Concepts of Thermodynamics
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Lecture – 44
Entropy Change in Closed System: Examples

In our previous lecture, we solved a few problems on the 2nd law of thermodynamics, quantified in terms of entropy and entropy generation for a control mass system.

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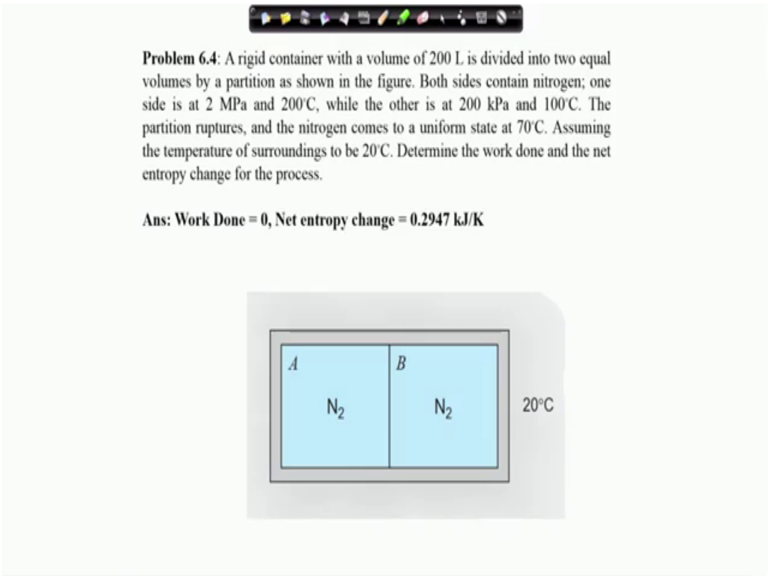

So, we will continue with the problem solving. The next problem is problem 6.4. A rigid container with a volume of 200 liter is divided into 2 equal volumes by a partition. So, A and B, both have nitrogen one side 2 MPa 200 degrees centigrade. Let us say side A and other side 200 kPa 100 degrees centigrade. The partition ruptures and the nitrogen comes to a uniform state of 70 degrees centigrade. Assuming the temperature of the surroundings to be 20 degrees centigrade, determine the work done and the net entropy change during the process.

So, let us work out this problem in the board. We will draw a schematic of the problem as per our regular custom and then we will solve.

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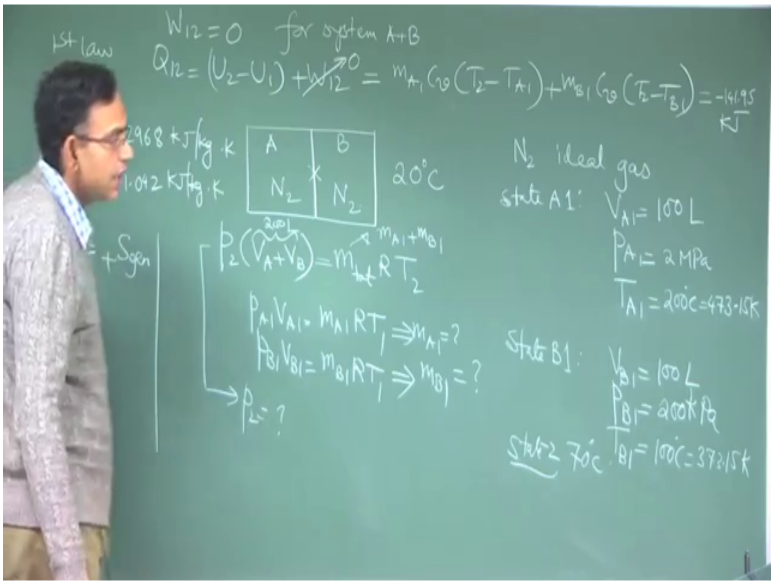

So, we will assume here nitrogen as ideal gas, this is an assumption. So, state A 1 V A is 100 liters because total volume is 200 liter; it is divided into two parts. Pressure is 2 mega Pascal, sorry 200 degrees centigrade; not 20 ha 200 degree centigrade, so, 473.15 Kelvin, state V 1, V B 1 100 liter, P B 1 2 MPa sorry 200 kPa, T B 100 degrees centigrade that is 373.15 Kelvin. So, what is the final pressure?

