Material and Energy Balances
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Lecture - 50
Psychrometric Charts

Welcome to today's lecture on psychrometric charts. So in the last class we had looked at some phase change operations and having looked at the tutorials associated with them, we are now moving on to the next topic which is psychrometric charts. What are psychrometric charts?

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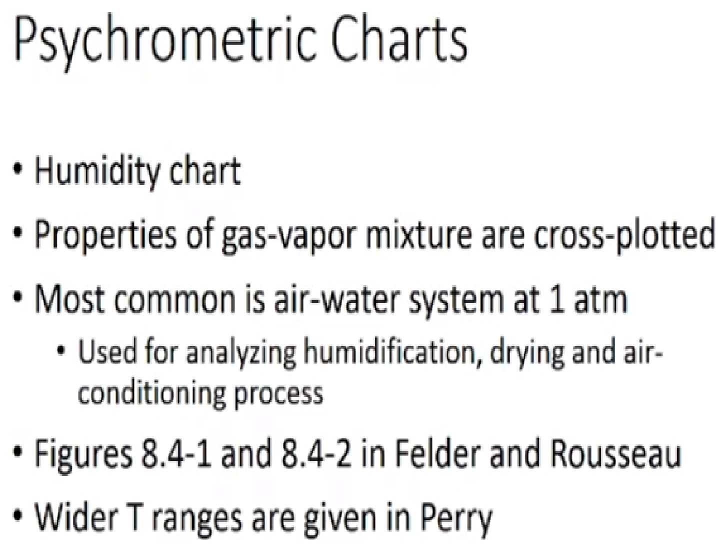

These are also called as humidity charts. So these are basically cross-plotted chars which give us the information about gas-vapor mixture. So most common one which is used is air-water system at 1 atmosphere. So this is used for analyzing humidification, drying, air-conditioning processes which are common in chemical and biochemical industries. So figures 8.4-1 and 8.4-2 in Felder Rousseau which is one of the prescribed text book gives you the psychrometric charts for SI units and for American Engineering units.

A wider range of temperatures can be obtained from Perry's handbook and there are many other handbooks where you can get such psychrometric charts. So the most common one as I said is for the air-water system which is what is commonly seen in many industries and applications.

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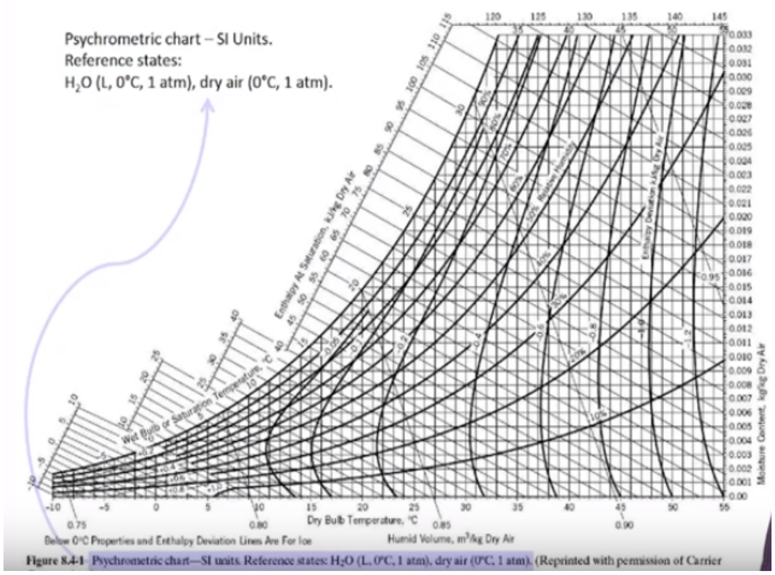

However, there are other psychrometric charts for other combinations of gas-vapor mixtures as well. But today we will talk only about the air-water system. So this is a psychrometric chart. Although it looks intimidating it is, because it is completely cross-plotted. We have usually seen graphs which have only two axis. However, here there are multiple axis which are all translated into a 2-dimensional sheet. That is why there is so many different lines which you see.

It is important for you to try and understand how this chart can actually be read so that we can actually get information about individual in systems very easily. So although currently many databases might be available from which you can actually select these data, it is important to learn how to use the psychrometric charts as these have been traditionally used in chemical and biochemical industries for air-water systems.

So this particular chart which you see here has been obtained from your textbook which is one of the text books which is Felder Rousseau, third edition and this is the figure 8.4 which is in SI units, 8.4-1 which is in SI units. The reference states are clearly mentioned at the bottom. So the reference state which is used for this chart is water liquid at 0 degree Celsius and 1 atmosphere and air which is dry air at 0 degree Celsius and 1 atmosphere.

