Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Engineering Thermodynamics

Lecture – 35
Gas-Vapor Mixture and Air Conditioning 1

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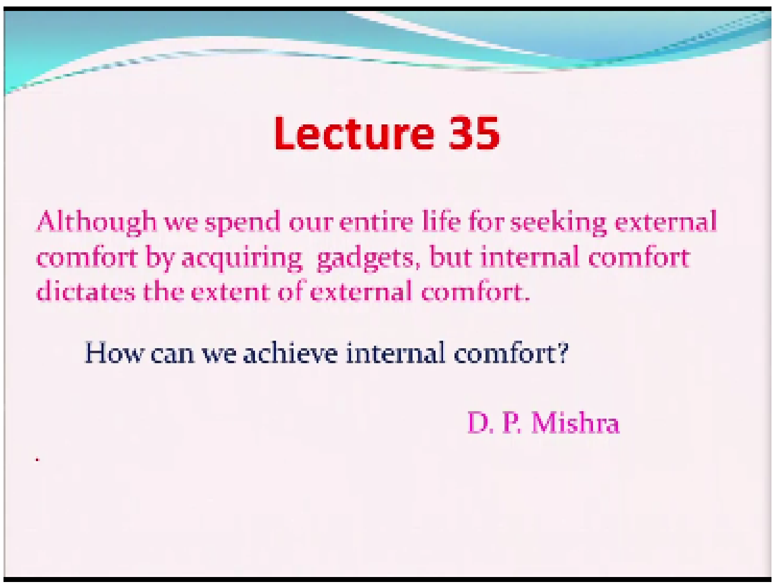

Let us start this lecture with a thought process what we do generally although we spend our entire life for seeking external comfort by acquiring gadgets, particularly in modern days, but internal comfort dictates the extent of external comfort question arises how can we achieve the internal comfort. And if you look at the previous lecture we are basically discussing about how to get comfort and also the await the vagaries of the weather conditions right.

And if you look at we started with the basic laws of how to handle the non reacting mixtures right like Dalton's law of partial pressure among at law and then we moved into looking at only how to handle or analyze the moist air, because that is the thing what you know dictates the comfort level for a person and then that is the basis of the air conditioning right. So if you recall that we define a term which is known as specific humidity right which is nothing, but the ratio of the amount of water vapor.

And the air amount of mass of air in a water or vapor air mixture or weight mixture we call it as also moist air wet air. So and that we had expressed in terms of also the partial pressure if remember specific humidity is equal to 0.622 PWS/PA right that is the thing what we looked at it. Now question arise show much amount of moisture the air can contain right and that will be dependent on the temperature right yes or no.

So we will see as you go along it will be dependent on temperature you might have experience right, if temperature is very high and it is humid you are feeling very uncomfortable particularly in this is nowadays weather is knocking at the door and then like we get and temperature also is quite high. And if it is, you can be at that temperature let us say 40°C if the moisture is not there it is dry it is not that uncomfortable you might have seen.

So now we need to evaluate basically how much moisture air can carry or at a particular temperature. And in other words you can say what is the capacity of the air to hold the water vapor that way.

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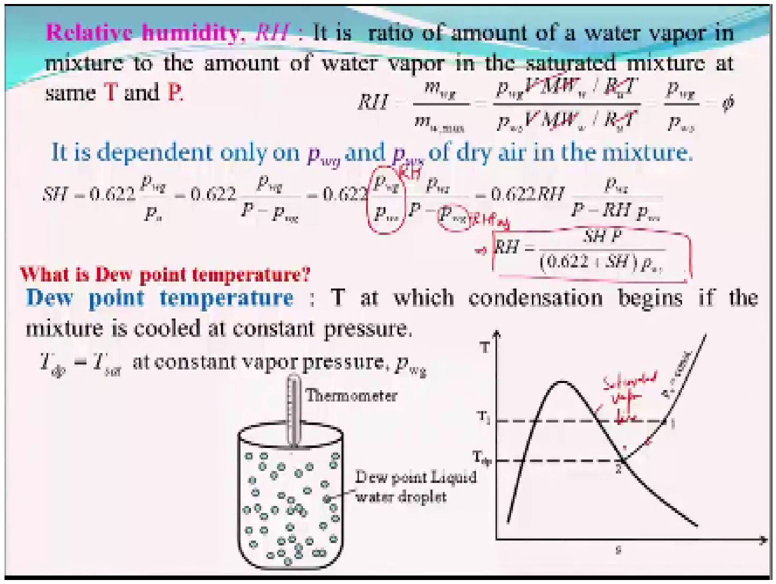

So for that we will be defining a term which you call basically relative humidity, because there is a capacity of air to hold some amount of water beyond that it cannot right, and that will be related to the saturation point. So therefore we are defining a term which is a relative humidity it is the ratio of amount of water vapor in the mixture to the amount of water vapor in the saturated mixture at a particular temperature and pressure right.

