Material and Energy Balance Computations

Prof. Rabibrata Mukherjee
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture –59
Humidity and Psychrometric Chart - III

Welcome back now to the penultimate lecture of the course. We will continue our discussion on humidity and psychrometric chart and today we are going to talk we I already introduced you to the concept of wet bulb temperature. And today we are going to talk on how to measure wet bulb temperature a very interesting measurement technique out there and then the much-awaited humidity chart or the psychrometric chart.

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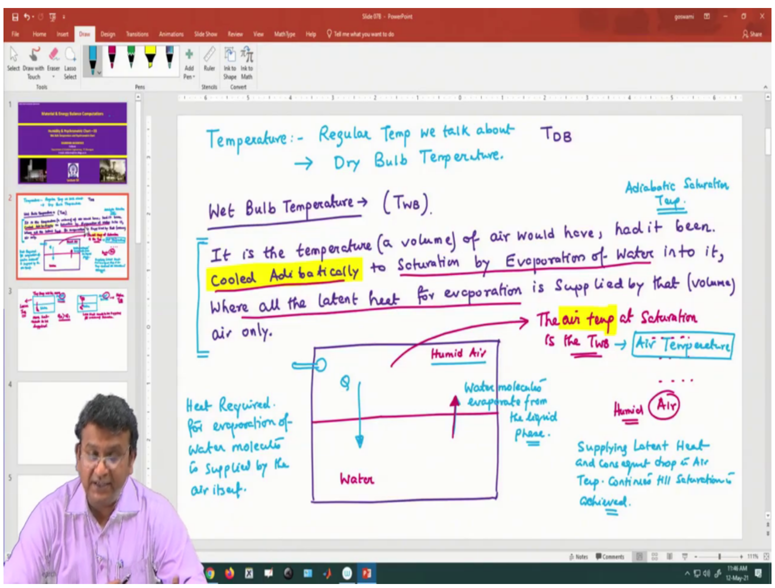

So, let us do a quick recap on what exactly is dry bulb temperature and wet bulb temperature. Dry bulb temperature is the temperature we talk about we all know how to measure the temperature. So, you have for atmospheric temperature measurement you have this min and the maximum temperatures are measured. We also know how to measure the body temperature, and which has now of course become digital with thermal scanning almost everywhere because of the ongoing situation.

But till maybe a year before measurement of temperature was always done by thermometer. So, typically in the context of atmospheric condition or humidity the dry bulb temperature is if you just keep a thermometer exposed to the atmospheric condition whatever is the temperature you record. Now wet bulb temperature we you learnt in the previous class it is actually something related to humidity.

So, we understood what exactly it is. So, wet bulb temperature is if you have some air some volume of air in an enclosed space and if it is not saturated of course then it can get saturated if it is in contact with a water body. For example, it can get saturated by progressive evaporation of water now how can you do this evaporation. So, you can do evaporation by heating up the whole system but that is not the definition because if you heat up the whole system the dry bulk temperature will also go up.

So, that is not exactly what we are looking at we are relying on you can also attain saturation of of the air phase by cooling right because we all know and we have seen in the previous lectures when we were talking about humidity as you cool down the water holding capacity of air sort of reduces. So, we are not doing that either. So, what are we doing? We are saying that water from this water body evaporates under adiabatic condition. and whatever is the heat required for this additional evaporation of water essentially comes from the air phase itself.

So, as the air phase supplies some heat to the water body its temperature drops and the water body consumes exactly the same amount of heat in evaporating that much amount you can calculate based on the latency the sensible lens latent heat calculations that much amount of water vapour is added to the system. So, simultaneously two things happen because the air phase is supplying heat which you can see here since the air phase is supplying heat its temperature drops and simultaneously since that heat is getting consumed in increasing the humidity its humidity goes up.

And eventually it attains 100% saturation and then the supply of heat also stops. So, this drop in temperature this drop in temperature to achieve saturation this is what is the wet bulb temperature at the point when saturation is achieved whatever is the drop in temperature that is called the wet bulb temperature we have the formal definition.