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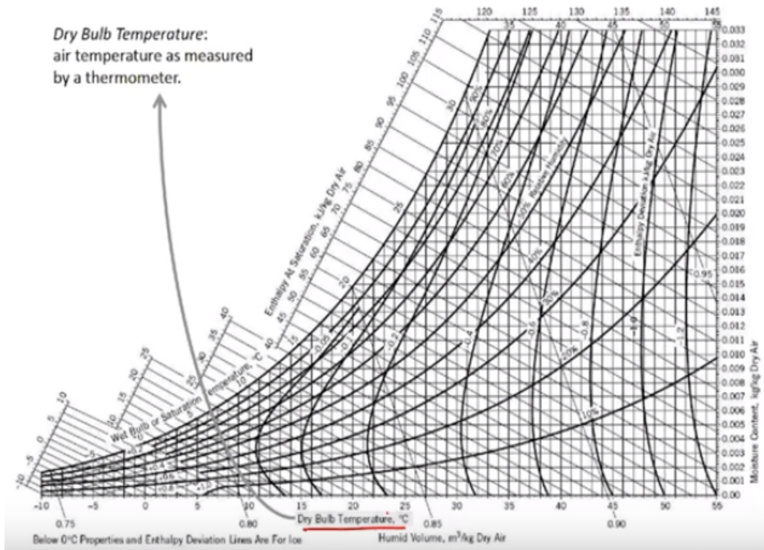

Figure 8.4-1 Psychrometric chart—SI units. Reference states: H_2O (L, 0°C, 1 atm), dry air (0°C, 1 atm). (Reprinted with permission of Carrier

So using these two reference states we have calculated and plotted all this information. So what information is readily available for us from here? The first thing we have is the dry bulb temperature. So the x axis you have here, this is the dry bulb temperature. So this dry bulb temperature basically is the temperature which you would measure using a thermometer. Any thermometer that hangs in an open space would be able to measure the dry bulb temperature.

So this is called as the dry bulb temperature because the bulb of the thermometer is dry while the temperature is being measured. So this is the x axis. So the values you see here, -10, -5, 0 and so on, these are the dry bulb temperatures for this graph. So the next information you can get would be the moisture content or the absolute humidity.

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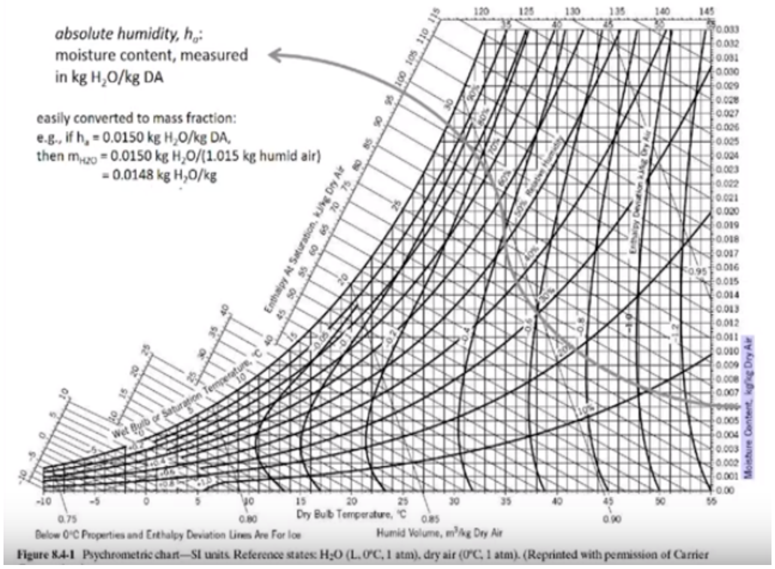

So absolute humidity is basically measured in terms of kilograms of water per kilogram of dry air. So this needs to be clearly understood. The denominator is kilogram of dry air, not kilogram of air total. So total air would contain water vapor and dry air. So that would be called the moist air. So here we are looking at the kilograms of the mass of water vapor which is present per kilogram of dry air.

If you have an absolute humidity of 0.015 kilograms of water per kilogram of dry air then you can calculate the total mass of the mixture which is humid air would be the 0.015 + 1 kilogram of dry air giving you the total mass of humid air as 1.015 kilograms. So using this the mass fraction of water in this mixture can be measured as 0.015/1.015 giving you 0.0148 which is the calculation that we have done here. So this information is useful for calculating mass fraction of water or air in the humid air.

