INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NPTEL
NPTEL ONLINE CERTIFICATION COURSE

Refrigeration and Air-conditioning

Lecture-22
Properties of Moist Air

with
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Indian Initiation of technology, Rookee

Hello I welcome you all in this course on refrigeration and air conditioning. Today we will discuss the properties of moist air.

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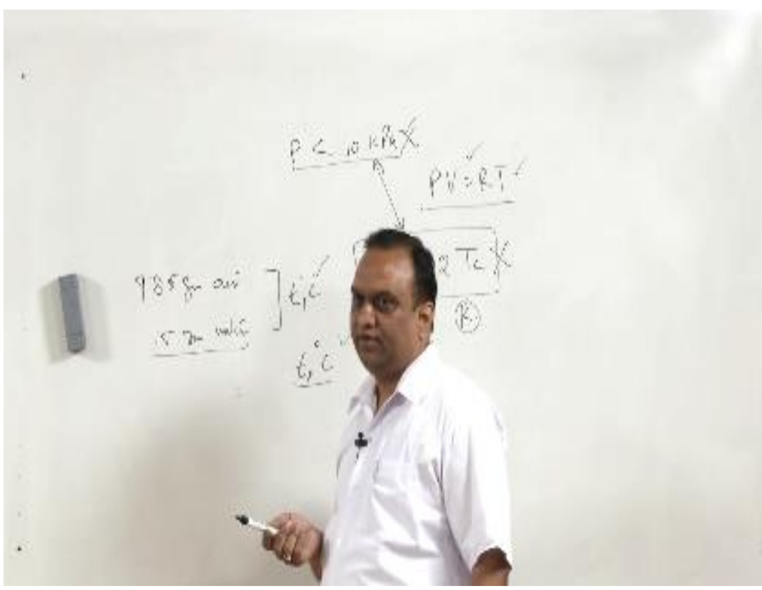

As you know the air which surrounds us is not a dry air it is a moist air and moist air consists of dry air and water, water vapor in the form of vapor. Now air is also a mixture of different gases and major components of air are nitrogen and oxygen I will not like to go into the details because this you must have done several times volume to volume ratio and weight to weight ratio. Air has traces of carbon dioxide, argon and many other gases.

But they are in the form of traces only the major components of air as are nitrogen and oxygen air which surrounds us also contains water vapour. The water is the partial pressure of the water I will give you some idea partial pressure of water is of the order of let us say 3 kilo Pascal. so out of 100 kilo Pascal, 3 kilo Pascal is the partial pressure of water and as for the Daltons law the total pressure in a given volume is the sum of algebraic sum of the pressure exerted by the individual constituent.

So air is considered as a pure substance so pressure of air and pressure of water partial pressure of water will give us the total pressure of air. Now we will go by the definition of psychrometry.

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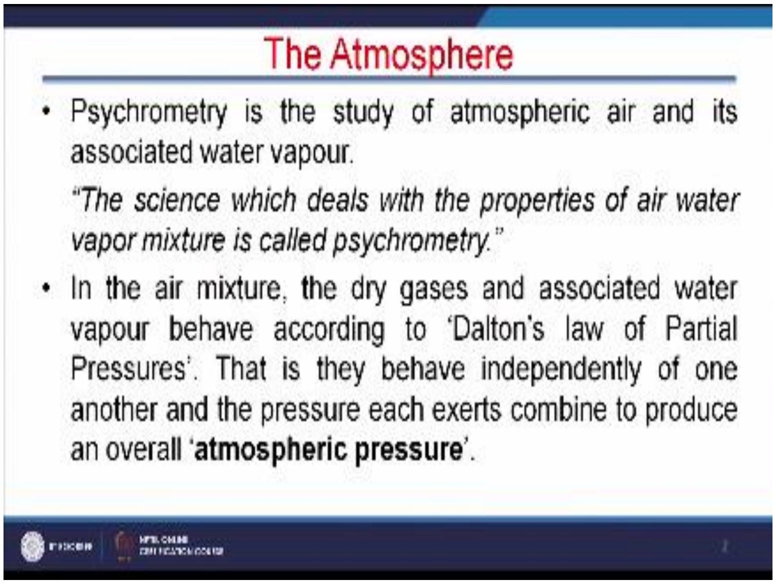

Psychrometry is the study of atmospheric air and its associated water vapor so thermodynamic study on this the mixture of pure air and the water vapor is known as psychrometry and psychrometry is very helpful in air conditioning processes, because in air conditioning normally we maintain the temperature and relative humidity. The humidity is denoted by π also, it is notated by RH also.

