Engineering Thermodynamics
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Lecture - 47
Gas-Vapour Mixtures: Psychrometry. Moist air properties

This is the second module on gas fluid mixtures and we will look at a particular subclass of mixtures of ideal gases or real gases, which is listed here as gas vapour mixtures. Its particular application is in psychometry which is the study of heating, cooling, humidification, dehumidification of air to achieve certain thermal comfort. So, us what we will be doing in this part of the study is to look at three general aspects.

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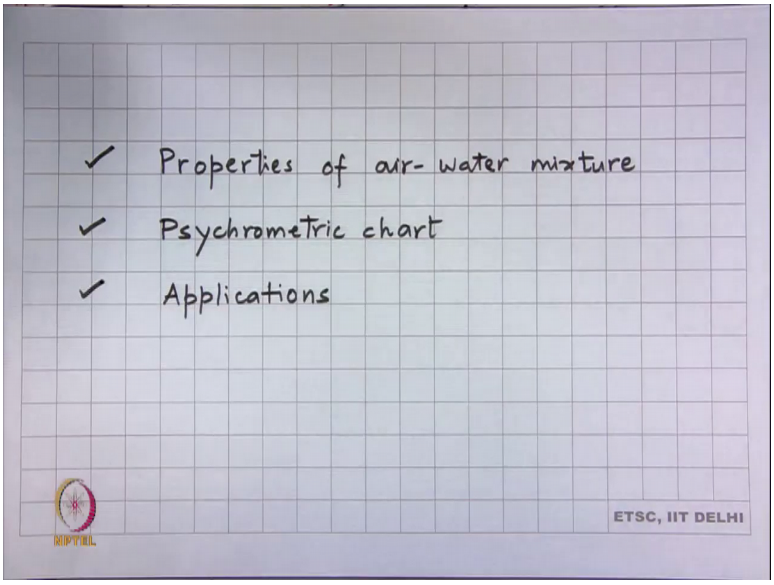

✓ Properties of air-water mixture
✓ Psychrometric chart
✓ Applications

First we will study the properties of a air water mixture and we see how which properties are there and how we specify them. We will follow this with study of the way the properties are plotted which is the psychometric chart. And then we will look at some applications.

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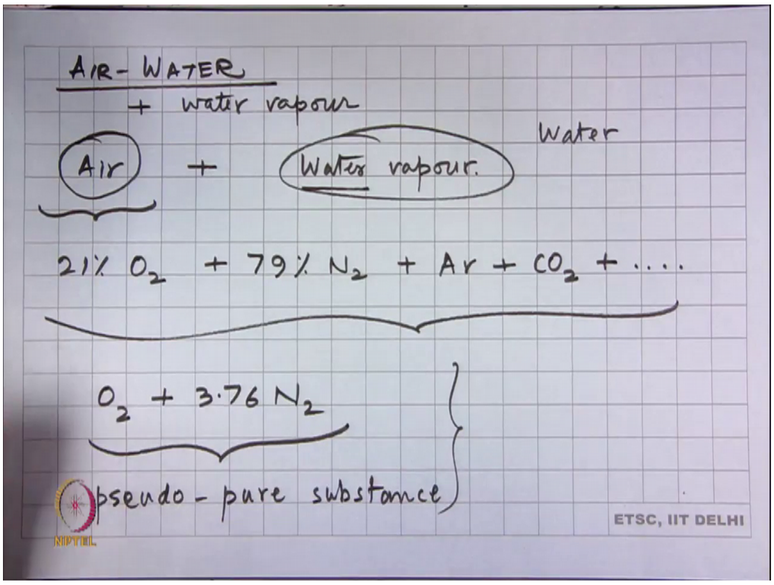

AIR-WATER

+ water vapour

$\underbrace{\text{Air}}$ + Water vapour

Water

$\underbrace{21\%\ O_2 + 79\%\ N_2 + Ar + CO_2 + \ldots}$

$\underbrace{O_2 + 3.76\ N_2}$

pseudo-pure substance

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So, to begin with we look at what is an air water mixture. Technically water is the name of the pure substance, but what we are looking at is basically air and a mixture of water vapour. So, this is the air that we live in we breath. So, we have two components coming up here, one what you have called as air and the second thing is water vapour. When we looked at these mixtures, we recognize that air is a mixture of 21 percent by volume oxygen, 79; approximately 79 percent by volume nitrogen and small amounts of argon, carbon dioxide and some other gases.

So, one thing we did in modelling air was to say that we will make it as a binary mixture as O 2 plus 3.76 N 2. So, this level of detailing is required say when we look at reacting systems when you ask the question how does the substance burn in air.

But as we also saw there are many applications where we really do not need to know what the oxygen and the nitrogen are doing. We considered this mixture as some sort of a pseudo pure substance, which means that we are ignoring that there are two different types of molecules in air, we homogenize them and say look forget these two we will have air only as one particular type of a molecule whatever it may be. And we will assign properties to it based on what we see as the properties of this mixture. So, this is what got us last time.

And now we will treat this as what we are calling here as air. Water or water vapour is nothing but water as the pure substance that has been studied in the earlier modules in thermodynamics; its properties are exactly will be taking from there only. We are calling it water vapour because we are looking at a vapour phase of water, mixing with air.

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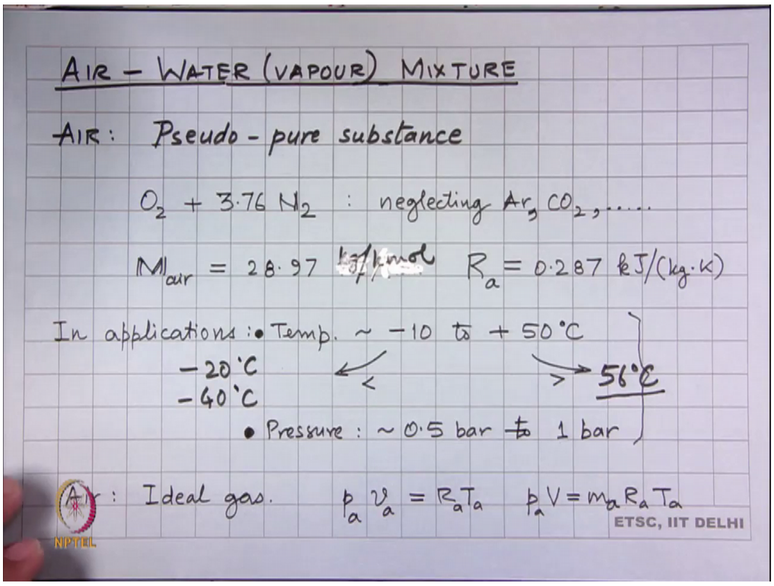

AIR – WATER (VAPOUR) MIXTURE

AIR : Pseudo - pure substance

$O_2 + 3.76\ N_2$: neglecting Ar, CO_2, ...

$M_{air} = 28.97$ kg/kmol $\quad R_a = 0.287$ kJ/(kg·K)

In applications : • Temp. ~ −10 to + 50 °C

−20 °C $\;<\;$ $\;>\;$ 56 °C

−40 °C

• Pressure : ~ 0.5 bar to 1 bar

Air : Ideal gas. $\quad p_a v_a = R_a T_a \quad p_a V = m_a R_a T_a$

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So, here is what we end doing. Having decided that air is O 2 plus 3.76 N 2 with a start assigning properties to it which we will require in our study. And the first one is the molecular mass molar mass 28.97 kg per kilo mole. So, we are calling it M air and this is the gas constant for air which is 0.287 kilo joules per kg per Kelvin. So, now, we have got back our binary mixture of air as one component and water vapour as the second component.

