# Applied Thermodynamics for Engineers
**Prof. Dipankar N. Basu**
**Department of Mechanical Engineering**
**Indian Institute of Technology – Guwahati**

## Lecture – 32
## Properties of Moist Air

Hello everyone. Welcome to week number 11 which is the penultimate week for this particular course. In the previous week, we have talked about the properties of gas mixtures where basically we talked about the mixture of non-condensable gaseous substances both in ideal and real sense. And we have seen how to calculate the properties of such kind of gas mixtures, when the mixture is behaving like an ideal gas or when it is an amalgamation of several kind of real gases.

In this week, we are going to deal with the mixture of gases and vapours. That is we are going to talk about the mixture where one or more components are condensable during a process. That is the one of the gaseous substances though normal it may be under gaseous condition but with change in the state, that is with decrease in the temperature on increase in the pressure, it can undergo a condensation process. Whereas some other components of the mixture may be non-condensable gaseous substance. The most common example of that one can be the atmospheric air only. Because you know that in atmospheric air we have several non-condensable gases, like oxygen and nitrogen at the most prevalent one, but we can also have some quantity of carbon dioxide and a few very small quantity of noble gases or gases like helium, and neon.

However, in atmospheric air, though it is very small quantities, but still have water vapour as well. And therefore, when you pick up a fixed mass of atmospheric air and subject that to some kind of cooling process, then while the non-condensable part will remain on you remain as it is, that is I should say it should retain its gaseous phase. There will be only change in the temperature of that. Therefore, only the heat transfer that is taking place with non-condensable part is only in sensible mode. But it is very much possible that the condensable part, that is the water vapour may tend to condense as the temperature drops to a certain value.

And therefore, whenever you are dealing with a mixture like this gas and vapour mixture, just like the example of atmospheric air, we have to deal with several other parameters and their property estimation. Therefore, we have to be very careful about the way we estimate their properties because we just cannot treat them similar to the mixture of gases, which we have discussed the previous week.

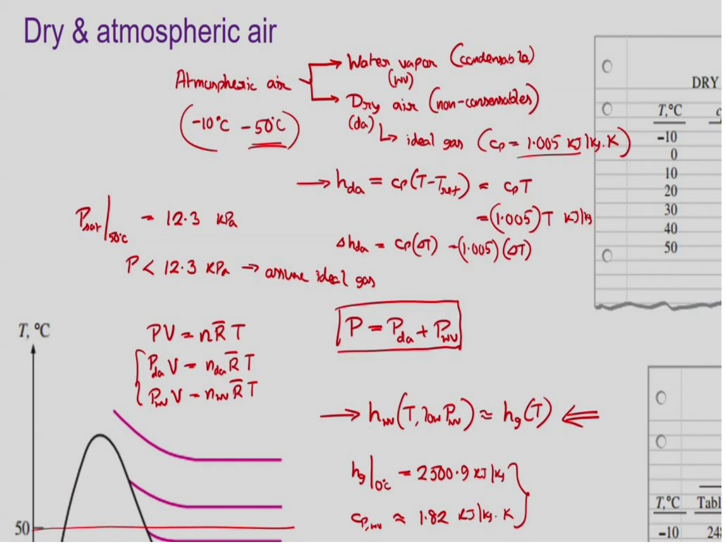
So, this week we shall firstly be seeing different properties that we define for the gas vapour mixtures, then we shall we seeing the ways to calculate those properties. Then I shall be introducing you to something known as the psychometric chart, where we can represent different processes involved in the gas vapour mixtures and then we shall be seeing the application of this one in engineering science.

And, what is the biggest application of gas vapour mixtures? Of course, in the field of air conditioning. Because whenever we are talking about any air conditioning application like the studio where I am sitting. Here, I have an air conditioner is running, but the objective of this air conditioner is not to control the temperature alone rather also to control the humidity of moisture content of the air.

And therefore, it is operating over the air that is covering the entire volume of the room which has both the condensable and non-condensable part, and therefore it is dealing with the gas vapor mixture. Of course, the air conditioner itself or inside the air conditioner we have something very similar to a refrigeration system. That is, we are having some kind of refrigerant which is passing through a common vapour compression refrigeration system. There is a condenser, an evaporator a compressor and also an expansion valve. But the refrigerant is treating this particular room as its cooling chamber from where it is going to pick up the heat in the evaporator and while picking up the heat it has to deal with gas-vapor mixture. Of course, the gas-vapor mixture is not coming in direct contact with the refrigerant, but to what temperature we should set the refrigerant or should we set the evaporator to that which is dependent on the properties of the gas-vapour mixture. And therefore, we are going to take this atmospheric air as a biggest example of a gas vapour mixture and whatever you want to discuss in this week, we are going to consider only a mixture of water vapour and some non-condensable gases similar to air.

However, I should clarify in the beginning itself whatever we are discussing here that is equally applicable to any other mixture of gas and vapour.

**(Refer Slide Time: 05:18)**



Dry & atmospheric air

Atmospheric air → Water vapor (wv) (condensable)
→ Dry air (da) (non-condensables) → ideal gas ($c_p = 1.005$ kJ/kg.K)

(-10°C - 50°C)

$\rightarrow h_{da} = c_p(T - T_{ref}) = c_p T = (1.005)T$ kJ/kg

$\Delta h_{da} = c_p(\Delta T) = (1.005)(\Delta T)$

$P_{sat}|_{50°C} = 12.3$ kPa

$P < 12.3$ kPa → assume ideal gas

$PV = n\bar{R}T$

$P_{da}V = n_{da}\bar{R}T$

$P_{wv}V = n_{wv}\bar{R}T$

$\boxed{P = P_{da} + P_{wv}}$

$\rightarrow h_{wv}(T, \text{low } P_{wv}) \simeq h_g(T) \Leftarrow$

$h_g|_{0°C} = 2500.9$ kJ/kg

$c_{p,wv} \approx 1.82$ kJ/kg.K

Now, atmospheric air can be visualised to be or can be viewed to be a combination of two types of substances. So, if you write atmospheric air, we can see there is a part which is the non-condensable one and there is a part which is water vapour. So, we have the water vapour part which is condensable, and the remaining all the non-condensable that we are going to club together into something conventionally called dry air, which is the combination of all the non-condensable elements. The term dry air is used because if you remove the entire quantity of water vapour from the atmospheric air, the thing that is left that is conventionally called dry air. So, dry air is the part of the atmospheric air after removing the water vapour. It is a combination of non-condensable gases. And therefore, whenever you are treating any air to conditioning process, then generally the quantity of dry air remains constant. In fact, forget about the air conditioning application even when we are talking about our open atmosphere generally the quantity of dry air that is a mass of non-condensable present there that does not very significant amount. Then the variation cannot mostly be neglected. Where is the quantity of water vapor that keeps on changing throughout the day, throughout seasons and also with the location that keeps on varying, at a particular time as well. Therefore, the water vapour part that keeps on varying and accordingly the water vapour role in deciding our comfort level. We know that when the moisture content in the air is too high, we feel quite uncomfortable, when the moisture content is too low then the air keeps on absorbing water vapour from our body.

And that may not be also a comfortable situation for this. So, in a nutshell the atmospheric air comprises of two parts, one is dry air whose mass generally remains constant. Other is the water vapour whose mass keeps on changing. Now in air conditioning application generally we are concerned about the temperature range of −10 °C to 50 °C. So, we are always bothered about this particular temperature range, where we hardly go outside this particular temperature is −10 °C to 50 °C.

And within this particular temperature range, we can often treat this dry air part to be an ideal gas. So here our discussion purpose, we are going to assume the dry air to be an ideal gas with constant specific heat of $c_p$ = 1.005 kJ/kgK. This is not a bad assumption because if you look at this particular table, here the magnitude of specific heat of $c_p$ for dry air is shown with its temperature and you can see that as we move on from−10 °C to 50 °C the change is quite small, it is changing in the third decimal place. That is over this 60 °C temperature the variation is only about ± 0.2%. And therefore, we are going to stick to this particular value of 1.005 kJ/kgK which will be fitting this dry air part as an ideal gas with constant specific heat.

