Applied Thermodynamics for Engineers

Dipankar N. Basu
Department of Mechanical Engineering
Indian Institute of Technology – Guwahati

Lecture – 34
Sensible Heat Factor and Bypass Factor

Good morning everyone, welcome to the third and last lecture for this particular week where we are talking about the gas vapour mixtures and its application to different kind of psychometric processes. Now over previous two lectures you have been introduced to different kind of parameters or properties that we commonly associated with the gas vapour mixtures. Then in the second lecture we have discussed about the psychometric chart and its application in the field of air conditioning to be particular.

And also, we have talked about different kind of psychometric processes like the sensible heating and cooling processes, humidification and dehumidification processes and also processes like heating and humidification or cooling and dehumidification etc. So, these are very common processes that we commonly encountered in air conditioning devices and therefore it is important to have some idea about each of them.

But as we have seen the thermodynamic analysis for such systems or such psychometric processes are not difficult, we just have to plot the processes on the psychometric chart for the representation purpose. And then using simple mass balance and energy balance we can get all the required thermodynamic parameters. And it is also important to note that the mass balance commonly needs to be performed on both the dry air part and the water vapour part separately because both of them can change individually.

Like the examples that we have discussed in the previous lecture there we were just modulating with the water vapour part, like during the humidification or dehumidification process it is the water vapour quantity that changes accordingly the specific humidity or may be relative humidity or may be both that keeps on changing, particularly the specific humidity I should say. Whereas during the sensible heating or cooling processes the specific humidity remains constant whereas relative humidity may change depending on the direction of change in temperature.

Similarly, when the processes where we have simultaneous modulation of temperature and humidity, we also have changes in the water vapour content. But in none of the processes there is any change in the dry air quantity and therefore quite often for analyzing these processes we just do not bother about the dry air part, simply because there is no change. We do not have to write any mass conservation equation for the dry air part, we just have to consider mass conservation for the water vapour part.

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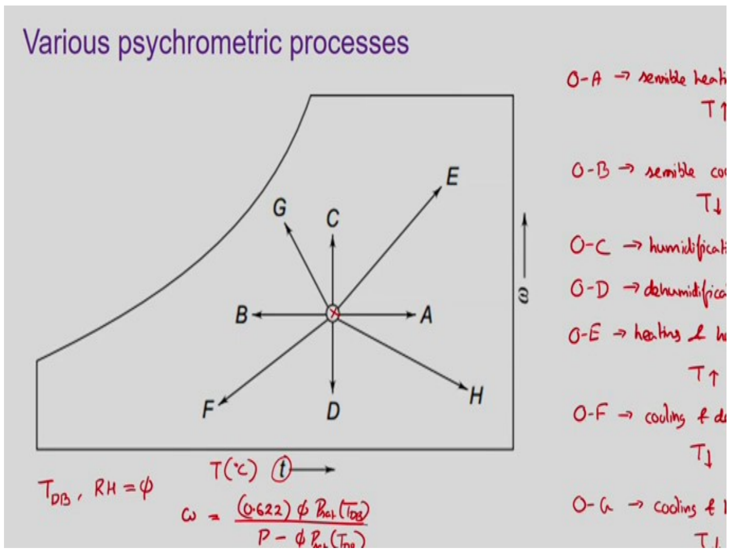

Again, as a quick recap here again I am having a psychometric chart where various psychometric processes are shown. Here the horizontal axis is just t let us use T which is commonly given degree Celsius. That is the convention that we are following so far. So, starting from this particular point shown by the circle there are eight different processes shown here. Let us try to identify the nature of each of the processes. So, if that is point is O.

Then OA, what kind of process is this, can you say? During the process the temperature is increasing specific humidity remains constant. Therefore, this process is a sensible heating process. Given the sensible heating process, what is happening to the concerned parameters? Your temperature is increasing and the specific humidity remains constant. What about relative humidity, what will happen to the relative humidity?

We know that as the temperature is increasing the saturation pressure corresponding to the temperature that also increases and therefore the denominator term in the definition of the relative humidity that keeps on becoming larger while the numerator remains the same and therefore ϕ decreases. You can also get that idea from the psychometric chart because this line is the saturation curve corresponding to the 100% relative humidity and as we are moving inwards then we are having different relative humidity lines. But the relative humidity is continuously decreasing as we are going forward, that is relative humidity increases in this particular direction. So, as we moving from point O to A, we are actually having a decrease in relative humidity.

Similarly, O to B, during this process temperature decreases and ω remains the same. So, it is a sensible cooling process during which the temperature decreases again ω remains the same. And relative humidity, what will happen to that? Now we are moving towards the saturation curve so relative humidity will increase. Process O to C what kind of process is this? Temperature is constant specific humidity is increasing. So, this is a humidification process. During this process the moisture content is changing but temperature is not changing. So, during this process the temperature remains constant ω is increasing what will happen to ϕ? What will happen to the relative humidity?

As temperature is constant, so like the in the definition of ϕ we know that:

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

As temperature is constant the saturation pressure is also constant. So, while the numerator changes the denominator remains constant. Now during this humidification process as ω is increasing means the moisture content in the sample is increasing accordingly the numerator is increasing so ϕ is also going to increase because the denominator remains constant.

And the reverse process of this one, O to D during which the moisture content decreases but temperature remains constant, so it is a dehumidification process. During which again the temperature remains constant, ω is decreasing and what will happen to ϕ? As moisture content is decreasing the partial pressure for the water vapour part will also decrease, denominator remains same, accordingly ϕ will also decrease.

