Concepts of Thermodynamics
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Lecture – 17
First Law For A Control Mass System: Representative Examples (Contd.)

In the previous, lecture we started working out some problems related to the first law of thermodynamics for a control mass system. And we will continue with working out such problems in this lecture as well.

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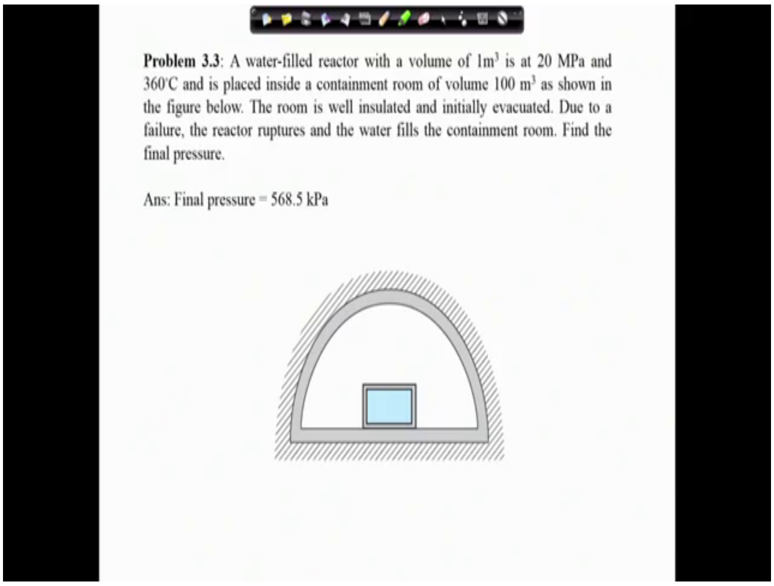

Problem 3.3: A water-filled reactor with a volume of 1m^3 is at 20 MPa and 360°C and is placed inside a containment room of volume 100 m^3 as shown in the figure below. The room is well insulated and initially evacuated. Due to a failure, the reactor ruptures and the water fills the containment room. Find the final pressure.

Ans: Final pressure = 568.5 kPa

So, the first problem that we will work out is this one which is given in the screen. A water filled reactor with a volume of 1 meter cube is at 20 Mega pascal very high pressure and 360 degree centigrade and is placed inside a containment room of volume 100 meter cube as shown in the figure. The room is very insulated and initially evacuated. Due to a failure the reactor ruptures and the water fills the containment room. Find the final pressure.

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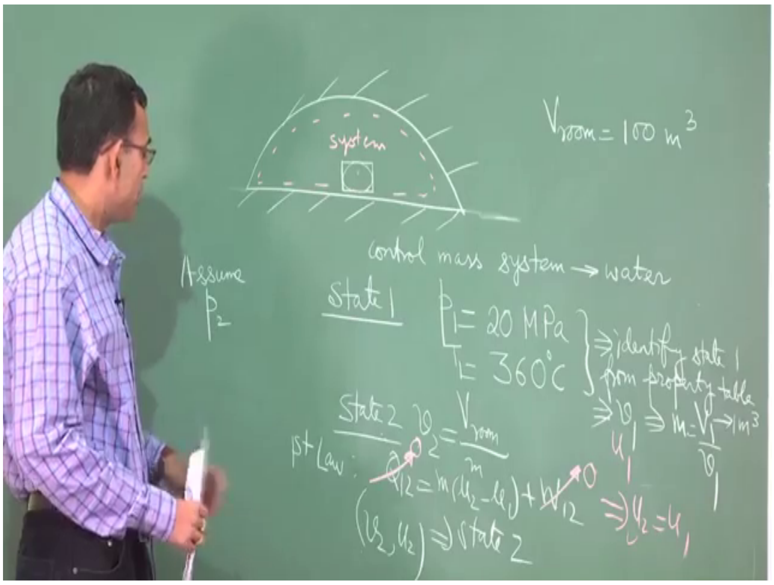

So, as our customary practice, we will draw a schematic of this. So, this is the room is insulated, typically this hatch is given in a heat transfer problem to indicate that this is insulated. It is also given that the room has a volume of 100 meter cube. So, the control mass system is the water. And for that state 1 is given by the following properties, p 1 is 20 MPa and T 1 is 360 degree centigrade.

So, with this combination of p 1 and T 1 identify state 1 from property table. So, once you identify state 1, you will know what is v1. And therefore, the mass will be this. So, what is v 1? The total volume is 1 meter cube, the water the reactor this one, this has a volume of 1 meter cube. State 2, now this is a tricky situation, you cannot identify the state 2 just from one property. State 2; so, once this container ruptures this water fills up the entire volume and the volume of the room is known.

