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NPTEL ONLINE CERTIFICATION COURSE

Course
on
Laws of Thermodynamics

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Lecture 08: First Law of Thermodynamics for
for Closed Systems (Part II),
Some examples

In today's section we will work some problems related to the use of first law thermodynamic for a closed system, so these problems will be based the tutorial problem that we have already given to you and we will I will project this problems one after another in the screen.

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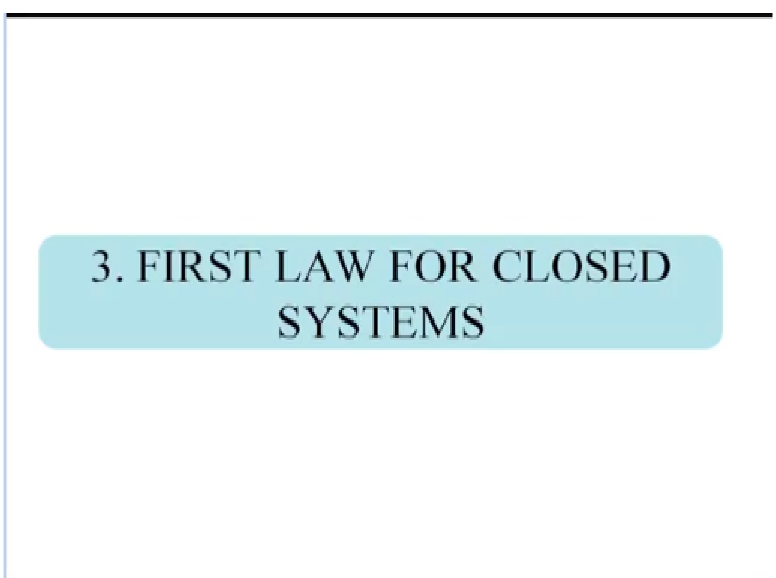

And we will try to go through the solutions up to certain details that is possible within the time limit.

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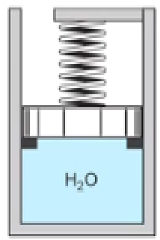
Problem 3.1: A piston/cylinder arrangement contains 1 kg of water as shown in the figure below. The piston is spring loaded and initially rests on some stops. A pressure of 300 kPa will just float the piston and, at a volume of 1.5 m^3, a pressure of 500 kPa will balance the piston. The initial state of water is 100 kPa with a volume of 0.5 m^3. Heat is now added until a pressure of 400 kPa is reached.

a. Find the initial temperature and the final volume.
b. Find the work and heat transfer in the process and plot the *p-v* diagram.

Ans: (a) initial temperature = 99.6 °C, Final volume = 1 m^3
(b) Work done = 175 kJ, Heat transfer = 2435 kJ



So let us look into the first problem 3:1 a piston cylinder arrangement contains 1 kg of water as shown in the figure below okay so you can see this figure that this kind of situation we have discussed earlier and this is again a linear spring and operation of 300 kPa will just float the piston and at a volume of $1.5m^3$ operation of 500 kPa will balance the piston, the initial state of water is 100 KPa with volume of $0.5m^3$ heat is now added until a pressure of 400 kPa is reached, find the initial temperature and the final volume work done on heat transfer in the process and plot the PV diagram.

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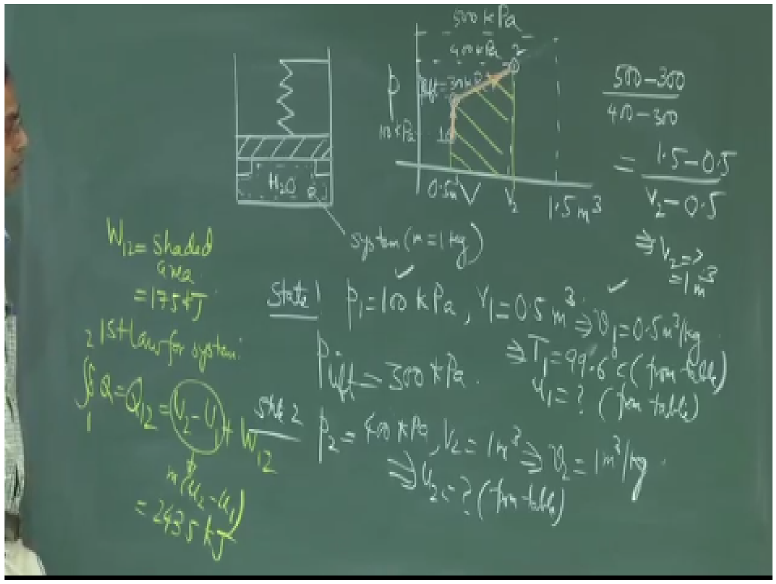