So we deal with the temperature and relative humidity when we talk about the humidity the presence of water immediately comes into the picture. So psychrometry is the study of atmospheric air and its associated water vapor, it is a science which deals with the properties of air water vapor mixture and that is called the psychrometry. In the air mixture I have already explained this the third point they behaved as per the Dalton's law and the total pressure in the mixture is is the partial pressure of air and partial pressure of water.

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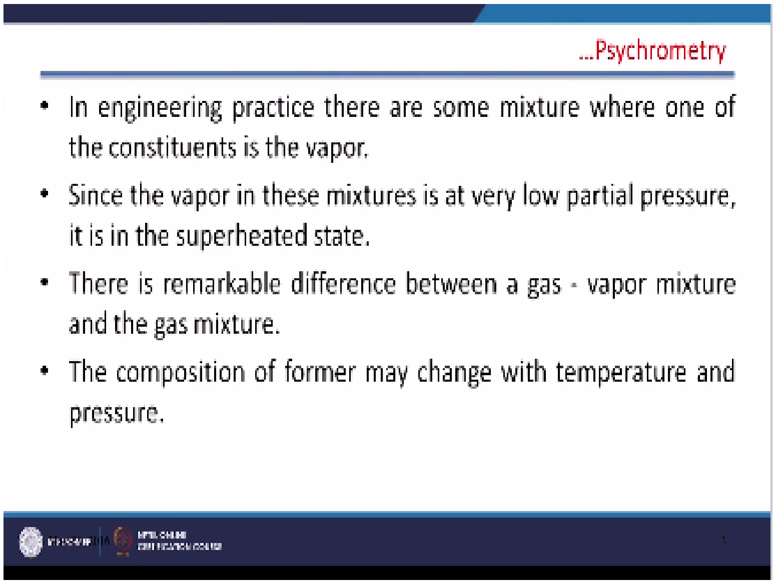

In engineering practice there are some mixtures where one of the constant is vapor. Since the vapor in these mixtures is very low partial pressure it is in the superheated state, in some of the mixtures in not all the mixtures in some of the mixtures when it is there in very small amount it has very low partial pressure. When the partial pressure of vapor I told you earlier also where the pressure is less than 10 kilopascal the vapor can be considered as a gas.

That is why in psychometric analysis the vapour, water vapour is considered as a gas. So we use often use PV is equal to RT relation for water vapour. But the same relation we do not use in the case of steam turbines analysis of steam turbines, because there the pressure is high and temperature is not that high that the vapor can be considered as a gas. When the temperature of any vapor is greater than 2 times the critical temperature in that case it is also considered as a gas.

There are two conditions for considering vapour as a gas, either pressure is less than 10 kilopascal or temperature is 2 times the critical temperature this temperature is in kelvin not in degree centigrade. So in steam turbines this requirement is not fulfilled, this requirement is also not fulfilled that is why in gas turbines for or sorry steam turbines not yet gas turbine, the steam turbines we use steam tables we do not use for steam turbines we do not use this relation.

However in the case of air conditioning because the pressure is less than in most of the cases I will give you some numerical values also is less than 10 kilopascal PV is equal to RT relation is used. Now the third thing is the very remarkable thing is here, here is in gas vapor mixture the composition may change I mean if I have let us say 970 grams of air dry air and 30 grams of water in this dryer right.

At particular temperature T°C T1°C. Now if I change the temperature to T2°C now let us it is on higher side actually this is 985 and 15, so 15 grams of water in 985 grams of air that is 1 kg of air and at a particular temperature this is the composition. If we change the temperature this composition may change 985 may remain same this may reduce to 10 grams. So 10 grams is associated with the 985 grams or it may increase to 20 grams. So 20 grams is associated with the 985 grams.

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°C	p	h_f	h_{fg}	h_g
2	0.706	8.39	2496.2	2504.6
4	0.814	16.81	2491.4	2508.2
6	0.935	25.22	2486.7	2511.9
8	1.073	33.63	2482.0	2515.6
10	1.228	42.02	2477.2	2519.2
12	1.403	50.41	2472.5	2522.9
14	1.599	58.79	2467.7	2526.5
16	1.819	67.17	2463.0	2530.2
18	2.065	75.54	2458.3	2533.8
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22	2.645	92.28	2448.8	2541.1
24	2.986	100.65	2444.1	2544.7
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°C	p	h_f	h_{fg}	h_g
28	3.783	117.37	2434.5	2551.9
30	4.247	125.73	2429.8	2555.5
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40	7.385	167.53	2406.0	2573.5
42	8.210	175.89	2401.2	2577.1
44	9.112	184.25	2396.4	2580.6
46	10.099	192.62	2391.6	2584.2
48	11.177	200.98	2386.8	2587.8
50	12.352	209.34	2382.0	2591.3
52	13.631	217.71	2377.09	2594.8

Now these values I have taken from rescirpoc 7 this is NST based software where the temperature I have taken temperature saturation temperature starting from 2°C to 52°C this pressure saturation pressure of steam or water vapour is given on the right side, and let us say at 4°C saturation pressure is only 0.814 and this room is supposed 26°C at 26°C this saturation pressure is 3.364 kilopascal.

