Material and Energy Balance Computations
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Lecture –48
Tutorial - IV

We will continue solving some more problems. let us see what we can do, and my plan is to solve all the problems in this class if possible else we will just be over to the next class and then we will resume our discussion. And what is coming up next is so far all the calculations we are doing they are essentially without any chemical reaction. Next we have to learn how to essentially handle the energy balance in systems where we have chemical reactions.

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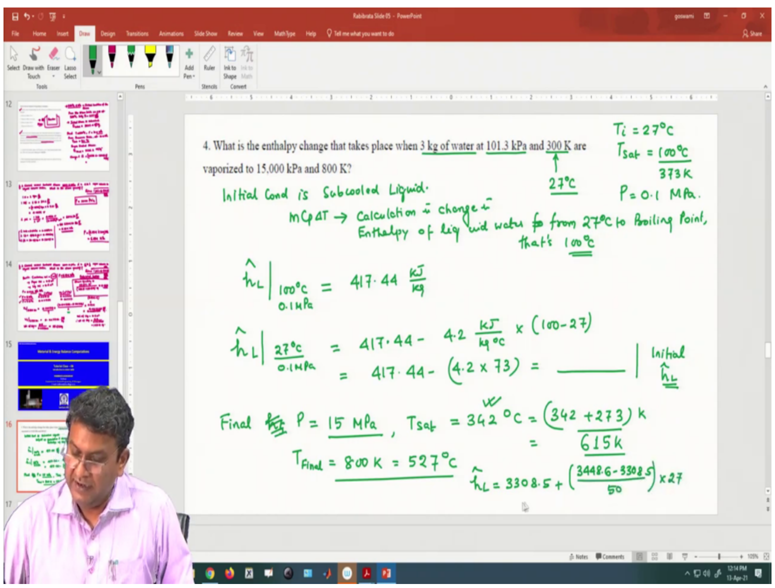

So, let us pick up problems and these are simple ones. now so what is the enthalpy change that takes place when a system 3 kg of water at 101.3 kilopascal and 300 Kelvin are vapourized to 15 megapascal and 800K. So essentially 300K means that the initial temperature is 27°C and 101.3 kilopascal so no; memorizing just go to the pressure side data so it is like 101 you can say 0.1 kilopascal which is the 0.1 megapascal which is atmospheric pressure and of course the saturation temperature is 99.62°C or approximately 100°C.

So, T_{sat} = 100°C and so that is essentially 373K but here given temperature is 300K, so which is 27°C. So, initial condition is sub cooled liquid and we have already visited the subcooled liquid data table. So, the minimum pressure for which you have some values of subcooled liquid is 5 megapascal. So here the pressure is only 0.1 megapascal; so what we will do we will simply use $mC_p\Delta T$ for the calculation of the change in enthalpy while of liquid water from 27°C to its boiling temperature that is 100°C.

So, this is what you need to do essentially. So, how do you go about it. You essentially have the h_L data. So, this at 100°C and 0.1 megapascal is available if you go to the pressure side table so at 0.1 megapascal 100°C h_L data is available 417.44 kJ/kg. So, this data is available this is equal to 417.44 kJ/kg. Now what do you do how do you calculate h_L at 27°C and 0.1 megapascal.

So, this is going to be 417.44 minus m is 1 of course with specific C_p is 4.2 kJ/kg°C multiplied by 100 minus 27. So, this you can calculate I will leave the calculations to you minus 4.2 into whatever is the value 73. So whatever comes out you can calculate it and you can find out that this is going to be the initial h L and then the final h_L of course it probably we need to check whether it is going to be liquid or vapour or whatever it says 15000 kilopascal.

So, the final pressure equal to 15 megapascal and at 15 megapascal again we go to the pressure side table I hope now you have learned the trick and you are able to follow how to go about it. At 15 megapascal the saturation temperature is 342.24°C. So, it is at 15 megapascal T_{sat} is 340°C which is (342 + 273) Kelvin which is equal to 615 Kelvin and the final temperature that is given is 800 Kelvin which is equal to 527°C.

So here the saturation temperature is 342°C here the final temperature is 527°C so you now know what to do it is now superheated steam so go to the super heated table go for 15 megapascal, thankfully 15 megapascal data is there. So, from here what you do you the final temperature is 527°C. So, it is between 500 and 550. Do the interpolation between 500 and 550; luckily you have the data.