So let us try to solve this problem, I am trying to draw this here in the broad so this is the system with m = 1 kg, so let us try to see what is state one P_1 is 100kPa and V_1 is 0.5 m^3 so you know what is the specific volume this volume pass so v1 is specific volume at state one is 0.5m3 per kg so the pressure and specific volume combination fixed up the state one now what happens is that heat is added until the pressure of 400kPa is reached.

So the pressure at which piston gets lifted its 300kPa so if you transfer the heat until and unless the pressure goes up 100 to 300kPa this piston will not leave so if you try to draw this in P_v diagram from state one you go to state lift this is 300kPa and then from this state because of linearity of the spring it will be like this but what is the slope of these line how will know so for that there is additional data point which is given that operation of 500 at a volume of 1.5 m^3 a peruse of 500 kPa will balance the piston that means 500 kPa AND $1.5m^{3.}$
This combination 500kPa and $1.5m^3$ this particular combination will lie on the process diagram that state what lift the end state the end state is 400kp so some here, this is state 2 and of course you can find out what is the V_2 / considering the equation of the straight line so at state 1 you have V_1 is $0.5m^3$ so you can write 500 – 300 / 400 – 300 = 1.5 – 0.5 / V_2 – 0.5 so this will tell you what is width this is the equation of this straight line essentially, so the entire process is governed by this diagram up to 2 between 2 to these is hypothetical just to help you to construct the process diagram so if you calculate in this way.

You will get the final volume as $1m^3$ so state 2 P_2 = 400kp and V_2 is $1m^3$ so state 1 V_1 is $0.5m^3$/ kg state 2 similarly V_2 is $1m^3$ / kg so identity given that you know we want an specific volume see again I want to emphasis on one very important thing as per state postulate to identify the state we you required two independent intense properties for a simple compressible pure substance, so to identify the state is not the total volume that is sufficiently in addition to pressure in addition to pressure.

You must know the specific volume in addition to pressure, so the specific volume is the total volume per unit mass so these two are the properties not this that will be required to identify the state so if you look it to the table of water so with this combination you will get what is T_1, T_1 is 99.6^0C from table and also you will get what us U_1 this is also from table so you can so why you require U_1 for calculating the what done you would not required U_1 or U_2 but for calculating the heat transfer you require that.

Why you required that for calculating the heat transfer the reason is that for calculating the heat transfer we have to relate the heat transfer with through the first law of thermodynamics and for that you required the change of internal neglecting the changes in kinetic energy and potential energy that is why we required these. So similarly for state 2 you will get U_2 from table so what is the work done. This is the shaded area this is 175kj okay and now if we apply the first law for the system.

So the heat transfer is nothing but the changing internal energy this is m x u2 – u1 + w1 so if you substitute the values of the internal energy and the mass and the work done this will be 24, 35kj that is the answer to this property so we have worked out the problem 3.1 next we will go to the problem 3.2.

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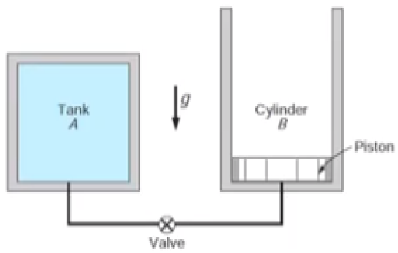
Problem 3.2: Consider the system shown in the figure below. Tank A has a volume of 100 litres and contains saturated vapor R-134a at 30°C. When the valve is cracked open, R-134a flows slowly into cylinder B. The piston mass requires a pressure of 300 kPa in cylinder B to raise the piston. The process ends when the pressure in tank A has fallen to 300 kPa. During this process, heat is exchanged with the surroundings such that the R-134a always remains at 30°C. Calculate the heat transfer for the process.

