**Concepts of Thermodynamics**
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**Lecture – 50**
**Entropy Transport for Flow Process: Examples**

We have been discussing about problems concerning Entropy Transport across a control volume and let me work out a few more problems to help you understand the concept.

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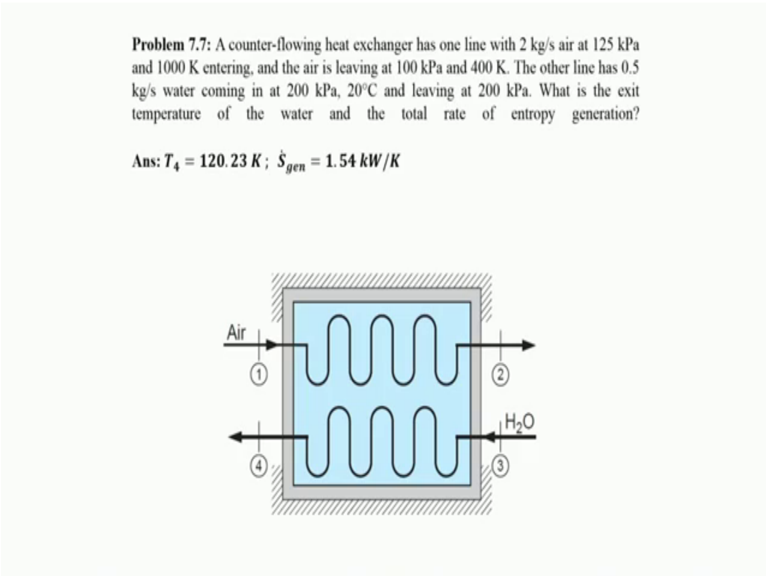


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So, the next problem is problem number 7.7. So, counter-flowing heat exchanger; counter-flowing heat exchanger means that you have two streams, they are flowing in opposite directions and the heat is exchange between the hot stream and the cold stream without any external heat transfer taking place.

So, it has one line with 2 kg per second air at 125 kilo Pascal and 1000 Kelvin entering and the air is living at 100 kilo Pascal and 400 Kelvin. The other line has 0.5 kg per second water coming in at 200 kPa, 20 degree centigrade and leaving at 200 kilo Pascal. What is the exit temperature of the water and the total rate of entropy generation?

So, let me go to the board and try to draw a schematic of this problem which this method we have followed for all the problems that we have discussed so far.

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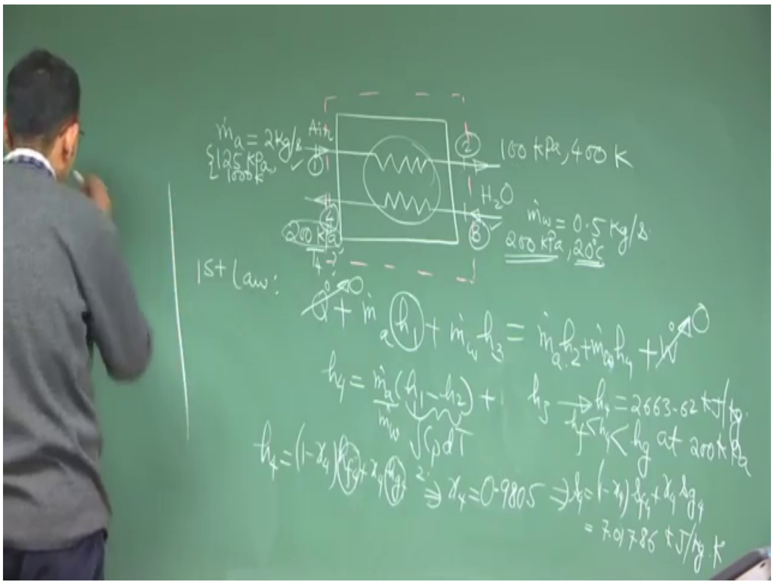


So, you have air, one line is air and the other line is water m dot air is 2 kg per second; the state points this is 1, this is 2, this is 3, and this is 4. So, this is 125 kilo Pascal, 1000 Kelvin this is state 1; this is 100 kilo Pascal. I am just writing the problem data, I have not actually started solving the problem. This is 200 kPa 20 degree centigrade and you have m dot water is equal to 0.5 kg per second.

