Lighter Than Air Systems
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Lecture - 28
Effect of Humidity Vapour Pressure

Now let us look at the effect of humid air. Now for this you have to go back to our class 11th and 12th chemistry in school. Some students hate the subject of chemistry I was one of them when I was in school, but we have to use it. So, just recall some definitions about humidity. What is humidity?

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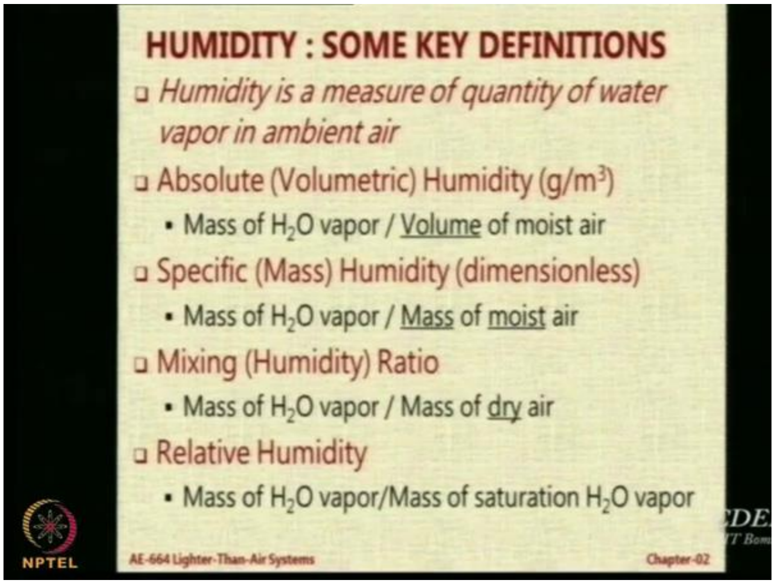

HUMIDITY : SOME KEY DEFINITIONS

- *Humidity is a measure of quantity of water vapor in ambient air*
- Absolute (Volumetric) Humidity (g/m^3)
  - Mass of H_2O vapor / Volume of moist air
- Specific (Mass) Humidity (dimensionless)
  - Mass of H_2O vapor / Mass of moist air
- Mixing (Humidity) Ratio
  - Mass of H_2O vapor / Mass of dry air
- Relative Humidity
  - Mass of H_2O vapor/Mass of saturation H_2O vapor

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It is an indication of how much water vapour is there in the ambient air? Interestingly there are several definitions of humidity. So we will revisit them very briefly. There is something called as absolute humidity also called as the volumetric humidity. There you look at the mass of the water vapour upon the volume of the moist air. Moist air means air which have got water vapour in it. So that is absolute humidity how much mass of water vapour you have per volume?

You also have something called as a specific humidity or mass humidity. This is mass upon mass. So, mass of water vapour upon mass of the moist air. Then you also have what is called as the humidity ratio a mixing ratio, which is the ratio of mass of water vapour upon mass of dry air. So now you remove the mass of the water vapour remaining thing is mass of dry air so that ratio is called as humidity ratio.

And most important for us is what is called as the RH or the relative humidity, which is mass of the water vapour divided by mass of the saturation water vapour. Does somebody remember that from your school chemistry what is meant by saturation water vapour after that what happens, it will condensed into water or ice or sleet whatever appropriate to the operating conditions, correct? How much how much water vapour can air hold without condensing?

That is called as the relative humidity. Normally we accept that as the percentage. Now the question is how do you measure it? This is something I want to leave it you for moodle. So note down on Moodle page whereas how the relative humidity is measured in real life. There are manyways you will remember I remember hot and wet bulb thermometer, thermometer. Then there is hygrometer. Just to revive your memory in your old school days on Moodle page I want but please do not copy paste from one source and put it.

Apply your own mind and make it in a slightly interesting fashion perhaps put a photograph of an instruments. Give some numbers about RH values of various places in Mumbai how it varies some information about humidity because this is going to affect. Now let us look at some other physical concepts about saturation.