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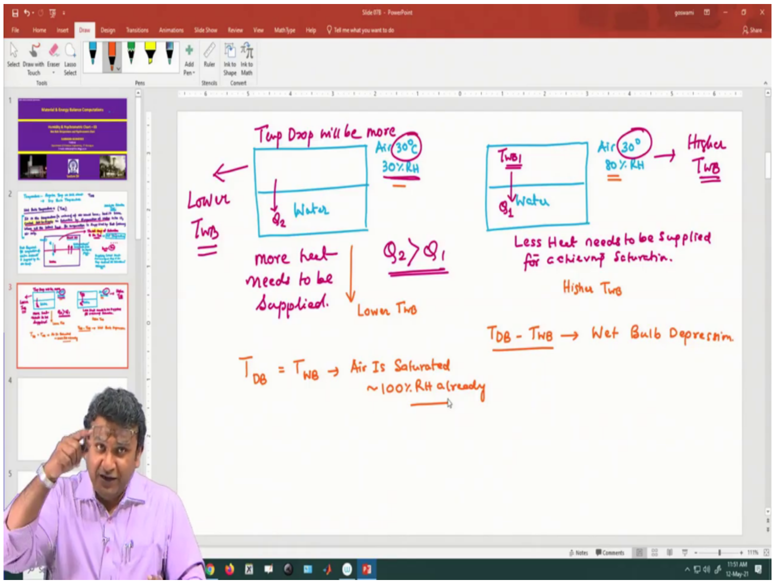

So, now we understand very clearly that if you have two conditions where you have humid air both at 30°C but one at least say 30% relative humidity and the other at 70% relative humidity or 80% relative humidity here you need much less amount of water to be added to attain saturation. Therefore, less heat needs to be transferred from the air phase to the water phase and therefore the drop in the temperature will be less or this will have a higher weight bulb temperature.

In contrast here you need more amount of heat to be supplied. So, here you have a lower wet bulb temperature and there is one interesting point. So, the difference between the dry bulb temperature and the wet bulb temperature for any given humidity is called the wet bulb depression. An immediate an obvious question that comes can dry bulb temperature ever be the wet bulb temperature the answer to this probably this class understands dry bulb temperature can be equal to the weight bulb temperature I probably should have written dry bulb temperature is equal to wet bulb temperature.

If under what condition if your air is saturated or you have 100% relative humidity already and for any given air under what condition you can achieve the minimum wet bulb temperature if your air is bone dry if there is no humidity present in air then the wet bulb depression will be maximum because air has no humidity. So, from starting from 0 to saturation the entire amount of water vapour you need to supply and therefore you need more heat from the air phase and therefore its drop-in temperature will be maximum.

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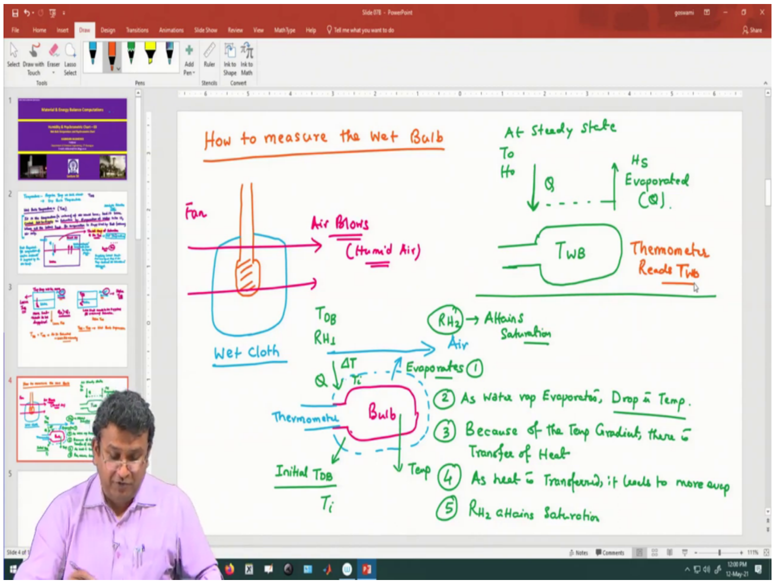

Now the question to ask is how you measure the wet bulb temperature well its very interesting setup you actually take a thermometer regular thermometer here is the thermometer bulb which contains the mercury that is another question why you use mercury and all that. And what you do you cover this bulb with a wet cloth. In fact, probably it is from here the terminology wet bulb temperature comes in you are actually covering the bulb of the thermometer with a wet cloth.

