Material and Energy Balance Computations
Prof. Rabibrata Mukherjee
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

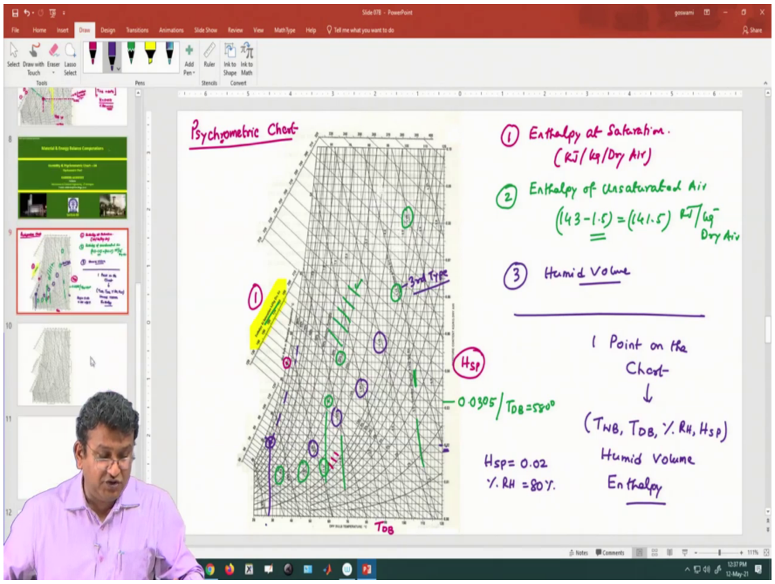
Lecture – 60
Humidity and Psychrometric Chart - IV

Welcome back for the last time. Now for this course and I hope you have enjoyed, and you have more importantly learnt something. This is a fundamental course for chemical engineering students. So, whatever you do in your life you actually have to learn the course subject well and based on that you can expand into any discipline in future what you want. Chemical engineers actually have been one of the most chemical engineering has been one of the most versatile disciplines of course there is lot of potential in the core, but you can do lot of things outside also.

So, that sort of brings us to the last lecture of the course and we will discuss on psychrometric chart which we started in the previous lecture. Any feedback or anything you want to know which is not clear. So, when the course is running of course there will be the live sessions where you can take advantage of interacting directly with me I will try to clarify your doubts but even other than that if you are listening to this lecture because these lectures will be available in YouTube and all that.

And if you have any doubt so please feel free to email me and I will try to respond. So, with that I sort of start the last lecture.

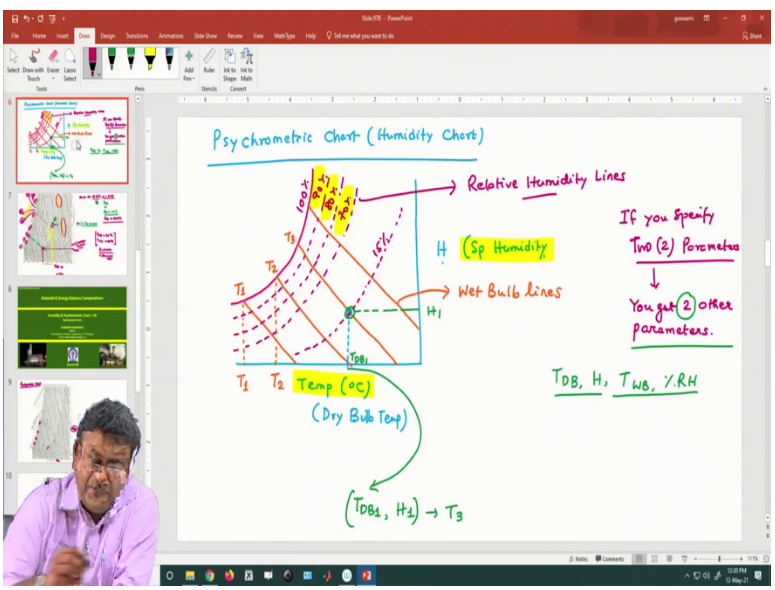
(Refer Slide Time: 01:26)



And this class or all of you who have been following this class rigorously now you should not be having any difficulty in understanding this rather complicated looking graph which we now know is the psychrometric graph. So, x axis actually is the dry bulb temperature and y axis is the specific humidity or the moisture content and then some of the lines we understand.