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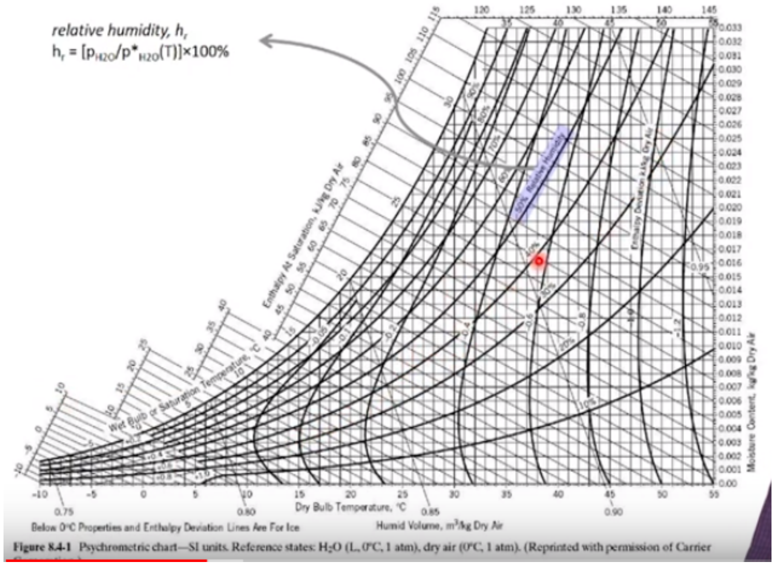

So the next information you can get is relative humidity. So relative humidity is basically the ratio of partial pressure to the vapor pressure times 100 for a given temperature. So this gives you the information about what is the relative level of humidity compared to saturation conditions. So for any temperature there is only so much water vapor that can be present in equilibrium along with air until it starts condensing. So that is the saturation condition.

So if we assume the saturation partial pressure to be 100% then the relative humidity would be calculated using that as the basis. So here you have different things. So the relative humidities are marked not as straight lines but as curves. What you see here, these curves that you see here are the relative humidities. So the relative humidity highlighted here is for 50% relative humidity. You also have for 10%, 20%, 30, 40, 50, 60, 70, 80, 90 and the last one which is the saturation curve would be at 100% relative humidity.

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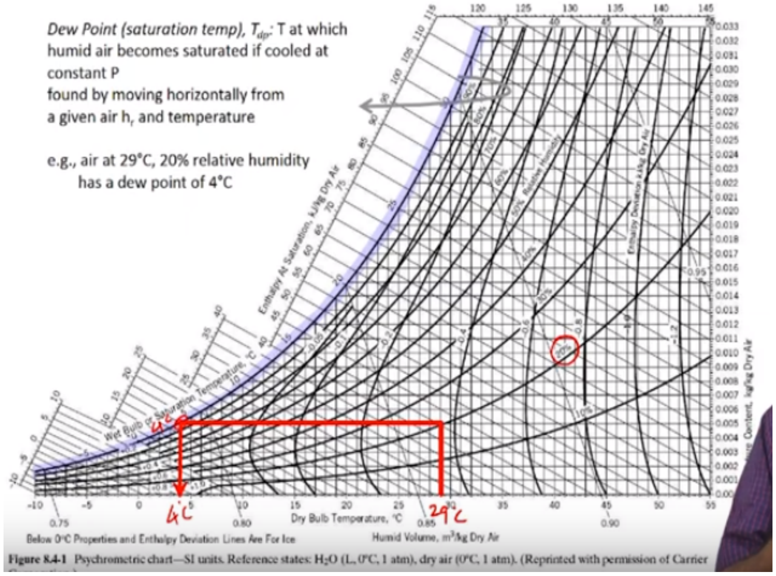

The next information you can get from this is dew point. Dew point or saturation temperature is the temperature at which humid air becomes saturated if cooled at constant pressure. So this is basically formed like this. So take the example here which is 29 degree Celsius and 20% relative humidity. So this is 29 degree Celsius, so the point is identified on the x axis and then you move vertically up till you reach the relative humidity curve of 20% relative humidity which is what has been given to us as the relative humidity.

So from here we have to move horizontally all the way to the saturation curve and the point at which it intersects this point you could either drop back down to get your temperature here on the x axis which is 4 degree Celsius or you could also look it up here. So along this curve also you have temperatures written down so if you can see this -5 given here and 0, 5, 10, 15, and so on. So here this would be 4 degree Celsius.

So you could either look it up here or here and this would be the temperature at which the first dew starts forming. So water would start condensing from the air-water mixture if it is cooled at a constant pressure and it reaches this particular temperature called as the dew point or saturation temperature. So since first dew is formed due to condensation at this temperature, it is called as the dew point.