State 4: it is 200 kilo Pascal and, there is a temperature which is not known. So, T 4 there is a question mark, if we can find out t 4 all the state points will be identified and then we can do a second law analysis to calculate the entropy generated in the process. So, see some very interesting thing, I mean there are many practical things that come out of problem solving that is why problem solving is so interesting.

So, look at the air line here you have 125 kilo Pascal and here you have 100 kilo Pascal; if I have not made a mistake that is what it is given. So, there is a pressure drop as the air is flowing from 1 to 2. However, there is no pressure drop as water is flowing from 3 to 4. This I would comment as an idealization rather than reality because in practice to sustain a fluid flow there will be pressure drop to overcome viscous resistances. So, that is a practical fluid dynamics issue. Solving a thermodynamics problem does not interfere with that, but it is important also to understand that while the data given for this line is quite practical the pressure constant pressure assumption of this line may be a bit questionable, ok.

Now, we will find out we will try to identify what is state 4. So, we will make a control volume analysis; so for this control volume if you write 1st law Q dot plus summation of m dot i h i in inlet is 1 and 3. So, m dot air h 1 plus m dot water h 3 is equal to m dot 2 h 2 plus m dot 4 h 4 plus w dot sorry m dot 2 we can write is same as m dot a and m dot 4 is same as m dot W. So, we can replace this.

Because this is heat exchanger there is no external heat transfer across this control volume we neglect it. It is the primarily the exchange of heat between these two streams. The purpose of heat exchanger is not to do any work. So, the work term is 0 and hence you are left with. So, you know h 1 you know because state 1 is known, 125 kpa 1000 Kelvin and this is 100 kPa 400 Kelvin.

Now, although there is a pressure drop, but in terms of enthalpy if you assume here as an ideal gas this pressure drop does not matter because enthalpy of an ideal gas is a function of temperature only and not pressure. So, you can write for example, what is our unknown? Unknown is h 4 h 4 is m dot a into h 1 minus h 2 plus m dot w h 3. So, this is integral of C p dT from 2 to 1.

Student: Sir, it is m dot a by m dot w.

So, m dot a by m dot w, if you divide both the sides by m dot w that will be there case, ok. So, this will be integral of C p dt. The range of temperature is from 1000 from 400 to 1000, it is quiet large range. So, it is better not to rely on constant C p, but calculate or get h 1 minus h 2 from air table; properties of air table h 3 at state 3 you know water at 200 kilo Pascal and 20 degree centigrade. So, h 3 will be roughly h f at 20 degree centigrade.

So, from here you will get what is h 4. So, h 4 if you calculate it will be 2663.62 kilo joule per kg. If you look at the table you will find that this is less than or this is between h f and h g at 200 kilo Pascal. So, if it is between h f and h g at 200 kilo Pascal; that means, it is in the two-phase region.

So, how do you calculate the quality at state 4? So, h 4 is equal to 1 minus x 4 into h f 4 plus x 4 into h g 4. So, from here h f and h g are corresponding to 200 kilo Pascal water h f and h g that you get from table. So, if you substitute that you will get what is x 4. So, x 4 will be 0.9805. For all the problems I am trying to give you some intermediate numerical values as much as possible because you can practice yourself and gain confidence if you see your answers and matching with these numbers at least closely.

So, when you have this x 4 in variably for entropy generation you need the property the entropy at state 4. So, let us calculate entropy at state 4, 1 minus x 4 into s f 4 plus x 4 into s g 4. So, entropy at state 4 is 7.01786 kilo joule per kg Kelvin.