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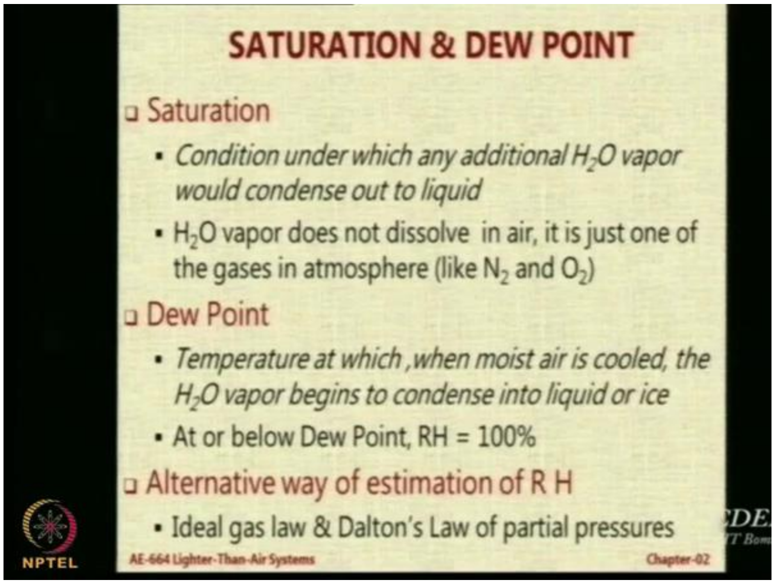

SATURATION & DEW POINT

- Saturation
  - *Condition under which any additional H_2O vapor would condense out to liquid*
  - H_2O vapor does not dissolve in air, it is just one of the gases in atmosphere (like N_2 and O_2)
- Dew Point
  - *Temperature at which, when moist air is cooled, the H_2O vapor begins to condense into liquid or ice*
  - At or below Dew Point, RH = 100%
- Alternative way of estimation of R H
  - Ideal gas law & Dalton's Law of partial pressures

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So this is what we have already seen saturation is a condition in which any additional water vapour will not remain water vapour it will condense into liquid. So There is one confusion which many people have. Many people feel that this water vapour these molecules of the water will actually go inside the molecules of the gas and it is not true. There is no mixing. You cannot break Avogadro's law. You cannot you cannot have intermolecular forces cannot be broken by some other particle unless you apply huge amount of energy.

So, the water vapour is just like any other gas just like air is a mixture of Nitrogen, Oxygen and also water vapour take it as gas. So this water vapour is a gas which is there in the air like any other gas? It does not actually mix. Now dew point is the temperature of the ambient air if you cool ambient air up to dew point then saturation vapour pressure occurs and this will start condensing. So, when you operate any vehicle or a airship if you operate at a temperature lower than dew point, the air will actually shed all its water vapour in the form of dew. So, at or below dew point the relative humidity is 100%.

And above the dew point you find it will be 80%, 90% etcetera. So there is a alternative way in which we can estimate RH. Now you cannot go around and calculating you cannot go around with a thermometer and checking the humidity at every point of time. Yes you need that number but there is a alternative way of measuring this and for that we again revisit our school chemistry and and we look at 2 laws, ideal gas law $PV = \rho RT$ and we look at the Dalton's law of partial pressure.

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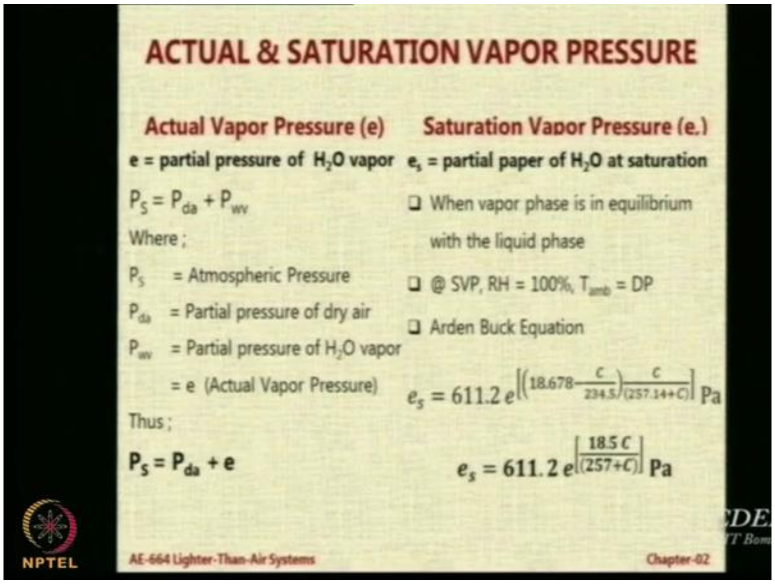