So, these set of inclined lines are the wet bulb lines and at the end of the wet bulb line it is written 30%, 30, 20, 20, 35, 40. So, these are the wet bulb temperatures.

(Refer Slide Time: 02:21)



And when in the previous lecture I was telling you that these two temperatures are same obviously because this is the 100% saturation line. So, on the 100% saturation line of course. So, this is up to 90% and this is the saturation line. So, of course if this is 30°C you go down and you see this is also 30°C because at saturation the wet bulb temperature and the dry bulb temperature are same.

So, we now understand four stuff. So, these are the wet bulb lines and the relative humidity. So, it is like 1%, 2% then 10, 15, 20, 30, 40 blah blah but in addition to that there are three other parameters which I highlighted. So, this small parameter is enthalpy at saturation kilojoule per kg dry air. So, let us mark this as one this is enthalpy at saturation and unit is kilo joule per kg dry air. So, this is enthalpy at saturation.

So, if you have air let us say this is the condition of your air then you automatically you can find out what is the enthalpy at saturation. So, per kg of dry air its enthalpy of saturation is 143. But then comes the question if you have humid air which is not 100% saturated you cannot use it because this is at saturation.

So, there is something that you can use and for that you have these set of lines you see this nearly vertical but slightly curved lines you have these are the third set of lines actually there are three sets of lines. So, these dry wet bulb lines we now know. So, these we know very well now but you see there are this nearly vertical but slightly curved lines and of course the x and y axis are the dry bulb lines and the specific humidity lines and here you see what is written is enthalpy me just see what exactly is the terminology they have used its enthalpy difference or something like that.

So, what it means is some numbers are written over here. So, this is minus 4. So, this is minus 5 this is -4 this is -3 this is -2 this is -1 this is -1 this is -0.5 and things like that. So, instead of being at saturation let us say if you have a condition over here. So, how do you find out its enthalpy of this humid air you can find out. So, you find out the enthalpy at saturation follow the wet bulb line and from there now you see how on which enthalpy deviation line it lies and you find that this is very close to -1.5 line.

So, this is -2, line. So, now what you can say that the enthalpy of the unsaturated air whatever that is it is an unsaturated air based on this condition and condition also you can find out. So, this has specific humidity of 0.0305 and dry bulb temperature of 58°C that is the point. So, you can straight away say that its relative humidity is 25% its wet bulb temperature is 37°C but in addition to that you can also say its enthalpy is 143 - 1.5 that is 141.5 kilo joule per kg dry air.

So, again I will repeat how do you get the number -1.5 or whatever. So, first you look into this point from here you find out you follow the weight bulb line find out the enthalpy at saturation then you find out the nearest enthalpy deviation line which are these lines and here we find it lies close to -1.5. So, it is like 143 – 1.5 its 141.5. So, enthalpy at saturation we understood this enthalpy deviation I am unable to read exactly what is written in this particular chart does not really matter but this is what is the function of it.