So if you look at saturated what you call water vapor, what you do could you can get from the steam table saturated steam temperature table you can use and you can get what will be the partial like pressure of that and also from that you can find it out what will be the amount of moisture, because if the temperature, the pressure you can use the ideal gas you can find it out very easily. So that is RH is basically, RH is nothing but your relative humidity which is nothing but amount of the water vapor in a moist air divided by the maximum amount of water vapor the air can hold at that particular temperature and pressure.

So and by ideal gas law I can write down m.WG is nothing but PWG in the volume of course the molecular weight of water divided by RU, RU is the universal gas constant T right, T is the temperature. So that is from the ideal gas law and similarly the amount of maximum water vapor a moist air can hold at a particular temperature and pressure can be written a PWSV molecular weight of water divided by RUT.

So if you look at R will be cancelled out this will be cancelled out, this will be cancelled out, and this also will be cancelled what remains is the, you know is the partial pressure of water vapor in a moist air divided by the saturated water vapor partial pressure right saturated means beyond that it cannot and that sometimes we call it is also ϕ I mean both the symbol are same relative humidity and ϕ right.

So it as I told earlier basically it is dependent only on the two pressure partial pressure one is the partial pressure of the water vapor right, and other is the partial pressure of water right at saturated condition right. So of the dry air mixture, so you can relate now the specific humidity to the relative humidity what we can do we will take this relationship that we know that is SH=0.622PWG/PA and we know that PA, partial pressure of air is nothing but P that the total pressure minus PWG right.

And in place up I can write down PWG/PWS x PWS I can replace that and this is nothing but what, that is your RH right and PWG this I can write down as RH=RHPWS. So therefore, SH is nothing but 0.622RH x PWS/P-RHPWS that means you can relate this specific humidity with the relative humidity right. So you can have that once you know one of them and you know the temperature.

So if you know the temperature PWS you can find it out from the saturated steam table and corresponding to saturated condition right and the temperature. And then of course you know the atmosphere is generally air conditioned when we are talking about atmospheric pressure this is P is basically atmospheric pressure then you can very easily find out specific humidity right and vice versa, if you know the specific humidity you can also find out the relative humidity provided you know the temperature at which you are working you know.

So in the similar fashion I can write down an expression RH=(SH x P/0.622+SH)PWS right. So that is from this relation just I have rewritten that is all nothing else more than that okay. So now we need to understand the dew point temperature right. So what do you mean by dew you might have observed right particularly in the summer season if there is a moisture in the air right what happens particularly in the early morning or in the late night the temperature will be dropping down.

If you drop down what happens to the moisture you might have observed over like in your day-to-day life right you have never seen the grass is having lot of water it condensed water in the early morning of course you people are not getting up early morning not going for a walk or look at the beauty of the mother nature. So you are devoid of that or deprived of that rather not divided as a deprived, because of your own lifestyle on an average scale I am not saying all of you are like that.

So please change your lifestyle it is very important because life is more important than anything else. So coming back to that that means you will get some water which is condensed and of course you need a surface to be condensed and that what you call grass or leaves and other places you know you will find so that is nothing but you dew point or the temperature why because in the summer the temperature will be high if there is a pond or a water bodies of course water bodies are receding at allowing greater not only in cities but also in the rural areas.

So if it is there and then lot of evaporation will be taking place right okay. And if evaporation will take place it will be there in the air atmospheric air and we call it basically moist air right, and that will be condensed back having said this thing. Let me ask another question what are the differences between the evaporation and boiling which we had seen in the boiler in the, you know earlier also steam and other things pressure cooker also we boil the water steam comes out several places what are the differences any idea, any idea no.

