Material and Energy Balance Computations
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Lecture –46
Tutorial - II

Welcome back. So, we started our discussion on steam table. And, I hope from the discussion we had in the previous class, you have already gathered some idea about the utility of steam in different process applications and different settings where you would like to have superheated steam or saturated steam. And, I also hope that you now understand the difference between superheated steam and saturated steam.

In this class of course so, whenever you have saturated steam you can potentially have a situation where you can have a mixture of water and steam at that particular temperature under the saturation condition. So, there is a term that I will teach in this class or maybe in the next class which is called the quality factor of the steam which actually gives you the ratio and which you can very easily calculate from the steam table.

Suppose you have saturated steam and it is condensing due to heat transfer, but it does not condense as the total amount of heat which corresponds to the entire latent heat does not get transferred. Let's say part of that heat gets transferred and you now have a mixture of steam and liquid water and those properties you can evaluate or find out using the steam table.

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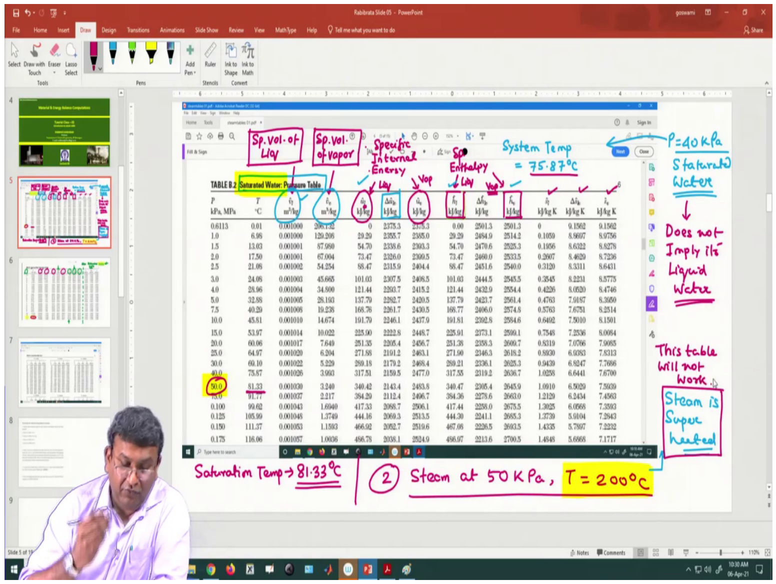

So, coming back to our discussion, so, we just started to talk about steam table, and this is the first table that we looked into great detail is the saturated water pressure table. Here the first column essentially is pressure, or the independent variable is essentially pressure. There are multiple pages of the steam table that is available with you and you get the saturation temperature from it.

And correspondingly you get the specific volume of the vapour from the liquid vapour specific internal energy of the liquid vapour and specific enthalpy of the liquid vapour. As I mentioned the first table of course is the saturated water temperature table. So, it is exactly same to the pressure table the only difference being that in the first column instead of it being pressure it is actually temperature.

So, you start off with temperature. So, if temperature is specified. Let us say that you have steam or saturated water at 110°C and please repeatedly I am telling by reading saturated water please do not conclude in this particular case that you have liquid water it can be steam also. Because steam water whatever or liquid water everything is water.

So, if it says that saturated water at 110°C all you need to do is to go to 110°C in the table and immediately you find out that your saturation pressure is 0.14328 MPa or in other words this also probably you may understand better from the pressure table that if you increase the pressure the boiling temperature increases and this is what you have studied in your school days the basic principle of pressure cooker.

Why cooking happens fast in a pressure cooker because what happens is as you increase the pressure the boiling temperature increases. The rest of the table is very similar to the previous case. So, you have specific volume of vapour and liquid specific volume of liquid and vapour specific internal energy of liquid and vapour and specific enthalpy of liquid and vapour. And these are essentially one can say the latent heats the latent enthalpy or the latent internal energy let us put it like that this is actually the latent heat of vapourization.

This particular thing and as we have discussed that this entropy you can also get. So, you can straight away calculate or put the values but we are not going to talk about it. Now suppose I tell you that I now have steam at 50 kPa and. So, I tell you that I now have steam the problem number two I have steam I will show you how to operate it 50 kPa and temperature is 200°C this is all that is given.