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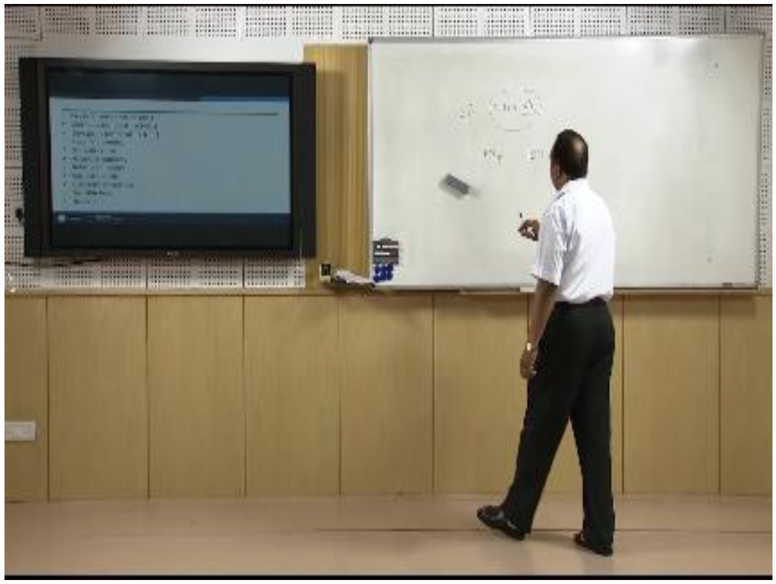

Now this is the saturation pressure at 26°C right, so you can imagine the order of pressure so the room pressure is again 101. So let us say 100 kilopascal so major chunk of pressure comes from the air pressure and vapor contribution is only 3.364 kilopascal and here definitely the vapor cause can be considered as a gas.

So I have taken priory I have taken properties starting from temperature 2 to 250°C because we will be meeting these values frequently in subsequent lectures. Now enthalpy of liquid at these temperature is also taken enthalpy is in kilo/J/kg and enthalpy of the gas and retained heat all these four values have been noted earlier and frequently we will be referring these values while exercising on psychrometry.

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Now there is a terminology in psychrometry like dry bulb temperature DBT. Now dry bulb temperature is normal temperature used with a thermometer to measure by using thermometer. So normal thermometer that is liquid in glass thermometer you must have seen liquid in glass thermometer or which is used for the medical purpose also it has a bulb.

And bulb is dry there is no coating on the bulb, there is no fluid on the bulb, and the temperature indicated by this liquid in glass thermometer is known as DBT. So normally when we say the temperature of this room is 20°C or 25°C it is nothing but DBT of the room. So DBT whenever we say the temperature of room is 25°C it is DBT of the room is 25°C. So normal liquid in glass thermometer measures the dry bulb temperature.

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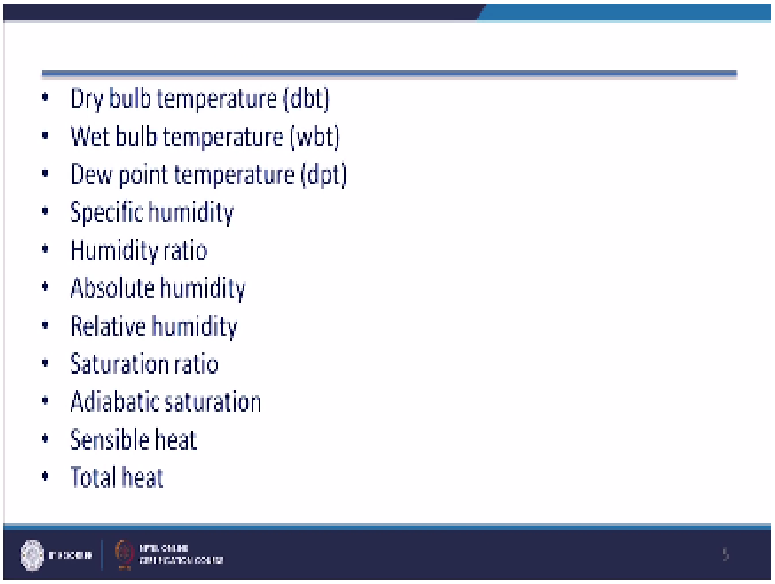

Another temperature is wet bulb temperature.