ACTUAL & SATURATION VAPOR PRESSURE

Actual Vapor Pressure (e)

e = partial pressure of H_2O vapor

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

Where ;

P_S = Atmospheric Pressure

P_{da} = Partial pressure of dry air

P_{wv} = Partial pressure of H_2O vapor

= e (Actual Vapor Pressure)

Thus ;

$P_S = P_{da} + e$

Saturation Vapor Pressure (e_s)

e_s = partial paper of H_2O at saturation

❑ When vapor phase is in equilibrium with the liquid phase

❑ @ SVP, RH = 100%, T_{amb} = DP

❑ Arden Buck Equation

$$e_s = 611.2\, e^{\left[\left(18.678-\frac{C}{234.5}\right)\frac{C}{(257.14+C)}\right]}\ \text{Pa}$$

$$e_s = 611.2\, e^{\left[\frac{18.5\,C}{(257+C)}\right]}\ \text{Pa}$$

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So there is something is called actual vapour pressure we call as small e. This is the partial pressure of the water vapour in the atmosphere. You take a small amount or let us say a unit volume of moist air. It consists of a mixture of many many gases homogenous mixture of many many gases one of the gas is water vapour and you know that mixture of gases in a container will exert their own pressures we call it the partial pressure.

So, the partial pressure of the water vapour in air is called as the actual vapour pressure. So, this is basically now P_S is the ambient pressure please note and I am not using P_A because P_A can be confused as pressure of pressure of the air. And you might get mixed up saying air and water vapour. That is why we use s subscript s will be used for something like an atmospheric condition instead of a. So, the pressure of the atmosphere is P_S it consists of many many gases.

So every other gas other than water vapour we could call it as dry air all the Nitrogen, Oxygen and also there are traces of helium in the ambient air and so many other gases all of it are clubed as dry air. And the partial pressure of that is called as P_{da} dry air, da for dry air and the partial pressure of water vapour is P_{wv}. Why are we doing all this? We are doing all this because we want to use pressure volume relationship to figure out a numerical way to calculate the humidity.

And water vapour will stay water vapour as long as we have temperature above Dew Point. So we need to also look at the concepts of relative humidity in that way. So, therefore P_S will be

$$P_S = P_{da} + e$$

I hope this is clear. Athough it may seem a little bit involved right now, but very soon we will use this to convert. Now lt us look at the concept called as e_s. e_s is the saturation vapour pressure this is what occurs in nature.

There is some saturation vapour pressure it is partial not paper but pressure of hydrogen at saturation. It is partial pressure of hydrogen or water vapour at saturation beyond that it will become fluid. So, what happened in this case is very interesting the physical phenomina is extremely interesting. At this particular condition the vapour phase is required in liquid phase. So, both of them are happening simultaneously anything below that. So we know that the RH is going to be 100% when the ambient temperature is equal to dew point.

Now, how do you calculate the saturation vapour pressure it will change based on the temperature of the ambient air. So for that there is an Arden Buck equation which relates the ambient air temperature in centigrade because you mostly measure in centigrade which directly give you the saturation vapour pressure. So it is slightly involved equation.

One can simplify this without much loss in accuracy and make it just like this. So this is a simple formula now. So

$$e_s = 611.2 * \ e^{\frac{18.5\,C}{257+C}} \ \ Pa$$

Then obviously when the value of C is 0 that means when the temperature of the ambient air is 0 e_s will be 1. So, you can calculate the value of e_s simply by noting down the ambient air temperature. I was a bit curious when I was making this transparencies on how much do we actually get in these two?