So, just because it is steam and temperature is given at 200°C do not assume anything do not assume. So, just the way by reading the word water you are not supposed to assume that it is liquid water similarly by reading the word steam you are not supposed to assume its saturated steam. So, you have to be very neutral it is given that steam at 50 kPa and the temperature is 200°C.

I am going to teach you how to go about it. So, let us remove all these previous earlier highlights. So, that we can work on it. So, 50 kPa, So, you go to the pressure side table that is the easiest thing to do. So, you find out 50 kPa and then you find out that your saturation temperature is 81.33°C.

And the steam you have has a temperature of 200°C. So, from here you now conclude that the steam I have or we have is superheated and the degree of superheat is roughly 118.67°C. So, therefore once you know that you have super heated steam this table is not going to work because it is for saturated water or saturated steam. So, the conclusion is the moments you have super heated steam the practical or the consideration from the standpoint of implementation is this table will not work.

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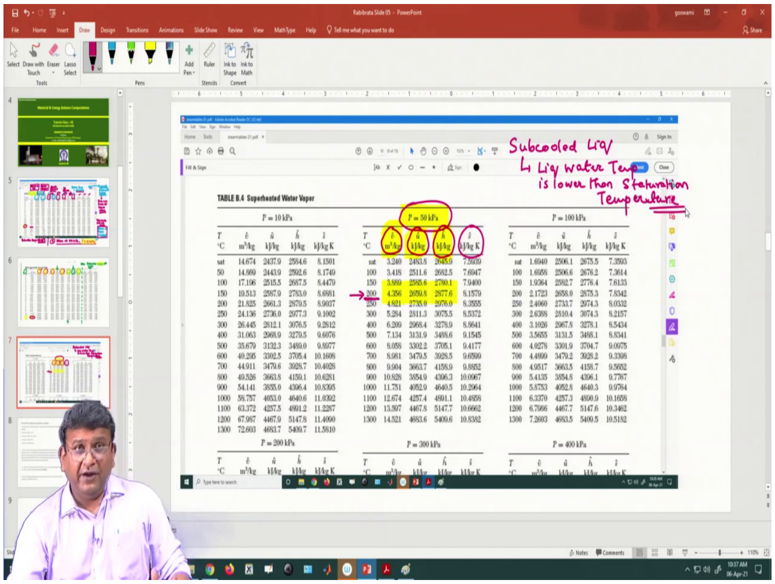

So, what you need to do is in the steam table you need to go to the super heated table and in the steam table we have it is the table set B4 and this is how the super heated table looks like. So, you essentially have the super heated table which is written super heated water vapour and for different pressure parameters are given up to 8 MPa.

I think or maybe even higher sorry about it, so, you have data for; so, I am extremely sorry you have data for 60 MPa up to 60 MPa. So, one important thing to note is that you do not have data it is not possible to have data at all pressure. So, you have data for let us say p the equal to 50 MPa and p equal to 60 MPa and suppose now you end up with some stream which has some intermediate pressure of course you have to do interpolation.

Similarly, you have data for different temperature interval like 400, 450, 500. So, for a given pressure or a given temperature if you have an intermediate data you have to do interpolation which is easy. So, what we have done is the problem that we are looking at says the steam is at 50 kPa. So, this is a landing exercise you can say. So, we go to the table the super heated table which is for 50 kPa and for your convenience I have copied it to the PPT or the out or our white board you can say.

So, here is the table. So, 50 kPa now that we know. So, I just want everyone to be very clear about it from the saturation temperature you cannot conclude straight away at 200°C looks like a high temperature therefore it is super heated nothing like that because it is looking like a high temperature because the pressure is very low at 50 kPa. If you have a high pressure, 200°C is not even the saturation temperature.

So, no random conclusions you need to conclude in a very, very logical and scientific way and that is like T equal to 200°C here the boiling temperature is the saturation temperature corresponding to this pressure is 81.33°C and therefore what you have is a super heated steam. So, if you have super heated steam; then now you go to the super heated steam table and luckily our pressure is 50 kPa.

So, we have data for 50 kPa. So, now you need to go to this table which is the super heated table for 50 kPa and let us look into the structure of the super heated table what are the stuff we have you see that the table is much, much more compressed here. So, here for the pressure for the different pressure you have you have data at different temperature and in our case the temperature is 200°C and you have data for 200°C.

So, you can straight away go over here and then what you find is you have specific volume you have specific internal energy you have specific enthalpy and you have specific entropy only four entities, why? Because when you were talking about the saturated steam there was a possibility that you might have liquid or air therefore you this is very, very important. So, when you are talking about the saturated steam table there was a possibility that you may either have liquid or you have vapour at that temperature and pressure.

