**Mass Transfer Operations II**
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**Lecture No 5**
**Humidification and Air Conditioning**
**Air conditioning, Example problems on dehumidification**

Welcome back to mass transfer operations II course. We were discussing on humidification in air conditioning till now we have discussed humidification and cooling tower design using this individual gas phase mass transfer coefficient as well as viral mass transfer coefficient now will be discussing on the dehumidification and air conditioning. So before entering into this subject we should know something about the dehumidification process and air conditioning. So the process in which the moisture or water vapor or the humidity is removed from the air keeping its drive up temperature constant is called the dehumidification operation. In actual practice the pure dehumidification process is not possible as the dehumidification operation is accompanied by either cooling or heating of this air.

- ✓ The process in which the moisture or water vapor or the humidity is removed from the air keeping its dry bulb temperature constant is called as the **dehumidification process**.
- ✓ In actual practice, the pure dehumidification process is not possible, as the dehumidification operation is accompanied by either cooling or heating of the air.
- ✓ This process is represented by a straight vertical line on the psychrometric chart starting from the initial value of relative humidity, extending downwards and ending at the final value of the relative humidity.
- ✓ The process in which the air is cooled sensibly and at the same time the moisture is removed from it is called as cooling and dehumidification process.
- ✓ Cooling and dehumidification process are obtained when the air at the given dry bulb and dew point temperature is cooled below the dew point temperature.
- ✓ The process in which the air is heated and at the same time moisture is removed from it is called as heating and dehumidification process.
- ✓ This process is obtained by passing the air over certain chemicals like alumina and molecular sieves.

**EXAMPLE PROBLRMS ON DEHUMIDIFICATION**

Moist warm air is to be cooled and dehumidified to a wet-bulb temperature of 30ºC using water of 25ºC in a dehumidification column. The air enters the tower with a dry-bulb temperature of 85ºC and wet-bulb temperature of 45ºC at 4800 kg/$m^2$h rate. The overall gas phase mass transfer coefficient is estimated to be 2150 kg/ $m^3$h. The flow rate of water is 1.4 times the minimum. Calculate height of the tower.

So now will be solving dehumidification problem and from there will be learning that how these moist warm air is cooled or we can say this one dehumidification operation is done in the body which is used in the air conditioning system. The problem is this moist warm air is to be cooled and dehumidified in the dry bulb temperature of 30 degrees Celsius using water of 25 degrees Celsius in a dehumidification column, the air enters the tower with a dry bulb temperature of 85 degrees Celsius and wet bulb temperature of 45 degrees Celsius at 4719 Kg per meter square hour rate that is we can say this one where rate of moist air the overall gas phase mass transfer coefficient is estimated to be 2150 Kg per meter cube hour the flow rate of what actually water is 1.4 times the minimum. Now we have to calculate this minimum water flow rate outlet water temperature, which will be coming out from the cooling tower and the moisture removed from air during this process and height of this tower. So we need to one design one dehumidification column.

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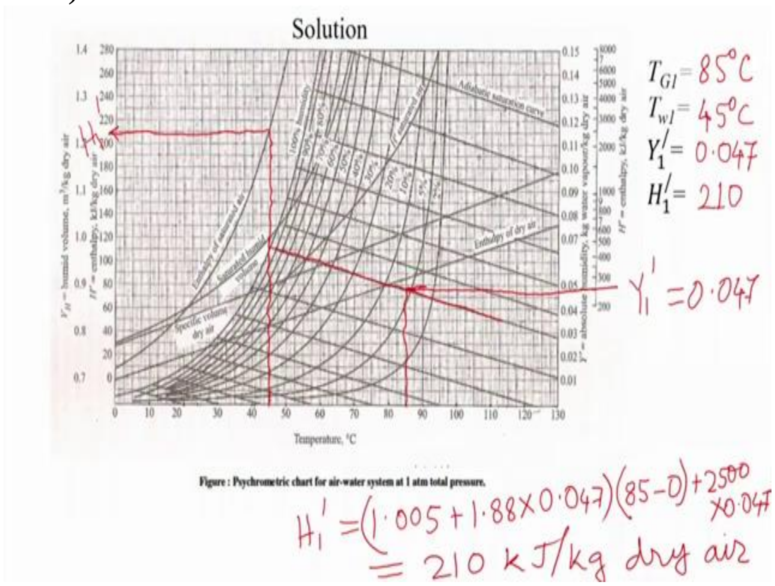


The process is the almost similar there are some changes will be discussing step by step this one, first of all we need to find out that what will be these relative humidity and enthalpy values for the given problem say TG one is 85 degrees Celsius that is given in the problem this TG1 is 85 degrees Celsius and TW1 that is 45 degrees Celsius. So now we will start from this here of 45 degree Celsius and we will move because this is TW one.