Let us say it is one of the primary things that we will calculate. It is not given as a part of the question that find out the final pressure. Why do you require the final pressure? You require the final pressure because to calculate the change in entropy. Entropy change for an ideal gas is a function of both pressure change and temperature change. So, final pressure will be required. So, how do you calculate the final pressure? So, when this is ruptured, A plus B will become the total thing in the chamber. It will have a common pressure and common temperature till it comes to, when it comes to equilibrium.

So, p 2 into V A plus V B that is the total volume is equal to m total R T 2 right; m total is nothing but m A 1 plus m B 1 because total mass does not change. It is just a redistribution of mass, but A plus B whatever is the mass within the chamber, that does not change. So, how do you get m A 1 and m B 1? You know, so p A 1 V A 1 is equal to m A 1 R T 1. So, this will give you what is m A 1 because all other things are known. Similarly, p B 1 V B 1 is equal to m B 1 R T 1. So, this will give you what is m B 1. So, these R is of nitrogen as I told that when you consider the mass basis, these R is not the universal constant. It is universal constant divided molecular weight.

So, for nitrogen, the value of R will be 0.2968 kilo Joule per kg Kelvin and C p of nitrogen which will require for one part of the problem is 1.042 kilo Joule per kg Kelvin. Once you have R and C p, you can calculate C v. That does not require additional input because C p minus C v is R. So, when once you have these m A 1 and m B 1, you can calculate p 2 from here. This is V A plus V B is 200 liter, right. So, now, have p 2.

So, then what is asked first part is what is the work done. This is the easiest part because when this is ruptured there is a redistribution of A and B, but overall there is no movement of the system boundary. So, work done is 0. So, work done is 0 for the system, for system A plus B. Now, you apply 1st law. So, what we have to find out is the entropy generation. So, entropy generation calculation will require two steps. The first step is you calculate the heat transfer and based on that heat transfer you put it in the expression for the entropy change to get the entropy generation. How do you calculate the heat transfer? For that, you require the 1st law of thermodynamics.

So, 1st law Q 1 2 is equal to U 2 minus U 1 plus W 1 2 ; U 2 minus U 1 is, U 2 minus U 1 of A plus U 2 minus U 1 of B. So, m A 1 C v into T 2 minus T A 1 plus m B 1 C v into T 2 minus d B 1 assuming constant C v. So, if you do that and final temperature what is the final temperature is 70 degrees centigrade. So, state 2, you have 70 degrees centigrade and pressure also you have found out. Here, pressure is not required because internal energy of an ideal gas is a function of temperature only.

So, you substitute all these values and you can get what is the heat transfer. So, this is minus 141.95 kilo Joule ok. So, then what do you require is the entropy generation. So, for that we will apply the entropy change formula. So, S 2 minus S 1, so if you substitute here temperature of the surroundings, this will include the total entropy generation that includes the heat transfer from the surrounding to the system or system to the surrounding in this case because it is a negative heat transfer.

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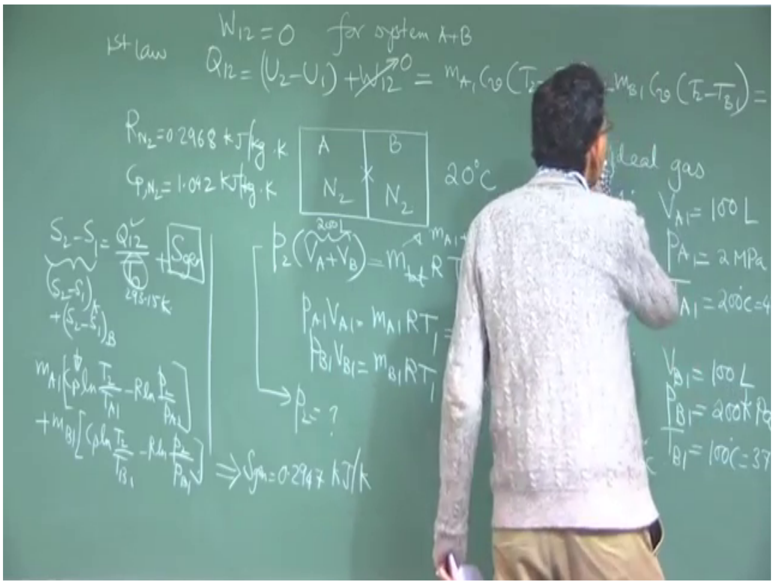

