Concepts of Thermodynamics
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Lecture – 49
Entropy Transport for Flow Process Examples

In the previous lecture, we started working with some examples on control volume analysis for entropy transport. We will continue with the problem solving in this lecture as well.

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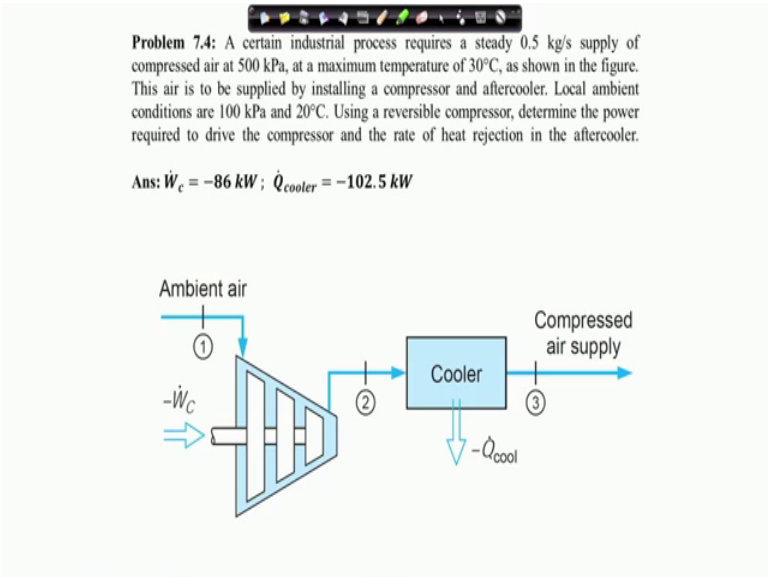

So, we refer to problem see 7.4: a certain industrial process requires a steady 0.5 kg per second supply of compressed air at 500 kilo Pascal at a maximum temperature of 30 degree centigrade, as shown in the figure. This air is to be supplied by installing a compressor and after cooler. Local ambient conditions are 100 kilo Pascal and 20 degree centigrade. Using a reversible compressor determine the power required to drive the compressor and rate of heat rejection in the after cooler.

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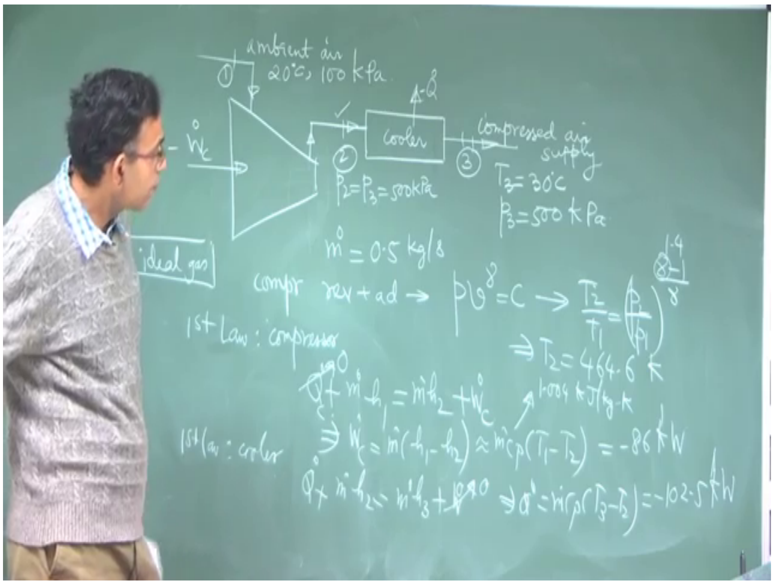

So, let us draw a schematic. This is a compressor, this is ambient air; 20 degree centigrade, 100 kilo Pascal. This is state 1, this is state 2 and this is state 3. So, this is 20 degree centigrade 100 kPa, p 2 is equal to p 3 is equal to 500 kilopascal T 3 is 30 degree centigrade and p 3 is equal to 500 kilo Pascal. So, there is a heat transfer at the cooler. There is a work input to the compressor.

