Engineering Thermodynamics
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Lecture 40
Energy transfer due to heat, mass and work, exergy destruction

Welcome back so we were discussing last lecture about Exergy which is nothing but availability or available energy or useful work potential okay.

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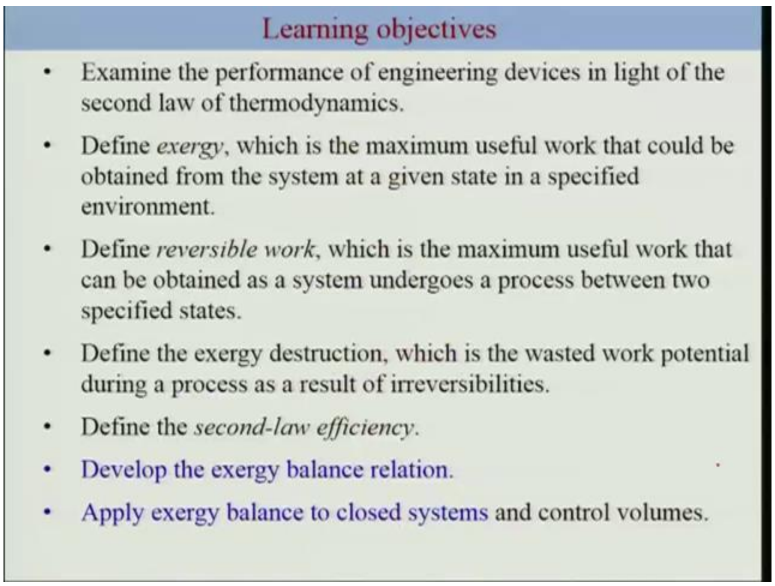

So in this particular lecture, we will be looking at specifically Exergy of a fixed mass of a closed system. Exergy like energy can be transferred to form a system in 3 different forms, that is heat, work and mass flow okay. Now let us first look at Exergy by heat transfer. Now, heat as we know is a form a disorganized energy and not all amount of heat can be transferred to a work okay.

Now if you consider or make use of a reversible heat engine then the maximum amount of a heat can be transferred to a useful work is simply efficiency of a reversible heat engine that Carnot Engine multiplied by your the heat supplied to the system. So that is something which would be the maximum useful work potential or in other words that would be your Exergy due to the heat transfer so that is what we are going to write here.

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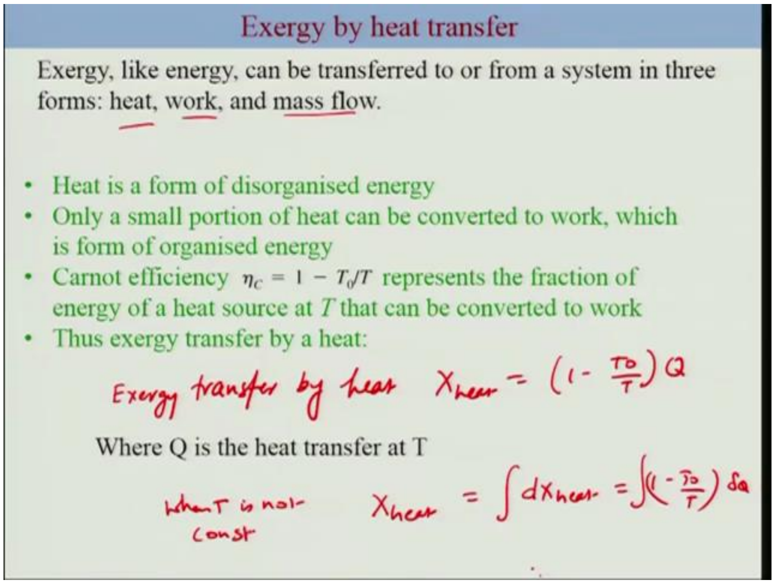

So the Exergy transfer by heat would be your X heat and that is going to be your Carnot efficiency multiplied by Q okay where Q is the heat transfer T and T0 is nothing but your surrounding or environment temperature okay. Now when T is not constant, that means when T is not contract, what we can do is we can consider X heat is simply your integral of dX heat or in other we can write 1 minus T0 by T so that is going to be when T is not constant.