Therefore, the enthalpy for the dry air part, this symbol da we are using to denote dry air. So, dry air will be denoted by *da* and for water vapor with *wv*. So, if we want to calculate the enthalpy for dry air at any particular temperature, we can often calculate this one as:

$$h_{da} = c_p(T - T_{sat})$$

And the common choice for reference temperature is equal to 0 °C and therefore, we can easily write this one as:

$$= c_p T$$

where $T$ is expressed in °C. This is an important term that you should remember. Here writing this $T$ in capital case which represent the absolute temperature. Here we are representing this T as the temperature in Celsius, because our choice of reference temperature is equal to 0 °C. And therefore, the enthalpy for dry air can often be taken as 1.005 multiplied by 3 kJ/kg.

And the change in enthalpy of this dry air,

$$\Delta h_{da} = c_p(\Delta T) = 1.005\ (\Delta T)$$

where ΔT can be represented either Celsius or in Kelvin. But if you want to use the British units it can be represented in fps terms. So the dry air part is very easy to deal with, you can just visualize dry air as an ideal gas just like what we have done in the previous week while we were talking about ideal gases. And here also, we are going to fix this dry air an ideal gas with a constant specific heat which is 1.005 kJ/kgK. And just the way we have calculated enthalpy, similarly we can calculate other parameters also if required. But what about the water vapour part?

Now, if we can deal with water vapour as an ideal gas that you have simplified analysis are quite a bit. And thankfully below this 50 °C temperature range we can actually consider as water vapour to be an ideal gas as well, without incurring too much of error. Because the saturation pressure for water vapour or water at 50 °C is 12.3 kPa. You know that we are talking about water vapour at a temperature below this for this given pressure or at a pressure above this.

For a given temperature it will be the superheated condition. I told wrongly, we are talking about water vapour at this particular pressure and temperature had been at 50 °C or at 50 °C, but at a pressure lower than this, it will be superheated vapour. Now from the property it has been seen that as long as the pressure of water vapour remains below this 12.3 kPa we can assume it to be an ideal gas, with hardly any error. This we will see shortly, because within this zone we can safely use a relation

$$Pv = RT$$

for water vapour as well and that simplifies the analysis quite a bit. We are going to treat this pressure or atmospheric air is a combination of two ideal gases: one is the dry air part and other is a water vapour part. And accordingly, the total pressure can be represented as the summation of partial pressures, the two components one is the dry air part plus the water vapour part.

$$P = P_{da} + P_{wv}$$

So that, total atmospheric pressure is a summation of the partial pressures of dry air and water vapour because we are assuming the dry air part and also the water vapour part as ideal gas. Why? It is not very surprising that the dry air is behaving like an ideal gas, but it may be a bit surprising the water vapour but, that is actually a great relief to us when we do not have to go to the table to calculate the properties of water vapour. We can easily calculate this by assuming that to be an ideal gas. So, both the dry air part and water vapour part follows the ideal gas equation of state. Like if we take a certain volume of atmospheric air often called the moist air. The dry air is without water vapour, when we mix a water vapour with a dry air at this mixture is often called the moist air.

So, if you take a particular quantity of moist air and we measure the corresponding volume in the temperature of the most air, then we can easily apply ideal gas equation of state throughout the entire mixture. Like when you talk about the mixture, then if P refers to the total pressure of the mixture and V is the volume and this should be equal to:

$$PV = n\bar{R}T$$

where this is for the total mixture that is total moist air.

Similarly, for the dry air part we can write:

$$P_{da}V = n_{da}\bar{R}T$$

and similarly, for the water vapour part:

$$P_{wv}V = n_{wv}\bar{R}T$$

So, we are going to treat both of them as ideal gas as long as the water remains in vapour state. Now for water vapor, how to calculate enthalpy? For dry air we have seen here, what about the water vapor part? For the water vapour part also, we can go by route something similar to this or another thing is with the help of the $Ts$ diagram that is shown here. Of course, we are assuming water vapor to be an ideal gas that means its enthalpy should be a function of only temperature. And thankfully that is what we can see here. Several constant enthalpy lines are shown here, these pink lines and in this superheated side below 50 °C, of course that is this particular temperature level, these lines are almost horizontal. That means, these constant enthalpy lines also represent isothermal condition and therefore if we draw an isotherm, which will be horizontal line, in the superheated zone both temperature and enthalpy remains constant along these lines.

And therefore, enthalpy for water vapour on the superheated side say, we want to get the enthalpy for this particular point, while the entropy change along the isotherm or along this constant enthalpy line, but enthalpy does not change and therefore the enthalpy of this particular saturated vapour point can be easily be used for the value of enthalpy along any point in this line.

And hence we are going to take enthalpy for water vapor for a given temperature and low pressure or I should say low value of this partial pressure of water vapour to be equal to as per on notation $h$ corresponding to the temperature.

$$h_{wv}(T, low\ P_{wv}) = h_g(T)$$

I should not equal to this should be almost equal to or nearly equal to:

$$h_{wv}(T, low\ P_{wv}) \approx h_g(T)$$

So, we are going to directly take $h$ for water vapour to be equal to $h_g$ for the given temperature. But the condition is temperature has to be lower than 50 °C which is generally true for air conditioning application. And also, the partial pressure for water vapour has to be low which is also true as we shall be seeing it very shortly. And of course, we can also use the relation similar to the dry air part, that is, generally

$$h_{g,wv}|_{0°\mathrm{C}} = 2500.9\ \mathrm{kJ/kg}.$$

And $c_p$ for water vapour over this entire range can be assumed to be constant over this range of minus −10 to 50 °C it is:

$c_{p,wv} = 1.82$ kJ/kgK

So, one option of taking the enthalpy for water vapour is equal to $h_g$ for the given temperature. The second option is, we can use these values of $c_p$ and $h_g$ at 0 °C very similar to the way you are calculated for dry air. There we shall be writing:

$$h_{wv} = h_g|_{0^0C} + c_{p,wv}(T - 0)$$

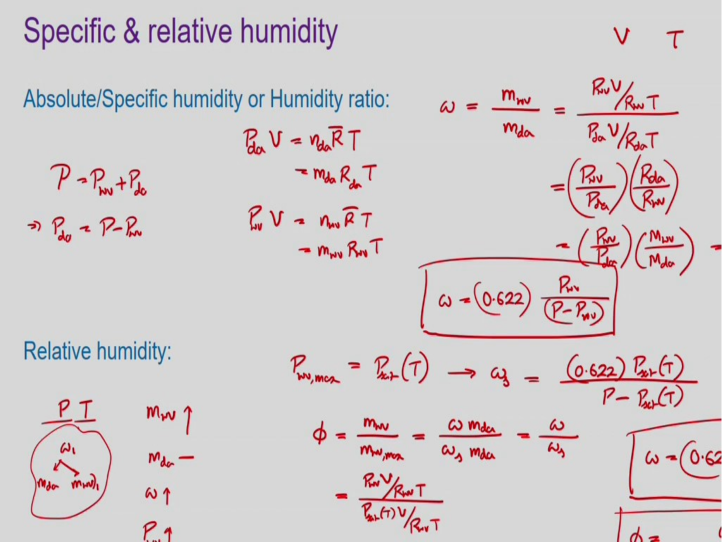
that is

$$= 2500.9 + 1.82\,T$$

$T$ again is Celsius. So, there are two ways to calculate enthalpy for water vapour. One is using the value of $c_p$ and other is to use the table and get the value of $h_g$ corresponding to the temperature because, I repeat with below this 50 °C constant enthalpy lines are also constant temperature lines and therefore enthalpy remains constant over this entire superheated zone hence, we can take the value of $h_g$. If we compare these two approaches using this table, see if we take up say, 20 °C, so if it follows this approach, then this is the value, if we follow this approach then this is the value.

So, there is only 0.1 kJ/kg difference in absolute magnitude. Over this entire range the maximum deviation is 0.6 kJ/kg or − 0.6 kJ/kg, which is extremely small compared to the largest number that we are talking about. And therefore you can go by any one of the approaches. So, we have seen that now moist air is a combination of dry air and water vapour both can be assumed to be ideal gas. And for both of them, we now know how to estimate their enthalpies.

