Applied Thermodynamics for Marine Systems

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Lecture - 21

Psychometric Processes

Good afternoon, yesterday we started discussing the properties of moist air or psychometrics and today, we will continue with this. Yesterday I have introduced the wet bulb temperature and I have said what the wet bulb temperature is and how to measure it. Today, I would like to elaborate a little bit, bringing a small amount of mathematics.

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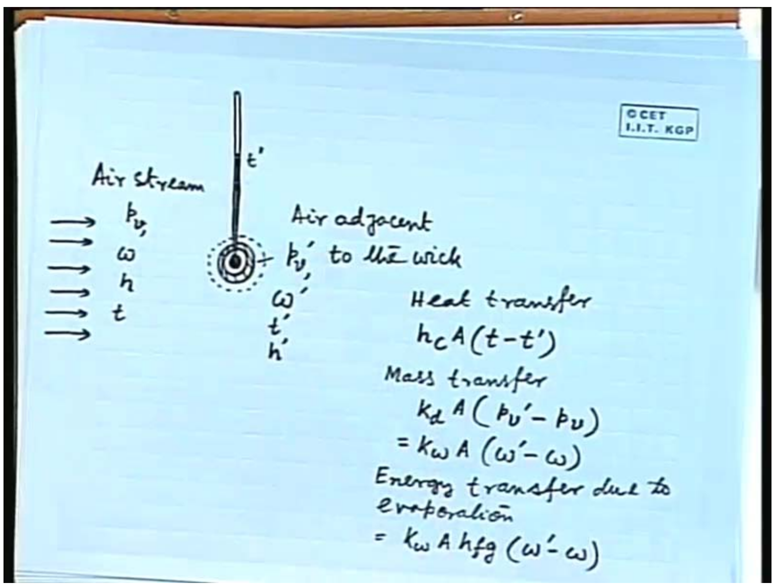

The construction of a wet bulb thermometer is something like this. This is the bulb. Basically it is an ordinary thermometer and on this you have got some wet wick which is this. The wick is wet with pure water. The bulb of the thermometer is wet with water and across this bulb we have got flow of air, with sufficiently large velocity. I have explained that there will be both heat transfer and mass transfer. Basically, some sort of a boundary layer will grow here and we will have a variation of temperature and we will have a variation of concentration; a variation of concentration of water vapour. That means the concentration of water vapour will vary from the outer surface of this wet wick to the air which is flowing past it.

I said that there will be two different transport phenomena. The first one is the mass transfer, which means as the concentration of water vapour is highest or the air just adjacent to the wet wick is saturated with water vapour. It is having high concentration of water vapour, whereas, the air which is passing past it, has a lower concentration of water vapour. Moisture will get transferred from the vicinity of the wet wick to the ambient air. As the moisture gets transferred so more and more water will get evaporated and there should be a continuous supply of water. That is why this wet wick is connected with some sort of a container.

When there is mass transfer or continuous evaporation then it is taking away some amount of latent heat. The temperature of this wick will fall. But, it is surrounded by the air which is having a higher temperature compared to this, so there will be heat transfer from the air to wick. After a short while equilibrium will be reached. That means energy transfer due to evaporation and energy transfer due to heat transfer will be equal. We will have a temperature indicated by the thermometer and that temperature is the wet bulb temperature.

Let us say the property of air - p_v is the vapour pressure in the air, omega is the humidity ratio of air, h is the enthalpy of air and t is the temperature of air. Here at the outer surface of the wick, the properties of air which is saturated with water vapour will be having a partial pressure, p_v dashed, then specific humidity w dashed, temperature t dashed and enthalpy h dashed. I am writing air stream. This is air stream; this is air adjacent to the wick. Mind that both are the properties of air only. What is the heat transfer? Let us say the heat transfer coefficient is h. Again, I am using h but, let us use h convection, h_c; heat transfer coefficient into area of the wick into temperature of the air stream minus temperature of the wick. This is our heat transfer.

What is mass transfer? Again it will be some mass transfer coefficient; this is diffusion mass transfer, so k_d and then we can have area and p_v dashed minus p_v. This can be written as k_w A_w dashed or omega dashed minus omega. Instead of partial pressure I am replacing the humidity ratio. The energy transfer due to evaporation is k_w A into h_{fg}. This is the latent heat of evaporation and w dashed minus w. Now, I can equate the energy transfer due to transport of heat and energy transfer due to evaporation.