So, S 2 minus S 1 is S 2 minus S 1 of A plus S 2 minus S 1 of B. S 2 minus S 1 of A is m A 1 C v or we can use C p or C v depending on whether we are calculating it on a volume basis or pressure basis. So, if we are calculating it on a volume basis, pressure basis, then C p 1 or C p into ln T 2 by T A 1 minus R ln p 2 by pA 1 plus m B 1 C p ln T 2 by T V 1 minus R l n p 2 by p B1 right. So, you can calculate the value. The T 0 is given to be 20 degrees centigrade. So, this is 293.15 Kelvin, this you already know, here you can substitute the values.

So, you will get entropy generation. Entropy generation is 0.2947 kilo Joule per Kelvin ok. So, we will move on to the next problem. Let me erase the board before we move on to the next problem. Next is problem number 6.5.

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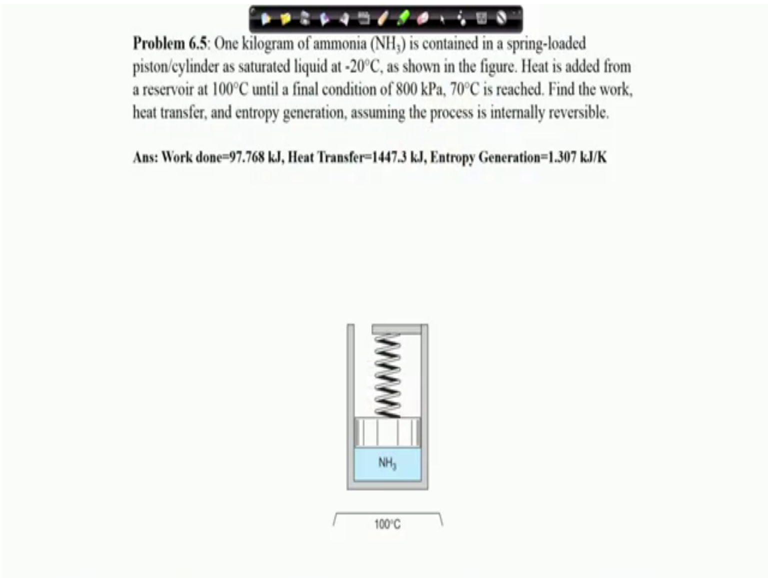

You have 1 kg of ammonia contained in a spring loaded piston. The state 1 is saturated liquid at minus 20 degrees centigrade. Heat is added from a reservoir at 100 degrees centigrade until a final condition of 800 kPa, 70 degree centigrade is reached. Find the work, heat transfer, entropy generation assuming the process is internally reversible ok.

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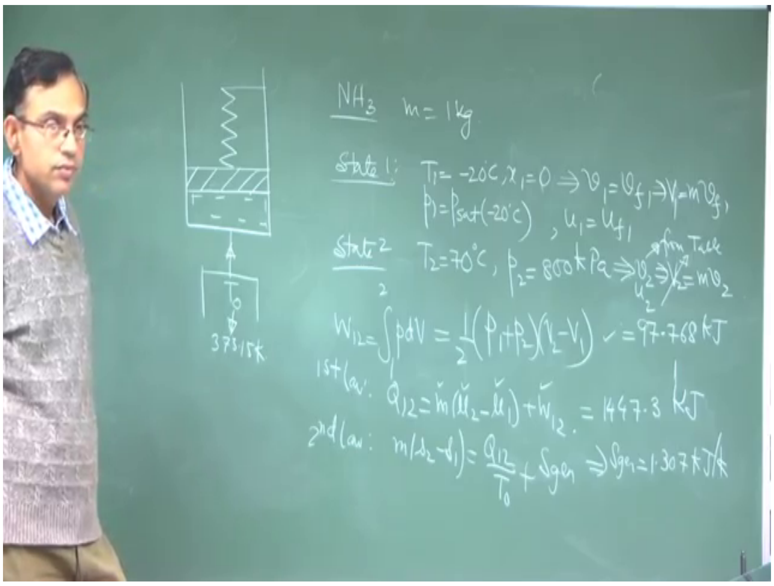

So, you have ammonia, m is equal to 1 kg, this is our system. State 1, T 1 is equal to minus 20 degrees centigrade, x 1 is equal to 1. So, what are the properties we will be require, I will come to that when we solve, but let us first identify the state's 1 and 2.