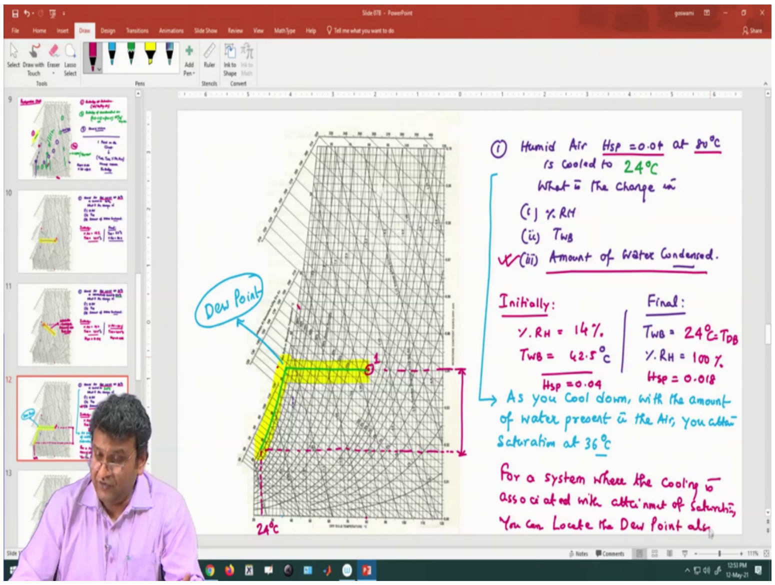
The third set of lines is these lines so where you have these numbers 1.15, 1.20, 1.10, 1.05 then you have 1 then 0.95 and things like that this is the third set of line these are also slanted lines but at a much lower higher slope as compared to the wet bulb lines and these are essentially these lines are as you can see over here in this enlarged or the magnified version volume these are the humid volume essentially.

So, this is essentially the volume of air the humid air meter cube per kg dry air is the specific volume or the humid volume. So, these are the third set of lines. So, these are the third set of lines third type of lines this gives you the humid volume. So, you actually if you can point you can identify one point. So, one point on the chart from there you can get four different entities. So, firstly wet bulb dry bulb relative humidity specific humidity these four obviously then you also get humid volume and the enthalpy.

So, these 6 terms, so, just look at one point and you get four more. So, you can essentially have a combination of any 2 to locate a point on the psychometric chart and then the remaining four you can straight away find out. So, let me tell you like we have a condition like the specific enthalpy the specific humidity 0.02 and the relative humidity is let us say 80%can you do that. So, here is the 0.02 and this is the 90, 80% line.

So, you need to locate of course it becomes a little clumsy but nonetheless. So, here is the point 0.02 is the humidity the specific humidity and 80% is the relative humidity. So, straight away you can find out the temperature which is 20°C the dry bulb wet bulb temperature is 26°C dry bulb temperature and wet bulb temperature very close to each other means that the system is very close to saturation. So, these things you can clearly understand.

(Refer Slide Time: 10:01)



So, I hope now you can sort of locate points on the psychrometric chart quite easily. Now let us quickly take up a few very interesting problems which you can also locate or do on the psychometric chart. So, let us say humid air with specific humidity 0.04 and 80°C is cooled to let us say 40°C what is the change in (1) % relative humidity and (2) wet bulb temperature (3) amount of water condensed. So, let see what is specified.

So, what is specified is that humidity the specific humidity is 0.04 and the dry bulb temperature is 80°C. So, here is 80°C and this is 0.04. So, you go like this. So, I guess yeah this is the point. So, this is the point. So, this is the initial point 0.1 let us say we mark. So, we find initially what we have is the percentage r h is somewhere again between ten and 15%. So, let us say it is about 13% the wet bulb temperature is somewhere between these two lines. So, it goes and hits here.

So, its 42.5 and it is said that it is cool to 40°C and H sp I must specify remains at 0.04 or its simply cooled to 40°C. So, if you just say that you are you have simply cooled it to 40°C, so, what do you mean it means that the dry bulb temperature has gone down. So, if the dry bulb temperature has gone down so this is the path it is going to follow because this is in the reduction in the direction of reduction of the dry bulb temperature.

And you see that it heats 40°C somewhere over here no not there sorry I made a mistake no I think I am. So, it is over here. So, now you see the wet bulb temperature. So, the final wet bulb temperature has now changed to 37°C sorry I made a mistake over here it is not percentage its 42.5°C. So, wet bulb temperature has gone to 37°C and the relative humidity has shoot up to 80%.

