Engineering Thermodynamics
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Lecture 20
Example problems on energy balance for closed systems & moving boundary work

Welcome to this tutorial. Myself Manish Mourya. I am a TA of this course in this tutorial I will take you through few examples based on energy balance for closed system and moving boundary work.

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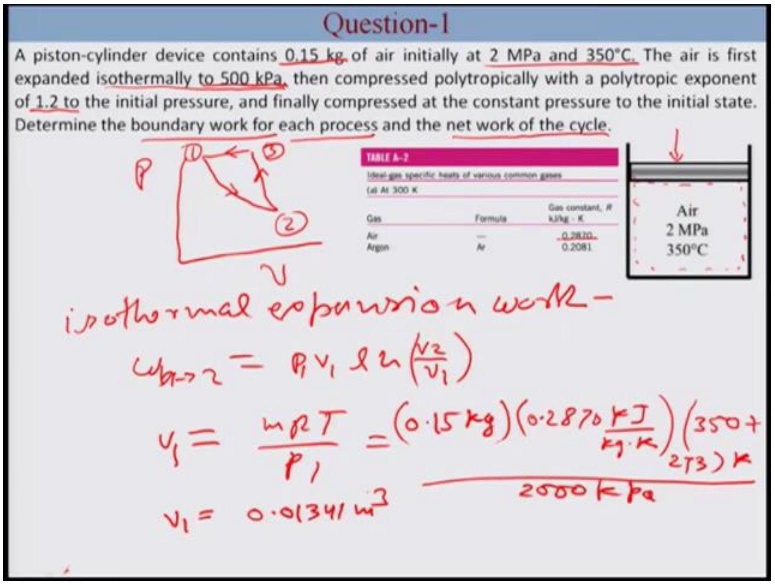

So let us start with the first question. A piston cylinder device contains point 15 kg of air initially at 2 MegaPascal and 350 degree Centigrade. The air is first expanded isothermally to 500 kiloPascal, then compressed polytropically with a polytropic exponent of 1 point 2 to the initial pressure, and finally compressed at the constant pressure to the initial state. Determine the boundary work for each process and the net work of the cycle.

So here we assume air as the system and this piston will compress this air polytropically and this air will expand isothermally as well. So if we see whole process on a P-V diagram, so from state 1 to state 2 this gas expands isothermally then from 2 to 3 it compressed polytropically to initial pressure and then finally it compressed at constant pressure to the initial state. So we have to determine boundary work for each process.

First we do calculation for isothermal expansion so work in isothermal expansion is Wb from 1 to 2 will be P1 ln of V2 upon V1 ok. Since here we do not know V2 and V1 we need to find this initial and final volume of air. So from the ideal gas assumption we calculate initial volume like mRT upon P1, so mass of air is 0.15 kg, gas constant can be taken from this table which is 0.2870 kiloJoules per kg into Kelvin and temperature is 350 plus 273 Kelvin divided by total pressure which is 2000 kiloPascal. So this gives us V1 equal to 0.01341 meter cube.

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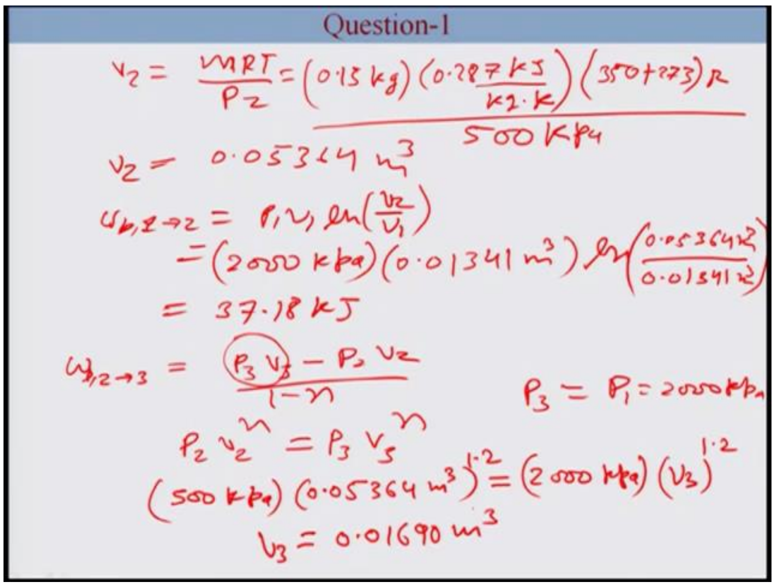

Now we need to know value of V2 so similarly we can calculate V2 equal to mRT upon P2. Since this is an isothermal expansion so temperature will be the same, so value of m is 0.15 kg, gas constant is 0.287 kJ per kg Kelvin and temperature is 350 plus 273, pressure is 500 kiloPascal. So this gives us V2 equal to 0.05364 meter cube.