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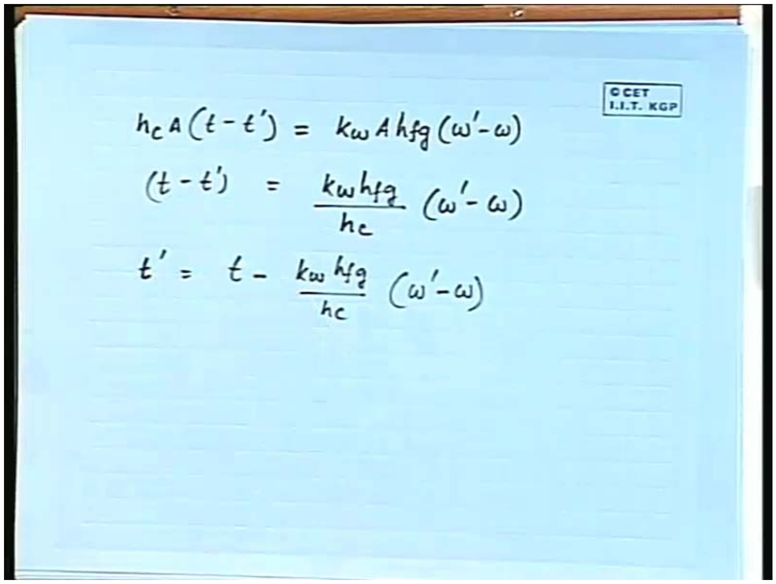

If I equate, I will have h_cA t minus t dashed then it is equal to k_w A h_{fg} w dashed minus w or t minus t dashed, A get cancelled from both the sides, is equal to k_w h_{fg} divided by h_c w dashed minus w. t dashed is equal to t minus k_w h_{fg} by h_c w dashed minus w. Let us say this is t dashed; t dashed is the temperature indicated by the wet bulb thermometer. t dashed is less than less than dry bulb temperature or t. Both of them will be equal when this quantity is 0. That means when w is equal to w dashed; when the air stream which is flowing past the wet bulb thermometer is fully saturated. That is what I said yesterday also.

In the psychometric chart on the saturation line we will have dry bulb temperature equal to wet bulb temperature. This t dashed is wet bulb temperature and for air water system it becomes also a thermodynamic property, not for other system. That proof also can be made, but I am not doing it here because that needs little bit involved knowledge of mass transfer; I am not doing it here; that is not needed for this course. But this t dashed then becomes another thermodynamic property for air water mixture and one can independently measure t dashed and t. Let us say pressure is fixed and that means it is atmospheric pressure. Three different properties are needed; any other property of the air water mixture can be determined. That is what we do with the help of a psychometric chart.

We will again go back to our discussion regarding other properties of moist air.

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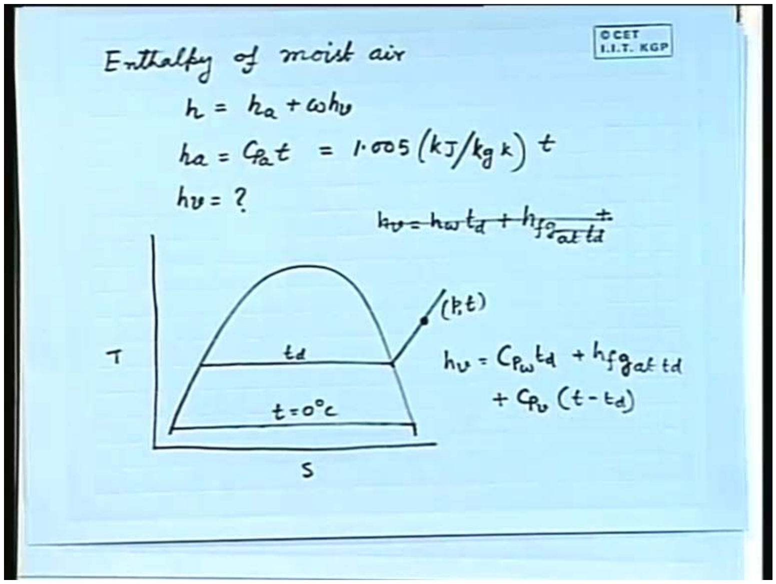

