Material and Energy Balance Computations
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Lecture –47
Tutorial - III

Welcome back. So, we were discussing we were solving some tutorial problems and primarily we were using, or we learnt how to use the steam table and we started to look at certain tricky type of problems which you can solve with the help of the steam table. For example, we looked into a problem which had densities or specific volume lying between that of water and steam at a given temperature therefore you now know it is sort of a two-phase system and stuff like that.

So, continuing in that line we I assure that we will handle quite a few exciting problems in the couple next couple of classes also which will make your understanding even better. So, the problem we were looking at is water at 10 megapascal (MPa) and 100°C. So, first what we should do?

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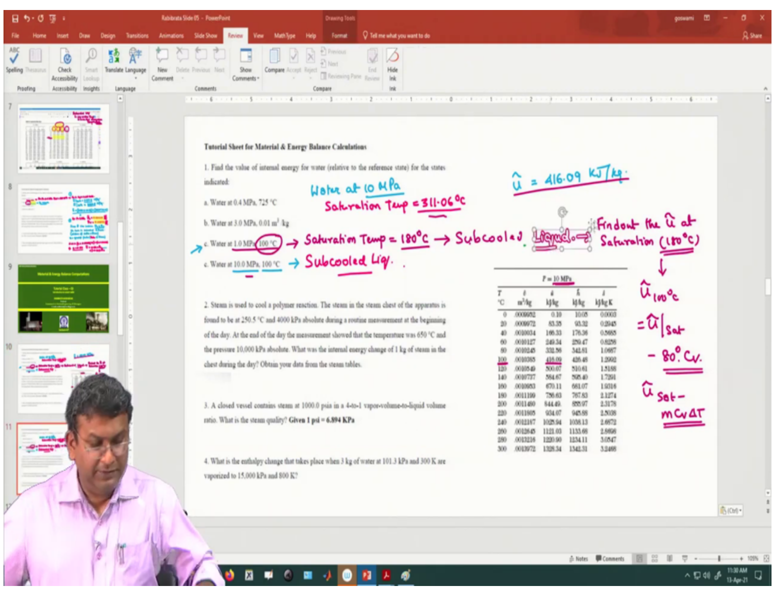

We should go to the steam table and from the steam table if we go to the pressure side table, we see that at 10 MPa the temperature the saturation temperature is 311°C. So, this is what you can see. And so, water at 10 MPa the saturation temperature is 311°C therefore what we have is a sub cooled liquid.

And therefore, we now go to the sub cool table which is the table B5 the last table which is a sub cool liquid water table and here you see that there is indeed a table for 10 MPa. So, whatever is the data we have just got that part picked up into our PPT and then you see that at temperature of 100 °C at a pressure of 10 MPa you essentially the u you are supposed to find out it is 416.09.

On the other hand, if you now have a problem which says like water at 1 MPa and 100°C how do you solve it? So, again we go to the pressure table first. So, we find out what is the its better to use the B2 table because you can directly correlate it to pressure. And here you see at 1 MPa the saturation temperature is 179.91°C or 180°C.

So, here what we have the saturation temperature equal to 180°C and here the temperature that has been told is 100°C. So, again this is also a case of super heated steam. So, this is a case I am extremely sorry it is a case of sub cooled liquid. However, if you now go to the sub cool liquid table what is interesting that you will find that there is data only from 5 MPa here your pressure is 1 MPa.

So, you do not have any data for that. So, what you do you find out thus the u at saturation that is at 180°C that you can find out and from there you simply subtract the; so, u at 100°C is going to be u at saturation minus the degree of sub cooling is 80 degree. So, you essentially do u sat minus M C v delta T and that is how you can find out the; what is the enthalpy.

So, in such cases where for sub cooling data is not available at a lower pressure, we can sort of assume that the C_p value or the C_v value of water to be known C_p value everybody knows it is 4.2. So, you can use that also and of course for a liquid C_p and C_v values will be quite close to each other. So, you can find out what is the C_v value of water and this way you can solve it. Let us also which is not there in the original tutorial.