Now putting these values in the ideal gas work expression P1 V1 ln of V2 upon V1, so P1 is 2000 kiloPascal, V1 is point 01341 meter cube ln 105364 meter cube upon 0.01341. So this gives total work in isothermal expansion 37.18 kJ. Now we have to calculate work in polytropic compression so in this polytropic compression work will be from the state 2 to the state 3 equal to P3 V3 minus P2 V2 divided by 1 minus n.

Since we do not know information about state 3 so we need to find this P3 and V3. So this can be obtained from equation of state for polytropic process so P2 V2 for n equal to P3 V3 to the power n, which we know P2, P2 is 500 kiloPascal V2 is 0.0364 meter cube to the power 1.2 its polytropic exponent is given to us and P3 it is said that polytropic compression is done to the initial pressure.

So that means P3 equal to P1 which is 2000 kiloPascal. So putting this value here and V3 that we need to calculate. To the power 1 point 2, so from here we get V3 equal to 0.01690 meter cube.

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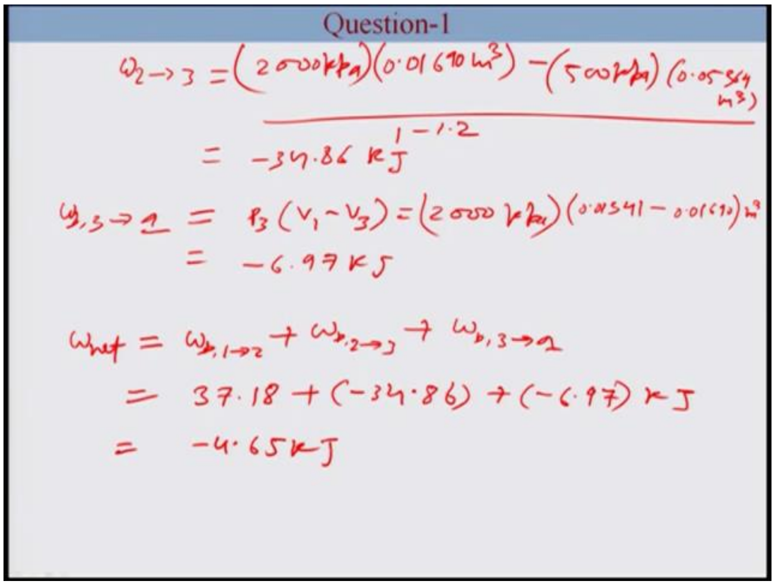

So after plugging these values into this expression we get W2 to 3 equal to 2000 kiloPascal into point 01690 meter cube minus 500 kiloPascal into point 05364 meter cube divided by 1 minus 1 point 2, so this gives us minus 34 point 86 kiloJoules, it's kiloJoules. Now finally we need to calculate work done for isobaric process which is from the state 3 to the state first so this will be P3 V1 minus V3 which is equal to 2000 kiloPascal into point 01341 minus 101690 meter cube. So this gives minus 6 point 97 kJ. Finally we have to calculate the net-work for the whole process so the net-work of the whole process will be the sum of the total work in each process.

So Wnet will be W from the state 1 to state 2 plus work done from the state 2 to state 3 plus W from the state 3 to state 1. So this gives 37 point 18 plus minus 34 point 86 plus minus 6 point 97 kJ which is nothing but minus 4 point 65 kJ. So this is the total work in a complete cycle, so moving to the next question.

