Engineering Thermodynamics

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Lecture 39

Energy of a fixed mass and flowing stream

Welcome back uh so in the last lecture, we were discussing Exergy.

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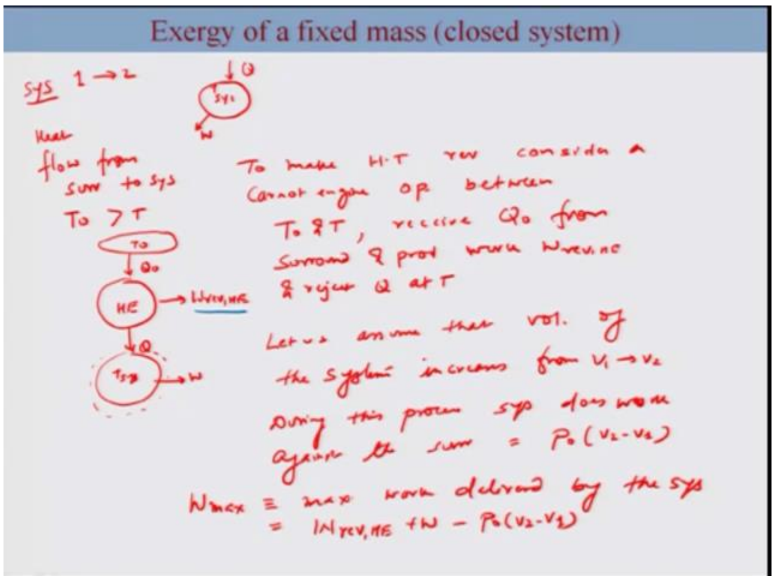

We will continue our discussion, particularly fixed mass or closed system so consider a system where the uh changes from let's say 1 to 2 so this is your system state. Okay so you can consider this system having uh interaction so this system, let's say a T. Okay and having uh heat and work into action and heat flows from surrounding to the system and surrounding temperature is T0 let's say and uh T0 is greater than T. T is your system temperature.

Now considering this is a finite temperature hence it is irreversible so to make heat transfer okay reversible, what we are going to consider Carnot Engine okay which operates between T0 and T and it receives some Q0 from surrounding and produce some work W reversible let's say heat engine okay and it rejects Q at T so in another word, I can represent this system in the following way. Okay, so it considers T0, Q0 and W reversible Q and this is your system.

Okay so the other which we we will be assuming is that the system, this process changes its volume okay so let us now assume that volume of the system increases from V1 to V2 okay so in other word, what we are saying that during this process, system does work against the surrounding okay so this is the work would be corresponding P0 (V2 minus V1) okay.

So now what we can do is we can find out what is the maximum work corresponding to this system of maximum work which can be maximum work delivered by the system so this is going to be your reversible work by the heat engine plus W by the system minus the work against the surrounding. Okay so this is going to be your W max okay. We can find out the W reversible heat engine value by simply doing energy balance.

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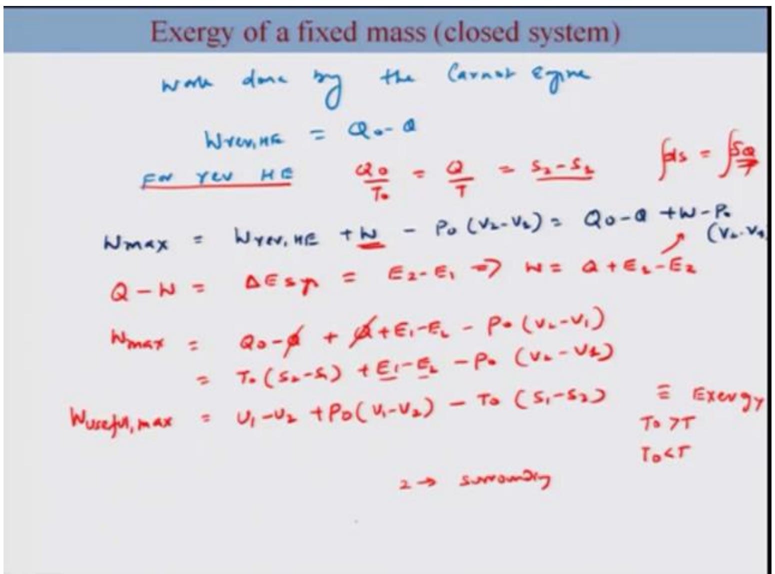