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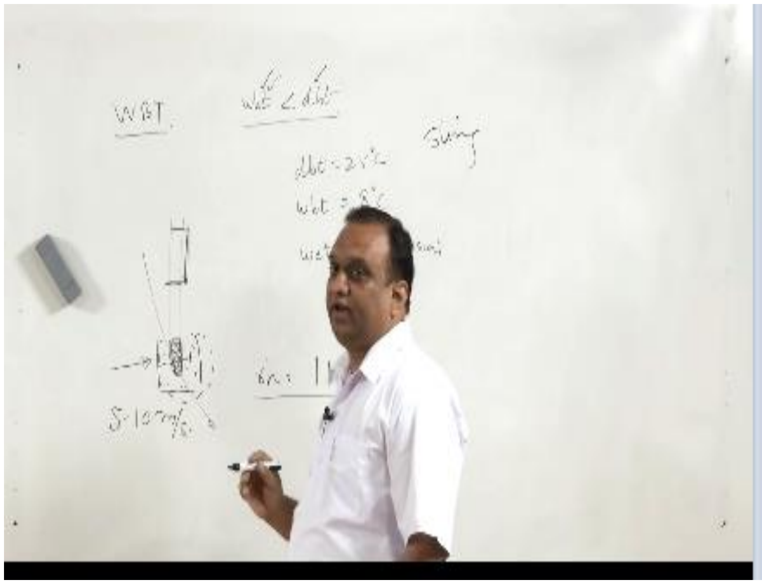

Wet bulb temperature, now if I put a width, if I put a width also wet cloth over the surface and blow air normally in order to find wet bulb temperature the velocity of air has to be between 5-10m/s, then what is going to happen. The moment the air is blown over the wet cloth the evaporation of water from the surface will take place and for the purpose of evaporation of water from the surface the heat will be taken from the bulb and the temperature of bulb will go down.

So normally the wet bulb temperature is less than DBT and this is known as wet bulb depression, the difference but suppose the dry bulb temperature is 25°C DBT is 25°C wet bulb temperature is let us say a 18°C. So wet bulb depression wet bulb depression is 25-18=7°C. Now this wet bulb temperature of 7°C if it is bore then what does it indicate if it is less than what does it indicate.

And if there is no change I mean both are equal, then what does it indicate when dry bulb temperature is equal to wet bulb temperature it means when if even when the wet is or the wet cloth is placed on the bulb air is blown there is no evaporation from the surface. Now you have precision of the surface means the air surrounding this bulb is already saturated with water. If the air is already saturated with water or 100% saturation is there, there will not be any evaporation from the surface of the bulb.

It means the humidity is 100% and which is known as relative humidity this I will explain in subsequently so the air is humid. If this temperature difference is too large, suppose this is 8 so depression will be 17° it means there is a lot of evaporation from the surface by the moment of this air.

And therefore, the air surrounding this bulb is dry it is it is not wet it is dry it is not wet. So this gives us the status of the air right, there is a machine which is known as hygrometer. Now hydrometer there are two types of hydrometer one is sling type of hygrometer, in sling type of hydrometer we just rotate the hydrometer this the thermometer toward with the wet cloth is rotated very fast.

And when it is rotated for a certain time period there is a dip in temperature when the temperature is stabilized then we measure the wet bulb temperature, that is one kind of a hydrometer and the hydrometer is aspirating hydrometer where this bulb is placed in a wet medium and air is blown over it, may be through a fan or through some other arrangement.

In that case also we get wet bulb temperature so these two temperatures are very important for us, these two temperatures are very important for us because immediately they gives us idea about the state of the air in the environment. Now the third is dew point temperature, now if I keep on reducing the temperature of the room right after certain temperature the water vapor in this room will start precipitating.

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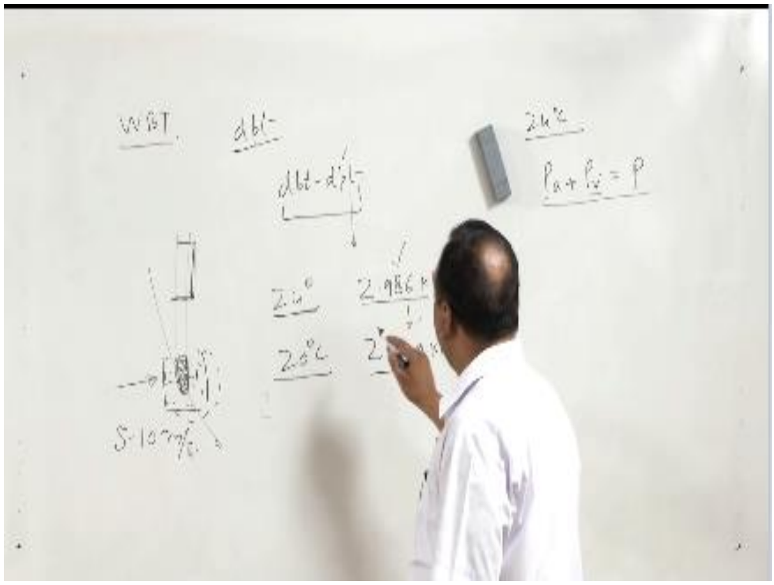

This precipitation will start and that temperature, that particular temperature is known as dew point temperature and difference between dry bulb temperature and dew point temperature is dew point depression. So if the humidity in this room is high the dew point temperature will be higher if the humidity in this room, humidity means the water content, if the humidity in this room is low the dew point temperature will also be lower.