Now in the study of psychrometry, the applications are such that we are working with temperatures typically minus 10 to plus 50 degree Celsius, but that is not to say that this is the only thing of interest and that thermal comfort is the only one that we are interested in. There are situations where temperatures could be much below 10 degree Celsius. For examples on the Siachen Glaciers temperatures of minus 20, minus 40 degree Celsius are not in common.

So, the question is that if we have to heat that air how can we know the properties of that air and then predict how much is the heat release rate that is needed. At the other end, temperatures in excess of 50 degree Celsius are a typical in many parts of India 55, 56, 58 degree Celsius are not in common in the Rajasthan desert and in some parts of Telangana.

So, we also have to worry about these extremes, and there would be some industrial applications where the temperature should go even beyond this say 80 degrees, 90 degree Celsius. The procedure and the concepts in the principles that we will learn here are by and large good for most of that (Refer Time: 07:00) In applications, we will also assumed this was the temperature variation that we come across.

The pressure variation that we will come across is like 0.5 bar to 1 bar. So, 0.5 bar is like the pressure at about 5000 meter elevation up in the Himalaya say; 1 bar is what you would see normally around sea level or in most cases. So, what we do is this is a these are the conditions under which I will have to study the mixture of air and water vapour.

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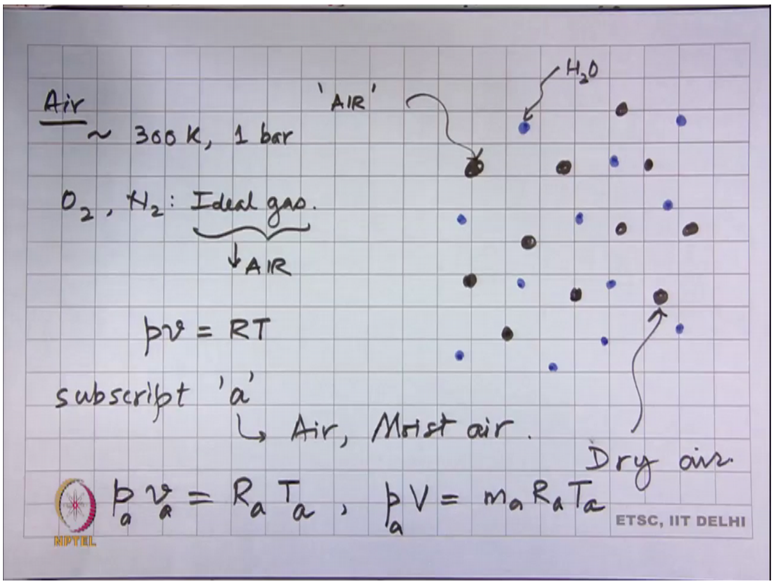

Air

~ 300 K, 1 bar

O_2, H_2 : $\underbrace{\text{Ideal gas}}_{\downarrow \text{AIR}}$.

$pv = RT$

subscript 'a'

↳ Air, Moist air.

$p_a v_a = R_a T_a$, $p_a V = m_a R_a T_a$

So, here is what one can draw is that we make a system where these are the molecules of air, and interspersed within that or water. So, what we are saying is that this is the pseudo pure substance called air, air molecule. And this of course, there is no problem with this; this is a H 2 O.

So, now let us look at what is one of these are doing, and see if we can make life a little more simpler then. If you look at air and look at these temperatures which are of the order of 300 k and pressures of 1 bar, then we realize that both O 2 and N 2, they behave like ideal gases. And so, it is reasonably good extension of this to the fact that air which we have now made into a pseudo pure substance, so with model air also as ideal gas behaviour.

In doing so life becomes very easy because the equation of state for air is very simple and elegant which tells you that pv is equal to RT. Now, because we have a mixture here, we need to be clear at every time throughout this discussion is to which is the substance whose properties we are dealing with. Nearly writing p and v and R and T does not tell us is it the big property of this mixture, is it the property of the air or is it the property of the H 2 O.

So, we will use some more variations on this and we will use the subscript a to denote ambient air or moist air. So, a means this is ambient air or moist air. And this air which is inside this so, this whole thing is moist air. And this thing which is here this we will find now call as dry air. So, if you look at air in there is a mixture equation of state becomes pa va is equal to R, which is the gas constant for air multiplied by the temperature, or p a times v is equal to m a R a T a.

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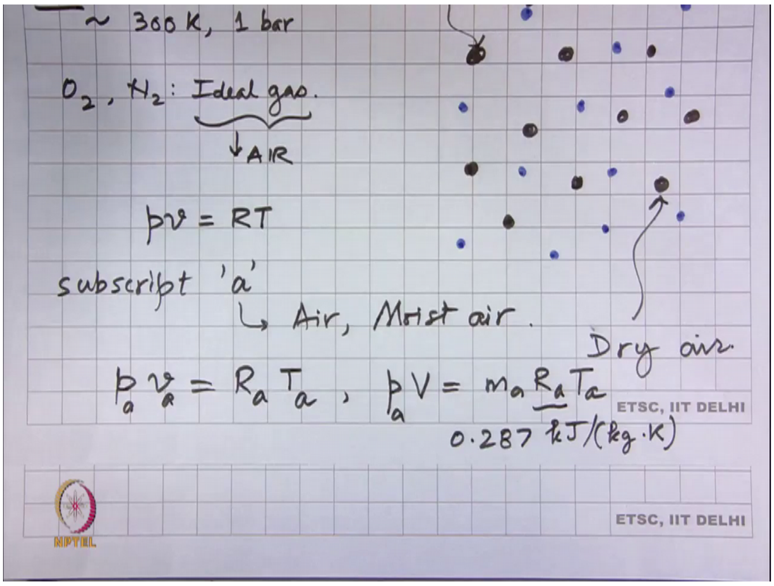

~ 300 K, 1 bar

$\underbrace{O_2, N_2 : \text{Ideal gas.}}_{\downarrow \text{AIR}}$

$pv = RT$

subscript 'a'

↳ Air, Moist air.

Dry air

$p_a v_a = R_a T_a$, $p_a V = m_a \underline{R_a} T_a$

0.287 kJ/(kg·K)

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R a we have been using earlier this is 0.287 kilo Joules per kg Kelvin. So, this is what this whole air was assuming it to be an ideal gas. Now, we look at dry air and say not dry air is also going to be modeled as an ideal gas.

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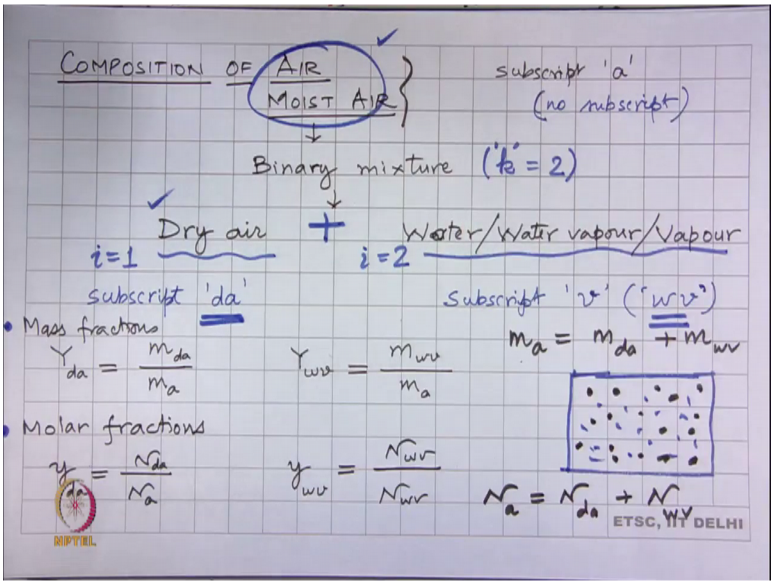

COMPOSITION OF AIR / MOIST AIR } subscript 'a' (no subscript)

Binary mixture ('k' = 2)

Dry air + Water/Water vapour/Vapour

$i=1$ $\qquad$ $i=2$

subscript 'da' $\qquad$ Subscript 'v' ('wv')

- Mass fractions

$$Y_{da} = \frac{m_{da}}{m_a} \qquad Y_{wv} = \frac{m_{wv}}{m_a} \qquad m_a = m_{da} + m_{wv}$$

- Molar fractions

$$y_{da} = \frac{N_{da}}{N_a} \qquad y_{wv} = \frac{N_{wv}}{N_{wv}} \qquad N_a = N_{da} + N_{wv}$$

So, we now have the composition of air or moist air as we make call it with the subscript a or you will find in some books and look other references, there is no subscript in which case it is implied that the property is the property of a binary mixture. So, this binary mixture contains two components between our mixture theory we can say i equal to 1 which is dry air, i equal to 2 is water, we may call it some polid water, some would refer to it as water vapour, others refer to is only as vapour, but it is meaning the same thing.

