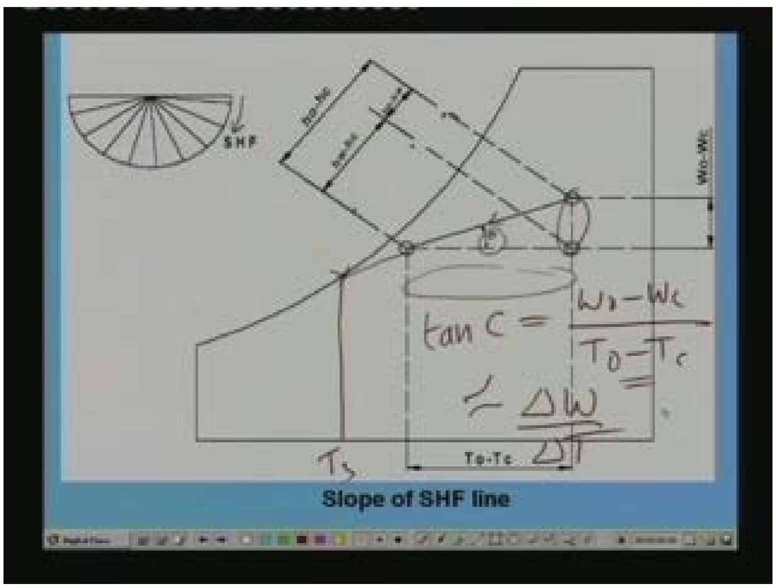


Now the slope of the cooling and dehumidification process line is given by what is slope of the lines? We have approximated this line we assumed that the process is taking place along the straight line okay. This is you are surface temperature of the coil. So the slope of the line is this okay. Let us say Tc is your angle then the slope of the line is tan c okay. And the tan c is nothing but this divided by this okay. What is this is nothing but the change in the humidity ratio that is Wo minus Wc divided by this is nothing but To minus Tc okay. So the slope of the line depends upon the ratio of the change in the humidity ratio and the temperature okay. Dry bulb temperature this can also be written as if you take a small this thing delta W divided by delta T okay.

So tan c is the slope that is equal to delta W by delta T from the definition of sensible heat factor. Now we write like this one minus SHF divided by SHF is equal to Ql by Qs. Because you can see that SHF is Qs divided by Qs plus Ql. So one minus SHF is nothing but Ql by Qt okay. Similarly SHF is Qs by Qt Qt gets cancelled. So one minus SHF divided by SHF is equal to Ql by Qs now we write this in latent heat transfer rate and sensible heat transfer rate in terms of the humidity ratio and temperature difference. For example Ql is written as ma into hfg into delta W divided by Qs is written as ma into Cpm into delta T. So mass flow rate gets cancelled here okay. This term gets cancelled now for hfg and Cpm we will take a approximate values hfg is written as taken as two thousand five hundred kilo Joule per kg latent heat of vaporization. Similarly the moist specific heat is approximately taken as one point zero two one six okay. So finally we find that one minus SHF by SHF is equal to two four five one into delta W by delta T okay. This two four five one is nothing but the ratio of two thousand five hundred one divided by one point zero two one six okay.

Now from if you look at these two equations from these two equations you find that delta W by delta T is nothing but the slope of the process line cooling and de-humidification line. So delta W by delta T is equal to tan c is nothing but one by two four five one into one minus SHF by SHF okay. So this is the important equation so what does this equation tell us this equation tells us that the slope of the cooling and de-humidification line is a function of sensible heat factor only okay. That means irrespective of the inlet and outlet condition. If I tell you that a particular air conditioning process has a cooling and de-humidification process has a sensible heat factor of point seven okay. Then immediately you can tell what what should be the slope of the cooling and de-humidification line okay. Ones you know the slope and once you know the inlet condition then you can draw the process line okay. That is the advantage of defining sensible heat factor okay.

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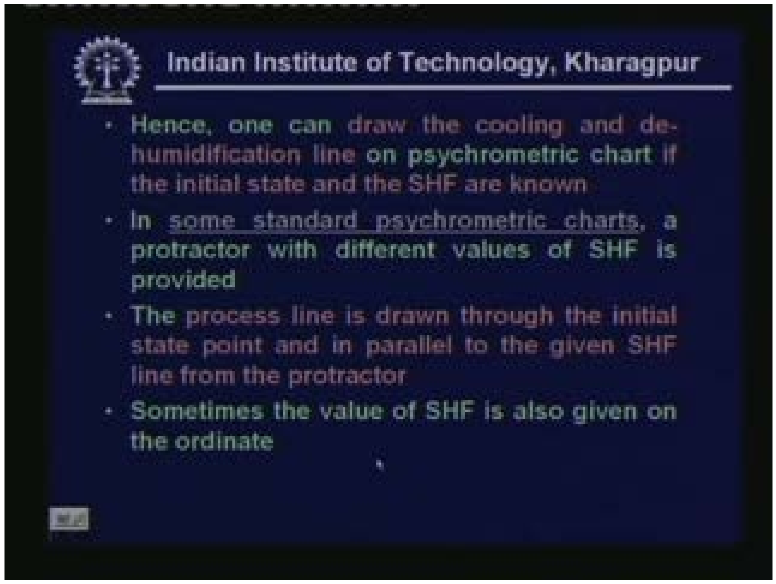


Now hence one can draw the cooling and dehumidification line on the psychrometric chart if the initial state and sensible heat factor are known okay. Because from the sensible heat factor you can find out the slope of the line and you also know the initial state and this line must pass through the initial state. And you know its slopes. So you can draw the process path in some standard psychrometric charts a protractor with different values of sensible heat fact is provided.