So state 2, you know what is the specific volume this is V room by m. So, with this specific volume, is it possible to identify the state? Remember that for a simple compressible pure substance, you require two independent intensive properties to specify the state of a system, right.

So, in this case you have only one property. So, how do you specify the state 2? So, for that the first law of thermodynamics will come into rescue. So, first law. So, in this case, what is the heat transfer and what is the work done? The heat transfer is very straight forward. This the system is this entire thing, right this is the system, it includes the container. So, the system is insulated from its surroundings. So, because it is insulated from its surroundings there cannot be any heat transfer. So, the heat transfer is 0. What about the work done? In this case work is done or work is not done.

So, for that we have to refer to the definition of work that work is done when there is a displacement of the system boundary against a resistance. In this case, there is free expansion. So, once this ruptures this fills up the entire volume freely. So, there is no resistance and therefore, there is no work done. And therefore, from this equation, we get u 2 is equal to u 1, what is u 1? u 1 is identified from property table. What is v 1 and also u 1, you can get from the table and that u 1 is same as this u 2.

So, now you identify from table state 2 by combination of v 2 u 2. It is easier said than done, because you have to look for the combination of v 2 and u 2 to get what is the final pressure P 2. So, for this specific volume v 2, you have to first check whether this u 2 is in between Uf and Ug. So, if or in other words if this, assume that this v 2 is in the two phase region, just as an example. So, I am just giving you some idea that how you know, how you can identify the state point from specific volume and internal energy.

So, assume that this v 2 is between vf and vg. So, assume any pressure. So, you have to do it in a little bit of iterative manner. So, at that pressure see whether this v 2 is between vf and vg, if that pressure is between if the v 2 is between vf and vg, just as an example, then calculate the quality. Based on that quality calculate u which is 1 minus x uf plus x ug and check whether that u is same as this u 2. And follow an iterative process by varying p 2.

So, it is not a very straight forward calculation, it requires a lot of you know thorough iteration using the thermodynamic table. To use this combination of property, but in principle, yes it is very straight forward. In implementation not that straight forward, because you have to identify a state point where assuming a pressure, you converge with the corresponding specific volume and internal energy, but you can always check the answers here. The answer is p 2 as 568.5 Kilo Pascal. We will work out the next problem. So, let us look into this.

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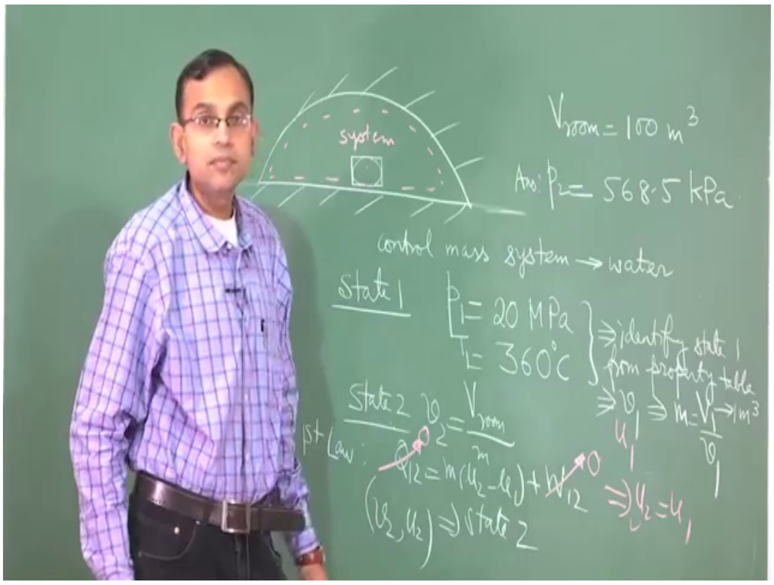