I am expecting that you should have some ideas what is the difference, because all our evaporation of the or the water is converted into the its vapor in the case of your, what you call evaporation and also in boiling right. So then what are the differences is there any differences or there are no difference at all what do you think both are change of phase from liquid to its vapor particularly the water what we are considering at this moment right what are the differences. Let me tell you that it is I will tell you briefly because a paucity of pan see the water evaporation always take on the surface of the water level.

Let us say in a pond right it will be evaporated right and if it is evaporated, then there will be of course the depends on the vapor pressure what it is having and then we will try to nullify that changes because away from that it will be having concentration gradient road that will be the driving force and in case there are in case of boiling you know the temperature on the bottom surface wherever you were giving heat you know heating surface right there will be very high higher than the what will be happening in the evaporation right and then the bubble will be formed right and the bubble will go up.

And then you know that the steam will be formed and then that is the boiling right we would not call unless bubble form am I right? Yes or no but in evaporation there would not be boiling there would not be any bubble formation right so therefore there is a lot of difference you know temperature here it will be higher because interface temperature between the water and the metal or the any other heart surface you know will be very high but here there it is dependent on the very you know like whatever temperature it is having.

So there are you know more circle points you can look at it so I was telling about the dew point dew point you know you can think of conducting experiment in your room itself or in your home so what you can take. I can take a what you call a glass of the water and little bit eyes on it so that I will drop the temperature you know and stir it so I can measure this temperature till the outside of the glass either it is if it is a metal it will be good even in the your glass you know are a tumbler what you call this a tumbler basically and even if we made of glass you know it will be having probably might have seen suppose you take something from the freeze and keep in the under table just to let it cool down you will find lot of moisture in the outside from where it has come it has come basically the from the atmosphere.

Like whatever the air will be in contact with the surface of the tumbler or any other container right if we just condense because it has reach a temperature that is known as dew point temperature right before that before it reach the water would not condensed so therefore we can define the dew point temperature as the temperature right at which condenses begins if the mixture is cooled of course at a constant pressure you know pressure changes that is but we are assuming that to be remaining constant this example.

Of course pressure will be remaining constant and you are not mixing it very vigorously right and what is the meaning of that that is basically the temperature of the water you know saturated temperature of the water right or the this thing at a constant vapor pressure right we call it basically dew point temperature if you look at in this TS diagram this two phase you know like process you are here somewhere T_1 and as you know cool it so that you will be moving towards that temperature will be down at this point what will happen.

This is what you call vapor this is your what you call the saturated vapor line this is saturated vapor line right saturated vapor line and at this point it will start condensing right after that little bit you know this thing it will be start condensing that is the point at which the vapor will start formed right now sorry it will be only vapor but it is a point at which the vapor will be started condensing right so that point we call it as a dew point temperature so we look at now the.

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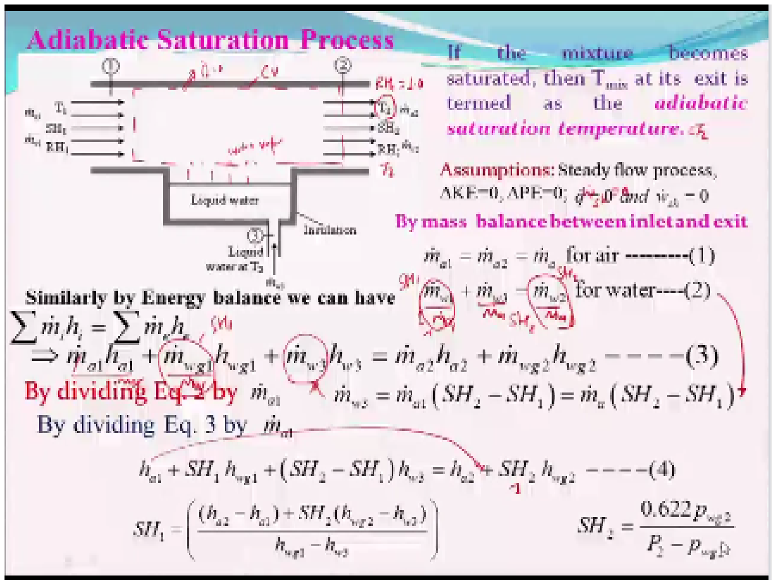

Adiabatic saturation process where you know if it is saturated and no heat being transferred we call it as adiabatic saturation point, so let us consider a that there is a moist air which is entering into this adiabatic saturator right that means no heat is going out here you know 0 anywhere right and it is having certain temperature right and of course this is the moist air it will be containing certain amount of air and also it will be some kind of vapor it is having some specific humidity let us say station 1.