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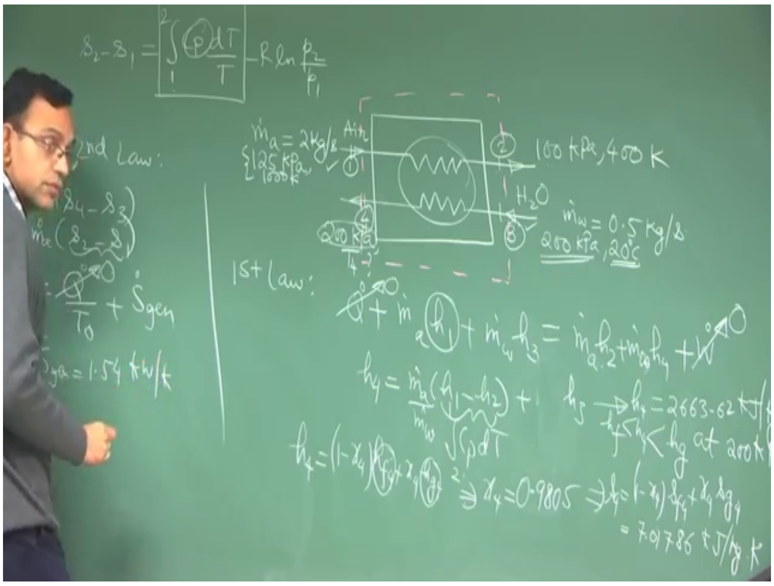


So, then if you make a second law analysis, the change in entropy which is m dot water into s 4 minus s 3 plus m dot air into s 2 minus s 1 is equal to Q dot by T 0 plus rate of entropy generation. If you take this T 0 this includes both effect of in internal and external irreversibility. There is no heat transfer across the control surface, s 2 minus s 1. So, as I told that it is important to recognize that over this large range of temperature C p and C v will be strong functions of temperature.

So, it is better to say C p integral C p dT by T, this is a function of temperature 1 to 2 this part is fine for R ln p 2 by p 1 is. So, this you can get from air table the data of this, this is tabulated properties of air table. So, s 2 minus s 1 you get in this way, s 4 and s 3 from steam table from water property table. So, if you substitute that here the entropy generation will be 1.54 kilowatt per Kelvin, ok.

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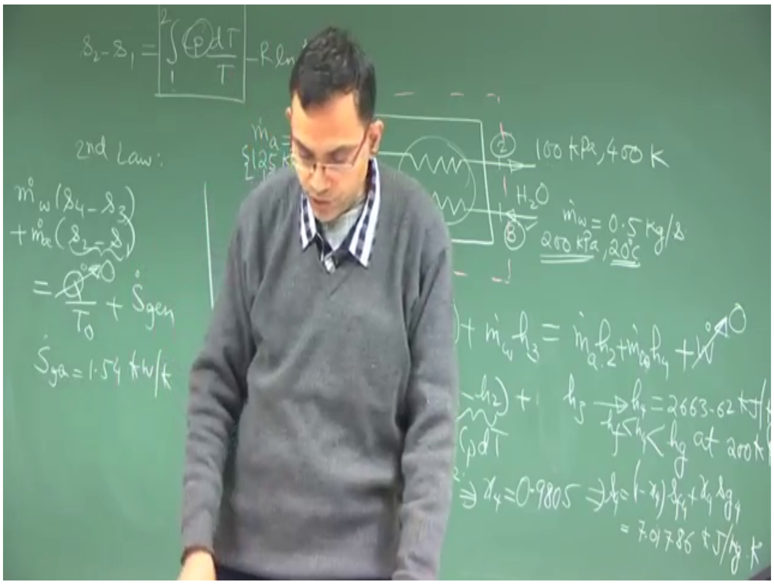


So, let us move into the next problem, problem 7.8.

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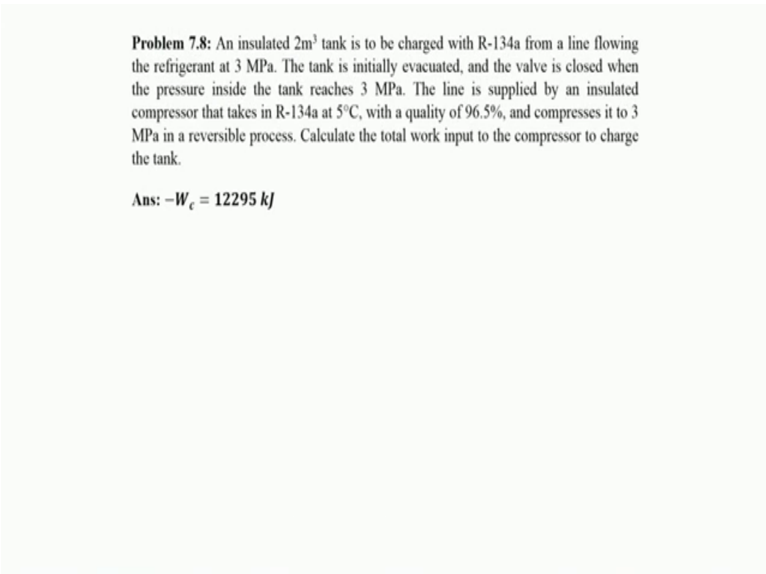