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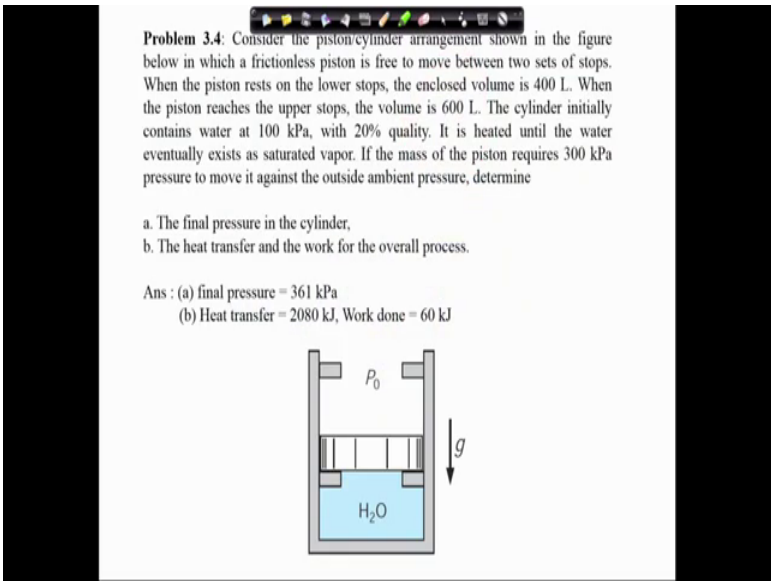

Problem 3.4: Consider the piston/cylinder arrangement shown in the figure below in which a frictionless piston is free to move between two sets of stops. When the piston rests on the lower stops, the enclosed volume is 400 L. When the piston reaches the upper stops, the volume is 600 L. The cylinder initially contains water at 100 kPa, with 20% quality. It is heated until the water eventually exists as saturated vapor. If the mass of the piston requires 300 kPa pressure to move it against the outside ambient pressure, determine

a. The final pressure in the cylinder,
b. The heat transfer and the work for the overall process.

Ans : (a) final pressure = 361 kPa
(b) Heat transfer = 2080 kJ, Work done = 60 kJ

Consider the piston cylinder arrangement as shown in the figure in which a frictionless piston is free to move between two sets of stops. When the piston rests on the lower stops, the enclosed volume is 400 litre. And when the piston reaches the upper stops, the volume is 600 litre.

The cylinder initially contains water at 100 Kilo Pascal with 20 percent quality. It is heated until the water eventually exists as saturated vapor. The mass of the piston requires 300 Kilo Pascal pressure to move against the ambient pressure. Find the final pressure heat transfer and work done. Again a very interesting problem let us work it out.

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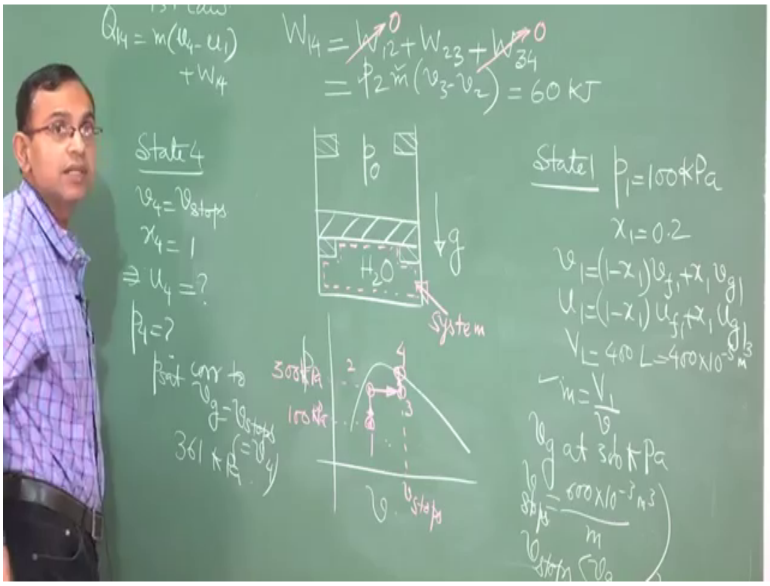

So, we have this water as the system state 1: p 1 is equal to 100 kilo Pascal, x 1 is equal to 0.2 which is the quality. So, this will tell you what are the different other properties. So, for example, v 1 like this and you can also calculate the total mass, the initial volume is 400 litre. So, the mass will be this.

Now, the pressure is 100 Kilo Pascal, but it starts floating when the pressure becomes 300 Kilo Pascal. So, if heat is transferred. So, let us try to draw it in a PV diagram, let me also draw the two phase region. So, the state point 1 is in the two phase region then. So, here the pressure is 100 Kilo Pascal. At constant volume from 100 Kilo Pascal, it will increase to what is given 300 Kilo Pascal and then it will start moving in a cos equilibrium process.

So, from here, it will start moving, question is it will follow this horizontal line which I had started drawing. But the question is will this line cross this two phased region or not. So, first you find out what is vg at 300 kilo Pascal and what is your v 2 or v stops not v 2, v stops is 600 litre divided by mass.