So do the interpolation of 3 it is going to lie somewhere between 3308.5 and 3448.6 you do the interpolation so it is going to be 3308.5 + 3448 - 3308 divided by 50 into 27 and that is the whatever is the value I can write it down so the final h_L is going to be final h_L is going to be 3308.5 + 3448.6 - 3308.5 divided by 50 into 27 and you can calculate and that will give you the change in enthalpy of course you multiply it for 3 kg.

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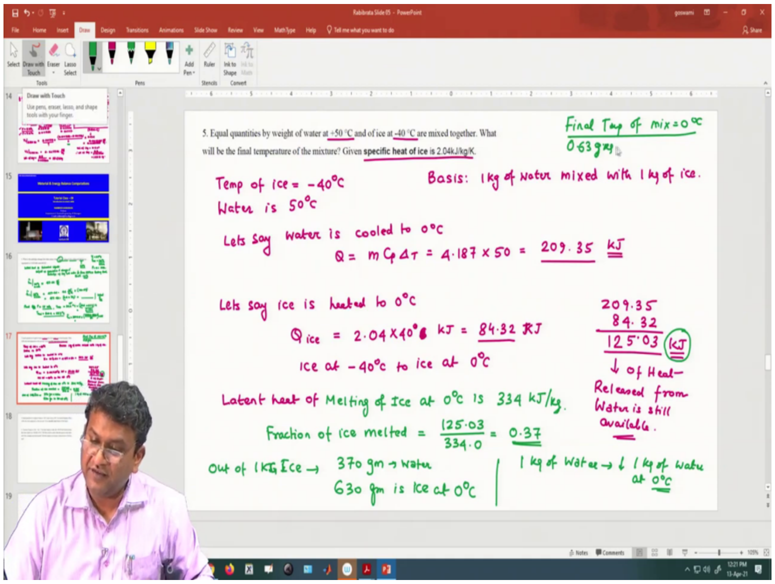

So, that that sort of solves the problem the next problem is also another I hope you have all understood the problem its very, very simple problem but very interesting one. So, the next problem we have equal quantities by weight of water this is a very interesting problem. So equal quantities by weight of water at 50°C and at minus 40°C they are mixed together.

What will be the final temperature of the mixture given the specific heat of ice is 2.04 kJ/kgK. So, what we do here is that temperature of ice of course is equal to minus 40 degree centigrade that of water is 50°C. So, what is going to happen so what other things can happen since ice is coming in contact with hot water it is likely to melt and since water is going to come in contact.

So first the temperature of ice in the solid state will go up from minus 40°C to 0°C then it may melt. On the other hand, water is being cooled so what will happen is that it may it may also its temperature will come down. So, these are the two things that can happen. So, let us see what happens. So, basis is 1 kg of water let us say the basis 1 kg of water mixed with one kg of ice.

Now let us say water is cooled to 0°C. So, what would that involve, so that will involve the total heat that is given up is $mC_p\Delta T$ and that is going to be 4.187 or 4.2 whatever you want to take into 50 is equal to 209.35 kJ. So, this is the amount of heat that will be released or sorry yeah that will be released if water which was at 50°C is cooled down to water at 0°C.

Now let us say the ice is heated to 0 degree centigrade. Therefore, q for ice, so its ice at minus 40 degree centigrade to ice at 0 degree centigrade it is going to be the specific heat is given (2.04*40°C*40 kJ). So, this is going to be 84.32 kJ. So please understand this. If water is cooled to 0°C it will supply 209.35 kg. Now what that heat will do? That heat will raise the temperature of ice.

Now, in the solid-state ice needs only 1 kg of ice needs only 84.32 kg of heat to get converted from ice at minus 40 degrees centigrade to ice at 0 degree centigrade. So, now how much amount of heat that is given by water is left 125.03 kg of heat released from water is still available. So, what this will try to do this will this excess amount of heat will try to melt ice however what is the latent heat?

Latent heat of vapourization latent heat of melting not vapourization I am sorry latent heat of melting of ice at 0 degree centigrade assuming 1 atmospheric pressure you can also get the data from steam table is 334kg. So, this is the latent heat of vapourization this is like kilo joule per kg and here you have 125.03kg. So, kilo joule heat is available so had there been a supply of 334 kilo joule of heat the entire amount entire 1 kg of ice would have now melted to water at 0 degree centigrade.

