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Course
on
Laws of Thermodynamics

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Lecture 09: Tutorial 2: First law of Thermodynamics for Closed Systems

In the previous session we discussed about some problems related to the first of thermodynamic for closed system and today we will continue with that so we worked out problems now problem numbers 3.1 to 3.4 and today we will continue with more problems.

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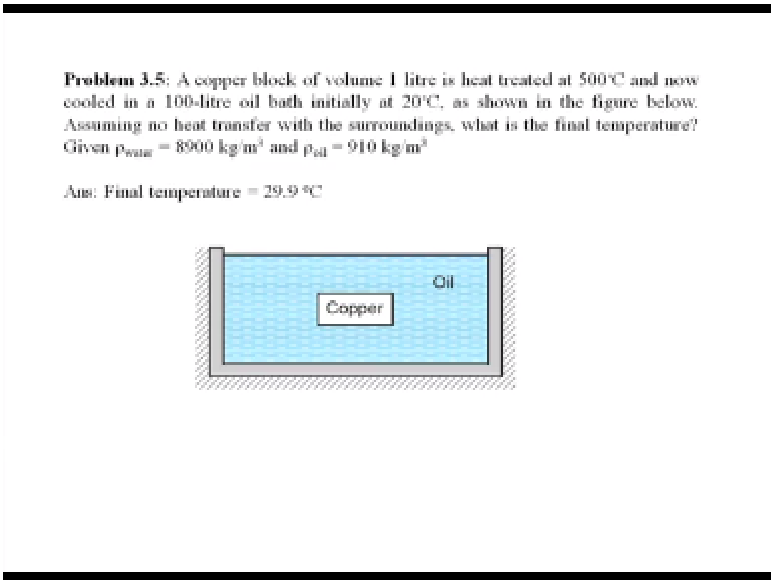

Problem 3.5: A copper block of volume 1 litre is heat treated at 500°C and now cooled in a 100-litre oil bath initially at 20°C, as shown in the figure below. Assuming no heat transfer with the surroundings, what is the final temperature? Given $\rho_{water} = 8900\ kg/m^3$ and $\rho_{oil} = 910\ kg/m^3$

Ans: Final temperature = 29.9 °C

So the first problem that we are going to address today is a projected in a screen you can see that there is a copper block of volume 1liter that is heat treated at 500^0 C and now cool in a 100liter oil bath initially at 20^0 C, assuming no heat transfer with the surroundings what is the final temperature given the density of water and the density of oil so this particular problem refers to mythological process which we call as quenching so I just want to give you a little bit if perspective of background to this because that will create more interest on you on this particular application.

So quenching means that basically your heat rating a particular material typically metal and then you are putting in a fluid bath to freeze or to cool it down so when you cool it down what you see is that there is a change in microstructure because of the gradients created and that will eventually dictate what will be the properties of the material, therefore it is very important to study the thermal characteristics of this kind of assistant so let us try to work out this problem in the board.

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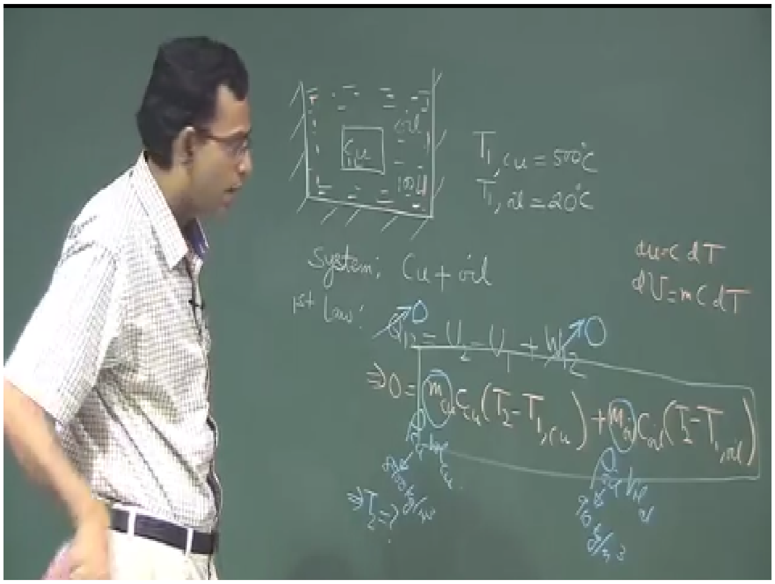