So from here will move in the vertical direction till the 100 percent saturation and then we need to follow the adiabatic saturation curve like in this line to this line. And we will move from 85 degree that is we can say this TG1 to the vertical direction and will be touching on point. And from here actually will be moving towards the y2 axis and from here will be getting this y1 prime that is nothing but it is 0.047 per kg dry air.

And if we move in the vertical direction in the wet bulb temperature we know that is this the wet bulb temperature and if we if it reaches the adiabatic saturation Enthalpy of the saturation here from there actually we will be getting this we can say Enthalpy of the air which is entering here that is H1 prime. That is H1 prime is nothing but say 210 here, it is 210. So this is 210 kg joule per kg dry air. So this is so now we have got this what is the relative humidity of this gas this air entering from the bottom of the cooling tower at H1 prime that is Enthalpy of this moist air, at that is 210 kg joule per this kg dry air.

So that is we have got this one 047 take this and also this H1 prime we already discussed this one H1 prime also we can get from this relative humidity also like H1 prime that we know that is nothing but is equal to 1.005 plus 1.88 into this one y1 prime that is nothing but 0.047 into this

TG minus T0 that is TG means for this case it is 85 minus reference temperature is 0 plus 2500 into 0.047 so that also will be coming as 210 kg joule per kg dry air. So now we have the all the conditions of the dry air which is entering from the bottom of the humidification tower. Okay.

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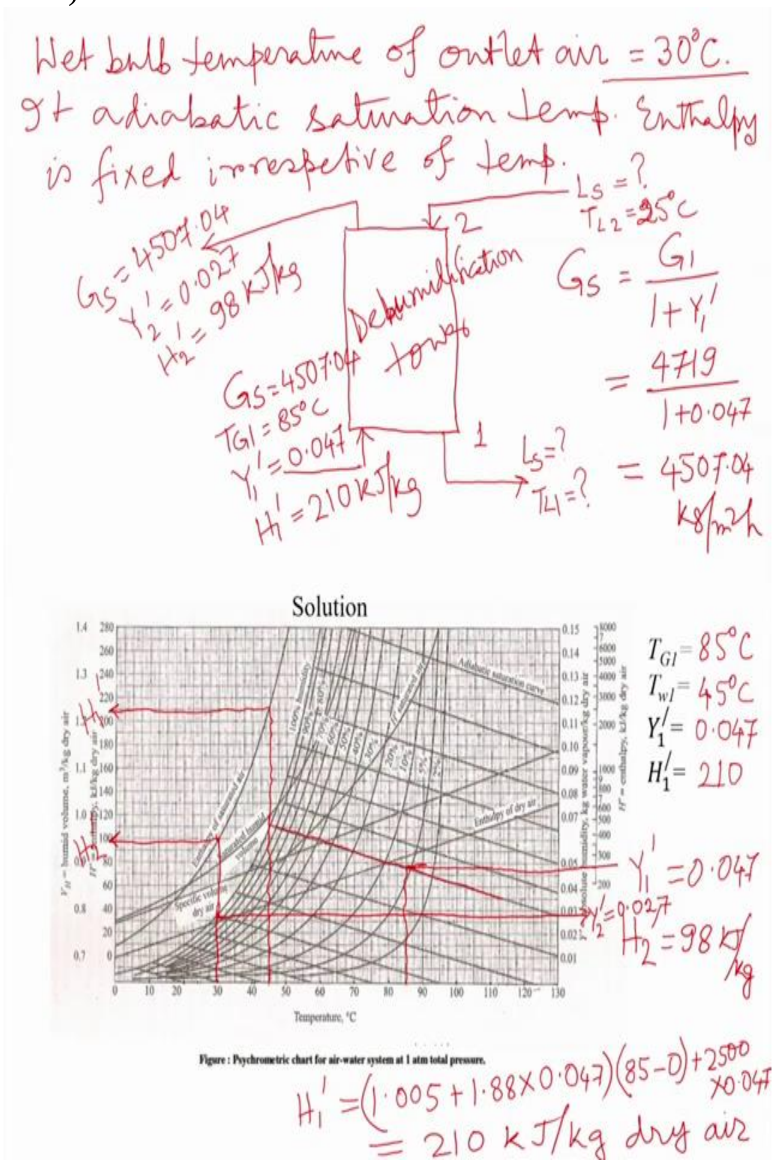