So, now what you do. So, this thermometer either can be mounted on a wooden panel for example or you can just typically its mounted on a wooden panel and what you actually do either you rotate you tie it with a string and you rotate it that was the earlier way you used to do it but more recently what people do is you just place a fan in front of the thermometer. So, air blows over this thermometer. So, air blows over this thermometer there is a fan somewhere and air blows.

So, now so, obviously we understand that wet bulb temperature is going to be dry bulb temperature if water is already saturated or relative humidity is 100%. So, obviously when we are saying we are measuring there is no reason for us to assume that water is 100% saturated. So, its humidity but it is not saturated. So, now what happens as this air passes over as this air. So, I just draw the peak of the bulb here again and here is our wet cloth this is of course the thermometer and here air is blowing.

So, air is not 100% saturated but its humidity. So, since it flows over this wet cloth or moist cloth. So, what happens some amount of water vapour saturates in sort of evaporates we all dry clothes under the fan. So this is exactly what you are doing some amount of water vapour evaporates this initial part for calculation of wet bulb temperature we need to understand that the heat must be supplied heat must be supplied from the air itself but initially everything is at the same temperature everything is at room temperature.

So, there is no temperature difference. So, therefore no heat is going to be supplied but as the air blows and as the air. So, this is the reason why you either rotate swing it or you blow air you want to bring in fresh air and as the air blows because of convective heat transfer some amount of water vapour gets evaporated. Now and so what are the things that happen the relative humidity whatever was the initial relative humidity the relative humidity progressively goes up second thing is as e this some water vapour is evaporating.

So, firstly, some water vapour evaporates; secondly, as water vapour evaporates there is a drop-in temperature. So, all of us understand because it has taken some latent heat. So, the shock temperature has dropped, and this thermometer is in intimate contact with that liquid wet cloth. So, this thermometer the temperature drops. Now let us say this is the initial dry bulb temperature with which air is flowing.

So, here initially everything was at the same dry bulb temperature. Please see if you understand this initially everything is at room temperature. So, that is the dry bulk temperature but now what has happened since some amount of water has evaporated this temperature has dropped to some intrinsic value. Now so, what happens now when next round of air comes in or air is flowing continuously now when fresh air comes in it now observes or finds a surface with lower temperature initially please remember this is very important initially when you start your experiment air actually encounters a surface which is at the same temperature.

So, there is no heat transfer. However, as the air a blow since there is a gradient in humidity or it is not such, I will withdraw the word gradient since it is not saturated. So, it picks up some amount of moisture from the wet cloth and as some amount of moisture evaporates from the wet cloth the temperature of the wet cloth now starts to drop and as the temperature drops now there is a delta T. So, there is some transfer of heat.

So, as we all know if there is a temperature gradient there is some transfer of heat. So, number three there is a drop-in temperature number three because of the temperature gradient there is transfer of heat and as heat is transferred it leads to more evaporation and up to what extent it can evaporate? The evaporation it can maximized when the outside air or this R H 2 attains saturation. So, at steady state what happens is initial temperature was let say T 0 and initial humidity was H 0.

So, at steady state Q_0 amount of heat is transferred. So, that leads to a drop in the temperature and so, now also please do understand as heat is transferred sorry there is no reduction in temperature as some heat is transferred. So, water gets evaporated and at steady state this evaporated water actually brings in Q amount of heat and as a consequence of that the temperature over here it drops but not over there the temperature over here drops right.

Since the same amount of heat is brought back there is no reduction in temperature. So, T 0 remains the dry bulb temperature here it was H 0 and finally it attains saturation H s but because of this evaporation initially the temperature drops to T W B and e as steady state is achieved after that there is no change in the wet bulb temperature. So, the thermometer now reads the wet bulb temperature. Of course, this experiment if you run for very long suddenly you will find that the temperature of this thermometer has started to increase again, and can you tell what has happened?

This will happen when the sock this is something that will not be written in your textbook when the sock has become completely dried. So, if you progressively see it is a wet cloth after all its a wet cloth. So, if you do this experiment for prolonged period of time then what will happen you will again see that the temperature of this thermometer is increasing it is. So, when that starts you know that all the water present in the wet cloth has essentially evaporated. So, that is where you should stop your experiment.

