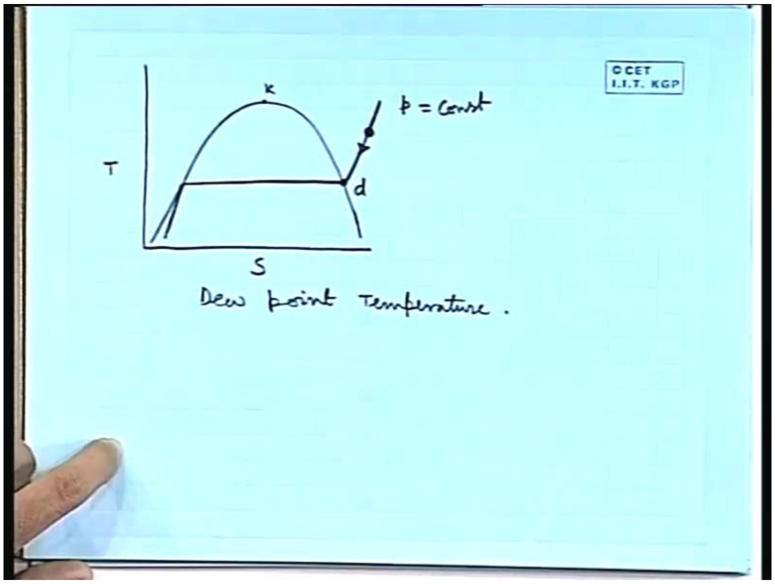
Applied Thermodynamics for Marine Systems
Prof. P. K. Das
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 20
Psychometrics (Contd.)

We have seen what the humidity ratio or specific humidity is. This gives some sort of a measure of water vapour present, water vapour actually present in a sample of moist air; but it has been seen that this does not give us much information regarding the comfort feeling in a particular sample of air. For that, we need to define certain other quantities. First, I would like to define dew point temperature and then we will go to the other quantities.

The dew point temperature, it is related to the process of condensation and we are familiar with this process. We know that when the temperature is lowered, then in a particular sample of moist air at certain temperature, we will find the presence of liquid water. This liquid water is generally formed in the form of small droplets on cold surfaces and they are most commonly known as dew. That is why the temperature at which these liquid droplets appear, that temperature is known as dew point temperature.

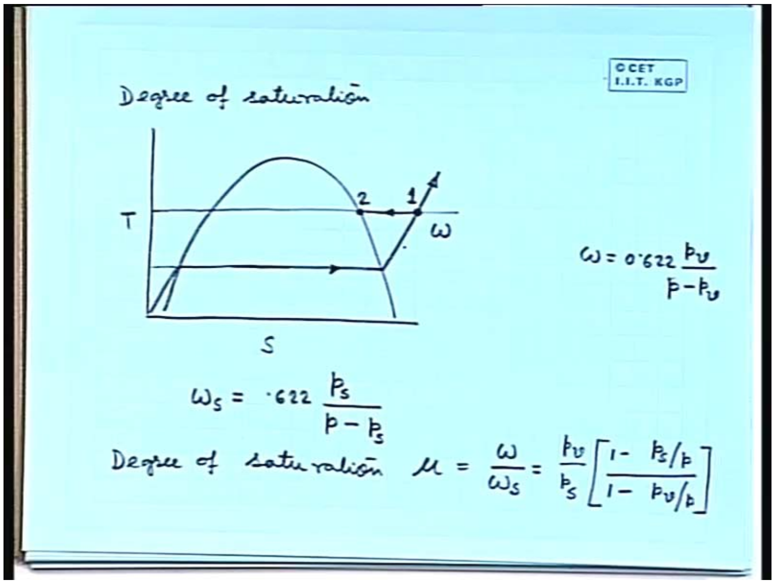
(Refer Slide Time: 02:49)



Thermodynamically the process is something like this. If we have the TS diagram and this is the two-phased zone. So a constant pressure line is something like this. This is the constant pressure line. This is the critical point K and condition of the water vapour in a particular sample of air is given by this particular point. This is p and it is equal to a constant. This is a constant pressure line. Keeping the pressure same if we cool the sample, then we are following this path. If we come to this point then what will happen? We will have saturated vapour and after this point, we will enter the two-phased zone. Here we are having super heated vapour and we are cooling it along this constant pressure path. Here we will come to the saturated vapour line. So now it is saturated. After this, even a small amount of heat rejection or heat extraction from the sample, then we will have condensation. Here, we will have the formation of water droplet or dew. So this temperature is called dew point temperature. Let us denote it by d. So, this is the dew point temperature.