If you look at here now in this table suppose I have saturated vapor I will give you an example if I have saturated vapor at 24°C at 24°C if I have a saturated vapor the saturation pressure is 2.986 if I reduce this temperature if I reduce from 24 to 20 then partial pressure of the vapor will reduce to 2.339 kilopascal partial pressure is reducing this is saturated this is also 100% saturated partial pressure is reducing it means amount of air, amount of water in the air this is amount of water vapor.

So water vapor is also getting condensed, I am repeating suppose I have air at 24°C the partial pressure of the water vapor in the air is 2.986 kilopascal I have noted from there. Now the temperature of the air is of this air is reduced to 20°C the partial pressure or saturation pressure of the water vapor will also reduce to 2.39 kilopascal.

So at this 24°C the air is a mixture of partial pressure of air plus partial pressure of water vapor that is a total pressure right. Now partial pressure of the vapor is reducing when we are reducing this partial pressure of water vapor is reducing when we are reducing the temperature it means some amount of vapor is getting condensed. So some amount of vapor is condensed that is why the partial pressure of the water vapor is reducing and we can say that this is the dew point because it is 100% saturated so this is a dew point of air which is already saturated.

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So now specific humidity specific humidity of the air is denoted by Omega or W it is mass of the vapor ratio of mass of the vapor and mass of the dry air in a given volume or per unit volume or a given volume of air mass of the water vapor and mass of air. Now here we can always used ideal gas equation so PVTV volume is equal to RV and T temperature is same in both the cases.

So W is equal to is equal to MVRV is equal to MVRV and P. So NV we can always take as PV partial pressure of the vapor multiplied by volume divided by gas constant for vapor multiplied by temperature of vapor. Similarly we can take these values for air partial pressure of air volume of air is same gas constant for air and temperature of air. Now these two will be cancelled out and we will be getting the expression as PV/RV/PA/RA.

Now gas constant is always universal gas constant by molecular mass so it is going to be = M V / MA × Pv /Pa, now molecular mass of water is 18, so W is 18 / 29 approximately for air it is approximately 29, and universal gas constant is same for all the gases, and PV / P n, this PV / PA and we also know that the total pressure is equal to, this is total pressure is equal to PA+ PV.

So W = 0.622 – PV / total pressure – PV, this is known as specific humidity of air, humidity ratio is same in some of the books this is writ 10 as specific humidity, and some of the book this it is indicated as humidity ratio, but that is a very this is a very important parameter in air conditioning, later on you will come to know that this is a very important parameter in air conditioning.

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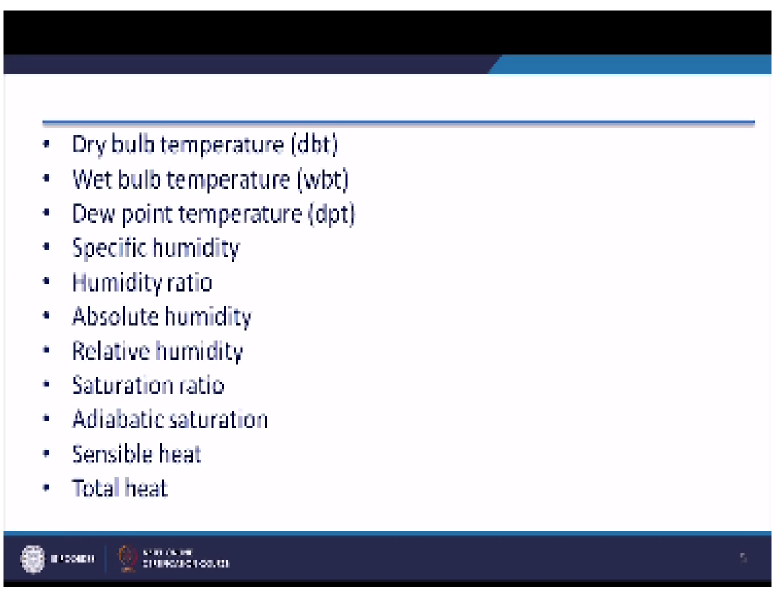

Now absolute humidity and relative humidity, ratio suspicion humidity ratio absolute ability absolute humidity, is the mass of water vapour associated per unit volume, so it is on volumetric basis, absolute ability nowadays it is not used as a parameter. Ready humidity is important it is used everywhere, in fact in order to express the state of moisture in the air rating this term relative humidity is used.