So will draw a schematic, of this problem first, so there is a oil bath in which you have copper so this copper block as volume of 1 liter is heat treated at 500^0 C so T_1 copper is 500^0 C, and the oil bath is initially at 20^0 C the volume of the oil bath is given it is 100 liter, assume that this is sufficiently insulated so that there is no heat transfer with the surrounding what is the final temperature.

So to solve this problem we have to first describe a system so here can you tell what is the covenant way of choosing the system is it copper is it oil or copper + oil, see technically there is no harm if you choose just copper as a system there is technically no harm if choose just oil as a system, but if you choose copper + oil as a system then you know it is easier for you to analysis the problem because why the reason is that there is heat transfer between copper and oil, the copper is hot and it is transferring heat to the oil.

So if you are considering copper and oil separately you have to consider the heat transfer but if you consider copper + oil together then as a total system there is no net heat transfer because it is insulate from the surroundings therefore let us identify the system as copper + oil so with this copper + oil as a system let us apply the first law.

This copper + oil as a system is insulated so there is no heat transfer the work done there is no work done with this system so that means U2 – U1 is 0 so copper and oil these are typically in compressible phases so that you can write the U = C x dt this means discussed in the one of our lectures related to the first law of thermodynamics, but the c is the specific heat capacity so basically so this is this small u so d U is mcdT, so you can write these has 0 = m copper c copper x T2 – T1 copper + m coil c oil x P2 – P1 oil okay.

So you will get mass of copper and mass of oil has the density of copper into volume of copper and mass of oil has density of oil into volume of oil and these are given in the problem statement give the density of water as 8900 this is 8900k/ m3 and density of while as 910 kg/m3, so the let us see what are given the specific heats are also known so you have to look into the table of specific heats to get the specific heat data, I mean unfortunately I do not have the data right now which means so I cannot share the data with you.

But you have to look into the specific heat data to I mean there are tables of specific heat or property data for copper and different types of wires and if you calculate this we will get the final temperature, so depending on what oil you take you will get you have to use the corresponding specific heat and that will give you a corresponding temperature so I am not giving you any specific answer to this although either tutorial sheet, we will be providing you with the specific answer and based on a specific.

A particular value of the specific heat but because today I am not using any particular data for the specific heat of oil and specific heat of copper so I am just keeping it in this generic form so that depending on the values that we substitute you will get the final value of this, now I want to discuss something on this problem see this kind of problem is a very simple problem which you might have addressed in the high school level and for that there is something that you use which is known as the principle of calorie metric.

And the principle of calorie matrix is like the loose statement heat gain equal to heat lost so there is something this copper is heated so it is losing some heat to the oil and oil is gaining some heat, so here this statement like this expression is as good as heat loss by copper is equal to heat gain by oil so you can see that the intuitive statement of heat gain equal to heat lost can be recovered from the first law of thermodynamics provided there is no net external heat transfer and work done between the resultant system and its surroundings.

So if there is if this Q1 to is not equal to 0 and W12 is not = 0 or either of these two is not equal to 0 then you cannot use this calorie metric principle here, so there are some assumptions that go behind the calorie metric principles that we have learned in the high school level okay.

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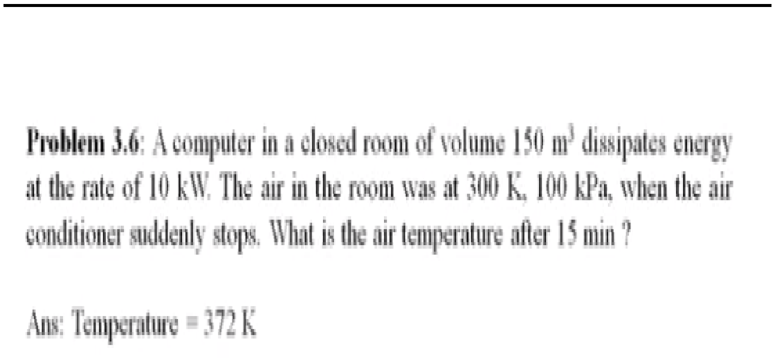

Problem 3.6: A computer in a closed room of volume 150 m^3 dissipates energy at the rate of 10 kW. The air in the room was at 300 K, 100 kPa, when the air conditioner suddenly stops. What is the air temperature after 15 min ?