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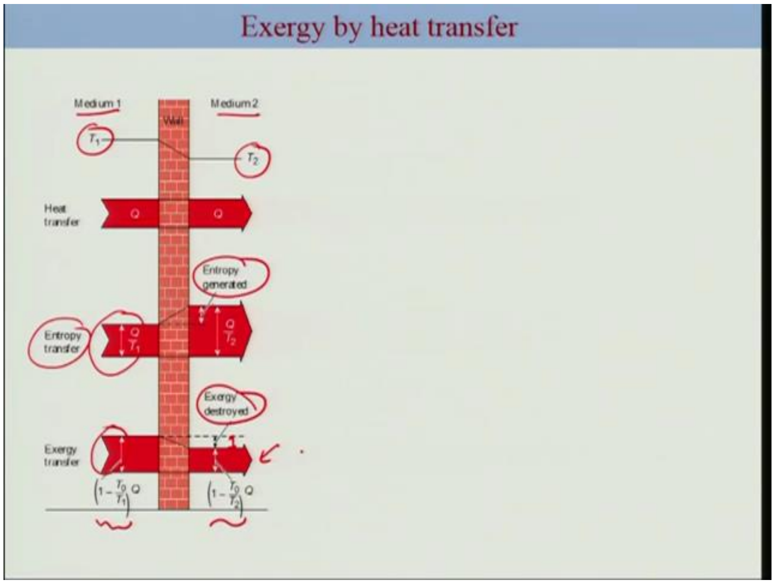

Okay so let us look at Exergy by heat transfer across this rigid wall so you have medium 1, medium 2, temperature is T1, higher than that of T2 of medium 2 so heat transfer is given by Q which is going to be of course constant across this wall. Now corresponding entropy is transfer is simply your Q by T for a medium 1 and for the case of medium 2, this is going to get increased because T2 is less so the difference her corresponding to that for medium 1 and medium 2 would be your entropy generator.

Now based on the previous definition, your Exergy transfer can be written in this form, 1 minus T0 by T1Q and that is going to be more okay. Note that T1 is more that means your efficiency this term is going to be more compared to this term where T2 is less okay so thus your Exergy is reduced here or in other word, when you compare this medium 1 and medium 2 Exergy, there is a certain amount of Exergy that gets destroyed, okay.

That means there is a less amount of useful work after the process okay corresponds to the energy or remaining in the medium 2 so thus that was the case of Exergy transfer by heat.

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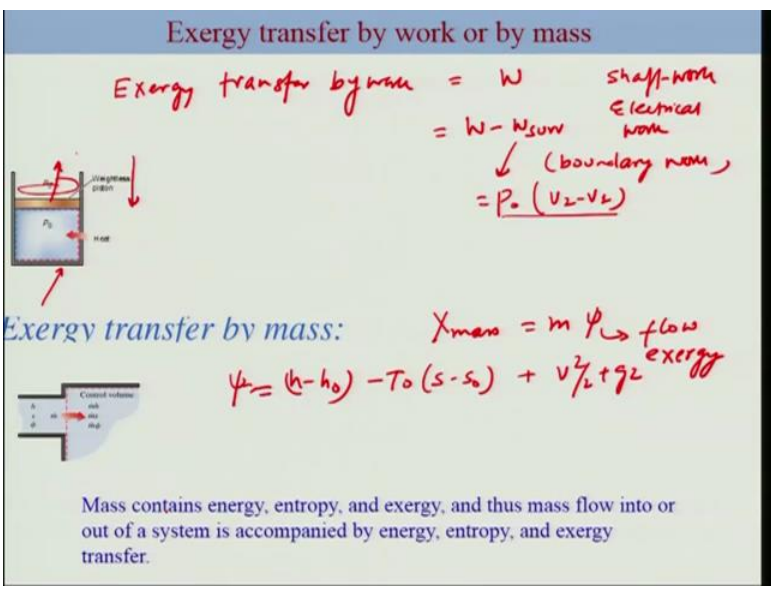

Now, we will look at Exergy transfer by work. Now, by taking an example of piston cylinder device so Exergy transfer okay by work okay would be simply work in case there is no boundary work involved so this would be for the case of your shaft work for example okay or for that matter electrical work however if there is any involvement of boundary (the) such as what we have seen here for the piston cylinder device.