Therefore, you as you have looked correctly or as we have learnt specific volume there were two sets of data specific internal energy there were two sets of data specific enthalpy there were two sets of data is it clear to all of you. But here when you have super heated steam of course there is no possibility of having liquid. So, it has to be in the vapour form and therefore you are only left with only one set of data.

And what is that set of data that set of data is the specific volume the specific internal energy and the specific enthalpy. So, I hope this is clear to all of you and now we are quite well poised to take up some practical problems from our tutorial sheet. And just for the sake of completeness we also have two additional tables one is the saturated water again the solid vapour table. So, if you understand what is the solid vapour table you are essentially in the lower left part of the phase diagram where below the triple point there is a possibility of transition of those triple point would do for one atmospheric pressure. There was a possibility for a direct transition from solid to vapour.

We rarely use this, but this is for the sake of completeness you must know that such data is also available. And this is a different pressure therefore you have this type of range. And so, this is one set of data you have the other the last set of data you have in table B5 is sub cooled liquid data sub cooled liquid water typically I will show you that we can we know the specific heat of water its 4.2 kilo joule per Kelvin kg.

So, we typically use that, but this is at different pressure. So, that that data is valid at one atmospheric pressure. So, this is a different pressure. So, this is like a high pressure that that C p value might change and here what you have is a different pressure you directly just like your super heated steam data you can sort of find out what is the sub cool liquid data. By the way what is sub cool liquid sub cool liquid.

So, water at 30°C at room temperature is actually some cool liquid because now you understand that normal boiling temperature. So, this is an important terminology I mean just make a note of it just the way we learnt about superheated steam. So, similarly there is another pedagogy called sub cooled liquid. So, it is like liquid water temperature is lower than saturation temperature. So, at one atmospheric pressure for example all the water you see around us the drinking water everything is actually sub cool liquid.

Sub cool liquid again does not mean that it has to be taken out from the refrigerator these are things these are important to note. Because at one atmospheric pressure saturated liquid is at

100°C. So, anything below that is actually sub cool liquid. So, I think with this we can now move on and try to pick up some problems from the tutorial sheet.

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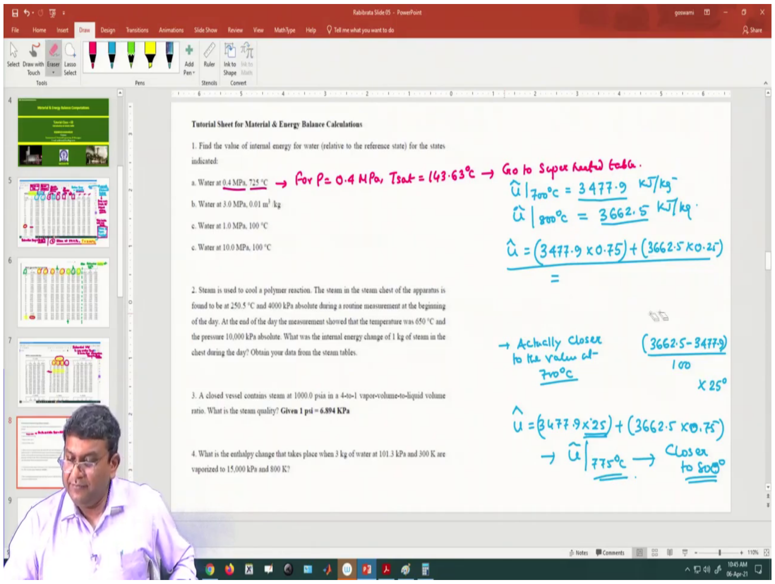

So, here is the first set of problems find the value of internal energy for water for the relative to the reference state which is at zero. What we have seen in the steam table for the states indicated below. It has told for internal energy, but it can also be like you can have it can you might be told that you can calculate the specific enthalpy or any property for that matter. So, le us see what the data is provided?

Data is provided is 0.4 MPa 725°C. So, what is the thing we should do we should first go to the pressure table and so, do not conclude straight away that 725 looks to be very high and therefore it must be superheated nothing like that so, 0.4 MPa you see its going kilopascal. So, here it turns point one. So, 0.4 MPa we find that the boiling temperature is the saturation temperature is 143.63°C.