Ans: Temperature = 372 K

So we will consider the next problem which is problem number 3.6 the problem number 3.6 is a computer in a close room of volume $150m^3$ dissipates energy at the rate of 10 kilowatt so that is a closed room in which a computer dissipates energy, the air in the room was initially at 300 Kelvin 100 KPA when the air conditioner suddenly stops, what is the air temperature after 15 minutes, so this is a very classical situation there is AC room in which computer is working.

And suddenly because of some reason because of some problem in power supply or whatever the AC suddenly stops but the UPS is running so the computer is still working, so the computer when it is running it is dissipating heat because of the power generation and that will heat the air in the room, so we have to figure out that what is the final temperature after 15 minutes what is the final temperature so let us write the problem data here in the board.

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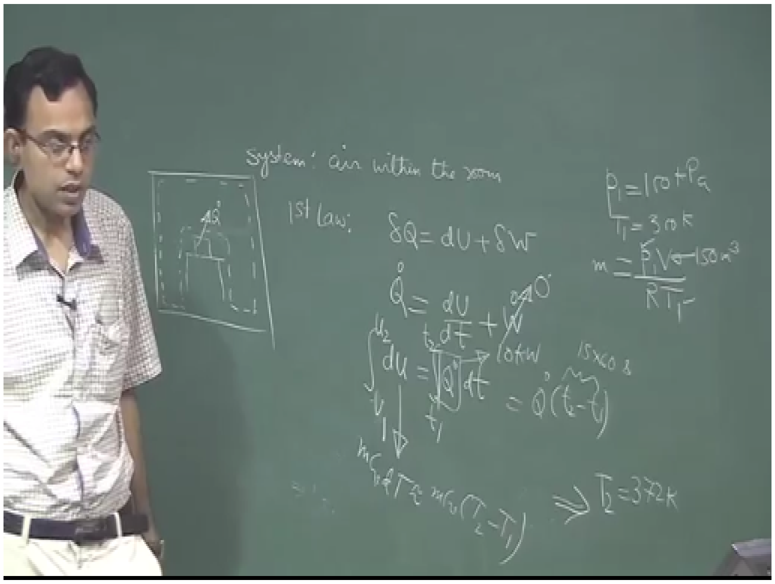

So for working out this problem let us try to so the system is air see we have to be careful what is the system here, the system is not computer, computer is dissipating heat so there is some heat transfer from the computer to the air but the system where we are considering the change of temperature is the air in within the room and not the computer, so system is air within the room, then what we will do is, we will try to apply the first law.

Now in this kind of a situation let us try to learn how to write the first law as the rate equation, so we can write if you divide these by so this is essentially δQ is the change in internal energy + δW you divide both by the δT that small time interval and take the limit as the time δT → 0, so if you do that this will become Q. = du/dt + W. okay, so in this problem there is no work done and you can therefore write this as du = Q, dt.

So if you consider the change from T1 to T2, this Q. is given as a constant what is this Q. the computer dissipates energy at a rate of T_N 10 kilowatt this is the rate at which heat is transferred to air, so if you draw a schematic so there is a computer table there is a computer and this is 0 system. So system is something which excludes the so let us draw the air boundary but excluding the computer.

So in this particular system to this particular system there is a heat transfer at a rate of Q. so these Q. is given as 10 kilowatt so this is equal to Q. x (t2 – t1), (t2 – t1) is 15 minutes so 15 x 60 seconds and du is how do you calculate what is du, du is basically mc_v dt okay. So now we have to make an assumption that here the range of temperature the heating is not over such a large range for which Cv is a strong function of temperature, so we may take Cv approximately as a constant so this will this integral will eventually be mCV(T2-T1) so this is based on the assumption that Cv is not a strong function of temperature otherwise you have to write Cv as a function of temperature and integrated from T1 to T2.