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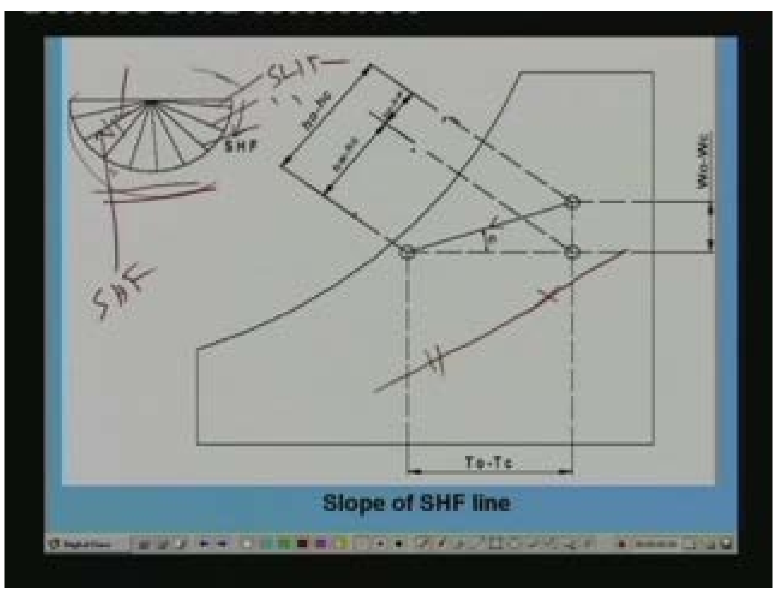


Okay for example this we will again discuss when we do the load calculations and all you can see that some of the standard psychrometric chart. They provide a sensible heat factor a protractor where the sensible heat factor values are given okay. So different values of these lines corresponds to different values of sensible heat factors okay. And what is the use of this for example let us say that in my process the sensible heat factor is like this. Let us say that this is the sensible heat factor of a particular cooling and de-humidification process okay. So the slope of the line is this right and, let us say that its inlet state is this okay. Now what all that you have to do is you have to draw a line in through this in such a way that this line is parallel to this line okay. So using a protractor you can draw the parallel line to this particular this thing and this is the process line that mean exit condition will lie somewhere on this line okay. That is the advantage of having this protractor. So as I said the process line is drawn through the initial state point and in parallel to the given SHF line from the protractor. Of course sometimes the value of sensible heat fact is also given on the ordinate okay. This again as I said we will discuss later.

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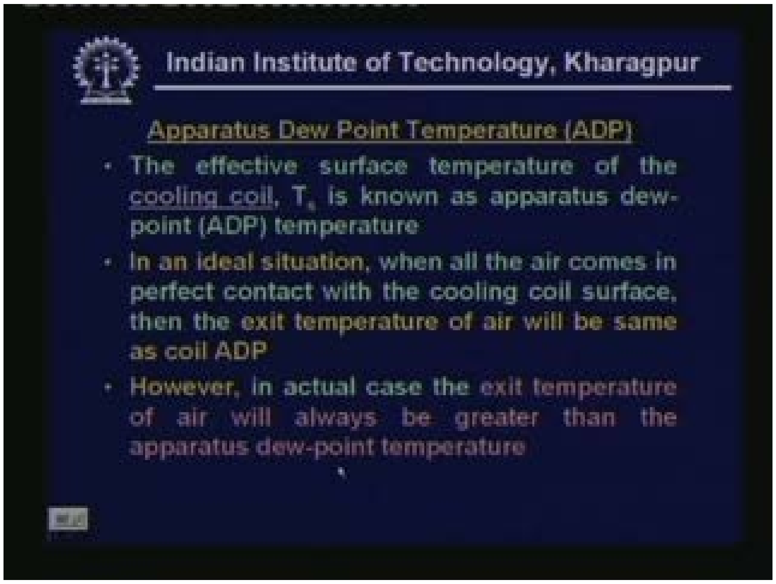


Let us discuss another important concept called as apparatus due point temperature or ADP the effective surface temperature of the cooling coil. Ts is known as apparatus due point temperature okay. In fact the actual temperature will be varying actual temperature of the cooling coil will be varying. Because the boundary line development and because the temperature variation the fins etc but we can conceptualize an effective temperature surface for the coil. Because the surface temperature does not remain constant on the coil okay. But we can define an effective surface temperature and we will have a single value okay.

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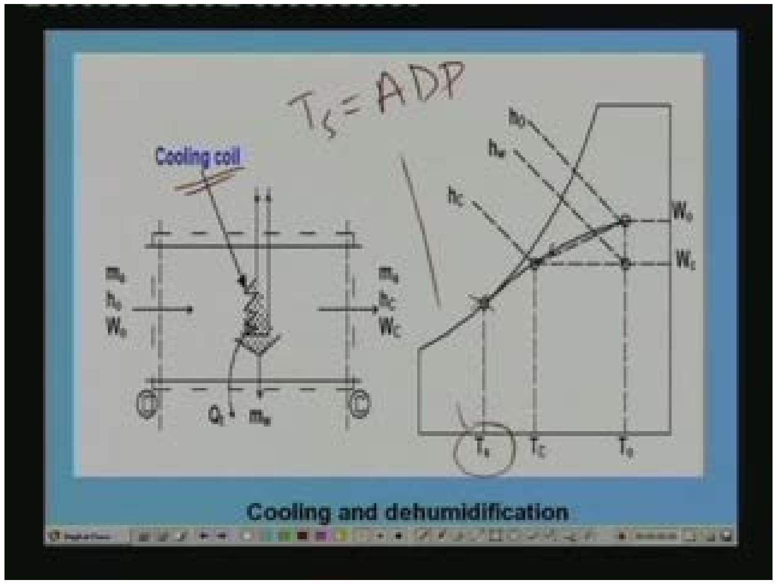


And you can see on the psychrometric chart here that Ts is the effective surface temperature of this cooling coil okay. And this Ts is known as your ADP that is apparatus dew point temperature okay. And as I already mentioned if you know this temperature. And if you know the inlet condition you can draw the straight line. And you can draw the process path in an ideal situation when all the air comes in perfect contact with the cooling coil surface then the exit temperature of air will be same as the coil ADP.

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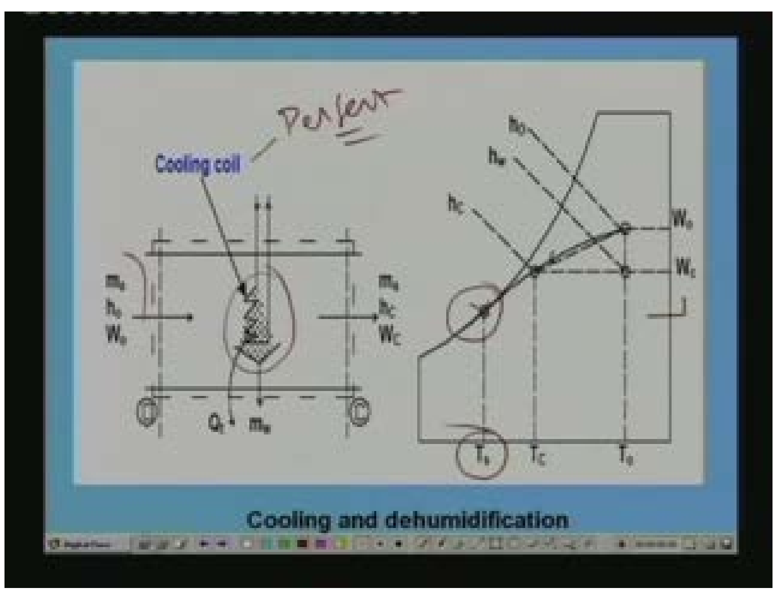

Okay, that means you have the let us say a perfect coil okay. This is a, this cooling coil is a perfect coil perfect in terms of heat and mass transfers. So when this coil is perfect the heat and mass transfers' rate between air and the coil will be maximum and you find that the exit condition will be same as will be at this point okay. Exit condition co-insides with the coil ADP right however in actual case the exit temperature of air will always be greater than the apparatus dew point temperature because of various resistances.