State 2 is T 2 is 70 degrees centigrade, p 2 is 800 kilo Pascal. The first thing that we will require like when it is transferred from this T 0 to here, there will be an expansion.

So, there will be a work done if it is internally reversible; that means, it will move in a cos equilibrium process. So, work done will be integral p d V, cos equilibrium we can write it. So, this will be, so pressure versus volume will be linear because the spring that is resisting is linear. So, the work done we have done such problems so many times that I can straight away write the expressions for the work done. So, integral p d V for linear pressure volume diagram will be half p 1 plus p 2 into V 2 minus V 1.

So, how will you know this V to minus V 1? So, this means you know what is v 1 which is nothing, but sorry this is saturated liquid not saturated vapor right, so, this is right. So, x 1 is equal to 0. So, v 1 is v f 1 at minus 20 degrees centigrade; m is equal to or capital V 1 is m into v 1. So, this is the mass in this case, for state 2 you can calculate v 2 from these T 2 p 2 it will be definitely super heated vapor state. So, V 2 will be equal to m v 2. What is p 1? P 1 is p sat of at minus 20 degree centigrade.

So, you know all these values. This will give you what is the work done that is 97.768 kilo Joule. Then, once you know the work done, you can calculate the heat transfer. Q 1 2 is equal to m into U 2 minus U 1 plus W 1 2. So, you can also calculate U 1, U 1 is u f 1 and U 2 is from v 2. This is from table of ammonia and U 2 also from table. So, you know U 2 minus U 1 you know W 1 2 you already know. So, from here, you can find out what is Q 1 2.

So, Q 1 2 is 1447.3 kilo Joule. In most of the cases, I am giving you answers of the intermediate steps with the hope that you know it will help you to check your calculations in between and allow you to have more confidence in problem solving with data taken from thermodynamic tables. And then, you can apply the 2nd law m into S 2 minus S 1 is equal to Q 1 2 by T 0 plus S gen.

So, T 0 is given 100 degrees centigrade right; that means, 3 73.15 Kelvin. So, this will give you what is entropy generation because everything else is known is 1.307 kilo Joule per Kelvin. So, this is a very straightforward exercise. We will move on to the next problem, let.

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Now, see this is very important. So, you are asked to calculate what is the entropy generation during the process? So, when it is entropy generation during the process, it includes the sources of irreversibility both internal and external. Had it been entropy generation during the process within the system, then T would be the temperature of the system bounding, but when it includes this heat transfer as well, the temperatures would be this one. So, this includes both internal and external irreversibility. So, let us erase this one before we move on to the next problems. We will solve a couple of problems more.

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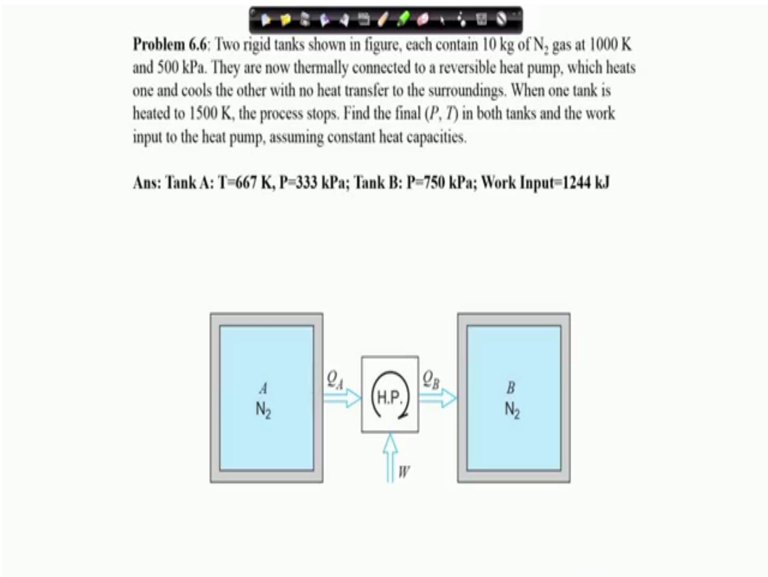

So, the next problem 6.6; you have two rigid tanks each contain 10 kg of nitrogen at 1000 Kelvin at 5 500 kPa. So, they are connected by a reversible heat pump which heats the tank B and cools the tank A. So, it effectively transfers heat from a colder tank to a hotter tank and that can be possible only by a work input. You have to find out the final pressure and temperature in both tanks and the work input to the heat pump assuming constant heat capacities and this process all the processes are considered to be reversible ok. So, let me draw the schematic.