So now there are other problem data which are given using which you can solve these problems so the pressure is 100Kpa initially T1 is 300K, so you can write m=P1/RT1 all of here that is universal constant divided by molecular weight of air, so typically 0.287 kJ/kgK. So P1v/Rt1 so P1 is known T1 is known volume of air in the room it is given I think the closed room of volume $150m^3$ so from this equation you can calculate by equation these two you can calculate what is T2 and T2 is 372K.

So you can see that it is really a very bad condition that if the Se suddenly stops and the computer is running and thee is not enough mechanism of dissipation of thermal energy then you like dissipation of thermal energy from the room so that the room gets cool, if you do not have that kind of a dissipation mechanism that is the room effectively remains insulated under that condition you can see that there is a significant rise in temperature possible because of a computer working in a room which cannot shade heat to the outside ambient, okay. So let us look into the next problem.

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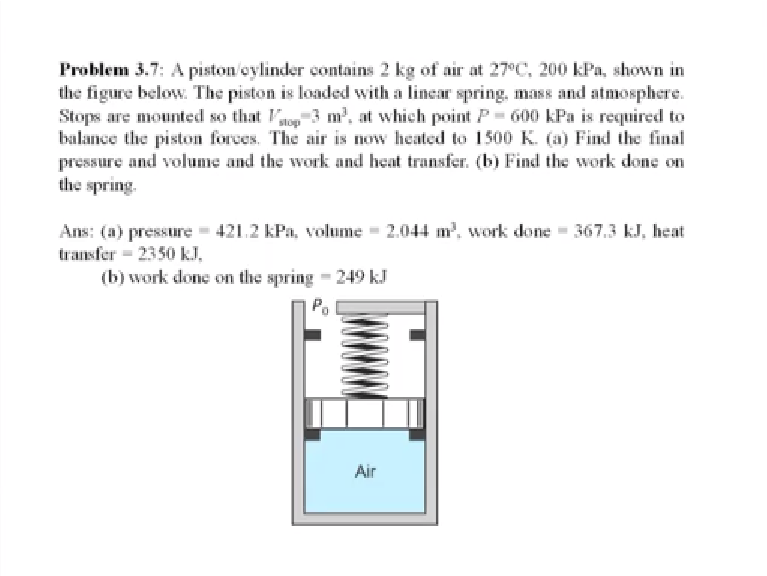

Problem 3.7: A piston/cylinder contains 2 kg of air at 27°C, 200 kPa, shown in the figure below. The piston is loaded with a linear spring, mass and atmosphere. Stops are mounted so that V_{stop}=3 m^3, at which point P = 600 kPa is required to balance the piston forces. The air is now heated to 1500 K. (a) Find the final pressure and volume and the work and heat transfer. (b) Find the work done on the spring.

Ans: (a) pressure = 421.2 kPa, volume = 2.044 m^3, work done = 367.3 kJ, heat transfer = 2350 kJ,

(b) work done on the spring = 249 kJ

Problem number 3.7, so a piston cylinder contains 2 kg of air at 24°C, 200kPa as shown in the figure. The piston is loaded with the linear spring mass and atmosphere. Stops are mounted so that V_{stop} is 3m^3 at which point pressure is 600kPa which is required to balance the piston forces. The air is now heated at to 1500K, find the final pressure volume and work done and heat transfer and find the work done on the spring.

So let us draw the schematic in the board and try to solve this problem here we have encounted similar problems previously so I am trying to like work out more and more problems of typical natures so that you get familiar with these types of situations if you need to address this for your problem solving purpose.