Now let us pick up O to E, what is happening during this process? Both temperature and ω are increasing so we should call this one as heating and humidification process. In the previous lecture we have seen this particular process and also solve one numerical problem on this. So, during this process temperature increases, ω also increases, what about ϕ? Now it is difficult to say actually from this diagram because it is very much possible that depending upon the combination of this temperature and ω, ϕ may increase, may decrease or ϕ may remain the same as well. So, we are not sure about the value of this ϕ because during this process if you look at the expression for this ϕ, ω is increasing so the partial pressure for water vapour is increasing. But as the temperature is increasing the saturation pressure is also increasing. So, both numerator and denominator are increasing. So, we are not sure about the change in ϕ.

Similarly, if we look at O to F then what is happening during this process? Temperature is decreasing, moisture content is also decreasing, so this is the cooling and dehumidification process. While the heating and humidification is the most common kind of process performed in colder areas, cold and dry areas. Cooling and dehumidification is the most common kind of process that you will encounter in warm and wet or warm and humid areas. So, during this process just it is opposite to the previous one temperature decreases ω decreases and again we are not sure about the changes in ϕ. Because in the expression for the relative humidity both the numerator and denominator are decreasing so the magnitude of ϕ can change in any direction.

Now we have the process O to G. First, what is happening during this one? Temperature is decreasing ω is increasing. So, temperature is decreasing means it is cooling, but it is humidification. This is cooling and humidification, means during this process temperature is decreasing but ω is increasing. What will happen to ϕ? Can you say from the chart? Here at this point, G is moving towards the saturation curve so ϕ should increase. And from the mathematical expression here the moisture content is increasing, so the partial pressure for water vapour that is in the numerator that will increase. And saturation pressure as the temperature is decreasing, the saturation pressure will decrease. So, we are having a numerator increasing, the denominator is decreasing, so ϕ has to increase in both counts.

Similarly, the last one O to H, during which temperature is increasing, so we are having heating but moisture content is decreasing. So, it is heating and dehumidification. And the last two processes may not be the most common one but cold and humidification you can find because in the dry areas where during the summer you may have to go for simultaneous cooling and humidification. Heating and humidification is much less common may be required in certain industrial processes but not very common in domestic air conditioning. So, during this process as you can see from the chart temperature is increasing, ω is decreasing.

What will happen to ϕ? So ϕ we are moving further from the saturation curve, so ϕ also has to decrease. Again, from the mathematical expression point of view, both the numerator and denominator, here the numerator is decreasing because ω is decreasing denominator is increasing so in both count ϕ has to decrease.

Now the most common information that are generally provided by the weather department are temperature, that is the dry bulb temperature you can say and the relative humidity which is nothing but the ϕ. And of course, pressure we are assuming as the atmospheric pressure. So, we can easily identify this point on a psychometric chart and identify other magnitudes of other relevant quantities or we can go by the mathematical relation that we have developed in the previous lecture or in the first lecture truly speaking.

Like if you know the dry bulb temperature and relative humidity, how can you calculate the specific humidity from this? How can you calculate ω from this? You know that ω and ϕ has a relation something like,

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

And once you get ω from this, we know how to calculate enthalpy. Enthalpy will become:

$$h = \left(C_{p,da}\,T_{DB}\right) + \omega[2500.9 + 1.82T_{DB}]$$

The first term in the above equation is this for the moisture part, so instead of writing this so we can really replace the C_p for dry air which is 1.005.

$$h = (1.005\,T_{DB}) + \omega[2500.9 + 1.82T_{DB}]$$

So, we can get the enthalpy using the ω and dry bulb temperature. We can also calculate the wet bulb temperature in the same way and if the wet bulb temperature is given like not very common but in certain industrial processes, particularly if you are having a wet bulb thermometer which is giving you the values of both dry bulb and wet bulb temperature, then instead of ϕ you know the value of wet bulb temperature (T_{WB}) and dry bulb temperature(T_{DB}).

So, from there how can you calculate ω, remember the mathematic analysis that we have performed corresponding to the adiabatic saturator. There ω was obtained by:

$$\omega = \frac{1.005(T_{DB} - T_{WB}) + \omega_s \times h_{fg(T_{WB})}}{h_{g(T_{DB})} - h_{f(T_{WB})}}$$

Here this ω_s corresponds to the specific humidity corresponding to the wet bulb temperature point, which is nothing but,

$$\omega_s = (0.622)\frac{P_{sat}(T_{WB})}{P - P_{sat}(T_{WB})}$$

So, this way, from the knowledge of this dry bulb and wet bulb temperature you get the ω and then successively you can get enthalpy, specific volume etc or if you know the dry bulb temperature and ϕ we can we can go for the same analysis.

Now I would like to talk about another psychometric processes like eight of the processes you have listed here and you know how to analyse each of them. But there is another one, all the eight that we are seeing here there we are not having any change in the dry air components, but they may or may not be changing the water vapour part but it is always compulsory that the dry air part remains the same.

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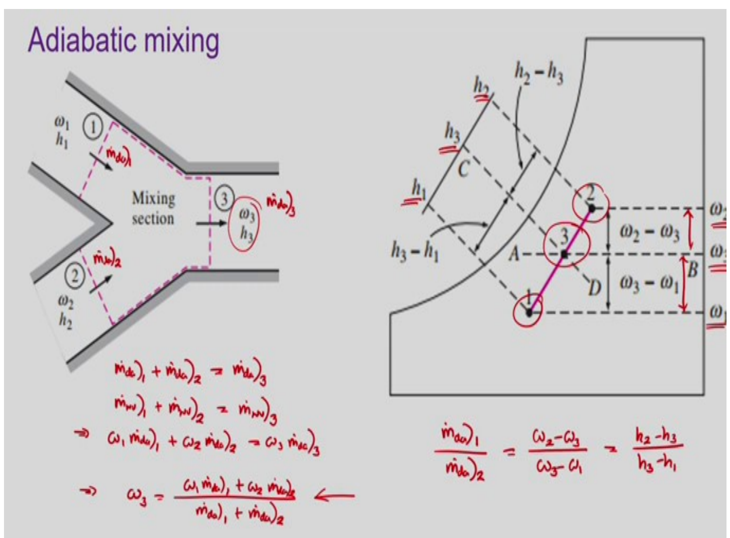

But that is not the case in this particular situation. Here we are talking about an adiabatic mixing we are having two different streams of air coming into the different properties like the stream 1 is having specific and humidity of ω_1 one and enthalpy of h_1 stream 2 is having specific humidity of ω_2 and enthalpy of h_2 and they are mixing with each other in this adiabatic chamber and finally coming out with ω_3 and h_3.