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Since no evaporator coil is perfect in terms of heat and mass transfer one can define a bypass factor BPF for the coil as by pass factor BPF is equal to Tc minus Ts divided by T naught minus Ts or this is also equal to Wc minus Ws divided by W naught minus Ws that is equal to hc minus hs divided by h naught minus hs here c is the actual exit state and s is the exit state corresponding to the coil ADP okay. So that is shown on this figure.

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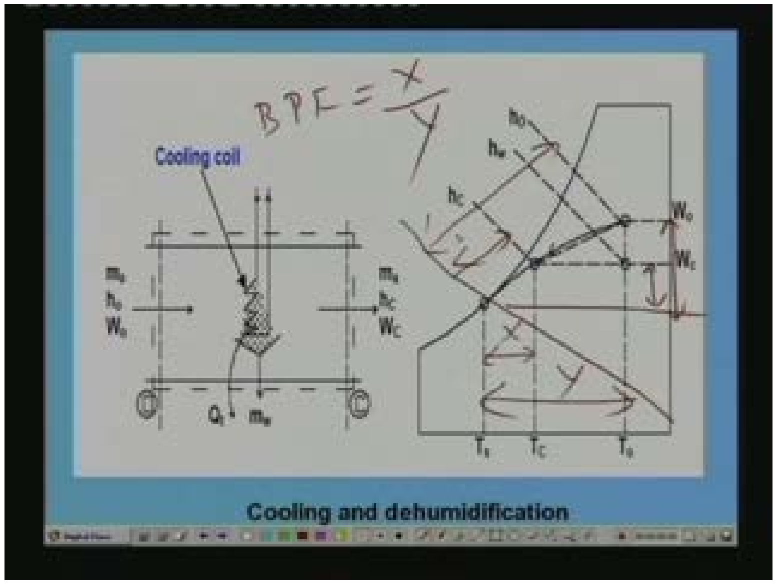


For example according to the bypass factor this thing let us say this is X okay. Let us say this is whole thing is Y then by pass factor is X divided by Y okay. That mean or you can also define this in terms of humidity ratio okay. This means this humidity ratio divided by this or in terms of enthalpies okay. If you have this enthalpy that means this enthalpy divided by this total enthalpy okay. So the value of bypass factor depends on a small type of bypass factor indicates a very effective evaporator coil. For example if you see that the bypass factor is zero. That means the exit condition of air is same as the coil temperature that means effective coil temperature okay. So this means the coil is very very effective all the air is coming in perfect contact with the coil okay.

So smaller the bypass factor higher is the effectiveness of the coil. The value of the bypass factor depends on the design of the evaporator coil. For example number of rows fin pitch etc. And also on the velocity of air the bypass factor can be decreased by increasing the number of rows or by reducing fin pitch and air velocity okay. So the design of the coil decides the bypass factor in addition to that the air velocity also decides the bypass factor for a given coil if you reduce the air velocity air has more time to spent with the coil. That means more de-humidification takes place and the temperature of air goes nearer the coil ADP okay. Next let us look at another process cooling and humidification.

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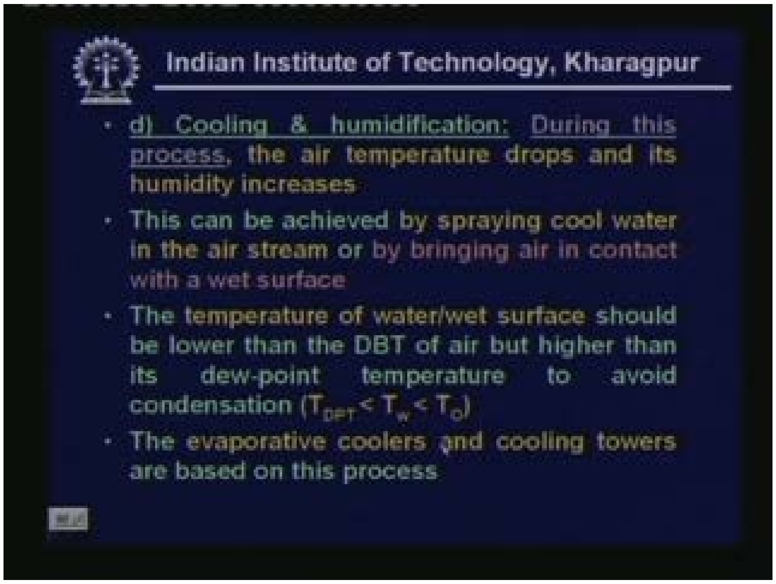


So as the name implies this is also cooling process. But instead of de-humidifying here we are humidifying air. That means moisture content of the air is increasing so during this process the air temperature drops and its humidity increases. How can we achieve this process this process can be achieved by spraying cool water in the air stream or by bringing air in contact with a wet surface okay? Suppose you have an air stream and you sprinkle or spray a cold water in the air stream or you bring the air stream in contact with the wet surface then air undergoes cooling and humidification process. The temperature of water or wet surface should be lower than the dew dry bulb temperature of air. But higher than its dew point temperature to avoid condensation okay. This is important you want to cool the air at the same time you want to humidify the air. That means you want to add moisture to the air okay. Since you want cooling that mean there must be sensible heat transfer from air right. That means water or the surface temperature should be lower than the air temperature.

Right that means air dry bulb temperature that. But it should not be lower than the dew point temperature of air. Because once it is lower than dew point temperature of air then moisture condenses okay. So instead of humidification you will have de-humidification okay. So to achieve cooling and humidification we must have a wet surface whose temperature is higher than the dew point temperature. But lower than the dry bulb temperature okay. So let me show this.