So, if the mixture of these two that we are saying is air. So, we have air or moist air is a mixture of dry air and water vapour. We had seen from earlier thermodynamics. And now all that this is reasonably well modeled as an ideal gas. Now, we will say you know the dry air is also is the same thing which moist air gone. It is you also behaving like an ideal gas. So, you got ideal gas behaviour here and ideal gas behaviour here. In a minute we will see how do we handle the water vapour in air.

So, a dry air we will use the consistently the subscript da, and for water vapour we will consistently use the subscript wv. You will find that these symbols are somewhat different in different text books, but I have chosen these just to make sure that when we use this subscript, there is no ambiguity or clash with a subscript that we have used earlier in the past. So, like becomes a little more involved writing da for dry air some people write just a otherwise would write only v, but we wills take with this that da subscript means dry air; w v subscript means water vapour.
]

So, now we go back to what we have learned in mixture theory, first property of a mixture is mass fractions. So, we can say the mass fraction of dry air is mass of dry air divided by the total mass of air in that volume. So, that what it is that if you have a system there, this contain some water vapour and there is some moisture in it dry air, then the mass of the dry air which is these black dots divided by the total mass of both in this system is the mass fraction of dry air. And similarly mass fraction of water vapour is the mass of water vapour divided by the total mass of the system.

The same thing can be modified to indicate the molar fractions which is indicated as we saw earlier with the lowercase y. So, y d a is number of moles of dry air divided by the number of moles of the total number of moles in the mixture. And the mole fraction of water vapour with number of moles of water vapour divided by total number of moles in the mixture.

So, basically what we have said here is that mass of the air is equal to mass of dry air plus mass of water vapour and same thing with the number of moles. Number of moles of air is equal to number of moles of dry air plus number of moles of water vapour. So, this is fairly standard notation that we have look at when you are dealing with mixtures. So, this we can say now that this is a binary mixture number of components which we have earlier set was k, k is equal to 2. So, you can say this is k is number of components and not the specific heat ratio.

So, now, we say what are the properties of air rather that we are actually looking for. So, like any pure substance we would like to know the same thing, but the temperature, then it is a specific heat, specific entropy, specific enthalpy, specific internal energy and anything else that is unique to this particular mixture is a series of definitions by which we call humidity.

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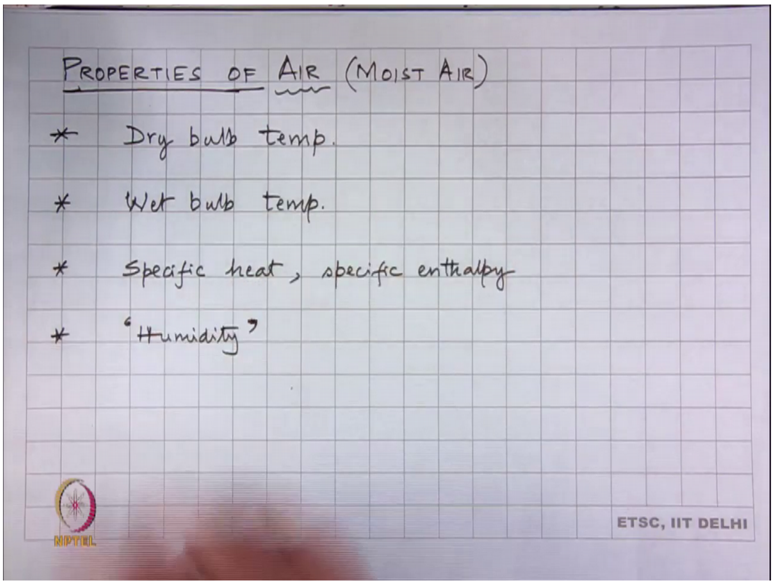

PROPERTIES OF AIR (MOIST AIR)

- * Dry bulb temp.
- * Wet bulb temp.
- * Specific heat, specific enthalpy
- * 'Humidity'

So, what we will do now is go one by one and look at all the properties that are there for a air water mixture or what may call it just as air or moist air. So, if I use the word air or sometimes I use the word term moist air, the meaning is the same. So, we begin with looking at the dry bulb temperature.

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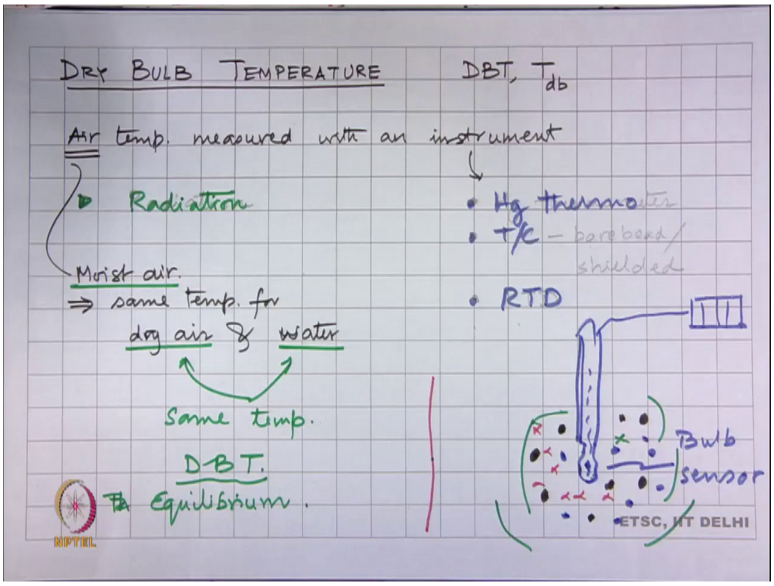

DRY BULB TEMPERATURE DBT, T_{db}

Air temp. measured with an instrument

- Radiation
- Hg thermometer
- T/C – bare bead/shielded
- RTD

Moist air.
⇒ same temp. for dry air & water

Same temp.

DBT.

~~Th~~ Equilibrium.

This is called abbreviated as DBT and sometimes T the subscript db. When we write equations, we use this and not this one. So, dry bulb temperature is what it is when we say what the air temperature. And what we are basically done is we just took an instrument and we just this was the sensor part of it say it could be a mercury thermometer or it could be a thermocouple either bear bead thermocouple or a shielded thermocouple, or this could be a RTD or any other type of a sensor, but these are the most common points.

So, if this is the sitting in the air or the airstream or a process whose where the air temperature is to be measured, then by just putting this, this is the bulb or you may call it the sensor, the temperature indicated by this instrument directly here or through this on a read out or on a computer these days. This is going to give us the dry bulb temperature.