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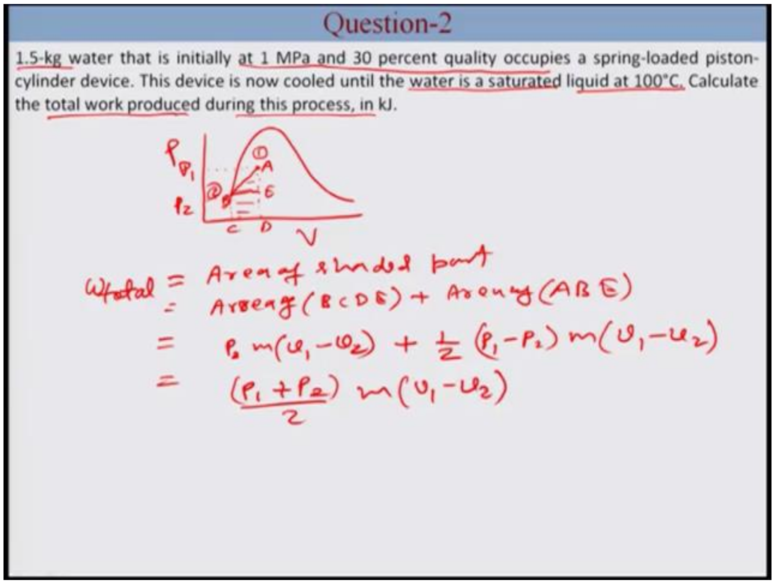

In this question 1 point 5 kg of water that is initially present at 1 MegaPascal and 30 percent quality occupies as spring loaded piston cylinder device. This device is now cooled until the water is saturated liquid at 100 degrees centigrade. Calculate the total work produced during this process in kJ. So it is said that initially cylinder is h filed with water vapor mixture having quality of 30 percent.

So if you see this process on a P-V diagram, so initial state would be somewhere here because it is a mixture of water and vapor so this state will be here and now it is further cooled until that water is saturated. So it will cool down to this state, state 2 because this is a saturated liquid so we have to calculate total work produced during this process and here we assume that the process is quasi equilibrium ok.

So the total work produced in this process would be area under this line, so Wtotal will be area of this shaded region, shaded part. So if we divide this area then in two part so this will be the area of this triangle ABCDE plus area of this rectangle so this will be the area of BCDE plus area of the triangle ABE ok. So area of BCD will be nothing but if we see pressure at this state will be P1 and pressure at this state will be P2.

So the total area of BCDE will be P2 into change in total volume so change in specific volume into mass plus area of this triangle which is 1 by 2 AE into BE, so AE is nothing but P1 minus

P2 and BE is total change in volume so mass times change in specific volume. So this gives a expression for total work during this process ok so this is our first expression. So now we need to know the value of these variables P1 and P2, V1 and V2.

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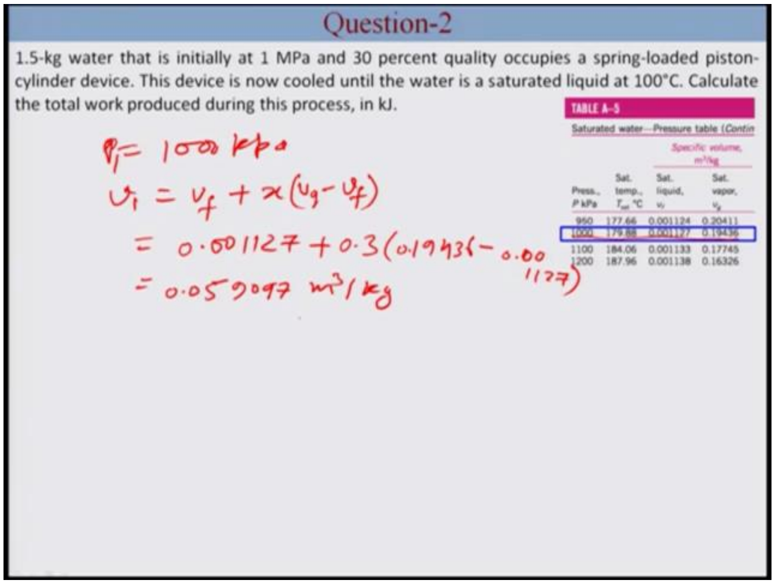

Since initially we know P1 equal to 1000 kiloPascal, so corresponding V1 can be calculated as vf plus x vg minus vf so this value can be taken from the saturated water table corresponding to 1000 kiloPascal which is here. So after plugging these value here we get point 001127 plus quality we know at it is 30 percent so point 3 vg is point 9436 minus point 001127 ok. So from here we get V1 equal to point 059097 meter cube per kg ok.