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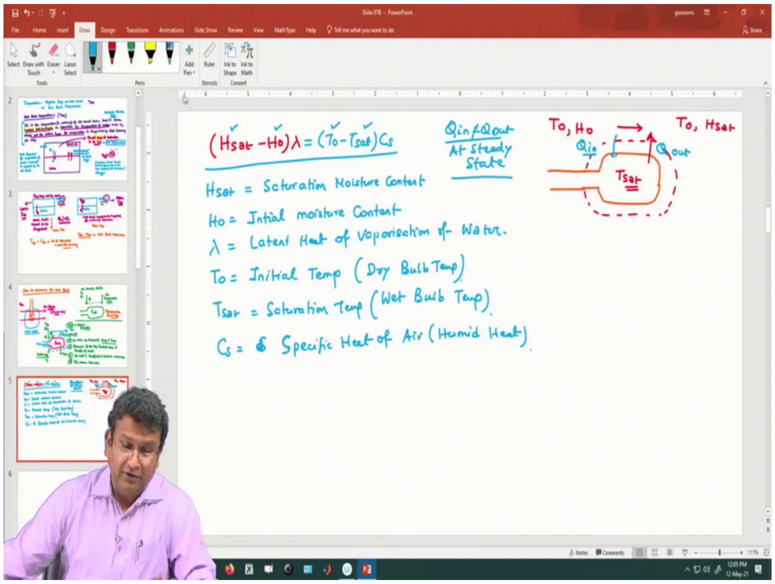

So, what exactly is happening what exactly happens between this thermometer. So maybe we should have this picture over there or so, what happen we can write is. So, let us quickly draw this picture again. So, this is the bulb this is the wet cloth, and this is air with initial temperature dry bulb temperature T 0 and humidity H 0 is impacting and this is T_0 and H sat and this is the saturation temperature or the wet bulb temperature or whatever. So, what actually happens is H sat minus H 0 into lambda what is this? This is the Q out.

So, if we write if we write this is Q_{out} and if we write this is Q_{in}. So, it is an adiabatic process. So, Q_{in} is equal to Q_{out} at steady state. So, what happens is H_{sat} - H_0. So, you can all refer to the previous days lecture and find out what is H_{sa}t and what is H_0 this multiplied by lambda the latent heat of vaporization this is the amount of Q that is going out is equal to the transfer of heat due to the temperature difference and which is (T_0 - T_{sat}) into the specific heat of humid here humid air.

So, H sat is saturation water content moisture content H_0 is initial moisture content lambda is latent heat of vaporization of water T_0 is initial temperature or essentially that is the dry bulb temperature T_{sat} is the saturation temperature or the wet bulb temperature we are doing a little bit of simplification but that is fine I will not go into the detail this is the specific heat of air or the humid heat. So, from here you see your H_0 is known if T_0 is known; and if H_{sat} is known T_{sat} you Can essentially measure and then you can just calculate whatever is required.

So, this is how the balance can be made. So, this is all about the wet bulb temperature. So, I hope you have understood this, and it is a nice concept you just if you have any difficulty please listen to my lecture again and again and you will get a clear idea about what it is. Particularly interesting is the initial part when you I repeat when you initially start the sock the thermometer over here the wet cloth the thermometer over here, they are all at the same temperature that is at initial temperature T 0 at the dry bulb temperature.

But as the air flows and if the air is not as the air is not 100% saturated it picks up some amount of moisture and as it picks up some amount of moisture there is a drop in the temperature. So, of this wet cloth and as the temperature drops and please do understand since the bulb of this thermometer is covered with the wet cloth. So, whatever is the cloth temperature that is reflected as the bulb temperature and as there is a temperature drop now.

Now there is a temperature gradient between the air that is coming over the wet cloth. So, that triggers a heat transfer and that heat that is received by the wet cloth actually favors more amount of evaporation of water. So, at steady state what happens the heat that is coming in the exact amount of same amount of heat goes out along with water. So, this is actually not only a heat transfer process but this also mass transfer process which you will read again in the context of mass transfer the very interesting process in the humidification operation. So, that is what I think is good enough for your chemical process calculation.