So that is not happening. So, what will now happen, so the fraction of ice melted is 125.03 divided by 334.0 and that is equal to 0.37so what has now happened? So out of the 1 kg of water you had 370 grams of out of 1kg ice you had 370 gram is now water and remaining 630 gram is ice at 0°C and the one kg of water you had that has been cooled to one kg of water at 0°C.

So, the final temperature of the mixture is 0°C where we have 0.63 kg ice and 1.37 kg water. So, this is how it stands, so this is how you solve it, it is an indirect way of solving but this is the easiest way where your concepts will become clear.

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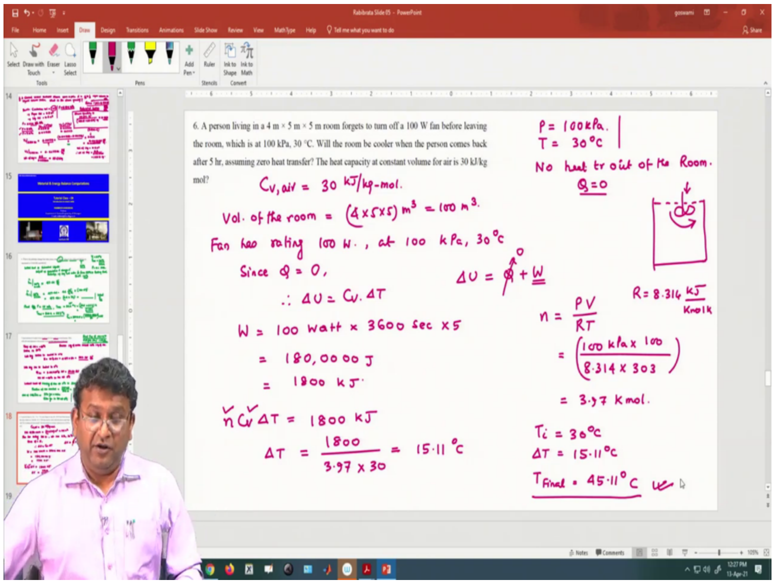

Next is a very interesting problem and this will give you an idea that something we do often actually does not help. So many times what we do is that as we are leaving a room particularly your hostel rooms or whatever our room we actually leave the fan running. So, let us lead the problem a person living in a 4 meter×5 meter×5 meter room forgets to turn off a 100 watt fan before leaving the room which is at 100 kPa and 30°C.

So, P and T are given so pressure is its atmospheric pressure 100 kPa and temperature is 30°C and so the he comes back after 5 hours and there is no heat transfer there is no heat transfer out of the room. So, Q is equal to 0 and the heat capacity at constant volume for air so C_v air is given which is 30 kJ/kmol this is given. So, what is the situation? Situation is you have a room through which Q is equal to 0 and the fan is rotating.

Now the volume of the that is all about it and it has run for 5 hours. So please do understand in a room like this some energy is entering through the in the form of electrical energy because the fan is rotating. So, what is going to happen what is going to be the fate of that energy since there is an input of energy and no heat can leave therefore the temperature is going to rise that is as simple as that and you can calculate it.

So, the volume of the room is of course $4*5*5m^3 = 100\ m^3$. So, the fan has rating of 100 watt at

100 kPa and 30°C. So, Δu since Q is equal to 0 therefore $\Delta u = C_v \Delta T$. Now what is Δu? 'Δu' is now or work done Q so now Q is equal to 0 it is given, so what is the work done? Work done is 100 watt*3600 second*5hr = 1800000 joule = 1800 kilo joule.

Now essentially what you get is so you can also find out the number of moles present which is PV by RT P is given to be 100 kPa V is given to be 100 m^3; R is the value you take is 8.314 kJ/kmol K. So, R equal to 8.314 into temperature is 303K, so n turns out to be 3.97 kmol that is the number of moles of air present in the room. So, now what we have n C v this is the molar specific heat.

So, n C v delta T is equal to Q equal to w which is equal to 1800 kilo joule and therefore so n is known C v is known what you find out is delta T which is 1800 divided by 3.97 and C_v is 30 which turns out to be 15.11°C. So initial temperature was 30 degree centigrade now there is a temperature rise of 15.11°C therefore T_{final} = 45.11°C. So, if you leave your room open like this it may actually become turn out to be very hot.