You can see that for a particular sample - a particular sample means it will be at a particular temperature and at a particular pressure. It will have a dew point temperature. Keeping the pressure same if we start extracting heat from the sample, then at one temperature, its temperature is falling; at one temperature, condensation will start in the sample and that temperature is known as dew point temperature. Let us call it dew point temperature.

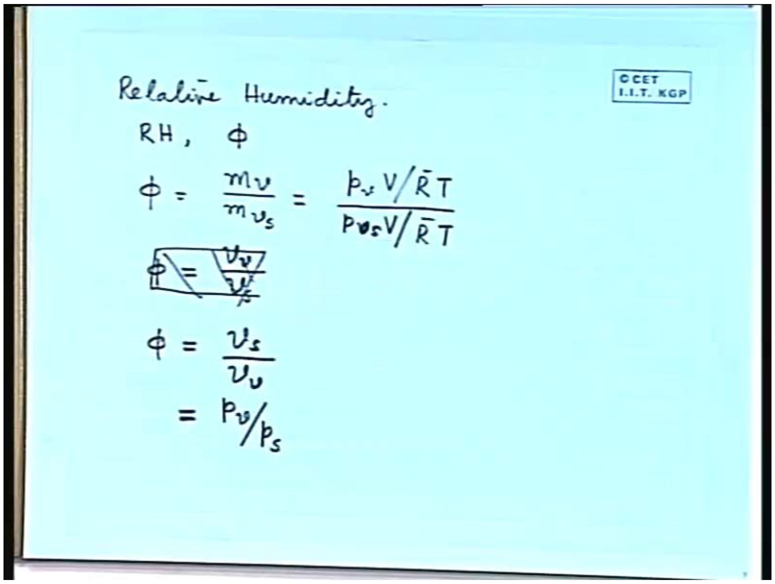
(Refer Slide Time: 06:23)



Next, we like to see the degree of saturation. Again, let us try to understand the process with the help of this TS diagram. This is a constant pressure line and the condition of the water vapour is somewhere here. This is the condition of water vapour. At this condition, it is having a humidity ratio is equal to w. For this, what relationship have we got? We have got w is equal to 0.622 p_v by p minus p_v. This pressure is p_v; this pressure, which I have shown here is p_v. I can come to the saturated condition. One way I have shown that I have come this way that means, keeping the pressure constant, I have lowered the temperature, but I can come to the saturated condition by this path also.

Let us say this point I denote as 1 and this point is 2. I can come to point 2 which is a saturated condition by this path also. What have I done here? I have kept the temperature constant, but there is a variation of pressure. So I can come by this path also. In that case, we will have another value of humidity ratio and as it is in the saturated condition, we can call it w_s and w_s will be 0.622 p_s by p minus p_s. The degree of saturation, we will define as mu and that is nothing but w by w_s. Then we can get this relationship p_v by p_s within bracket 1 minus p_s by p divided by 1 minus p_v by p. So this will be the degree of saturation. Once we have learnt what the degree of saturation is, then we can go to another quantity which is very important that is known as relative humidity.