So therefore I am giving sh1 and relative humidity and then when you will come in contact with this liquid water what will happen there will be some vapor water vapor will be going you know like this thing something water vapor will be right carried over by this air and in such a way that it will be long enough right so that it will be giving you the point here that it will be saturated almost or saturated, saturated means it cannot take more than amount of moisture at the temperature of course there will be some drop.

In temperature right yes or no because if they get carrying at evaporation therefore there will be some you know heat of vaporization has to be given and that will take care so therefore temperature will be dropped down of course the liquid level will be coming down we will give some amount of liquid years as that this level remains same right and what happens to the relative humidity what happens to the specific humidity at the exit of this adiabatic saturator what will happen.

If it is saturated from the definition of relative humidity we know which is nothing but the ratio of mass of water vapor divided by the mass of water saturated mass of water so therefore it is same so RHE will be equal to RH2 will be equal to 1 right. Okay so do you find this application anyway see if you go to other city right you have gone to father politically the fourth you please visit their earlier days this is a very hot also and the same and they were having this kind of channel what a channels right that which will make it cool there you know the king or the queen or the other people will be in comfort.

With you right okay so you can see in our insane time people may not be knowing that much what we are talking in the class but they know how to design and develop okay it is not only that you can go to earlier forth several code whatever we are having you will find lot of science and technology there so let us now look at that how to analyze it as I told that if the mixture becomes saturated and this case we are giving enough length of this water or allow the water to come in contact with the air which is entering into the adiabatic saturator.

So that you know it will be saturated at the end of this so then the mixture at this exit is termed as the adiabatic saturation temperature right are you getting the temperature whatever it will be at inlet us say this is T_2 to write this temperature right T_2, T_2 is there already okay this temperature T_2 then that temperature is basically the adiabatic what you come saturation temperature okay so is it different than that of the your dew point temperature yes or no it will be different or will it be same.

So we see that you please think about it so we want to analyze this right what do we do we will be doing standard assumptions that is steady flow process change in kinetic energy is 0 so also change in potential energy is 0 right and there is no sapped work are you giving any staff to work or some power Nona right so there would not be any shaft works are shaft work will be 0 so what we will do will basically do two things one is your mass balance other is you energy balance right.

And this is a flow process therefore we can take a control volume right we can take this is my control volume right okay this is control volume so I can consider you know like 12 station 12 and also we are giving some amount of water and generally this water is given you know and says that this is liquid is at temperature T_2 right that is being supplied and they said that it will be the label will be maintained otherwise analysis will be difficult and also then it would not be very effective you know like because water level will go then what air has to come in and take it you know it will be difficult.

So and you know why this water has to be given because if you be evaporated if it is evaporate the label will go down over a certain period of time if you operate longer period of time okay so by mass balance between the inlet and exit this station one is your Inlet station 2 is your exit what we will do we will basically look at this mass of air at station 1 is equal to amount of air that is the mass flow rate of air at station 2 is equal to mass flow rate of air because nothing more is added there is no addition of air in this step you know through the this port at the station 3 right so therefore that is not and whereas for the when we do the water balance right what is that mass flow rate of water at station 1 plus mass flow rate of water at Station three because you are giving some water.

Is equal to mass flow rate of water which is going out of this adiabatic saturator make sense right this is just a mass balance right. So we similarly do the energy balance and that is summation of the enthalpy is equal to summation of the enthalpy at the exit this is the inlet you know left-hand side is inlet and right-hand side is your exit and if you look at how many inlets are there here in this case there are 2 1 is station 1 and station 3 and exit is only one that is special too so by that we can write down this energy balance.

That is m.a1x ha1that is the enthalpy of the air which is entering right + $m._{wg}$ that is the water vapor mass flow rate into h_{wg} at station 1 + the amount of enthalpy due to water which is entering into the into this channel liquid what you call container right and is equal to the amount of enthalpy which is exiting out from this adiabatic saturator that is m.12 x h_{a2} + m.wg2 h_{wg2} is the enthalpy due to water vapor right.