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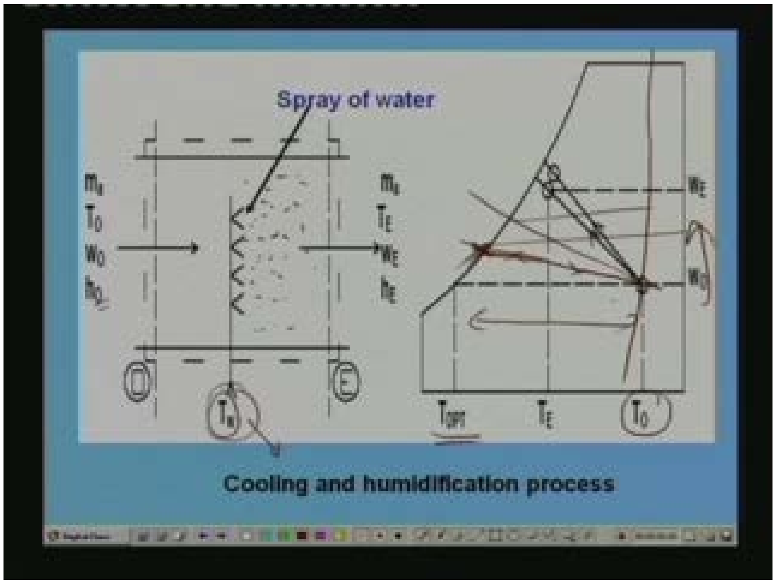


Let us say that this is the water spray and Tw is the temperature of water that is being sprayed okay. Water spray means fine droplets of water here at a temperature of Tw and moist air is coming in contact with this water droplets as is said this water droplet temperature Tw is greater than the dew point temperature. That means let us say that Tw is somewhere here okay. It could be anywhere from this point to this point okay. But not less than this point okay. It has to be lower than the dry bulb temperature but higher than the dew point temperature. That is what I mentioned okay. Suppose it is somewhere at this point right. Then what happens since its temperature is lower than the air temperature drops and since its partial pressure or vapour pressure is higher than the vapour pressure of air the some moist air evaporates from the water droplets. And the moisture is added to the air okay. That means air gets purified and from straight line law we know that if you know this point and the inlet condition the exit condition must lies somewhere here.

On this line. Okay. So you can see that the process will be somewhere along this line or along this line depending on your temperature okay. So what is happening the temperature is reducing at the same time moisture content is increasing okay. The moisture content is going up right so this is the cooling and humidification process. So what is practical application of this process the evaporative coolers or what is known as desert coolers and cooling towers are based on this process. That means in evaporative coolers and cooling towers the air undergoes cooling and humidification. Of course the evaporator coolers or desert coolers we need to cool the cool and dehumidified air. That means air is important to us but in cooling tower water is important to us we need to get cold water from the cooling tower.

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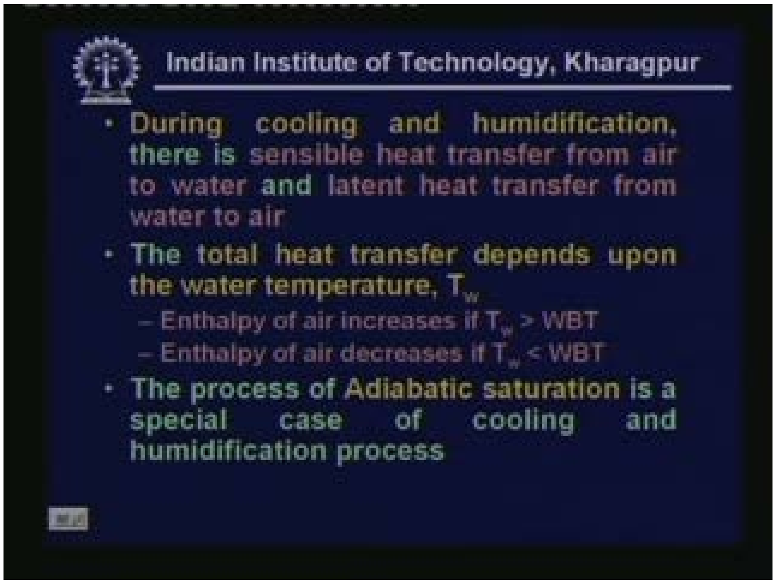


During cooling and humidification there is a sensible heat transfer from air to water and latent heat transfer from water to air okay. Obviously you are reducing the temperature of the air at the same time we are increasing the humidity ratio of the air okay. That means since we are reducing the temperature of the air that means sensible heat transfer is taking place from air to the wet surface okay. Whereas latent heat transfer because moisture is added to the air latent heat transfer is taking place from the wet surface to the air okay. That means the direction of sensible and heat transfers processors are opposite. The total heat transfer depends upon the water temperature Tw okay. This is very important for example the enthalpy of air increases if water temperature is greater than the WBT. That means Tw is greater than the wet bulb temperature. That means if you are spraying water or if you are bringing air in contact with the wet surface whose temperature is lower than the dry bulb temperature but greater than the wet bulb temperature. Then you find that the enthalpy of the air increases. That means there is net heat transfer to the air why there is net heat transfer to the air. You will find that latent heat transfer to the air is higher than the sensible heat transfer from the air okay. So as a result there will be net heat transfer to the air when the water temperature is higher than the wet bulb temperature okay. In the reverse case the enthalpy of air decreases if water temperature is lower than the wet bulb temperature the process of adiabatic saturation. We have discussed the, this process in the last lecture this adiabatic saturation process is a special case of cooling and humidification process during which the wet bulb temperature remains constant.

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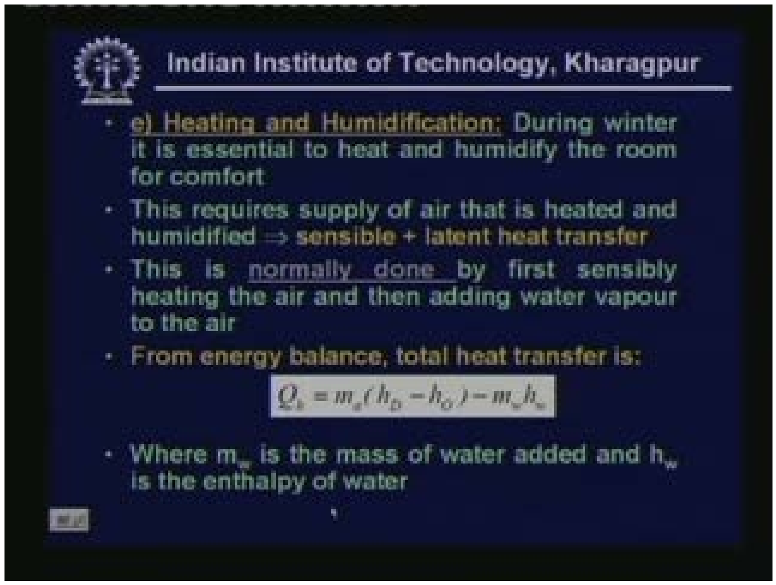


Now let us look at another process called heating and humidification process. During winter it is essential to heat and humidify the room for comfort okay. So this is basically required in the cold countries for winter air conditioning systems okay. So you have to heat and humidify the air that means you have to increase its temperature and also we have to increase its moisture content. This requires supply of air that is heated and humidified okay. That means both sensible and latent heat transfer are involved again this is normally done by first sensibly heating the air and then adding water vapour to the air okay.