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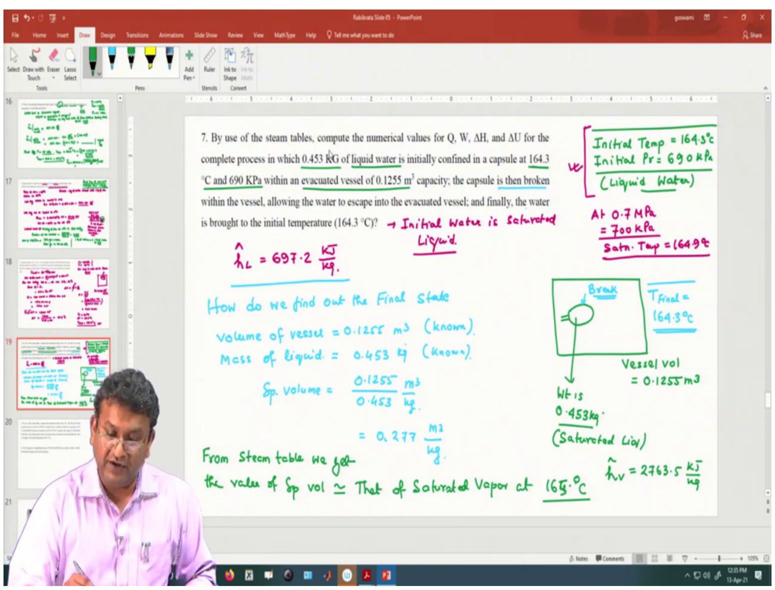

Now the last two problems and these are really exciting problems I actually there is a really tricky and real concept builders. So, let us see what they are so the of the previous problem is an easy problem it is more of a social awareness problem as I call so do not leave the room open. So, what you have here is a very interesting problem by the use of steam table compute the numerical values of Q, W delta h and delta u for the complete process in which 0.453 kg of a liquid initially confined in a capsule at 164°C and 690 kilopascal.

So initial temperature is 164.3°C initial pressure equal to 690 kPa is given and it says its liquid water see its liquid water. So, let us visit the pressure table first. So, pressure it says 690 kPa and initial temperature is 164.3°C. So, if you go to the pressure table you see 0.69 kPa it says but here you have 0.70 kPa and the saturation temperature is you see 164.97. So, from steam table what we get from the pressure table what we get at 0.7 mPa which is equal to 700 kPa saturation temperature is 164.9°C.

So, you can assume roughly within the limits of error that the initially initial water is saturated liquid and once you assume that it is a saturated liquid. I am not going to solve the numbers for you but you can do it. Once you know it is a saturated liquid, so you get all the values. So essentially it is a liquid now, so you get the specific volume you get the u_L you get the h_L everything. So, for example h_L is 697.2 kJ/kg.

So, h_L let us say one calculation I will show 697.2 kJ/kg. Now the system is very beautiful system. So, what happens is you have a within an evacuated vessel. So, the vessel volume is 0.1255 m^3 this is given and what you have is a capsule initially you have a capsule, and this capsule the weight is also given its 0.453 kg. So, this we know and what we additionally know from the pressure and temperature that this is saturated liquid.

Now what it says that we are going to break the the capsule is then broken within the vessel. So, this is the vessel and now you break the capsule break the capsule and so water escapes into the evacuated vessel. So, now this water it may be in the liquid form it may be in the vapour form whatever it escapes into the evacuated vessel and final temperature T final is equal to 164.3°C. So, final temperature is again 164.3 degree centigrade but how do you find out? So, the question now emerges how do we find out the final state?

Any clue temperature is given but you do not know the pressure, but you know something you know something very interesting and what is that what you know is that the volume here is the crux of the whole problem. Volume of the vessel is 0.1255 m^3 these is known and mass of liquid earlier the vessel was evacuated. So, there was nothing. So, now the; mass of liquid which is equal to how much 0.453kg.