**(Refer Slide Time: 18:39)**



Specific & relative humidity

$V \quad T$

Absolute/Specific humidity or Humidity ratio:

$P = P_{wv} + P_{da}$

$\Rightarrow P_{da} = P - P_{wv}$

$P_{da}V = n_{da}\bar{R}T = m_{da}R_{da}T$

$P_{wv}V = n_{wv}\bar{R}T = m_{wv}R_{wv}T$

$$\omega = \frac{m_{wv}}{m_{da}} = \frac{P_{wv}V/R_{wv}T}{P_{da}V/R_{da}T} = \left(\frac{P_{wv}}{P_{da}}\right)\left(\frac{R_{da}}{R_{wv}}\right) = \left(\frac{P_{wv}}{P_{da}}\right)\left(\frac{M_{wv}}{M_{da}}\right) =$$

$$\boxed{\omega = (0.622)\frac{P_{wv}}{(P - P_{wv})}}$$

Relative humidity:

$P_{wv,max} = P_{sat}(T) \rightarrow \omega_s = \frac{(0.622)P_{sat}(T)}{P - P_{sat}(T)}$

$\underline{P \ T}$

$m_{wv} \uparrow$

$m_{da} -$

$\omega \uparrow$

$P_{wv} \uparrow$

$$\phi = \frac{m_{wv}}{m_{wv,max}} = \frac{\omega\, m_{da}}{\omega_s\, m_{da}} = \frac{\omega}{\omega_s}$$

$$= \frac{P_{wv}V/R_{wv}T}{P_{sat}(T)V/R_{wv}T}$$

$\omega = (0.62$

$\phi =$

Let us now move to two terms which are very common specific and relative humidity. Or atleast the term relative humidity must be well known to all of you because whenever we hear any news bulletin about the local temperature etc. they also keep on mentioning about the relative humidity. And we also know that relative humidity high means, it generally is of very moist situation and may not be a very comfortable situation.

But what is the definition of relative humidity? That we shall be learning here, but before that this term specific humidity or often called the absolute humidity or humidity ratio that needs to be defined. So, we generally use a symbol ω to define the absolute humidity. The definition of absolute humidity is very simple, in a sample of moist air absolute humidity or specific humidity or humidity ratio is just the ratio of the masses, i.e., mass of water vapour divided by mass of dry air:

$$\omega = \frac{m_{wv}}{m_{da}}$$

As I have mentioned that the quantity of dry air generally does not change during air conditioning application, so quite often we represent different properties in terms of per unit mass of dry air. Like we shall shortly be seeing the total enthalpy and a few other parameters are defined in terms of per unit mass of dry air. Very similarly here the mass of water vapour is defined as per unit mass of dry air and that is what we call as the humidity ratio. Now, we know that both dry air and water vapour can be assumed to be ideal gases and we can use the

$$Pv = nRT$$

relation on this. So, for a given sample of volume $V$ and temperature $T$, if we write them I wrote in the previous slide also, but I am repeating a for the dry air part:

$$P_{da}V = n_{da}\bar{R}T$$

Similarly, if we write this as:

$$= m_{da}R_{da}T$$

Similarly,

$$P_{wv}V = n_{wv}\bar{R}T$$

$$= m_{wv}R_{wv}T$$

So, taking the mass of water vapour from here, we have:

$$\omega = \frac{m_{wv}}{m_{da}} = \frac{P_{wv}V/_{R_{wv}T}}{P_{da}V/_{R_{da}T}}$$

Separating out the terms, so we are left with now:

$$= \left(\frac{P_{wv}}{P_{da}}\right)\left(\frac{R_{da}}{R_{wv}}\right)$$

Now R for water vapour is very well-known we can easily convert this relation in terms of molecular weight as well, because we know that for any substance $R$ given as:

$$R = \frac{\bar{R}}{M}$$

So, if we convert that, in terms of partial pressures for water vapour divided by partial pressure for dry air, can be converted into molecular weight of water vapour divided by molecular weight of dry air. The expression for ω now becomes:

$$= \left(\frac{P_{wv}}{P_{da}}\right)\left(\frac{M_{wv}}{M_{da}}\right)$$

Now molecular weight for water vapour we easily know which is actually above 18. How can we calculate the molecular weight for dry air? In the previous week we have learnt if we assume water vapour to be comprising of say, 79% by nitrogen and 21% oxygen on molar basis, then by using the mole fraction and the molecular weight of nitrogen and oxygen individually we can get the apparent molecular weight for this. So, if you put that out then you are going to get this ratio to be equal to 0.622 putting the values of this *m* for dry air and *n* for water vapour multiplied by the ratio of partial pressure for water vapour to partial pressure of dry air and is expressed as follows:

$$= (0.622)\left(\frac{P_{wv}}{P_{da}}\right)$$

Now, we have also seen that as air is a combination of these two, so the total pressure $P$ is equal to:

$$P = P_{wv} + P_{da}$$

Therefore, $P_{da}$, the denominator can be written as:

$$P_{da} = P - P_{wv}$$

So, replacing this we are getting finally ω to be equal to:

$$\omega = (0.622)\,\frac{P_{wv}}{(P - P_{da})}$$

So, some have if you have idea about the partial pressure of the water vapour, we can calculate the humidity ratio or vice versa. If you know the specific humidity, we can calculate the partial pressure of the water vapour from the knowledge of the total pressure or atmospheric pressure. Now here relative humidity, let us say we have certain sample of air, we know the pressure and temperature for this one, we know the total pressure and total temperature.

And at a particular instant of time is specific humidity is $\omega_1$. So, corresponding to this $\omega_1$, we know that it has some mass of dry air and some quantity of water vapour. Now we keep on adding more and more water vapour to this the mass of dry air remains unchanged, but the mass of water vapour keeps on increasing and if is a mass of water vapour keeps on increasing their; it is specific humidity also keeps on increasing. But as specific humidity increases, then initially there will be no change in the total pressure or temperature of the system or actually the pressure and temperature of the system will remain the same. But as the mass of water vapour is increasing whereas the mass of dry air remains the same. Then while ω is increasing, the partial pressure for the water vapour is also increasing.

But the partial pressure corresponding to dry air keeps on decreasing because total pressure and temperature remains the same. And if we keep on increasing the quantity of water vapour of the moisture content of the moist air, then you will reach a certain situation where the moist air cannot take any more water vapour. I repeat we shall finally be reaching a situation where the moist air will not be able to take any more water vapour.

There we call that the water moist air or that atmospheric air has become saturated with the d water vapour. In that condition, another saturated condition, whatever partial pressure of water vapour that we have, let us say we call that should be the maximum partial pressure let us we call this $P_{wv,max}$ that is the maximum partial pressure of the water vapour that we can have.

Now, once we know the pressure and temperature for the sample, total pressure and total temperature. Then how can estimate the maximum value of this one? This maximum value of the partial pressure of water that it can be, that has to be the saturation pressure of water corresponding to the given temperature. That is the maximum pressure it can have because any further increase in pressure will lead to some lead to condensation.

