Engineering Thermodynamics
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Lecture 41
Energy balance and second law efficiency for closed systems and steady flow devices

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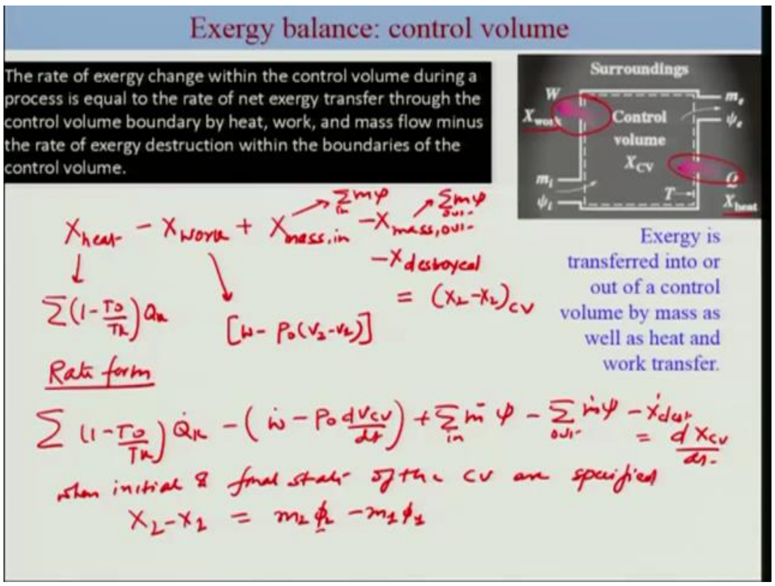

Welcome back. Uh this would be the last part uh of the topic on Exergy. We were discussing the Exergy balance uh for the single for fixed mass (an) closed system. Okay and uh we have done some exercises. We will continue our discussion (an) particularly now for control uh volume. So uh this is our representation of the control volume and what we have done is, we have illustrated this in terms in of sign as well that there is a heat supply and work done on the surrounding and thus the corresponding Exergy would be X heat which will be you net Exergy in and this will be your net Exergy out.

Okay so we can write down the balance so in addition to the uh work and heat Exergies we will have to now include the Exergy due to the mass in and out okay so this would be your net Exergy in and you can minus your net Exergy out. What we are doing is we are trying to keep the same nomenclature as we have used for energies or simple energy balances so this is your heat in work out Exergies and now I am going to write here your mass in minus mass out.

Okay so in other word, this is nothing but your Exergy transfer to the system, this whole term and then I am going to subtract minus X destroyed okay. And this would be your change in the Exergy of the control volume. Okay. Now you can write this in terms of your summation 1 minus T0 TK this will be your X heat and this is going to be your W minus P0 (V2 minus V1) okay and what about X mass in mass out? So this you can write in terms of your summation m Psi okay.

So this would be your in and this would be your out. Okay. So we can write this in terms of rate form also. Okay so this would be your 1 minus T0 Tk Qk dot minus W dot minus P0 dVcv dt plus summation m dot Psi in minus summation m dot Psi out minus X dot destroyed is equal to dXcv by dT so this is the rate form for the Exergy balance of control volume open system. In case your initial and a final state of the control volume is specified that means your X2 minus X1 then you can write uh this in terms of your m2 Phi2 minus m1 Phi1.

Okay so not that this Phi is Exergy of the non flowing system. That is corresponding to your control volume so this is when your initial and final state of the CV is specified, they are specified. So now what we can do is, we can look uh look at uh Exergy balance for the steady flow uh devices or steady flow systems and uh we know that most of the devices which we are interested in such as turbines, a compressor, pump and nozzle operate at steady uh state conditions okay.

