Material and Energy Balance Computations
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Lecture –57
Humidity and Psychrometric Chart - I

Welcome back and as promised in the previous class we are going to start now the last major topic of this particular part of energy balance on chemical process calculation and that is on ‘humidity’. So, what exactly is humidity? Humidity is some water vapour remains suspended in air and we all know that. So, why humidity is important because in industry we have to work with humid air. For example, if you are working on an air conditioner or on cooling of air etc. you might actually be using air. So, now we know from our discussion in the mass balance part where you have learnt about combustion of fuel. You know very well that for combusting any fuel you do not really use molecularly pure oxygen you are always going to use air. And though we always assume that the composition of air is 21 to 79 but in reality, the air might have certain amount of humidity.Or in certain cases as you will learn later in mass transfer some processes like humidification and dehumidification and equipments like cooling tower where the performance depends significantly on the seasonal variations. For example, we all know that in winter the air is mostly dry as there is less amount of humidity. In contrast in late summer or during the monsoon, you have more amount of humidity.

And for example, even during summer in some parts of India, you sweat a lot for example if you are from the part where I am, West Bengal and the coastal parts of the country as you have heat as well as very high humidity. In contrast if you go up north for example in places like Delhi and Kanpur you hardly sweat because its dry heat. So why all these changes actually happen? This happens qualitatively because of the variation in the humidity. Now, as a part of this course we will start learning or quantifying ‘humidity’ and which is in fact a very important and often a confusing factor. So, ‘humidity’ can be defined in several ways and as knowledgeable chemical engineers you must know which approach or which definition of humidity is suitable under what condition and what does each of these ‘definitions of humidity’ means.

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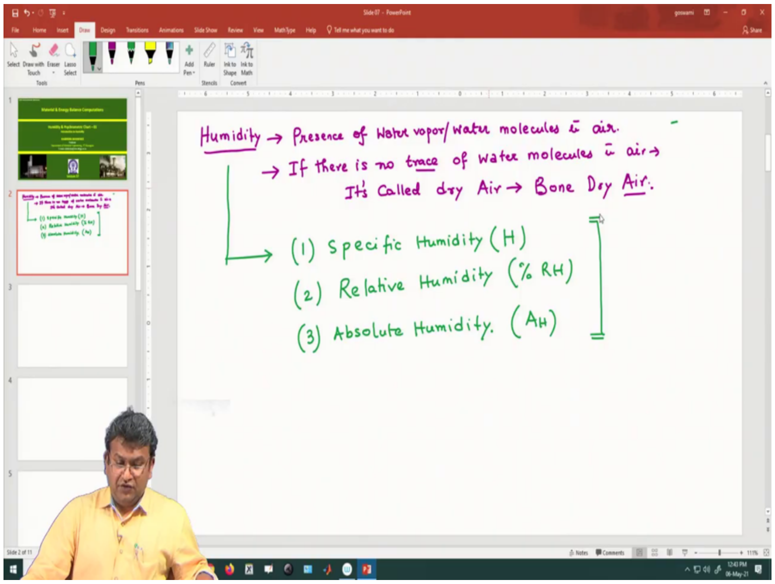

So, humidity is due to presence of water vapor or water molecules in air. Let us start our discussion on 'humidity'. So, humidity is zero if there is no trace of water, it is called dry air or often a particular term is used Bone dry air. So, essentially humidity is the amount of the water molecules present in air. So, the first thing that you should know that humidity can be defined in three ways such as (1) specific humidity (H); (2) relative humidity (%RH) and (3) absolute humidity (A_H). In fact, most of you use cell phone apps these days for checking weather and in monsoon you see there is 90% or 95% humidity and you all know if the humidity is 100% there is possibility of rainfall and precipitation. So, the humidity what you talk about here is relative humidity.