What one has to take care about though in this case is that every time we have some things anywhere in the air, there is always radiative transfer between the surrounding surfaces and that sensor. So, if you really want to measure only the temperature of air, we need to cut out as far as possible all this radiation that is happening; which means that if there are other surfaces that are in this vicinity, then we need to make sure that this radiation does not affect this. Because even if there is a small difference in this temperature and say this surface temperature which could be a wall or could be the skin of a person or it could be some other engineering device, then this is going to radiate also, and this will affect this will show a temperature which is not exactly with temperature of the air.

So, what we are interested in is the temperature of the molecules over there, and we only want these this to be the system, but now there is radiative transfer taking place. So, one of the things that is done is that around this one puts a series of shields which are nothing but very thin pieces of metal, so that there is no direct radiative transfer from here to the surrounding surfaces. This is particular true when we are making measurements of atmospheric air, where you are trying to put a thermometer out in the open. And you have to make sure that that thermometer will not expose to radiation from other surfaces not radiation from the sun and also the sky. So, radiation shield is a necessity to accurately and reliably make a measurement of dry bulb temperature.

So, when we measure the temperature of air, this air is moist, it has got water vapour in it. So, what we are saying is that irrespective of how much each one of these is there, we have some air over there which is these black dots, and we have some water vapour in there which are these blue dots. The temperature of each one of these species is the same;

that means, in moist air the dry air and the water have the same temperature which is nothing but the dry bulb temperature.

In fact, even in the later analysis we look at other applications. Wherever we are dealing with the mixture and we say what is the temperature; we will always mean that it is the temperature of the mixture which is in equilibrium which means that water and air are at the same temperature. There will be no such distinction that what is the temperature of air in it and what is the temperature of water in it. This could be an issue with industrial say processes where one air stream is warmer than the other, and the two are mixing. But then our analysis will be limited to the fact that we have finally, reach then equilibrium and we are then applying the equations to that.

So, there is equilibrium and the temperature whenever we talk in this discussion it will always be same for either of the components as it is for the mixture, so that is the idea of the dry bulb temperature. It is a relatively straight forward. And even if you look at whether forecast anywhere or what are the, whether in the last so many days it is the dry bulb temperature that people are reporting.

And when we talk of climate change and global warming we are basically saying that what is the mean temperature of air and in that we are actually saying what is the mean dry bulb temperature of air and you are looking at a historical trend on that basically that is what you are doing. So, that is the concept of dry bulb temperature and it is a importance.

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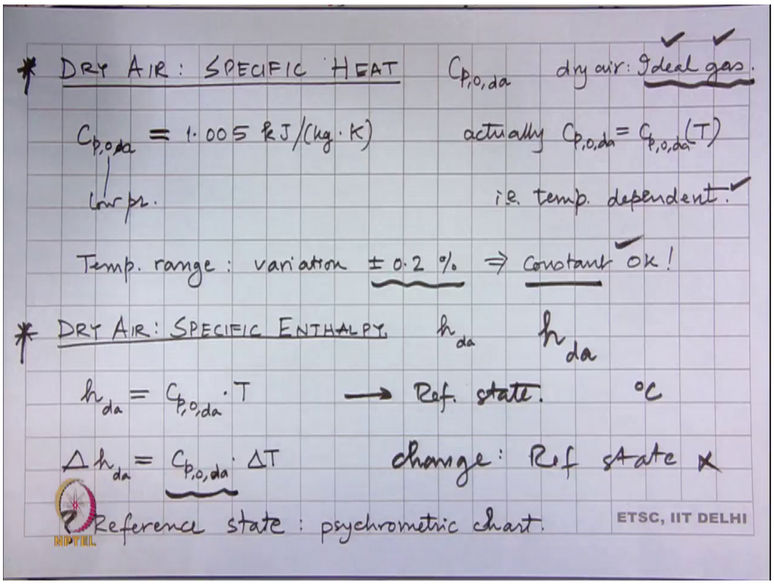

* DRY AIR : SPECIFIC HEAT $C_{p,0,da}$ dry air: Ideal gas.

$C_{p,0,da} = 1.005$ kJ/(kg · K) actually $C_{p,0,da} = C_{p,0,da}(T)$

low pr. i.e. temp. dependent.

Temp. range : variation ± 0.2 % ⇒ Constant ok!

* DRY AIR : SPECIFIC ENTHALPY h_{da} h_{da}

$h_{da} = C_{p,0,da} \cdot T$ → Ref. state. °C

$\Delta h_{da} = C_{p,0,da} \cdot \Delta T$ change: Ref state ✗

Reference state : psychrometric chart.

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The next property we will look at is that for dry air how do we get the specific heats. Now, because that we are said that moist air was an ideal gas. So, the first thing is that we say dry air again O 2 plus 3.76 N 2 at the temperatures and pressure that we are interested in is an ideal gas. And which means that we can now define the specific heat at constant pressure at low pressures for dry air da which is same as what we have learned earlier, the circuit for air 1.005 kilo Joules per kg Kelvin.

This is reasonably over the small temperature range. Actually the specific heat of air or any of the substance for that matter is a function of temperature. But fortunately for us our temperature range over which we were doing these analysis is reasonably compact. And so even if you took the specific heat variation across those temperatures and use the temperature dependence specific heat, the value you would get from there would not be very much different from this constant 1.005 kilo Joules per kg Kelvin. And this variation is quantified and it is less than plus minus 0.2 percent. So, we are quite justified in assuming that dry air has constants specific heat and we will work with that.

Now, we come to the next property so that was the dry air specific heat. Now, we come to the next property which is the specific enthalpy of dry air. And this we will use the symbol h is a subscript da. So, this is same dry air, there is no moisture unit the pseudo pure substance which is ideal gas of this specific heat. So, we can write that the specific heat of dry air as the specific enthalpy of dry air is the specific heat times the temperature. On change in the enthalpy of dry air is specific heat of dry air which we have said that is constant. And difference of the temperatures delta T.

Now, there is an issue in this that if you are talking of change in specific enthalpy, the reference state to which h is taken from becomes a non issue. So, here reference state does not matter, it is not an issue. But if you are looking at this and you are trying to make a plot say h plot of specific enthalpy versus something else, then you have to have some reference state, so that you can start putting numbers on that plot. So, you need a reference state.

In the tables that you have used earlier 0 degree Celsius saturated liquid the specific enthalpy was taken as 0 that is a completely convenience selection. And people have use different temperatures for different substances. So, absolute numbers on chats may look different or tables may look different, but the differences will always be pretty much the same.

The same thing happens later on when we look at the psychometric chart when we plot specific enthalpy we ask you know what is the reference state to which we are referencing the specific heat of air; the a specific enthalpy of air. The same issue will also come up when we look at the specific enthalpy of water, but for dry air it is a fairly straight forward relation that is given here.

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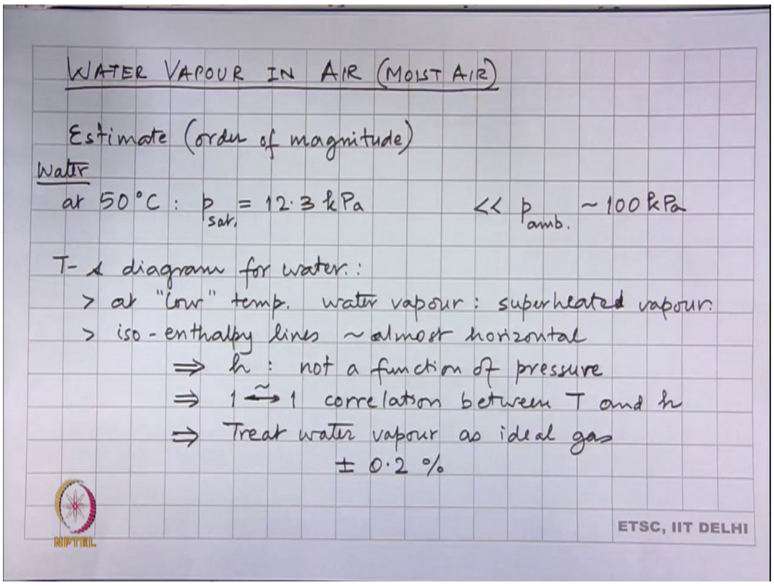

WATER VAPOUR IN AIR (MOIST AIR)

Estimate (order of magnitude)

Water

at 50°C : $p_{sat.} = 12.3\ kPa \qquad << p_{amb.} \sim 100\ kPa$

T-s diagram for water :

> at "low" temp. water vapour : superheated vapour.