When this particular device does a work during the expansion process, the work is done to push the air okay as it moves up and thus it this particular work which does against the surrounding cannot be transferred and thus this particular or the total work which is useful would be your W minus W surrounding so this is for the case of a boundary work.

Well, W surrounding is nothing but P0 (V2 minus V1) okay but it should be noted that W surrounding which we have written for the expansion, this would mean that there will be less amount of useful work for the compression process we need less amount of useful work from an external source.

In another word, during a compression process, part of the work is done by that atmospheric air and thus we need to supply less useful work from an external source so W surrounding may be mean loss or gain as well okay. Next we will consider Exergy transfer by mass, it's going to be simply your X mass is M, this is nothing but Psi which is nothing but flow Exergy okay and Psi is your H minus S0 as we have already derived earlier or defined in a previous lecture so this will be your enthalpy change minus T0 change in the entropy plus the kinetic energy term and potential energy term so that is for the unit mass case.

Okay so in another word what we are saying that the mass contains energy, entropy and of course now we are saying that the mass also contains the Exergy and thus mass flows into and out of the system is accompanied by the changes in these particular properties. Okay.

Now, as we have already discussed this fact that during an isolated system or during an isolated process, your entropy keeps increasing, in another word, the entropy is being generated and thus or we have defined that you X generation is greater than or equal to 0 okay so that we talked about earlier is that is the principle of increasing entropy.

You can make use of this similar analysis and come up with a decreasing Exergy principle which is a alternate statement of the second law so we can talk about second law in terms of entropy gain or we can talk about second law in terms of Exergy decreasing the Exergy principle okay.

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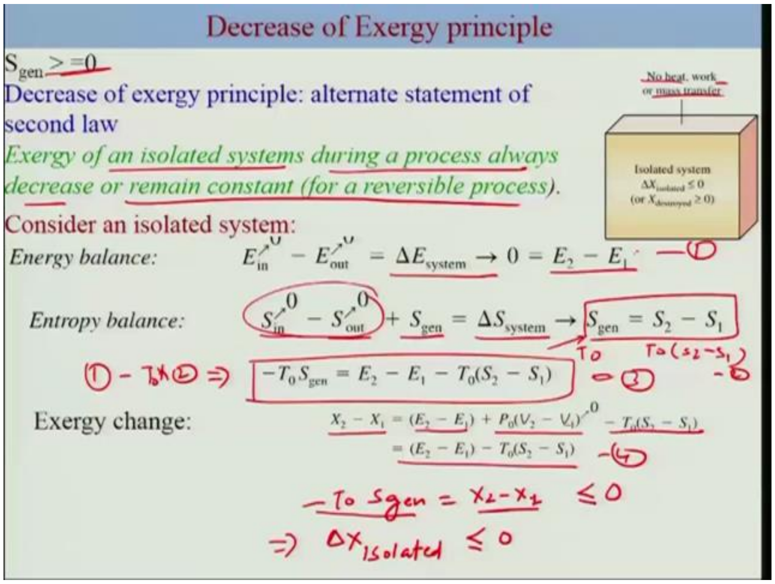

So in another word, what we are saying is Exergy of an isolated system during a process always decrease or remain constant for a reversible process. So we can try to derive this so we consider a isolated system okay for which the energy balance would be simply delta E system is 0 because there is no in there is no out okay because there is no heat, work or mass transfer and thus E2 is equal to E1.