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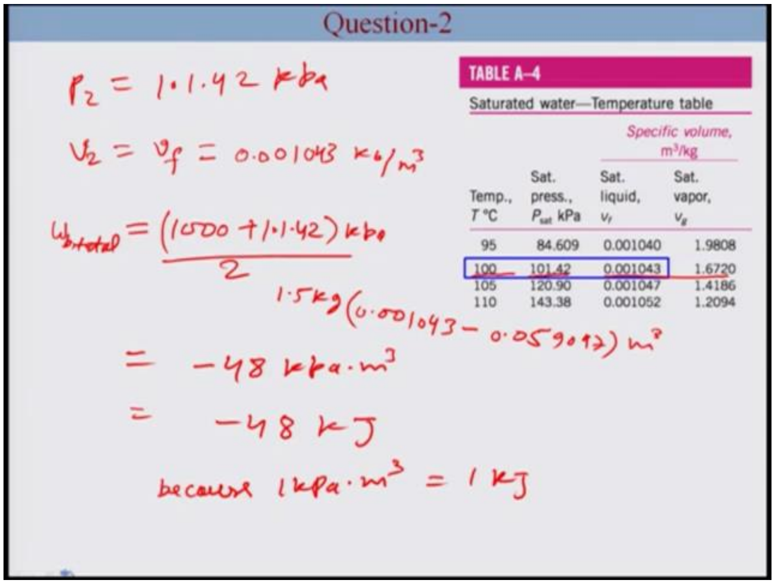

So now we have to calculate P2 and V2 for the state 2. Since the state 2 is a saturated liquid temperature at this state would be 100 degree centigrade so from the saturated water table at 100 degree centigrade we can calculate P2 and V2. So P2 would be 101 point 42 kiloPascal and corresponding volume V2 equal to volume of the fluid because it is a saturated liquid so there is no vapor.

So V2 will be nothing but point 001043 kg per meter cube so after putting these values in the expression 1 we get total work equal to 1000 plus 101point 42 kiloPascal upon 2 into mass time, which is mass is 1 point 5 kg change in specific volume which is point 001043 minus point 059097 meter cube. So from here we get minus 48 kiloPascal meter cube which is nothing but minus 48 kJ because, 1 kiloPascal in meter cube equal to 1 kJ, so this is the total work in this process.

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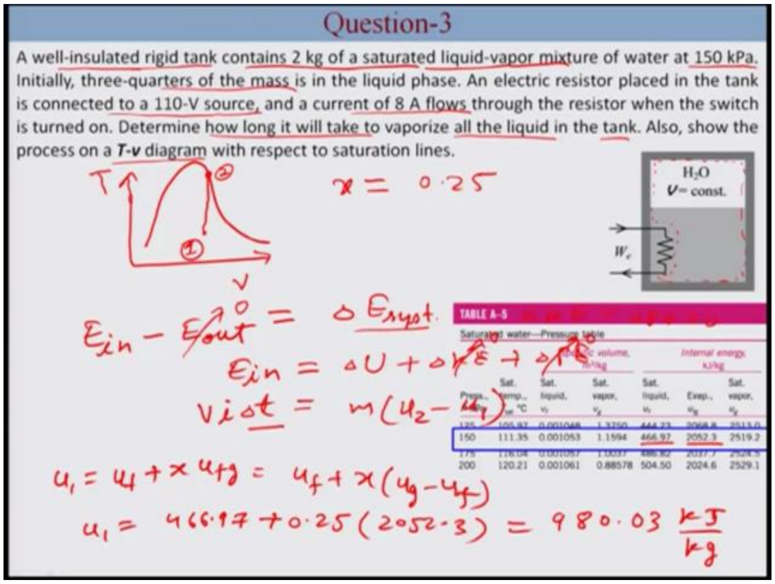

So moving to the next question. A well- insulated rigid tank contains 2 kg of saturated liquid-vapor mixture of water at 150 kiloPascal. Initially three-quarters of the mass is in the liquid phase. An electric register placed in the tank is connected to a 110 volts source, and a current of 8 Ampere flows through the register when the switch is turned on. Determine how long it will take to vaporize all the liquid in the tank. Also, show the process on a T-V diagram with respect to saturation lines.

So here we consider vapor liquid mixture as a system and this is the boundary of the system and this is a closed system since there is no mass crossing the boundary and it is given that three-quarter of the mass is in the liquid phase that means quality of this mixture is 25 percent which is point 25 ok. So it is desired to determine how long it will take to vaporize all the liquid in the tank.

Since it is given that tank is rigid, ok that means volume is not going to change during the process. So if you see the whole process on a T-V diagram so initially it is a mixture of liquid and vapor with a quality of point 25. The initial state would be here, now it is heated and it is heated such that all the liquid is in vapor state. So now this is a state 2 and this is a state 1 and it is occurring at constant volume since it is a closed rigid tank.