Because, we actually pressurizing the water vapour by continuously adding mass to it increasing the pressure of this one. As we keep on pressurizing, we know that then it will lead to the condensation process. So, the maximum pressure water vapour can have the saturation pressure corresponding to the temperature. The relative humidity given by the symbol $\phi$ is defined as the ratio of the original partial pressure $P_{wv}$ in a given sample divided by this maximum partial pressure, $P_{wv,max}$ it can have at that particular temperature.

$$\phi = \frac{P_{wv}}{P_{wv,max}}$$

Or for a given temperature we can say that $\phi$ is given as:

$$= \frac{P_{wv}}{P_{sat}\,(T)}$$

Now the other way we can write this one is, it can be written as:

$$= \frac{\omega}{\omega_{sat}}$$

So, under this particular condition let us say that the value of specific humidity is $\omega_s$. $\omega_s$ is the maximum value of specific humidity that this sample of moisture can reach. Then how can I get the value of this $\omega_s$? Simply by replacing is partial pressure of water vapour in the previous expression with this maximum value. So, your $\omega_s$ will be equal to:

$$\omega_s = \frac{(0.622)\,P_{sat}\,(T)}{P - P_{sat}\,(T)}$$

Now, relative humidity, $\phi$ is defined as the mass of water vapour that we had in the original sample divided by the maximum mass of water vapour that we can have.

$$\phi = \frac{m_{wv}}{m_{wv,max}}$$

Now using the definition of the specific humidity, we can say write the above equation as:

$$= \frac{\omega m_{da}}{\omega_s m_{da}}$$

The mass of dry air is remaining unchanged, so, this is equal to:

$$= \frac{\omega}{\omega_s}$$

so, this relative humidity is nothing but the ratio of the specific humidity to the maximum possible value of specific humidity which is possible with this sample at a given temperature, that also corresponds to the saturated condition. Now if we represent this relation: the mass of water vapour divided by mass of water vapour maximum, in terms of the $P$ - $v$ - $T$ relationship, we can write it as:

$$= \frac{P_{wv} V / R_{wv} T}{P_{sat\,(T)} V / R_{wv} T}$$

So, it then becomes:

$$= \frac{P_{wv}}{P_{sat}\,(T)}$$

Therefore, $\phi$ can be represented in different possible ways: relative humidity relates to the mass of water vapour present in a given sample divided by the maximum mass of water vapour that sample can hold, or the specific humidity to the maximum possible value of specific humidity, or the ratio of partial pressure of water vapour to the saturation pressure of water vapour at a given temperature.

You can represent in whatever way that is comfortable to you, all will lead to the same result. Now how can you relate these two quantities, $\phi$ and $\omega$? For a given sample let us say our specific humidity is $\omega$ and relative humidity is $\phi$. Then what should be the relation? We know that:

$$\omega = (0.622)\,\frac{P_{wv}}{(P - P_{wv})}$$

So, one possibility is that, replace this $P_{wv}$ using the definition of $\phi$, it should become $\phi$ $P_{sat}$(T). Similarly, in the denominator also it becomes $\phi$ $P_{sat}$(T).

$$\omega = (0.622)\,\frac{P_{sat}(T)}{P - \phi P_{sat}(T)}$$

So, this is one possible relation from the knowledge of relative humidity we can calculate specific humidity this way.

Other possibility is that where we use the definition of $\phi$ and $P_{wv}$. So, let us substitute from the definition of ω here. If you do that way, it is going to be:

$$\phi = \frac{\omega P}{(0.622 + \omega)P_{sat}(T)}$$

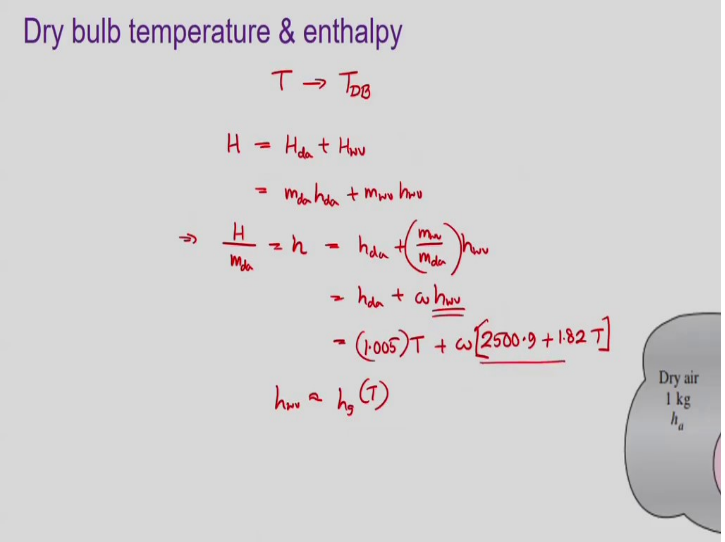
this way we can get the relation between the specific and relative humidities. The relative humidity is generally represented in percentage. It can vary from 0 to 1 or 0 to 100%, because it is just a ratio and the denominator is always higher. So, the numerator can have the maximum value that is equal to the denominator that is why relative humidity can never be greater than one.

Now, for a given temperature, suppose for a given sample the temperature increases. Then what will be the effect on the specific humidity? Remember specific humidity is a ratio of mass. As the temperature is changing, the mass of water vapour and mass of dry air, none of them are changing. Therefore, specific humidity remains the same. What about relative humidity? Now partial pressure for water vapour is the same because the masses are not changing total pressure is also not changing.

But as the temperature is increasing, the saturation pressure for a given temperature that also keeps on increasing. And therefore, relative humidity that keeps on decreasing. Therefore if the temperature of a sample increases, its specific humidity remains constant but relative humidity decreases the reverse is to when the temperature decreases. What will be the effect of pressure? You think about that, I am leaving that to you.

Next, I move to the term called the dry bulb temperature. Dry bulb temperature is nothing but the temperature of the air, the normal temperature that we can measure with thermometer or by any temperature measuring device that we generally called dry bulb temperature. Here the term bulb refers to the bulb of a thermometer, mercury or whatever liquid that fill the thermometer we use. From the bulb of that we use the term dry bulb temperature.

**(Refer Slide Time: 32:59)**



Dry bulb temperature & enthalpy

$T \rightarrow T_{DB}$

$H = H_{da} + H_{wv}$

$= m_{da}h_{da} + m_{wv}h_{wv}$

$\Rightarrow \frac{H}{m_{da}} = h = h_{da} + \left(\frac{m_{wv}}{m_{da}}\right)h_{wv}$

$= h_{da} + \omega \underline{\underline{h_{wv}}}$

$= (1.005)T + \omega\underline{[2500.9 + 1.82T]}$

$h_{wv} \approx h_g(T)$

So, the temperature that we are using quite often this temperature is also written as temperature $T_{DB}$, where *DB* refers to dry bulb. And what about the enthalpy? We are talking about mixture of ideal gases. So, enthalpy for the air will be equal to the enthalpy for the dry air part plus enthalpy for the water vapour part, i.e.,

$$H = H_{da} + H_{wv}$$

$$= m_{da}h_{da} + m_{wv}h_{wv}$$

Now, if we divide everything by the mass of dry air, then we get the specific enthalpy for the moist air and this is represented as per unit mass of dry air.

$$\frac{H}{m_{da}} = h$$

So, here the specific enthalpy for the moisture we are writing in terms of we are not divided by the mass of the total sample rather we are dividing by the mass of the dry air only because the water vapour part may keep on changing but the dry air part generally remains constant. So, the right-hand side will be equal to:

$$= h_{da} + \left(\frac{m_{wv}}{m_{da}}\right)h_{wv}$$

$$= h_{da} + \omega h_{wv}$$

because the bracketed term is nothing but the specific humidity. And we now know how to estimate these values,

$$= (1.005)T + \omega[2500.9 + 1.82T]$$

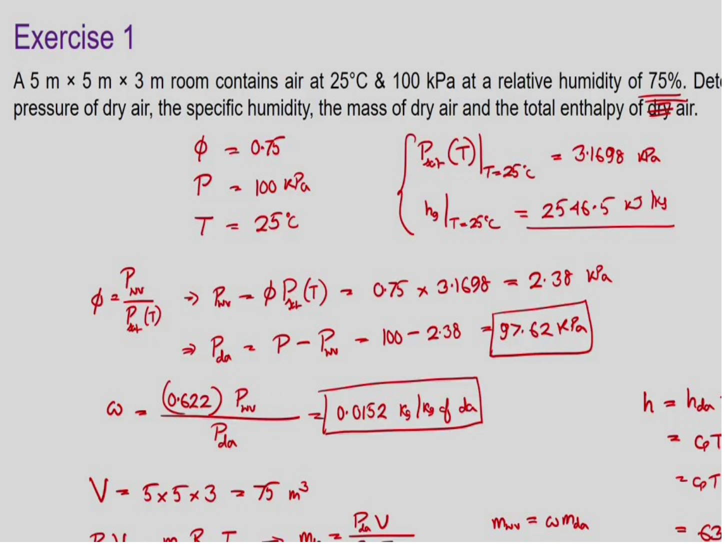
the subscript is not put here, but you can also the subscript *DB* for *T* in the equation. So, this way we can get specific enthalpy of the moist air sample. Remember, this $h_{wv}$, which we are writing in this particular form, we can also write this as:

$$h_{wv} = h_g(T)$$

as we have seen in both of them nearly gives to the same value. So, this is the idea, here the moist air part is $\omega$. Suppose we are taking 1 kg of dry air then they will be $\omega$ kg of moist air and the total mass of the moist air will be (1+ $\omega$) kg. So, we are having this as the total enthalpy or I should say the specific enthalpy for the mixture.