You can also do this analysis for your entropy balance so entropy balance would be your again S in minus S out plus S generation is delta S system, this is going to be 0 again because of the fact there is no interaction with the surrounding okay and thus your S generation will be simply S2 minus S1 okay.

Now you can multiply this term by T0 okay and what it do is you can multiply this and then you can subtract this from this particular equation and this will yield this equation okay so if this is 1 and this is 2 then 1 minus T0 into 2 is going to give you this okay. Now we know based on the definition of our Exergy, the Exergy change is going to be simply E2 minus E1 plus P0 (V2 minus V0).

Now considering this is isolated system okay which essentially means that your V2 and V minus V1 is going to be 0 and then we have this term minus T0 delta S. Now after eliminating this term, what you get is this so if you compare this equation 3 with 4, what you get. You get minus

T0 S generation is nothing X2 minus X1 okay and we know that X generation is greater than and equal to 0 which means this is nothing but less than and equal to 0 so in other word, delta X which is this for isolated system is going to be less than equal to 0.

This is the derivation which tells you that entropy increased principle for an isolated system as which is equivalent to second law of thermodynamics statement, this also can be written in terms of decrease in (I) Exergy for an isolated system as shown here.

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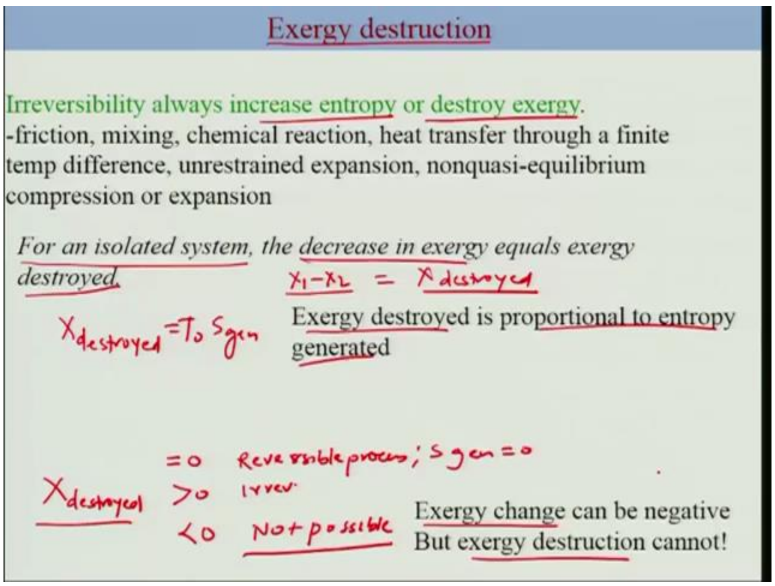

Okay so now we can touch upon the irreversibility aspect and in particular look at Exergy destruction okay so irreversibility as we have already have discussed earlier that always increase the entropy. Equivalent statement is irreversibility always destroy Exergy.

Okay so this is coming from the fact that X generation is greater than 0 and in other word you delta S is less than 0 so now the fact is, the irreversibility is because of various difference aspects which we already know now.

It's because of the friction, mixing, chemical reaction, heat transfer through a finite difference, unrestrained expansion okay and nonquisi equilibrium compression and expansion so the statement irreversibility always destroy Exergy is now clear for simply in isolated system.

In other word, decreasing Exergy is your X1 minus X2 okay. So this will be the decrease in

Exergy. This would be your nothing but X destroyed okay or we are saying that X destroyed is nothing but is equal to T0 multiplied by S generation okay so it's very clear that your amount of Exergy which is destroyed is directly related to your entropy being generated okay so Exergy destroyed is proportional to the entropy generated.

Okay, now X destroyed okay this would be your 0 for your reversible process because your S generation is 0 okay is going to be greater than 0, for irreversible process, okay because that generation is of course greater than 0. Can it be negative? No, it cannot be negative so this would be your impossible or not possible process okay. Now this is very clear that your Exergy destruction cannot be negative though Exergy change can be negative as we have already discussed.