So we will basically Club this kind of values in from the mass balance and then simplify it right if I divide this thing by m.a1 right whole m.a1this will be canceled it out and this is a1 and this is m.a1 this is $m._{a1}$ right m.a1right we know that m.a1 = $m._{a2}$. And this is $\dot{m}_{a1}$ this is $\dot{m}_{a1}$ right, we know that $\dot{m}_{a1}$= $\dot{m}_{a2}$ right, so therefore this will cancel it out right, this will be 1 why because $\dot{m}_{a2}$ = $\dot{m}_{a2}$ from this air we have done so similarly here also we can write out $\dot{m}_{a2}$ so what is this term then by definition this term what is this is basically SH_2 specific humidity yes or no, right. Similarly this if you look at this will be SH_3 one can say and similarly of course the here we can say very happily that is SH_1 right, and this you can say SH_3 right.

So if you look at from this expression right, you can get that what you call from your this expression right we can get mw_3 right is equal to $mw_{a1}SH_2\text{-}SH_1$ right will you get this one how will get this is one what I do I just do that $\dot{m}_{a1}$ we will divide it $\dot{m}_{a1}$ in that $\dot{m}_{a1}$ and this is nothing with your SH_2 and this is nothing but your SH_1 right okay, so from these I can get mw_3 is equal to from this expression I can get $mw_3= \dot{m}_{a1}SH_2\text{-}SH_1$ and $\dot{m}_{a1}$ is nothing but $\dot{m}_a$ from this equation one right are you getting.

So now so if I divide this equation as a told this is coming and that is mw_3 you know we have already seen that is nothing but you $mwSH_1$because we have seen that mw_3 so if you look at like what I am doing here and this is from equation 3 we get that ha1is nothing but SH_1 h_{w1} and this m_{w3} here if you look at I can get basically I can use this expression here i can get $(SH_2\text{-}SH_1)h_{w3}=h_{a2}$ right from this expression $+SH_2h_{w2}$ right and if you simplify this thing I can get $SH_1=h_{a2}\text{-}h_{a1}+$ because I will take this side right and SH_2 I can take to this side right, so SH_2 h_{w2} sorry you can take to this side basically to this side $SH_2(h_{w2}\text{-}h_{w3})$ okay.

What I you basically, what you will do you can take this what you call SH_2 side into one side and then SH_1 this one and then you can SH_1 you can take one side and then you can get these relations if that is specific unit is equal to $h_{a2}\text{-}h_{a1}(SH_2)$ in the bracket $h_{w2}\text{-}h_{w3}/h_{w1}\text{-}h_{w3}$ so this is the expression what you can get for the specific humidity at the station one. So if you look at if I know these values right h_{a2} and h_{a1} and if you can find out SH_2 because we know the relative humidity right and we can find out this h_{w2} and h_{w3} and h_{w1} h_{w3} then we can very easily evaluate the SH_1. So because if you look at SH_2 you know already that 0.622pwg2/P2-pwg2.

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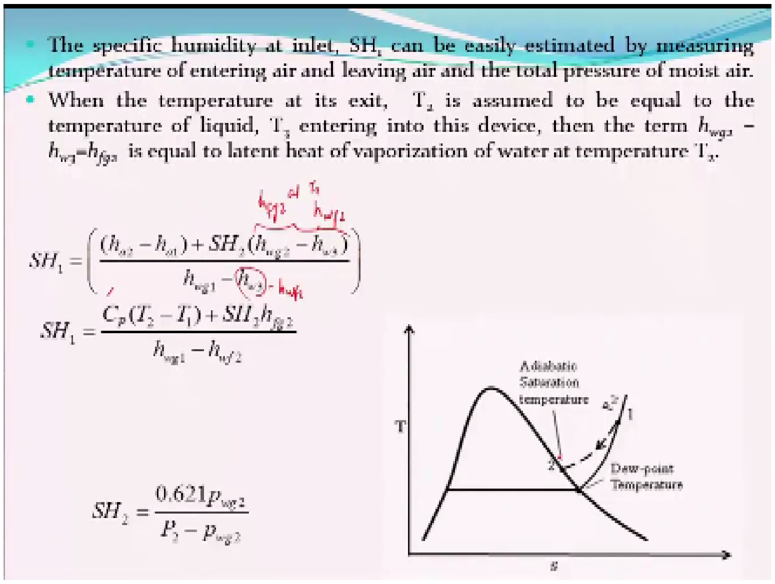

And if we look at that this h_{w3} what we can say that it is corresponding to the what values that is nothing but your h_{wf2} right, because that is the thing what we are saying at the same temperature it will be saturated liquid so therefore at temperature T_2 so you can look at this portion will be nothing but here if you look at h_{fg2} at T_2 right, and this way similar way I can replace this thing here with the h_{wf2} right and I can also write down this thing because if you look at this is about the air and I can say that C_P is remaining constant is not changing with the change in temperature.