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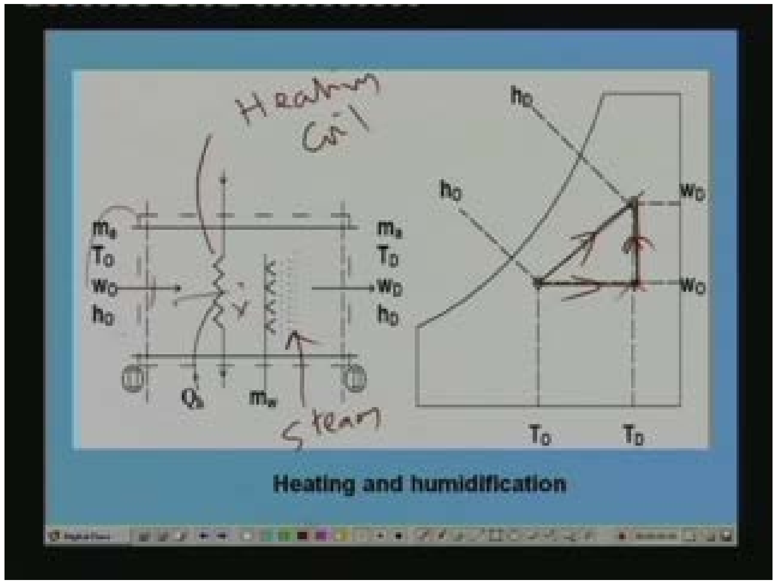


That means you have a heating coil here okay. So this is your heating coil are simply heated okay. So air first flow for heating coil for example like this. So its temperature increases that means this is sensible heat transfer process okay. So at this point after this you add let us say steam okay or some water vapour. So it undergoes a latent heat transfer process okay. So the process is like this okay. So the combined process is something like this right. So this is the heating and humidification process. So from energy balance total heat transfer rate is again if you can apply the energy balance to the control volume.

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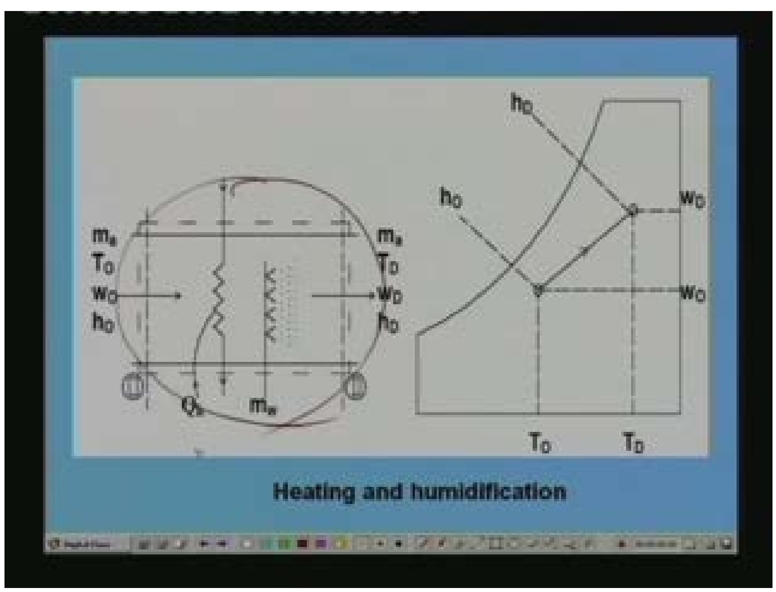


Okay, take the control volume and apply energy balance to this the total heat transferred. During this process is given by this equation Qh is equal to ma into HD minus h naught minus mw hw where hd and h naught are the exit and inlet enthalpies of air ma is the mass flow of dry air mw is the mass of water added and hw is the enthalpy of water okay.

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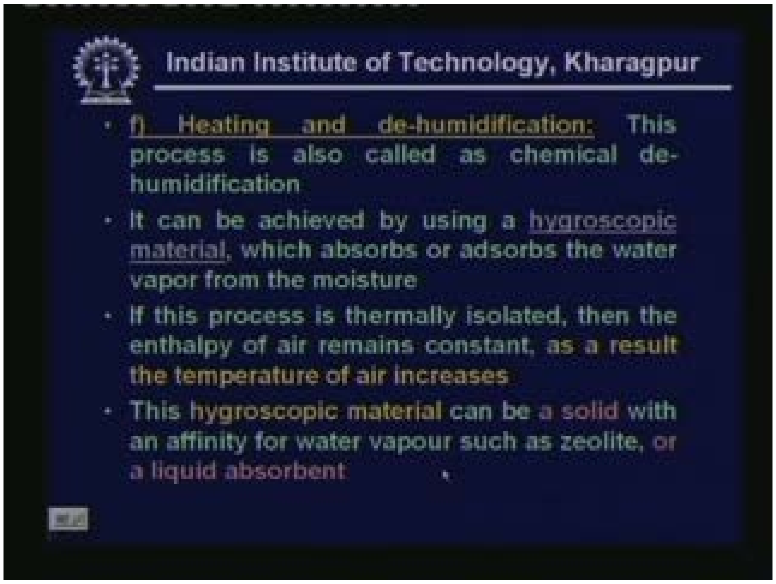


Next process is heating and de-humidification process okay. So here temperature increases as the name implies at the same time moisture content reduces this process is also called as chemical de-humidification it can be achieved by using a hygroscopic material. That means the material which has affinity for water okay, which absorbs or adsorbs the water vapour from the moisture.