An insulated tank is to be charged with R 134 a which is a refrigerant from a line flowing the refrigerant at 3 mega Pascal. The tank is initially evacuated on the value is closed when the pressure inside the tank reaches 3 mega Pascal. The line is supplied by an insulated compressor that takes in R 134 a at 5 degree centigrade with the quality of 96.5 percent and compresses it to 3 mega Pascal in a reversible process. Calculate the total work input to the compressor to charge the tank. So, let me draw a schematic of this problem.

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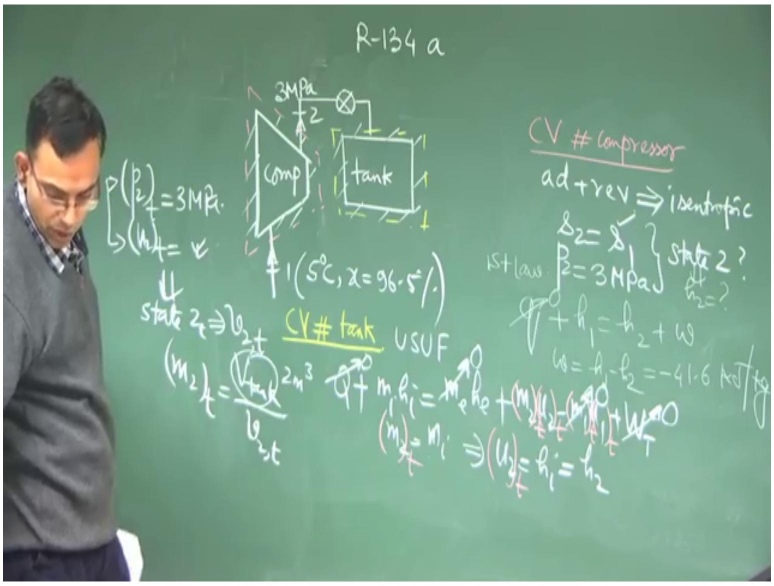


So, there is a compressor which compresses R 134 a and charges that R 134 a there is a valve in a pipe line. So, if the valve is closed this R 134 a is not coming, but if it is open then it is filling up a tank; the tank is insulated. So, state 1 so the fluid is R 134 a, state 1 is 5 degree centigrade and x equal to the quality is 96.5 percent that completely specifies the state, ok.

So, at state 2 the pressure is 3 mega Pascal and then the compressor is also insulated, this is also told. So, I am just symbolically putting it. The tank initial is evacuated and this supply line is used to charge the tank and the charging process is stopped when that is the valve is closed when the pressure inside also become 3 mPa because that is the maximum pressure which you can develop within a tank and then you stop it, the entire process is reversible, ok. So, if the entire process is reversible calculate the total work input to the compressor to charge the tank. So, this is the compressor and this is the tank. Let us take a control volume around the compressor; so, the control volume compressor.

So, the compressor is adiabatic and also process is reversible. So; that means, it is isentropic reversible plus adiabatic. So, because it is isentropic what we can say is that s 2 is equal to s 1. Since s 2 is equal to s 1 and p 2 is equal to 3 mega Pascal, using this combination we can identify what is state 2 from the R 134 a table; s 1 is from table because you know this 5 degree centigrade and quality you know by this time how to calculate this I am not wasting time for that.

So, when you have state 2 then the question that is asked is what is the work input to the compressor this information does not tell us what is the total mass that has flown in across the compressor. So, per unit mass flow we can calculate the work from this data. So, per unit mass if we write the first law for the steady state right neglecting changes in kinetic potential energy and all this. So, there is no heat transfer across the compressor. So, w is h 1 minus h 2. So, state 2 will tell you what is h 2.