So, you must write all this when you are solving saturation temperature or T sat is a valid for P equal to 0.4 MPa T sat equal to 143.63 I can use my steam table that I have with me. So, that I do not have to swap back and forth its 143.63°C and therefore now you know what to do. So, now we move on go to super heated table. So, go to super heated table and for 0.4 MPa pressure.

So, we now go to superheated table and 0.4 MPa is 400 kPa. So, this is the data set 400 kilopascal you can see probably I will enlarge it a little bit. So, you can see for four hundred kilopascal this is 0.4 MPa and the temperature that is given to us is 725°C this is important and therefore we now understand that specific internal energy will be between these 2. So, that is very important.

So, let us quickly take this data in the slide you will be solving all this in fraction of seconds. But I prefer that you learn things thoroughly and. So, if this is the data set you have there is a small catch there which I would like to demonstrate. So, you pick up the data and you see that at four hundred kilopascal or 0.4 MPa you have specific enthalpy specific internal energy for 700°C its go it is given as 3477.9 kilo joule per kg and u cap at 800°C it is going to be 3662.5 kilo joule per kg this is enough for us.

So, we do not need the data any further. So, let us have a look into what to do. So, what is the value now? The value is; so how do you calculate. So, you have the data at 700°C you have the data at 800°C. So, all you have to do is you have to do an interpolation. So, please do understand if the system was at 700°C its value would have been 3479, and had it been at 800°C the specific enthalpy would have been 3662.

Here is a problem many people actually make a mistake. So, we find it at 725. So, many people will do a multiplication of 0.25 into 3477 + 0.75 into 3662 this is wrong. So, the final u I am telling why it is wrong is actually 3477.9 into 0.75 + 3662.5 into 0.52. This is whatever is the; value you just calculate we can do it quickly over here. So, it is 3477.9 into 0.75 + 3662.5 into 0.25 and it turns out I made some mistake because the brackets are not there. So, you can anyway make it.

So, just find out what is what it is that is not very important the numbers I do not have the numbers calculated sorry about it. You can just do it yourself and or I will just do it or whatever you just do it. The important thing to note is it is not 3477.9 into 0.25 that is the important thing because what you are actually doing is you are you know the value at 700°C then you are doing a linear interpolation. So, what is that the value is 3662.5 at 800°C -3477.9 at 700°C divided by

100 and multiplied by 25°C. So, that is what you are doing that is how you get the value at 725°C. It is not that the effect is 25% of what you have at 70 is a 700°C and 75% of what you have at 800°C. If you calculate that I do not know how many of you are; understanding what I am telling this is a very, very common mistake that people do.

So, if you actually and you can think over it not too many teachers will tell you all these things in detail and many people have these wrong concepts you end up getting the u value at 775°C this way please remember the reason for this is u at 775 is actually closer this is a logical way to remember maybe actually closer to the value at 700°C. So, if you use this just 25% of the value of 700°C and 75% of the value of 800°C this is actually closer to 800°C.

So, this is the Lever rule this is actually what is known as the inverse Lever rule and this is from where it comes. So, just fill up the blanks and you will fill up the numbers and you will get the desired value as shown in the ppt.

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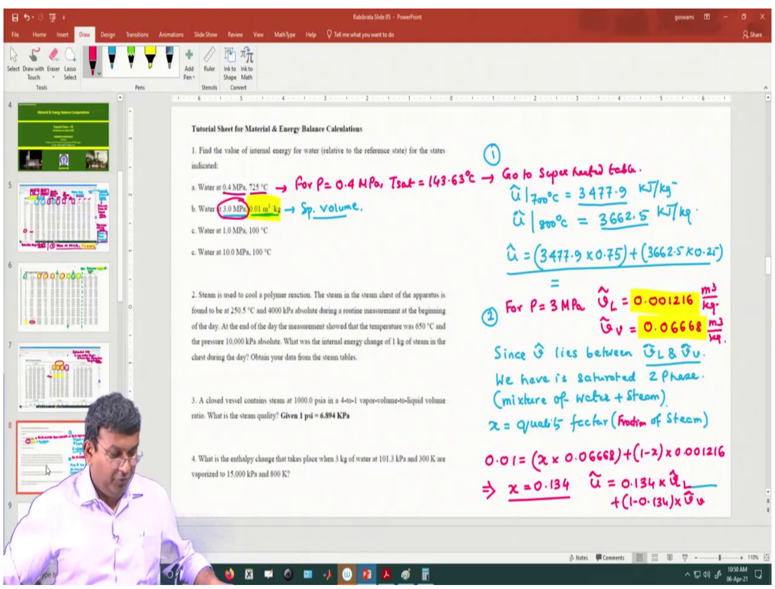

So, what is the next one? Next one is water at 3 MPa and you see what is specified. 3 MPa and the density is given, or the specific volume is given. So, that is very interesting. So, this is problem one this is problem two. So, what we do we again go to the pressure side table and we find out the data for 3MPa. So, for 3 MPa we find these numbers for 3 MPa we find these numbers.