(Refer Slide Time: 10:57)

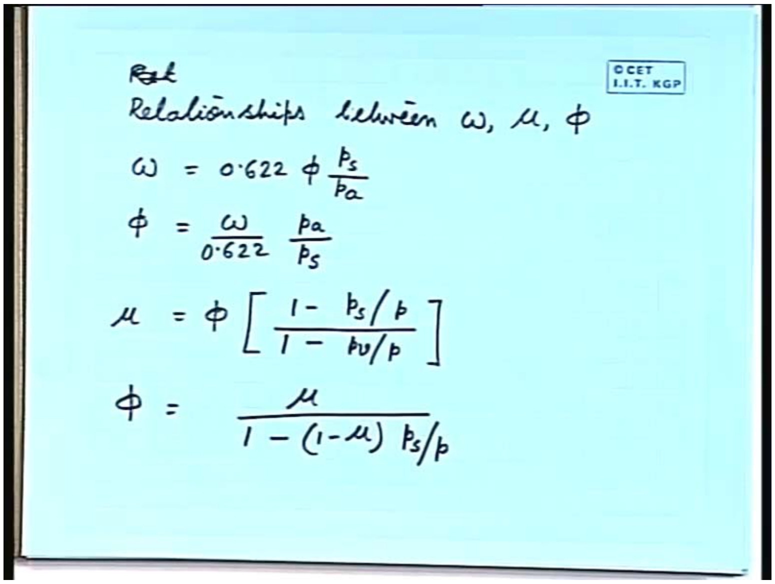


Relative humidity is expressed either as RH or phi. It is denoted either by RH or by phi. Relative humidity is defined like this - phi is equal to mv by mv_s. What does it mean? mv is the amount of water vapour actually present in the sample at a particular pressure and temperature. We have taken a sample and that sample has got some pressure and temperature. So at that pressure and temperature, we have got mv amount of water vapour present in 1 kg in the sample that means with 1 kg of air. That will give you, w.

At that particular pressure and temperature, if we want to make that sample saturated, let us say we need mv_s amount of water vapour. The ratio between mv and mv_s gives you the relative humidity. It is very simple, we can express it p_v V by RT and pv_s V by RT or simply it is p_s V by RT. Then, ultimately if we do the simplifications, we can have phi is equal to v_s by v_v or we can have p_v by p_s. You can see that it is given by either the ratio of partial pressure or the ratio of the specific volume. As it is a ratio of two similar quantities, so it will not have any unit and sometimes or most of the times, it is expressed as percentage. When the sample is such that it is already having water vapour needed for saturation, that means mv is nothing but mv_s, then phi becomes 1 or the relative humidity becomes 100%. Similarly, we can have other percentages of relative humidity.

Relative humidity is a better representation of the condition of air as far as evaporation or condensation is concerned. If the relative humidity is less, then we can assume that the sample of air has got a higher capacity or a larger capacity of absorbing water vapour or moisture. At that condition, if somebody is sweating, or there is water present or water spray inside the sample then it will readily evaporate. How is it important for air conditioning? If somebody is sweating, then we will see that from his body the sweat will evaporate very fast. He will have the feeling of comfort. If the relative humidity is high - let us say 80%, 90% or 95% - if somebody is sweating, the sweat will collect on his body as a layer and he will not have the feeling of comfort. Similarly, if we have got wet clothes etc., that will not dry faster in the air. That is why absolute humidity gives us the absolute quantity of water vapour present in the air. Maybe, it is important for some calculation, for some analysis, but if we want to have an idea of how fast the evaporation process will be, then the relative humidity is a better property to know and it is more commonly expressed as percentage. We will see in our weather forecast etc., we will have moisture content expressed as relative humidity. These three quantities, that is, relative humidity, humidity ratio and the degree of saturation, they are related to each other and I like to write down this relationship.