> iso-enthalpy lines ~ almost horizontal

$\Rightarrow$ h : not a function of pressure

$\Rightarrow$ $1 \xrightarrow{\sim} 1$ correlation between T and h

$\Rightarrow$ Treat water vapour as ideal gas

± 0.2 %

So, now, we look at water how to handle the properties of water vapour. So, these are all those blue dot that we showed in those pictures. And first before we actually go to numbers, let us try to get some idea of what the order of magnitude of how much water vapour is there in air. And so what is what it tells us is that if there is air and the maximum amount of water vapour that it can hold, we all know from experience is the saturation condition that means once the vapour is dry saturated in air it cannot hold any more moisture it will condense or precipitate or freeze.

So, let us get some typical number and taken at 50 degree Celsius. The saturation pressure of water from the steam tables is a 12.3 kilo Pascal's. And this is significantly smaller than the ambient pressure which is 100 kilo Pascal so although not very very small but still 10 percent, 15 percent in that range. So, what it also tells us is that when we look at water vapour at this sort of a condition and look at a TS diagram, then at lower temperatures water vapour is like a superheated vapour.

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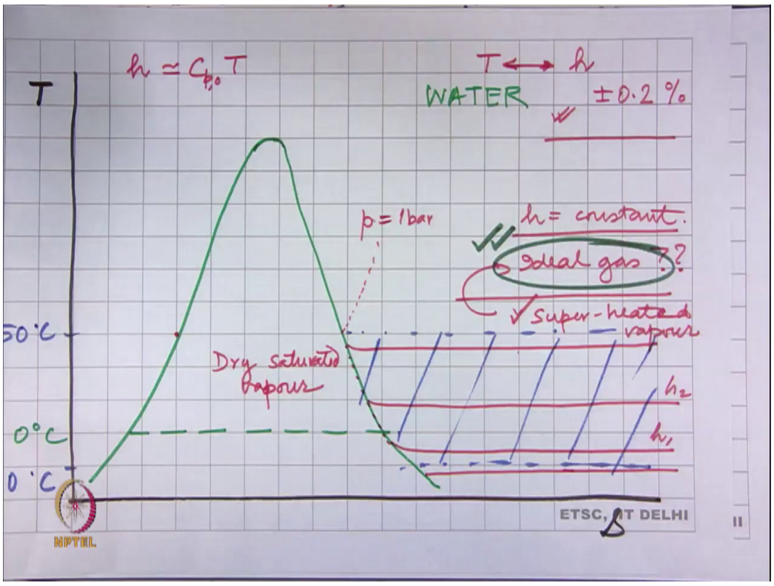

So, here is what we are actually is saying now that is if look at the TS diagram. Then on this we can draw the saturation states which is given by the dome and now we say where are the states that we are looking at. So, what we are doing is we said it is this graph would say get the triple point at say some point here, and then we have the other limits that we are looking at there is somewhere there is 50 degree Celsius say roughly let us calls this 50 degree Celsius and temperatures could go down minus 10, minus 20, whatever it is here.

So, we are looking at water vapour in some sort of a regime region like this. So, the states that we are looking at for water vapour they are here. So, we are looking at a very small region of the total TS diagram or the TV diagram if you have to look at that. So, what happens in this case, if you look at this part there, then the lines of constant enthalpy they are like this; near the dome there is the slight nonlinearity, little away from it this lines are parallel.

And as you go further up also in the dome all the way to may be 500, 600 degree Celsius, once we have far away from this region or this dome region or the critical region, h lines constant isenthalpic lines are like this. So, this is h equal to constant. The other thing we learns from this picture is that all these states are superheated vapours.

At the extreme we could say that these states come onto this line, where we could say that there dry saturated vapours. So, we know from experience that 50 degree Celsius and 1 bar pressure comes somewhere over here, pretty much on the saturated liquid line it is a liquid state. We are at 50 degree Celsius, but we are in the vapour phase and that is because the pressure instead of being 1 bar is actually much lower this is say the 1 bar line over there.

We are over here where the pressure is much less than 1 bar pressure. So, this is one thing with that water vapour that we are dealing with is the superheated vapour and at most dry saturated vapour. We are not looking at the fact that some of this is condensed and become if it as condensed it will become a dry with a saturated liquid there we are not looking at that. So, that is one.

The second thing is that the lines of constant enthalpy at pretty much straight. And so we ask the question you know this information plus this, what is it tell us. The question we are asking is if is superheated vapour then can I say this is an ideal gas? And if you say yes, it is an ideal gas then within how much error plus minus how much. So, the fact that these lines have become constant it means that for every given T, there is a unique value of h. So, these are all different values of h whatever we can call it and say this is h 1 h 2, and 1 and two are purely numbers that I am using for description sake, they are not states or components or anything like that.

So, what this is telling us is that if you know the T, we can uniquely get h in this region that means, there is the one to one correspondence between these two. And that is pretty much what we saw just now for air where we said that h is pretty much equal to constant pressure specific heat multiplied by the temperature. So, if you have a constant specific heat, this is the same relation that we are seeing over here.

So, that is nice to know because now we can say that given all these things this superheated vapour could actually be treated like an ideal gas, and that is another very nice thing to have because makes the calculations much more elegant. And when we do that, the error that we get in the value of h is less than plus minus 0.2 percent. And so we have been pretty good shape to say that this air, this water vapour is behaving like an ideal gas, so that is the second thing that we have just now looked at. And now let us see what the implications of this thing with the very first thing it tells us is that the mixture that we were talking of right in the beginning is now a mixture.

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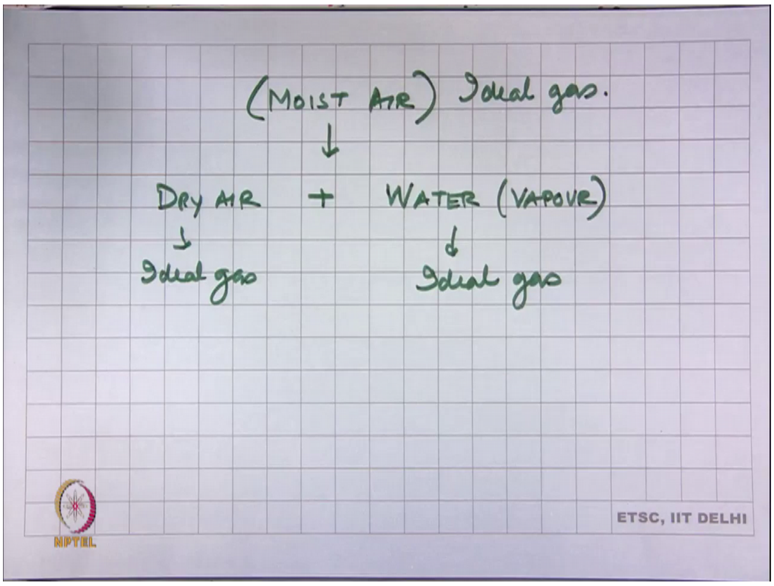

So, what about the binary mixture or what you called as moist air, we call this as dry air plus water or water vapour. This has been independently taken as an ideal gas. Now, we have just argued that for the temperatures and pressures we are interested in, this is also an ideal gas. And we have also been saying that air this itself is also pretty much behaving like an ideal gas. So, now, our objective becomes to get the properties of this air in terms of properties of these two which we have just seen can be modeled as ideal gases. So, let us do that now we will look air we have already seen what the equation of state is. We will now see what happens for water vapour.