Just make a note of the unit that we are using here kJ/kg of dry air. It is important to mention this dry air part in the suffix or in the denominator. Because we are defining specific enthalpy not in terms of per unit mass of the moist air rather per unit mass of the for dry air only.

**(Refer Slide Time: 35:40)**



Exercise 1

A 5 m × 5 m × 3 m room contains air at 25°C & 100 kPa at a relative humidity of 75%. Det
pressure of dry air, the specific humidity, the mass of dry air and the total enthalpy of ~~dry~~ air.

$\phi = 0.75$

$P = 100 \text{ kPa}$

$T = 25°C$

$P_{sat}(T)\big|_{T=25°C} = 3.1698 \text{ kPa}$

$h_g\big|_{T=25°C} = 2546.5 \text{ kJ/kg}$

$\phi = \frac{P_{wv}}{P_{sat}(T)} \Rightarrow P_{wv} = \phi P_{sat}(T) = 0.75 \times 3.1698 = 2.38 \text{ kPa}$

$\Rightarrow P_{da} = P - P_{wv} = 100 - 2.38 = \boxed{97.62 \text{ kPa}}$

$\omega = \frac{(0.622) P_{wv}}{P_{da}} = \boxed{0.0152 \text{ kg/kg of da}}$

$V = 5 \times 5 \times 3 = 75 \text{ m}^3$

$m_{wv} = \omega m_{da}$

$h = h_{da}$

$= c_p T$

$= c_p T$

$= 63$

Let us quickly solve one problem, just we see the application of this. Here we are talking about a room, the volume of the room is given it is at maintained at a temperature 25 °C and 100 kPa and its relative humidity 75%. So, we have:

$\phi = 0.75$

P = 100 kPa

T = 25 °C.

I repeat generally you use as symbol capital $T$ to denote absolute temperature but only when you are talking about air conditioning application that is gas and water vapour mixture, then generally we keep on using capital $T$ but define everything in Celsius. Now have to define the partial pressure of the dry air, the specific humidity, mass of dry air and the total enthalpy of dry air.

So, we need to know the properties at this given temperature 25 °C. So I have noted down the properties, saturation pressure for this given temperature where T is equal to 25 °C is taken from the saturation table.

$$P_{sat}\,(T)|_{T=25^0C} = 3.1698\,kPa$$

$h_g$ for water at this temperature of T equal to 25 °C is:

$$h_g|_{T=25^0C} = 2546.5\,kJ/kg$$

these values are taken from the table corresponding to the 25 °C.

So, first we have to get the partial pressure of dry air. Then what is the partial pressure for water vapour? We know the relative humidity, so use the definition. As per our definition relative humidity is given as:

$$\phi = \frac{P_{wv}}{P_{sat}\,(T)}$$

That is,

$$P_{wv} = \phi P_{sat}\,(T) = 0.75 \times 3.1698 = 2.38\,kPa$$

Hence partial pressure for dry air will be equal to:

$$P_{da} = P - P_{wv} = 100 - 2.38 = 97.62\,kPa$$

You can see the partial pressure for water vapour is such a small fraction, it is just about 2.3 % of the total pressure. But still it can have a huge impact on the comfort level. So, the first answer we have got. Now you need to get the specific humidity, we now know the relation for specific humidity. So, we can calculate this one to be equal to:

$$\omega = (0.622)\left(\frac{P_{wv}}{P_{da}}\right) = 0.0152\,kg/kg\ of\ da$$

So, this is the specific humidity or humidity ratio.

Now, to calculate the mass of dry air, to get the mass of the dry air, we need to know the total volume of the sample. It is given as:

$$V = 5 \times 5 \times 5 = 75m^3$$

which is the total volume of the room. And as you talk about a mixture of two ideal gases therefore each of the gases occupying the entire volume, both the dry air part and the water vapour part.

So, if we apply the ideal gas equation of state on the dry air part that we can write:

$$P_{da}V = m_{da}R_{da}T$$

So, mass of dry air then should be equal to:

$$m_{da} = \frac{P_{da}V}{R_{da}T}$$

$$= \frac{(97.62 \times 10^3) \times 75}{(287) \times (25 + 273)}$$

$$= 85.61\ kg$$

If you want to calculate mass of water vapour, how can we calculate that? You now know $\omega$, you know mass of dry air, so it will be:

$$m_{wv} = \omega m_{da}$$

$$= 0.0152 \times 85.61 = 1.3\ kg$$

So, this is the third result that you looking for. And finally, you have to get the total enthalpy of air sample. Now, we know that specific enthalpy for the sample is defined as:

$$h = h_{da} + \omega h_{wv}$$

$$= C_pT + \omega[h_g(T)]$$

$$= C_pT + \omega[2500.9 + 1.82\ \ T)]$$

putting the value for T as 25 $^0$C here and check what values you are getting. I think you are going to get something like 2546.4, its almost same.

So, putting the values of $c_p$ for air as 1.005 and $T$ as 25 °C we are going to get $h$ to be equal to:

$$= 63.8 \text{ kJ/kg of dry air}$$

So then total enthalpy will be equal to:

$$H = m_{da}\, h$$

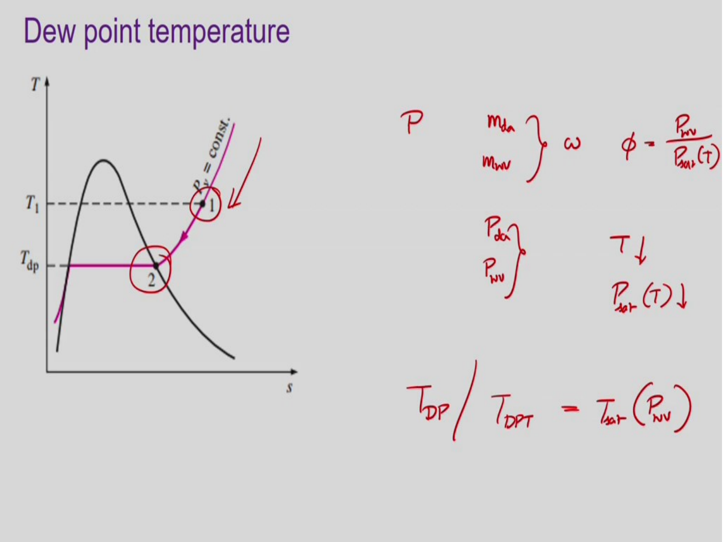
$$= 5461.918 \text{ kJ}$$

is the total enthalpy for the sample. And if you are interested to get the total enthalpy for the dry air part, as I mistakenly typed, then that also you can calculate as:

$$H_{da} = m_{da}\ (c_pT)$$

Similarly, you can also calculate the enthalpy content of the water vapour part. So, we have now made use of the concept of relative and specific humidities. Let us move to another concept known as the Dew point temperature.

**(Refer Slide Time: 43:13)**



Dew point temperature

$P$

$\left.\begin{matrix} m_{da} \\ m_{wv} \end{matrix}\right\} \omega \qquad \phi = \frac{P_{wv}}{P_{sat}(T)}$

$\left.\begin{matrix} P_{da} \\ P_{wv} \end{matrix}\right\}$

$T \downarrow$

$P_{sat}(T) \downarrow$

$T_{DP} / T_{DPT} = T_{sat}(P_{wv})$

Let us say we have a fixed quantity of moist air at a given pressure and temperature. Now if the total pressure of the system, let us say as P, mass of dry air and mass of water vapour these are given. If these two are given, then from this we know the value of $\omega$ and also if we know the $\omega$ at least to start with, you also know the value of $\phi$. Because $\phi$ will be equal to:

$$\phi = \frac{P_{wv}}{P_{sat}\,(T)}$$

Now, we are not going to change the mass. And as we are not going to change the mass and also the total pressure remaining constant, therefore the partial pressure for the dry air part and partial pressure for the water vapour part also remains the same. So, I repeat we have a sample of a fixed quantity of moist air that we have which contains some fixed quantity of dry air and water vapour.