But we know this one this wet bulb temperature of the outlet air that is actually 30 degree Celsius. Now we can say this one Wet bulb temperature of outlet air that is given in the problem that wet outlet air will be equal to say 30 degree Celsius that is actually our requirement. Okay. So it nothing but we can say this one this is nothing but it is adiabatic saturation temperature, so in that case as it is adiabatic saturation temperature so whatever the Enthalpy value that is actually fixed, so this Enthalpy will become now this one irrespective of this we can say the temperature. Enthalpy is so that is at this one at this condition that is you can say this one Enthalpy is now fixed and that is irrespective of cold temperature.

Whatever the dried out temperature it will act in but this Enthalpy will remain constant because that we have this one given the problem as this wet bulb temperature of the outlet air will be 30 degree Celsius. Okay. Now say we need to find again that what would be this why to find that would say again we will be going to that this psychometric chart.

Say now you see this one this now this is 30 degree Celsius that 30 degree Celsius say we can say this one we will be following this line. So whatever the saturated Enthalpy that will be getting that will be H2 prime just simply just we can say this we can go up to this one and from here will be moving to this one that is H2 prime.

So this H2 prime will be say 98 kilo joule per kg dry air and correspondingly at that 30 degree Celsius whenever it will be at any this wet bulb temperature of 30 degree Celsius the relative humidity that is also fixed like this it will be like this. That is we can say this one y2 prime that is say it is nearby 0.027, 0.027 that is kg per kg dry air. Okay so now we have this H1 prime, H2 prime, then Y1 prime, Y2 prime, TG1, TW1 so we have most of the values. Now we are trying to make this we can say this one we can say humidification column like this we trying to get this humidification column like this.

So this is this station1 this is station 2 and this hot air is actually entering from this bottom, and cold water is falling from the top. So now we need to get whatever the GS value will be getting we are getting this. GS is equal to say whatever the G1 gas flow rate is there plus 1 plus this y1 prime. So this flow rate is given that that is given as 4719. 4719 divided by 1 plus 0.047. So it is coming out to be as 4507.04 say kg per meter square hour. So that is kg per meter square hour. So GS is equal to 4507.04 and then TG1 that is given as 85 degrees Celsius.

And y1 prime is obtained as 0.047. That is we can say kg per kg dry air that is present and H1 prime that Enthalpy value is obtained as 210 this kilo joule per kg. And whatever the cold air that will be coming out from this dehumidification chambers we can say this Dehumidification tower. So there GS that is fixed. So GS that actually will demand constant. That is nothing but 4507.04 and y2 prime that is as this we can see the wet bulb temperature is fixed as 30 degrees Celsius the Y2 prime will become like 0.027 and H2 prime that is we can see this one that is that is becoming 98 kilo joules per kg.

And here this whatever the cold water actually is entering that say liquid flow rate we need to find out whatever liquid flow rate actually we have but we know that TL2 that is already given that that is 25 degrees Celsius. And whatever the hot water will be coming out, So this liquid flow rate till now we do not know because it's so we need to find out what is the minimum water flow rate will be finding out and then we will be multiplying with 1.4 times then we will be getting whatever the liquid flow rate is.

And we do not know this TL1 also that is also now we do not know this liquid flow rate we do not know this the, We do not know this liquid flow rate as well as we do not know whatever the outlet temperature of this water that is we can see this coming out from the bottom of this dehumidification column. Okay. Now we have this one say bottom condition. We have already or we can say this one that is the lower terminal of the operating line.