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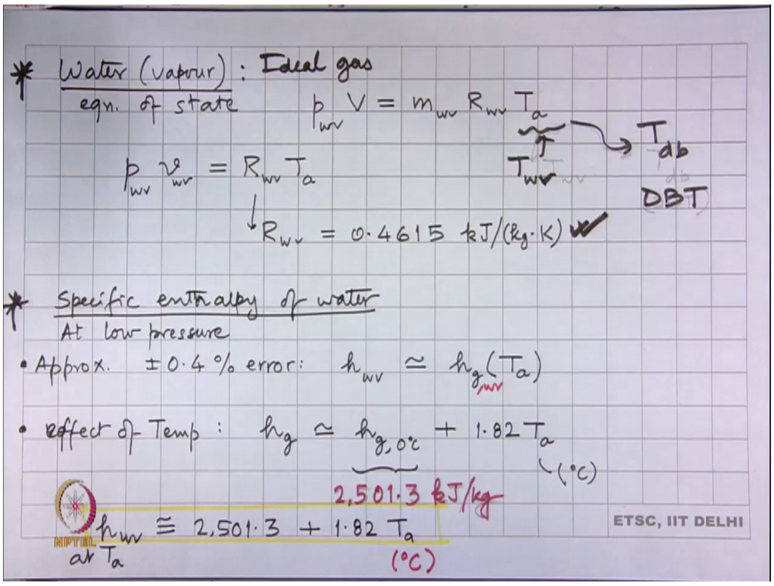

* Water (vapour) : Ideal gas

eqn. of state

$$p_{wv} V = m_{wv} R_{wv} \underbrace{T_a}_{T_{wv}} \rightarrow T_{db}$$

DBT

$$p_{wv} v_{wv} = R_{wv} T_a$$

$$\downarrow R_{wv} = 0.4615 \text{ kJ/(kg·K)}$$

* Specific enthalpy of water

At low pressure

- Approx. ± 0.4 % error: $h_{wv} \simeq h_{g,wv}(T_a)$
- effect of Temp : $h_g \simeq \underbrace{h_{g,0°c}}_{2,501.3 \text{ kJ/kg}} + 1.82 \, T_a$ (°C)

$$\boxed{h_{wv} \cong 2,501.3 + 1.82 \, T_a}$$

at T_a (°C)

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So, what we do since we have said that to a very good extent water vapour can be said to be an ideal gas. We can write the equation of state as p w v we are now using the subscript w v wherever we are dealing with water. So, make be just very clearly; p w v times V is equal to m w v R w v T a. Now, T a is the temperature of the; mixture of the temperature of the air subscript a means air it was the moist air. The correct thing to write would have been that we put here T w v, but just we argued that we are not going to be bothered about the fact that there is a temperature difference between the two components within the mixture. The mixture is in thermal equilibrium. So, the temperatures are the same, so that is what we have put that is T a. We will not talk of this thing at all.

And what is this T a, T a is something that you just measure using what we just learned now as the dry bulb temperature. So, technically this is T d b. So, the thermometer just place there without any radiation effects tells us the dry bulb temperature which is the temperature of the air which is the temperature of the two components. So, we can write this equation in the as a specific volume thing and we get the gas constant for water vapour R w v as 0.4615 kilo Joules per kg, so that is another good thing we got.

Now, we do the same thing what we did for air few what we few minutes back. Now, you look at specific enthalpy of water. So, one thing that we can see is that those lines which we are going horizontal, these lines this is a very slight bend near this. And if you go to even lower pressures and we can actually see the property charts, this line is actually straight right from this point itself. Basically saying that at even though we are very close to the saturation state, the pressure and temperature is such that the even the dry saturated vapour is behaving reasonably well like an ideal gas that is what this chart is telling us.

The deviation becomes more as pressure gets higher and higher. So, one of the things that can be done is that we can say that this value of h is approximately equal to this value. And this value is easy to get because this is nothing but the specific enthalpy of dry saturated vapour which in the past we have denoted by h g. Remember the subscript f and g, f was for the saturated liquid, g was for the saturated vapour, we are using the same notation now. So, this is h g.

So, one can say now that with about 0.4 percent error, the specific enthalpy of water vapour in the regime we are interested in you almost equal to h g at that particular temperature. So, whatever temperature was there, at the temperature what is the specific enthalpy of as h g for water vapour that is going to be the h 4 water vapour. To get the effect of temperature which is what we are seeing they are have been slightly, we can write h g as h g at 0 degree Celsius plus 1.82 times T a, T a is in degree Celsius. This comes about from a very small little derivation, which is there in the nodes, I will not go in to the details here.

But after doing that what you get is h g at 0 degree c is 2501.3 kilo Joules per kg. And so the equation that we will see being used is that the specific enthalpy of water vapour is almost equal to 2501.3 plus 1.82 T a, where T a is in degree Celsius, so that is another relation we have now how to get the specific enthalpy of water vapour. So, we got the specific enthalpy of air, we got the specific enthalpy of water vapour. Now, we move on to see how do we quantify the composition of this mixture. And like we define for mixtures in general here also we defined two things the partial pressure and the partial volumes.

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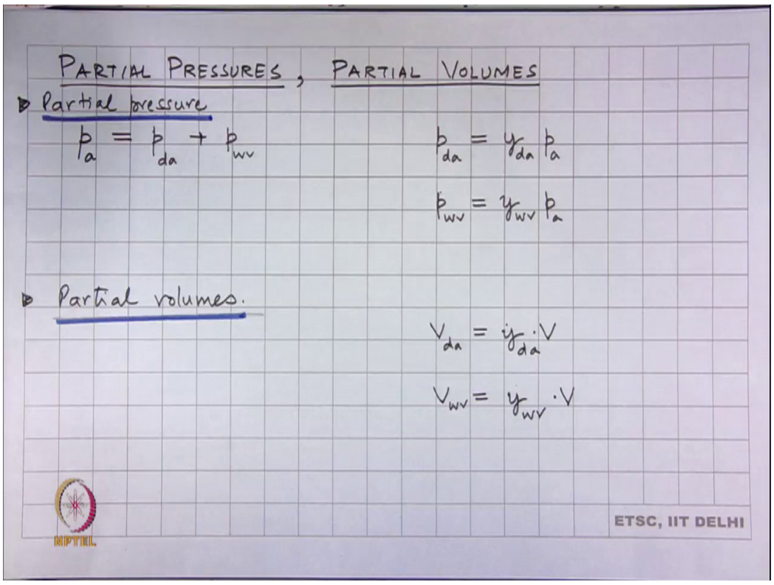

PARTIAL PRESSURES , PARTIAL VOLUMES

- Partial pressure

$$p_a = p_{da} + p_{wv}$$

$$p_{da} = y_{da}\, p_a$$

$$p_{wv} = y_{wv}\, p_a$$

- Partial volumes.

$$V_{da} = y_{da} \cdot V$$

$$V_{wv} = y_{wv} \cdot V$$

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So, the total pressure of air p a is the partial pressure of dry air plus the partial pressure of water vapour. And we derive this thing for mixtures that the partial pressure of the component is equal to its molar fraction multiplied by the system pressure, so that is what we have here, p w v is equal to y w v into p a. Same thing we can do now with the so this is a partial pressure, now we look at partial volumes. And what we have done last time which is exactly the same thing we are doing here that the partial volume of a component is its molar fraction multiplied by the volume of the mixture.

So, v is the total volume of the mixture and V da is the volume occupied by that particular component if it were to be alone at the same pressure and temperature. And the volume of water vapour is molar fraction of water vapour multiplied by the volume of the system.