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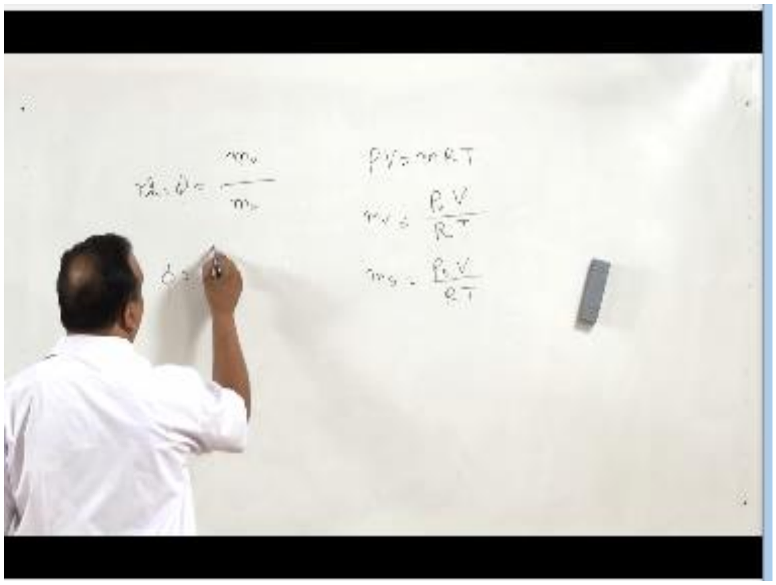

Now relative humidity is denoted by RH or Φ is equal to mass of the air, mass of the vapour in the air and, mass of the vapour in the air, when air is saturated, again we will be using the relation PV = RT right, P sorry! PV = MRT, MRT so M V is equal to pressure is same pressure is PV, VR is same P is same and MS = PS V (Rd).

So at the same temperature mass of the vapour present in a sample, of a given volume and mass of the vapour in a given value for the saturation at the same temperature, so if I put these values here then Φ = PV V / RT /PS V (RT), then these will be cancelled out and related ability is PV / PS, now if I go back to the previous slides suppose here at 24^0C,

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°C	p	h_f	h_{fg}	h_g
2	0.706	8.39	2496.2	2504.6
4	0.814	16.81	2491.4	2508.2
6	0.935	25.22	2486.7	2511.9
8	1.073	33.63	2482.0	2515.6
10	1.228	42.02	2477.2	2519.2
12	1.403	50.41	2472.5	2522.9
14	1.599	58.79	2467.7	2526.5
16	1.819	67.17	2463.0	2530.2
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42	8.210	175.89	2401.2	2577.1
44	9.112	184.25	2396.4	2580.6
46	10.099	192.62	2391.6	2584.2
48	11.177	200.98	2386.8	2587.8
50	12.352	209.34	2382.0	2591.3
52	13.631	217.71	2377.09	2594.8

Partial pressure of the vapour is point 2 9 8 si0.2986, so partial pressure of the vapour is 0.2986 at 24 ^{0}C, and saturation pressure is also 2,986 so air is 100% saturated, now if I ask you to find the partial pressure of the vapour, when the relative humidity of the air is 50%, 50 % at 24degree centigrade, DBT now in this case what I will going to do? I will take relative unity 50 % s TV I do PVS I can take from here 24 ^{0}C, it is per 2.986 and multiplication of 2 . 9 8 6 with 0.5, will give 1. 4 9 3, this will give us the value of partial pressure in kilopascal.

Now if I want to find the mass of water vapour in the air, total pressure is 100kilopascal, then W is 0. 622 we'll use the specific humidity expression for specific humidity, we have driven earlier P V / P - PV or P total pressure - PV we have got from here, now we will be putting the value of PV here total pressure is known to us, we can find the kilograms of air associated with the kilograms of per kg kilograms of diarrheal.

Because the unit is kg of water per kg of dry air dryer, so we will get how much water is associated with the per kg of dry air now.