So, this will be minus 41.6 kilo joule per kg, the question that is asked is what is the total work input we are not just per kg. So, you have to find out how much kg of R 134 a has flown across the compressor and come to the tank. So, for that the control volume will be the tank for that analysis. So, control volume tank. So, for the tank it is a uniform state uniform flow process. So, q plus m i h i is equal to m e h e, I am just writing symbolically then I will substitute values. So, we use a different symbol let us say W tank. So, there is no work done for the tank it is rigid. So, the work is 0, there is no heat transfer, there is no exit and m 1 is 0 and from mass balance m 2 is equal to m i, right.

So, you can find out so from here you can see that you will get u 2 is equal to h 1 h i; h i is h 2. So, this 2 so let us not confuse symbols. So, I will use different symbol for this 2 is final. So, these let us call m 2 tank m 2 t this is u 2 t, right; this is m 1 t this is different from states 1 and 2 right, 1 and 2 are these.

So, m 2 t is equal to m i which means u 2 t is equal to h i which is; so, u 2 t you can get from here because you know what is h 2 already. How to identify state 2? You also know that p 2 tank is 3 MPa this is given and u 2 tank is whatever you get from this state. So, from pressure and internal energy to independent properties you can identify the state it is quite tricky to find it out from the table, but you know you can in principle find it out. So, this will give you state 2 t. Once you know state 2 t you know what is specific volume at state 2 t and what is m 2 t is the volume of the tank by the specific volume. So, the volume of the tank is 2 meter cube. So, this is the mass that is coming in.

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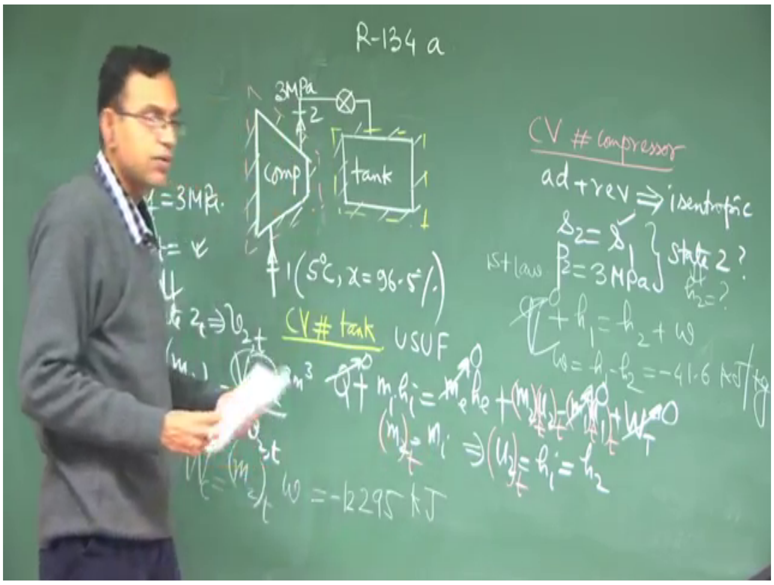


And, so the total work done for the compressor is this total mass that has come to the tank times the specific work which is this one. So, that will be minus 12295 kilo joule, this minus indicates that work is input to the compressor. We will work out one more problem.

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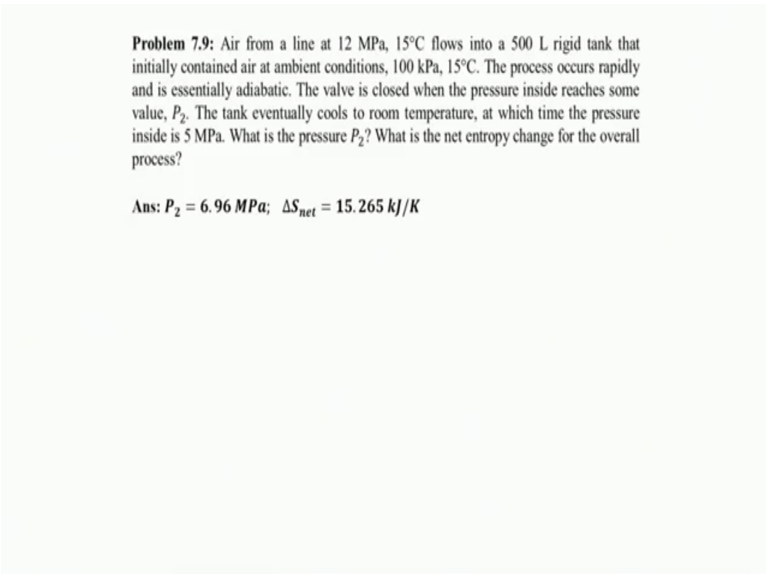