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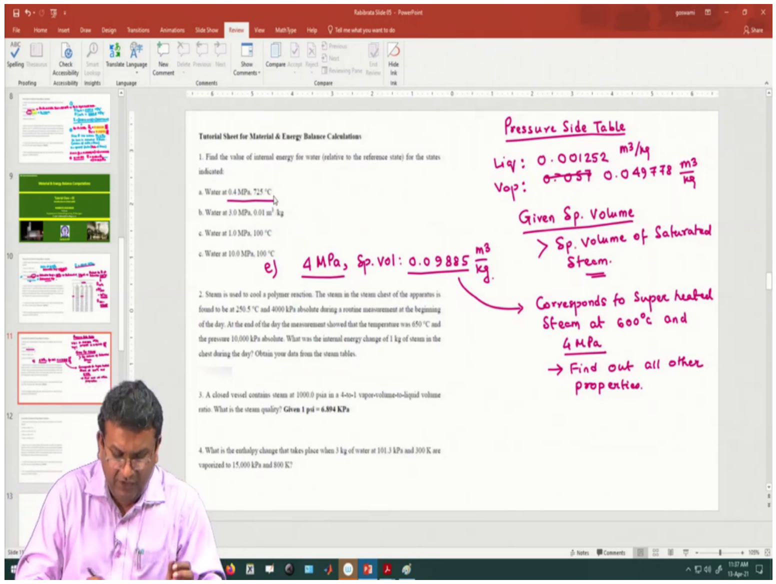

But let us also look into one interesting problem what we have is let us take another problem and that is 4 MPa. So, given condition is 4 MPa. So, you can take it as a 5th problem I will add it in the tutorial sheet and the specific volume is 0.09885 m^3/kg. So, this is what is given. So, how do you solve this problem? So, what you do first is that you go to the pressure side table just one minute please.

So, you go to the pressure side table and from there you first find out what is the condition at 4 MPa. So, here we go at 4 MPa and then we see that it is 250°C is the saturation temperature which is perfectly fine but what is more important is the specific volume data these are 0.001252 and 0.05707. So, 0.001252 and 0.057 something 0 4 MPa sorry its 1252 and 0.049778 is the sorry for liquid and for vapour I hope all of you have got what I have done.

So, this is the specific volume for the liquid, and this is the specific volume for the vapour. Of course, the specific volume of the liquid is much, much smaller as compared to that of vapour which is all fine. But what do we find here what we find that the specific volume is actually beyond this range? The given specific volume given specific volume is actually greater than the specific volume of saturated steam and that is all that you have.

Now does it carry an indication. The answer to this is if you carefully look at the superheated table let us say we are again looking at 4 MPa. Now you see that this is at saturation this is the specific volume for vapour at saturation and now as the degree of super heat increases or as the temperature starts to increase what happens is the specific volume also increases or the density reduces. So, you can see that the specific volume increases here and the value that is given is 0.09885 matches with this particular value.

Of course, I have chosen the problem in such a way. So, that it remains simple. So, you find that 0.09885. So, the given value corresponds to superheated steam at 600°C and 4 MPa then correspondingly you can find out all other properties. So, what these are the simplest sort of problems and what it means is of course you can have direct problems like point 4 MPa and 725°C where also you essentially need to go to the pressure table first and then find out what is the saturation temperature.

Then as you find the temperature is higher than the saturation temperature then you go to the super heated table but there can be tricky ways also tricky ways of specifying. So, one combination can be pressure and specific volume the other combination can be temperature and specific volume then you can also have essentially the sub cool liquid stuff like that. So, what is very, very important is whatever pressure or temperature that is one of the primary variables that is given for the system with that first you check what is the saturation temperature.

And so, essentially you need to find out what is the saturation temperature and corresponding properties at saturation temperature and from there you please go to the appropriate table if you want to go to the super heated table go to the super heated table. If you want to go to the sub cool table go to the sub cool table or if the properties lie between two values like it can be specific volume it can be specific enthalpy it can be specific internal energy they can lie between the values.

In case any such property lies between that of saturated liquid and saturated vapour then of course you know that you essentially have a two phase mixture and then therefore the question of quality factor and all these things coming as we discussed in the previous class.