So W reversible work done uh by the Carnot Engine would be W reversible heat engine is Q0 minus Q okay. And we know that for reversible heat engine your Q0 by T0 is nothing but Q by T okay so this is by for the Carnot Engine which we have earlier uh developed and this is nothing but your S2 minus S1 okay so this is based on the fact uh your ds for the reversible case is delta Q by T and then this integral would be this the case of reversible and that's your change your entropy would be simply Q0 by T0 or Q by T.

Now we can simplify their expression of work maximum. Okay this can be written in the following way. Your W reversible heat engine okay. Let me also make a point here that your W, we can also do a energy balance, apply the first law of thermodynamics for the system where we can write uh Q minus W as simply delta ES this is for the case of your closed system so this is heat supplied and this is the work done by the system.

And this we can write as E2 minus E1 so this also means that W is Q plus E1 minus E2. We can express this here and write your W max as simply the following way. Q0 minus Q plus Q plus E1 minus E2 minus P0 (V2 minus V1) okay. Now, this expression which we have written for reversible heat engine can now be made used.

First we can cancel these Qs and Q0 can be written as simply T0 (S2 minus S1) plus E1 minus E2 minus P0 (V2 minus V1) okay and considering the kinetic energy and potential changes as 0, we can write this just uh simply U1 minus U2 so I can rewrite this expression in this form, U1 minus U2 plus P0 (V1 minus V2) minus T0 (S1 minus S2).

So note that what I have done is I have swapped this particular variable and a negative sign is converted to positive okay so we have rewritten it in this way okay. Now, this particular expression is what we are going to write as useful maximum. Okay this is nothing but your Exergy. In this particular case, we have taken your T0 greater than T but this derivation is also true if your are taking your T0 less than T okay so in another word your Exergy is uh for the closed system is greater than or equal to 0 okay.

So now uh you can consider your T0 as as a limiting case as an environment and if that is the case then U2 would become your corresponding surroundings. so for as as I was saying that this uh if you consider your 2 to be your surrounding then we can write the useful maximum for a given state of a system in the following form okay.

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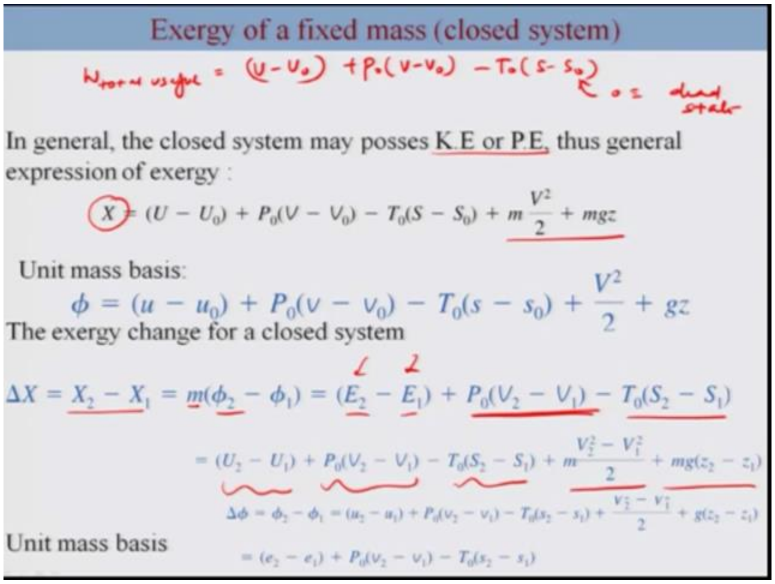

So we can write simply in this following way so we can write your W useful or total useful for a given system as simply U minus U0 plus P0 (V minus V0) minus T0 (S minus S0) okay where 0 here is represent that state okay so what you are doing is you are changing your system condition at a for a given specified system state to corresponding to the I mean taking a system state to the dead state and during this process, whatever the work which has been generated is the maximum possible work okay.