Their mass flow rates are also different. Let us say the mass flow rate for this one at least the dry air part is 1. This is corresponding mass flow rate for dry air part is 2 and this final mass flow rate for the dry air part is 3 in this case. This is the representation on the corresponding psychometric chart. I am coming there but before that let us just perform the mass balance on this. So, here the dry air quantity is changing, so we have to perform the mass balance on the dry air as well.

So, we can easily write,

$$\dot{m}_{da})_1 + \dot{m}_{da})_2 = \dot{m}_{da})_3$$

So, we are having the mass of the final mixture the dry air component. Now if you write the water for the water vapour part, we have:

$$\dot{m}_{wv})_1 + \dot{m}_{wv})_2 = \dot{m}_{wv})_3$$

assuming there is no condensation happening or no additional moisture being added to the mixture. Then from there we can write for the first part it can be written as,

$$\omega_1 \dot{m}_{da})_1 + \omega_2 \dot{m}_{da})_2 = \omega_3 \dot{m}_{da})_3$$

from here we can get the specific humidity for the final mixture to be equal to:

$$\omega_3 = \frac{\omega_1 \dot{m}_{da})_1 + \omega_2 \dot{m}_{da})_2}{\dot{m}_{da})_1 + \dot{m}_{da})_2}$$

This is the final the specific humidity for the final mixture.

Similarly, if we perform an energy balance on the same,

$$\dot{m}_{da})_1 h_1 + \dot{m}_{da})_2 h_2 = \dot{m}_{da})_3 h_3$$

from here we can write the enthalpy for the final mixture to be equal to:

$$h_3 = \frac{\dot{m}_{da})_1 h_1 + \dot{m}_{da})_2 h_2}{\dot{m}_{da})_1 + \dot{m}_{da})_2}$$

So, if we know the mass flow rate for the dry air part and also the properties for both the streams, we can also get the properties for the final stream. Now if we just compare these expressions that we have just developed. From this one and also from this one, actually there is something very interesting that we can develop. That is if we write,

$$\frac{\dot{m}_{da})_1}{\dot{m}_{da})_2} = \frac{\omega_2 - \omega_3}{\omega_3 - \omega_1} = \frac{h_2 - h_3}{h_3 - h_1}$$

this is just simple manipulation of the two expressions we have just developed.

From there we can easily obtain this particular expression. So, like from the mass balance expression that we have got, just separate out the $\dot{m}_{dry\ air}$ part and similarly $\dot{m}_{da1}$ and even $\dot{m}_{da2}$. So, from there you will be able to get this one and same from the energy balance you will be getting expression in terms of enthalpy. So, what does that shows? Look at the graph that we have here, so this point 1 is the state for stream 1, point 2 refers the state for the stream 2. There are temperatures T_1 or corresponding enthalpy for stream 1 is h_1, specific humidity here which is ω_1 similarly for stream 2 it is h_2 and ω_2.

Now during this mixing process of course the final point 3 will be lying somewhere along the straight line joining point 1 and 2. But where that straight line will be? For that we can easily identify this particular magnitude of h_3 and ω_3, because the ratio of the mass flow rate for these two streams will determine the position of this ω_3 and h_3. Now as this ratio is always given by this:

$$= \frac{\omega_2 - \omega_3}{\omega_3 - \omega_1}$$

Therefore, the distance between this $\omega_2 - \omega_1$ actually is getting divided into two parts. We can write this one as

$$(\omega_2 - \omega_1) = (\omega_2 - \omega_3) - (\omega_3 - \omega_1)$$

and this is the first part $(\omega_2 - \omega_3)$ this is the second part $(\omega_3 - \omega_1)$. Now depending on the ratio of the mass flow rates for this stream there is only one possible value of ω_3 and therefore the final point 3 should lie along this particular dotted line corresponding to this ω_3. But the enthalpy ratio also has to be maintained and therefore whatever the dotted line that we are getting corresponds to h_3 this point should also lie on that particular line. That was the only position that we can have is the intersection of these two dotted lines, the one corresponding to ω_3 and the one corresponding to h_3. Only by balancing the mass flow rates for these two quantities or the ratio of the mass flow rates for the dry air part we can change the position of 3. Such kind of adiabatic mixing is very common in air conditioning application.

Like in common air conditioners you will find there are two fans, in one the fresh air which has just been conditioned inside the air conditioner is supplied to the room whereas using the other fan which is a suction fan the used air from the room is picked up, it is being dragged back and it goes to the surroundings. But in every cycle, we are just trying to remove entire quantity of air and again fill that particular gap by a fresh supply of conditioned air then the load on the fence will be too high and also, the load on the air conditioners will be too high. So, quite often we just do not discard the entire quantity of the exhaust, rather a part of the exhaust comes back and gets mixed with the freshly conditioned air thereby reducing the quantity of conditioned fresh conditioned air requirement. And it is very much possible like suppose if we are taking say 100 units of air back from the room wherein may be only 30 units of that goes to the surroundings, remaining 70 unit comes in and that gets mixed with 30 units of fresh conditioned air and subsequently the entire 100 unit of this mixture comes back to the room.