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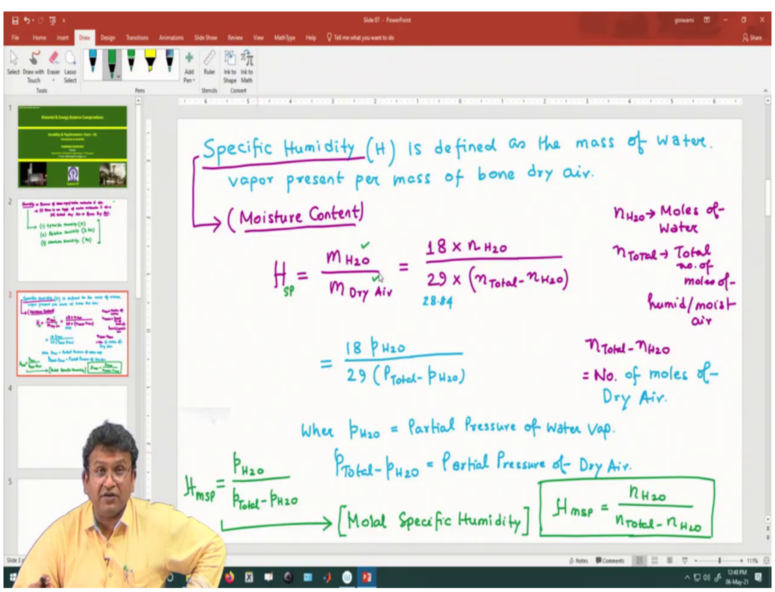

So, let us now talk about specific humidity. It is defined as the mass of water vapour present per mass of Bone-dry air. So, specific humidity sometimes is also referred to as the moisture content. And so, how do you define specific humidity (H)? It is defined as mass of water vapour divided by mass of dry air and this can be represented as

$$H = m_{H2O}/ m_{Dry\ Air} = (18n_{H2O}) / \{29(n_{total} - n_{H2O})\} \text{------------- (1)}$$

Where n_{H2O} is moles of water and n_{total} is total no of moles of humid air and $(n_{total} - n_{H2O})$ is number of moles of dry air. I think this is clear to all of you. And, why 18 and 29? You are simply multiplying the number of moles with the respective molecular weight. If you want to be very precise you can write 28.84 instead of 29. Now, we also know that this can be represented as $18p_{H2O}/29(P_{total}- p_{H2O})$. As we know that the molar ratio is equal to mole fraction which is equal to partial pressure. Where p_{H2O} is the partial pressure of water vapour and of course $(P_{total} - p_{H2O})$ is partial pressure of dry air. And this particular term $p_{H2O}/(P_{total}- p_{H2O})$ is referred to as 'Molal specific humidity' (H_{msp}). So, for specific humidity you can write H or H_{sp} whichever is convenient to you. H_{sp} is essentially the mass of water divided by mass of dry air and that you can express in terms of the number of moles present as shown in eq (1) and here you can also define the molar specific humidity which is the moles of water vapour divided by moles of dry air and that also turns out to be the ratio of partial pressure of H_2O divided by the partial pressure of dry air.

As it is a ratio of weight by weight, therefore there is no unit; but you can also have something called specific molar humidity where it is essentially moles by moles. So, you can obviously understand the relation between the two as $H_{sp} = (18/29)\ H_{msp}$. So, this is obvious and there is reason why in certain cases the Molal specific humidity might be more useful.

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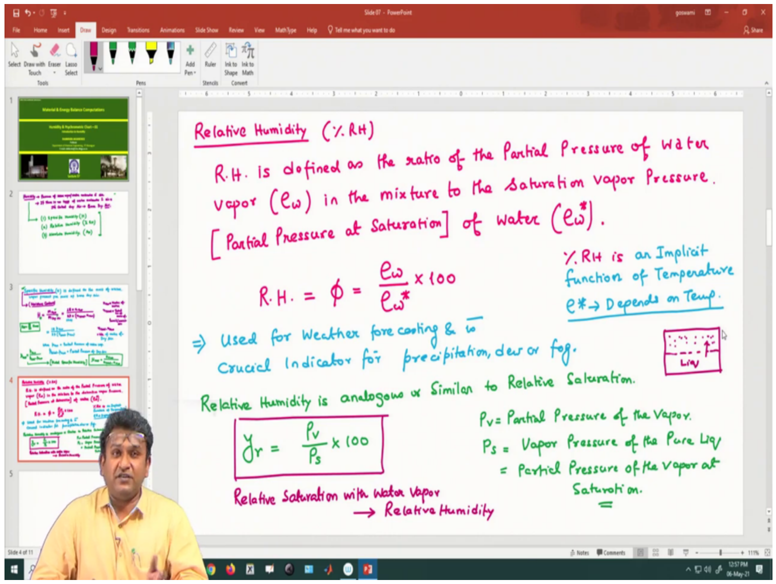

Next we move on to the next set of definition which is the most important definition at least from the standpoint of weather forecasting and weather prediction and stuff like that; which is the ‘relative humidity’. Relative humidity is an interesting parameter and please do understand that you can define the specific humidity, but it does not talk about the temperature anywhere. So, we will see what the relation between this humidity and the temperature is.