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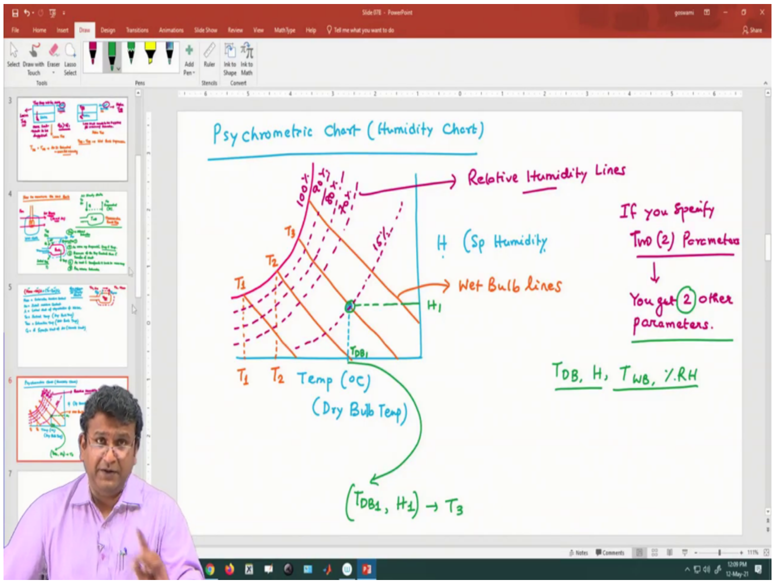

And now the last thing that we will introduce is what is known as the psychometric chart or the humidity chart. It looks very difficult to read initially but I am telling you it is one of the easiest and most useful things. So, generically this is how the chart will look like you will have an axis at the bottom which reads the temperature it can be centigrade or Fahrenheit whatever you have. So, these you can take as the x axis this is actually your dry bulk temperature here you have a y axis which actually gives you the specific humidity or the moisture content.

So, if the; so as of now just think about these two lines, so, if you know the dry bulb temperature and the specific humidity you can immediately locate a point on this graph but then the graph comes with some additional features. So, you will find a line like this is actually the saturation line something like this and you will also find some inclined line these are the important lines then there can be some other lines also some inclined lines like this and some temperature will be written over here.

So, every incline line actually comes with some temperature mentioned over here and if you read here that is the same dry bulb temperature these are the wet bulb lines. So, what does it mean it means that if you locate a point let us say its dry bulb temperature is T_{DB1} and its specific humidity is H_1. So, this is let us say H_1 and this is T_{DB1} since you have located this point over here from the graph you can straight away read its wet bulb temperature is T_3 you do not have to do any calculation and there is a fourth set of important lines which also decorate this graph which are like lines like sort of parallel to this curve.

So, here you will find 100% is written and here you will find 90% 80% 70% and stuff like that. So, these are the relative humidity lengths these are the relative humidity lines. So, here let us say another you find that this point is also lying on some relative humidity line let us say 15%. So, what are you getting straight away if you specify two parameters I am just wait for a minute and I expose you to the actual humidity chart you get two other parameters actually you get more you do not only get 2 parameters you do not get only two other parameters you get more numbers.

So, what does it mean that amongst T dry bulb specific humidity this is the most straightforward way of defining but T wet bulb and relative humidity if only 2 are specified you do not have to go to any calculation you can just look into the humidity chart and straight away find it. So, that is the beauty of humidity chart there are 2 additional parameters which can be calculated, and the other important thing is you can actually look at a process.

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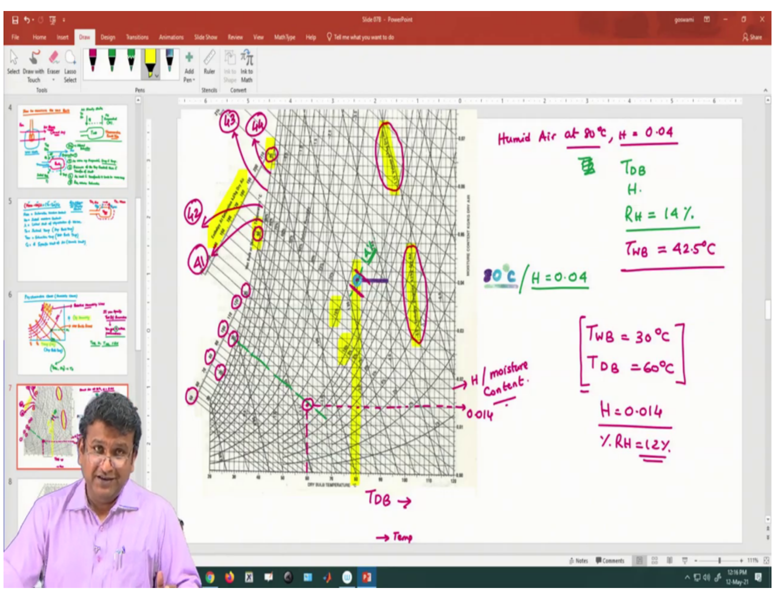