So, this is known, so if these 2 are known then immediately what you can find out is the specific volume. So, the specific volume is 0.1255 divided by 0.453 m^3/kg and this turns out to be equal to 0.277 m^3/kg and temperature is given. So, temperature is given at 164.3°C. So now what we can do we can go through to the temperature table and see at 165°C data is there and you see the specific volume of saturated vapour at 165°C this is important the specific volume of saturated vapour at 165°C is 0.2726.

So here what we have its very close to that its 0.277 so from steam table we get the value of specific volume approximately equal to that of saturated vapour at 165 degree centigrade so which you can approximate as 164.9 and therefore now from again from the steam table you can find out the values of everything you want. So, for example we were looking at h_L, so now you have saturated steam, so the value of enthalpy specific enthalpy is now given by this particular value which is h_v which is 2763.5.

So here for example h_v is 2763.5 kJ/kg and so you can calculate what is the change in the enthalpy of course do not leave it per kg basis because here the mass of the water is given. So, the actual change you have to multiply with 0.453. So, I hope you understood this problem this is a real nice problem and a real clever way of how you can actually use your concepts to calculate the specific volume and from there you can find out all the essential parameters.

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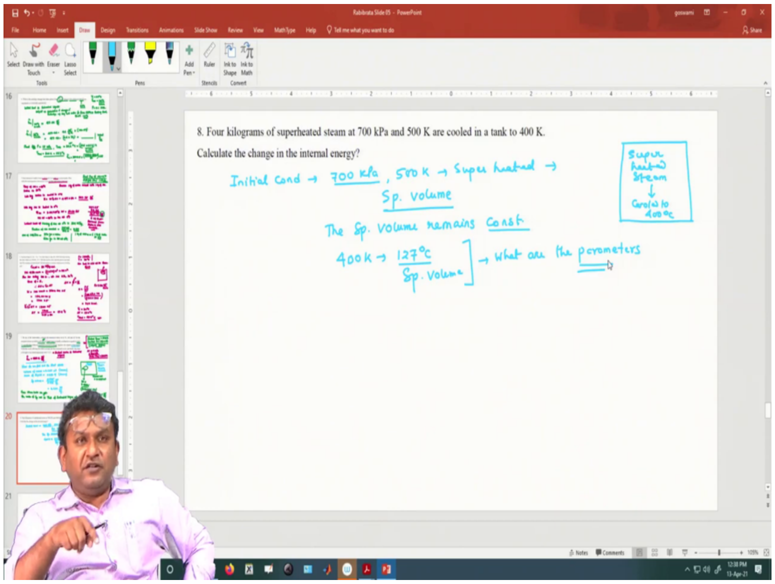

So, the last problem is also a very interesting problem. So, let us see what it is. And, I will give you a clue for example for this one sorry about it. So, what it says is just a second yeah so here what is given so 4 kg of superheated steam at 700 kPa and 500 K. So, initial condition is not a problem 700 kPa 500 K superheated. So, go to the super heated table and get the data is cooled in a tank to 400°C.

Now this is cooled inside a tank so what you had was super heated steam and this is cooled now. So, this is a classic problem where people tend to use the PV = nRT. So, P_1 and V_1 are given and based on that T_2 is given so let us calculate the pressure and you are completely wrong. What you do here because steam is not an ideal gas. What you do here is from this condition you get the specific volume.

So, you get the specific volume for the given condition and now even you do a cooling the specific volume remains constant why because the mass of steam remains constant and the volume is defined by the volume of the tank so the specific volume of the system remains constant. So now what you do you essentially find out at 400K or that is 127°C and that specific volume what are the parameters?

And you can essentially find out what are the parameters and that specific volume. So, what are the parameters means first thing you will what you will as you solve this problem you will find that at 127°C the specific volume is actually falling between that of liquid and vapour. And therefore, you can do an interpolation and can find out the fraction of vapour present. So please solve the problem I will not solve it in the class.

And if there is a problem with this particular problem, I will take it up during the live interaction session. So, that sort of brings us to the end of the tutorial problems we decided to discuss in the class for your enhancement of your understanding. And I am sure you are solving the assignments on a regular basis. So those assignments will give you a very good idea of handling the steam table and solving problems of different variety.

Thank you very much from the next class we will start something new. And that is essentially what happens when or maybe one lecture one more lecture I will have on the physical estimation of physical parameters. I need to probably talk about the reference plot and then we can move on to the systems with chemical reactions, thank you very much.