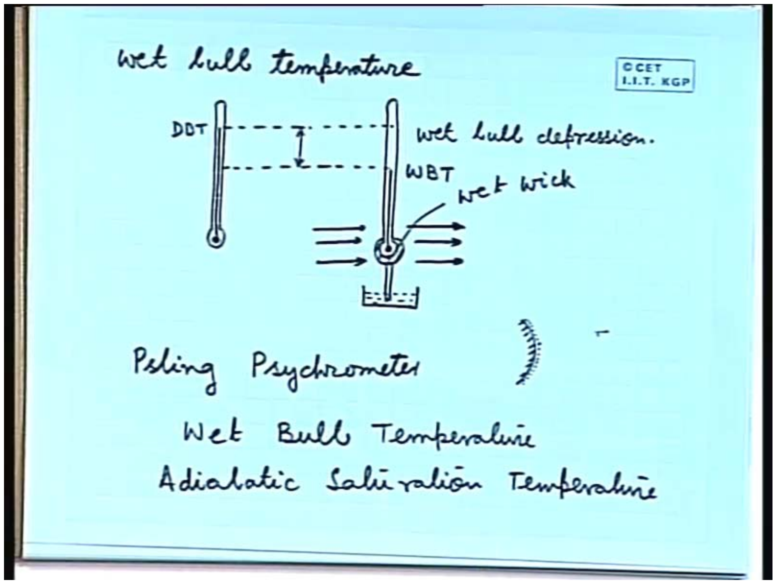
(Refer Slide Time: 17:40)



One can have the relationships between omega, mu and phi. One can have omega is equal to 0.622 phi p_s by p_a. Similarly, one can have phi is equal to omega by 0.622 p_a by p_s. mu is equal to phi into 1 minus p_s by p divided by 1 minus p_v by p. phi is equal to mu divided by 1 minus 1 minus mu p_s by p. These are the relationships between relative humidity, degree of saturation and humidity ratio.

Before going to some other property, I like to describe another measurable quantity. These quantities, absolute humidity or humidity ratio, degree of saturation, relative humidity – all are measurable but they cannot be measured in a very direct manner. I have just explained how one can measure omega, but directly they cannot be measured. Maybe they can be measured - some quantities can be measured and then using some mathematical relationship we can get these quantities. But there is another quantity in case of air water vapour mixture which can be measured directly.

(Refer Slide Time: 20:17)



That is known as wet bulb temperature. This wet bulb temperature - there is some thermodynamic principle behind it. We do not have much time to give a very elaborate description of the thermodynamics principle and that derivation. In a nutshell, I will try to explain what a wet bulb temperature is and how it is measured. Now before describing the wet bulb temperature, let us see what dry bulb temperature is. Dry bulb temperature is the temperature, which we will get, if a thermometer is placed in a sample of air. In a sample of air, if you place the thermometer, then you will see somewhere there is the mercury level and that gives the temperature of the sample. So that is dry bulb temperature or simply we can call it temperature of the sample.

For wet bulb temperature what we do is, we have a similar thermometer but the bulb of this thermometer is wrapped with the help of a layer of cotton and then, this cotton is kept moist with the help of pure water; pure water means distilled water. With the help of pure water, this layer of cotton is kept wet. How can it be kept wet? This is one of the methods by which it can be kept wet or kept moist. With this cotton, we have got certain strips which are ultimately dipped in a container that contains distilled water. Due to capillarity, water will come up and this hatched portion will also remain wet. One has to ensure that across this bulb, there is enough amount of air flow. The sample of moist air which I have taken should have enough relative velocity with this moist bulb of thermometer. That can be ensured by different means. One is that if it is in some air conditioning duct etc., or just after the dehumidifying coil, cooling coil, where the fan is blowing the air, so we already have a large velocity of air. So, we need not bother. We can simply hold the thermometer like this.

In a stationary room like this, suppose in this room, we want to find out the wet bulb temperature. Then in this room, we have to create this motion. There are different methods of creating this motion - there can be a small fan which is drawing the air with enough velocity across the bulb. If that is also not there then there are arrangements where you have to rotate the thermometer with your hand, so that you are creating a relative motion between the bulb and the air. Generally, this wet bulb temperature is a psychometric measurement. What is done? A dry bulb thermometer and a wet bulb thermometer are placed side by side. The whole arrangement you can rotate with the help of your hand. That piece of instrument where you have got both wet bulb temperature and dry bulb temperature and arrangement for rotating it you call it a Psling psychrometer. The process, which takes place, is a bit complex and it is some sort of conjugate process. What will happen in this thermometer bulb? What type of transport process will take place, any idea?