So, let us have a look into a regular or a proper humidity chart. So, this is how a humidity chart looks like and if you look carefully as I already mentioned here you have temperature here you have the specific humidity or the moisture content. So, now let me specify some numbers and lets say we have humid air at 80 degree centigrade and moisture content is 0.04, 0.04. So, then what you can see is that 80 degree centigrade.

So, this is 60 maybe we can enlarge it a little bit I do not yeah it can be enlarged. So, you see it is 80 degree centigrade. So, this is 80 degree. So, we all know that along this line everything will be 80 degree centigrade and what is mentioned is moisture content is 0.04. So, this is 0.04 this is 80 degree. So, this is the point. So, you can straight away locate this particular point which is eighty degree centigrade I do not know what pen I have picked up and H equal to 0.04. So, as we already mentioned that the moment you can specify the dry bulb temperature.

So, what you have mentioned is the dry bulb temperature and the moisture content you now see this lies between 15% or each line and 10% are each line and you do a sort of a random or sort of a reasonably approximated interpolation with your own eyes. So, this is 15% this is ten percent. So, maybe we see we can say that this is 14% R H. So, straight away what comes out is R H is 14% and that is not all.

So, now if you proceed you will find as I was telling. So, there are some inclined lines what you will realize that there are some other inclined lines also. So, take note which I did not mention that carefully or deliberately I did not want to confuse. So, you can now correlate that on the actual plot whatever I have told is the truth. So, this is the temperature this is the specific humidity you have this relative humidity lines which you have already seen you have the relative humidity lines and then you have some inclined lines at the end point of which some temperature is written and which is the wet bulb temperature.

So, you these are the series of these inclined lines and you can see that over here its 40°C over here its 45°C. So, obviously this is 41 this is 42, 43 this is 44 these are the wet bulb temperature lines. So, I will probably write it nicely. So, this is 40 you can read this is 45. So, obviously you understand this is 41, this is 44, this is 43 and this is 42. So, this one lies between 42 and 40.

So, this as we realize is the 42°C wet bulb line this is 43°C wet bulb line this lie is halfway in between. So, it is logical to conclude that the weld bulb temperature is 42.5°C I hope it is clear to all let us pick up another example. So, let us say we are given that the wet bulb temperature is 30 degree centigrade and dry bulb temperature is 60 degree centigrade. So, can you all solve it I will give some problems in your assignment.

So, that you can solve it, so, let us see how it goes. So, here is the wet bulb temperature this is 30 degree centigrade. So, you follow the 30°C line like this and the dry bulb temperature is 60 degree centigrade. So, you follow the dry bulb line like this and you what significance of this problem is you do not always need to specify your initial conditions in context of dry bulb temperature H only just if two are specified that is good enough.

And so, from here you can actually now you can find out. So, you can now find out actually the moisture content. So, which is like 0.014, 0.014 and you can also find the saturation. So, again this lie is between 10, 5% and 15% but maybe it is around 11% or something like that or maybe 12%. So, we are running out of time, but I will like to highlight at this point of time there are two more entities written over here.

So, at the end of every wet bulb line, so wet bulb temperature is specified over here of course at the end of the wet bulb line there is some number that is written that is number one and there are apart from this wet bulb lines there are another set of inclined lines ah. So, something is written over here and a third type of line which are nearly horizontal lines or nearly vertical lines is these lines. So, in the next class we will understand what these entities are or how they can be used to find out even more parameters.

And we will also do some processes some processes on which requires which the processes can be shown on a psychrometric chart. So, thank you very much.