So, what is given let me just write down what is given m dot is equal to 0.5 kg per second. The compressor is reversible and also we can assume that the compressor is adiabatic. So, normally compressors are well approximated as adiabatic devices. So, for compressor it is reversible plus adiabatic; that means, you can write here it is an air compressor. So, if air is treated as an ideal gas this is very important. So, you can write pv to the power gamma equal to constant where gamma is the ratio of C p and C v, reversible adiabatic of an ideal gas, not any general thing.

So, this leads to T v to or this leads to T 2 by T 1 is equal to p 2 by p 1 to the power gamma minus 1 by gamma. This we have used in one of our previous problems. It is very simple you combine this with pv by T equal to constant. So, this combination gives this one. So, gamma for air is 1.4, if you take constant C p, C v. You know what is p 2, you know what is p 1, so, you can get what is T 2 from here. Remember in these expressions temperatures are to be in Kelvin. So, T 2 is 464.6 Kelvin.

Now, you apply the first law for the compressor. So, if you apply first law for the compressor, there is no heat transfer, neglect changes in kinetic energy and potential energy ok, heat transfer is 0, let us call it Q dot c for compressor. So, W dot c is m dot into h 1 minus h 2, you can approximate it as m dot C p into T 1 minus T 2 ok. So, you can substitute the values C p for air is 1.004 kilo joule per kg Kelvin. So, this will be minus 86 kilo watt. So, that is the first question power required to drive the compressor and rate of heat rejection in the cooler.

So, now, you apply the first law for the cooler. So, Q dot plus m dot into h 2; here the inlet is 2 is equal to m dot into h 3 plus W dot there is no heat transfer for the cooler. See it is a same first law you have to just see what is inlet and what is exit; for the cooler inlet is 2, exit is 3. So, from here you can calculate what is. So, again this is minus 102.5 kilowatt for calculating the work for input to the compressor oh this one. So, this one yes exactly the same this is minus integral v d p only.

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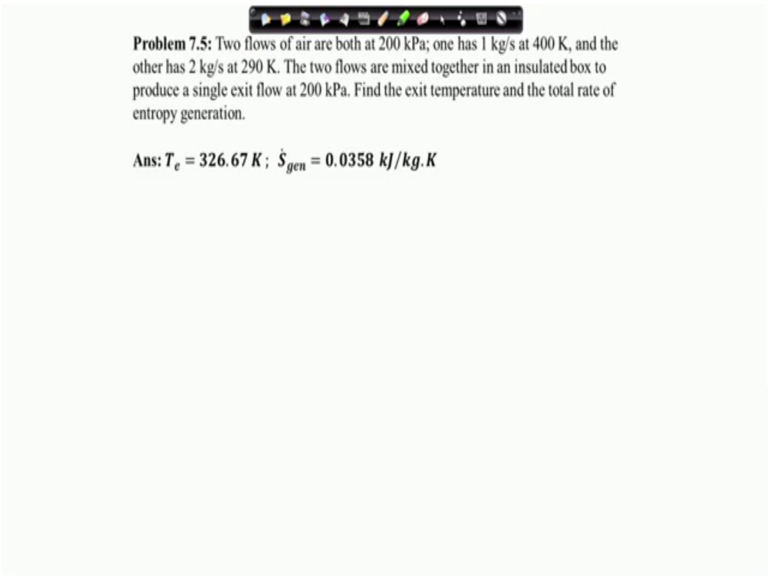

Problem 7.5: Two flows of air are both at 200 kilo Pascal; one has 1 kg per second at 400 Kelvin, and the other has 2 kg per second at 290 Kelvin. These two flows are mixed together in an insulated box to produce a single exit flow at 200 kPa. Find the exit temperature and total rate of entropy generation. So, this is the first problem that we are encountering numerical problem where we are talking about an irreversible process with entropy generation. So, let us see how we tackle it.

Let us go to the board and draw the schematic of this problem. So, any problem before solving if you draw the schematic and write what is known then that helps you to you know solve the problem very easily.