So, if we are rejecting or exhausting this entire 100 units of air, then your air conditioner has to condition again 100 units of air. But in this situation because of the mixing we just have to condition only 30 units of this. Of course, this fraction like the 70:30, that I have mentioned that depends upon what kind of applications you are in. This 30 or 40% is a very common ratios that we get in domestic air conditioners. Whereas in critical applications like say in a hospital, there probably 100% fresh air is supplied.

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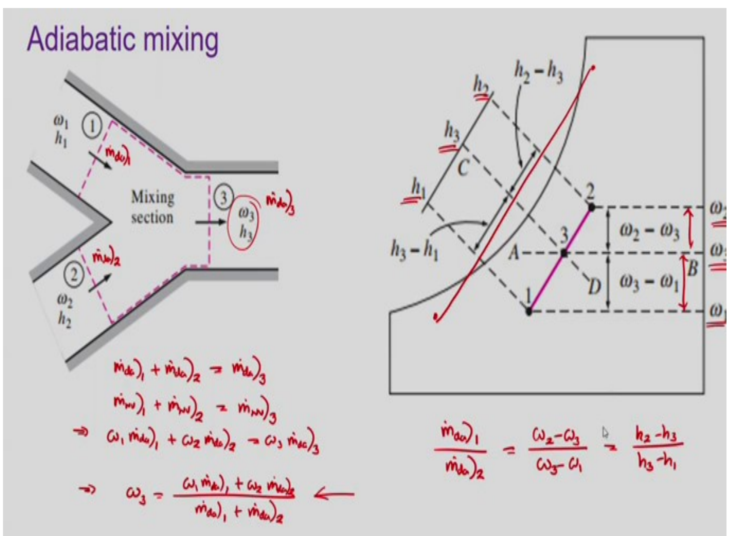

Now let us try to solve one quick example to see this mixing process. Here there are two streams. So, for the stream one,

$$\dot{V}_1 = 30\ m^3/min$$

$$T_{DB,1} = 15^0C$$

$$T_{WB,1} = 13^0C$$

for the second stream,

$$\dot{V}_2 = 12\ m^3/min$$

$$T_{DB,2} = 25^0C$$

$$T_{WB,2} = 18^0C$$

We have to determine the dry bulb and wet bulb temperature of the resultant mixture.

Now we know the dry bulb and wet bulb temperature for both the streams. So, from there we can easily calculate the value of ω. Like for the first one, we can easily calculate:

$$\omega_{s1} = \frac{(0.622)P_{sat}\,(T_{WB})}{P - P_{sat}\,(T_{WB})}$$

here everything is happening under standard atmospheric pressure, so

$$P = 101.325 \text{ kPa}$$

If you are trying to plot this on a psychometric chart, then you have to use a standard psychometric chart corresponding with the standard atmospheric pressure. So, once we have ω_{s1} you can just check this particular relation, from there we can get the final value of ω. So, putting this using the information about ω_{s1} and the enthalpy values corresponding to the dry bulb and wet bulb temperature you have the value of ω_1 which in this case will be coming as: $\omega_1 = 0.0084$ kg/kg of dry air.

And accordingly, the enthalpy,

$$h_1 = \left(1.005\ T_{DB,1}\right) + [2500.9 + 1.82T_{DB,1}]\omega_1$$

that putting the value of the dry bulb temperature which is 15 in this case remember here these temperatures are put in Celsius that I keep on repeating because this is a deviation from whatever convention that you have followed so far. So, accordingly we are getting the value of enthalpy to be

$$= 36.85 \text{ kJ/kg of dry air.}$$

The same way you can calculate a specific volume as well for the dry air part we need to know the specific volume because you have to calculate the mass flow rate also. So, a specific volume for dry air corresponding to 1, how much it should be? So, it should be:

$$v_{da,1} = \frac{R_{da}T_1}{P} = \frac{0.287 \times 288}{101.325} = 0.827m^3/kg$$

This is for the dry air part only, accordingly the mass flow rate for this dry air part becomes:

$$\dot{m}_{da,1} = \frac{\dot{V}_1}{v_{da,1}} = \frac{30}{0.827} = 36.2\ kg/min$$

Just repeat the entire procedure for the second stream for this case your ω will be coming the following the similar procedure as:

ω_2 = 0.01 kg/kg of dry air

h_2 = 51.1 kJ/ kg of dry air

And specific volume for the dry air part for this is:

$$v_{da,2} = \frac{R_{da}T_2}{P} = 0.859\ m^3/kg$$

from where we are getting the mass flow rate for the dry air part in the second stream which is:

$$\dot{m}_{da,2} = \frac{\dot{V}_2}{v_{da,2}} = 13.9\ kg/min$$

So,

$$\dot{m}_{da,3} = \dot{m}_{da,1} + \dot{m}_{da,2}$$

because dry air part is directly getting added and therefore, we are having:

$$= 36.2 + 13.9 = 50.1\ kg/min$$

So, from there you have to get the final dry bulb and wet bulb temperature. Using this mass flow rate, we can get ω_3, we know that ω_3 will be equal to:

$$\omega_3 = \frac{\omega_1\dot{m}_{da})_1 + \omega_2\dot{m}_{da})_2}{\dot{m}_{da})_3}$$

which is coming to be equal to:

$$= 0.00886\ kg/kg\ of\ da$$

Again

$$h_3 = \frac{\dot{m}_{da})_1 h_1 + \dot{m}_{da})_2 h_2}{\dot{m}_{da})_3} = 40.8\ kJ/kg\ of\ da$$

So, we have to identify these two points we can go for a mathematical analysis or we can just try to identify this point on the psychometric chart to locate this particular state point and all you can go by the mathematical analysis like as you already know ω_3 and h_3. So, you can replace this:

$$h_3 = (1.005)\ T_{DB,3} + \omega_3[2500.9 + 1.82\ T_{DB,3}]$$

from where you can get the value of dry bulb temperature at this point.