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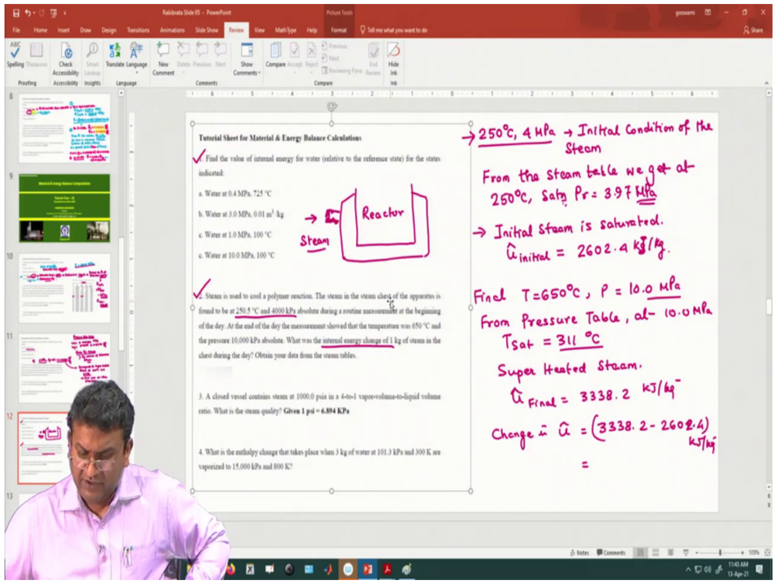

Now let us take up the second problem. So, this is a very easy problem and what it says is steam act. So, steam at steam is used to cool a polymer reaction. So, steam in a; so, essentially it can sound strange but this can happen. So, you must understand of course not that you need to make it. So, here is a reactor and it has a jacket outside jacket right and where you essentially introduce steam. The moment it says that steam is used to cool down a polymerization reaction you can understand that the reaction is a high temperature reaction of course the steam is used as a coolant it is a rare thing.

The steam in the steam chest of the apparatus I am sorry it is not entering. So, you put some steam in the morning at 250.5°C and 4 MPa. So, given condition is 250°C and 4 MPa is the initial condition of the steam. This is the initial condition of the stream. Now go to the; I can either go to the pressure table or the temperature table either is fine. So, at 250°C we are using the temperature table for a change you see that at 250°C the saturation pressure is 3.97 MPa.

So, from the steam table we get you do not have to write like this, but this is for your understanding. So, you can assume that initial steam is saturated and what have they asked you to change what is the change in the internal energy. So, therefore you can find out the u cap initial which is saturated steam. So, this is the vapour side. So, of course there is a question that whether you take saturated steam or saturated liquid because pressure and temperature combination actually gives you I mean on the temperature and pressure.

But since no other parameter is specified you can say that steam in the steam chest is found to be. So, you can assume it to be maybe in the vapour phase. So, if you assume it to be in the vapour phase then this is actually your data for the saturated steam the specific internal energy is 2602.4 kilo joule per kg. So, it is going to be 2602.4 kilo joule per kg kilo joule per kg and then the final what it says at the end of the day the measurement shows the temperature is 60°C pressure ten thousand kilopascal that is equal to 10.0 MPa.

So, what we do we go to the pressure table and we see that at 10 MPa the saturation temperature is 301.06. So, saturation temperature is 301.06°C. So, we know we get from stream table from pressure table at 10 MPa, T_{sat} = 311°C. Therefore, what we finally have is super heated steam I hope you are all able to follow that is why I am going very slowly.

So, that you understand because typically these things are rushed and as you do that now what we do we go to the super heated table and how do we find it out see the superheated table comes for all different values of pressure. So, we now know the pressure is 10 MPa. So, we go to the 10 MPa data and the final temperature is 650°C is given.

So, it is 3338.2 kilo joule per kg. So, u cap final 3338.2 kilo joule per kg. So, the change in u is very simple 3338.2 – 2602.4 kilo joule per kg. So, which you can find out, so, this we have done, this we have done. Let us now take up the next problem which is a very interesting problem if you want to see.

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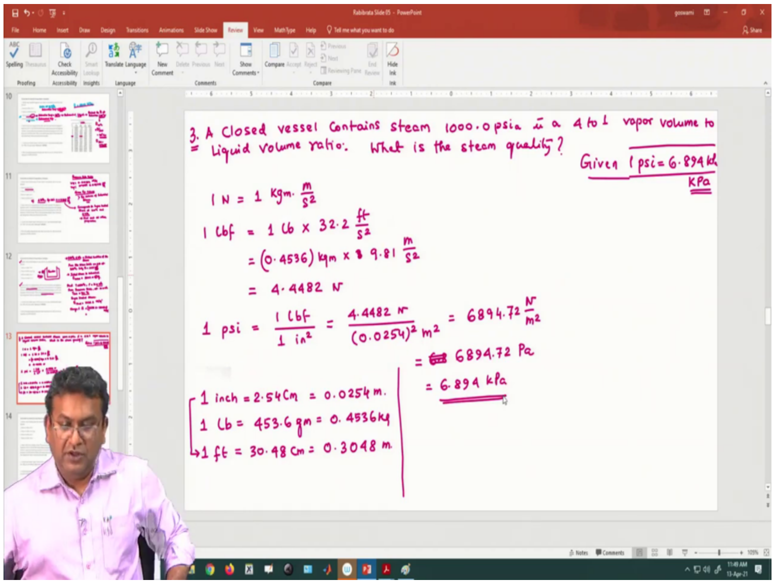