So, question is, is v stops less than vg or not. So, from the table if you look into this data for this particular problem, you will find that v stops is less than this vg; that means, before reaching the saturated vapor line it will hit the stops , at 3 it hits the stops. So, this is v stops and once it reach the stops that is it reaches here, it has to undergo a constant volume process till the pressure is increased. And the final state is saturated vapor state that is given. So, state 4 is quality equal to 1.

So, how do you identify state 4 here? State 4 is v 4 is equal to v stops and x 4 is equal to 1 so; that means, you can from here calculate what is u 4, this you will require for the heat transfer calculation. So, now, your job is very simple find the work done and the heat transfer and before that what is the final pressure.

So, what is p 4 this is nothing, but p sat corresponding to vg is equal to v stops which is equal to v 4. So, this is 361 kilo Pascal. The remaining job that is left is only to calculate the work done and the heat transfer. So, work done that is W 12 plus W 23, this is 0. So, W 23 is you have p 2 into m into v 3 minus v 2.

So, m is known p 2 is 300 kilo Pascal that is known, v 3 is v stops and v 2 is same as v 1. So, if you substitute all this, this is 60 kilo Joule. And finally, the heat transfer using the first law, you can calculate what is the heat transfer. So, the heat transfer is 2080 kilo Joule.

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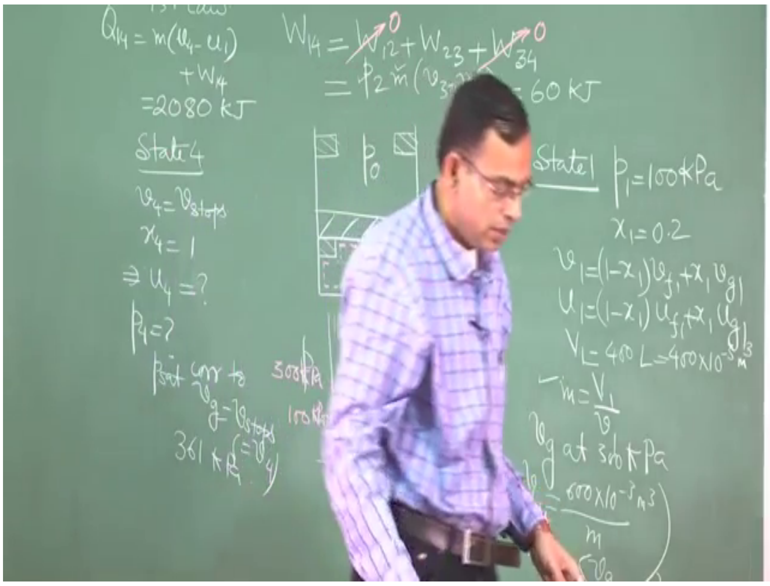

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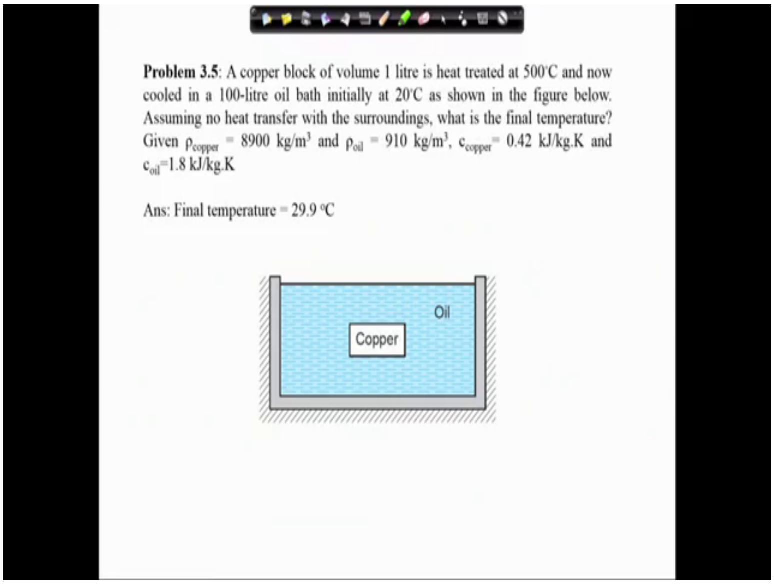