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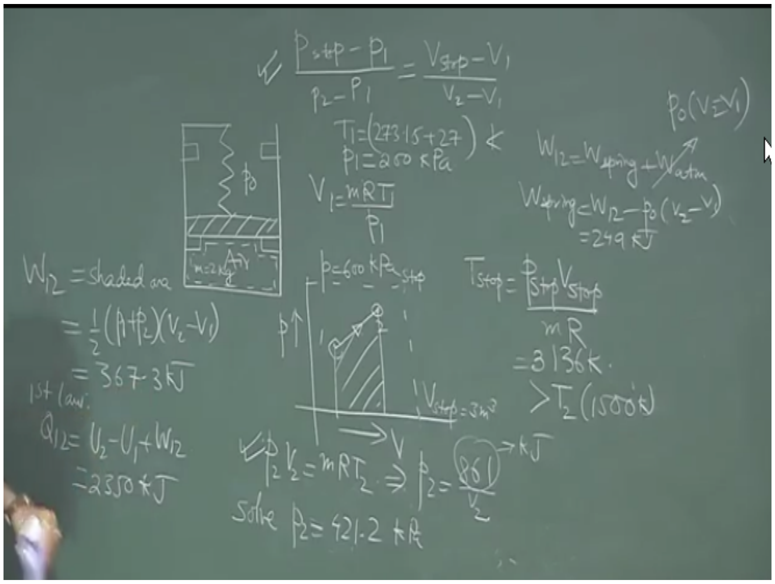

So this is air the system is this air so I am drawing system boundary with the mass of 2 kg so you can calculate the volume v1, so T1 is 273.15+27 K and P1 is 200kPa so assuming the air to be an ideal gas see this is very important whenever you are working out a problem you need to see what is the substance then you need to make a judgment this is the judgment based on your practical considerations whether you can treated as a ideal gas or you need to look into the property tables to get the property data.

So suddenly do not start using the equation of state of ideal gas or whatever first look in to the substance what is the substance? And then accordingly use your judgment. So v1 is a0 t1 / p1 so you get the state one so this state one you can plot in the Pv diagram by the way just another obtuse I want to ask you a question see from the very early days in school we draw pv diagram with v in the horizontal axis and p in the vertical axis.

Never we draw a pv diagram with p in the horizontal axis and v in the vertical axis although scientifically or mathematically there is nothing wrong with that because p is a function pv or the inverse function of p so we could plot v as function of p also, but we never do that do you know why? See the answer to this is very simple when you are doing an experiment in the experiment what you are independently able to vary is the volume and not the pressure.

So this remain the independent variable which in the experiment you are able to tune that is why because this is something which you are independently varying this we are keeping in the horizontal axis that is the convention that we always fallow. So now we have got the state one now what is that let us look in to the problem the air heated so if the air is heated this will move and because it is linear spring the pressure watts volume will be linear.

Now we have to get at least another data point on this straight line to fix up the straight line of straight line requires two points to be fixed up, so the other data point is that at the stops the volume is $3m^3$ at which point pressure is 600 Kilo Pascal. So this is v stop = $3m^3$ this pressure = 600Kilo Pascal, but this is not the actual data point this is just a possible points so that you can construct this straight line.

The actual data point is that the air is now heated to 1500 Kelvin so what is the temperature here is it greater than 1500 Kelvin or less than 1500 Kelvin. So let us see so if the temperature here is t stop is p stop v stop / mr this is if you substitute the values this is 3136 Kelvin, therefore see this is greater than the t2 which is 1500 Kelvin that means state 2 is not at such a high pressure but it is lower than this.

So see why we are calculating this our objective is to figure out whether the state 2 is at a location extra plotted from this or not if it is located at a location extra plotted from this then that will not be correct because then it has already heat the stop so the volume cannot change right. So if it is not within this then that means it should be at the stops and then at a constant volume the pressure will raise.

So you cannot really you have the point 2 extra plotted on this straight line at the most it has to be within this if not then it will be at a location where at these stop you will have pressure building of at constant volume because the piston has already reach the stops. The volume cannot increase anymore but here the situation is not like that T2 is 1500 k which is less than the temperature at the stop so two will be somewhere in between if not then 2 will be at a location which is of vertical line from here that you have to understand.