For in the considering is the reversible way you are able to do this operation and this is expression for the total useful work where 0 subscript represent the dead state. In general closed system may opposes the kinetic energy or potential energy so you may have to write this expression or for the general expression of the Exergy okay.

So this instead of saying W2 to useful we are making use of this particular symbol X here for the Exergy of the system. One can rewrite this in terms of unit mass where U becomes small u and the rest of the terms the mass uh cancels out so everything is in the specific unit. The change in a Exergy of a closed system is simply the change in X that is X2 minus X1 and that be written in terms of Phi m times Phi 2 minus Phi1 so naturally it can be written as E2 minus E1.

Now since the kinetic energy is included so we simply say E2 minus E1 plus P2 plus this term, the pressure multiplied by the volume term minus this term okay or you can simplify in terms of

U and of course you have to consider the kinetic energy difference and potential energy difference if you want to expand your E.

Okay and that's your Exergy change for a closed system can be written as simply the change in the internal energy, P0 multiplied with the change in the volume minus T0 multiplied by the change in the entropy and the kinetic energy difference and the potential energy difference or this becomes Exergy change of a closed system. You can rewrite this expression in terms of uh unit mass basis as described in this form. Okay.

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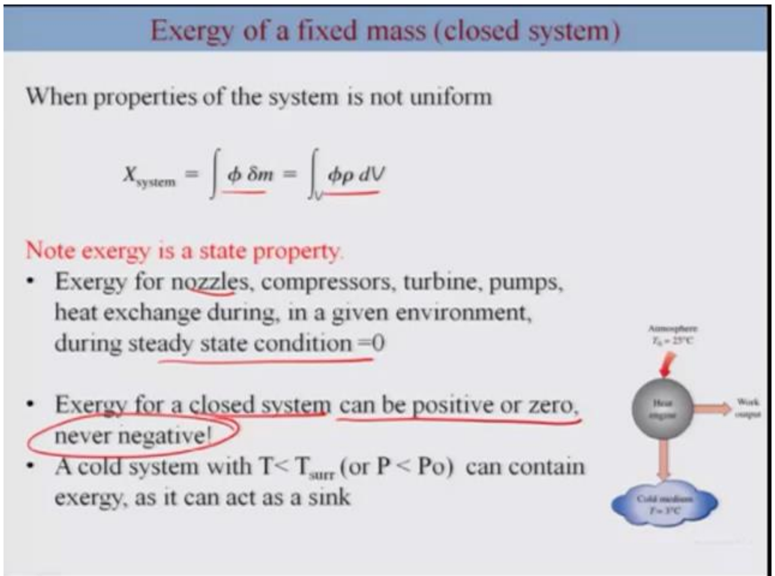

In case of a system is not uniform, one can also calculate exergy as exergy is a state property okay. The reason for that is very clear that other property which is associated with a state property and hence you can simply integrate this over the volume okay and that is what we here as we have shown for the state property cases.

Exergy for nozzles, compressors, turbine pumps, heat exchange during in the given environment during steady stage should be 0 okay because for a steady stage, there is no change in the energy conditions and that means there is no change in the property of the system for the steady stage and hence Exergy for the nozzles, compressors, turbine pumps heat exchanger has to be 0 okay.

As I was saying that for the case of a closed system the Exergy can be positive or 0 but cannot be negative and the expression is true for cold system or hot system which essentially means that uh the T of the system can be greater than uh the surrounding or the uh less than the surrounding okay.

So because you can come up with any specific uh heat engine with 2 and consider the system as uh your sink or the source okay so the expressions are true for irrespective of the different science of the temperature with respect to surrounding so the expression which we have developed was for the case of a closed system. We can extend this expression for exergy (ba) for the case uh flow systems or flow streams so let us consider this now.