Water will start evaporating because we are assuming that the sample in which it is being rotated or the air which is flowing over this bulb is not saturated, that is unsaturated. If it is unsaturated, if we see closely, this is the wet surface. Just near the wet surface, this air is also saturated with water vapour, but here the air is not saturated with water vapour. So the molecules of the water vapour that will move from here to here. This is some sort of a diffusion process or mass transfer process; so some amount of mass transfer will take place. When it is transferring it, that means when liquid water is there and due to diffusion from that liquid evaporation is taking place and that is being removed to the air stream itself; due to evaporation, it will take up a certain amount of latent heat. That means its temperature will fall down. But the air which is moving will have a higher temperature; so, a heat transfer will also take place because there is a temperature gradient. There is a concentration gradient; a high concentration is there on the body of the wick. This is called wick - wet wick. We have got a high concentration of mass on the body of the wick, low concentration of mass in the air. So mass transfer will take place from the body of the wick to the air stream; but we have got a high temperature in the air and low temperature on the body of the wick because a certain amount of latent heat has been taken. So a heat transfer will take place from air to wick and this process will continue till equilibrium is reached. Equilibrium, will reach very fast. Then, the temperature indicated by the thermometer will be the temperature required for the equilibrium. Here, one can assume that the radiative heat transfer etc., are negligibly small.

For air-water system, one can show that this temperature is equal to adiabatic saturation temperature. This wet bulb temperature is equal to adiabatic saturation temperature. We can call it DBT. We can call it WBT. Actually one can derive the process involved. Some sort of heat transfer and mass transfer equations are also needed. So far we have not done those things; I think that much detail is not needed for this course. For the air-water system, we will see that when this equilibrium reaches then the temperature denoted by the wet bulb thermometer is the adiabatic saturation temperature and it is also known as the wet bulb temperature.

So I am writing these two keywords - wet bulb temperature and adiabatic saturation temperature. Here we will see that if the sample is not saturated, the wet bulb temperature will be different from dry bulb temperature and the wet bulb temperature will be lower than the dry bulb temperature. This is known as wet bulb depression. Knowing the dry bulb temperature and wet bulb temperature, we can determine the other properties of the moist air. That can be done readily with the help of a psychrometric chart. Now itself, I can introduce the psychrometric chart and then in some of the tutorial classes, we will see how to read the chart. Now itself, I can introduce the psychrometric chart.

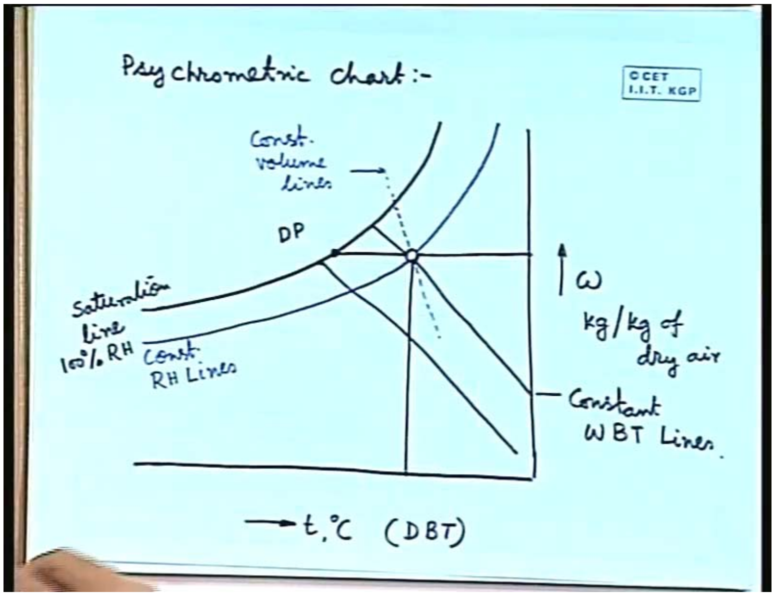
So far, I think whatever I have told, those are clear. What have I introduced? I have introduced these quantities. First, I have introduced the humidity ratio or specific humidity, dew point temperature, the degree of saturation, the relative humidity which is very important and then we have come to wet bulb temperature. I told you that whatever quantities I have introduced earlier, those can be measured, but we cannot measure them conveniently in a direct manner. But the wet bulb temperature, we can measure in a direct manner. We will see that if we use wet bulb temperature and dry bulb temperature both of which can be measured directly with the help of psychrometric chart, we can get the other properties very easily. Also we will see that our different air conditioning processes and calculations can be done with the help of our psychrometric chart quite easily.