So therefore I can write down that what you call $SH_1=C_P(T_2-T_1)+SH_2$ that i was telling $h_{fg2}/h_{w1}-h_{w2}$ right. So if you look at if I know this C_P values right and that is for a you know air you can take one point 1.005 kJ/kgK and T_2 and T_1 is if you care if you know that temperature right, so then you can find out easily and SH_2 you can find out very easily provided you know the temperature right and h_{fg} already you can get from the steam table and these all these values you can get and then we can calculate very easily.

So if you look at that as I was telling that this is the you know dew point temperature where you know temperature is changing and there is also that thing but whereas the adiabatic saturation temperature take this path it will be different temperature because the heat is you know being not going out therefore there will be little higher temperature as compared to the dew point temperature right it is not going out by that.

So what we will do we will see how we can basically apply these you know equations and finding out the various properties will take this you know kind of an example we can take an example and look that but before that let us ask a question what do we mean by psycho meter.

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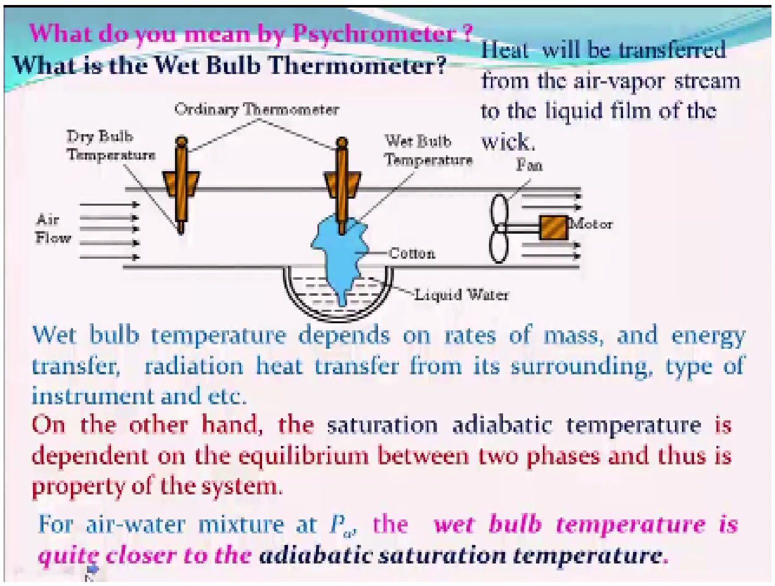

Because we want to find out this the dew point temperature and then what you call dry bulk temperature and kind of thing so that we can find out what is the relative humidity what is the specific humidity and other things. So and if you recall that we had discussed about wet bulb temperature there is a temperature which will give you basically corresponding to the moist air right and if we can have a device for this like we can think of using you know like air here right air is going and when you will just put a thermometer I know whatever the glass bulb thermometer we are having that will give me that drywall temperature right.

But if I will you know put into a liquid and then of course this a cotton or a week whatever you use and is moist air so therefore that will give me the wet bulb temperature of course you need to suck the air at a particular velocities right so that it would not get affected and then it will be this thing that is the you know laboratory what people use to have a very precise measurement of the dry bulb temperature and the wet bulb temperature right and this is known as psycho meter.

Because once you know this you can find out very easily what is the relative humidity what is the specific humidity right and kind of things and you can know. So of course if you look at this wet bulb temperature depends on the rate of mass and energy transfer right, and of course the radiation heat transfer from the surrounding and kind of things one has to take care of that but here it would not be because you are keeping and then this temperature would not be that much.

So that there would not be radiation there is no other heat sources and we will see that this can be done very simply using a thermo meters which will be discussing in a very simple way. And on the other hand if you compare this dew point temperature is the or what we call you know this thing saturation adiabatic temperature is dependent on the equilibrium between the two phases thus is a property of the system right, okay.

I mean therefore the situation adiabatic temperature is basically the property of the temperature and which will be closer to the what to call dew point temperature right, and for a air water mixture of a P_a the wet bulb temperature is quite closer to adiabatic saturation temperature right, wet bulb temperature is closer.