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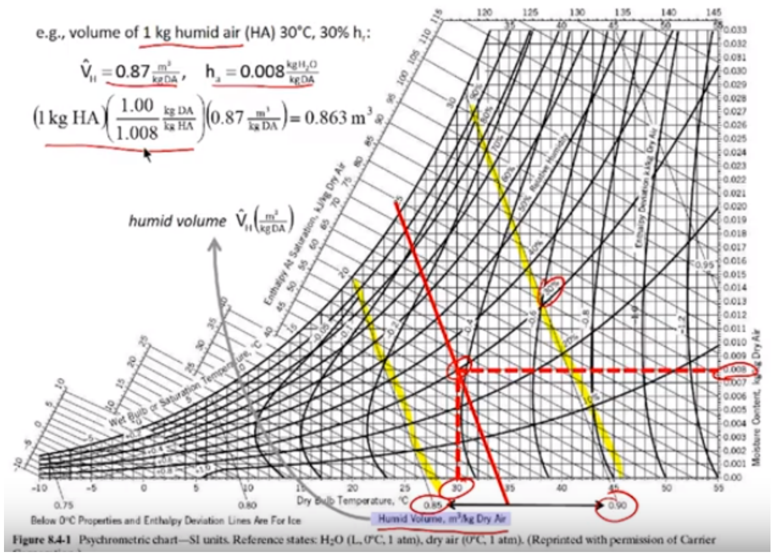

The next information which you have here from this cross-plotted chart is the humid volume. What is a humid volume? Humid volume is basically the volume occupied by humid air. So how do we find humid volume from this curve? So what you have here is you see this axis, again along this particular x axis you have another line which you see here. So this is basically, these are the lines you see slanted lines, these slanted lines that you see here and the values you see here which are 0.75, 0.8, 0.85, and 0.9 correspond to something called as the humid volume.

So now for a given condition, relative humidity we would be able to calculate the humid volume. So which would give us the volume of the air, which we are looking at. So take the example of 30 degree Celsius and 30% relative humidity. So this is 30 degree Celsius and we want to go to the 30% relative humidity curve. So we take this line all the way to this point and from here we can actually calculate the humid volume and by drawing a line parallel to these axis which are the cross axis. So you see these cross-plotted axes here?

So you draw lines parallel to this, these 2 axis through this point, the point of interest which is 30 degree Celsius and 30% relative humidity. When you do that you get this line which falls between 0.85 and 0.9 which are the axis for your humid volume. So using that we can actually identify what the humid volume would be. What you would do is measure the distance between these two points and measure the distance between these two points and use interpolation to identify the value for this.

So having done that I have gotten 0.87 meter cube per kilogram of dry air. So this is the specific humid volume for the conditions given in terms of volume occupied per kilogram of dry air. So if we need to calculate the total volume occupied which would not only account for the dry air but also for the water vapor associated then we would have to use the absolute humidity to identify how much moisture is present and use that and what would be mass of dry air for this condition. So we have been given 1 kilogram of humid air as the basis.

So in this 1 kilogram of humid air, we have to identify how much is dry air. So that we can do using the absolute humidity. So using this absolute humidity axis, we identify that the absolute humidity for this system is 0.008 kilograms of water per kilogram of dry air. So this means 1 kilogram of humid air basically contains water + dry air and we need to convert it into only dry air. So what we can do here is the calculation shown here.

So 1 kilogram of dry air would actually contain 1.008 kilograms of humid air. So 1 kilogram of humid air would contain 1/1.008 kilograms of dry air. So that would be this job. So that would give us the mass of dry air in the given conditions. So that multiplied by the humid volume will give us the volume of the humid air. So which is calculated as 0.863 meter cube and this gives us an idea as to how to perform these calculations.

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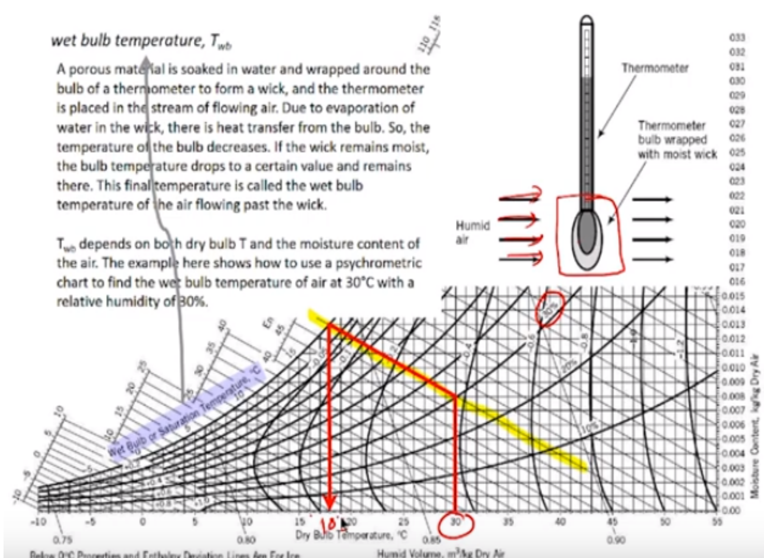

Figure 8.4-1 Psychrometric chart—SI units. Reference states: H_2O (L, 0°C, 1 atm), dry air (0°C, 1 atm). (Reprinted with permission of Carrier

So another parameter which is shown here and described here is called as the wet bulb temperature. What is the wet bulb temperature? So the definition is given here. A porous material is soaked in the water and wrapped around the bulb of a thermometer to form a wick and the thermometer is placed in the stream of flowing air. Due to evaporation of water in the wick there is heat transfer from the bul. So the temperature of the bulb decreases.