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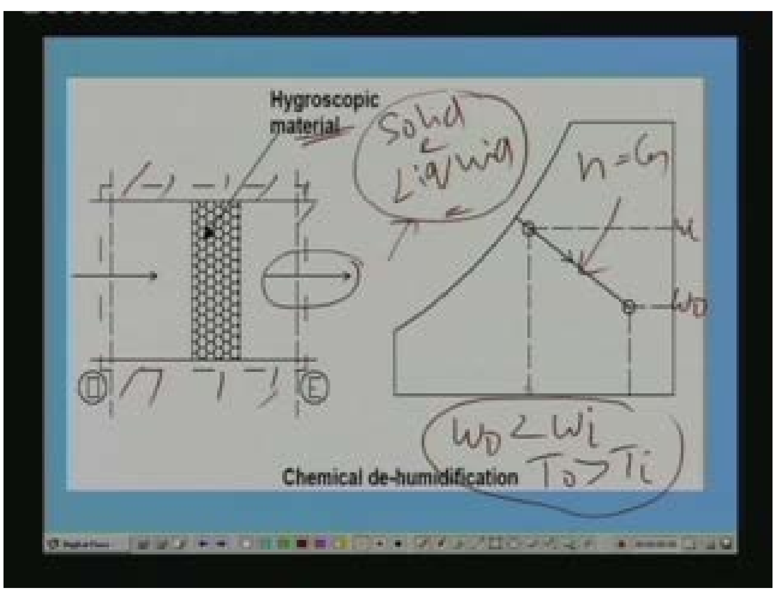

Okay, so this is the for example we have some hygroscopic material which could be either solid or liquid with an affinity for moisture okay. It can be solid or liquid. So when air comes in contact with this solid or liquid since this has affinity for moisture it will absorb the moisture or adsorb the moisture from the air. So as a reason moisture content of the air reduces and if you assume that this process is taking place adiabatically. That means everything is perfectly insulated. Then this process will be taking along a constant enthalpy line that means enthalpy remains constant okay. So you can see that during this process the humidity ratio okay. If this is inlet and this is outlet humidity ratio is reducing okay. At the same time the temperature is increasing. That means T naught is greater than Ti okay. So this is the example of chemical de-humidification or heating and de-humidification process okay. This i have already explain. So hygroscopic material could be for example a solid such as a zeolite or a liquid absorbent.

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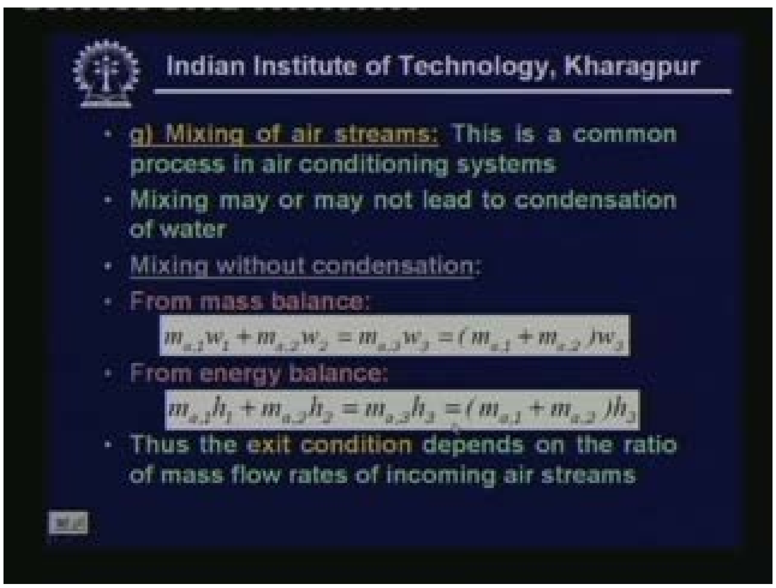


Now next let us discuss another important process called mixing of air streams this is a common process in air-conditioning systems okay. So mixing may or may not lead to condensation of water okay. So what is this?

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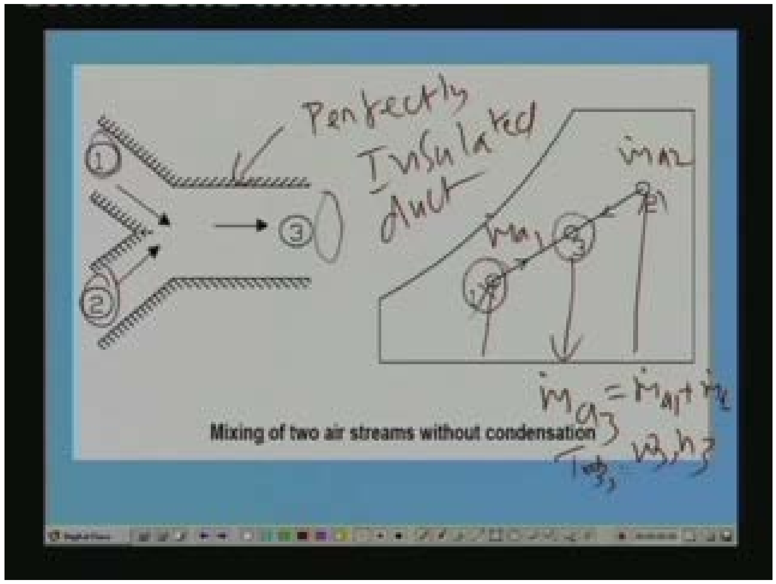


Let us say that we have two air streams air stream one and air stream two they are adiabatically meets that means this is a perfect insulation perfectly insulated duct insulated duct okay. So simply we are mixing the air streams and you would like to find out what is the exit condition right. So since it is an adiabatic process let us say that this is state one and this is a state two okay. So air at this condition with certain mass flow rate let us say m dot a one and m dot a two is a mass flow rate of the air stream two these two air streams are getting mixed. And you get a resultant air stream with a mass flow rate of m dot a three that is equal to m dot a one plus m dot a two from mass balance and at the state point three. That means you have temperature at the exit T three humidity ratio W three enthalpy h three like that okay. So there is no condensation or anything during this process.

So from mass balance you can easily write this is the mass balance what I have written is for the mass balance for the water vapour ma one W one plus ma two W two is the amount of water vapour coming into the duct that is equal to the amount of water vapour leaving the duct. All these equations are for steady state okay. So this is equal to ma three W three where ma three is nothing but ma one plus ma two into W three okay. Similarly from energy balance if you do in energy balance you can write that ma one h one plus ma two h two is equal to ma three h three okay. That means energy coming in is energy going out so that can be written as ma one plus ma two into h three thus the exit condition depends on the ratio of mass flow rate of incoming air streams okay.