Now further we need to determine the time it takes to vaporize all the liquid, since it is a closed system so energy balance on the closed system will be total energy in minus total energy out equal to change in total energy of the system. Since this h tank is well insulated so there is no energy coming out of the system only energy in will be here equal to change in total energy of the system, this system is stationary ok.

So delta K and delta P will be 0. Delta E system is nothing but change in internal energy k plus P so these parts are 0 only internal energy of the system will change which is mass time change in specific internal energy, and energy in is nothing but energy coming out from this register which is V times current into delta t. So the total energy during this interval will be Vi delta t. So we have to find this delta t, so for that do we need to know U2 and U1 and we know V and i.

So initially it is given that h initial pressure is 150 kiloPascal so we know initial pressure is 150 kiloPascal so corresponding h internal energy can be calculated as u1 equal to you of the t plus x time ufg, ok. So it is given here uf is here this one and ufg is nothing but ug minus uf. So ufg is this one, so u1 will be 466 point 97 plus quality which is given plus point 25 and into ufg which is 2052 point 3. So this gives us 980 point 03 kJ per kg.

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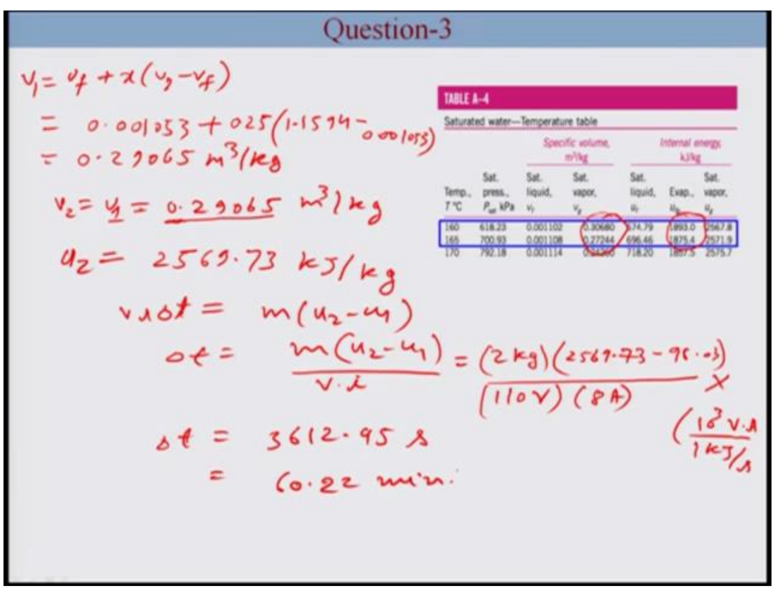

And corresponding specific volume can also be calculated as V1 equal to vf plus x time vg minus vf so vf is given point 001053 which is here in this table. This point and this point so

1001053 plus point 25 into 1 point 1594 minus point 001053 ok. So this gives us point 2905065 meter cube per kg ok. So now we need to know internal energy and specific volume at state 2 so since it is given that volume is not changing so V2 will be equal to V1 ok which is point 29065 meter cube per kg ok.

We have to calculate internal energy at this state ok, so internal energy can be calculated at this given specific volume from this table. We do not have internal energy corresponds to this specific volume exactly so we have to interpolate the internal energy between these two volume. So after interpolating internal energy in between these two values we get 2569 point 73 kJ per kg, so this is the internal energy at this specific volume.

So after plugging these values in the energy balance which is V1 delta t square equal to mass times change in internal energy ok. So delta t will be equal to m U2 minus U1 upon V into i, so after putting these values m is 2 kg which is given, U2 is 2569 point 73 minus 980 point 03 upon 110 volt into 8 ampere and since 1 kJ per second is equal to 1000 volt into ampere. So this gives total time equal to 3612 point 95 second which is nothing but 60 point 22 minutes. So this much time it will take to vaporize all the liquid in the tank.