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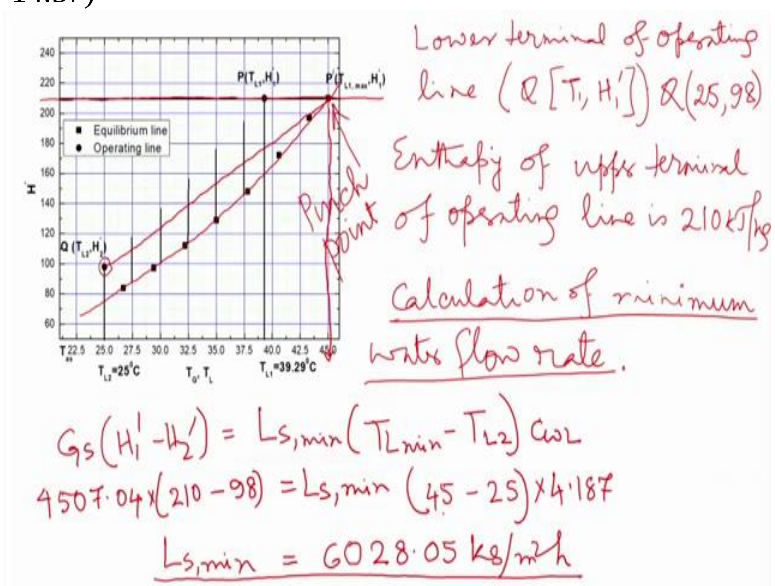


So now we will be drawing this. The equilibrium line whatever we draw this one for this case also it will be like the same will be drawing this equilibrium line. I think we know how to draw the equilibrium line and then we have this bottom terminal of this we can say dehumidification column. Now it is you see it is above this. We can see equilibrium line that is TL2 is equal to this 25 degree Celsius. And so we can see this Q is this we can see this lower terminal of the operating line.

So, lower terminal operating line that is Q which has the diamond around like this temperature and Enthalpy value T1 and that is as Qs 25 degrees Celsius and 98. So now we have located this this lower terminal of the operating line for that we can say this one point Q. Okay. Then the

Enthalpy of the feed air at the bottom point actually that is we can see this one at P. We do not know where the actual P is we can see this on it but you see this one that Enthalpy value we actually we know because you see this one whatever the moist cold air which will be living from this dehumidification chambers that temperature is fixed as the wet bulb temperature or adiabatic saturation temperature as 30 degrees Celsius. So Enthalpy of this we can say this one bottom point or we can see this one bottom this one upper terminal of the operating line we can see this one. That Enthalpy, Enthalpy of upper terminal of operating line, line is 210 kilo joules per kg.

So that what will be doing this now we will be doing one parallel line of this temperature line so it will be like this but where this point P actually we can see this one we do not know. So the point p of this we can see this one or we can say this one upper terminal. We do not know where this actual P will be, but whenever we will be doing this we can say minimum water flow rate. So now we will be doing that calculation of the minimum water flow rate. So we will be doing this one. So for that, so we can say we need to find a pinch point whatever we did this for the humidification column. So from the lower terminal we have drawn that engine to the equilibrium line. Here also will be drawing. We can say this one, one straight line to this we can say this one pinch point where it will be touching these 210 kilo joule per kg, So from here actually we will be drawing one straight line up to this.

We can say this on 210 kilo joule per, these are what is called that is the Enthalpy of the existing air so that is actually where it will be touching that is called pinch point. So this is actually nothing work pinch point. So this point is called this pinch point. So their Enthalpy values definitely it be 210 kilo joule per kg dry air. Okay. Now so we can say whatever the water flow rate, minimum water flow rate actually will begin getting. We have this one if we do this overall we can say this Enthalpy balance then it will be like this say GS in to say h1 prime minus H2 prime is equal to say LS minimum in to TL minimum minus TL2 into TL2 into cwl. So here if all the are known to us except this LS minimum. So we will be putting here like this that is that is 4507.04 into that is 210 minus 98 is equal to LS minimum into TL minimum that is we can say this one whatever the water that will be coming out from this dehumidification column that is we are getting as here it is say 45 degrees Celsius.