One property which is very important is enthalpy of moist air. In moist air there are two components. One is dry air and another is water vapour. Enthalpy of moist air will be the summation of enthalpy of dry air and enthalpy of water vapour. If we indicate h as the enthalpy of moist air, this will be given by h is equal to h_a plus wh_v, because with 1 kg of dry air there is w kg of moisture. This is the formula. If we write down separately, the expression for h_a and the expression for h_v, we will get the enthalpy of moist air. h_a is equal to C_{Pa} into t assuming that our datum for enthalpy calculation is 0 degrees Celsius. That means at 0 degree Celsius we assume the enthalpy to be 0, then we get this particular formula. C_{Pa} is equal to 1.005, this is basically in kilo Joule per kg degree centigrade or Kelvin; this is the value of C_P multiplied by t. There is some difficulty in calculating h_v. How should we calculate h_v?

What I have done here is I have calculated the enthalpy h_a at a particular temperature t. I also need to calculate h_v at that particular temperature t. So, how should we do it? Let us look into the process. This is our TS diagram and our sample is somewhere here. That means it is at a pressure p and at a temperature t; this is actually p and t. At this point we want to calculate what h_v is. Our reference is somewhere here; 0 degree Celsius if we take it as a reference, this is somewhere here. We can write t is equal to 0 degree C. If we imagine one process of energy transfer, in the sample the moisture which is there that was initially at 0 degree Celsius, then its temperature has been raised to this temperature t, which is nothing but the dew point temperature of the sample.

The sample, keeping the pressure constant, if its temperature is reduced then it will condense at this point. It is like this; the moisture in the sample, initially it was at 0 degree Celsius. Then, its temperature has been raised to its dew point temperature. At the dew point temperature, it has been evaporated and here, at the dew point temperature we are getting saturated vapour. The temperature of the saturated vapour has been raised from the dew point temperature to temperature t. This is the process involved while the moisture has attained an enthalpy h_v. This is the process. It could be thought of as responsible for attaining the enthalpy h_v. I can write h_v is equal to h water into this temperature, I am writing t_d dew point temperature; h water into t_d plus h_{fg} at t_d, because we know that latent heat of evaporation changes; for the pressure and temperature, it also changes and that means for different temperature it also changes. We can write that. Then I can write, let me write it here. h_v is equal to C_{Pw}, not h_w, C_{Pw} into t_d plus h_{fg} at t_d plus C_P vapour t minus t_d.

How many different constants do I have to use? I have to use the specific heat of water, I have to use the latent heat of water, which is again dependent on temperature and I have to use the specific heat of vapour. If any sample is given I have to use these three constants to determine what its enthalpy is. This process is a bit cumbersome. Instead what I can do is like this. I will draw the figure once again.

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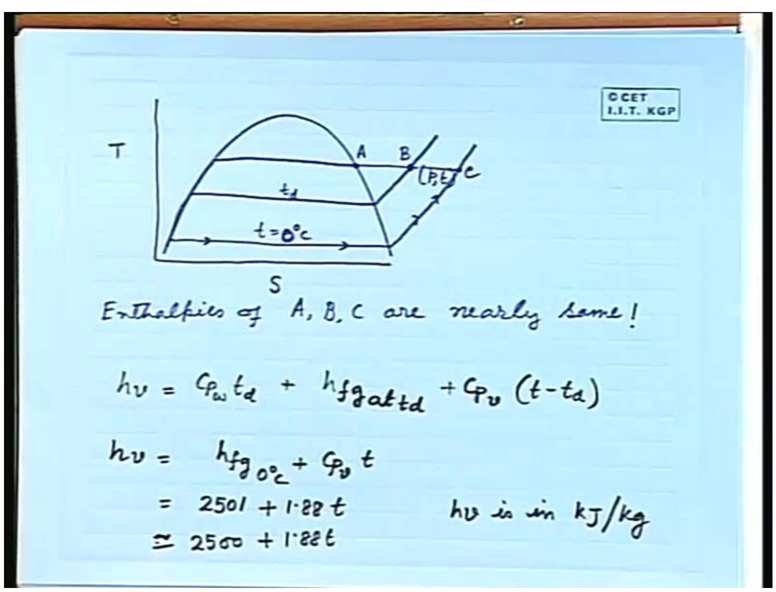