If the wick remains moist, the bulb temperature drops to a certain value and remains there. This final temperature is called as the wet bulb temperature of the air flowing past the wick. I know this definition does not make it very easy to understand. So let me try to explain it in a more, in simpler terms. So what you have is something like this. So the setup you have here is you have a thermometer and this regular thermometer is actually wrapped with something called a wick.

So this, it could be a cotton or something which can or some cloth which is always going to be which will be moist. So this would have to be maintained moist by adding some water to it so that what happens is when the air, humid air flows through this thermometer, some of the water is going to get evaporated, right? Because the humid air if it is not under saturation, you are going to have more air getting evaporated. So that is how you dry your clothes right?

So once the water starts evaporating there is going to be some amount of heat which is lost. So this means the temperature is going to come down. So as you have more and more water evaporating, the temperature is going to continuously keep coming down. So assume that the humid air which you start with is in circulation. If it keeps going round and round across this wet wick which remains wet, more and more water is going to get evaporated till the air-water vapor mixture reaches saturation.

Once there is saturation of water vapor, then what you are going to have is, you will still have the wet wick but the water is not going to get evaporated. See that is why you would usually have the clothes drying slowly on a rainy day compared to clothes drying faster on a summer day even if the temperatures are the same. Because the humidity is different which means the time taken for the moisture to evaporate would be different.

So as the humidity increases, the moisture, only lesser amount of water can evaporate and thereby the temperature will drop only to a small level. If the humidity is very low, then a lot of water can actually evaporate thereby the temperature will keep falling significantly lower so that you can get your wet bulb temperature. So your dry bulb temperature will always be higher than or equal to your wet bulb temperature.

Your wet bulb temperature can never be higher than your dry bulb temperature. So once you reach 100% saturation, you would have wet bulb temperature equals dry bulb temperature. So this can also be seen in this graph. So here you have a condition which has been identified as 30 degree Celsius and 30% relative humidity. So we go to this curve and across, along this slanting line which we have, so we had looked at another slanting line earlier.

So now we have looked at this slanting line for humid volume earlier. There is another slanting axis that we see here, which is this axis. So across this axis if we were to move, we would be able to move all the way to the 100% saturation curve which is our saturation condition. So at his point you then can either identify the temperature given here itself as I said temperature is listed along this curve as well so which is called the wet bulb or saturation temperature or you can again drop back here to identify the temperature on the x axis.

So if you were to do here, this is 15, 16, 17, and 18 or you could go here 15, 16, 17, and 18. So 18 degree Celsius is the wet bulb temperature for 30% relative humidity 30 degree Celsius air-water mixture. So this parameter is useful for us to understand how much moisture is present in your air-water mixture. Dry bulb temperature just gives us the temperature conditions. Whereas wet bulb temperature not only provides us the temperature condition but also gives us an indication of how much moisture is present.

Knowing the wet bulb temperature and dry bulb temperature, we would actually be able to identify the relative humidity.

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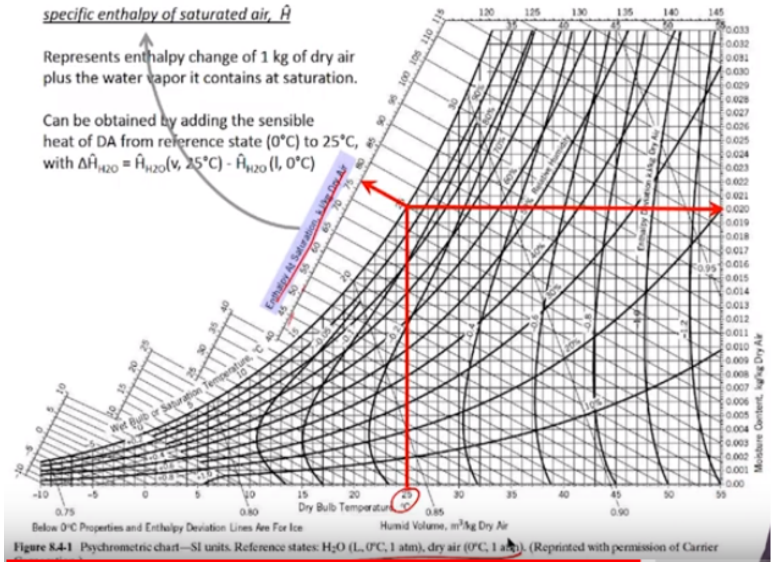

Since these psychrometric charts have to be used for performing energy balance calculations, enthalpy values can also be obtained from here. So for saturated air, you can get enthalpy values directly. You see that enthalpy at saturation listed here and you can calculate the enthalpy at saturation from these graphs.