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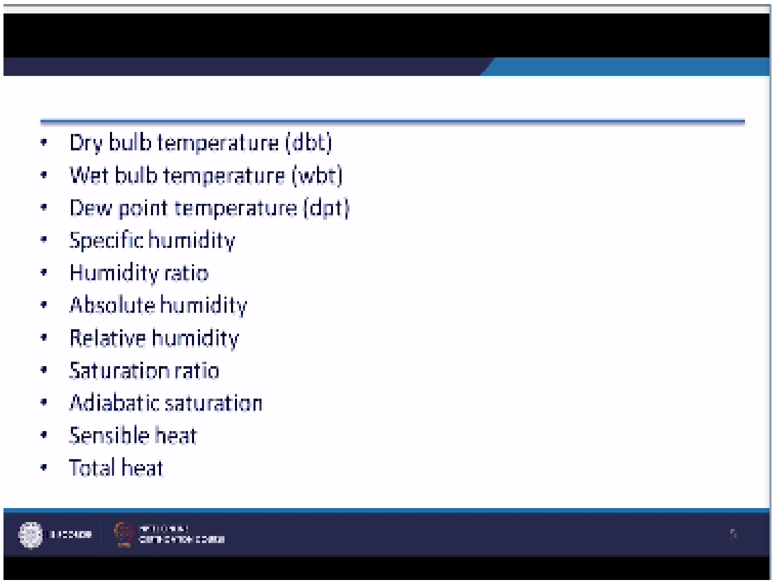

Third one is saturation ratio nowadays this is not used, it is again saturation ratio is the set is equal to the specific humidity.

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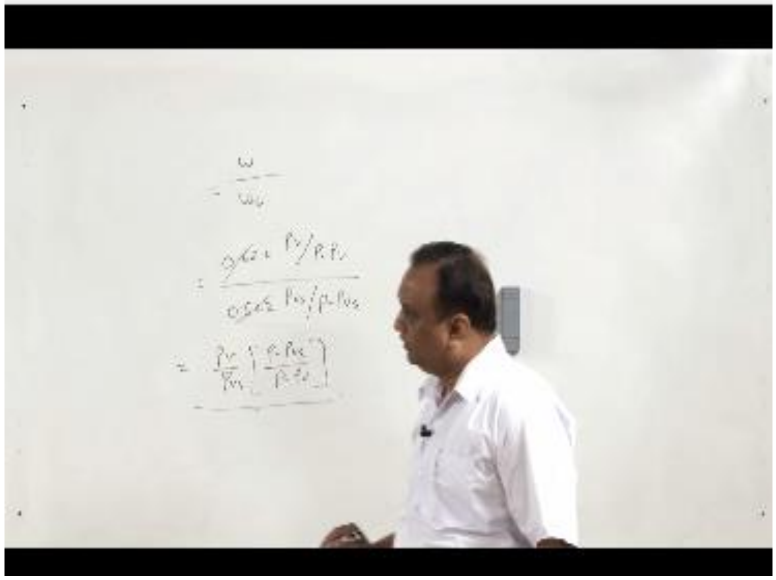

Of the air when specific humidity where the air is saturated, right so if we take a specific humidity of air ,0.622 PV / P – PV, and a specific humidity of the air when it is saturated that PV s / P/ n Pvs, and then we are going to have PV / PVs, P- P V s and P – PV, we are going to get this expression for this saturation ratio.

And this is the thing but relative humidity and P is much larger than PVs, so this expression is not 1 but very close to 1, is very close to 1 but so therefore nowadays we only go for relative unity in express, to in order to express the state of the air or if you want to have some calculate some amount of water then we go for specific humidity, now adiabatic saturation now adiabatic saturation is 1 of the way.

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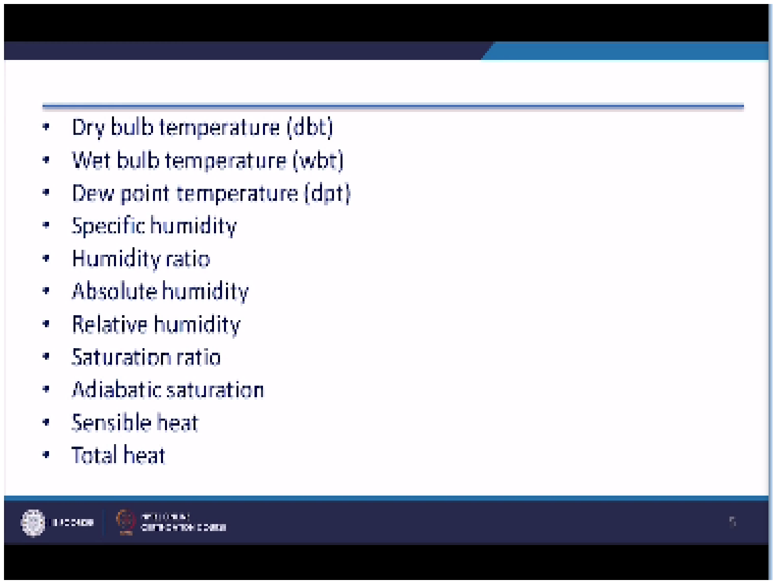