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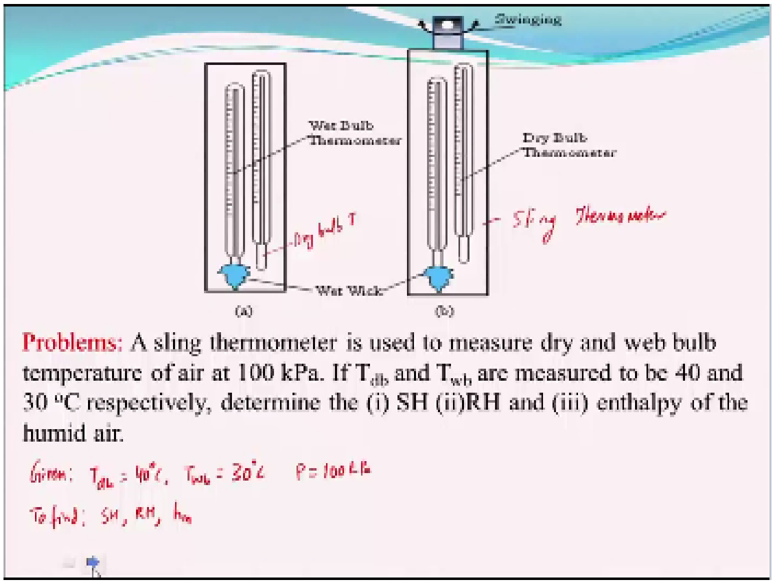

And if you look at that is a complex system what I looked at but if you might have seen these thermometers in your laboratory and other thing there is a 100 meter here which will give me the dry wall temperature so this will give me dry wall temperature right, okay thatis the dry bulb temperature right and you this week is there which you will have to put moisture like or the cotton that it will measure that will give me the wet bottom bitch this you might have seen in there any laboratory it will be having.

But however it may be giving not giving the right temperature for the wet bulb say what people do that they will have to swing it you will rotate it you know so that there will be some velocity of the air which will be coming and then there will be some vaporization will be taking place and water answer that it will be it will be taken out and then it will be temperature wait was it will be saturated right.

So that this kind of things and it will give with a wet bulb temperature and let us see how we can use that we will take this example let us say a sling thermometer is used to measure and in a dry and wet bulb temperature of air at 100 kPa and the dry bulb temperature is 40˚C and wet bulb temperature 30˚C and we need to find out specific humidity a relative humidity and enthalpy of the humid mixtures and keep in mind that this you know the thermometer which is rotated we call it a basically the sling thermometer this is known as sling thermometer and this is being used to measure that.

Now how to go about this thing, so if you look at it is given right what other things are given the dry bulb temperature DV is given 40^0 Celsius right and wet bulb temperature is given as 30^0 Celsius right and of course the pressure is given 100 kilopascal and to find we will have to find out S_h R_h and also H_M the mixture of the humid air we need to find out enthalpy. So how to go about you can say that as I told that this is the sling thermometer but we can assume that you know is they basically situated adiabatic mixtures right kind of things.

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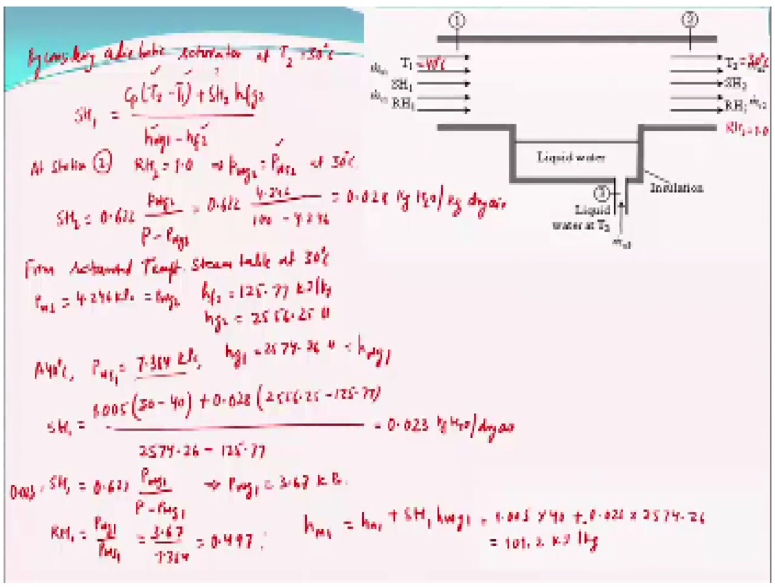

So if we do that and what is given here if you look at this t1 is equal to 40^0 Celsius right and the t2 is equal to 30 degrees Celsius it is given right and we can find out enthalpy at the basically sh1 we need to find out what is the moist air is entering into saturated adiabatic saturator right. So what will have to find out basically that by considering adiabatic saturator right at temperature is equal to 30^0 right and we can find out the SH one we have already seen SH 1 = CP T_2 - t 1 + S h 2 hFG 2 / h/w 1 - h f_2 right.