So now we can extend this understanding and we can apply this Exergy balance for the complete system just as we did such kind of exercises, such kind of balances for energy, entropy and now we are going to extend this this concept to Exergy so what will be the Exergy balance so this will include the transfer due to the heat, mass and work okay and then this will also include any Exergy which is being destroyed in the process and that would finally yield the change in the Exergy of the system.

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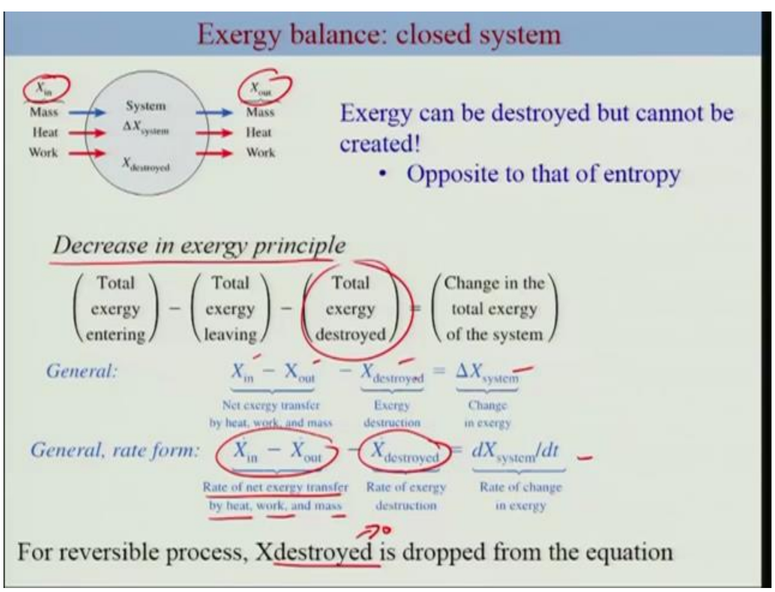

So this is the schematic representation of the system. So we have Xin Xout due to mass, heat, work and the concept which we have just developed based on this Exergy principle or the decrease in Exergy principle can be now written more formally that total Exergy entering minus total Exergy leaving minus any destroyed Exergy should be equal to the change in a total Exergy or the system or in other word, we can write this in a general expression in terms of Xin Xout (mi) minus Xdestroyed equal to delta X system or this would be a rate from okay.

So this this would be the rate of net Exergy transfer, the heat, work and mass minus X-destroyed, the rate of Exergy destruction that will be your change in the or the rate of change in Exergy of the system okay. Now, it should be obvious that for reversible process as we discuss destroyed is 0 okay and hence it should be dropped from the equation.

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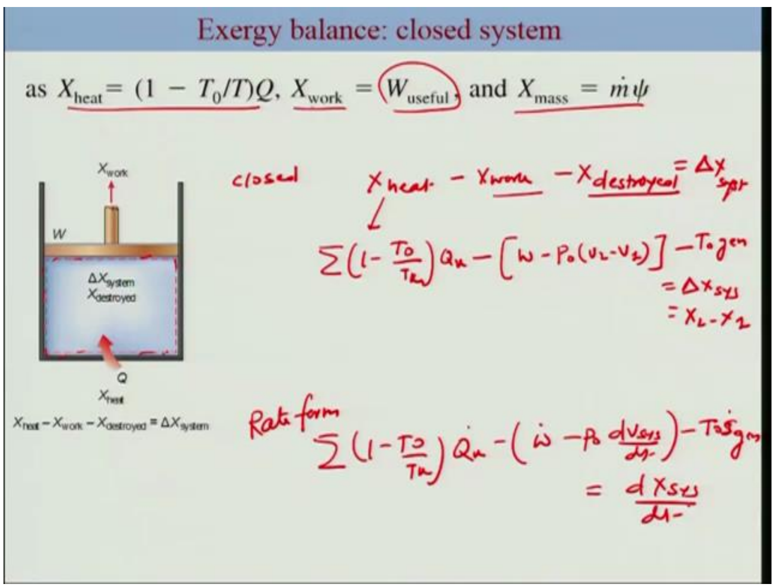

Now, (ex) Exergy of the heat is now very clear that we write in this form. Exergy of work would be useful. Now this would be your W for shaft and electrical work otherwise this will be your W minus W boundary. For the boundary work (I) or where the system involves boundary work and this X mass is simply mass (temp) your Exergy of the flowing fluid okay.