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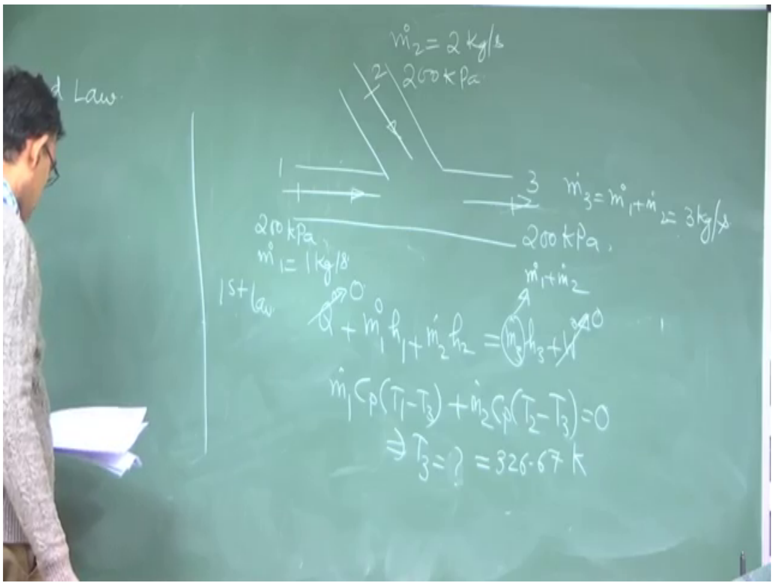

So, there is one stream of air which comes at state 1. There is another stream of air which comes at state 2; these two streams mix. So, this is like a mixer and finally, that comes out is state 3. All pressures are 200 kilo Pascal so this entire thing is constant pressure process. Pressures are important not for calculating or using the first law, but for using the second law because entropy change will be a function of pressure, even if it is an ideal gas. So, these are all 200 kPa; m dot 1 is 1 kg per second; m dot 2 is 2 kg per second. So, m dot 3 just by mass balance is equal to m dot 1 plus m dot 2. So, that is 3 kg per second.

So, now you apply the first law. There is no net heat transfer right. The box the entire thing takes place in a box which is insulated. So, Q dot which is 0 plus m dot i h i summation of m dot i h i that is m dot 1 h 1 plus m dot 2 h 2 is equal to m dot 3 h 3 plus W dot. There is no work here it is insulated. So, there is no heat transfer therefore, you can calculate. So, m dot 3 is m dot 1 plus m dot 2, right. So, you can write m dot 1 into h 1 minus h 3 that is C p into T 1 minus T 3 if you assume constant C p plus m dot 2 h 2 is C p into h 2 minus h 3, this is 0. So, this will give you what is T 3. So, T 3 is 326.67 Kelvin, ok. Then you apply the second law.

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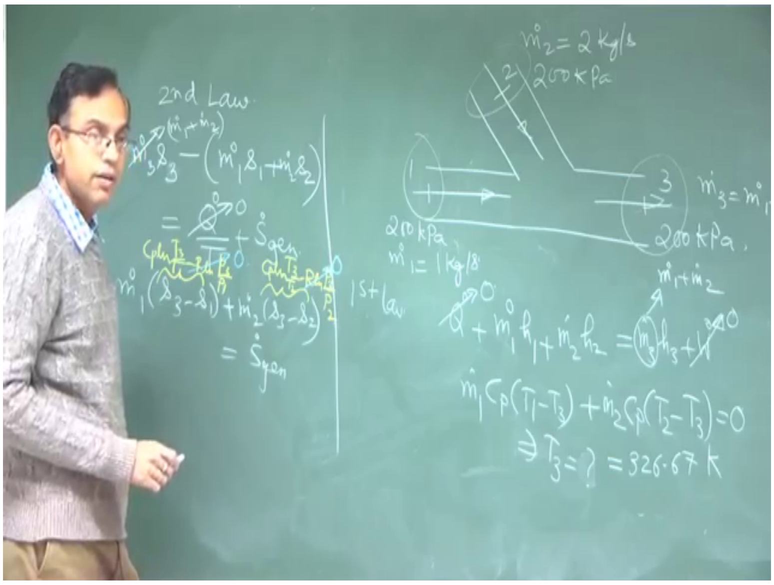

So, second law when you apply the change in entropy, so exit minus inlet; this is exit and these are inlet. So, m dot 3 s 3, this is exit minus inlet there is no heat transfer and m dot 3 is m dot 1 plus m dot 2. So, m dot 1 into s 3 minus s 1 plus m dot 2 into s 3 minus s 2 is equal to S dot gen.