So, you can see this amount of water condensed well nothing has condensed because water has not got saturated. So, this is a type of problem you can very easily do next another problem we can do is that air at H sp of 0.04 and at 80°C is now mentioned to be adiabatically cooled is adiabatically cooled to 50°C yeah I am just changing the number for some reason what is the change.

So, adiabatically cool. So, the first problem is over where we just mentioned that it is cooled. So, if it is mentioned it is cooled you just look into the change in the dry bulb temperature here what we are mentioning that air with this let's say it is the same initial condition. So, let us try to locate the point first this is the point. So, 80°C and 0.04, so, this is the point. So, it is adiabatically cooled it says adiabatically cool to 50°C.

Now what exactly is adiabatic cooling means. So, initially so, the problem is same percent what is the change in the% relative humidity the wet bulb temperature and the amount of water condensed and. So, initial condition since the initial condition is same even for this particular problem. So, you can again cross check the initial condition is like probably we took a wrong point in the previous case because of the mix up this is a problem particularly if you are doing it online be very careful.

So, we probably see the relative humidity is not exactly thirteen% but it is close to 14% its closer to the 15% line and the wet bulb temperature we calculated correctly 41, 42. So, it is around

42.5°C that is perfectly fine. So, maybe in the previous problem also we should check what mistake we did we make a mistake no I think we took 13% we should have taken 14% its fine. So, we can always do a correction. So, this is the initial condition over here and now it says that it is cooled adiabatically.

So, any idea what do you mean by cooled adiabatically that means that instead of the cooling line following horizontally the cooling line will now follow the wet bulb line because the wet bulb temperature is the under adiabatic condition wet bulb temperature is achieved under adiabatic condition you know that. So, now the process actually propagates like this following a line parallel to the wet bulb line and when does it stop it says its 50°C.

So, when this line intersects the 50°C dry bulb line which will be somewhere over here yeah. So, it is over here. So, then you stop this is your adiabatic cooling. So, what we learn that if it says that you are doing adiabatic cooling then you are essentially following wet bulb line. So, then under the final condition what are the things that have happened and please do also understand that here H sp was 0.04 since you have cooled it adiabatically the H has also changed, and it has now gone up to 0.04.

So, it is like 0.056 but since you are following a wet bulb line there is no change in the wet bulb temperature. So, I do hope all of you have understood these yellow lines have no meaning actually this is the process I hope all of you have understood what is meant by adiabatic cooling. So, if it mentions that you have adiabatic cooling you actually follow the corresponding wet bulb light and then you can also find out what is the change in the humid volume this and that which you can all do.

So, here there is actually no change in the wet bulb temperature because you are following a wet bulb line. So, where the wet bulb temperature remains constant but what about the humidity? Humidity was initially at 14% and here you can see that it has shot up to let us say 68%. So, this way you can do the or draw a process draw a process on a on the psychometric chart about the third part of the question again there is no question because you have not attained saturation.

So, only when you attain saturation then the question of water condensing out will be important since you have not attained saturation there is no question of any water condensing out. So, water condensing out is 0 we will immediately come to an example of when this thing happens. So, this is like normal cooling this is how the normal cooling looks you sort of follow the same specific humidity specific humidity remains same but as the temperature reduces the water holding capacity of dry air progressively reduces and that is why the relative humidity goes up.

So, as temperature reduces with the same amount of moisture present in the system you are now closer and closer to saturation and therefore the relative humidity goes up this is how it looks like. Now let us take another problem which is very close to this initial problem we looked into and let us say now instead of 40°C we are cooling to let us say 24°C. No adiabatic cooling, instead we are doing a normal cooling up to 24°C.