So for 25 degree Celsius or saturated air, all you do is identify the point on the x axis, go all the way to the saturation curve which is the 100% relative humidity curve which you see at the end and identify so what would be the specific enthalpy for this saturated air. So which can be identified along this axis which is given as 40, 45, 50, and so on. So here it is about 76.8 or so. So the units are kilojoules per kilogram of dry air.

Again it is given in kilograms of dry air, not kilograms of humid air. So you can actually calculate this value and you can use it for performing energy balance calculations. So we need to understand that this is used, this is obtained with the reference state as water liquid at 0 degree Celsius and dry air at 0 degree Celsius which is the reference states used for this system, okay. So with that in mind we can use this chart to get the enthalpy for saturated air.

However, air which is used for calculations, used in real life does not always have to be saturated. You would usually have some percentage of relative humidity. So you might have relative humidity of 20%, 30%, 70% and so on. So how do we calculate the specific enthalpy for different relative humidities which is different from 100%.

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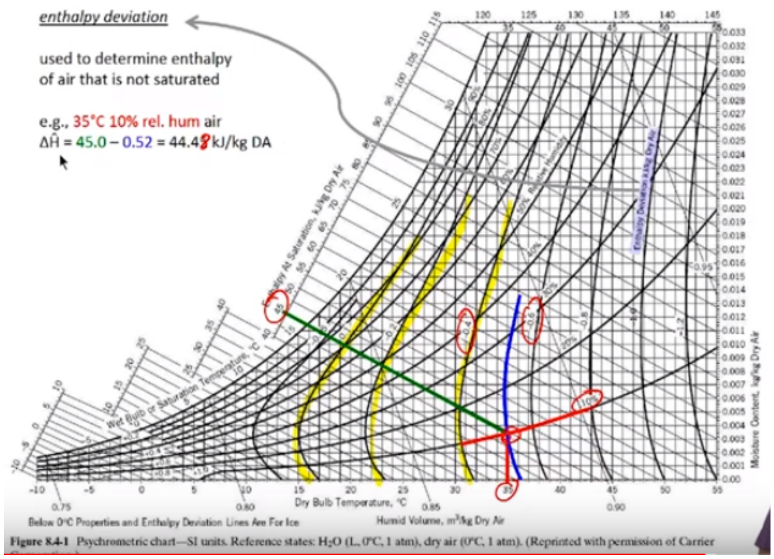

Figure 8.4-1 Psychrometric chart—SI units. Reference states: H_2O (L, 0°C, 1 atm), dry air (0°C, 1 atm). (Reprinted with permission of Carrier

That can be obtained by using the enthalpy deviation curves. So now other than the straight lines which we had looked at and the curves for relative humidity that we have looked at we also have other curves which are shown here. So these are the curves that we have. You see the curves here. So those curves are called the curves for enthalpy deviation. So we can actually calculate enthalpy changes, specific enthalpy for non-saturated air using these enthalpy deviations.

So how you go about doing that is you basically first identify the conditions. So here it has been identified as 35 degree Celsius and 10% relative humidity. So you have 35 degree Celsius and 10% relative humidity. You identify the point and in this point you draw a line through the slanting line which is used for measuring the enthalpy for the wet bulb temperature. You go all the way to the enthalpy at saturation which is identified as 45 and from this value you subtract the enthalpy deviation.

So what you do is you draw a curve which fits between the curves that are given here. So the enthalpy deviation curve which is shown in blue is drawn here. And again we would interpolate between these points to identify what the value for this enthalpy deviation would be. Each of the curves have an enthalpy deviation value given. So this is -0.44 and this is -0.6. So using this curve we would be able to identify the enthalpy deviation that has to be accounted for.

So this was identified to be -0.52. So it would be 45 - 0.52 should actually be 44.48 not 45 kilojoules per kilogram of dry air. So this would be the delta H cap. So this gives you the way you can actually get specific enthalpy for any air-water mixture from this curve.

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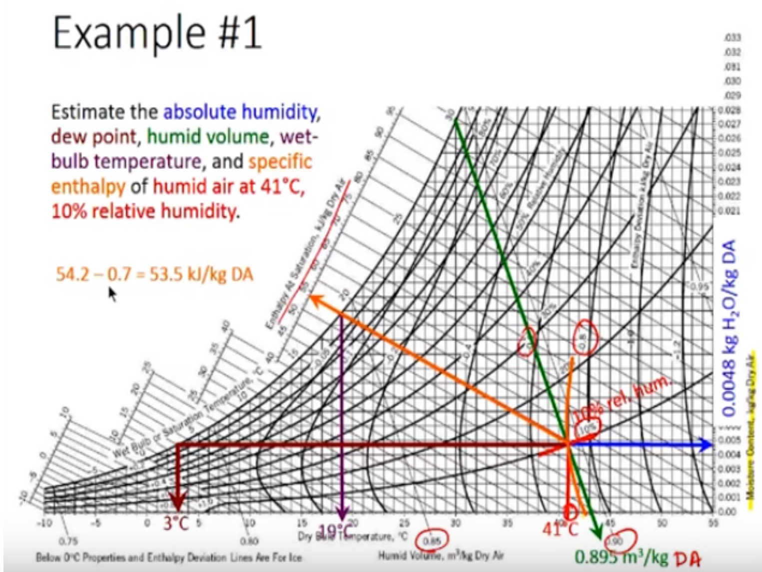