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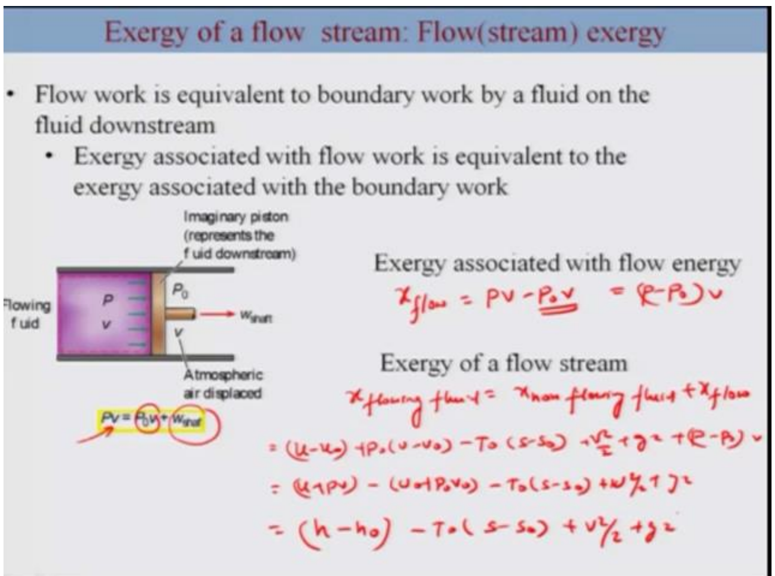

So the flow work here is uh nothing but is equivalent to boundary work by a fluid on a fluid on a fluid downstream so flowing fluid has to do work in order to displace the fluid here and thus your PV is the flow work is nothing but your P0 work plus the W shaft okay and thus you can write that Exergy associated with the flow.

Energy is nothing X flow PV minus P0V and this is the amount which the if you consider imaginary piston, this is the work which it does on the surrounding by displacing the air and thus you have subtract it in order to get the Exergy associated with the flow energy or in another word P minus P0V is the Exergy associated with the flow energy.

So thus you can write your Exergy of flow stream simply as X flowing fluid is nothing but X non flowing fluid plus X flow okay or that means you can write this as U minus U0 plus P (V minus V0) minus T (S minus S0) so we can have the kinetic energy and potential energy terms plus P minus P0 P okay.

You can rearrange these in terms of U plus P minus U0 plus P0V0 minus T0 S minus S0 and these terms can be written as well and this really can be written as now H in terms of enthalpy H minus S0 minus T0 S minus S0 plus your kinetic energy plus potential energy okay.

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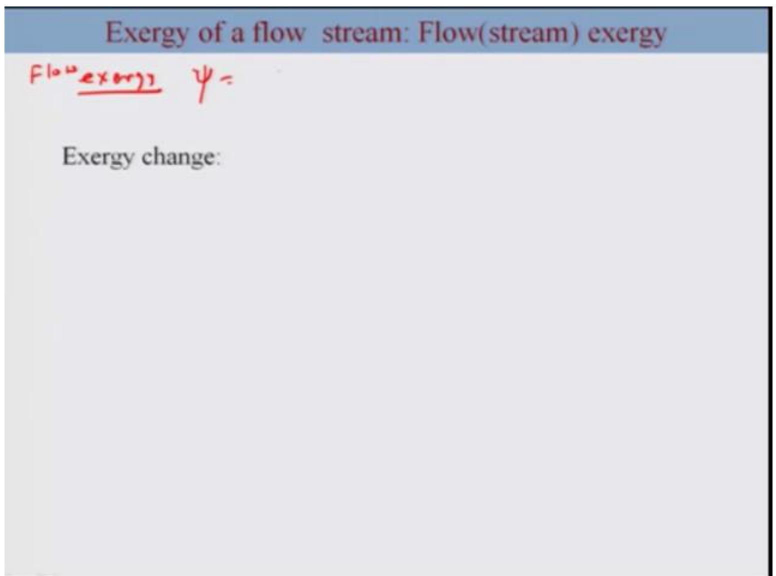

So thus your flow Exergy now note that I am writing flow Exergy not energy here is defined Psi and this is your the term which we defined this.