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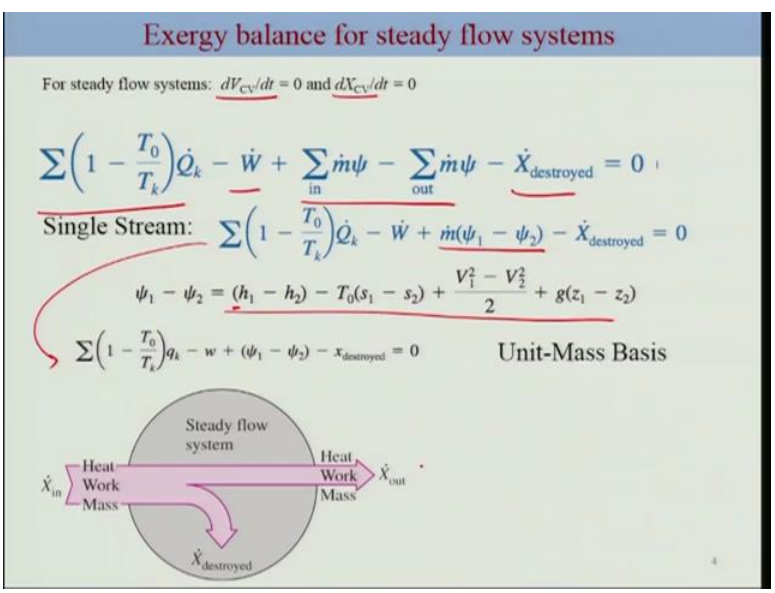

So for such case, what we can do is we can consider the change in the properties to be 0 that means dXcv to 0 and we can write this rate expression in this form okay so this is due to heat, work, mass and then you have to also include the destroyed okay. So let me first look at uh the single stream here so when your if there is only one stream is involved which would be in most of the cases of a turbine, compressors and nozzle or when we consider only a single stream then uh you can write this uh mass term in this form.

Okay and then this expression can be simplified. Now, X1 and X2 uh can be related to your we can write X1 minus X2 in this form which we have derived earlier. That is the definition of a flow Eexergies. Okay. Now, it will a change in (an) uh change in the Exergies of the flowing fluid so for the unit mass expression, the same expression can be written in this form so this is much simpler form now. Okay so this is the uh Exergy balance for the steady flow system and uh now we can make use of now this is a representation in sum form, okay.

So before making use of this expressions to solve the problem so let us first look at a reversible work.

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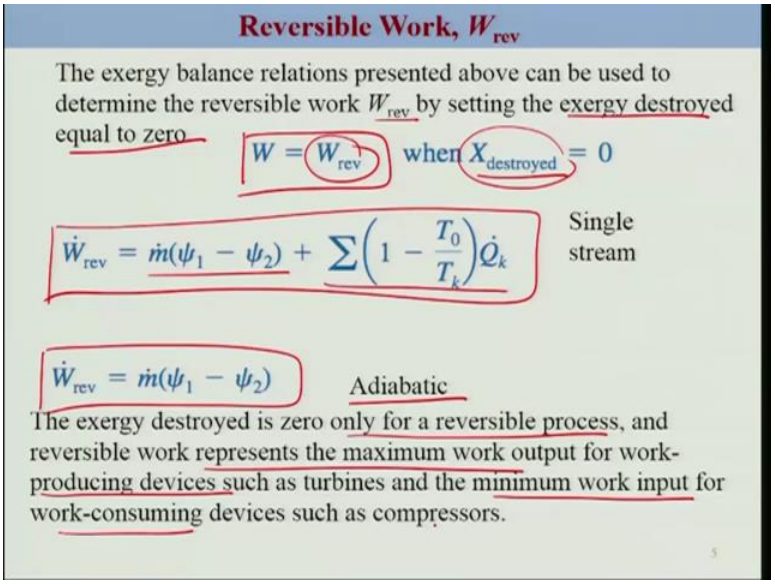

Now Exergy balance relation presented in the previous slide can be used to find out the reversible work by setting the Exergy destroyed equal to 0 so when you say X destroyed equal to 0 then the corresponding work is going to be W reversible so you can plug this information in the previous expression for the Exergy balance, for the control volume.

Then it turned out to be uh that your W reversible is simply equal to the change in the Exergy due to the flowing fluid plus the heat transfer contribution okay or the Exergy contribution due to heat transfer. For the case of adiabatic system, this is going to be simply m dot time your Psi1 minus Psi2.

So what stated here is that for the case of a reversible system, your W is simply W reversible work or in other word, X destroyed is 0 that means X destroyed is 0 for reversible work and this particular work okay represents the maximum work output for work producing device such as turbine and a minimum work input for work consuming device such as compressor. Okay so we have uh emphasized many times in this particular course now these aspects of uh reversible work.