I am giving you the final answer, the dry bulb temperature for this stream 3 is coming to be 17.5 ^{0}C and the wet bulb temperature will be 14.5 ^{0}C. I have shown you how to get the dry bulb temperature, try to find a way of estimating this wet bulb temperature, that I am leaving to you. Now when this mixing process happening if I just quickly go back to the previous slide here you can see here the final point 3 is located on the straight-line joining point 2 and 1.

So, suppose if you are dealing with a situation where one stream is extremely cold, whereas the other stream is hot and high in moisture content, like suppose your point 1 is located somewhere here and point 2 is located somewhere here, then if you join them by a straight line then it is very likely that point 3 is located somewhere outside the psychometric chart. In that situation of course, the additional moisture that is present and this situation is not feasible and therefore the additional moisture that is present here that will get condensed.

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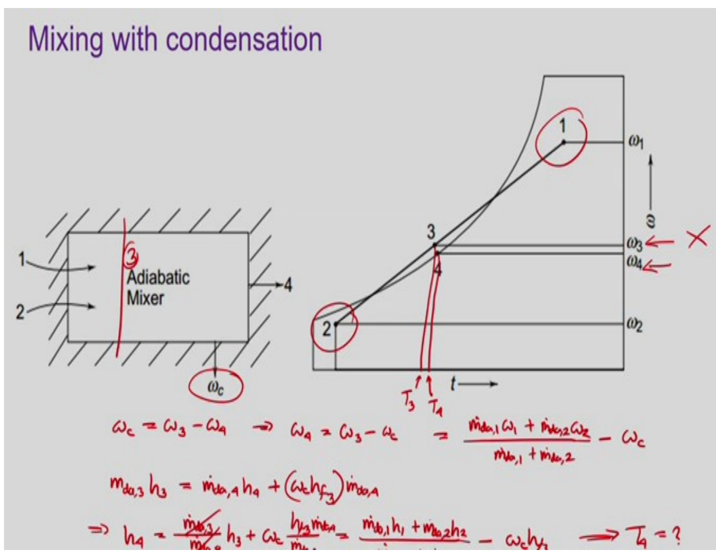

Just like a situation here, in certain situations we get this mixing with the condensation process. It happens when we are mixing one very cold stream of air and another quite one stream of air which is also high in moisture content and then depending upon the ratio their mass flow rates their final state may be located at this point 3, which is outside the psychometric chart. And so, to have a feasible solution it has to reject this additional amount of moisture so that its moisture content comes back from ω_3 which is not feasible to this ω_4 and accordingly the final state point will be ω_4 which will lie on this saturation curve. Correspondingly there will be also change in the temperature because as this additional moisture which is present in the final mixture that gets condensed that will reject its latent heat and by receiving that latent heat there will be rising the temperature also. Like if we draw the projection this is your T_3 and this is your T_4. So, this point is your T_3 this point is your T_4, depending upon the location of 3, T_3 and T_4 may have very small difference like in these situations or may have quite significant difference as well. Now in order to identify the magnitude of this ω_c which refers to the mass of condensate that has been collected that gets separated out.

Then look at this point 4, so what will be your ω_c? ω_c is the difference between the specific humidity between 3 and 4, so this is nothing but,

$$\omega_c = \omega_3 - \omega_4$$

and therefore

$$\omega_4 = \omega_3 - \omega_c$$

Now from the previous analysis we the expression for ω_3 can be substituted in the above equation as:

$$\omega_3 = \frac{\dot{m}_{da,1}\omega_1 + \dot{m}_{da,2}\omega_2}{\dot{m}_{da,1} + \dot{m}_{da,2}} - \omega_c$$

So, from measuring ω_c you can identify location of this point number 4 from here. Also, if we perform that energy balance to identify the temperature of this, then the final. Let us say, in the adiabatic mixture is in between states 1 and 2, then at this point your state is 3 and then it is getting separated into 4 and ω_c. Then if we perform an energy balance on this then,

$$\dot{m}_{da,3}h_3 = \dot{m}_{da,4}h_4 + \omega_c h_{f4}$$

Because it is most likely that, actually it is difficult to say ω_c will be at which temperature. Let us assume ω_c to be at the temperature of 3 only, because it is getting formed because of the condensation of the moisture which is present at temperature T_3. Then from there we have to identify h_4, so your h_4 is becoming now:

$$h_4 = \frac{\dot{m}_{da,3}}{\dot{m}_{da,4}}h_3 + \omega_c \frac{h_{f3}\dot{m}_{da,4}}{\dot{m}_{da,3}}$$

Now $\dot{m}_{da,3}$ and $\dot{m}_{da,4}$ are same because there is no change in the dry air quantity during this condensation process. In the first term they cancel out and h_3 remains. As h3 is:

$$h_3 = \frac{\dot{m}_{da1}h_1 + \dot{m}_{da2}h_2}{\dot{m}_{da1} + \dot{m}_{da2}}$$

Substituting this value of h_3 in the equation for h_4, h_4 can be written as:

$$h_4 = \frac{\dot{m}_{da1}h_1 + \dot{m}_{da2}h_2}{\dot{m}_{da1} + \dot{m}_{da2}} - \omega_c h_{f3}$$

As we have already calculated ω_c from practical measurement or maybe from some other information then you can easily look at the view of h_4. And once you know h_4, from h_4 you can get the value of this T_4 as well, using the formula that we keep on using so till now. So, this mixing with condensation is not the most common process in air-conditioning application but in real life you must have seen this particular scenario.

Like just think about the scenario of a winter day where this stream 2 corresponds to a very cold air in contact with the ground. Whereas the 1 may correspond to the warm and moist air which may appear in the higher atmosphere in the evening time or when the sun is out. When these two streams with mix with each other, then what we see? We have seen the formation of fog or frost, which basically is the air containing lots of water molecules in the liquid form in the form of various fine droplets.