This is actually t is equal to 0 degree C. This is this is our p,t and this we have called t_d. This is temperature and entropy. Our psychometry application is at low pressure region and in this region, the enthalpy is a very weak function of pressure but it is a function of temperature. Suppose I take three points at same temperature, this point, let us say A, B and C, both are at same temperature, then their enthalpies will not be much different. I like to write, enthalpies of A B C are nearly same. If it is so, then what can I do? Every time I take different temperature, I have to take different values of latent heat of evaporation. Instead of doing this, I can take this 0 degree C for the calculation of enthalpy. That means I can take this route of calculation. In that case our h_v, earlier I have written C_{Pw} t_d plus h_{fg} at t_d plus C_P plus C_{Pv} t minus t_d. This was my earlier expression. Instead of it, I am now writing h_v is equal to h_{fg} 0 degree C plus C_{Pv} t; t minus 0 so t. This is much simplified.

Always I am using a constant value for h_{fg} and also I am using only one constant that is C_{Pv}. This t_d is dew point temperature. No; temperature of the sample. What you are asking me is what this t is. This t is the temperature of the sample; not the wet bulb temperature, it is the dry bulb temperature. So $h_{v,}$ I have got by this formula - please once again you note that it is h_{fg} at 0 degree C plus C_{Pv} multiplied by the temperature or dry bulb temperature of the sample. I will put the values and I will ask you to remember then. This is 2501 plus 1.88 into t. h_v will be obtained in kilo Joule per kg. h_v is in kilo Joule per kg; t is in degree centigrade or kelvin. Generally, people write it as 2500 plus 1.88 t, to make it more simple or easy to remember 2500 plus 1.88 t. Now, we know how to calculate the enthalpy of moist air.

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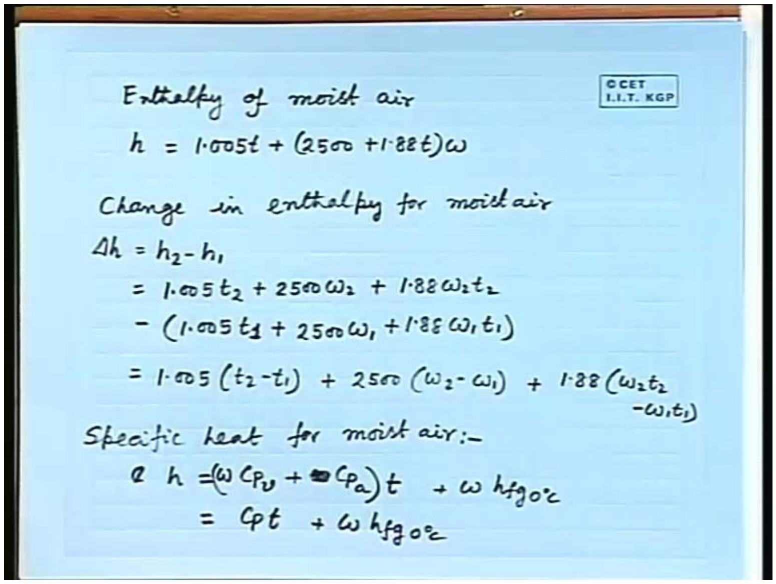

The enthalpy of moist air, h is equal to 1.005 t plus 2500 plus 1.88 t multiplied by w. This will be the enthalpy of moist air. Change in enthalpy for moist air, delta h that is equal to h_2 minus h_1; h_2 is equal to 1.005 t_2 plus 2500 w_2 plus 1.88 w_2 t_2 minus 1.005 t_2 t_1 plus 2500 w_1 plus 1.88 w_1 t_1. One can write 1.005 t_2 minus t_1 plus 2500 w_2 minus w_1 plus 1.88 w_2 t_2 minus w_1 t_1. The problem is that h can be expressed as a C_P delta t. But, in this case we can see that it is exactly not sure; these are the other terms which are coming into picture. One can do a slight change in this equation. With some approximation one can define specific heat. Specific heat for moist air can be defined like this. One can write h is equal to wC_{Pv} plus C_{Pa} into t plus w into h_{fg} at 0; this one can write. This thing one can write, C_{Pt}, this entire thing if you call it C_P, so C_{Pt} plus w h_{fg} at 0; this is actually 0 degree Celsius. So, this you can write. This C_{Pt} is a composite function of C_{Pa} C_{Pv} and w. h is becoming the summation of these two and here though temperature is appearing, here we don't have a temperature term. Generally w is small and contribution by w is small so one can make some sort of an approximation.