Now, I will introduce the psychrometric chart. Psychrometry is the property of moist air. As I have described it, we are taking this moist air as mixture of two ideal gases. One is dry air and one is water vapour. We are taking it as a mixture of two ideal gases. This is a two component mixture. If it is a single component substance, then if we know two independent thermodynamic properties, then any third property can be determined. Knowing two independent thermodynamic properties, any third property can be determined. Here, what do we get? Here, we are getting two components. So here, three properties should be known; then only the fourth property can be determined. Actually, it comes from thermodynamics and Gibbs phase rule which is not within the scope of the present course. As we can draw some sort of an analogy, we can say that for any pure substance, if it is a single component pure substance, then we have to know two independent thermodynamic properties to know any other thermodynamic properties.

As, in the present case, it is a mixture of two components, two gas components; so, we need to know three properties to know any third property. What does it mean? It means that any property chart should have a three dimensional figure, because three things should change independently then we will get the fourth one. What is done? Psychrometrics, particularly for air conditioning and some such application, we need it at a pressure near atmospheric pressure. For our practical use, we can teach one property - that means - we will make the chart at atmospheric pressure. So pressure we make it constant.

If one property is fixed, we now need two properties to get any other property. Now we can express the chart on a two dimensional plane - that is what is done in a psychrometric chart. We will have a chart which is represented on a piece of paper; that means it is a two dimensional plot and in that, pressure is kept constant - that is we are having the chart at atmospheric pressure. If we have to do this for other places like at some elevation where the pressure is lower, we need to have corrections or we need to have a separate psychrometric chart. The psychrometric chart has a typical look. This is how the psychrometric chart looks.

(Refer Slide Time: 37:37)



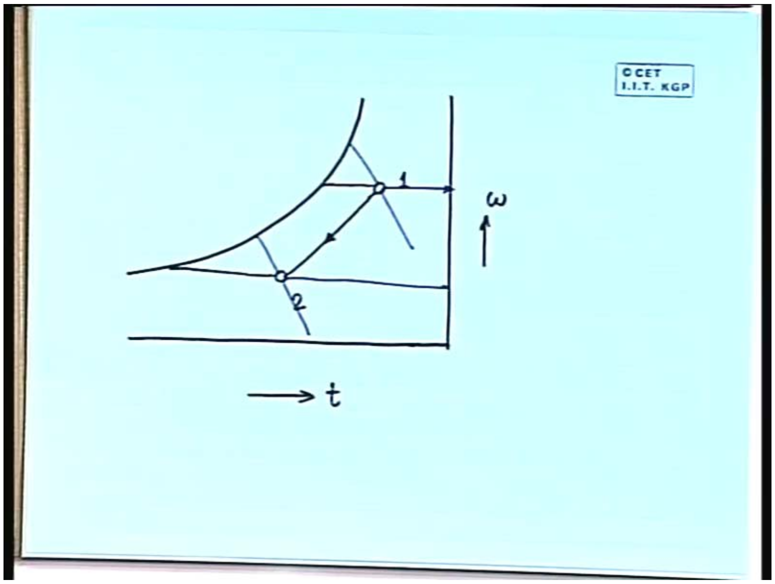
In this direction, we have got t in degrees centigrade; this is DBT or dry bulb temperature. In this direction we have got omega - that is kg per kg of dry air. Let us say that we have some sample somewhere here. This is sample of moist air. How will we get different information? This line is called saturation line. This is 100% relative humidity; saturation line for 100% relative humidity. We can use some other colour. From the sample, if we draw a straight line which is parallel to the DBT axis, we will reach the saturation line. This point is known as DP or DPT, dew point. If we drop one vertical line from the sample, it will cut the DBT axis and will give the DBT. So this will give the dry bulb temperature.