And this is nothing but this mixing with condensation, the mixing of very cold air in contact with the ground and warmer air with high moisture content. They are mixing with together and for leading to the formation of lots of minute water droplets which keeps on floating with the air, that is what we call the fog. Now I would like to close this lecture by defining 2 factors which are very commonly used in standard air conditioning calculations.

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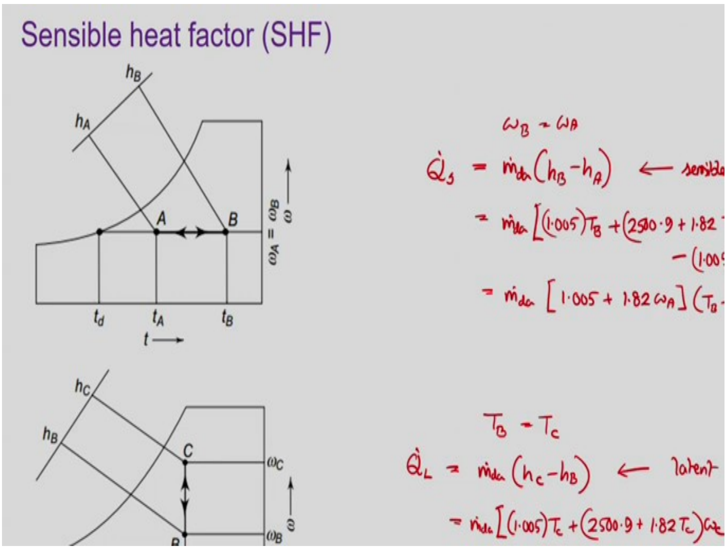

The first one is called the sensible heat factor. Before going to that factor let us look at this diagram. Which process is this one referring to A to B or B to A, these sensible heating or cooling process? So, during this process, how much is your total heat transfer? If $Q_{dot\ s}$ refers to the total heat transfer then we can easily write this one as:

$$\dot{Q}_s = \dot{m}_{da}(h_A - h_B)$$

This is purely a sensible heat transfer because the moisture contents remain the same. we know in this case,

$$\omega_B = \omega_A$$

there is no change in a moisture content that is why it is purely sensible heat transfer and that is why using this subscript Q $_{dot\ S}$. The expression for this we can easily identify you are putting the values for enthalpy. If we want to do that in this case,

$$= \dot{m}_{da}[(1.005\,T_B) + (2500.9 + 1.82T_B)\omega_B - (1.005\,T_A) - (2500.9 + 1.82T_A)\omega_A]$$

Now Omega B and Omega A are equal to each other so in this case the 2500.9 that goes off that gives us:

$$= \dot{m}_{da}[1.005 + 1.82\omega_A]\,(T_B - T_A)$$

So, this we can calculate the total amount of sensible heat transfer involved in this sensible heating or cooling process. Of course, $T_B - T_A$, symbol of that will depend upon the direction of the process. Now what about this particular process? No change in temperature, but change in specific humidity, humidification and dehumidification. Process B to C is humidification and C to D is dehumidification.

Here there is no change in temperature, so we are having

$$T_B = T_C$$

Then how is the total heat transfer in this case? The total heat transfer is:

$$Q_L = \dot{m}_{da}\,(h_C - h_B)$$

and the entire heat transfer is actually is latent heat transfer because there is no change in temperature but only change in the moisture content, so it is pure latent heat transfer. And that is why you are using the subscript L. How can you calculate the magnitude of this latent heat transfer? Here temperature is constant so,

$$= \dot{m}_{da}[(1.005\,T_C) + (2500.9 + 1.82T_C)\omega_C - (1.005\,T_B) - (2500.9 + 1.82T_B)\omega_B]$$

Now in this case T_C and T_B are equal to each other while ω is changing. So, 1.005 into temperature that cancels out, and accordingly we can write this one as:

$$= \dot{m}_{da}[(2500.9 + 1.82T_B](\omega_C - \omega_B)$$

So, this is the corresponding latent heat transfer the way we can calculate this for such kind of processes.

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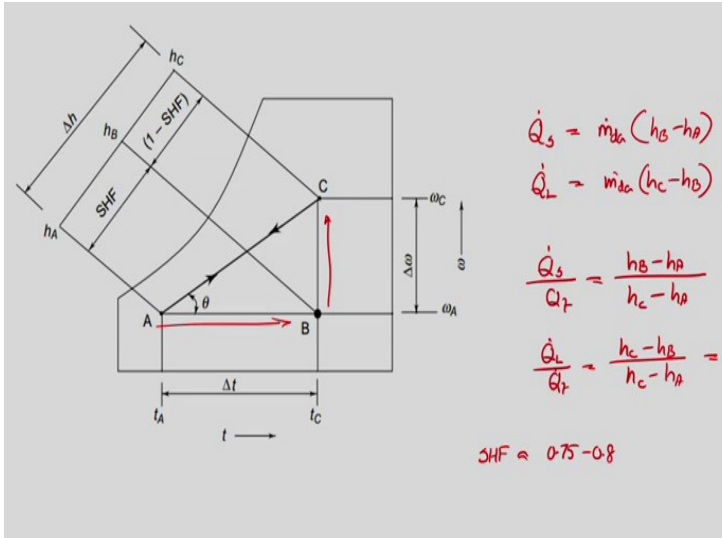

Now if we somehow combine these two processes, something like this a heating and humidification or cooling and dehumidification process during which both temperature and specific humidity are changing. Visualizing the process from A to C or C to A, let us make this one into two ways. Let us consider a heating and humidification process A to C. So let us visualize that the process initially happens from A to B as a sensible heat transfer and then from B to C as a latent heat transfer.