So, relative humidity as it is called the %RH or RH simply. Relative humidity is defined as the ratio of the partial pressure of water vapour (e_w) in the mixture to the saturation vapour pressure which is nothing but partial pressure at saturation vapour pressure of water. So, RH is typically represented as

$$RH = \phi = (e_w / e_w^*) \times 100 \text{---------------------(2)}$$

Now, most importantly though not explicitly %R H is an implicit function of temperature. Why? because e* depends on temperature. How do you know it depends on temperature? We will talk about it. This is as I mentioned used for weather forecasting and is crucial indicator for precipitation that is rainfall or snowfall, dew or fog. Now, relative humidity is for water of course we use it, but it is very similar to what is known as relative saturation. Because please do understand that partial pressure and vapour pressure are terms which are not specific to water. These are perfectly valid terms for any liquid which evaporates in air for example. So, relative humidity is analogous or relative saturation. Now, relative saturation (y_r) is given as

$$y_r = (P_V / P_S) \times 100 \text{---------------------(2a)}$$

Where P_V is the partial pressure of the vapour, and P_S is the vapour pressure of the pure liquid which is equal to partial pressure of the vapour at saturation. It is very interesting to note that vapour pressure is actually a property of the liquid and not a property of the vapour. So, what exactly is vapour pressure? Vapour pressure is nothing but partial pressure at saturation. So, if you have a liquid in a container, the surrounding space gets completely saturated with the presence of vapour. So, vapour pressure is nothing but partial pressure of the vapour at saturation. So, that is what is y_r which is relative saturation. And so, now we understand essentially relative saturation with water vapour that is when we are talking about relative humidity nothing else. What I mean to say that if you have a container closed container which has some liquid and at a particular temperature some liquid molecules evaporate, and it sort of gets saturated. Let us say the vapour space you have here relative saturation to be 100% in this particular case. Now if that liquid is water then you say relative humidity is 100%. So, relative humidity and relative saturation are identical only where the liquid concerned is water.

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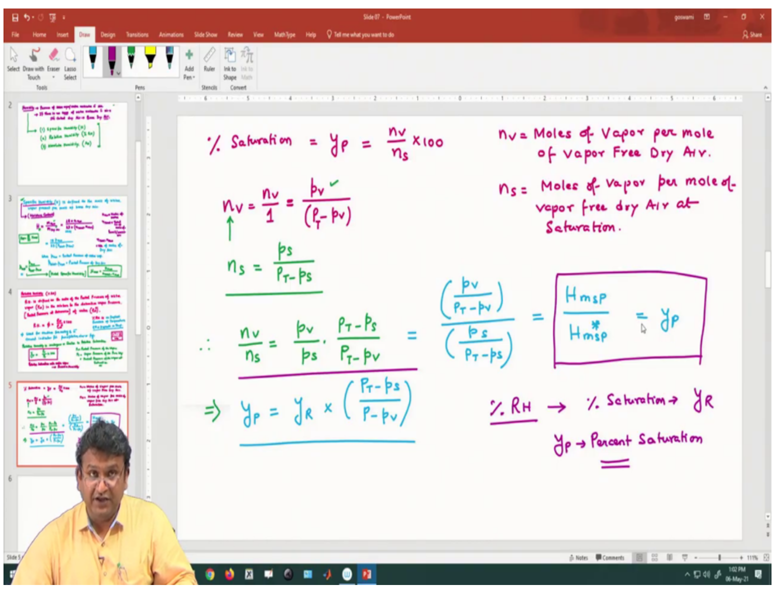

Now let us define another term which is percentage saturation. Percentage saturation we can refer to as y_p which can be represented as

$$\% \text{ Saturation} = y_P = (n_V/n_S) \times 100 \text{ -------------------------- (2b)}$$

where n_v = moles of vapour per mole of vapour free dry air and n_s = moles of vapour per mole of vapour free dry air at saturation. Actually, if you see n_v is (n_v / 1) and n v is the moles of the vapour per mole of dry air. So, $n_v = n_v/1 = p_v/(P_T-p_v)$. And therefore, $n_s = p_s/(P_T-p_s)$ and $n_v/n_s = (p_v/p_s)\{(P_T-p_s)/(P_T-p_v)\}$ and it can be further represented by different derived forms as shown in the above slide.