If we draw another horizontal line from the sample and if we go to the w-axis or omega-axis, it will give you the specific humidity or humidity ratio. There are lines which are curved lines; there can be infinite number of lines like this. These are constant RH lines, constant relative humidity lines. Then there are number of lines which are straight lines but neither horizontal nor vertical. These are constant WBT lines; these are constant wet bulb temperature lines. In some psychrometric charts, you will find some lines whose slopes are less than the constant wet bulb temperature lines. These are constant volume lines; one can get constant volume lines.

As I have told earlier, for determining psychrometric properties we need to know two independent properties. Using this psychrometric chart, we can determine any other property. Basically, one needs to know the dry bulb temperature and the wet bulb temperature. Both of them are measurable quantities. You know the dry bulb temperature. You know your sample will lie on this straight line. Then, you know the wet bulb temperature. So you have to find out which is the wet bulb temperature, causing this straight line. Knowing the wet bulb temperature means it will cross somewhere here so this is the point where your sample will lie. Once you know this, you can determine the relative humidity, the dew point temperature, the specific humidity or humidity ratio and the volume. All these things you can determine. As an engineer, generally, we measure these two quantities with the help of a psling psychrometer and after knowing this, we use the psychrometric chart to get all the other properties.

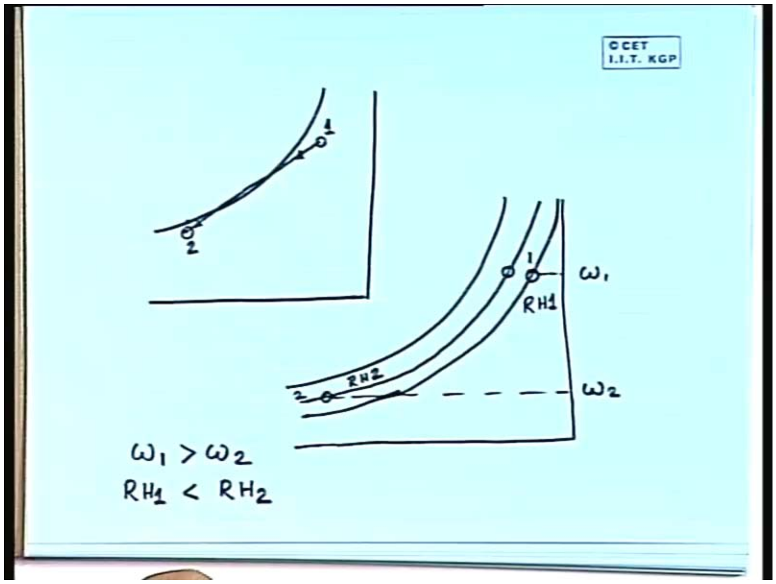
There is another property - enthalpy - we will come to that property slightly later on. The important thing is, this is the saturation line. If your sample lies on this saturation line then you will find you will have identical value of dry bulb temperature, wet bulb temperature and dew point temperature. If your relative humidity is equal to 100% then you will have same dry bulb temperature. It means identical values of dry bulb temperature, wet bulb temperature and dew point temperature. That is what we can get from this psychrometric chart.

(Refer Slide Time: 45:40)



Let us say this is the psychrometric chart. This is t. This is omega. This is the sample at state 1. This is the sample at state 2. Let us say, there is a change from state 1 to state 2. We can have all the required quantities. We can find out how the dew point temperature has changed from state 1 to state 2. We can find out how the wet bulb temperature has changed from state 1 to state 2. If we are interested in this, we can find out how the humidity ratio has changed from state 1 to state 2. That we can find out. Then there are certain interesting things.