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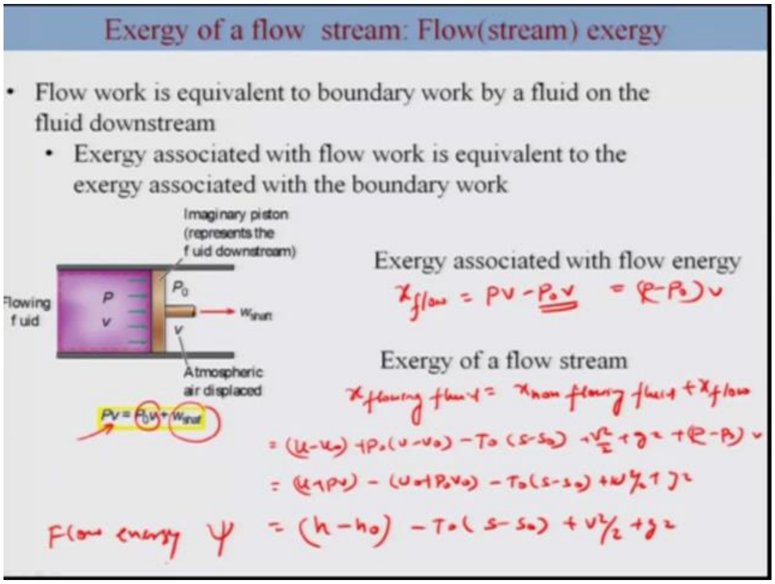

So this is nothing but your Psi okay. This is your flow energy.

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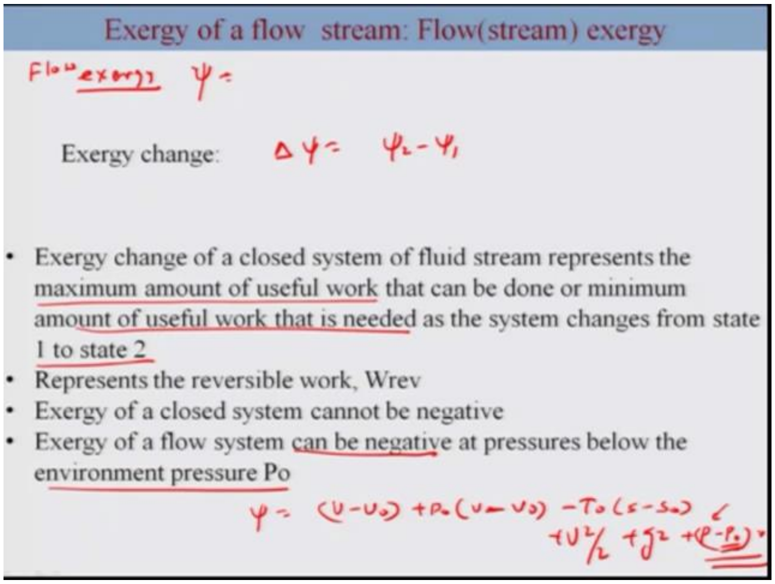

Okay so we can also find out the Exergy change and that will be your delta Psi will be your Psi2 minus Psi1 so Exergy change of a closed system of a fluid represents the maximum amount of useful work that can be done or minimum amount of useful work that is needed as the system changes from state 1 to state 2 okay so thus Exergy represents the reversible work. Exergy of a flow system however can be negative because it depends on your pressure so let's look at your term here.

We mention in this terms of your Psi was your U minus U0 plus P0 (V minus V0) okay minus T0 (S minus S0) plus V square by 2 then you have this uh P minus P0 okay so if this turns out to be quite uh high or in other words if P is quite low than P0 then this would be negative term and hence your Psi for the flow system can be, Psi can be negative. There is a possibility of being negative as well.