So, a closed vessel yeah a closed vessel contains steam at 1000 psia. So, let me do one thing let me create some space and let me just write down a closed vessel contains steam it is at psia and I have deliberately kept it psia a stands for absolute in a 4 to 1 vapour volume to liquid volume ratio. What is the steam quality? Given for making your life simple but I am sure you have read about 6.894 kilopascal you have read about psi, psi is a very, very important unit because many times what will happen if you actually go to the plant different.

So, you can say that I have studied all my life in SI unit but what may so, happen that many instruments that are on display at the plant they have different units. So, it is extremely important that you know how to convert and therefore though it is given I will actually quickly run you through to how to convert psi into Newton or into Pascal. So, 6.894 kilopascal this is given. So, we can straight away solve the problem in SI unit.

But suppose this statement was not given. So what do we know in fact this these fundamentals should be very, very clear what is one Newton it is actually 1 kg mass is the force that acting on an object of one kg mass produces an acceleration unit acceleration that is what comes from Newton's second law one meter per second square. So, the essentially one Newton is equal to 1 kg mass meter per second square.

Now what is one pound force? Similarly one pound force is the force that acting on an object of one pound producing an acceleration of 32 feet per second square. So, 32 feet per second square I am deliberately doing it, it you can you can just use it or you can learn it the way. Now one pound we know is 0.4536 kg mass into 32.2 or 32 feet per second square this translates to this is the gravitational acceleration this is 9.8 meter per second square you can use that straight away or you can do a conversion using feet the same thing will come.

This is not a big deal actually feet to meter if you do the conversion you roughly divide 32.3 divided by 3.048. So, you roughly get something like 9. So, this turns out to be 4.4482 Newton. So, one pound force turns out to be 4.4482 Newton. Now what is 1 psi? 1 psi is 1 pound force divided by one inch square this we all know. So, one pound force is equal to 4.4482 Newton divided by one inch square one inch is 2.54 centimeter equal to 0.0254 meter.

The other conversion I have used is one pound is 453.6 gram equal to 0.4536 kilogram and one feet is equal to 30 point it is actually same thing if you multiply this by 12 we will get 30.48 centimeter is equal to 0.3048 meter. So, essentially feet to meter conversion you just multiply it with 0.3048 and this now you divide. So, essentially it is one in square. So, its divided by 0.0254 square it becomes Newton per meter square.

And if you calculate it turns out to be 6894.72 Newton per meter square and which is nothing but Pascal. So, this turns out to be 6 point sorry today unfortunately for this lecture my eraser is not working kindly bear with me, Pascal and therefore it is 6.984 kilopascal I hope all of you understood this problem how to solve it. So, this is just a sort of a quick run through that even if this data is not given how we can use our knowledge and can do the conversion ourselves.

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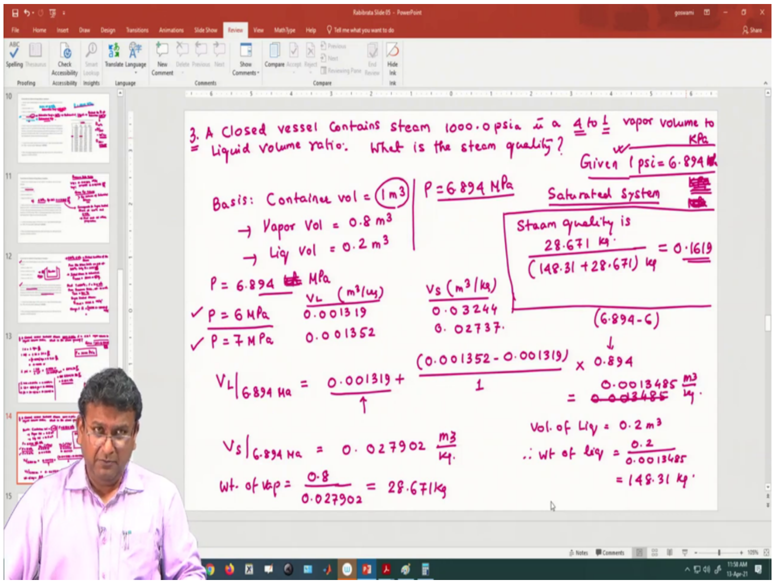