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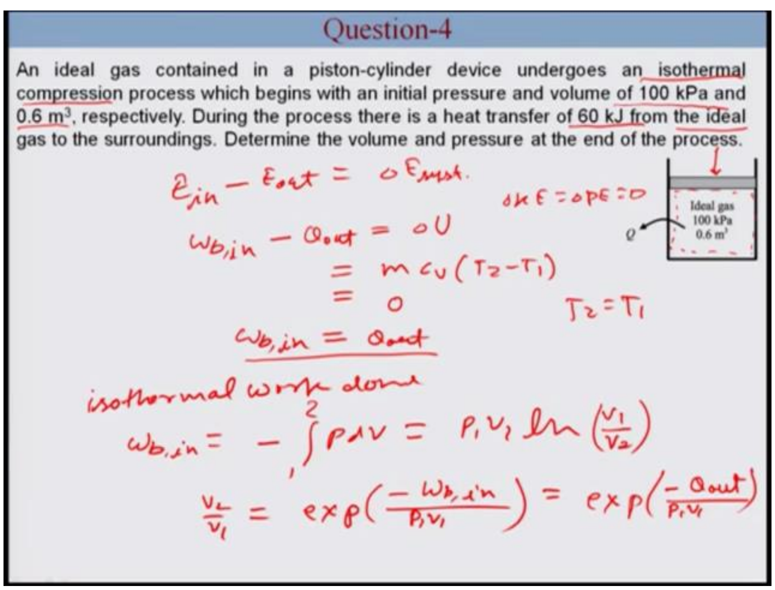

So let us move to the next question. An ideal gas contained in a piston cylinder device undergoes an isothermal compression process which begins with an initial pressure and volume of 100 kiloPascal and point 6 meter cube volume respectively. During the process there is a heat transfer of 60 kJ from the idea gas to the surroundings. Determine the volume and pressure at the end of the process.

So here is the air compressed in this piston cylinder device. So this is the boundary of our system ok so since this is a close system because there is no mass crossing the boundary of the system. So energy balance for this close system will be total energy in minus total energy out equal to change in total energy of the system ok.

So energy in will be from the work done by this piston on the cylinder so that work in is the energy coming inside the system and since it is losing its energy to the surrounding so that becomes our Qout and delta e of the system will be changing total internal energy because system is stationary.

So delta K and delta PE will be 0. So since this h since this is an ideal gas so delta U will be mcv delta t that is T2 minus T1 ok. So from here we get since this is an isothermal expansion so this will be 0 because T2 equal to T1, so from here we get Win will be equal to Qout that is total work done on this system is equal to total energy coming out of the system.

So we know isothermal work done Wbin is nothing but the Pdv work from the state 1 to 2 which is P1 V1 ln of V1 upon V2, so this is work done during this isothermal compression. So this gives us V2 up to V1 after rearranging this exponent of minus W work in upon T1V1 ok, so from here we know that Wb is equal to Qout ok so plugging this value here minus Qout upon P1V1 ok.

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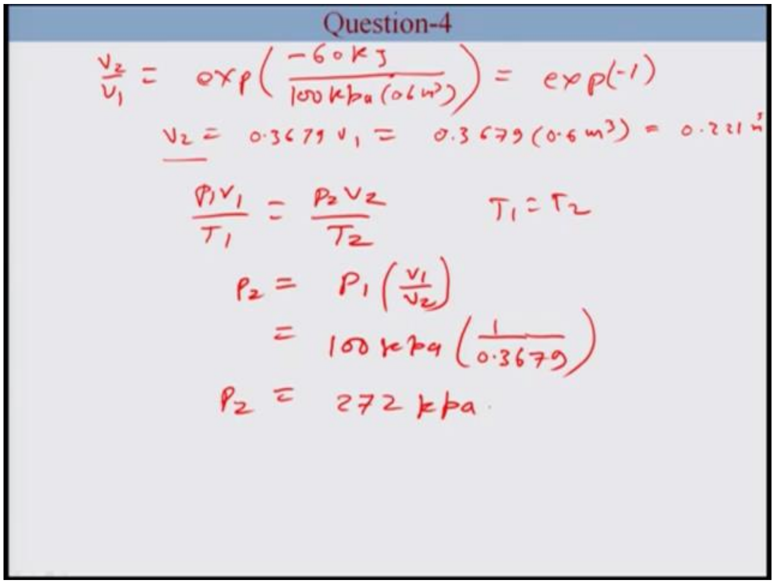

So now since we know Qout is 60 kJ so V2 upon V1 equal to it is given in the question that energy coming out of the system is 60 kJ. So this is minus 60 kJ upon initial pressure is 100 kiloPascal and volume is point 6 meter cube so this gives exponent to the 1 minus, so from here V2 will be equal point 3679 times V1 ok and V1 is point 6 meter cube so point 3679 into point 6 meters. So this gives V2 equal to point 221 meter cube, so this is the final volume. 1

We need to find the final pressure of the ideal gas as well so that can be found the ideal gas log. So from the ideal gas log P1V1 upon T1 will be equal to P2 V2 upon T2 ok. So P2 will be P1 times V1 upon V2 ok because this is an isothermal process. So P1 is 100 kiloPascal V1 by V2 is nothing but 1 upon point 3679, so this keeps final pressure equal to 272 kiloPascal.