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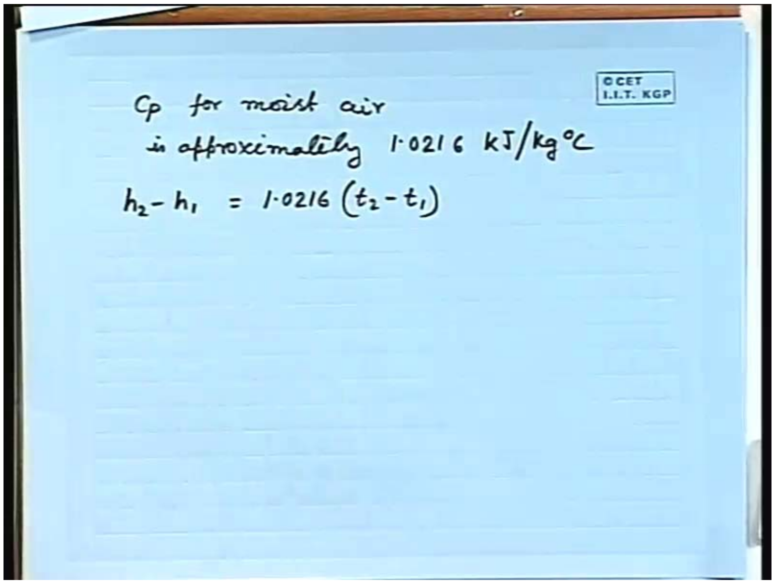

With that approximation we can write, C_P for moist air and again this is approximately 1.0216 kilo Joule per kg degree Celsius. If we use this value then h_2 minus $h_1$will be equal to 1.0216 t_2 minus t_1. Mind that this is approximate calculation. Only for quick calculation we use this value, otherwise we use the formula which we have derived earlier. So this is how we calculate the enthalpy of moist air. I have shown you the detailed calculation, also the value which is used for quick calculation, quick estimation; for practical calculation we can use this particular value. With this again I will quickly sketch the psychometric chart.

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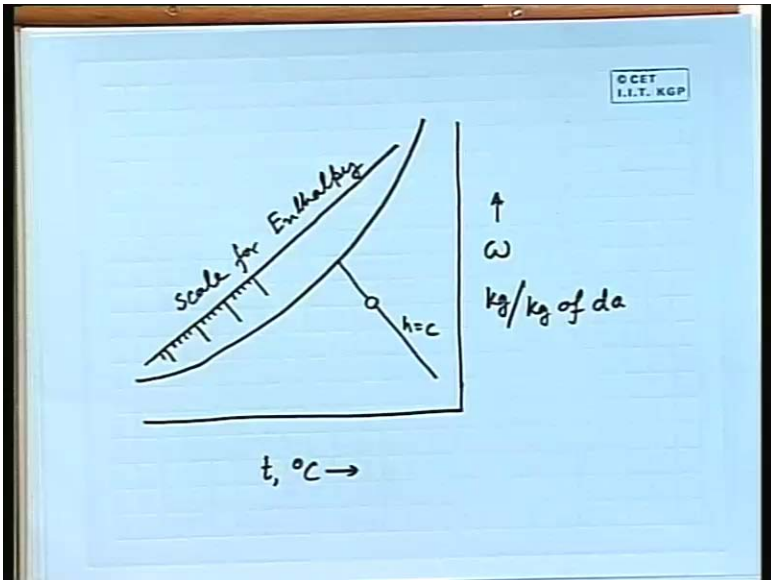

Psychometric chart looks like this. Temperature is in degree Celsius in this direction kg per kg of dry air in this direction. This is the sample here, sample point. In the sample point, we can have constant enthalpy lines. h is equal to constant. What is done is in most of the psychometric charts one scale is provided over here. There the values of enthalpy are written. From the sample, we can take a line go up to that scale and find out what is the enthalpy. So we can write scale for enthalpy.