So that 45 degrees Celsius minus TL2 that is already given in the problem like this 25 degrees Celsius and that is cwl is equal to 4.187. So from here we will be getting LS minimum is equal to that is 4507.04 into 210 minus 98 divide by 45 minus 95 into 4.187 that is coming out to be as

6028.05 so kg per meter square hour. So this is the minimum water flow rate required to get that wet bulb temperature of 30 degrees Celsius but the other outlet temperature of the water will be shoot up from 35 to 45 degrees Celsius but actually flow rate actually is given as that actual flow rate will be...

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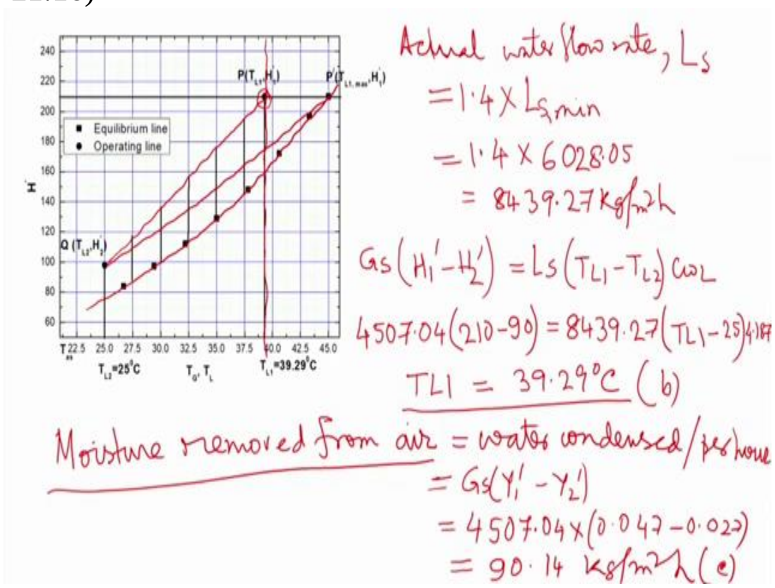


So this either fast this one question which is ask in this problem that what is the minimum water flow rate that is nothing but 6028.05 kg per hour meter square. Now we say we need to get this actual water flow rate. Like this again we are drawing this equilibrium line than from here say we are coming to this point P but you see this one actual water flow rate is equal to 1.4 times of this L this LS minimum. So it is coming out as 1.4 into 6028.05 is nothing but 8439.27 kg per meter square hour.

Okay so that is say for this case we can see what will be this said now we have this one. These actual water flow rate or we can see this one LS that is we can see this one LS through now LS is equal to 8439.27 kg per meter square hour. So say using the same equation like this overall Enthalpy balance equation across the dehumidification tower, so we will be getting what the minimum temperature of the water to be maintained if this actual water flow rate is 1.4 times of the minimum water flow rate.

So will be again applying this same equation like these GS into H1 prime minus H2 prime is equal to LS into TL1 minus TL2 in to cwl. So here GS is equal to say 4507.04 into that is 210 minus 98 is equal to, now we have this LS is equal to 8439.27 into, so we need to get this whatever the TL1 that is what we the water temperature that is leaving the dehumidification tower, done. TL1 is equal TL2 is equal to 25 in to 4.187. So here, so we will be getting this TL1 is equal to say from this equation after manipulation we will be getting TL1 is equal to say 39.29 degrees Celsius. So this is the second question asked that is we can see this on B.

So this liquid whatever the liquid water will be exiting from the cooling tower it will attend 39.29 degrees Celsius. Now you see this one is like this. So 39.29 degree Celsius this is the this, this line so now we have this we know that this temperature this Enthalpy of the we can say this one air which will be leaving the dehumidification tower is 210 kilo joule per kg dry air and the liquid temperature is 39.29. Now we have this upper terminal of this one and now we need to draw a straight line from this lower terminal of the operating line to the upper terminal of the operating line. Now we say will be giving the third question asked like this moisture. Moisture removed this from air that is nothing but we can say this how much amount of water actually is condensed during this process per hour.