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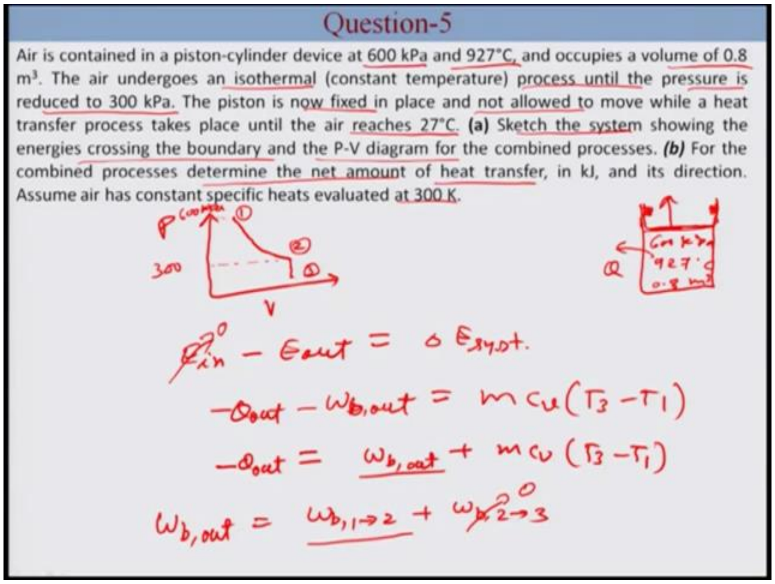

Coming to the final question. Air is contained in a piston cylinder device at 600 kiloPascal and 927 degrees centigrade and occupies a volume of point 8 meter cube. The air undergoes an isothermal process until the pressure is reduced to 300 kiloPascal. The piston is now fixed in place and not allowed to move while a heat transfer process takes place until the air is reaches 27 degrees centigrade.

First we have to sketch the system showing the energy crossing the boundary and the P-V diagram for the combined processes. Second for the combined process determine the net amount of heat transfer in kJ and its direction. Assume air has constant specific heats evaluated at 300 K

So first we have to draw this sketch of this system, so initially air is contained in a piston cylinder device at 600 kiloPascal ok. Temperature is 927 degree centigrade and volume is point 8 meter cube. It is said that air undergoes an isothermal process until the pressure is reduced to 300 kiloPascal that means air will do some work on the piston and it will lose its pressure to 300 kiloPascal.

So that means it will lose its energy to the surrounding as well, it is also said that after sometime piston is not allowed to move, that means after some time piston is not moving ok it is constant here. So volume of this system will not change, so this is the sketch of the system so if we see the whole process on a P-V diagram. So it is said that h initially expands isothermally from a pressure of 600 kiloPascal to a pressure of 300 kiloPascal ok then it is cooled at a constant volume.

So let us say this state is state 1 and this is state 2 and it is cooled at constant volume at some state so this is our state 3. In the second part of the question says that, the net amount of heat transfer in KJ. So we need to determine the net amount of heat transfer. So for that this is a closed system so for closed system energy balance would be like Ein minus Eout equal to change in energy of the const. system.

Since there is no heat coming inside of this system so that means energy in is zero. There are two things crossing the boundaries in a system that is Qout and the work done by the system on the surrounding which will be equal to change in total internal energy of the system because system is stationary. So total change in internal energy of this system will be nothing but mcv delta T T3 minus T1 here we assume that this air we have as an ideal gas. So form here we get minus Qout equal to net work done by the system plus change in internal energy ok.

So we know this is the total work done by the system, since process undergoes an isothermal expansion from the state 1 to state 2 and then it goes an isochoric process from state 2 to 3 so total work Wbout will be W from state 1 to state 2 plus of the state 2 to the state 3. So this is an isochoric process so the work done will be zero, because volume is constant. The only work done by the system is during the isothermal expansion ok.