Ans: Total Heat transfer = 84.61 kJ



In the problem 3.2 you consider the system as shown in the figure below, the tank has a volume of 100 liters and contains saturated vapor R-134a at 30^0 centigrade this R-134a see R is for refrigerant so R-134a is a typical refrigerant which is used for refrigeration or air conditioning purposes, so when the valve is crack open so you see there is a valve which connects the tank with a cylinder when the valve is cracked open R-134a flows slowly into the cylinder v.

The piston must requires a pressure of 300 kilopascal in the cylinder be today is the piston the process ends when the pressure in the tank A has fallen to 300 kilopascal, during the process heat is exchanged with the surroundings such that R-134 a always remains at 30^0 centigrade, calculate the heat transfer for the purpose. So let me try to draw a schematic of the problem.

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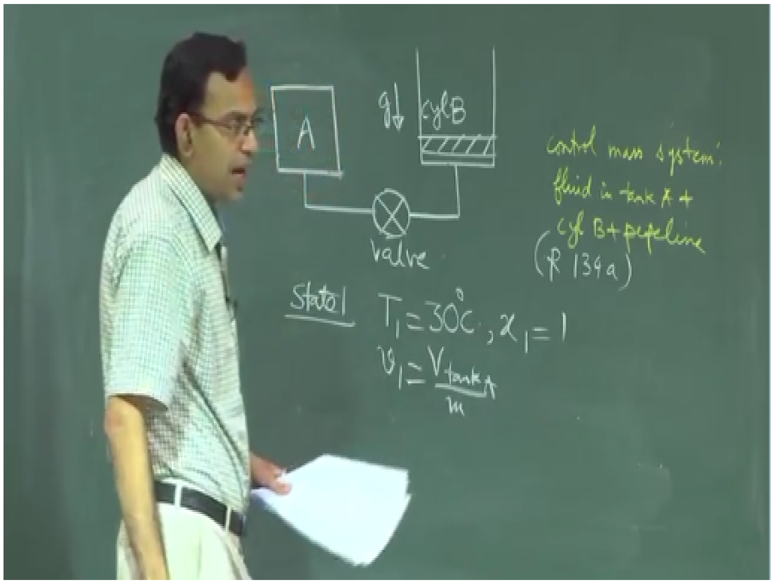

This is the direction of gravity given in the director and this is the valve. So state 1 first of all before considering state 1 we have to identify a control mass system, so let me ask you something, what is the control mass system here, the fluid in the tank A the fluid in the tank B sorry cylinder B or the fluid in the tank A + the fluid in the cylinder B so I give you three options, what is the appropriate control mass system to be chosen for solving this problem.

The fluid in the tank A option 1, the fluid in the cylinder B that is here option 2 and the fluid in the tank A + within the cylinder B that is option four, so to answer this question let us try to analyze this, by definition a control mass systems should be something which for which the mass will be identified and that will not change with time, so if you consider the tank A when the valve is open the mass within the tank A is decreasing.

Because the fluid is coming out from tank A through this valve and this pressurizing and filling up the cylinder B, so mass within A is varying, mass within B is carrying but if you consider A + B the total mass within these tank + cylinder with along with this pipeline that remains the same therefore your control mass system, fluid in tank A+ cylinder B + pipeline. So for this the state 1 is given so for this system, what is the state 1? T1 = 30^0 centigrade the fluid is R-134 a and it is at saturated vapor that means quality=1, what is v1 at state 1 everything is there in the tank A so volume of the tank A is divided by the mass, the mass is given so you have tank A as a volume of 100 liters.

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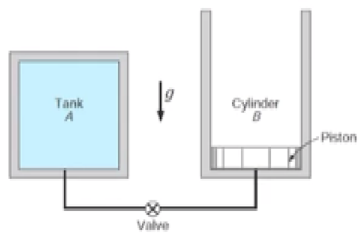
Problem 3.2: Consider the system shown in the figure below. Tank A has a volume of 100 litres and contains saturated vapor R-134a at 30°C. When the valve is cracked open, R-134a flows slowly into cylinder B. The piston mass requires a pressure of 300 kPa in cylinder B to raise the piston. The process ends when the pressure in tank A has fallen to 300 kPa. During this process, heat is exchanged with the surroundings such that the R-134a always remains at 30°C. Calculate the heat transfer for the process.