Let us look at a couple of example problems which will help us understand how to read these psychrometric charts to get the different parameters that we looked at. So we have been given a condition of 41 degree Celsius and 10% relative humidity and asked to calculate all the parameters that we had looked at till now. So the first thing we want to calculate is the absolute humidity. For that let us first identify the points which we are interested in. 41 degree Celsius.

So 41 degree Celsius is here. 40 + 1, 41. So this would be the point which is 41 degree Celsius. So let us draw a line from 41 degree Celsius all the way to the 10% relative humidity curve, which is this curve. So for this particular curve we have this as the line 41 degree Celsius and we have drawn a line all the way to the 10% relative humidity. The first thing we need to identify is the absolute humidity which is given in your y axis here.

So the absolute humidity you have is given here. So because you have an absolute humidity on your y axis you would draw a line from this point all the way to the y axis. So that value can be identified from this particular y axis. So this is 0.0048 kilograms of water per kilogram of dry air. So that is the absolute humidity. So you can get that directly from the psychrometric chart. The next aspect which has been asked to identify is dew point.

So dew point is the temperature at which the first dew starts forming or water starts condensing if cooled at constant pressure. So that can be identified by moving all the way to the saturation curve on the other side using a horizontal line. So if we do that we can get to this point and we can identify the temperature as 3 degree Celsius. So this is 3 degree Celsius which you have here and that would be the dew point for this particular mixture.

So as you see you have to cool the 41 degree Celsius or 10% relative humidity air all the way to 3 degree Celsius for the first dew to start forming. So if the relative humidity were higher this value would be higher. The dew point would also be higher. Now, the next aspect which we need to identify is the humid volume. So if you remember, humid volume can be identified using one of the slanting axis. So the slanting axis which we see here can be used for the humid volume.

So these slanting axis can actually be used to identify the humid volume. So we need to draw a line through this particular axis through this point parallel to this axis which is what I have done here. So this green line has been drawn through the point of interest and it is parallel to the slanting axis for humid volume. So this value lies between 0.85 and 0.9 and by interpolation we can identify that to be 0.895 meter cube per kilogram and this would be meter cube per kilogram of dry air. Now, the next aspect we need to identify would be the wet bulb temperature.

So for calculating the wet bulb temperature, again we have to draw a slanting line but parallel to this axis, parallel to these axis that are shown here. So you have to draw something parallel to these axis and that would give us this wet bulb temperature when we go all the way to the saturation curve which is what I have done here. The purple line goes all the way to the saturation curve along the slanting axis.

I could either identify the temperature here or come back down here to identify the temperature. The temperature is identified as 19 degree Celsius. So here also you can see that it is 19 degree Celsius and here also it is 19 degree Celsius. So this would be the wet bulb temperature. So this means that if I had a thermometer which is covered by a wet wick and the air, 41 degree Celsius 10% relative humidity air keeps circulating through this wet wick, water will keep evaporating till the temperature in that thermometer drops to 19 degree Celsius.

So as you see there is a huge difference between the dry bulb temperature and the wet bulb temperature indicating that the relative humidity is very low. The next aspect is to identify the specific enthalpy of humid air at 41 degree Celsius and 10% relative humidity. Again, for identifying the specific enthalpy, you would again have to draw the same line along the lines which we used for wet bulb temperature and measure the point, value at this enthalpy axes given.

So this lies between 54 and 55. So this has been identified as 54 point something and we also need to account for the enthalpy deviation which is drawn here. You see the curve that is drawn here, the curve in orange that has been drawn. So that curve actually accounts for the enthalpy deviation. This falls in between -0.6 and -0.8. So the value would be roughly -0.7 something. So using this, we can actually calculate the actual specific enthalpy for humid air as 54.2 – 0.7 giving us 54.5 kilojoules per kilogram of dry air.

With this we have identified all the terms that have to be calculated from the psychrometric charts. So as you see, using this chart seems intimidating at first. However, if we follow simple procedure it actually can provide a wealth of knowledge and can be used very effectively. Although the previous example showed us how we can use a psychrometric chart, many of you might not really understand or appreciate how valuable some of these informations are.