Air from a line at 12 MPa, 15 degrees centigrade flows into a rigid tank that is that initially contains air at ambient conditions which is 100 kPa, 15 degree centigrade. The process occurs rapidly and is essentially adiabatic. The valve is closed when the pressure inside reaches some value P 2. So, up to 1 and 2 the process is adiabatic then the tank cools to room temperature at which time the pressure inside is 5 mPa. So, what is the pressure P 2 and what is the net entropy change?

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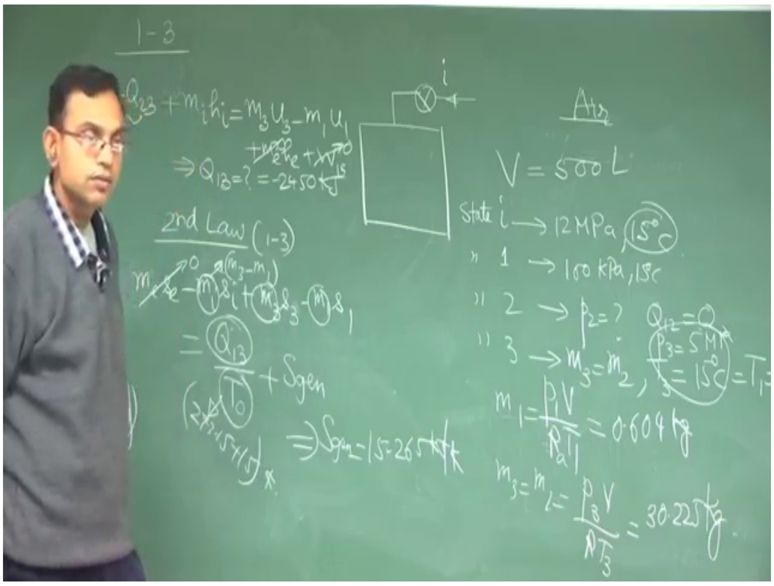


So, let us make a schematic. So, this is the tank there is a supply line with state i. So, the tank V is 500 liter state i is 12 MPa, 15 degree centigrade this is all air; state 1 100 kPa, 15 degree centigrade; state 2 you do not know p 2, but what you know is Q 12 equal to 0; state 3 at state after reaching state 2 the valve is closed.

So, that means, mass inside tank at state 2 and state 3 are the same and T 3 is equal to 15 degree centigrade which is essentially equal to; which is essentially equal to T 1 equal to T I. So, T 3 is 15 degree centigrade which is T 1 equal to T i; this is what is given. So, then what else I mean if it is given air so you can treat this as an ideal gas. So, straight way you can write m 1 is p 1 V by RT 1. So, this is 0.604 kg this is R is R of air, m 3 is equal to m 2 is equal to p 3 V. So, p 3 is given right p 3 is 5 MPa. So, I have forgotten to write it here p 3 is 5 MPa p 3 v by R p 3, this is 30.225 kg.

So, the mass that has come in m i, that is m 2 minus m 1 this is 29.621 kg, for the process 1 to 2 heat transfer is 0. So, if you apply the USUF energy equation, so, Q 12 plus m i h i is equal to m 2 u 2 minus 1 u 1 plus m e h e plus W; W is 0 there is no m e.

Student: (Refer Time: 28:49).

Yes, there is no dot, right. So, then m 2 m 2 you know u 1 from state 1 you know, u 1; from state 2 you do not know what is u 2 right, this is what you do not know h i you know and m i is already known this is m 2 minus m 1. So, this will give you what is u 2.

Student: Q dot Q is also.