That is we can say this one GS in to say y1 prime minus Y2 prime. So that is we can see this one 4507.04 into 0.047 minus point 0.027. So that is coming out as 90.14 say kg per meter square hour. So this is that we can see this on how much moisture removed from the air during this process that we can see this one the answer of this problem C. Now we need to find out what will the height of this dehumidification tower.

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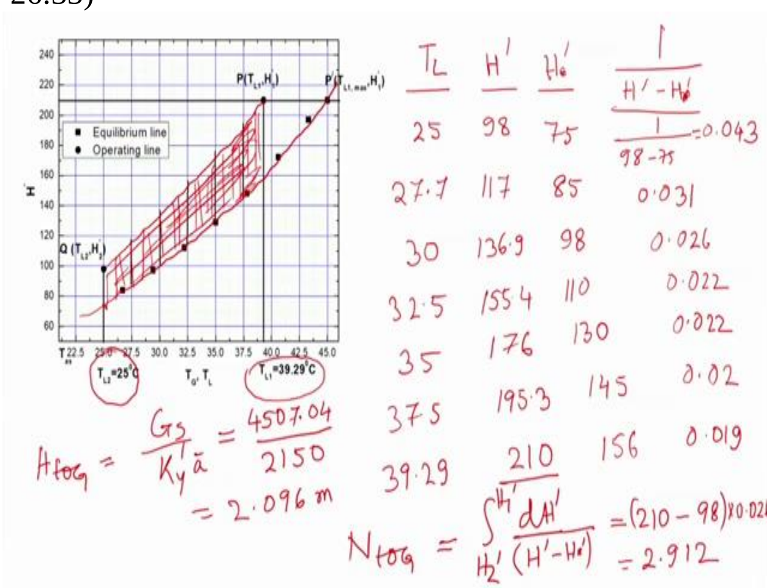


So now what we will be doing will be getting these Ntog and Htog and then will be multiplying these Ntog and Htog and will be getting like. Now say we need to get what is the area under this curve. Say it is worthy to mention here that for the case of this humidification tower the operating line was just below the equilibrium line. But in case of this dehumidification tower the operating line will always lie above this equilibrium line. Now you see we need to do. This on what is called we need to get the area under the curve for that will be will start from say this one we know that the temperature of this liquid water this is 25 degrees Celsius and the we can see this one temperature of this hot water that is 39.29 degrees Celsius.

So in between these we need to get what will be the Enthalpy value and what will be the Enthalpy we can say equilibrium Enthalpy value or in all the cases you see this equilibrium Enthalpy value will be much more long than the actual Enthalpy value in the say air. So we need to find out this one. Now the equation will be like this for this area under the curve, So we will be taking say suppose we will be taking one TL for that we will be getting one Enthalpy and we will be getting one equilibrium in Enthalpy like this one and is now this for getting this area will be getting H star or by H star minus H star prime because here it is all the time this H star will be lower than the this one actual Enthalpy value. So we will start from 25 degrees Celsius for that this Enthalpy value from this  one what is called Graph will be getting 98 that is already we have derived and whenever we will be moving towards this equilibrium line that value is actually 75. So now it is 1 by 98 minus 75 that is coming out to be 0.043

I guess for this again we will be taking any temperature say increment we can do this one. So whatever we have this following this 27.7 for that this Enthalpy value is 117 and this equilibrium Enthalpy value is 85 and then 1 by H prime minus H star prime we are getting as 0.031 or 30 degrees Celsius. We have this Enthalpy value as 136.9 whereas equilibrium Enthalpy value is 98 and this one by H prime minus H star prime that is coming out 0.026 and then for 32.5 degrees Celsius.

The Enthalpy value is 155.4 and equilibrium Enthalpy value is 110 and the one by H star minus H star prime is 0.022. For 35 degree Celsius the Enthalpy value is 176 H star prime is equal to 130 and one by H prime minus H star Prime is point this is also 0.022. For 37.5 degrees Celsius that this Enthalpy value is 195.3 whereas this equilibrium Enthalpy value is 145 and 1 by H star minus H star prime is 0.02 and for 39.29 degrees Celsius these we know that Enthalpy value we have already calculated that is at 210 kilo joule per kg dry air and equilibrium Enthalpy is 156 and this 1 by H star minus H prime minus H star is 0.019.