Then how can we estimate the total heat transfer that can take place in these processes? During this particular process total sensible heat transfer that is:

$$\dot{Q}_s = \dot{m}_{da}(h_B - h_A)$$

as we have seen the previous case, where the latent heat transfer which is taking place during the second process which is:

$$\dot{Q}_L = \dot{m}_{da}(h_C - h_B)$$

of course, addition of this is to giving you the total heat transfer:

$$\dot{Q}_T = \dot{Q}_S + \dot{Q}_L = \dot{m}_{da}(h_C - h_A)$$

And addition of the first two terms definitely is giving you the total heat transfer. Now quite often here we define one particular parameter which is written as:

$$\frac{\dot{Q}_S}{\dot{Q}_T} = \frac{h_B - h_A}{h_C - h_A} = SHF$$

This particular factor is called the sensible heat factor, SHF. Similarly, the latent heat transfer part by the total heat transfer that is:

$$\frac{\dot{Q}_L}{\dot{Q}_T} = \frac{h_C - h_B}{h_C - h_A} = 1 - SHF$$

we do not need to define any other factor because this is just 1 minus the sensible heat factor.

The sensible heat factor is an important term in the designing of the air conditioning apparatus because depending upon what kind of environment we are dealing with the sensible heat transfer factor that keeps on varying. And accordingly, you have to make modifications in the internal circuitry or in turn arrangements of the internal cooling tubes. Common air conditioning applications are the domestic air conditioners in a normal climate, in normal dry climate, the sensible heat transfer reaction is quite high, latent heat transfer is quite low and you may have sensible heat factor in the range of 0.75 to 0.8. Whereas if we are dealing with a very humid climate, like outside the relative humidity may be in the range of 90% or something or maybe it is raining, so it is very humid. Then the sensibility transfer will go in the range of 0.6 which is quite low, which refers to extremely humid environment. And depending upon the sensible heat factor that is expected for your device for your air conditioner we have to design the system accordingly.

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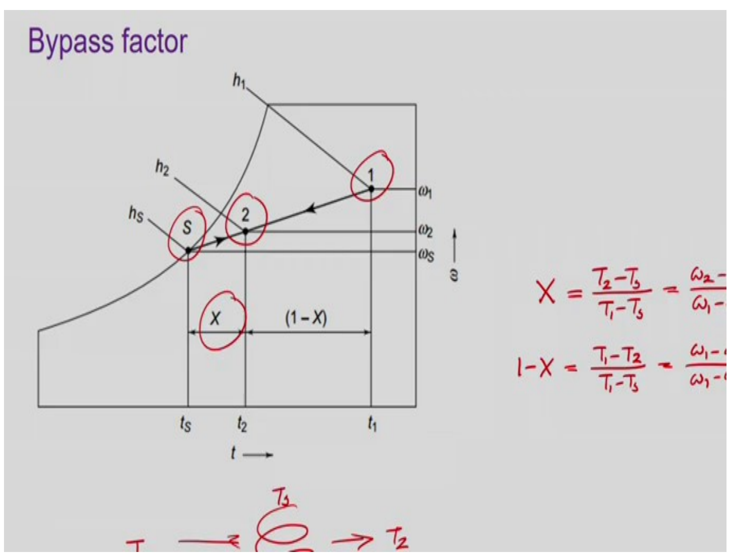

Another design parameter that is also important that is called the bypass factor. Just see the scenario that is shown here. Here we are starting from point 1 and we want to reach this temperature S, S refers to a point on the saturation curve. Now to have this point we of course have to provide a cooling surface. The moist air is coming in contact to the cooling surface will lose this energy accordingly there will be both cooling and dehumidification and we may be having the final temperatures T_S.

Now let us say this is your cooling coil, this cooling coil you can visualize as an evaporator of your refrigeration cycle. The refrigerant is flowing through the cooling coil and accordingly the surface of this cooling coil is maintained at very low temperature. Now the moist air is flowing over this. As the moist air is flowing over this it is never possible that all the molecules of the air will be coming in contact with these cooling coils. Only a fraction of this total mass of air that you are supplying will be able to come in contact with the cooling coils and accordingly they will be trying to approach this temperature S. So, this air is coming with temperature T_1 and this coil is maintained a temperature T_S. Now the portion of the air which comes in contact to the cooling coil, they will try to approach the temperature T_S. Whereas the portion which is not coming in contact with this coil they probably will be retaining its temperature T_1. And therefore, the final temperature that we are going to get after the air passes to the cooling coil that will not be equal to T_S rather that will be equal to T_2, this particular one.

And this T_2 can be visualized as a result of a mixing process between two streams: one stream which is not coming in contact the cooling coil continuing temperature T_1 and the other fraction which is coming in contact with a cooling coil has reduced to the temperature T_S. So, this T_2 of course will be located somewhere along this straight line joining 1 and S and the magnitude of this T_2 or the position of this point 2 will definitely depend upon what fraction of air is coming in contact with this cooling surface.

And to define that we define this factor bypass factor we denoted it by X. Bypass factor refers to the fraction of air which has not come in contact with the cooling coil, this is the one. The portion which has not come in contact with the cooling surface. And there are several ways we can define the bypass fraction bypass factor like we can define it in terms of temperature directly. In that case the bypass factor will be defined as:

$$X = \frac{T_2 - T_S}{T_1 - T_S}$$

$T_1 - T_S$ is the maximum possible temperature change. Practically what is happening is $T_1 - T_2$. So, $T_2 - T_S$ is the lost potential. That way you can visualize this bypass factor. We can also define this in terms of specific humidity.

$$X = \frac{\omega_2 - \omega_S}{\omega_1 - \omega_S}$$

Like the maximum possible change is $\omega_1 - \omega_s$, but practically we are having changed only from ω_1 to ω_2, so the lost portion is $\omega_2 - \omega_S$. Similarly, in terms of enthalpy also we can write it as:

$$X = \frac{h_2 - h_S}{h_1 - h_S}$$

bypass factor can be defined following any of the three approaches and because of the lack of information in fact is quite often we take all three of them to be equal to each other.