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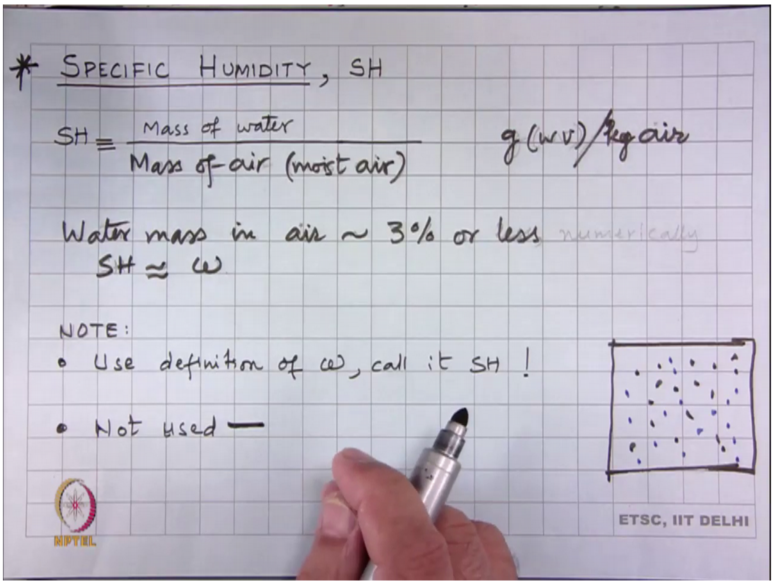

* SPECIFIC HUMIDITY, SH

$$SH = \frac{\text{Mass of water}}{\text{Mass of air (moist air)}} \quad g(wv)/kg\ air$$

Water mass in air ~ 3% or less numerically

$SH \approx \omega$

NOTE:

- Use definition of ω, call it SH !
- Not used —

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Now we come to defining a series of terms which are unique to psychometric air conditioning and these type of applications. First we look at what is called specific humidity. It symbol is SH, and it is something that is not used very frequently with good to know what it is in the first place. So, specific humidity is mass of water over mass of air which is moist air.

So, what we are saying is we make system in which we have both types of molecules, the air there and the water there. And what we are saying is that the mass of water in this system which is the numerator divided by the total mass that is there here with a mass of air, this ratio is called the specific humidity. And although it is a ratio and both are mass it is not a non-dimensional number, because this is a expressed as grams of water vapour per kilogram of air.

Now, we can do a what we are looked at partial pressures there earlier, we saw that the mass of water in air this is about of the order of 3 percent or less; 3 percent more than 50 degree Celsius and 100 percent humidity that means, completely full of air moist air. But at 25 degree Celsius and say 50 percent humidity which is water and air conditioned room typically would have this reduces by about a factor of 2 so which is much smaller.

By enlarge specific humidity is not used in calculations and not shown on charts, because this depends on the temperature of the system. And so it is good to know that this is the definition of specific humidity, but also be clear that it is not used; in a minute we will come back to it for a different region.

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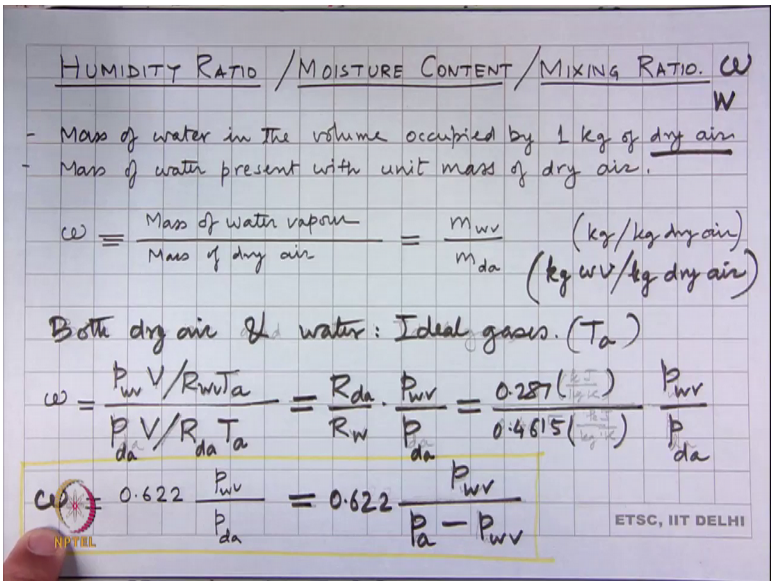

HUMIDITY RATIO / MOISTURE CONTENT / MIXING RATIO. ω W

- Mass of water in the volume occupied by 1 kg of dry air
- Mass of water present with unit mass of dry air.

$$\omega \equiv \frac{\text{Mass of water vapour}}{\text{Mass of dry air}} = \frac{m_{wv}}{m_{da}} \quad (\text{kg/kg dry air}) \quad (\text{kg wv/kg dry air})$$

Both dry air & water: Ideal gases. (T_a)

$$\omega = \frac{p_{wv} V / R_{wv} T_a}{p_{da} V / R_{da} T_a} = \frac{R_{da}}{R_w} \cdot \frac{p_{wv}}{p_{da}} = \frac{0.287 \left(\frac{kJ}{kg\,K}\right)}{0.4615 \left(\frac{kJ}{kg\,K}\right)} \frac{p_{wv}}{p_{da}}$$

$$\boxed{\omega = 0.622 \frac{p_{wv}}{p_{da}} = 0.622 \frac{p_{wv}}{p_a - p_{wv}}}$$

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The term that is used widely and shown on the charts is variously called humidity ratio or moisture content or mixing ratio. So, this is mass of water in the volume occupied by 1 kilogram of dry air or what mass of water present per unit mass of dry air. So, we are now differentiating that it is not reference to the mixture mass, but the mass of dry air alone. And we do that because in many applications, the mass of dry air going to the system or in a system is pretty much constant, the amount of moisture when it goes up and down. So, practicing engineers have found it convenient to use this definition and work with this everywhere.

So, this is got the symbol omega; some books notes you will find the symbol w. So, this is defined as mass of water vapour; divided by mass of dry air which is a mass of water vapour upon m da. And again is although it is a ratio of two masses it is not non-dimensional, because what you are looking at is kg of water vapour per kg of dry air. So, everywhere when we do calculations for use charts or property tables, we must put this set of units after the value that we have got.

Now, we have seen that both the components of air which is dry air and water vapour both are ideal gases. So, what we will do is that is where this upper little bit and expresses the mass using the ideal gas equation of state and then we do a simplification.

So, let us see what we get. So, this becomes for water vapour m is a p V upon R T. So, pressure of water vapour this is remember this is pressure of water vapour and not pressure of air. And T a which has said that temperature everywhere is T a there is no differentiation component wise as for as temperature goes, p da into V upon R d a into T a.

And we simplify this. So, this becomes R da upon R w multiplied by p w water vapour pressure partial pressure over dry air partial pressure. And both these numbers are known. So, this can be written as 0.287 into kilo joules per kg Kelvin divided by 0.4615 into its units which is the same multiplied by the partial pressures of water vapour divided by partial pressure of dry air.

And when you simplify this we get this relation that omega is equal to 0.622 p wv upon p da. And we simplify it a little more, this is 0.622, and getting rid of p da as p a minus pressure of water vapour, we get this upon p a minus p w v. So, this is an important relation that we have arrived at. This is something we will use very frequently that humidity ratio is 0.6 to 2 multiplied by the partial pressure of water vapour or partial pressure of dry air or 0.62 partial pressure of water vapour upon p a which is the mixture pressure minus the partial pressure of water vapour. So, what we tells us it only depends must p a is fixed, it is only the partial pressure of water vapour which determines the humidity ratio.