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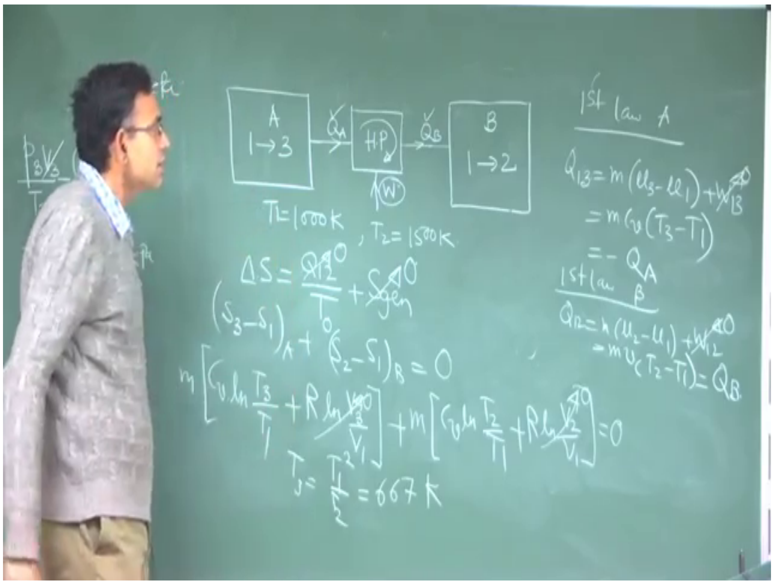

So, you have A, so this is heated, let us say it goes from state 1 to state 2. This is cooled; let us say this goes from state 1 to state 3. So, now, you can write, so T 1 is 1000 Kelvin this is given whatever is given am writing T 2 is 15 1500 Kelvin, T 3 we do not know ok. So, then because this entire process is reversible, we can right delta S is equal to Q 1 2 by T 0 plus entropy generation, right.

So, this delta S is the changing entropy of the nitrogen in A plus the change in entropy of nitrogen in B there is no change in entropy for the heat pump because it is a cyclic process it comes back to the same state. Heat transferred, if you consider this entire thing as a system there is no external heat transfer. This you have to understand very carefully. This heat transfer is internal within the system your here the system is A plus heat pump plus B ok. So, then this is 0 and because the heat pump is functioning reversibly, all the heat transfers and changes upstate are reversible and therefore, the entropy generation is 0. So, the change in entropy is 0. So, S 3 minus S 1 of A plus S 2 minus S 1 of B that is equal to 0.

So, this is C v ln T 3 by T 1 ah. I can write in addition plus R l n V 3 by V 1. So, this is 0 because there is no change in volume of these plus ah. So, the mass each contain 10 kg. So, if this is m, this is also m; m is 10 kg. Similarly, C v ln T 2 by 2 T 1 plus R l n V 2 by V 1 ok; so, you can from here get ln T 3 T 2 by T 1 square is equal to 0; that means, T 3 T 2 equal T 1 square. So, you have T 3 is equal to T 1 square by T 2 right. So, this will be

667 Kelvin, all right. Once this is 667 Kelvin, you can now use the ideal gas law p 3 by T 3 is equal to p 1 by T 1. Actually, p 3 V 3 by T 3 is equal to T 1 V 1 by T 1; V 1 and V 3 are the same. So, if you want, I can write that and cancel if it helps you.

So, you can find out from here what is p 3; p 1 is known right; p 1 is 500 k Pa; 500 k Pa. So, this will give you what is p 3. This is 333 kPa. This is similarly p 2 by T 2 is equal to p 1 by T 1 again. So, here also, you will get same way p 2 is 750 kPa. Now, you want you to get this work done you require heat transferred here and heat transferred here. So, for that you have to apply 1st law separately for A and B to get this heat transfers. Otherwise, if you apply 1st law for the whole system, you will not get that, so, 1st law for A.