And therefore, if the bypass factor is specified for a given air conditioner then we can easily locate the point 2 from the knowledge of your evaporator temperature T_S. Similarly $1 - X$ sometimes also called the contact factor that refers to the fraction of air which has actually come in contact with a cooling coil. So, that is just the other part of that which is the ratio of the actual change in temperature that has taken place to the maximum possible change and is expressed by the relation:

$$1 - X = \frac{T_1 - T_2}{T_1 - T_S}$$

Similarly, in terms of ω,

$$1 - X = \frac{\omega_1 - \omega_2}{\omega_1 - \omega_S}$$

in terms of enthalpy it is:

$$1 - X = \frac{h_1 - h_2}{h_1 - h_S}$$

Both the specific heat factor and bypass factors are important design parameters. Similarly, there are several other design parameters also but that is not required in the context of this course because here we are more focused on the thermodynamic analysis. Any further progress or if I proceed from this particular point that will enter really air conditioning calculations. But still I decided to mention about these two factors because they are very, very common for any kind of air conditioning devices.

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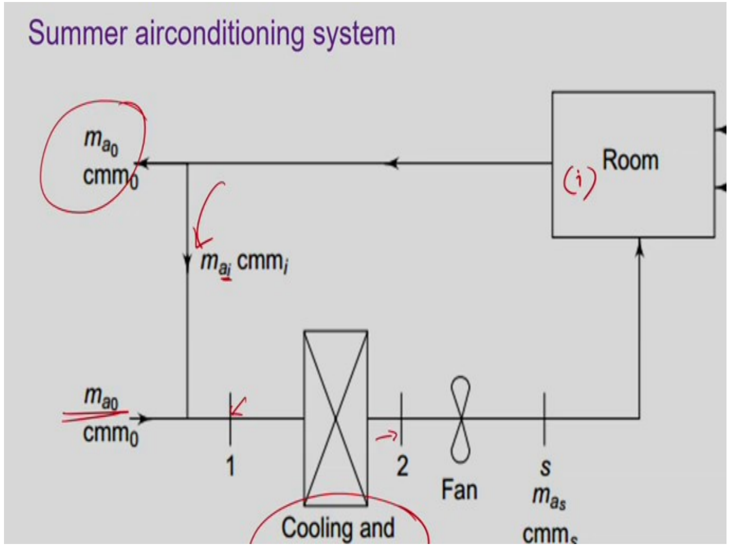

So, this is the final diagram that we may have for a common summer air conditioning system. As the conditioned air goes to the room it will pick up sensible heat and latent heat so it will pick up a total Q_T amount of heat. Then it is coming back at, let us say i refers to an indoor condition that is coming back thee condition a_i and once it is coming back only a fraction of that is allowed to go out like this. Remaining portion comes back and that gets mixed with this fresh conditioned air to have this state point 1 through which it enters your cooling and dehumidification apparatus which you should visualize as the evaporator of your refrigeration system.

Then 2 is the outlet condition, you may have a fan here to drive the flow and with that it goes back to the room. This is a typical summer air conditioning system where we have the cooling and dehumidifying operation as the primary operation. Whereas if you are talking about a winter air conditioning system, you may find that heating and humidification may be the most prominent mode of operation. But rest of the assembly may remain very much the same.

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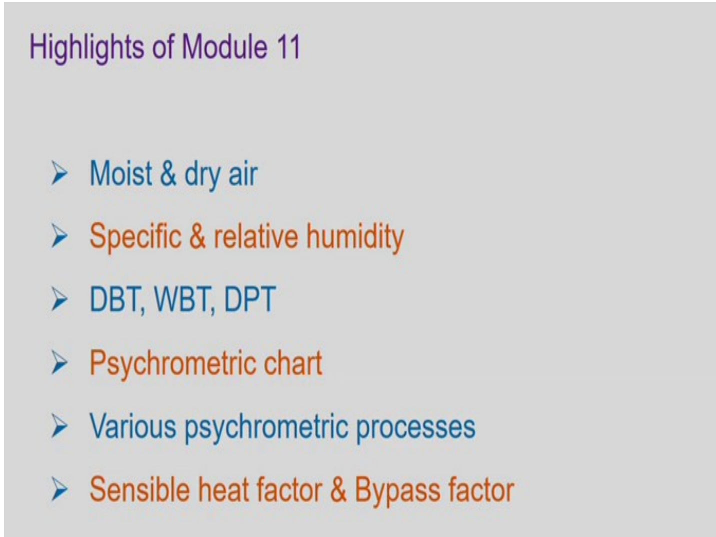

So, that takes us to the end of module number 11, where we have talked about the properties of gas vapour mixtures, you were introduced to the concept of moist and dry air, specific and relative humidities. Then different temperatures, dry bulb temperature, wet bulb temperature dew point temperature. We have seen how we can we can combine this information with the specific humidity to calculate enthalpy and specific volume of the mixture of moist air.

Then the psychometric chart was introduced and have seen how we can use the chart to identify the state point or rather identify the properties corresponding to a given state point. We have seen different psychometric processes both from mathematical point of view and also plotted them on the psychometric chart. And finally, we are finishing with the definition of these two important factors the sensible heat factor is SHF and the bypass factor often called the BF.

So, that takes us to the end of module number 11, air-conditioning is an exhaustive area of research and therefore huge volume of literature excellent books or very large books are available on this. So, if any of you are interested about this you can easily go through any of the books of air conditioning. Several Indian authors and also foreign authors books are available and please pick up any standard textbook to learn more about air conditioning, if at all you are interested.

But if your interest is only in applied thermodynamics then this discussion should be sufficient. So, please solve the assignment problems and if you have any query write back to me. Thank you.