So that is what I am repeating depending on the problems that are the solution may change all together that is why do not try to prepare a formula base stereo type understanding of problem solving in thermo dynamics. Depending on the problem data same problem might lead to different types of Pv diagram different types of solutions etc, so this is now the state 2 so the state now you do not know what is v2 but you know p2v2 = mr t2 so if you substitute the values here you know everything except p2 and v2 so you know p2 = 861/v2 if you substitute all the values.

So this is this 861 is 861 KJ so p and v have to be there in the adjusted units and then you can write the equation of the straight line wanted to in this way so p stops $–P_1$ by P_2 $–P_1$ is equal to V stop $–V_1$ by V_2-V_1 this is the equation of the straight line Y-Y_1 by Y-Y_1 is equal to X-X_1/ X_2-X_1 so simultaneously solving this equations see the two unknowns are P2 and V2 and there are two equations.

So you can solve for P_2 AND V_2 so if you solve you will get P_2 is 421.2kPa so then W_{12} that is the shaded area this is ½*P_1+P_2*V_2-V_1 this is 367.3kg joule and if you apply the first law now Q_{12}=U_2-U_1+W_{12} see here the temperature range is large and because of the temperature range is large it is not legitimate to keep C_p and C_v as constant.

So depending on the temperature you can get the internal energy of here from something called as heat table which is their appendix of any thermodynamics state books so instead of taking C_p C_v as constants you can convolve the het table to calculate U_2-U_1 and what done is already there so the answer to the heat transfer is 2350kg joule.

And there is a interesting tricky part which is last part of the question what is the watt done on the spring so watt done on the spring is not the total watt done so the total watt done is W spring+ W atmosphere right so what is W atmosphere, W atmosphere is P_0*V_2-V_1 this is the work that is done to overcome the atmosphere resistance and create a change in volume where P_0 is an atmospheric pressure.

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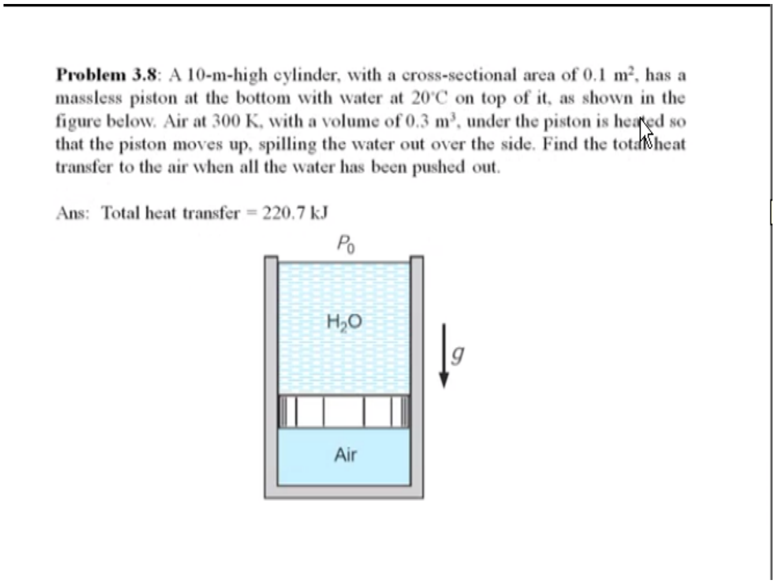

Problem 3.8: A 10-m-high cylinder, with a cross-sectional area of 0.1 m^2, has a massless piston at the bottom with water at 20°C on top of it, as shown in the figure below. Air at 300 K, with a volume of 0.3 m^3, under the piston is heated so that the piston moves up, spilling the water out over the side. Find the total heat transfer to the air when all the water has been pushed out.

Ans: Total heat transfer = 220.7 kJ

So W spring will be not the total work the total work -P0*V_2-V_1 this is 249 kg joule you can very easily see that this is less than the total watt done oaky so we will work out another problem before we close this tutorial session and the another problem is a final problem in this assignment for first law for closed systems and that is problem number 3.8.