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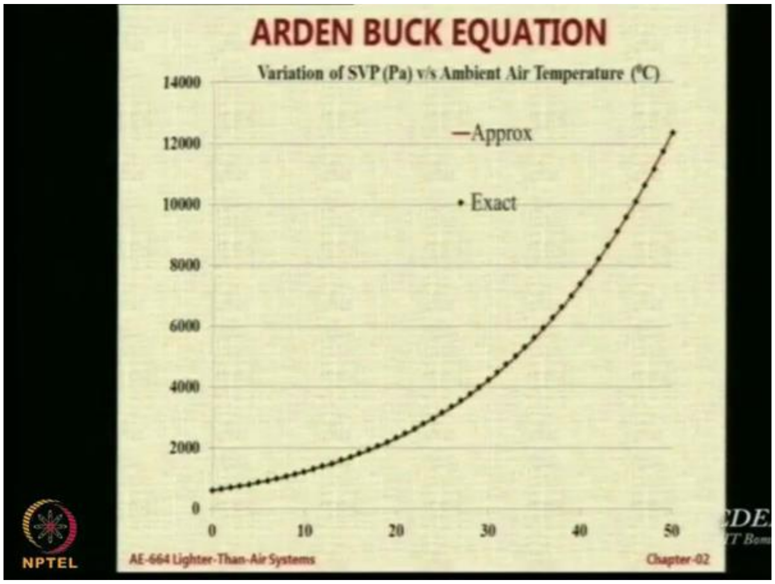

What I did is actually plotted this graph. So the dark line is the approximate value and the points are the exact value you can see there is hardly any difference. So we can safely use a simple formula without much loss and accuracy. So, on the y-axis we have the saturation vapour pressure I will call it as SVP or we can call it as e_S. On the x-axis we have; and if you look at the ambient condition we have around 15 degrees centigrade, you have sucessusful value of around 1700 also. So at 1700 pascal ambient pressure that will be the value.

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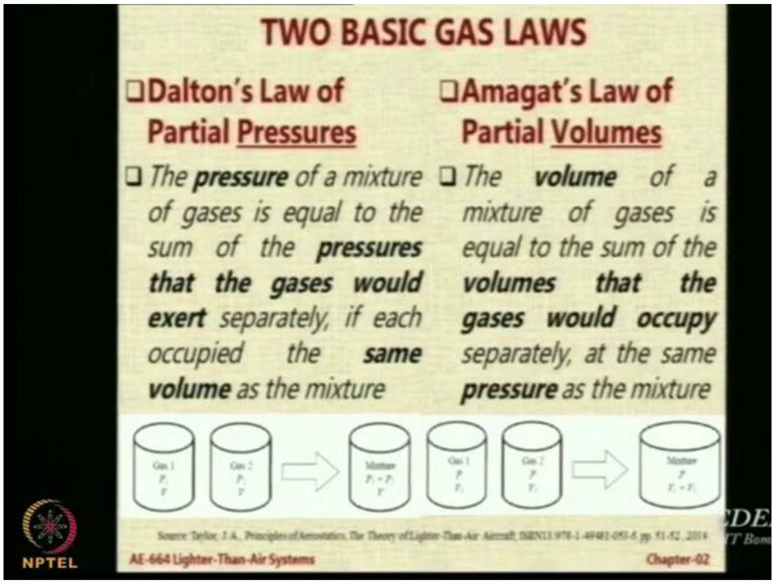

TWO BASIC GAS LAWS

- Dalton's Law of Partial Pressures
  - *The **pressure** of a mixture of gases is equal to the sum of the **pressures that the gases would exert** separately, if each occupied the **same volume** as the mixture*
- Amagat's Law of Partial Volumes
  - *The **volume** of a mixture of gases is equal to the sum of the **volumes that the gases would occupy** separately, at the same **pressure** as the mixture*

Source: Taylor, J.A., Principles of Aerostatics, The Theory of Lighter-Than-Air Aircraft, ISBN13 978-1-49481-053-6, pp. 51-52, 2014

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Now let us revisit to basic gas laws. I must tell you when I made this slide I went back to my own old memories about the schools So Dalton gave us a law of partial pressure though everybody will remember it. I could not recall when I was making this slide. Please tell me what is the Dalton's law of partial pressure, some of the partial pressures. So, if you have gas 1 and gas 2 at pressure P_1 and P_2 but same volume.