Now, what we can do is we can do this analysis for your Exergy balance for the closed system so we have considered closed system here which means the mass contribution is not there so for a closed system okay your X heat minus X work would be your total contribution or net Exergy transfer to the system minus your X destroyed okay.

So that would be your change in the Exergy of the system. Okay so we can further expand this and bring (the) you can write Exergy in terms of T0 by TK okay just the way we have done for entropy balances where basically k means different element of the boundary where the heat is being transferred okay and this would be simply your work minus if there is any possible boundary work involved so that will be your X of work minus X destroyed is nothing but T0 generation, this would be your delta.

X system which is X2 minus X1 okay. You can write this in terms of rate form. For the rate form, you have the same expression except that you have to write dot and W become the rate and P0 dV system by dT. That will be the rate of change of the volume T0 as generation dot okay that will be your dX system by dT so that would be your expression for the rate form okay.

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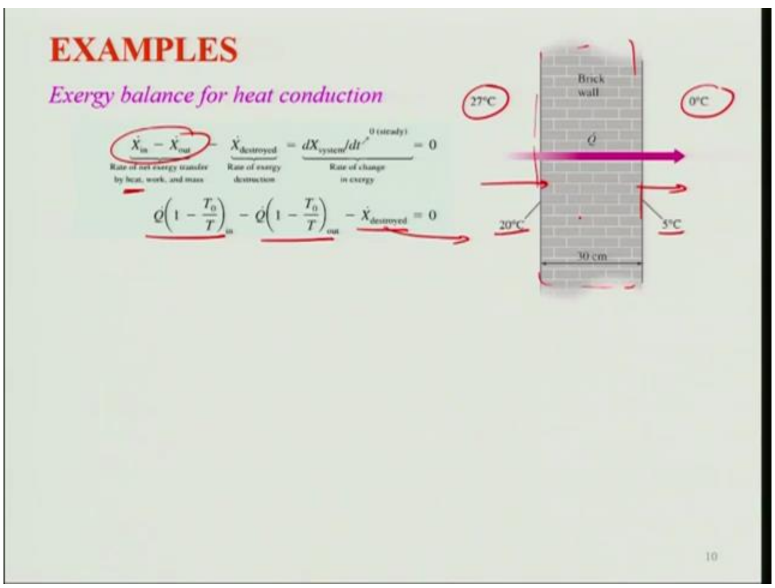

We can do certain examples, now in order to demonstrate this exercise for the Exergy balance so this is Exergy balance for heat conduction, the atmosphere on the left on the brick is 27, this could be your room and this is your outside temperature which is 0 degree. At the wall, it is 20 degree celsius and this is at 5.

Okay so one of the question could be is to find out your X destroyed for the system which could be your wall okay if you can consider this wall as a system. Okay. In that case, you can write this expression in this form where you have heat transfer in and out so that means contribution of

Exergy in and out is due to the heat only that is written in this form and then you have this X destroyed. This for the steady state condition, this would be 0 and hence X destroyed can be directly calculated. So this will be your Exergy destroyed within the system. Okay.