And in terms of partial pressure therefore you can write this as

$$y_P = y_R \times (p_v - p_S) / (P_T - p_v) \text{ ------------------------- (2c)}$$

where y_p is percent saturation, y_R is relative saturation, P_T is the total pressure, p v is the partial pressure of the vapour and (P- p_v) is the partial pressure of dry air. Now, what is p_v/ (p_T - p_v)? It is nothing but specific molar humidity. So, this is nothing but specific molar humidity and p_s/ (p_T - p_v) is specific molar humidity at saturation. So, this way they are all in fact connected and therefore you now know a relation.

And we can also find out the relation between the percent saturation and the relative saturation and we also can correlate percent saturation in terms of the molar specific heat and ratio of molar specific humidity not heat sorry molar specific humidity and the molar specific humidity at saturation. So, all this can be done these are all very simple concepts and you mostly know about it.

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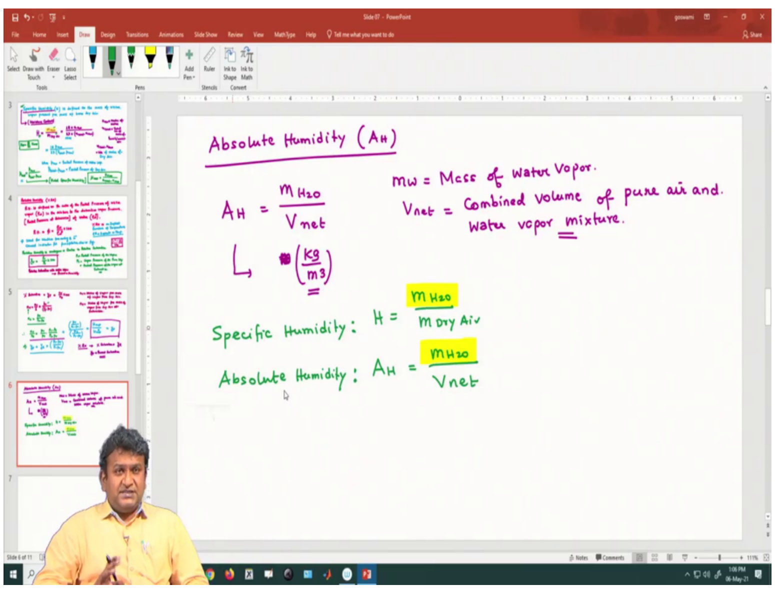

The third way of defining humidity is what is known as absolute humidity and absolute humidity as it referred to as A H,

$$A_H = m_w/V_{net} \text{ ------------------------- (3)}$$

Where m_w is equal to mass of water vapour and V_{net} is the combined volume of pure air and water vapour mixture. So, this is how it is defined. it is a ratio but what is the fundamental difference between the previous two both specific humidity and relative humidity. they did not have any unit. Of course, relative humidity if you multiply it with 100 you express it in terms of percent relative humidity; but absolute humidity comes with a unit and not only that its mass per volume. So, it is of the form kg per meter cube or whatever but more importantly what you should really keep in mind right is that when you are calculating absolute humidity you are essentially considering the volume of both dry air and the moisture that is present.

So, the collective volume the total volume we will soon see that in presence of moisture the volume increases. And when you were calculating the specific humidity you were dividing the weight of water vapour of course it was weight by weight that was one part of it here it is weight by volume there also it was essentially we are looking into the mass of the water vapour present. So, the numerator please remember that the numerator in case of the specific humidity and absolute humidity are same.

Numerator for specific humidity and absolute humidity are same that is mass of H_2O, m_w. But the denominators are different. Not only they are different that in the first case it is weight and the second case it is volume. Most importantly for specific humidity what we have is the denominator contains only the weight of dry air and in case of absolute humidity the denominator contains the total volume that is the volume of dry air as well as that occupied by the water vapour.

So, we are running out of time and we will stop this lecture here and after this lecture I expect that all of you have understood very nicely how in three different ways humidity can be expressed apart from understanding what exactly is humidity. And we will now understand how if the humidity is different how that is going to show up or manifest in terms of temperature in our next lecture, thank you.