We are maintaining the pressure and also the masses of both constituent as the same. And therefore, it is a specific humidity and also the partial pressure for both the components remains constant. Now we start lowering the temperature. So, this is the point where we are initially present this the temperature. So initially the substance is actually superheated corresponding to its water vapour.

This graph we are plotting, this *Ts* diagram only for the water vapour part. So, for the given pressure, that is given partial pressure of the water vapour and for the given temperature it is actually superheated. Now maintaining system pressure and the masses the same, we just keep on lowering the temperature. As the temperature is getting lowered it will follow the isotherm just shown here something like this.

So, initial temperature say is $T_1$ like shown here and here we have plotted the isotherm, which corresponds to is $P_{wv}$ water vapour. As it keeps on decreasing it is becoming increasingly closer to the saturated vapour line and then at certain temperature, it will reach this point number 2 where, it actually reaches the saturated vapour point. Now as we are moving from point 1 to point 2 what is happening to the specific and relative humidities? Specific humidity remains constant because the masses are not changing, so specific humidity is a constant. What about the relative humidity? During this process as we are moving from 1 to 2 the temperature is decreasing. Therefore, the saturation pressure corresponding the temperature is also decreasing.

But the partial pressure for water vapour remains constant and therefore your relative humidity, just look at the expression here, the numerator is constant, but the denominator is decreasing. So, the relative humidity keeps on increasing and while we read this point number 2 the relative humidity becomes 100% that is a mixture becomes saturated by whatever moisture originally it had by that only.

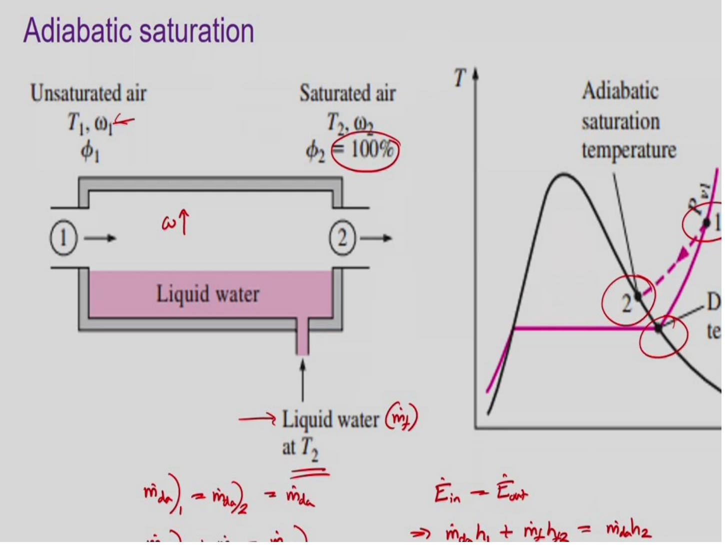
We have just lowered the temperature and by continuously lowering the temperature we have reach the point where the mixture of the moist air is getting saturated only by the water vapour content that it originally had. This particular temperature, point $T_2$ is known as the Dew point temperature. I repeat this temperature is known as Dew point temperature, $T_{DP}$. We can write it as $T_{DP}$ or we can also write $T_{DPT}$, whatever you would like to represent. This Dew point temperature therefore, how can you calculate this if you know the partial pressure for water vapour? This has to be the saturation temperature corresponding the partial pressure for water vapour, and partial pressure for water vapour we can calculate from the expression for this relative humidity that we originally know. So, for a given relative humidity we can easily calculate the value of the Dew point temperature. Now, what is the physical significance of it? Just think if we lower the temperature any further then what will happen? If we lower the temperature any further, then t at even lower temperature, it will not be able to hold that much amount of moisture. So, some moisture will get separated from the moist air sample and it will condense, it will get converted to liquid water and it will get deposited. And you definitely have seen the formation of dew, the formation of mist and that is just relevant to this. Just take a say a cold can of some soft drinks from the refrigerator, immediately you will find, take outside and immediately you will find that lots of moisture has got deposit on the outer wall of that can.

That is happening because the temperature of the can surface is lower than the Dew point temperature of the surrounding air because it was inside the refrigerator so it is at a very low temperature and therefore the moisture which was their present in the surrounding air that gets condensed and gets deposited on the surface of that can. So, the concept of Dew point temperature is very important from air conditioning application as we shall be seeing in the next lecture.

Next, we move to something known as adiabatic saturation. Now the idea of Dew point temperature is very important as I have mentioned. But the next question is, how can we calculate the value of the Dew point temperature, one option is to measure the partial pressure for water vapour because if you know the partial pressure for water vapour, then from the temperature we can calculate the saturation temperature.

And from that saturation pressure rather and then from that ratio we can calculate the relative humidity. And also using that partial pressure of water vapour we can calculate the,

**(Refer Slide Time: 49:07)**



Adiabatic saturation

$\dot{m}_{da})_1 = \dot{m}_{da})_2 = \dot{m}_{da}$

$\dot{E}_{in} = \dot{E}_{out}$

$\Rightarrow \dot{m}_{da} h_1 + \dot{m}_f h_{f2} = \dot{m}_{da} h_2$

Dew point temperature directly, but that may not be the easiest of procedures. For that purpose, we can often go for this particular arrangement that is shown here which is known as a set up for getting adiabatic saturation. Here a quantity of air with initial temperature $T_1$, specific humidity $\omega_1$ and relative humidity $\phi_1$ is allowed to enter a long adiabatic duct just like shown here. In this duct we are having liquid water stored up to certain level. If the air is initially unsaturated then when it flows over the water surface it will keep on picking up water vapour from this pool of water. And as it picks up liquid water, then its $\omega$ keeps on increasing. However, this water that is stored as shown by pink color, that is stored in the liquid condition.

So, if water molecules have to go to the air side, then it has to get converted to vapour. And therefore, it needs that latent heat of vaporization. That latent heat of vaporization, as this duct is ideally insulated, it is perfectly adiabatic then this a latent heat vaporization will be from the body of this air only and also from the liquid water. So, the temperature of air and liquid water both keeps on decreasing.

And finally, if the channel is sufficiently long, we can expect that at the outlet condition we shall be getting a 100 % saturated mixture. That is, it will come out with relative humidity of 100 % and $\omega_2$ will be greater than $\omega_1$. And $T_2$ will be lower than $T_1$ because both water and air has lost energy in order to supply the latent heat of vaporization to the water vapour.

And therefore, the temperature will fall, specific humidity will increase, while the mass of dry air remains the same. And relative humidity finally reaches 100 %. Now, of course some quantity of water is getting lost from the liquid side, so we need to make up for that liquid water at the same temperature $T_2$. Now the temperature $T_2$ at which it is coming out this temperature is often known as the adiabatic saturation temperature.

And if you represent the process on a $Ts$ plane, this is the point from we are starting. Remember we are not following any constant temperature or constant pressure process because temperature is decreasing whereas, the pressure for water vapour will increase as a more and more mass of water is getting added to this, so we shall finally be reaching a point like this.