What is important or what is interesting to note is that in a psychometric chart we will have also constant wet bulb temperature lines. You will find that a constant wet bulb temperature line and constant enthalpy lines, they are almost coincident. There is a very small angle between these two lines, they are almost coincident. If we move along a constant wet bulb temperature line we will find that enthalpy change is very small. If there is a constant wet bulb temperature process, if any process is there which is constant, where the wet bulb temperature does not change, we will see that change in enthalpy is also negligibly small in that process.

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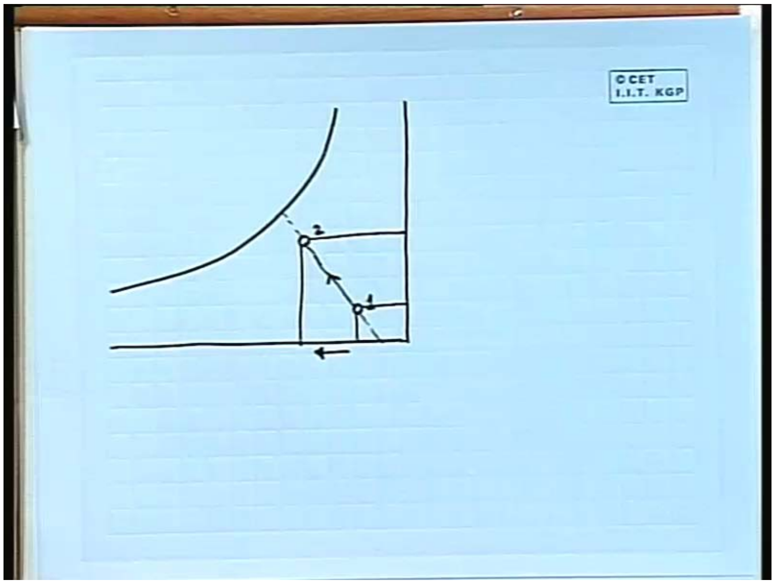

Initially my state point is here and finally my state point is here. 1 and 2; you can see there is lot of change in temperature between 1 and 2. There is lot of change in specific humidity or humidity ratio between these two points. But, these two points I have taken such that they are lying in the constant enthalpy line. Both of them are situated on sorry constant wet bulb temperature line. I will find that the change in enthalpy between 1 and 2 is negligibly small. If they are on the constant wet bulb temperature line then change in enthalpy between point 1 and 2 is negligibly small.

One hint can be given here. Between 1 and 2 what has happened? Let us say the process goes from 1 to 2. When it has gone from 1 to 2, then there is a decrease in temperature. …… dry bulb temperature has reduced - what does it mean? When the dry bulb temperature can reduce? If it is cooled if certain amount of energy is extracted from it. But, we can see that there is a considerable amount of increase in the specific humidity when the sample has gone from state 1 to state 2. That means moisture has been added and when moisture has been added then certain amount of latent heat of evaporation that has also come along with the moisture, so energy has been added. These balance each other - one is extracted from it, another is added to it; so both of these things, these two things they balance each other and that is why we will get almost negligible change in enthalpy. So, enthalpy of the mixture will remain almost constant, but not exactly, because there is a small angle of deviation between the constant enthalpy line and the constant wbt line, wet bulb temperature line.

Should we move to some other topic? Let us go for different air conditioning processes or different psychometric processes.

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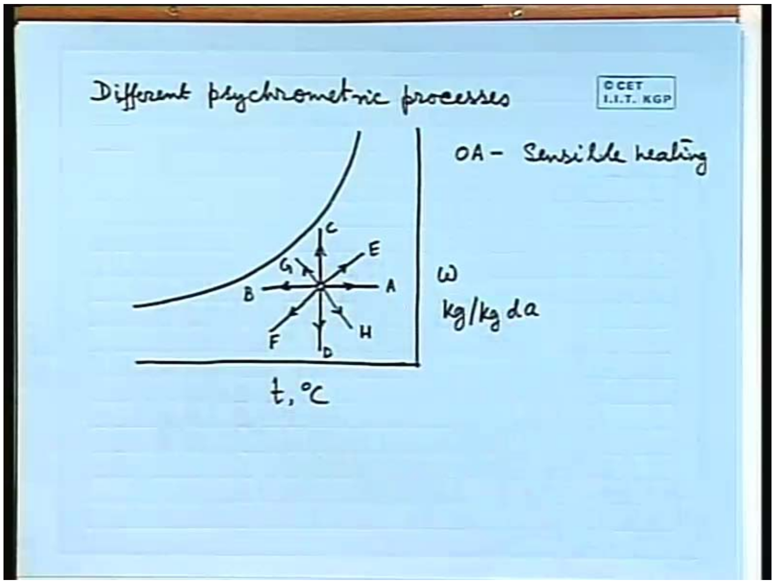