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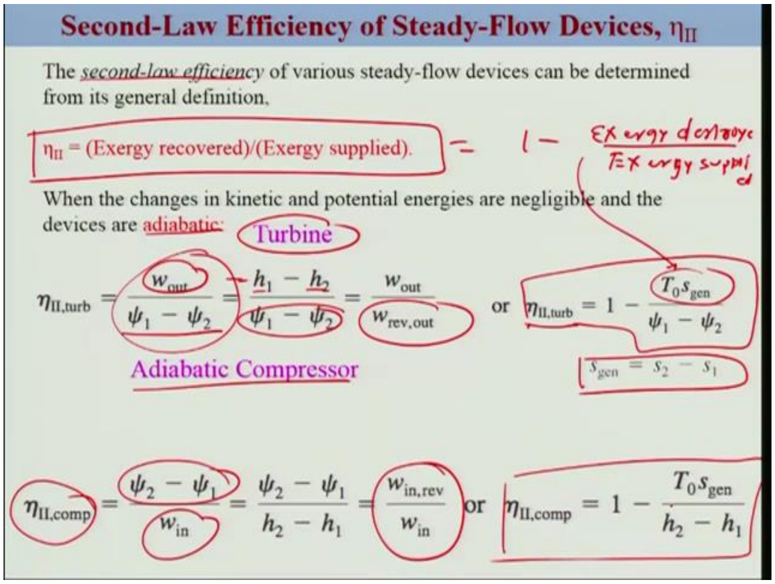

So now let us look at the efficiency or study flow devices, how do we make use of uh Exergy to evaluate the second low of uh efficiency. Now uh so we have already mentioned the second law of efficiency is nothing but your ratio of efficiency with respect to your corresponding reversible uh devices or uh such as devices based on Carnot Cycle and this can be written in terms of Exergy, recovered Exergy and Exergy supplied so this is the definition of uh second law of efficiency.

So what we are doing to do is, we will just take the ratio of Exergy recovered and Exergy supply. Now, let us take an example for the turbine. Okay. If we consider that kinetic energy, potential energy is negligible and the device is adiabatic then what would be the energy recovered for turbine? It is going to be simply the work uh net work out from the turbine and what would be the corresponding Exergy supplied, that would be your simply your Psi1 minus Psi2, the fluid which is being used such as steam in order to for the net work okay.

So the Exergy recovered is W out and Exergy supplied would be simply Psi1 minus Psi2 for the case of adiabatic turbine where we have considered kinetic energy, potential energy are negligible okay and this can be now also written in terms of H1 minus S2, okay, this would be clearly H1 minus S2 for isentropic process which we have already looked at when we discussed the entropy part. This term is nothing but your W reversible out okay so this was exactly the case where we considered the efficiency with respect to Carnot cycles okay or reversible cycle.

So now let us take uh other examples. Okay before I do that let me also touch upon this fact that this uh second law of efficiency based on Exergy can also be re written in terms of uh this term where you can write this in terms of 1 minus T0 X generation which is nothing but X destroyed so this could be simply written as 1 minus Exergy destroyed divided by Exergy supplied okay.

Clearly Exergy recovered is nothing but Exergy supplied minus Exergy destroyed and thus since Exergy destroyed is T0 S generation thus you can write your efficiency in this term okay. So S generation is nothing but your S2 minus S1 for the case of adiabatic system which we have considered. Okay.

Now we can extend this for adiabatic uh compressor, adiabatic compressor, the efficiency would going to be Exergy recovered again divided by Exergy supplied. What is Exergy supplied, it's the work done or work in to the compressor and Exergy recovered is simply the change in the uh flow, energy okay of the fluid which will be your Psi2 minus Psi1 and this also can be written in this form. You can also write the efficiency of the compressor, second law of uh efficiency of the compressor in this form, in the form of generation.