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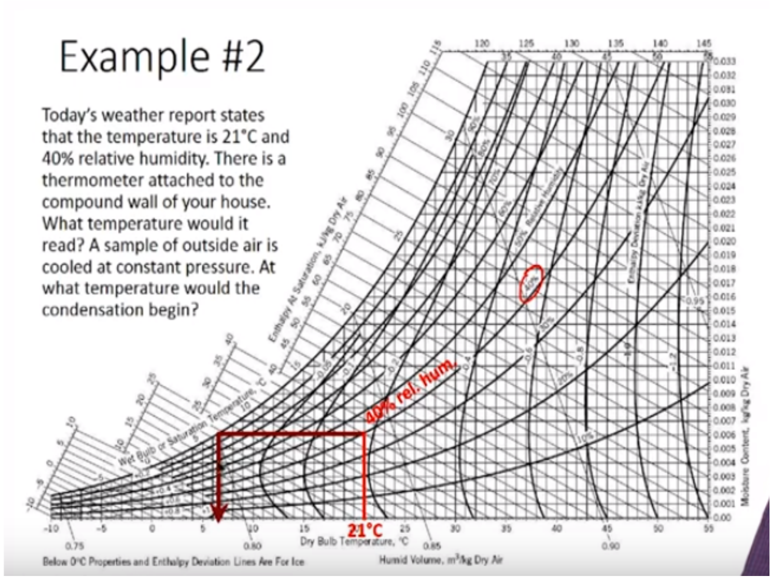

So we will look at an example problem which has everyday applications. Today's weather report states that temperature is 21 degree Celsius and 40% relative humidity. There is a thermometer attached to the compound wall of your house. What temperature would it read? A sample of outside air is cooled at a constant pressure. What temperature would the condensation begin at? So the first point we need to look at is we have a thermometer hanging out and we need to know what thermometer it would read.

We have been told that the weather report says temperature is 21 degree Celsius and 40% relative humidity. So what temperature would your thermometer read? Your thermometer is a dry bulb thermometer. Anything which just hangs outside is going to have a dry bulb. So the temperature you would see is the dry bulb temperature which would be 21 degree Celsius. So using this we will start the calculations.

So the next aspect is we have been asked to identify at what point the condensation would begin if were to cool this temperature. So if I were to keep cooling this air, at what point will the first dew start forming. So that would happen at the dew point. So I know it is 21 degree Celsius and 40% relative humidity. So this is the 40% relative humidity curve. So I have identified the point here and I have drawn a line to that point.

So that is the 40% relative humidity and from the 40% relative humidity, I now have to calculate the dew point which would be along this curve so I move to the left using a horizontal line all the way to the saturation curve and I can either identify the temperature here or the temperature below and the value is roughly 6.6 degree Celsius. So if this air-water mixture is cooled from 21 degree Celsius to 6.6 degree Celsius you would have the first droplet of water forming.

The next aspect is, let us say you are in a swimming pool. You are in the swimming pool, you are swimming and then you come out and before you dry off, before you use a towel to dry yourself off, you feel cold in this weather where you have 21 degree Celsius and 40% relative humidity. Why do you feel cold and can you estimate your skin temperature while you are still wet and would you be able to explain your answer?

Would anything be different if the relative humidity was 90%? If yes, why? So now let us see this problem step by step. First thing is why are you feeling cold other than the fact being the temperature is 21 degree Celsius and most of us in India would never have experienced 21 degree Celsius especially people in South India like me would never have experienced 21 degree Celsius in our conditions. Other than that, why do you think you are experiencing the chillness?

Because the water on your body would actually be evaporating. The relative humidity in the air is actually only 10%. So this means you are going to have water rapidly evaporating from your skin. As water keeps evaporating the temperature of your skin keeps falling down, is coming down. As it keeps coming down, you are going to feel colder and colder. So that is why the longer you stand in this air, the cooler and colder you would feel because there is more and more water being evaporated.

So if you keep standing with a wet skin standing outside and assuming the skin remains wet, your temperature will drop all the way to the wet bulb temperature. The temperature on your skin can actually drop to the wet bulb temperature which would be 13 degree Celsius. Although the actual temperature of air in your surroundings is 21 degree Celsius, the temperature your skin would be experiencing would be 13 degree Celsius.

That is why you feel a lot colder when you are wet compared to when you are dry at the same temperature. So if you had 90% relative humidity instead of 10% relative humidity, so instead of 40% relative humidity what you would have is a wet bulb temperature of about 19.8 degree Celsius which means it is much closer to what is actually present in the environment.

Therefore you would feel a lot better. So that is the reason you would feel less cold if the humidity, relative humidity was higher and this would explain to you how some of these factors actually are important in day-to-day life. With this we come to the conclusion of the psychrometric charts lecture. In the next class we will look at how to use these psychrometric charts to perform energy balance calculations. Thank you.