Ans: Total Heat transfer = 84.61 kJ



So if you look into the problem statement the tank A has a volume of 100 liters and contains saturated vapor at R-134a at 30°C, so how do you know the mass, so you know the volume of the tank A which is 100 liters.

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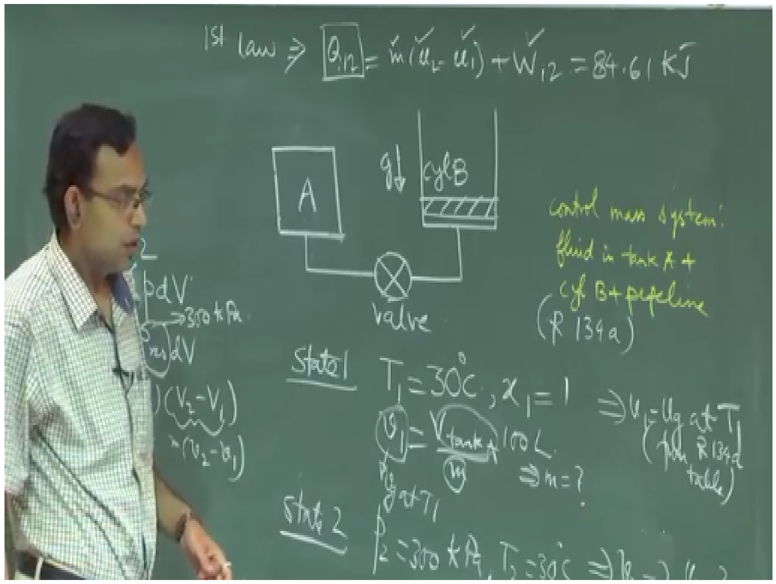

And v1 is vg1 vag at T1 so this will give you what is m, state 2 it is given that during this process it is exchanged with the surroundings and the final pressure is the pressure in the tank A is 300 kPa because the system is in mechanical equilibrium the pressure B is also 300kPa so the final pressure is 300kPa and temperature during this entire process remains a 30°C so this will tell you what is specific volume at state 2.

So what is the work done, how do you calculate $\int pdv$ here, so this is nothing but $\int p_{res}\, dV$ and p_{res} is 300 kPa it is a constant. So this is (300kPa) (v2-v1), so this is m(v2-v1) v2 how will you get from the table, so this is the work done but the question asked is not what is the work done but what is the heat transfer, so for that you have to use the firs law. So you require u2 and u1 also so u1 is nothing but ug at T1 this is from table.

And u2 v2 and u2 both you get from the table, so this data you can substitute from the table m you already know and work done you already calculated so this will give you what is Q12, so the Q12 is 84.61kJ that is the answer to this problem, okay. Next we will consider the problem 3.3.

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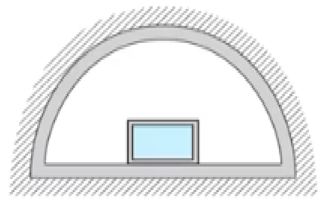
Problem 3.3: A water-filled reactor with a volume of $1m^3$ is at 20 MPa and 360°C and is placed inside a containment room, as shown in the figure below. The room is well insulated and initially evacuated. Due to a failure, the reactor ruptures and the water fills the containment room. Find the final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

Ans: final pressure = 568.5 kPa



Which is projected in a screen you can see here, so problem 3.3 the statement is like this water filled reactor with a volume of $1m^3$ is at 20 MPa and 360°C, so this small rectangular box with the blue color inside this is the water filled reactor and the hemispherical dome is a room the room is well insulated and initially evacuated due to a failure the reactor raptures and the water fills up the containment room, find the final question okay so let us work out this problem let me draw the schematic of this.