If you consider constant C p C v ideal gas this is C p ln T 3 by T 1 minus R ln p 3 by P 1. This is C p ln T 3 by T 2 minus R ln p 3 by P 2. All the pressures are same, so this term is 0 and this term is 0, temperatures are known. So, you can or remember again I am repeating all temperatures should be substituted in Kelvin.

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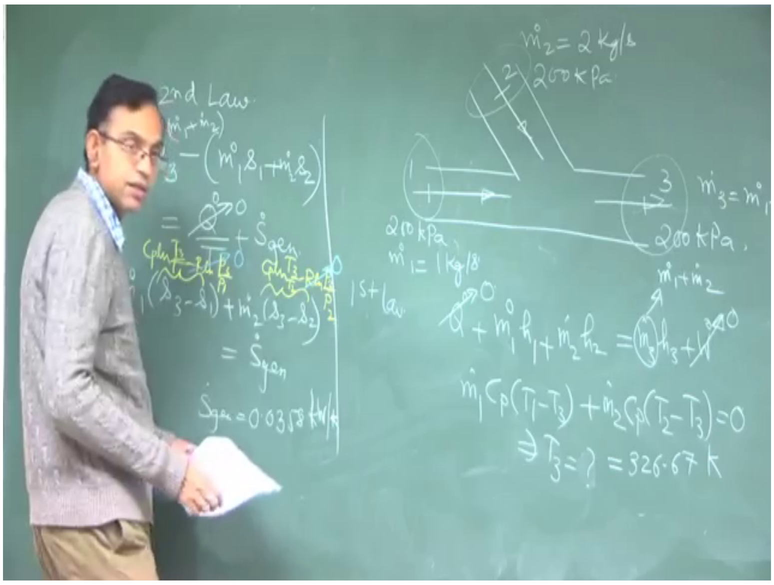

So, if you do that you can calculate what is entropy generation rate which is 0.0358 kilo watt per Kelvin this is rate, so kilo watt per Kelvin. We will work out one more problem in this lecture before we stop.

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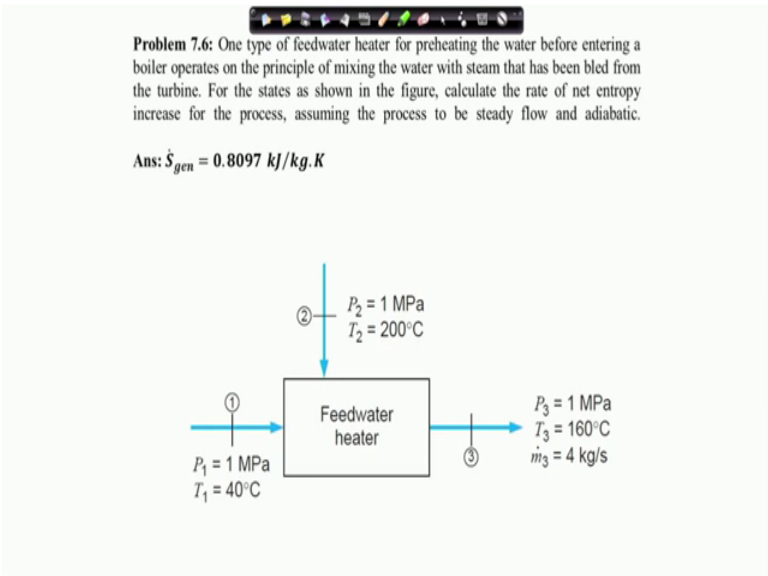

Problem 7.6: One type of feed water heater for preheating the water before entering the boiler is based on the principle of mixing of the water with steam that has been bled from the turbine. So, I will explain you what this feed water heater does. See boiler requires energy for getting converted the fluid from or the water from low enthalpy to high

enthalpy, because the enthalpy at the output outlet of the boiler is utilized to drive the turbine. So, the heat input to the boiler is expected to be less if the water already enters at a high enthalpy.

So, how that is possible? You bleed a part of the steam from the turbine which is at higher enthalpy than the water that is circulating out of the pump and then you mix it with the boiler inlet fluid. So, if you mix it with the boiler inlet fluid. So, the boiler inlet fluid may have a low enthalpy intrinsically, but you bleed a part of the steam that is already at an elevated temperature from the turbine and mixed with that. This mixture will effectively have quite a high enthalpy so that the energy required to drive or energy required to heat the steam in the boiler to convert it to a superheated state is much less. And, this mixing process can take place in a device called as feed water heater.