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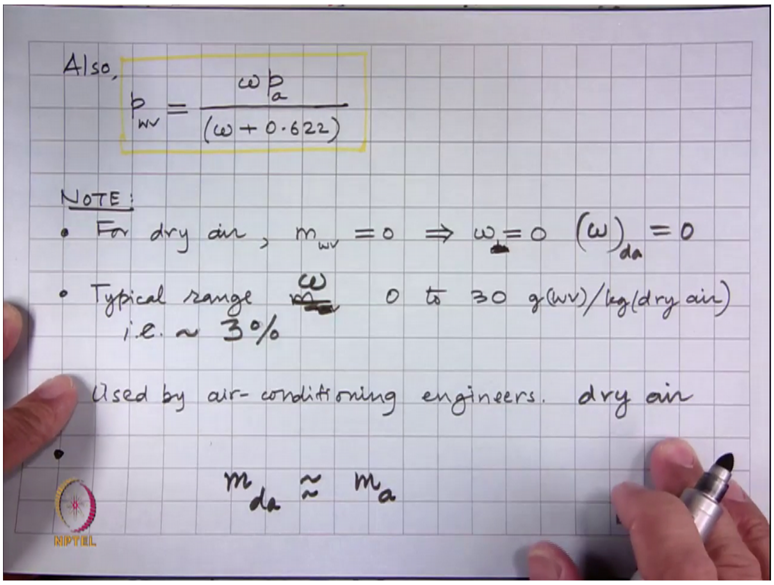

Also,

$$\boxed{p_{wv} = \frac{\omega p_a}{(\omega + 0.622)}}$$

NOTE:

- For dry air, $m_{wv} = 0 \Rightarrow \omega = 0$ $(\omega)_{da} = 0$
- Typical range ω 0 to 30 g(wv)/kg(dry air)
  i.e. ~ 3%
- Used by air-conditioning engineers. dry air
-

$$m_{da} \approx m_a$$

So that is we can rewrite that equation earlier and express partial pressure of water vapour in terms of omega and p a, which is over here omega p a upon omega plus 0.622, and so this is also something which is of interest to us. So, what is it tell us is that for dry air, it means that it is only air and no water vapour unit, mass of water vapour is 0. So, omega is 0 or we can to be is a clear you can say omega dry air is 0.

If you look at the charts in the temperature range that we have looking at the mass of water vapour or sorry not this one, the value of omega is typically 0 to 30 grams of water vapour per kg of dry air. This is a field for some numbers what, what it is like. So, what it is telling us is that the mass of water vapour to the total mass of the dry air is of the order of 3 percent.

So, what happens is, they have an approximation at we will see in some places where we say you know this is so small that I can take m da almost equal to m a and use it in the formula for specific humidity. So, numerically the specific humidity and the humidity ratio may have similar numbers, but strictly specific humidity is not the same as humidity ratio or mixing ratio, so that what it was here because mass of water is three percent or less. So, then as far as the number and values go specific humidity is almost equal to omega. And there are some books will say that humidity ratio is also known as specific humidity that is strictly not the case although by numerical values it will be pretty much very close to each other.

So, we must differentiate and we will keep our bookkeeping clear because this is going to be an issue that keeps popping up all the time. We will always use the term humidity ratio or at most moisture content in looking at omega. We will not call this as specific humidity. This is the term that is used widely by air conditioning engineers, it has come to be known and it is much simpler to use because as I mentioned dry air mass in many processes remains the same. So, it is much easier to correlate with omega.

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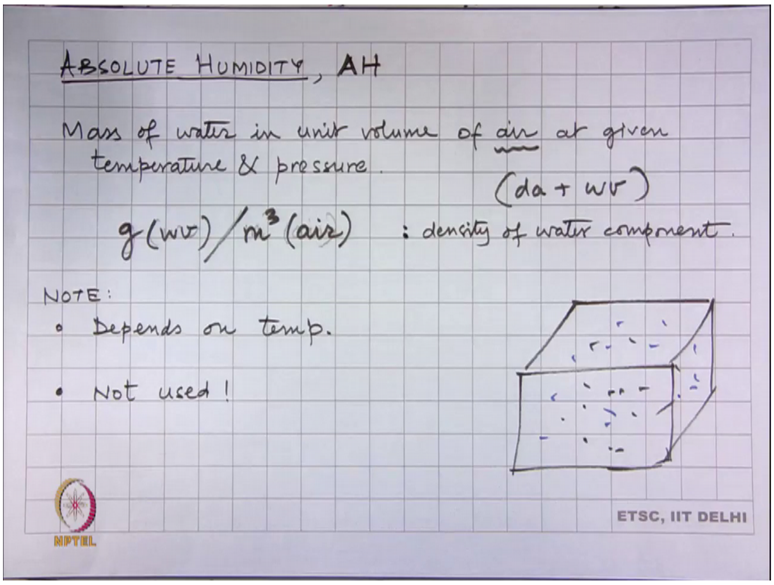

ABSOLUTE HUMIDITY, AH

Mass of water in unit volume of air at given temperature & pressure.

(da + wv)

$g(wv)/m^3(air)$: density of water component.

NOTE:

- Depends on temp.
- Not used!

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Now we look at the third concept that comes out and this is called absolute humidity AH. This is the mass of water in unit volume of air at a given pressure and temperature. So, when you are talking unit volume of air, air as we have seen this is our mixture of d a plus w v. So, we are saying that in a given system say sample like that in which we have both these gases around water vapour and dry air, then the absolute humidity is grams of water vapour in this per unit volume which is per meter cube of air, air or the mixture. So, in some sense we can call this as the density of the water component ok. So, this is definition of absolute humidity ok.

Now to proceed further, we need to have to define a new concept which is what is saturated air and from there another set of definitions will come out.

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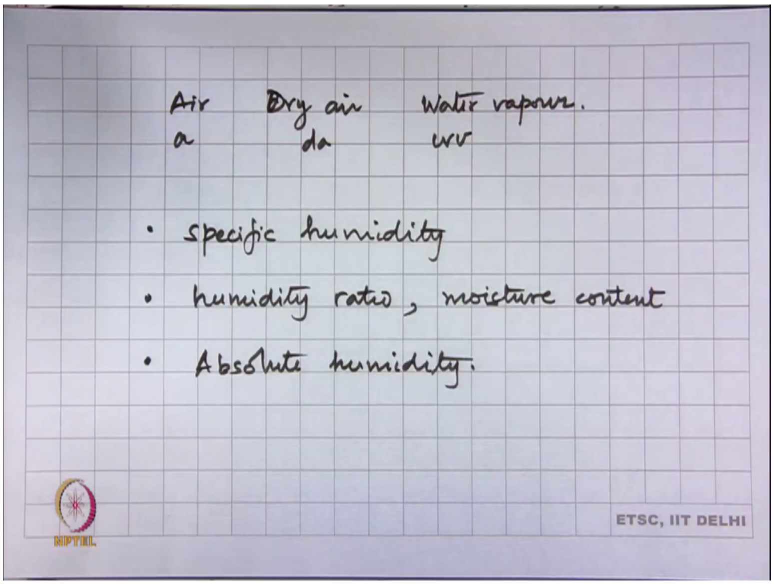

Air Dry air Water vapour.
a da wv

- specific humidity
- humidity ratio, moisture content
- Absolute humidity.

So, we will conclude this part of the definitions over here, saying that we looked at several properties that came about, and we made an important distinction here between what is a specific humidity what we called as the moisture content or the humidity ratio and absolute humidity. And this was proceeded by bunch of definitions where we said that what is air and was subscript a, then we said what is dry air and this we called subscript da and what is water or water vapour we said that we will call it w v.

So, we will take a pause at this point, and then come back and look at the whole thing about saturation and all that other properties that follow from that.

Thank you.