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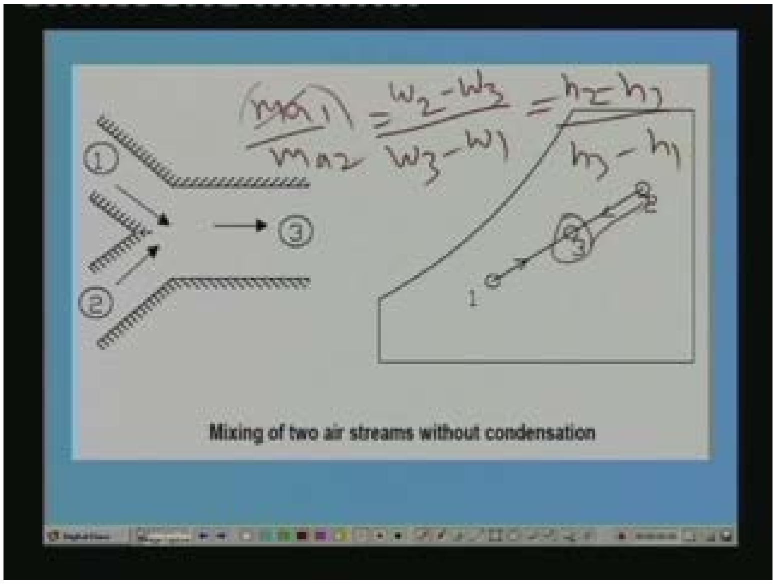


For example using the two equation you can show that ma one divided by ma two is equal to for example if you are writing in terms of humidity ratios or this can also be equal to h two minus h three divided by h three minus h one okay. So you can see that the exit conditions depends upon the ratios of the mass flow rate. For example when ma two is zero when ma one is zero let us say ma one is zero means W two will be equal to W three. That means this point is I think move to towards this point similarly when ma two is zero W three will be W one h three will be h one also this point.

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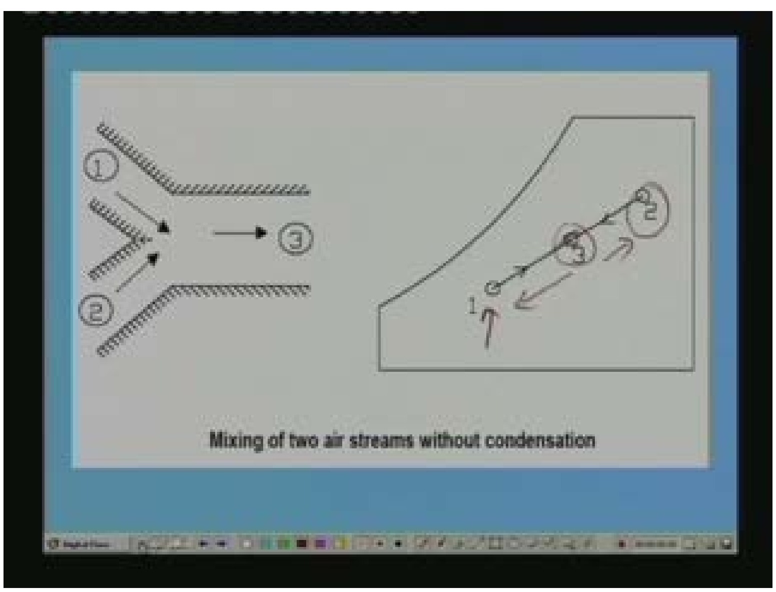

Okay, so as the mass flow rate of one or other air stream increases this point shifts towards that air stream okay. If this air stream has a higher mass flow rate three will be closer to one okay. Reverse case if this is higher mass flow rate three will be closer to two when the mass flow rates are same three will be the midpoint. So this is the process without condensation.

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You can also have a process called mixing with condensation okay. This happens when large quantity of cold air mixes with warm air at high relative humidity some amount of water vapour condenses okay.

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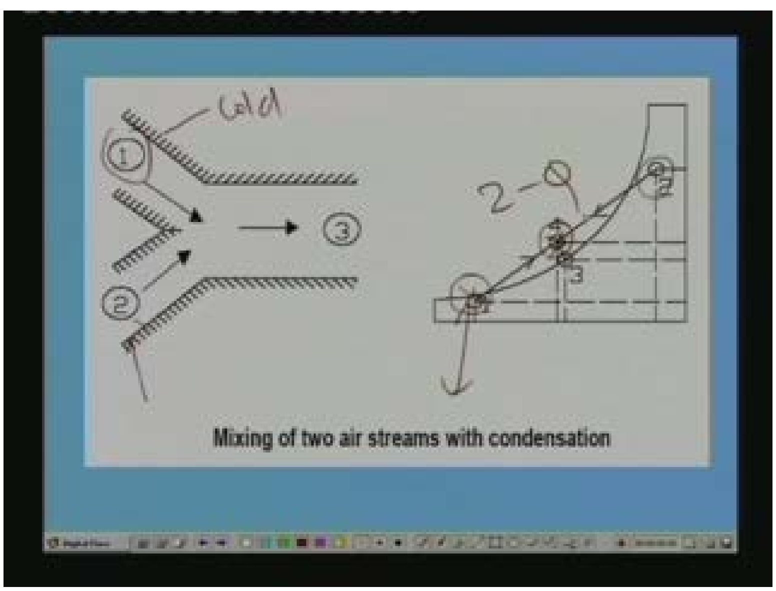

For example you have a special case again this is a mixing process let us say that incoming air one is very cold okay. The temperature is very low this is mixing cold air okay, is mixing with hot and humid air. That means point two okay. So the mixed condition must lie on the same line joining these two point. So if you when you join the straight line these two point in straight line you find that the resultant condition is in the two phase reason region okay. Because this is the two phase region okay. That means an unstable and the liquid droplets must separate out okay. So liquid droplets will be separated from the air stream as a result its humidity ratio reduces. You find that finally the exit condition point three will be exit condition of the air that is will be at this point okay that means at a lower humidity ratio. Hence the humidity ratio of the resulting mixture will be less and there will be an increase in temperature of air due to the release of latent heat of condensation okay. Temperature increases humidity ratio decreases this process rarely occurs in air conditioning systems. You mean normally we do not encounter this process however this is the phenomenon which is the which is behind the formation of fog or frost in winter okay.