What could be the different processes? Let us say, the central point is called O and let me give different names A, B, C, D, E, F, G and H. So these are different processes, these are different possible psychometric processes. You can identify the processes. Let me put some arrow mark here - so what are the different processes I have drawn?

OA; let us say process OA - OA is what? Let me put this; degree C and this is kg per kg of da, dry air. OA is increase in temperature but there is no change in w. So, this is called sensible heating, OA is sensible heating. Quickly let me give all the names or let us identify all the processes. OB is sensible cooling. Then, OC is addition of moisture and keeping the temperature same, addition of moisture and you see by addition of moisture though the dry bulb temperature remains constant, wet bulb temperature increases. Through O if I send some wet bulb temperature line it will be something like this, but through C if I send some wet bulb temperature line that will be quite high and wet bulb temperature has increased. Sweating will take place or we will see that if there is any wet surface we will have difficulty in drying it up.

OD is condensation process, purely condensation process. Then there are mixed processes. If we go for OE, this is heating plus humidification; OE we have got heating plus humidification. If we go for OF we have got cooling plus dehumidification, cooling plus dehumidification. Then if we go for OG, then we have got cooling plus humidification and finally, if we have OH then we have heating plus dehumidification.

OC is cooling plus humidification; No. OC is purely humidification, addition of moisture, only humidification. There is no change of dry bulb temperature. Wet bulb temperature is changing but dry bulb temperature remains constant. OF is cooling and dehumidification. Cooling and dehumidification is a very important process, because in summer air conditioning, we need to have cooling plus dehumidification. The surrounding air we need to cool. Particularly for tropical countries, we need to cool it and hot and humid atmosphere we need to cool it and we need to also lessen the load of moisture from the air. We will see how to do it. These are the basic psychometric processes and there are methods of achieving it and there are small amount of mathematics which can be used for analysis of all the processes.

There is another process which has not been shown here which is very important.

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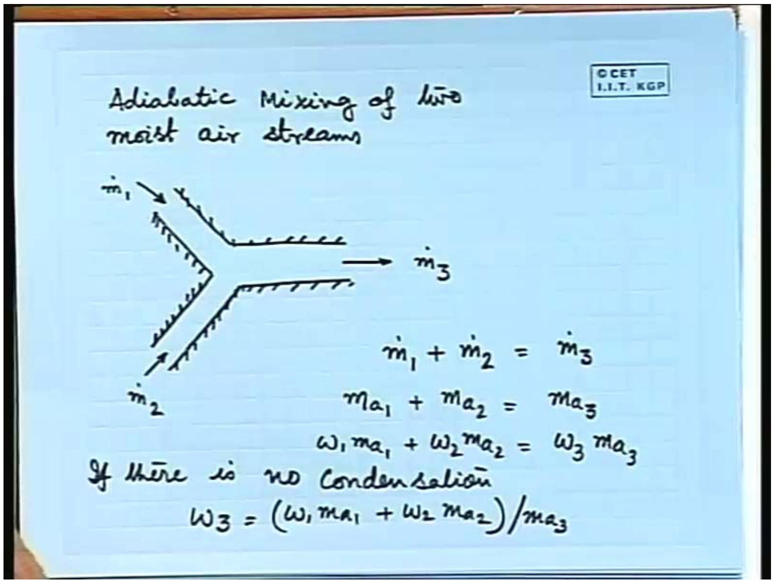

Adiabatic mixing of two moist air streams is a very useful and important process. We can have number of example, like in air conditioning let us say, the room air is coming out. What do we do? We do not through away the entire room air into atmosphere. Part of it is thrown out and part of it is re-circulated. With the re-circulated air, we mix certain amount of fresh air. Here we can see that two moist air streams are mixing together. What we want to do is we want to find out the property of the mixed air stream knowing the property and mass flow rate of the individual air streams. It is like this. Let us say, I have shown some sort of a ducting which has got two inlets and one outlet. So this is m dot 1 mass flow rate, m dot 2 mass flow rate and this is m dot 3. The total mass flow rate, if there is no condensation inside, if there is no separation of water vapour inside, then one can write m dot 1 plus m dot 2 that is equal to m dot 3; this is what we can write.