Problem 3.5: A copper block of volume 1 litre is heat treated at 500°C and now cooled in a 100-litre oil bath initially at 20°C as shown in the figure below. Assuming no heat transfer with the surroundings, what is the final temperature? Given ρ_{copper} = 8900 kg/m^3 and ρ_{oil} = 910 kg/m^3, c_{copper}= 0.42 kJ/kg.K and c_{oil}=1.8 kJ/kg.K

Ans: Final temperature = 29.9 °C

We will quickly work out another problem which is problem number 3.5. Then it is a straight forward problem, but we will learn a few things from here. So, a copper block of volume 1 litre is heat treated at 500 degree centigrade and then cooled in a 100 litre oil bath initially at 20 degrees centigrade. Assuming no heat transfer with the surroundings, what is the final temperature? Final temperature of the copper and oil will be a common temperature; given the density of copper density of oil specific heat of copper and specific heat of oil.

So, it looks like a school problem, but in school problem of this type, we used a simple calorie metric principle heat gained equal to heat lost. And here we will see that how that simple calorie metric principle follows from the first law of thermodynamics.

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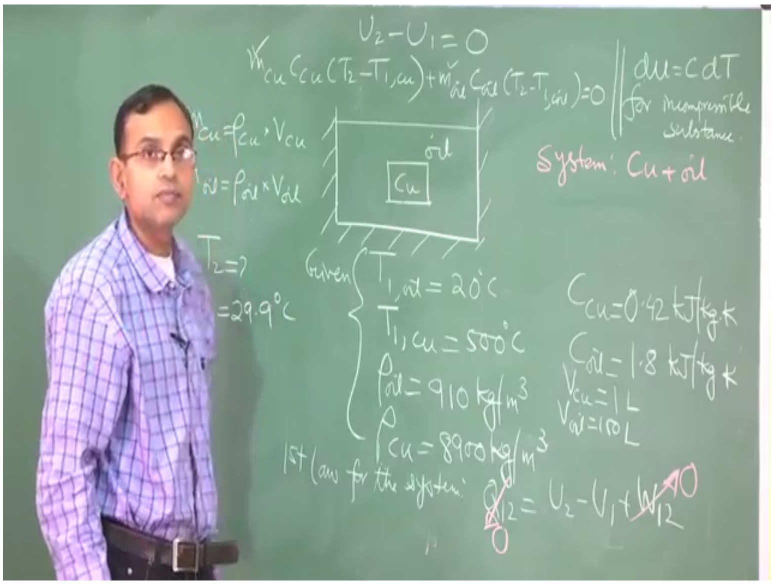

So, let me make a schematic of this. Then you have a copper block and you have oil. So, you system is copper plus oil. So, what is given? It is given that T 1 oil is 20 degree centigrade, T 1 copper is 500 degree centigrade. Then rho oil is rho copper, then specific heats are also given. I suppose specific heats of copper is 0.42 kilo Joule per kg Kelvin. And specific heat of oil 1.8 Kilo Joule per kg Kelvin, all this data are given. So, these are given data.

Now, we apply the first law for the system Q 12. See in this case, there is exchange of heat between copper and oil, right. The copper is heated it transfers some of its heat to the oil, but copper plus oil together as a system that does not interact with the surroundings by means of heat transfer. So, the heat transfer is 0, the work done is also 0, because the heat interaction between copper and oil does not involve any work. So, you have U 2 minus U 1 is equal to 0.

So, du remember is equal to C into dT for incompressible substance for incompressible substance. If C is a constant that means, u 2 minus u 1 into c into T 2 minus T 1 so, this is specific internal energy and this is total. So, that has to be multiplied by mass. So, mass of copper into C of copper into T 2 minus T 1 copper plus mass of oil, C of oil into T 2 minus T 1 oil equal to 0, ok where T 2 is the common final temperature that you will have to find out. What is mass of copper? So, you are given what is the volume of copper V copper as 1 litre and V oil as 100 l itre.

So, mass of copper is rho of copper into volume of copper and mass of oil is rho of oil into volume of oil. So, if you substitute that here, you will get from this equation what is T 2? So, this equation is simply heat gained equal to heat lost. So, the final temperature of copper is less than its initial temperature, because it is cooled. So, this is heat lost and the oil gains heat from the heated copper block. So, T 2 minus T 1 oil this is positive. So, this is heat gained by oil. So, this is nothing, but a calorie metric principle heat gain equal to heat lost. The final temperature the answer to this problem is 29.9 degree centigrade. Let us stop here for the time being, we will work out a few more problems concerning the first law for a control mass system in the next lecture.

Thank you.