One ways I told you hygrometer can be used for finding out the century specific, you sorry! The wet bulb temperature, now another or and in another method of finding out

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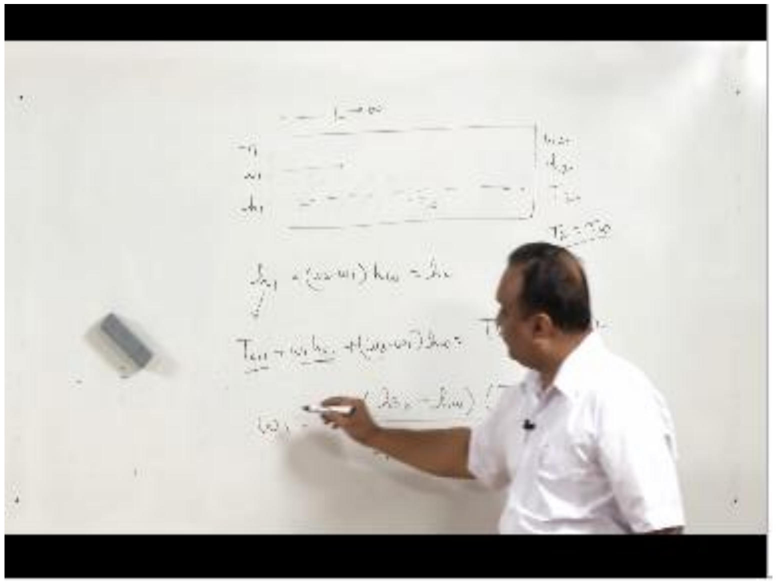

The humidity of the entering air, is through adiabatic saturation process, in adiabatic saturation process, there is a passage of in violent length, into the passage of infinite length and vapour is entering from this side, having T 1 temperature T1, is specific humidity W 1 and enthalpy H 1, so any air any air which is entering from this side will have certain temperature specific humidity and enthalpy.

Now this air will leave from this side, this is the temperature of water, and this is the specific humidity on this side enthalpy, on this side and temperature on this side, while this air is completely saturated when this air is completely saturated, the T 2 will be equal to TW, when T 2 = TW, and will say that air is because during this course evaporation from here will take place, and water will get mixed with the air till it is 100% saturated right.

If we do the energy balance that is going to be equal to H 1=H 1 + W 2 - W 1(HW) = H 2, the enthalpy of air leaving this side, is equal to the enthalpy of air entering from this side plus enthalpy added to air by virtue of evaporation of water from this water at the bottom of the passage.

Now H 1 is because it is a mixture of liquid and vapour, so it is going to be Tdv tribal 1 + W 1 H s1, we are taking T DB 1 because FR enthalpy because, enthalpy is change in enthalpy change in enthalpy is CP Δ T, now CPT 2 - T 1 here, T 1 we are assuming to be zero, so this is temperature in degree centigrade, so T 1 is assumed to be 0, so enthalpy at temperature 1 is assumed to be 0, so it becomes CP t2 now CP for air again we are assuming 1, though it is 1.005.

So when we are CP or for air is assuming 1 the enthalpy at this temperature is going to be T DB 1, this is specific humidity multiplied by the enthalpy of saturated vapour, now why we are taking enthalpy of saturated vapour? in this case now here it means.

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°C	p	h_f	h_{fg}	h_g
2	0.706	8.39	2496.2	2504.6
4	0.814	16.81	2491.4	2508.2
6	0.935	25.22	2486.7	2511.9
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50	12.352	209.34	2382.0	2591.3
52	13.631	217.71	2377.09	2594.8

If the temperature of incoming air is at 40 ^{0}C, and enthalpy of saturated vapour is 2 5 7 3 . 5 but in most of the cases the vapour is superheated, so this energy of superheat is neglected also neglected here in this expression, similarly W 2 - W 1 enthalpy of the water which is added here is equal to again PB 2 +W2 HS2.

Now this is the expression if we drive the final expression out of it for W 1 = W2 Hs2 - Hw t2 - t1,W2 H S2 - HW T2 - T1 / H s1 – HW, now if there is 100% saturation then we can definitely find the value of W2, these values are already available with us we can find the specific humidity of incoming air, this is another matter of finding out specific humidity of incoming air and this method is known as adiabatic saturation method.

Now sensible heat of air, the sensible heat is the heat added and there is a change in temperature, and there is no change in the phase, both conditions should be fulfilled so sensible heat is equal to always CP(t2 - t1)

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And total heat is equal to, the sensible heat and latent heat of air, suppose if the room temperature is 27 ^{0}C, in if I inject steam of 27 ^{0}C, the room temperature will not change but the total heat of the room will change, because there is a latent heat addition in the room, so I think that is all for today next time we will start with the psychometric chart thank you.

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