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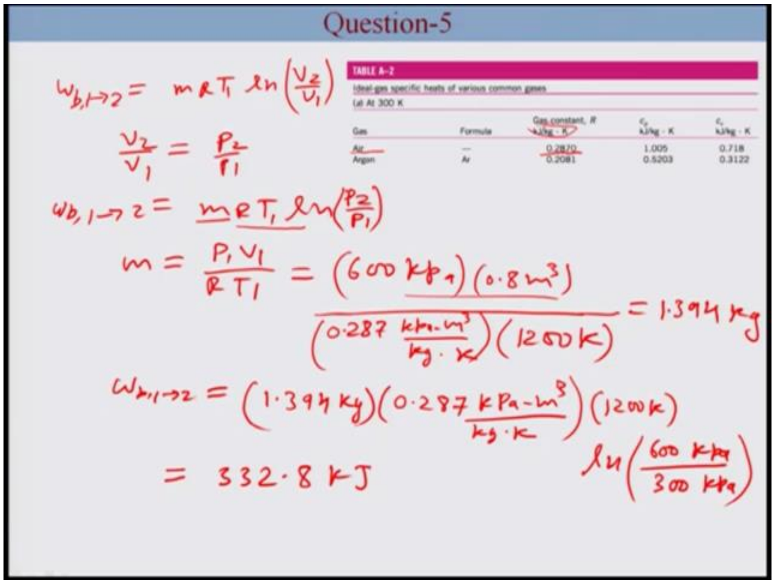

So isothermal expansion work for an ideal gas will be mRT ln of V2 upon V1 ok but for isothermal process V2 upon V1 equal to P2 upon P1, so from here Wb 1 to 2 will be mRT ln of P2 upon P1. So in this expression we do not know mass of the air initially present in the system, so from the ideal gas (())(36:49) we can calculate the mass of the air P1V1 upon RT1 ok. So after plugging the values of PV1 and RT1 we get 600 kiloPascal initial pressure, volume is given that point 8 meter cube. The value of R for air can be taken from the ideal gas table which is point 287.

So R is point 287 kiloPascal, we have convert this unit according to numerator unit ok. So kilo pascal into meter cube upon kg into Kelvin times temperature which is 1200 Kelvin. Initially air is at 927 degree centigrade. So this gives 1 point 394 kilo gram ok, so total work will be 1 point 394 kilo gram into R point 287 kiloPascal into meter cube upon kg and into K and initial temperature is 1200 K into ln of P2 by P1 so 600 kiloPascal to 300 kiloPascal. So from here total work will be 332 point 8 kJ ok. So now plugging this value into the energy balance equation.

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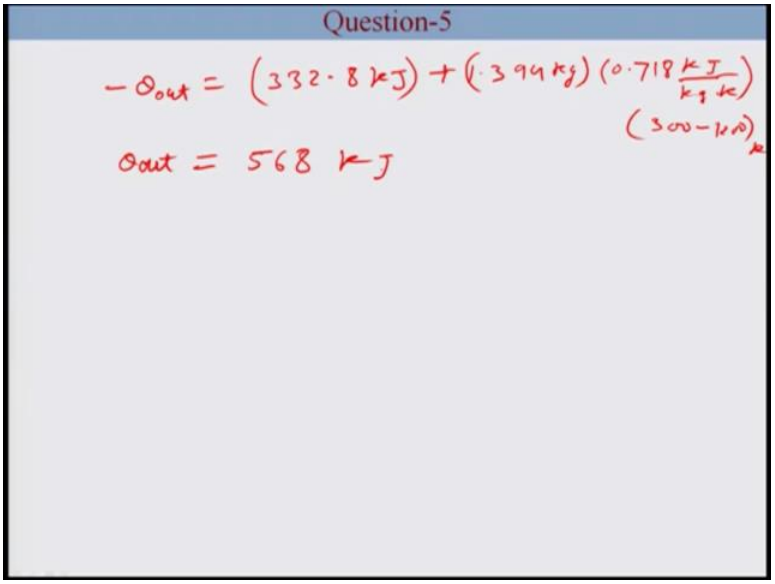

So from there we get minus Qout equal to work done which is 332 point 8 kJ plus change in internal energy so mcv delta t. So m is 1 point 394, cv of the air can be taken from this table which is listed here point 7818 that can be used here point 718 kJ per kg into K and delta t delta t is 300 minus 1200 K ok. So this gives total heat coming out of the system is 568 kJ, so this much amount of heat will come out of the system so here we will stop. We will meet you in the next tutorial. Thank you.