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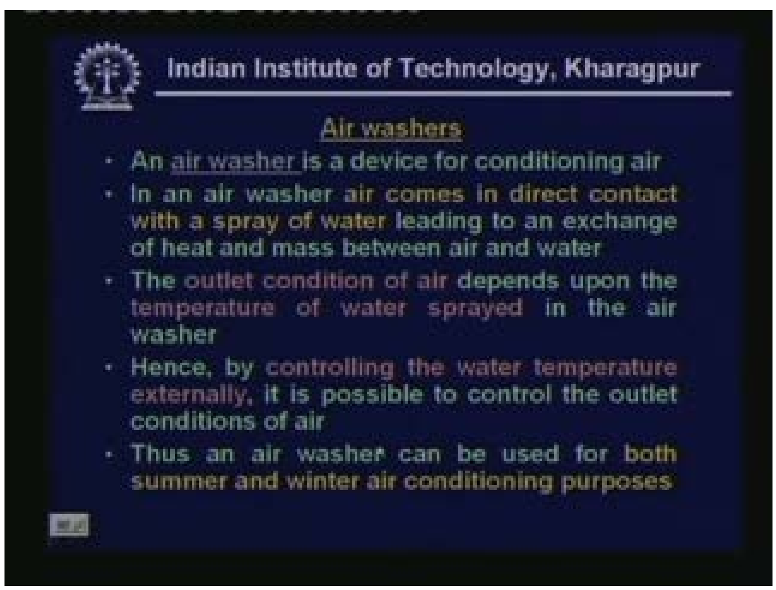


Now let me quickly describe what is known as an air washer an air washer is a device for conditioning air in an air washer air comes in direct contact with a spray of water leading to an exchange of heat and mass between air and water okay. Let me show this.

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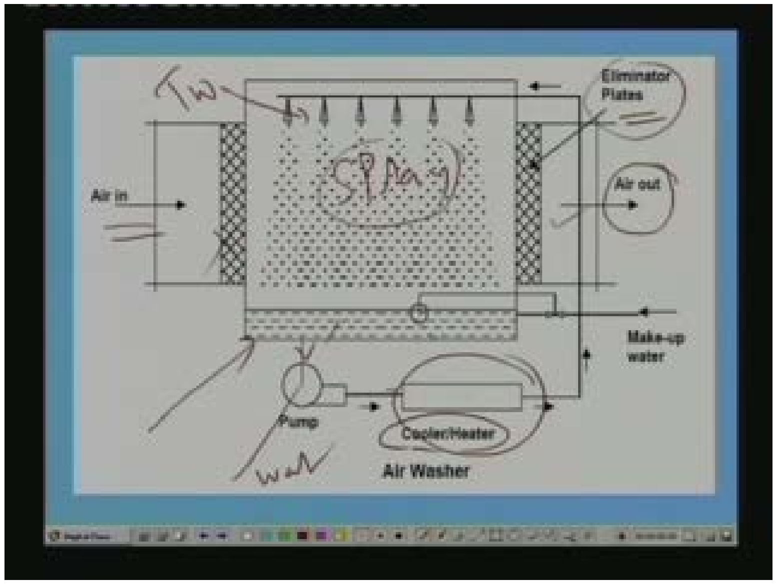


So what we have this is the air washer we have a water pump this is the water okay. So this is connected to a pump the cooler or a heater. So water is taken from the sump it is either cooled or heated and it is again sent back to the air washer and it is sprayed you have the spray of the same water is sprayed after conditioning it okay. So the air enters this air washer through this drift eliminators which eliminate the, of course you do not require a terminator here. You may require at the exit the air enters, let us say through a filter. And it comes in contact with the spray of water and during this contact the sensible, either sensible or latent heat transfer takes place or both take place okay.

Depending upon the temperature of the water right. So by controlling the temperature of the water. That means this water temperature you can achieve different exit conditions okay. So this unit is known as an air washer. The outlet condition of air depends upon the temperature of water sprayed in the air washer hence by controlling the water temperature externally it is possible to control the outlet conditions of air okay. Thus an air washer can be used for both summer and winter air conditioning system. That means the same system can be used for cooling and dehumidification in summer and for heating and humidification in winter by controlling the temperature of the water.

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Let me just give you an example quickly for example in an air washer one can achieve cooling and de-humidification by circulating water whose temperature is lower than the dew point temperature. Since there is a transfer of enthalpy from air to water air gets cooled and water gets heated up okay. So water has to be externally cooled okay. Here both latent and sensible heat transfers are from air to water. The reverse process heating and humidification you have to spray the water whose temperature is higher than the dry bulb temperature. Here both sensible and latent heat transfers are from water to air hence water has to be heated externally okay. In the first case water has to be cooled in the second case water has to be heated.

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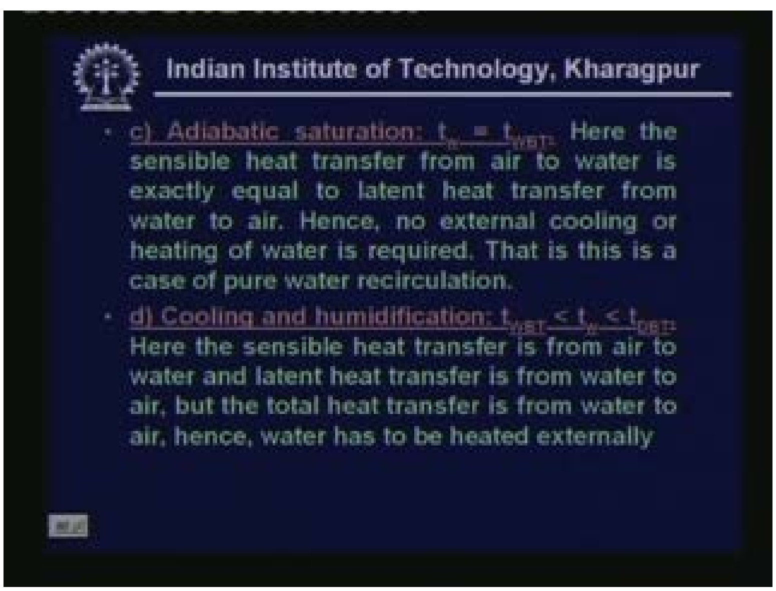

Then you have adiabatic saturation process here all that we have to do is simply re circulate the water here the sensible heat transfer from air to water is exactly equal to latent heat transfer from water to air. Hence no external cooling or heating of water is required that means this is a case of pure water recirculation okay. And the last process is cooling and humidification here you have to spray the water whose temperature is higher than the wet bulb temperature but lower than the dry bulb temperature. Here the sensible heat transfer is from air to water and latent heat transfer is from water to air but the total heat transfer is from water to air okay. That means water has to be heated externally okay because it is loosing energy.

So you have to heat externally this is an example of a cooling tower okay. Cooling tower is what happens right. So like that by controlling the water temperature. That means by controlling the cooler or heater you can achieve the required condition at the exit of the air washer okay. So that means the air washer can be used as in a all year air conditioning system okay. So at this point I stop this lecture and we will continue this in the next lecture.

Thank you.