Same initial condition I we can take different initial conditions. But since this graph and particularly on online PPT it is little clumsy. So, I do not want to change the initial condition. So, here we know this is the initial point. So, initial point again we have located based on H sp equal to 0.04 and temperature equal to 80°C. So, based on that we know the initial humidity is 14% and the wet bulb temperature is 42.5°C.

So, now it says that it is cooled to 24°C. So, perfect. So, we know how to draw cooling now and we start drawing the line. So, we go follow the line the specific humidity remains same and you cool all the way but here you see that this temperature is 36°C this temperature if you see over here is 36°C and you have been told to cool down to 24°C. So, what happens as you cool down.

So, this is a very interesting problem. So, as you cool down with the amount of water present in the air you attain saturation at 36°C. So, now its 100% saturated but you still want to cool it down. So, now what will happen, now the cooling trajectory will follow the saturation line. So, this is 24°C up to here. So, you are cooling.

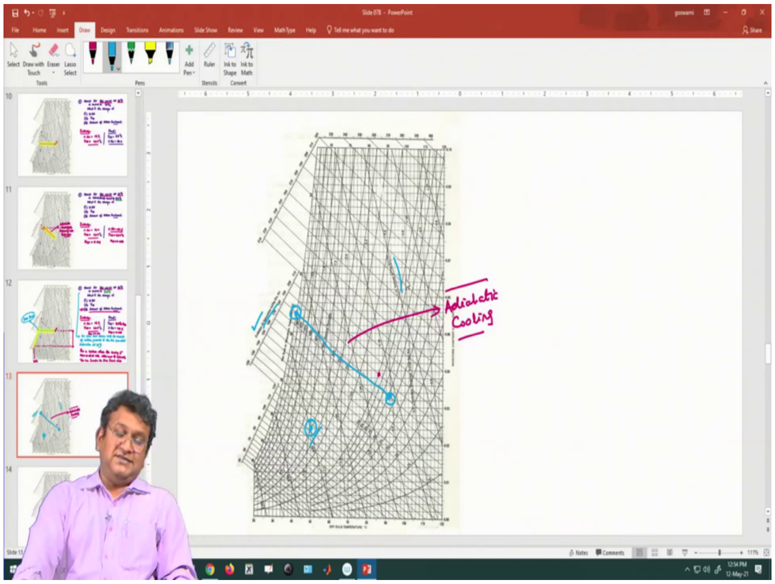
So, this is the cooling line, but it has now two parts the first part is a cooling till saturation is attained and after that if you progressively cool now what happens is you are cooling but you are following the saturation curve and consequently. Now what happens beyond this stage or during this phase now there is a change in the specific humidity. So, initially the specific humidity which was 0.04 now drops to 0.018.

So, for this problem the third part is very relevant. So, what you can say 0.022 kg per kg of bone-dry air water has condensed out more importantly what about the final condition? Final condition your final dry bulb temperature is given as 24°C but now you realize that water or the air is saturated. So, the dry bulb temperature and the wet bulb temperature are going to be same. So, dry bulb temperature now equal to 24°C is equal to the dry bulb temperature and of course this happens at relative humidity of 100%.

So, now I guess all of you can understand the physics of dew formation in the early morning in winters this is exactly happens. So, let us say you have 70% relative humidity air at the time and now at night because of the cooling let us say the temperature drops from 30°C to 13°C and. So, maybe at certain temperature with that amount of whatever is the moisture that is present it attains saturation and if you now cool further this additional amount of the water that is condensing actually appears in the form of dew and therefore this particular point is the dew point.

So, the moment dew point there is no curve or anything like that but for a system like this where the cooling is associated with attainment of saturation you can locate the dew point also of course I gave three representative problems you can also in principle have a system where you do adiabatic cooling to such a temperature that you attain saturation and in that case the graph will look like this.