So if you look at what is T $_2$ T_2 is given this is given right 30^0 Celsius p_1 is given CP of course you can take as air CP that is 1.00 5 kilo joule per kg Kelvin and we need to find out SS_2 this is not known this is not known right we need to find out and h FG_2 will have to find out we will have to find out sw1 and hf to all those things we need to find out but how to go about them how will get SS_2.

Let us say because we know that R h_2 =1 right okay, that means it is saturated condition at station 2 right rh_2 = 1 that means the p/w g $_2$ = p ws_2 that is saturated condition. Now if I know these things right okay, so I mean like we can and that is what is happening that is basically at what at 30^0 Celsius right. So if I know RS_2 can I find out the SS_2 right I can find out very easily right?

So let us take the properties of these because I need to know this why SS_2 we know is equal to 0.622 pw z 2 / p - p z 2, now what is this p WS to that if I will know this then I can get very easily that is equal to that okay pw s 2 = p WG two partial pressure of the water vapor at station 2, so 4 for that we need to use the steam saturated steam table so from saturated temperature right steam table at 30^0 Celsius what we can find out we can find out all these properties that is p WS = 4.246 kilopascal and which is equal to p w g 2 and h up to I can find out 1 2 5.7 7 kilo joule per kg and hg2 is 25 56.25 kilo joule per kg right.

And let us also look at the from the you know saturated steam table at 40^0 Celsius right Pws = that is of course s 1 is equal to 7.384 kilo Pascal and SG_1 is 2574.26 kilo joule per kg right, so here I can put these values that is basically 0.622 and we have taken that pressure is 100 kPa right generally people take a 101325 right 101.325 kilo Pascal but here it is given so you need not to take at most pressure right.

And pw z is basically what we call 4.246 / 100 - 4.246 he will get the value is basically 0.028 kg of water but what kg dry air that means SS_2 is equal to 0.08 kg of water it is caring for 1kg of water right and if you look at now we can substitute these values all the things we know now okay is it do you know I think I made a mistake this is g1 right just check that so we know this is nothing but your h1 right this is now known hf2 is known right and this h FG is nothing but what h FG 2 is nothing but here what you call 2556 in hf h g 2 -HF to okay.

Let me write it down so I can evaluate Sh_1 is equal to CP C P is1.005 T_2 is a swell 30^0 – 40 + SS_2 is 0.028 x h FG basically hg_2 25 56.25 - 125 77 / hWG_1 that is 2574.2 6 – 12577, so if you do this you will get basically 0.023 kg of water per dry air. And once we know this is the one I can find out what is our h1 right can I find it out very easily what we will do we know Sh_1 is nothing but 0.62 to of course you can use the other formula but we can use this is simpler 1 z 1- p -w g 1 and from this because we know this value this is sh10.023 then I can get pw z 1 is equal to basically 3.67 kilo Pascal.

So Rh1 is nothing but you p WG 1 / p WS which is what is pw is one what is that that is nothing but your seven point you know this is this one 7.38 for you will give basically 0.49 seven okay and we need to evaluate now hm1 that is nothing but h a1 + s h 1 h w g 1 = CP that is 1.00 5 x 40^0 Celsius + sh1 we know that is basically 0.023 x HW g one that is nothing but 2574.26 and which will be equal to 1 0 1.2 kilo joule per kg.

So what you can get is basically you know like all these values questionnaire edges you know you'll have to do all this calculation to find out these properties but is there any other simpler way of doing that that we are going to do how we can use a chart which is very quickly to you know find out and then we will see in the next class thank you very much.

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Tapobrata Das
Ram Chandra
Dilip Tripathi
Manoj Shrivastava
Padam Shukla
Sanjay Mishra
Shubham Rawat
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Aradhana Singh
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