Let me, for the time being, remove the dot. It indicates the air flow rate; whatever, I am writing mass flow rate that is flow rate not the total mass. m_{a1} plus m_{a2} is equal to m_{a3}; dry air from stream 1 plus dry air from stream 2 is equal to dry air from steam 3. This we can write always. But the second one, that is w_1 m_{a1} plus w_2 m_{a2} that is equal to w_3 m_{a3}, we cannot write always. We can write only when there is no separation of moisture. When there is no separation of moisture we can write it. If there is no separation of moisture, if there is no condensation, then w_3 is equal to w_1 m_{a1} plus w_2 m_{a2} divided by m_{a3}. This is how we will get the moisture content of the mixed stream.

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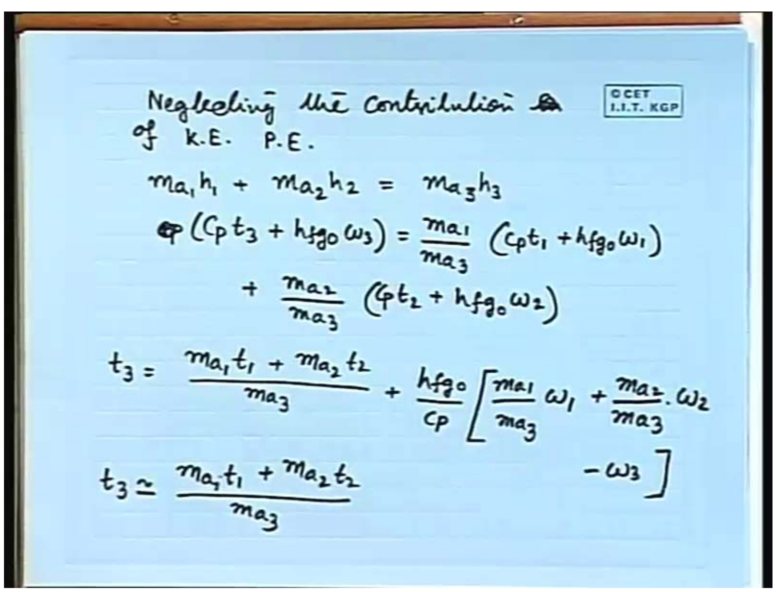

Neglecting the contribution of kinetic energy, potential energy etc. one can write, m_{a1} h_1 plus m_{a2} h_2 is equal to m_{a3} h_3. This is actually energy equation. Enthalpies are written here. We can express in terms of different changes in enthalpy. That means enthalpy of air and water vapour that is what we can write. We can actually write like this - C_P into t_3 plus h_{fgo} w_3 is equal to m_{a1} by m_{a3} C_P t_1 plus h_{fgo} w_1 plus m_{a2} by m_{a3} C_P t_2 plus h_{fgo} into w_2. This is what I can write. This formula I have already introduced. C_P means the specific heat and here the air specific heat, and water vapour specific heat that will come. So that way it has been written.

If we want to make it a little bit simplified, t_3 is equal to m_{a1} t_1 plus m_{a2} t_2 divided by m_{a3} plus h_{fgo} by C_P and here we will have m_{a1} by m_{a3} w_1 plus m_{a2} divided by m_{a3} multiplied by w_2 minus w_3. This will be the expression. What happens is, generally w_1, w_2 and w_3 these are very small quantities. One can have an approximate expression for t_3. So, one can write t_3 is approximately, not exactly but approximately, m_{a1} t_1 plus m_{a2} t_2 divided by m_{a3}. I will stop here and in the next class I will show what the implication is and how the process can be represented on psychometric plane. I think that is all for today. Thank you.