This is your Dew point temperature and this point number 2 that we are reaching that is called the adiabatic saturation temperature. Using this adiabatic saturation temperature $T_2$ we can actually get a measure of the value of this $\omega_1$, this entire apparatus our object used to get the value of this $\omega_1$ and that we can obtain from the measured value of the initial temperature

$T_1$ and finally obtain the adiabatic saturation temperature $T_2$. From the Dew point temperature also, we can get the value of $\omega_1$, but that is more difficult to get and therefore we can go for this particular element which is called the adiabatic saturation temperature. Now, how can we get the value of $\omega_1$ here? Remember you can also measure $\omega_2$, but generally that is not required because if we know $T_2$ we know $\phi_2$ is equal to 100 % so you can easily get $\omega_2$. Now, we have to get $\omega_1$, if we perform a mass balance for the dry air part. So,

$$\dot{m}_{da})_1 = \dot{m}_{da})_2 = \dot{m}_{da}$$

because there is no change in the dry air. Now we perform mass balance for water vapour side, so,

$$\dot{m}_{wv})_1 + \dot{m}_f = \dot{m}_{wv})_2$$

Now using the concept of $\omega_1$ and $\omega_2$ we can say that,

$$\omega_1 \dot{m}_{da} + \dot{m}_f = \omega_2 \dot{m}_{da}$$

$$\dot{m}_f = (\omega_2 - \omega_1)\dot{m}_{da}$$

Now you have to confirm from energy balance, as there is no other source of energy and this chamber is insulated, we can write:

$$\dot{E}_{in} = \dot{E}_{out}$$

Now, how energy much we are adding? The amount of energy we are giving initially is:

$$\dot{m}_{da} h_1 + \dot{m}_f h_{f2}$$

it should be equal to:

$$= \dot{m}_{da} h_2$$

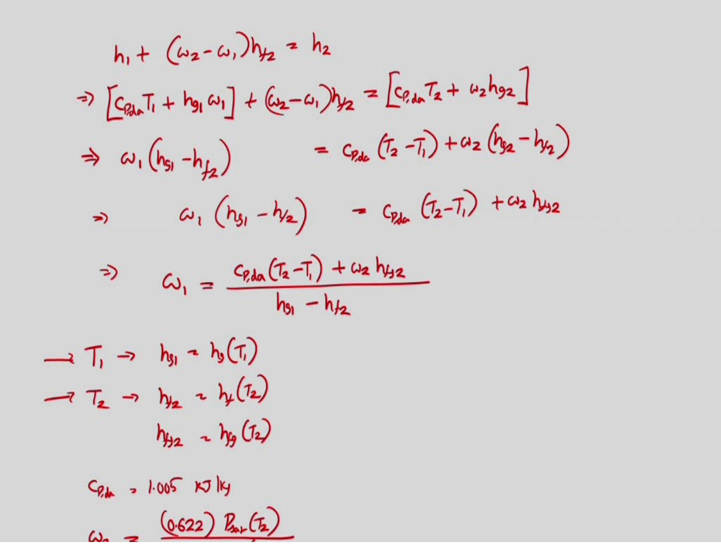
let us now divide everything by $\dot{m}_{da}$. So, we have,

$$h_1 + \frac{(\omega_2 - \omega_1)\dot{m}_{da}}{\dot{m}_{da}} h_{f2} = h_2$$

separating that out removing $\dot{m}_{da}$, we have,

$$h_1 + (\omega_2 - \omega_1) h_{f2} = h_2$$

**(Refer Slide Time: 55:24)**



$$h_1 + (\omega_2 - \omega_1) h_{f2} = h_2$$

$$\Rightarrow \left[C_{p,da} T_1 + h_{g1}\omega_1\right] + (\omega_2 - \omega_1) h_{f2} = \left[C_{p,da} T_2 + \omega_2 h_{g2}\right]$$

$$\Rightarrow \omega_1 (h_{g1} - h_{f2}) = C_{p,da} (T_2 - T_1) + \omega_2 (h_{g2} - h_{f2})$$

$$\Rightarrow \omega_1 (h_{g1} - h_{f2}) = C_{p,da} (T_2 - T_1) + \omega_2 h_{fg2}$$

$$\Rightarrow \omega_1 = \frac{C_{p,da}(T_2 - T_1) + \omega_2 h_{fg2}}{h_{g1} - h_{f2}}$$

$\rightarrow T_1 \rightarrow h_{g1} = h_g(T_1)$

$\rightarrow T_2 \rightarrow h_{f2} = h_f(T_2)$

$h_{fg2} = h_{fg}(T_2)$

$C_{p,da} = 1.005$ kJ/kg

$\omega_2 = \frac{(0.622)\, P_{sat}(T_2)}{\;}$

The above equation can be written as:

$$\left[C_{p,da} T_1 + h_{g1}\omega_1\right] + (\omega_2 - \omega_1) h_{f2} = \left[C_{p,da} T_2 + h_{g2}\omega_2\right]$$

So, if we separate out now the $\omega_1$ part, so we have,

$$\omega_1 (h_{g1} - h_{f2}) = C_{p,da} (T_2 - T_1) + \omega_2 (h_{g2} - h_{f2})$$

So, taking $\omega_1$ outside and if we combine what is inside the bracket, this we have:

$$\omega_1 (h_{g1} - h_{f2}) = C_{p,da} (T_2 - T_1) + \omega_2 h_{fg2}$$

which gives a final value of $\omega_1$ to be equal to:

$$\omega_1 = \frac{C_{p,da}(T_2 - T_1) + \omega_2 h_{fg2}}{h_{g1} - h_{f2}}$$

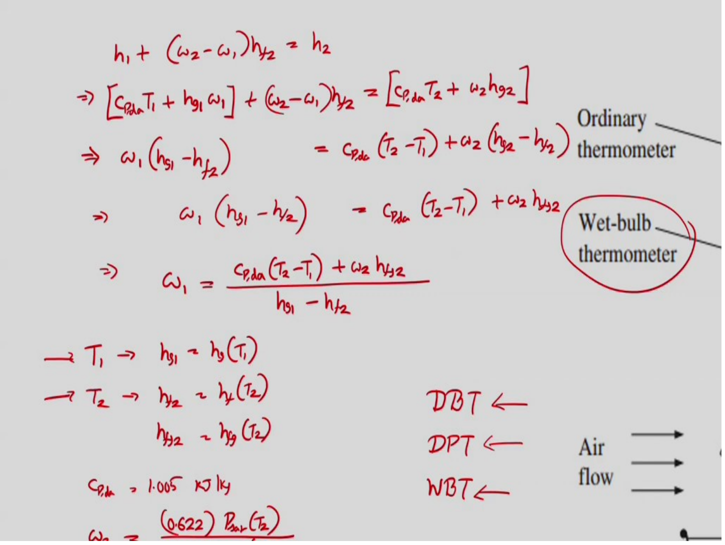
*Cp* for dry air which is nothing but 1.005 kJ/kg, the change in temperature $T_1$ and $T_2$, both are known quantities. Now what are parameters that we have to measure? We have to measure $T_1$ the initial temperature and once we know $T_1$. Then your $h_{g1}$ is hg corresponding to this $T_1$. We have to measure $T_2$, the final temperature and once you measure final temperature, then, $h_{f2}$ is $h_f$ corresponding to this $T_2$ and $h_{fg2}$ is $h_{fg}$ corresponding to $T_2$, so we know the properties $C_p$ for dry air is 1.005 kJ/kg we know that. But what about $\omega_2$, how we can get $\omega_2$ ? Remember $\omega_2$ response to saturated air that is the maximum specific humidity it can have at this temperature $T_2$.

So, $\omega_2$ is:

$$\omega_2 = (0.622)\frac{P_{sat}(T)}{P - P_{sat}(T)} \quad as\ \phi = 1$$

$P_{sat}$ corresponding $T_2$ that also we can get so have just have to measure the to temperatures $T_1$ and $T_2$. The $T_1$ is the initial temperature of the sample, $T_2$ is the final temperature once it comes out after becoming saturated and under the adiabatic saturation temperature basically. And then by getting certain property values corresponding to the temperature $T_1$ and $T_2$, we are getting the measure of initial specific humidity, i.e., $\omega_1$. So, this is a very interesting arrangement this adiabatic saturation condition by which we can easily measured the specific humidity and once we know specific humidity, we can calculate anything. We can calculate relative humidity, we calculate the partial pressure of water vapour, we can calculate enthalpy and also the Dew point temperature. But generally, we need to provide a very long duct and the sufficient amount of time to get this process done, also getting ideal insulated condition perfectly adiabatic process may not be very practicable. So quite often we go for a much stringer arrangement. We take a thermometer and we cover the bulb of the thermometer by a piece of cotton or a wick and the arrangement is such a way that the wick is partially immersed into pool of liquid water so that it always remains saturated with water. Then air or whatever medium for which you want to measure the temperature, it is allowed to flow through and it will pick up certain amount of moisture from this as it passes over the wick.