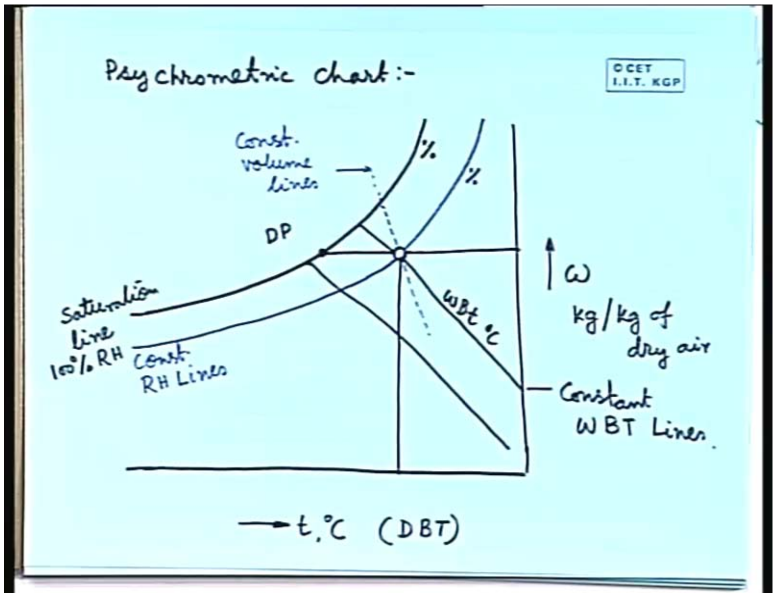
(Refer Slide Time: 47:23)



Our state 1 is somewhere here. This is our state 1. State 2 is somewhere here. This is our state 2. Part of the process is outside the saturation line, so, there will be a certain amount of condensation. Heat transfer is there. Definitely there is a change in temperature; certain amount of condensation and depending on the situation what will happen? If these particles are small, then they may get suspended in the air and they may create a situation like fog kind of a thing; that they may make create. Seeing this, one can say that here and here the moisture content has reduced to a great extent. Another thing you can see that is very interesting.

Let us take the previous example – no, let me draw another figure. This is our psychrometric chart. These are constant relative humidity lines. Let us say, we are having two different points like this. Here you see let us say this is 1 and this is 2 and here this is omega$_1$ and this is omega$_2$. This is RH2 and this is RH1. What I mean to say is that you can get omega$_1$ is greater than omega 2, much greater than omega$_2$. But RH$_1$ is less than RH$_2$. You see the tendency for evaporation or tendency for transformation into water vapour will be higher. Where will it be higher; where your relative humidity is less. Not less moisture content; moisture content is higher here but even then relative humidity could be lower. Even with higher moisture content the relative humidity could be lower because it depends also on temperature; whereas here the moisture content is much lower but the relative humidity could be much higher. That is how the psychrometric chart gives us lot of information. This information, we will see, how we can utilise for our basic calculation of the air conditioning processes.

(Refer Slide Time: 52:24)



If we quickly recapitulate: on a psychrometric chart, we will have two axes - one axis is the dry bulb temperature and this one is humidity ratio or specific humidity. Apart from these two, the important points which we will have on the psychrometric chart are this wet bulb temperature line and relative humidity line. From any point, if we draw a horizontal line and if we go to the saturation line that is 100% relative humidity line, then we will get the dew point temperature. If our point or sample is on the 100% relative humidity line, then we will have identical values of dew point temperature, dry bulb temperature and wet bulb temperature. That means these wet bulb temperatures they are also, let us say WBT, in degree C. These are in percentage, this is 100% and this is also in percentage. These lines are in percentage. These lines are in degree C. This axis is degree C and this is kg per kg of dry air. If you see the psychrometric chart in any book, whatever I have discussed that will be clear.

We will take a break here and in the next class, we will start the enthalpy of moisture and how to calculate the enthalpy of moisture. Thank you.