So, now let us come to the problem. So, what do we do we actually have that let us say that the basis is container volume is one meter cube. So, it is given that 4 to 1 vapour volume to liquid volume. So, vapour volume equal to 0.8 meter cube liquid volume equal to 0.2 meter cube. Now what is given the pressure is given at 6.894 Pascal nothing else is given but what we know that this must be a saturated system otherwise unless it is a saturated system it cannot contain vapour and liquid together.

Because super heated steam will only contain super heat only contain steam and saturate sub cooled liquid will only contain liquid. So, here is the crux this is actually a saturated system. So, even if it is written or not it does not matter unless being a saturated system it is not possible for it to remain in this two-phase state. So, what we get from the steam table is that for 6.894 kilopascal. So, we go to the pressure side table I will not show the calculation, but you can do it yourself I will give you enough lead.

So, what we have that 6.894 of course the data will not be there. So, you have all the data for 6 MPa and for say 6 kPa and for 7 kPa. So, let me find out. So, its 4, 5 yeah. So, there is a mistake one yeah. So, there is a small mistake in the problem statement it is actually 6.894 MPa. So, we have all the data for we have all the data for P equal to 6 MPa we have all the data and P equal to 7 MPa we have all the data.

And what are the data the liquid volumes we have at 6 MPa it is 0.001319 m^3/ kg and at 7 MPa it is 001352 m^3/kg and V steam or V_v is what we have is 0.03244 and 0.02737. So, therefore specific volume at 6.694 MPa for liquid is how do you calculate. So, you essentially calculate 0.001319 + 0.001352 – 0.001319 divided by 1 MPa or 1000 kPa divided by 1 into you are essentially looking at 6 MPa + 0.894 MPa.

How do you get this? This is actually 6.894 - 6. So, here is the value for 6 here is the data for 6 MPa and then we are doing a linear interpolation and therefore V of liquid turns out to be 0.0013485134, 0.0013485 m^3/kg. Similarly, you can find out the value for steam which turns out to be 0.027902 m^3/kg and then you know the specific volumes. So, the volume of liquid is 0.2 m^3. Therefore, weight of liquid is equal to 0.2 divided by 0.0013485 is equal to 148.31 kg.

And weight of vapour is equal to 0.8 divided by 0.27902 which is equal to 28.671 kg and therefore what is steam quality. So, I will dig out some space from here and solve it. So, the steam quality 28.671 kg divided by 148.31 + 28.6 kg that is the total mass the mass of steam divided by the total mass and this turns out to be equal to 0.1619. So, this is what is the steam quality. So, this is a very very interesting problem forget about this conversion I made some minor mistake over here, so, which I will try to rectify during the live interaction. So, kindly remind me ah.

So, Newton per meter square I think there is a calculation mistake over here. So, let me quickly check yeah. So, 4.4482 divided by 0.0254 and this turns out to be 6894.7 Newton per meter square it turns out to be Newton per meter square. So, I will just check whether this conversion is or whatever. So, oh I am sorry I am sorry see everything was actually correct. So, we it says that it is 1000 psi. So, I did a mistake. So, the pressure given was 1000 psia sorry everybody gets confused and today the unfortunately the pins are not working properly.

So, p is 1000 psia, now we have found out that 1 psi is equal to 6.894 kilopascal. So, the pressure of the system is 6.894*1000 kPa = 6.894 MPa and therefore rest we have done everything correctly where the; so, this statement is wrong this is perfectly valid one psi is equal to six point eight nine four I am really sorry about it. So, this conversion that is given is absolutely correct and here the pressure is equal to 6.894 MPa rest you can see everything is perfectly fine.

So, container volume we assume that it is $1m^3$. Therefore, the vapour volume and liquid volume is given and you have all the data for 6 MPa and 7 MPa. Do a linear interpolation and this way you can find the stream quality I hope you have all understood this problem. So, we take up some additional problems in the next class, thank you very much.