So, Q 1 2 is equal to or Q 1 3 m into U 3 minus U 1 plus W 1 3, W 1 3 0. So, U 3 minus U 1 is equal to m C v into T 3 minus T 1 right, m is 10 kg. So, this will be I do not have a separate answer for this, but whatever Q 1 3 comes out, that is equal to minus Q A right that much we can say. Why minus Q A? Because the Q A direction in the figure is shown to be heat transfer from A and Q 1 3 positive by definition, heat transferred to A not from A. So, and we can apply the 1st law for B Q 1 2 is equal to m into U 2 minus U 1 plus W 1 ok. So, this is m c v into T 2 minus T 1.

So, this is equal to Q B right. Now, what is the work done? So, from energy balance of the heat pump, if we apply the 1st law for the heat pump, you have Q A plus W is equal to Q B.

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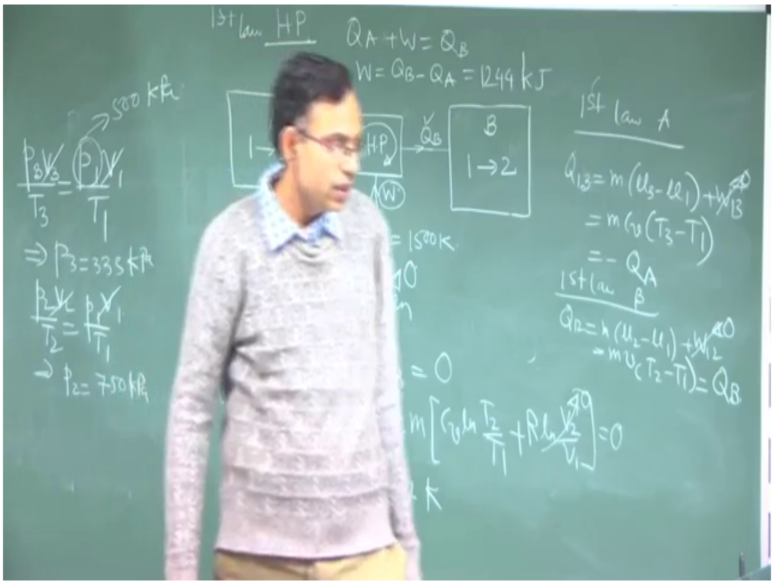

So, W is equal to Q B minus Q A which you get from these two and that will be 1 2 4 4 kilo Joule. There is a final problem for this particular part of the chapter and that problem, I will not solve fully, but I will give you a hint how to solve that is problem number 6.7.

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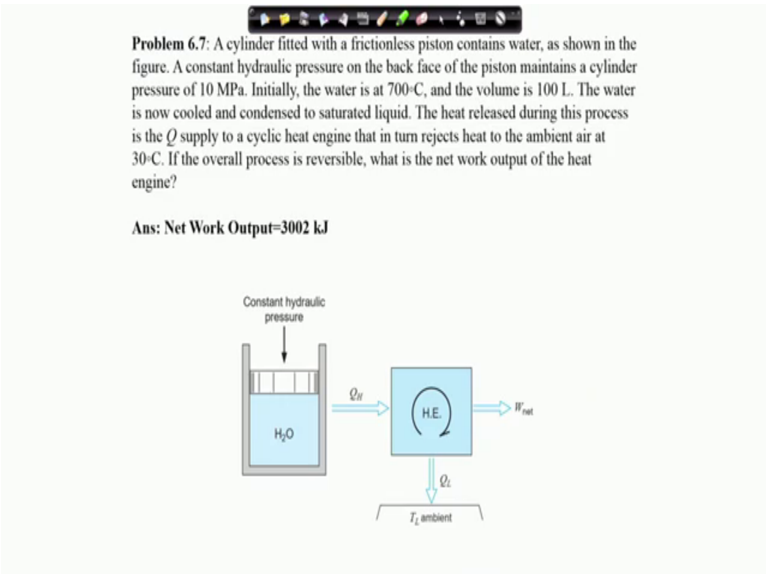

So, let me erase the board. I will not draw the picture completely, but I will give you some hint at least one or two problems you should try by yourself with little bit of hint and I will of course, give you the final answer. So, let us look into the problem. A cylinder fitted with a frictionless piston contains water a constant hydraulic pressure maintains the cylinder pressure at 10 MPa.