Q is 0. So, u 2 you will get. So, if you take constant C v this is as good as C v into T 2. So, this will tell you what is T 2; if you do not take constant C v from air table with u 2 as internal energy you can find out what is T 2. So, T 2 is 401.2 Kelvin and p 2 V which is V tank is equal to R T 2 which will tell you what is p 2, this is one part of the question and this is 6.96 mega Pascal.

Student: T 2 V equal to m 2 R T 2 right (Refer Time: 30:20).

Yes, yes p 2 V is equal to m 2 R T 2 yes, right. So, p 2 V is equal to m 2 R T 2 from here you will get what is p 2. So, this is one part of the question. Then the next part was what is the total entropy generation.

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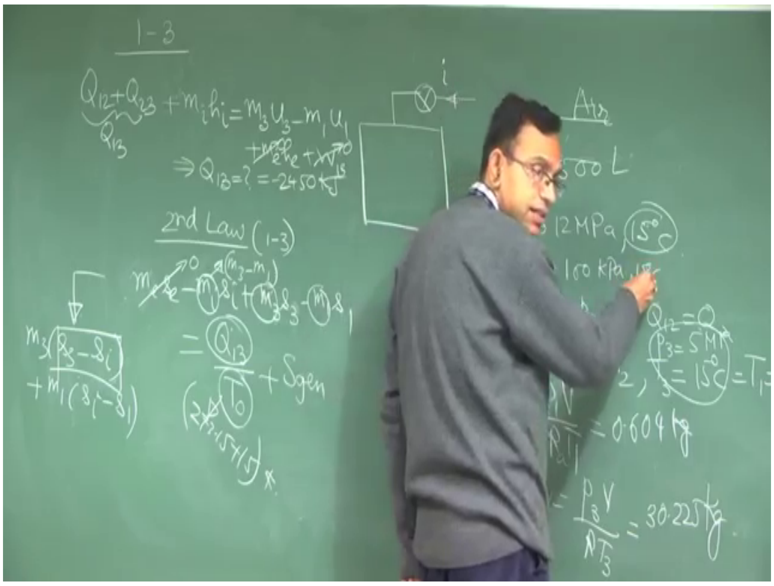


So, now you have to consider the process from 1 to 3. So, Q 12 plus Q 23 is total Q 1 to 3 is equal to this is Q 13 plus m i h i, now it is m 3 u 3 minus m 1 u 1 plus m e h e, this is 0 and the work is also 0.

So, here you know everything except you do not know what is Q 13 you also know what is u 3. How do you know what is u 3? You know p 3 and T 3. So, you know what is u 3. So, from here you know the unknown that you can figure out is what is Q 13. So, Q 13 is minus 2450 kilo joule, ok. So, this is the first law analysis we require to calculate what is the entropy generation.

So, for the second law Q, so, change in entropy; change in entropy is m e s e minus m i s i plus m 2 s 2 minus m 1 s 1, right, this is the total change in entropy is equal to Q 13 by T 0 plus entropy generation, right. So, all these values you can substitute s e is 0. So, this is 2 is this is actually 3 not 2 1 to 3.

Student: (Refer Time: 33:06) minus m e plus m.

This is the change final minus initial. The change in entropy, so, you look at the entropy transport equation this is the final minus initial. So, I have derived it using the Reynolds transport theorem you can verify it. So, you know what are these one and this one. Change in entropy you can calculate by from the air table and this heat transfer is known T 0 is what T 0 is 15 degree centigrade, right; so, 273.15 plus 15 Kelvin ok. The entropy part, see a simple trick you can play is that m i is m 3 minus m 1 then it is split into two parts. So, this is split into m 3 into s 3 minus s i plus m 1 into s i minus s 1, right.

So, now you can use the difference in entropy formula integral C p dT by T minus R ln p final by p initial. Here 3 and i; see this is 15 degree centigrade 3 is also 15 degree centigrade. So, the temperature dependence part of the entropy here is 0 it is only the pressure dependence and i and 1 also the temperature is same. So, it is only the pressure dependence. So, these entropy is at changing only due to pressure not due to temperature substituting the values. So, the entropy change here will be simply minus R ln final pressure by initial pressure. So, this will give you entropy generation is equal to 15.265 kilo joule per Kelvin.

So, let us stop here for the time being. We will continue with more problem solving in the next lecture.

Thank you.