So now we are getting these one the entire space actually we are getting this area under the curve this total portion will be getting so we will be getting now Ntog and Htog like this one. Now we see Htog will be getting from the equation that is well known equation this Htog, that will be nothing but GS by capital Ky prime a bar. That is given as this GS, GS is the 4507.04 divide by that is given as Ky prime a that is given as 2150. So it is coming out as say 2.096 meter and Ntog so Ntog will be getting this is as say H2 prime to H1 prime into dH prime by H prime minus H star prime.

So in case of the humidification column that denominator was H star prime minus H prime because you see this one in case of this humidification column the operating line was below this one that is why the difference of equilibrium Enthalpy and the actual Enthalpy was positive but in this case as the operating line is above this equilibrium line. So the actual Enthalpy minus equilibrium Enthalpy gives a positive value, so this we are getting as for the entire range say 210 minus 98 into 0.026 so that is we are getting as 2.912.

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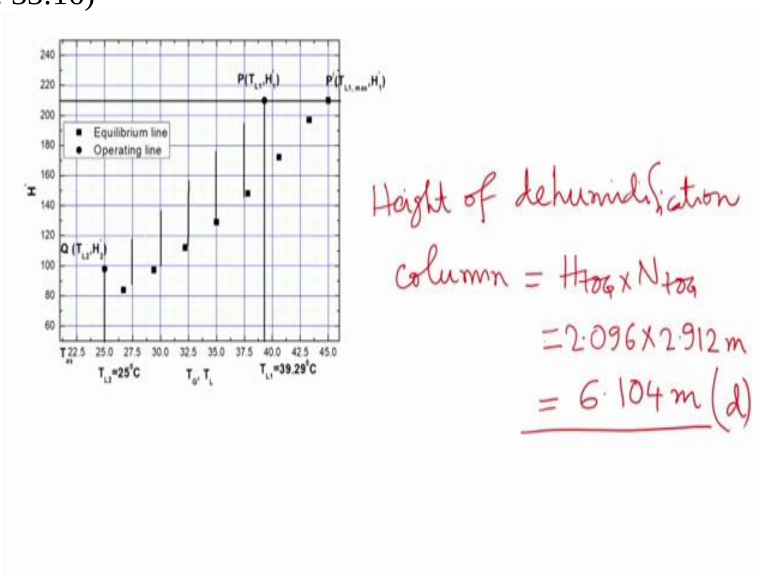


So now we have this Htog and Ntog from there will be getting this height of this dehumidification column that is we can see this one total height of dehumidification column is equal to Htog in to Ntog that is coming out as we can say 2.096 into 2.912 meter. So that is nothing but 6.104 meter. We can say this one the height of the dehumidification column.

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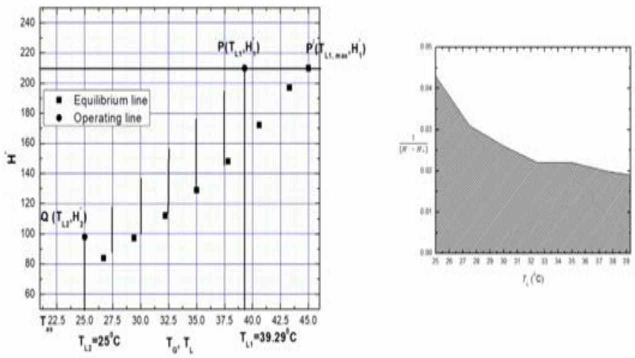


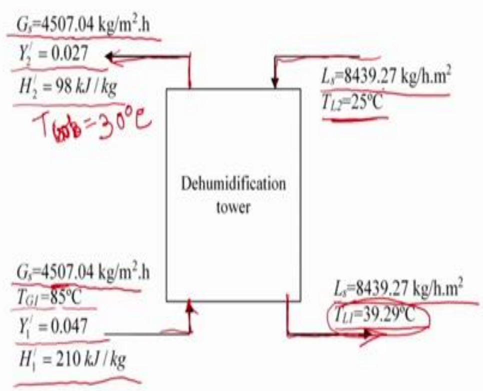


So that is the end of this say the area under the curve is obtained as this one. And so will be the, Now the total system is like this the gas flow rate is 4507.04 kg per meter square hour, this inlet air temperature is 85 degrees Celsius with humilities 0.047 kg per kg dry air. That is the absolute humidity and Enthalpy value is 210 kilo joules per kg dry air which is this.