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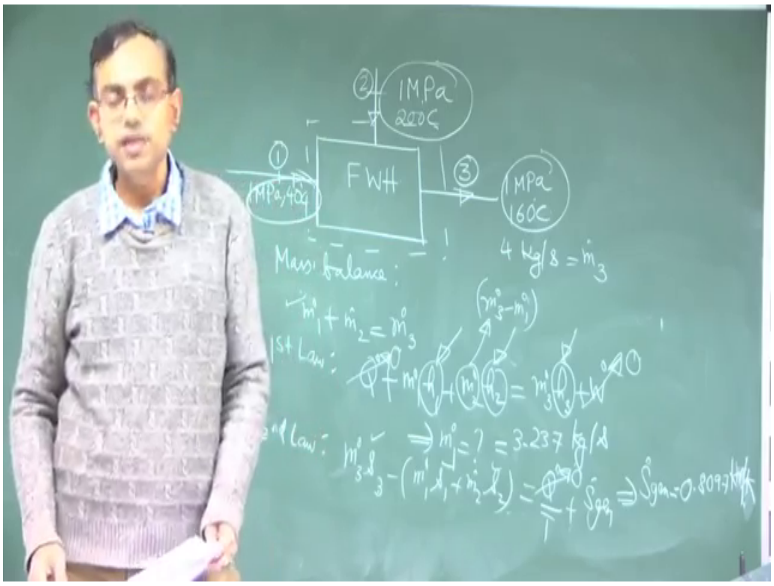

So, let me draw the schematic of the feed water heater. So, this is 1 MPa 40 degree centigrade, this is state 1; state 2 is 1 MPa, 200 degree centigrade this is already at a higher temperature. It is already at a higher temperature because it has been bled from the turbine and the net final state is 1 MPa, 160 degree centigrade and 4 kg per second. These two flow rates are not known. So, from the thermodynamic states given and the first law we can find out the mass flow rates of 1 and 2.

How we can do that? First you apply the mass balance. So, this is our control volume, mass balance m dot 1 plus m dot 2 is equal to m dot 3, ok. Then, first law, Q dot plus m dot 1 h 1 plus m dot 2 h 2. This is summation of m dot i h i is equal to m dot 3 h 3 plus W dot. So, here there is a heat exchange internally; externally there is no heat transfer. So, this is 0, there is no work transfer and in place of h 1, h 2 and h 3 you can substitute properties from the table.

So, you can calculate. So, what is required, what is m dot 1 for example? m dot 2 you can write, m dot 3 minus m dot 1, from here and m dot 3 is 4 kg per second. So, from this equation only unknown is m dot 1 which is 3.237 kg per second. What is asked? Calculate the rate of net entropy increase or entropy generation rate. So, for that we have to apply the second law.

So, the net change of entropy that is m dot 3 s 3 minus m dot 1 s 1 plus m dot 2 s 2 is equal to Q dot by T plus entropy generation rate. This is 0 s 1, s 2, s 3 these are all from property table at these conditions, ok. So, at these conditions from table; so, this is water. So, from steam table at these conditions you can calculate from the table s 1, s 2 and s 3, m mass flow rates are known and this will give you what is rate of entropy generation. So, entropy generation rate is 0.8097 kilo joule per Kelvin. So, rate of entropy generation kilowatt per Kelvin, right, kilowatt per Kelvin.

So, we have worked out three problems in this particular lecture. We have worked out a few other problems in the previous lecture. We will work out more problems in the subsequent lectures, but I want to give you a broad you know structure of these problems concerning entropy. So, invariably although the problem is related to entropy, you also invoke the first law. There is absolutely no problem that we have solved where bypassing the first law we can just utilize the entropy transport to solve the problem. The reason is that entropy transport is very important but, we also have to make sure that the problem solution satisfies mass balance and energy balance.

So, if we calculate entropy transport without satisfying mass balance and energy balance that remains physically unrealistic. And, that should be the message from the problem solving desk so far that for solving the entropy transport problems we commonly have to combine first law and second law sometimes along with that the TDS relationship and that gives a structure of the basic equations that you need to solve the problems related to entropy transport across a control volume. We stop here today.

Thank you very much.