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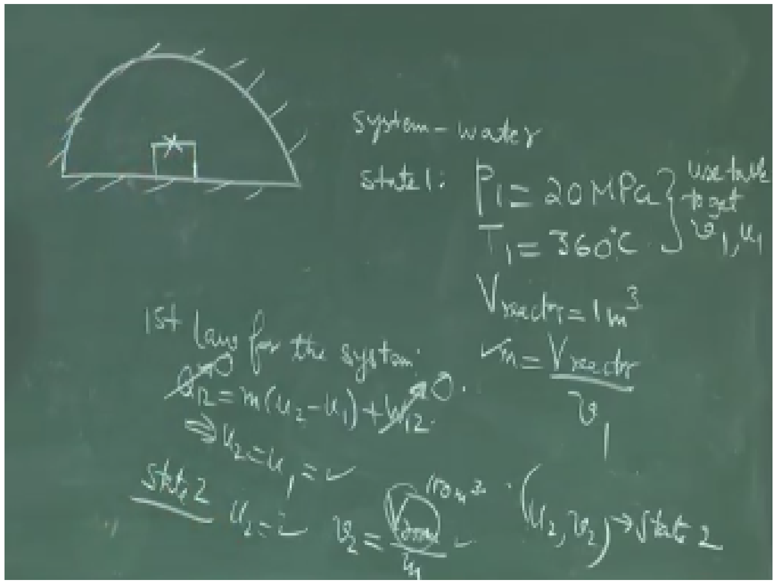

So this system must be the water state one we have po1 20MPa T_1 360^0 C, the volume of the reactor is $1m^3$ so from the p_1 and T_1 you can use the table to get table means property table of water that in short we are writing table to get V_1. So V reactor is $1m^3$ so what is the mass of the system V reactor by V_1, say initially this is evacuated so whatever is the mass which is their inside that mass is the that mass eventually does not change with time so this is the mass that you get.

Now you apply the first law for the system, so how do you know what is the work done here so logically you will think that there is some watt done because when this want to raptures there is a change in volume of the water which occupying this small space now it will occupy the big room but there is actually no water, why? Because this was initially evacuated and therefore this is water is expanding freely, free expansion or unrestraint expansion will not involve any work as I told you in the chapter relating to heat and work that there is no watt done when there is free expansion because there is no resistance.

So in this case the watt done is 0 this is very important concept what is the heat transfer? The heat transfer is also 0 because it is insulated, insulated means there is no heat transfer so that means you have $u_2 = u_1$ so how do you get the value of u_2 you stable to get v_1 and also u_1 and because $u_2 = u_1$ you know what is this. So state 2 how do identify state 2 you require two independent intense properties one is u_2 what is another property see another property is you know what is the specific volume at state two what is this?

This is the final volume is the volume of the room and the mass you already know. So the volume of the room is given the volume of the room is $100m^3$, so you know what is v_2 so u_2 v_2 combination will give you state two this is very interesting is not always pressure volume pressure temperature, temperature volume these combinations give a state, sometimes the other property combination also if they are independent intensive like here internal energy and specific volume that combination also give state two.

So why using these two from the table you should be able to identify the state two these days there are interesting software so that by without looking in to the physical or the hot copy table you can use you can enter these two data and using the software that is the digitized property table you can get the corresponding other properties for state 2, but I always suggest that as a beginner you should look in to the physical table.

So that you get a physical feel of where the property data lies, what is the corresponding state is it saturated is it super heated and so on that kind of physical insight you will not get if you use this digitize table where you entered this property and get the other properties as an output.

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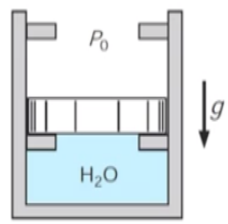
Problem 3.4: Consider the piston/cylinder arrangement shown in the figure below in which a frictionless piston is free to move between two sets of stops. When the piston rests on the lower stops, the enclosed volume is 400 L. When the piston reaches the upper stops, the volume is 600 L. The cylinder 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



So you can get what is the state two and the state two corresponds to the P2 of 568.5 kilograms okay this is the answer to this problem we will work out another problem before closing this session that is problem number 3.4 so let me project the problem 3.4 in a screen you see this is again the piston cylinder arrangement consider the piston cylinder arrangement shown in the figure in which our friction less piston is free to move between two sets of stops when the piston rests on the lower stop the volume is 400 liters when the piston is there in the upper volume is 600 litres.

The cylinder initially contains water at 100kPa with 20% quality it is heated until the water comes saturated vapor and the mss of the piston is requires at 300kPa to move again the outside pressure determine the final pressure and the heat transfer and the work done so let us try to draw the schematic of this problem .