So now mix them it will become 2 times volume. Because there will be 2 volume mix but if you half it you will find that the pressure of a mixture of gases is equal to the sum of the pressure when the gas would exert separately is each occupy the same volume as the mixture. So, water vapour, Nitrogen, Oxygen they will not all have the same pressure. Depending on their partial contribution there be partial pressure.

There is also interesting law called as the Amagat's law. This is for partial volumes. This somebody remember this law? This is not something that we really read. So Amagat’s laws is kind of a corollary to the Dalton's law of pressure. What Amagat’s law say is that by volume of a mixture of gases is equal to the sum of the volumes that they would occupy when they are under the same pressure as a mixture.

So, what we will do is, we will use a combination of these two laws to try and get a numerical expression for calculating the effect of relative humidity or RH

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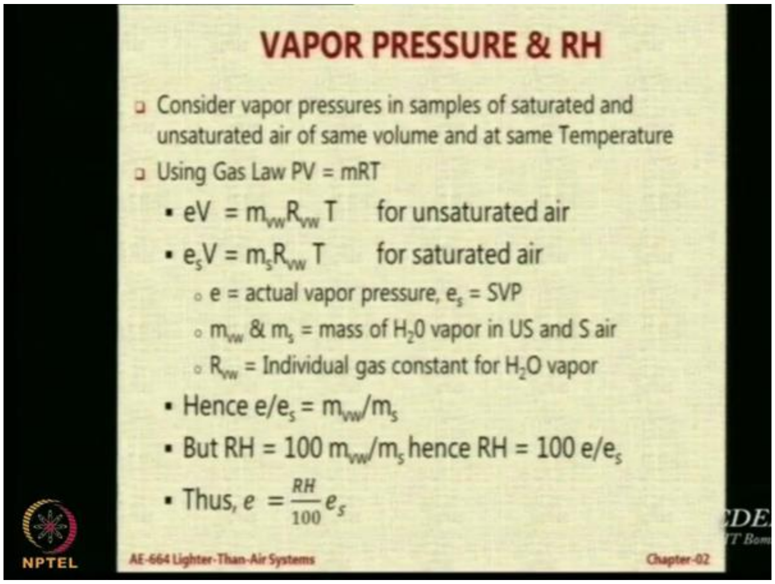

VAPOR PRESSURE & RH

- Consider vapor pressures in samples of saturated and unsaturated air of same volume and at same Temperature
- Using Gas Law PV = mRT
  - $eV = m_{vw}R_{vw}T$ for unsaturated air
  - $e_sV = m_sR_{vw}T$ for saturated air
    - e = actual vapor pressure, e_s = SVP
    - m_{vw} & m_s = mass of H_20 vapor in US and S air
    - R_{vw} = Individual gas constant for H_2O vapor
  - Hence $e/e_s = m_{vw}/m_s$
  - But $RH = 100\ m_{vw}/m_s$ hence $RH = 100\ e/e_s$
  - Thus, $e = \frac{RH}{100} e_s$

So we will look at vapour pressure and RH so what we do is; so consider two kinds of situations one is situation in which the air is saturated with water vapour so it cannot take any more any more water vapour it will condenses into water. And same temperature so gas law is PV = mRT. So for unsaturated air e into V will be now here I have not put e and V, I just V as a volume. So, e is bascically P pressure so the an actual vapour pressure and actual partial masses. Mass of the water vapour and mass of the dry air.

Now just take a ratio you will get $\frac{e}{e_s} = \frac{m_{wv}}{m_s}$. So therefore e which is the vapour pressure of unsaturated air is equal to humidity as a percentage into saturation vapour pressure. So, this is very nice because e_s is a number that you can calculate using that Arden Buck's formula for a given ambient temperature.

So, RH is completely known, RH is given by the atmospheric conditions. RH is an input and e is pressure that you require. Now what do we do with this e we are not dealing with the vapours we are dealing with the combined mixture.