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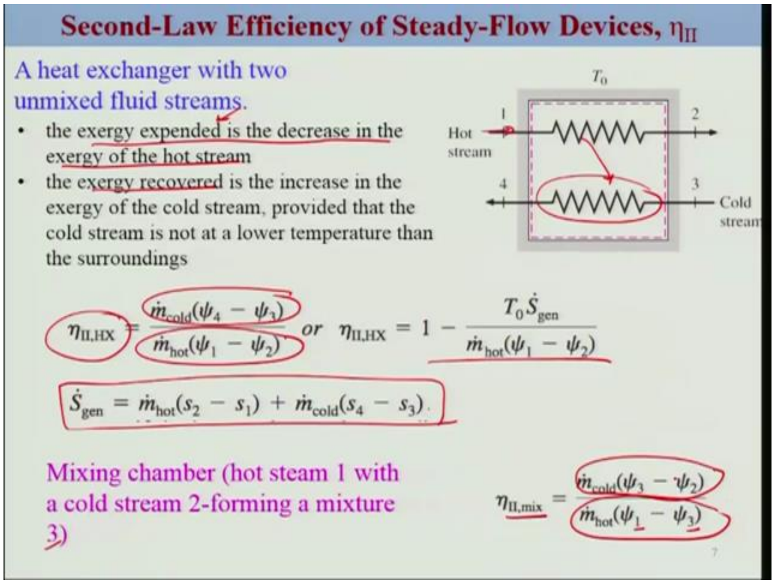

So now, let us look at for the second law of efficiency for uh heat exchanger. Okay. Now, here is a heat exchanger with 2 unmixed fluid stream and uh in order to find out what is the Exergy expanded so what we can consider here is uh the hot stream is 1 and 2 or particularly 1 which uh loses energy to uh 2, uh to uh to cold stream and thus your Exergy expanded is a decrease in energy of the hot stream.

What about the Exergy recovered, this is nothing but Exergy supplied. What about the Exergy recovered, it's the increase in the Exergy of the cold stream so this would be Exergy recovered is going to be the Exergy increase in the cold stream and thus we can find out the ratio of the recovered this is your Exergy recovered and this is your Exergy supplied or expanded and this would be your second law of efficiency of heat exchange.

This you can also write in terms of generation and based on the steady state condition, you can find out the X generation in terms of changes in the entropy of individual streams. For the case of mixing chamber, that means your 1 and 2 gets mixed and forms a mixture of 3, the Exergy supplied is going to be 1 minus 3, that will be Exergy supplied and Exergy recovered would be corresponding to your 3 minus 2 changes in the flow energy flow Exergy of uh 3 minus 2 okay.

So that would be ratio uh for the case of mixing chamber okay and that would be your second law of efficiency so one has to do this analysis very carefully to make sure that you find out uh the Exergy recovered directly and Exergy supplied directly in order to find the second uh law of efficiency of such devices which we are going to say steady flow devices okay.

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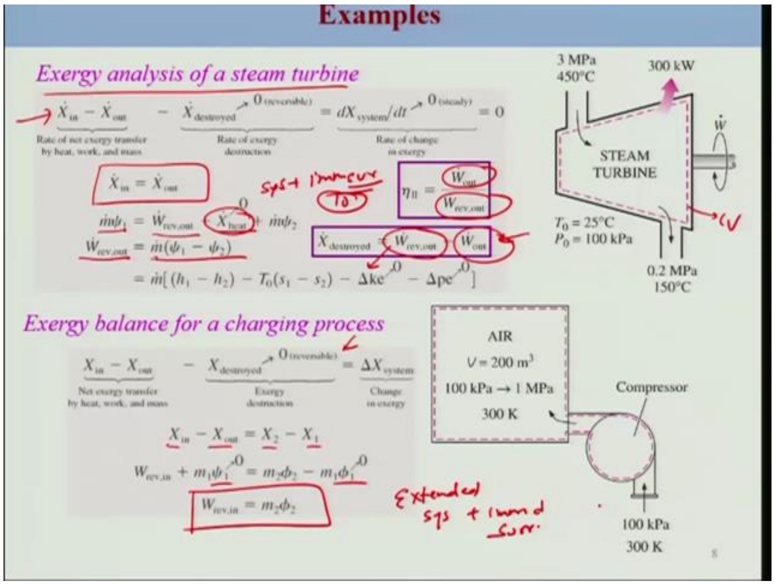

So we can end this lecture with uh this example. The first example is uh Exergy analysis of steam turbine which is we are going to consider steady uh flow device and this is your control volume okay. What we need to find out is the second law of efficiency of such steam turbine and then the second thing which we have to find is basically the Exergy destroyed so you can go, start with the Exergy balance here, what we have to calculate here is the maximum power output or the reversible power which is uh determined from the rate form of Exergy balance okay which is applied to the extended system so we are going to consider steam uh system plus surrounding.