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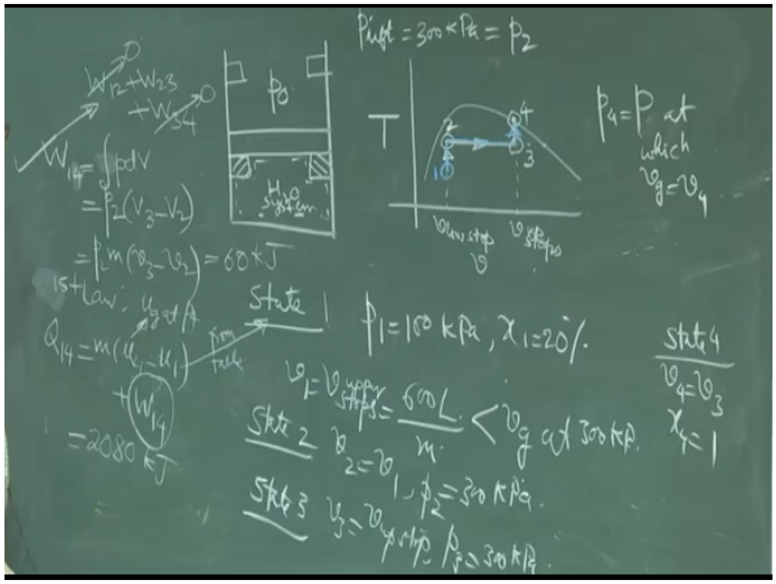

So clearly the system is water control mass system let us try to draw a P_1 diagram of this process state 1 is P_1 is 100Kpa and quality is 20% so this identifies state one the state final is the stops so state one is two face region let me draw it like this so just for a change let us try to draw T_v direct so now the first step is from one to two during the process the heat is added so it will go up like this.

At wt pressure it will go up it will go up to the temperature corresponding to which the saturation pressure is the P lift, P lift is 300 kPa so this is P_2 from at this state you will find the corresponding volume is between Vf and Vg therefore it is in a two face region then it will be heated and until and unless the face change process is complete a constant pressure heating will ensure that it is a constant temperature heating also.

The question is what final state is, the final state is a it is the water eventually exists as saturated vapor so will continue up to this we have to see what is the volume of the stops if the volume of the stops is greater than this then it will continue up to this, but if the volume of stops is less than this, so what is the specific volume at this stops, specific volume at this stops is what? That is 600 l the upper stops, 600/ by the mass, so how do you what is the mass? So initial volume is you know the initial sate when the piston on the lower stops the enclosed volume is 400litre. So you know the specific volume at state 1 you know the total volume, so you know the mass.

So you divide this by the mass you will get the specific volume at the upper stops and you will see that this specific volume at the upper stops is such that this is less than Vg at 300 kp therefore the stops will be encountered some at here, let us say this is state fill and then so this is V upper stop and this is V lower stop. Then from 3if you want to go to the saturated vapor only way at state physically what is happened.

This piston has reached here, so once this piston has reached here only way when the heat is transferred it is temperature will increase but will increase at constant volume. So from 3 to 4 it will be a constant volume process. So state 4, state 2 is $b_2 = V_1$and p_2 = 300kp, state 3 v_3 = v upper stop and P_3 is 300 kp and what is state 4 $V_4 = V_3$ and $x_4 = 1$, this is the saturated, so how do you find what is the pressure at state 4?

Pressure at state 4 is the pressure corresponding to which Vg is this on V_4, so V_4 is the saturation pressure or V_4 is the pressure let us write in the another way at which Vg = V_4. So the process diagram is something like this and what is the work done? So the work done is only between 2 to 3, other process 1 to 2 and 3 to 4 are constant volume process. So this is p_2 x $V_3 – V_2$ this is p_2 x m x $V_3 – V_2$ this is the work done and W_{14} is W_{12} to + W_{23} + W_{34} so W_{12} =0.

So now the first law if you apply Q_{14} = m x $U_4 – U_1$ + W_1, so U_4 is U_g at p_4 U_1 you already know from state 1 from table and W_{14} is calculated here so if you substitute all these you will get the expression the value for the heart transfer which is 208000, if you want to check the answer for the work done as an intermediate calculation this is 60kj okay. So interestingly although we have plotted the diagram the Pv diagram will also look similar.

For this case and you can visualize the work done if you replace the T with G in this kind of scenario, so to summarize we have worked out few problems typically 4 problems in this particular session we will continue with discussions on some questions and problems relate to first law of thermodynamics for a closed system in the next session when we meet for the tutorial, thank you very much.