**(Refer Slide Time: 1:00:19)**



$$h_1 + (\omega_2 - \omega_1)h_{f2} = h_2$$

$$\Rightarrow [c_{P,da}T_1 + h_{g1}\omega_1] + (\omega_2 - \omega_1)h_{f2} = [c_{P,da}T_2 + \omega_2 h_{g2}]$$

$$\Rightarrow \omega_1(h_{g1} - h_{f2}) = c_{P,da}(T_2 - T_1) + \omega_2(h_{g2} - h_{f2})$$

$$\Rightarrow \omega_1(h_{g1} - h_{f2}) = c_{P,da}(T_2 - T_1) + \omega_2 h_{fg2}$$

$$\Rightarrow \omega_1 = \frac{c_{P,da}(T_2 - T_1) + \omega_2 h_{fg2}}{h_{g1} - h_{f2}}$$

$$\rightarrow T_1 \rightarrow h_{g1} = h_g(T_1)$$

$$\rightarrow T_2 \rightarrow h_{f2} = h_f(T_2)$$

$$h_{fg2} = h_{fg}(T_2)$$

$$c_{P,da} = 1.005 \text{ KJ/kg}$$

$$\omega_2 = \frac{(0.622)\,P_{sat}(T_2)}{}$$

DBT ←

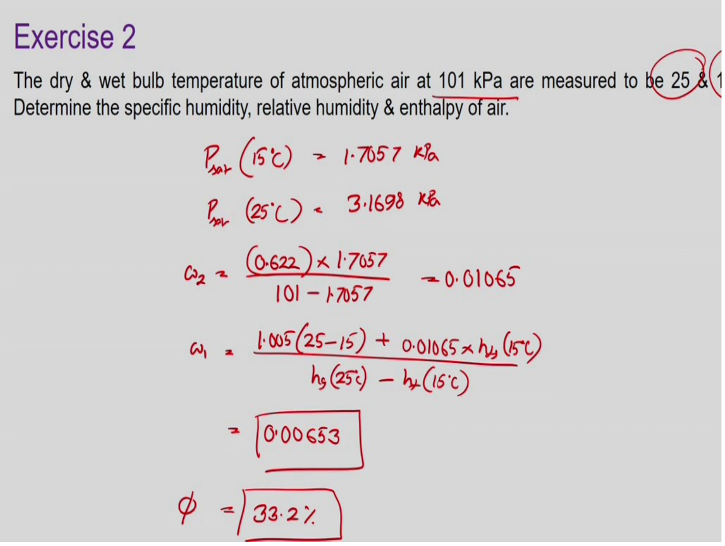
DPT ←

WBT ←

We can expect to be saturated and once it picks up the water vapour from the wick the corresponding latent heat has to be provided from the bulb of the thermometer. And hence whatever temperature we get that we call the wet bulb temperature. This wet bulb temperature practically, may not be exactly equal to adiabatic saturation temperature but for most of the practical purposes we take this wet bulb temperature to be equal to the temperature for adiabatic saturation. So, we know that there are three temperatures that we are talking about, one is the dry bulb temperature, one is the Dew point temperature and final is the wet bulb temperature. These are the three temperatures that we will commonly keep on using in practice. The dry bulb temperature which is the ordinary temperature only which you can measure using any temperature measuring device.

For measuring wet bulb temperature, we have to get an arrangement something like this, the bulb of thermometer covered by a wet wick and the wet and the wick also has to be in contacted liquid water always and the Dew point temperature refers to the temperature at which the moist air sample becomes saturated by its own moisture content.

**(Refer Slide Time: 1:01:54)**



Exercise 2

The dry & wet bulb temperature of atmospheric air at 101 kPa are measured to be 25 &
Determine the specific humidity, relative humidity & enthalpy of air.

$$P_{sat}(15^\circ C) = 1.7057 \text{ kPa}$$

$$P_{sat}(25^\circ C) = 3.1698 \text{ kPa}$$

$$\omega_2 = \frac{(0.622) \times 1.7057}{101 - 1.7057} = 0.01065$$

$$\omega_1 = \frac{1.005(25-15) + 0.01065 \times h_{fg}(15^\circ C)}{h_g(25^\circ C) - h_f(15^\circ C)}$$

$$= \boxed{0.00653}$$

$$\phi = \boxed{33.2\%}$$

So, to finish with, I have a very small numerical example where I shall will be using the concept of both dry and wet bulb temperature. So, we are having atmospheric air at this pressure of 101 kPa and the dry bulb temperature is 25 °C and wet bulb temperature is 15 °C. So, you have to measure specific and relative humidities and the enthalpy of the air. So, as we know the two temperatures, the saturation pressure corresponding to 15 °C is 1.7057 kPa and corresponding to 25 °C it is 3.1698 kPa. These two properties we have taken from the table. And once we have this, we basically can have everything. Because we know that,

$$\omega_2 = (0.622)\frac{P_{sat}(T_2)}{P - P_{sat}(T_2)}$$

$T_2$ is the wet bulb temperature.

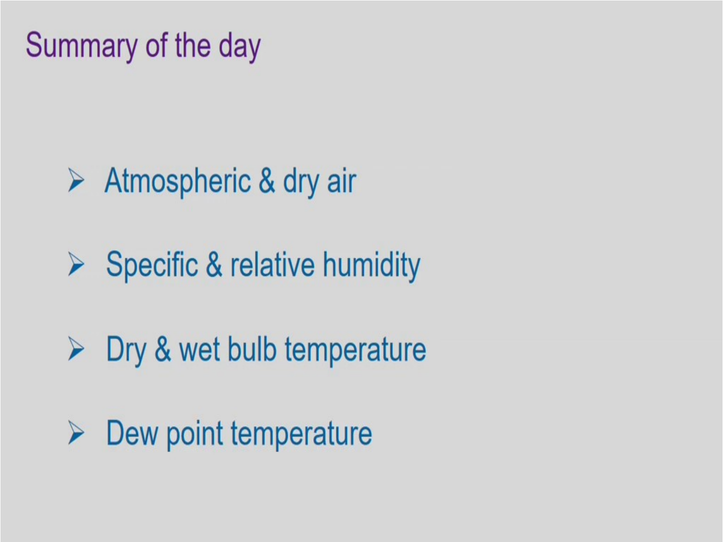
$$\omega_2 = \frac{0.622 \times 1.7057}{101 - 1.7057} = 0.01065$$

So, you know $\omega_2$ so, $\omega_1$ we can calculate just like you have calculated from the formula here. So, we have $C_p$ for here to be equal to 1.005 into change in temperature $T_1$ is 25 °C, $T_2$ is 15 °C. And if we go back $\omega_2$ is 0.01065. Hence using the values $\omega_1$ can be calculated as:

$$\omega_1 = \frac{1.005(25 - 15) + 0.01065 \times h_{fg\,(15^0C)}}{h_{g\,(25^0C)} - h_{f\,(15^0C)}} = 0.00653$$

Then how to calculate $\phi$ from there, we know the relation between $\phi$ and $\omega$. There are several ways you can find from this just check it out. Your $\phi$ will be something like 33.2% and once we know this you also know how to calculate the total enthalpy or at least the specific enthalpy for this mixture. Try to calculate this one.

**(Refer Slide Time: 1:04:28)**



Summary of the day

- Atmospheric & dry air
- Specific & relative humidity
- Dry & wet bulb temperature
- Dew point temperature

So, that takes us to the end of our discussion for the day, where we have talked about the atmospheric and dry air ,the concept of dry air and moist air, concept of specific and relative humidities, dry bulb and wet bulb temperatures, Dew point temperatures and finally we have talked about the adiabatic saturation, which is also associated with this concept of wet bulb temperature. Please rehearse this concept carefully because in the next lecture I am going to talk about something known as the psychrometric chart which allows us to calculate or get the values of different parameters which we have defined here directly, without doing any kind of calculation. Of course, we can get all the parameters by calculation but you can also get them directly from the psychrometric chart. And then we shall be trying to plot a few air-conditioning processes and the psychrometric chart to get into more detailed about air conditioner calculations. Thank you very much.