So, just a minute please yeah, we find these numbers what are these numbers for 3 MPa we find V_l (specific volume of liquid) is 0.001216 m^3/kg you can check it in the steam table and V_v is 0.06668 m^3/kg. So, do you get an idea what is happening, the what is happening is very interesting. You see here only the pressure is specified temperature is not specified. But something else is specified and the specific volume.

Now the value of specific volume that is given to us 0.01 m^3/kg lies between these two values you can see that 0.01 lies between these two values. So, what is the conclusion? Conclusion is since specific volume lies between V_l and V_v what we have saturated two phase or mixture of water and steam. So, how do we go about it we go about it like x is the quality factor let us say x is the quality factor that is the ratio of steam or the fraction I would say ratio sorry about it fraction of steam.

So, what it means what it means is 0.01 is equal to x into 0.0668 + 1 - x into 0.001216 and if you solve for it you will get x equal to 0.134. So, your final u will be 0.134 into specific volume of liquid + 1 - 0.134 into specific volume of vapour and you can calculate it. You can from 3 MPa pressure table find out the specific volume of liquid and the vapour which are given here you have a copy of the steam table.

So, there should not be any problem it is these two numbers and you can find them out. So, this much amount I do expect from all of you to do. So, next we move on to the third problem may be the last problem we take up in today's class its better we go a little slow which is perfectly fine.

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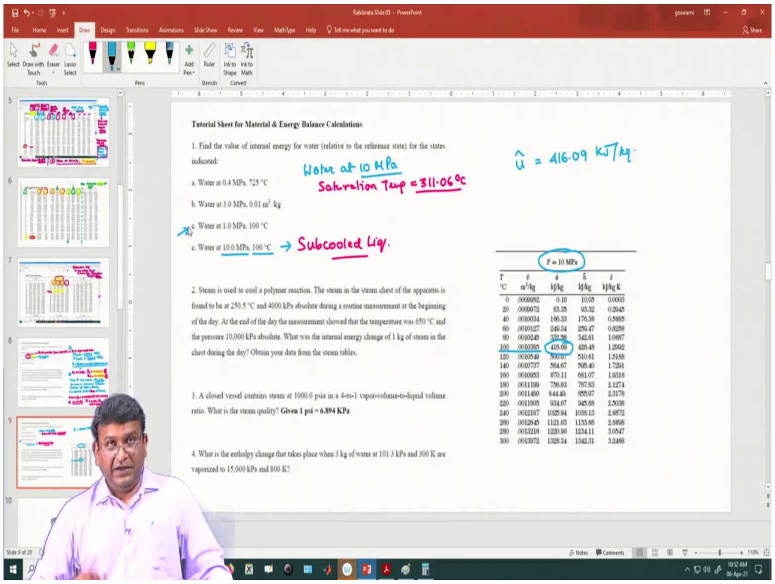

And so, what is the third problem we have let us pick up the fourth problem first water at 10 MPa and 100°C. The third one you can do yourself, but I will show probably. So, water at 10 MPa. So, we first go to the pressure table we go to the pressure table and see the 10MPa the boiling point or the saturation temperature is 311.06°C. So, saturation temperature, so, what is the conclusion?

Conclusion is this water is sub cooled liquid. So, if it is sub cool liquid then what we should do we should see or we should go to the sub cool liquid table and which is the table B5 and we find that the pressure here is adequately high and for 10 MPa of course some data is given. So, we pick it up and which is now becomes very simple. So, we just look into the data this is the sub cooled water data and for 10 MPa what we have is the temperature is 100°C. So, you straight away get the specific internal energy.

So, specific internal energy in this particular case is 416.09 kilo joule per kg. This one I request all of you to try and we pick up the next set of problems in the next class. Thank you very much for your attention.