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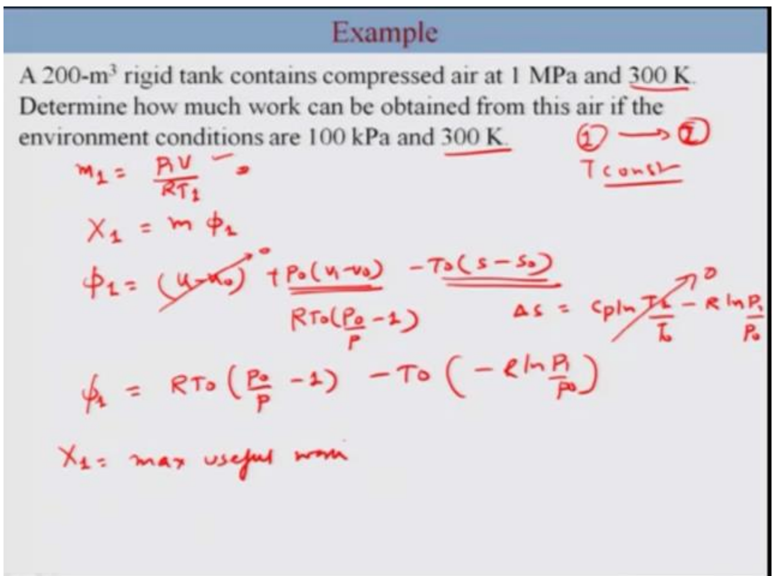

Okay so let me try to do an exercise here (flipping pages) so this is your 200 meter cube rigid tank contains compressed air at 1 megaPascal and 300 Kelvin and what we have to do it to find out the work which can be obtained from this air if the environmental conditions are 100 kilopascal and 300 Kelvin so we need to find out the Exergy okay the maximum work which we can expand. So the first thing we need to do it find out uh the mass. Okay.

So the mass can be calculated from here then we need to find out your it is a closed system so we are going to use X1 and Phi1 and what is your Phi1? So Phi1 is your U (U minus U0) plus P0 (V minus V0) minus T0 (S minus S0). We will consider kinetic energy and potential energy as negligible. Okay. Now, this term, since it is a ideal gas, that's what we are going to assume for the air, this can be written as our T0 P0P minus 1 okay.

What about this? Now we will be using the delta S for the ideal gas so this is going to be CpLn T1 by T0 okay minus R Ln P1 by P0. Okay. Now, note that the temperature is not changing here. That means state 1 to say 2, your T is constant or if the pressure is changing correct so if that is the case, you this is 0 because U is the same as U0 for the idea gas and this would be also 0 okay because T1 is same as T0. Thus this expression can be written as minus T0 minus 1 Ln P1P0. Okay.

So it one can calculate this and this would be so X1 would be your maximum useful work which can be obtained from this compressed air stored in the tank in the specified environment okay so that was the example illustrating the calculation Exergy of a closed system.

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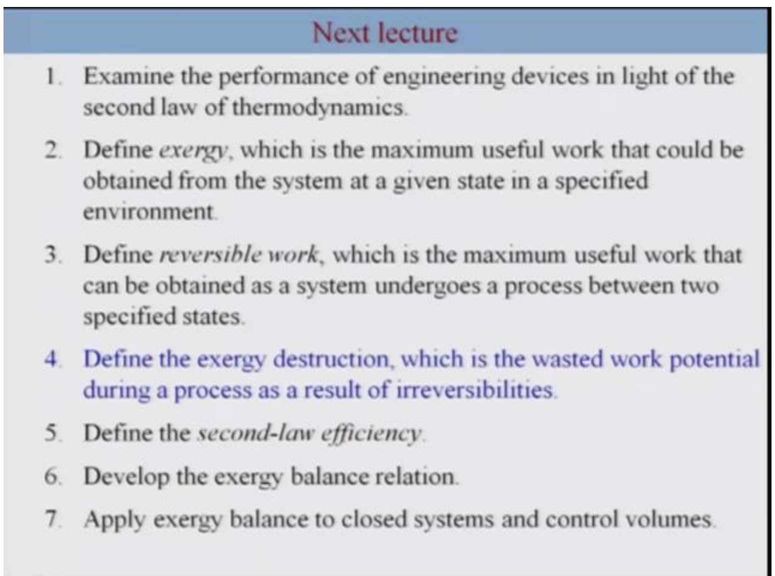

And this is the this would be the end of this lecture. In the next lecture, we will continue this discussion on Exergy. Okay so I will see you in the next lecture.