So that is why so we can say more hot air is entering and whatever the cold water is entering that is at 25 degrees Celsius with the actual flow rate is 84039.27 kg per meter square hour so but that is the we get 1.4 times of the minimum water flow rate and the whatever the cold water actually air that is leaving from this dehumidification column that is we can say this wet bulb temperature actually we can say this one TG2 we can say this one coming out as so that is T wet bulb actually we can see this one wet bulb temperature that is as 30 degrees Celsius.

Okay and the the flow rate will remain the same because this is this one per kg dry air let say 4507.04 kg per meter square hour and with the humidity much lower than this whatever humidity was there in the inlet this one air that is 0.027 kg per kg dry air and Enthalpy value is 98 point 98 kg joule per kg and whatever the liquid water this one we can say this hot water will be leaving the dehumidification tower that the temperature is 39.29 degrees Celsius and liquid flow rate that is we can say this one 8439.27 kg per meter square hour and if this liquid this one the what is called this outlet liquid water temperature is if it is 45 degrees Celsius then the liquid flow rate will be 1.4 times less than 8439.27 kg per meter square hour

So in the next class we will be discussing on drying operation.

Thank you.

**Appendix- Psychrometric Chart**

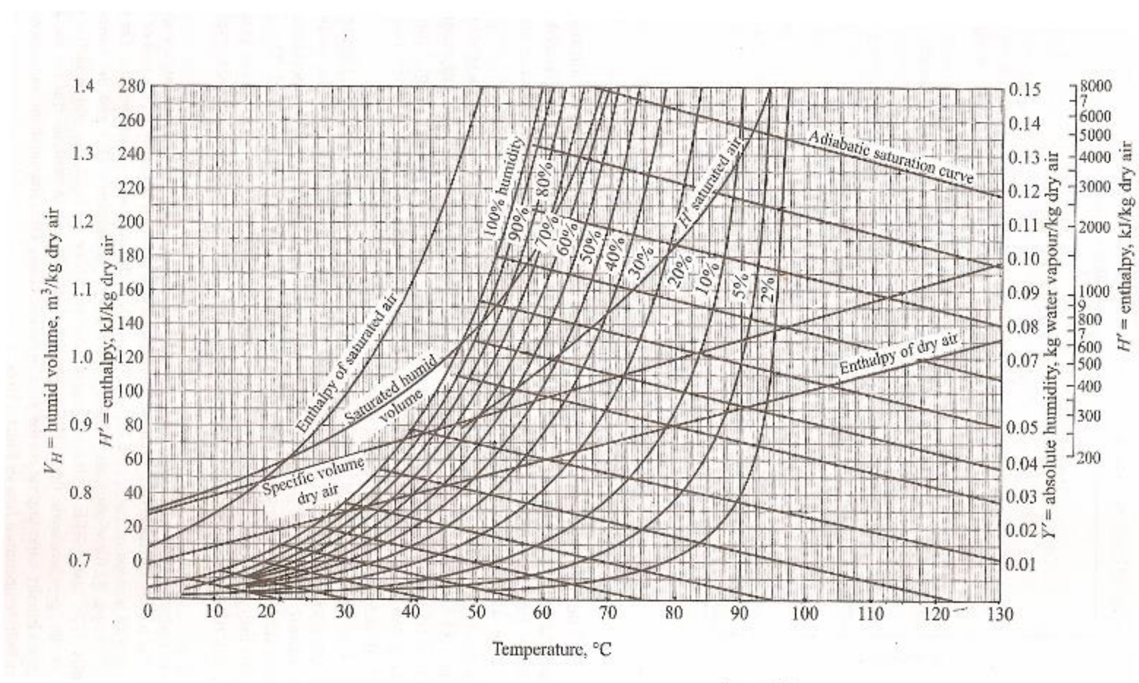


**Figure : Psychrometric chart for air-water system at 1 atm total pressure.**