So, the process is a constant pressure process, constant pressure process. Initially, the water is 700 degrees centigrade and volume is 100 liter and then heat is transferred from the water. So, it is cooled and piston will come down, it is volume will come down. This heat is transferred to a heat engine and the heat engine rejects it Q L to the ambient and in the process, it does some work.

If the entire process is reversible, find the net work output. So, this problem is very much similar to the previous problem. Only difference is previous problem that tank was rigid. Here, instead of that, there is a cylinder with a flexible with a moving boundary. So, in this case, I will just give you a hint of how to solve the problem.

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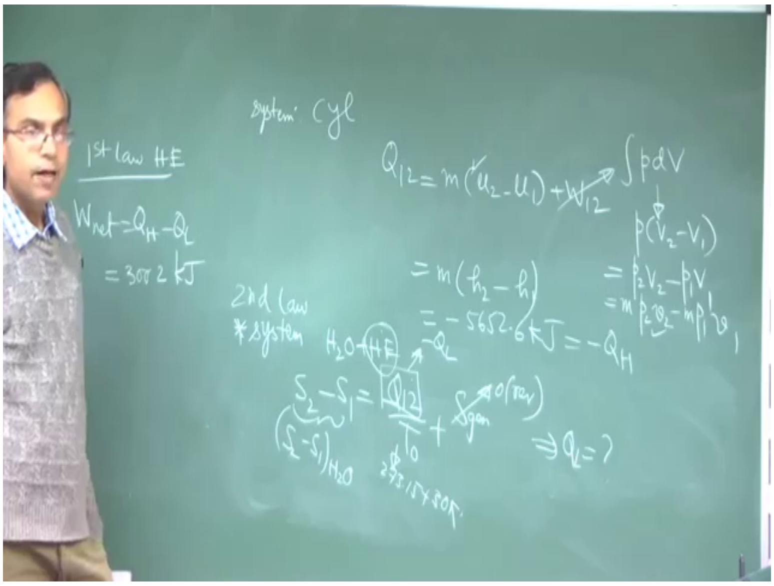

So, you have the cylinder as the system first. So, you have Q 1 2 is a equal to m into U 2 minus U 1 plus W 1 2. W 1 2 is integral p d V right it is a constant pressure process. So, this is p in to V 2 minus V 1. So, this you can write p 2 V 2 minus p 1 V 1 because p 2 and p 1 are the same.

So, this is m p 2 small v 2 minus m p 1 small v 1. So, if you combine U 2 with p 2 V 2, U it is m into h 2 similarly h 1. So, by looking into the property tables, state 1 and state 2 you can get the enthalpy and then you will get m. So, state 1 is 700 degrees centigrade 10

MPa. It is defined by that. State 2 10 MPa and it is condensed to saturate saturated liquid 10 MPa and quality equal to 0, that is state 2. So, if you calculate these heat transfer, this is minus 5 6 52.6 kilo joule. This is equal to minus Q H because he transferred to the cylinder is positive.

So, heat transferred from the cylinder is negative. And then, to calculate the net entropy generation, you appeal to other to the second law, but 2nd law applied to the cylinder plus the heat engine. So, second law, you apply for the system water plus heat engine together. This is very important because the overall process is said to be reversible. So, S 2 minus S 1 is equal to Q 1 2 by T 0 plus entropy generation right Q 1 2 by T 0. So, S 2 minus S 1 is S 2 minus S 1 of water because for the heat engine because the process is cyclic, there is no S 2 minus S 1. What is this Q 1 2? If you take the water under heat engine together, look at the figure of the problem.

If you look at, yes just look into this figure. Water and heat engine the Q H is internal is like action reaction force in free body diagram. So, water and heat engine together that net heat transfer is minus Q L right, water and heat engine together net transfer is minus Q L and T 0 is temperature of the ambient air which is 30 degrees centigrade that is 273.15 plus 30 Kelvin. Entropy generation is 0 because the overall process is reversible. So, from here, you can find out what is Q L, right.

And then you apply the 1st law for the heat engine to calculate the work done. So, W net is equal to Q H minus Q L. This is for this problem 3002 kilo Joule. So, with this we have solved quite a few problems on the understanding of entropy change and entropy generation for a control mass system. How do these considerations change if it is a control volume instead of control mass system? That we will take up in the next lecture.

Thank you.