(Refer Slide Time: 25:47)

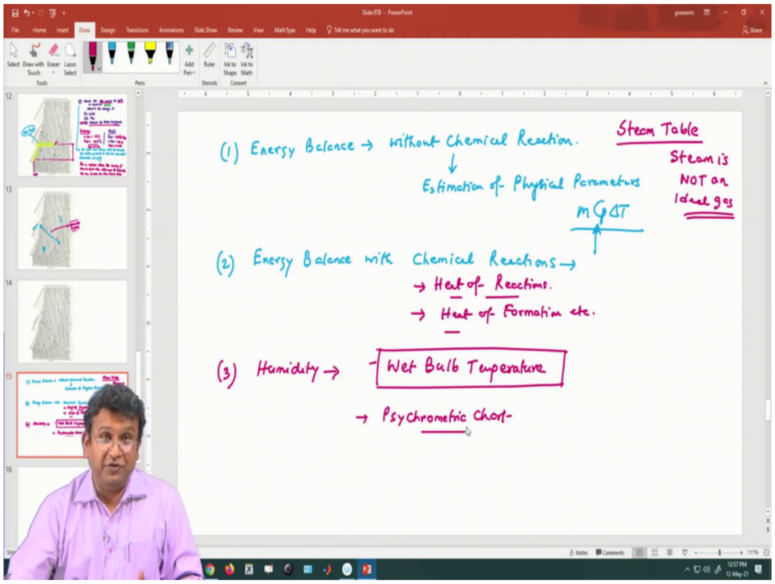


So, of course beyond saturation or in other words adiabatic cooling is only possible up to saturation is attained because after that you cannot have adiabatic cooling the moment it condenses out there is actually net transfer of it. So, if you strictly if somebody ask you how much you can do adiabatic cooling you can go only up to the level of 100% relative humidity please do understand that this part of the curve will not be present but this will not be adiabatic.

So, adiabatic cooling you can go only up like this following a wet bulb temperature the other thing which I am not emphasizing. So, if you have a point which I request all of you and this graph I will tell the NPTEL team to share with all of you as a course material any point if you look at you can also find out probably the other parameters that enthalpy at saturation what is the actual enthalpy and humid volume.

So, this needs a little bit of practice. So, that sort of brings us to the end of this particular course and all I will say is thank you.

(Refer Slide Time: 26:59)



But more than that what are the things we have learnt we have essentially learnt energy balance we have learned the basic pedagogy the terminologies what is the system this and that. So, energy balance first we learnt energy balance without chemical reactions and one important thing what we have learnt here is estimation of parameters because many of you will ultimately say sir after doing all this we actually have done this integration of mC_Ptdt from T_1 to T_2 but what this course has also taught you is how to estimate C_p in certain cases in the next part of the course we learnt about thermo chemistry you can say.

So, energy balance with chemical reactions and if you would like to add of course while handling chemical balance without energy balance without chemical reactions you probably have learnt rather well to handle how to handle the steam table and please remember as a last time warning of this as I end this course today is that steam is not an ideal gas under any circumstances. So, please do not use do not get tempted to use PV equal to nRT for steam it is not an ideal gas.

So, then we learnt about energy balance with chemical reactions and we learnt some nice concepts like heat of reaction of course one thing we have not talked about that is activation energy which is fine. So, heat of reaction and then we learnt terminologies like heat of formation etcetera and the third thing we learnt is essentially the concept of humidity and how to handle. So, different forms of humidity; the concept of saturation and most importantly very important concept is the wet bulb temperature.

So, here actually you have learnt in mass transfer particularly we will realize that if you understand wet bulb temperature how it is measured what it is you actually understand quite a bit of very intricate phenomena because it is not that easy to visualize the condition under which wet bulb temperature can be measured. So, of course is a preliminary course and I have taught it in that manner and then finally we learnt how to handle the psychometric chart which is my personal favorite because you can have.

So, much fun with the psychometric chart including locating processes. So, with that I would log off and I would like to thank all of you. and I do hope that you all had an enjoyable time and all the best for your future, thank you very much.