Okay and uh in that case, your X destroyed is going to be 0 considering the reversible and you can write down this expression in this form considering steady state uh device so you have mX1 is equal to W reversible out and plus X heat. Now considering that we have taken system plus immediate surrounding, so here we have considered system plus immediate surrounding, so as a bond of the immediate surround is as environment temperature T0 or considering this extended system, you know X dot heat is doing to be 0 okay and thus your W reversible out is nothing but going to be simply this expression and you can find out the reversible.

Now, this would be the condition for your reversible maximum power work based on this uh

Exergy analysis of extended system where you consider system plus immediate surroundings. The reason for immediate surrounding you have considered because that would be the yield the maximum uh work for such a system and then we can find out the effective uh X destroyed based on the total X destroyed would be simply this where this would be the actually out and this would be your reversible out okay which we have calculated from here. So this would be the destroyed Exergy and of course you can calculate the second law of efficiency by taking the ratio of W out divided by reversible out okay.

So we can extend this uh exercise for Exergy balance of a charging system so here again so have this particular tank containing air and which you are using compressor to feel the air and so it the charging process. You can consider this external system here as well so out interest is to find out the uh minimum work required for the process okay. Now, in order to find the minimum work, what we have done is, we have also considered here this uh reversible process so X destroyed is going to be 0 and X in minus X out is basically X2 minus X1.

Your X1 and Phi is 0 because initially air in the tank and the air entering are at the same state of environment and hence your Psi1 and Phi1 is equal to is basically 0 okay so this is going to be your minimum w ork required for a process which is reversible, okay. Note that I have not included any heat transfer because what we have done is we have considered also here extended system plus your immediate surrounding such that your boundary of the immediate surrounding is at the environment temperature T0 and thus your Exergy transfer is uh due to heat is 0.

Okay and by considering that we have got in this case the minimum reversible work for this particular process okay. So this is the exercise which we are going to perform, making use of Exergy in order to find uh the maximum or minimum work and uh of course, making use of other uh assumptions if it is a air, we are going to make use of ideal gas and thus we can calculate uh your minimum or maximum work and doing so, we can also evaluate uh second law of efficiency based on Exergy information.

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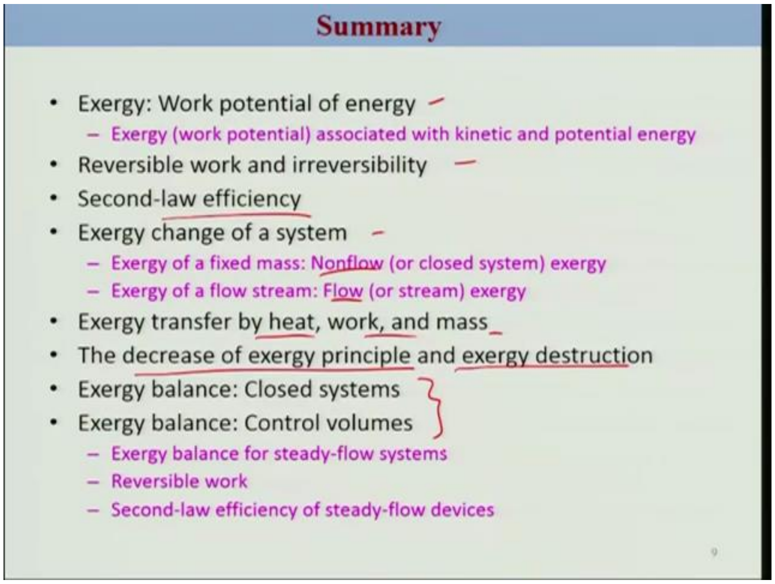

Okay so this would be the end of the particular topic so let me just summarize which what we have gone through in this particular topic on uh Exergy. We defined Exergy which is nothing but availability, available energy or useful work or work potential of energy. Okay and we also looked at reversible work, irreversibility, second law efficiency we talked about, we made use of uh Exergy in this. Okay.

We defined Exergy change of a system for non flow and flow system, Exergy transfer occurred by heat work and mass and then we we defined that decrease of Exergy principle is also equivalent of uh your second law of thermodynamics.

And we also define the Exergy destruction which is your related to entropy generation and then we looked into the balances for the closed and control volume followed by few uh very short examples illustrating how to solve such problems okay so that will be the end of this topic uh so hopeful uh uh this clarifies uh the making use of second law in more clear terms called Exergy and we will start a new topic.