So this problem says that there is a cylinder with the cross sectional area of $0.1m^2$ which has a mass less piston with water at 20^ocentigrade on the top air at Kelvin and $0.33m^3$ volume is there under the piston and it is heated so that piston moves up spinning the water out find the total het transfer when all the water has been pushed out okay.

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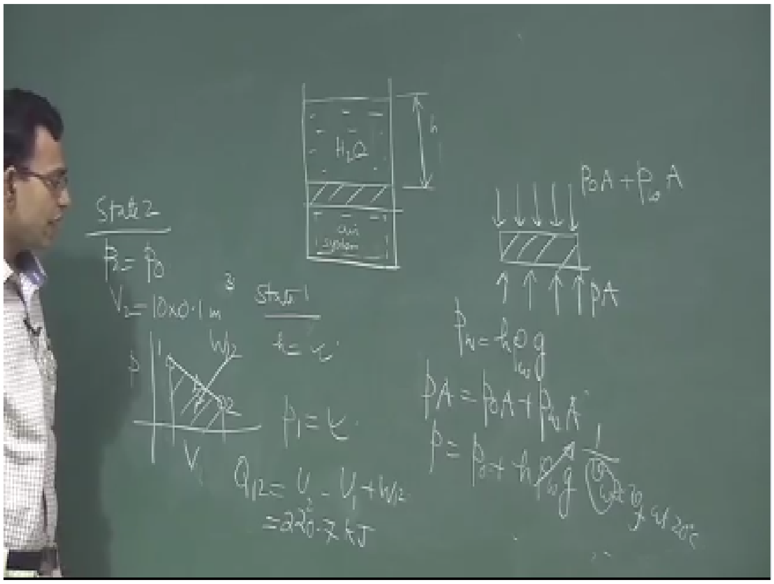

So let us try to draw a schematic of this problem I will try to give you guideline on a outline of a solving this problem and give you the final transfer so here you have a air and here you have a water so let us say that age is a height of the water which is gladding with time so what is the system here thermodynamics system control mass system what are the air or water plus air, see out of all these option only air is the mass which is remaining in valiant, so for doing a controlled mass based system analysis the air has to be the identical controlled mass system. So this is our system.

So the pressure on the air for equilibrium, see if you draw the free body diagram of piston you will have on this side atmospheric pressure plus water pressure and on this side you have air pressure. So what is the water pressure?

The height of the water x ρ x g so you can write sorry p x a = p0 A + p water x A, so P = p0 + h ρ water, ρ water is 1/ specific volume of the water and this you can approximate as vf at 20 ^{0} cent grate from the table because the water is given at 20 ^{0} cent grate and so initial h at state 1, you have h = what? How do you calculate h at state 1, you know the total volume, total height 10m right, out of that you subtract the air height.

You subtract the air height make like this piston height, there is practical considerations 10 m is a long height out of that it is not that important, so you subtract the air height you will get the water height, so this is state 1 so if you know that you will get what is p1 from here, so once you get p1 then what is state 2? What is p_2? State 2 all water is spilled, so sate 2 p_2 is only p atmosphere and V_2 is this one, so V_2 is 10m height x 0.1 m/s this total 10m will be occupied by air only.

All water has spilled out, so you can plot the process in a Pv diagram how it will look physically, because the water is spilling the pressure is falling, so and because the water pressure varies linearly with the height this is like a linear spring. See there is no spring here but the effect is like the spring because the effect of the water on the top is varying linearly with the height. So this is 1 to 2, so once you know the pv diagram you can calculate the heat transfer and you can calculate the work done.

This is the area under the curve and $Q_{12} = U_2 - U_1 + W_{12}$, so W_{12} is this, for this particular problem because the temperature range is not that large it is not the significant amount of heating or cooling, so you can use constant Cv for calculating this and if you substitute all these you will get the answer of the total heat transfer as 220.7KJ.

Okay so we have worked out a significant number of problems consulting this first law of thermodynamics for a closed system, in fact we worked out 8 numbers of problems and I believe these are sufficient enough to give inside on problem solving, so thank you very much for this, so subsequent to these there will be discussion on first law for slow process and then problems for first law for slow process and there will be discussion on second law and we will continue with that subsequently thank you very much.