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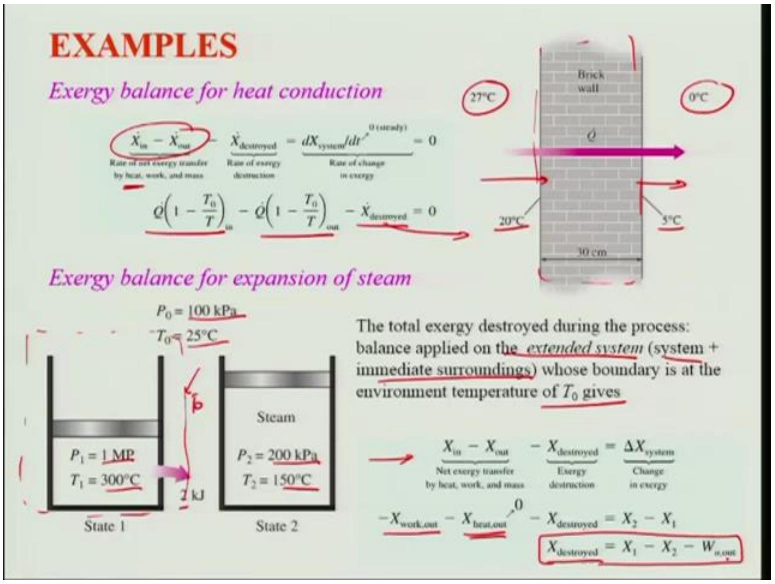

Now, you can take another exercise which would be your (stea) expansion of steam okay so here you have a piston cylinder device which has initial state is given and the final state is given and what is being asked is to find out the total Exergy destroyed. Now, the total Exergy destroyed would also include the immediate surrounding because your outside temperature is P0 is 100 kilopascal and 25 degree Celsius so if you include surrounding such that your temperature difference is at the boundary of this immediate plus surrounding, this would become your T0.

In that case, your if you apply this Exergy balance then this particular term is going to be 0 okay so please note here that X in is going to be 0 because there is no contribution as far as the transfer in is concerned. The out is your X work out it was working against, so this would be your out work on the surrounding, so this would be your work out minus X heat out which is going to be 0.

If you consider extended system okay where the boundary is at the environment. Okay and thus your X destroyed can be written in this form okay. WU out useful out X1 minus X2 minus W useful out. Okay.

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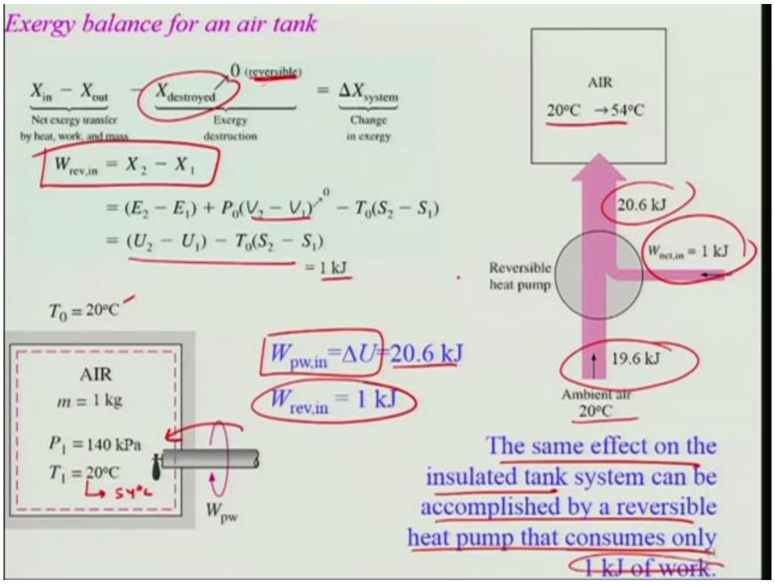

Now we can take another example which is Exergy balance of an air tank. Okay and this problem is following. So you have insulate tank with air and there is a shaft which is applied and the outside temperature is 20 degree Celsius so what has been done is it has been asked to do certain work in order to raise the temperature to 54 degree Celsius so what we can do is or it's been asked to find out what is the corresponding reversible work for this process.

So what we do is, for the case of a reversible, we know that Exergy destroyed is going to be 0 so you apply your Exergy balance and this is going to be 0 for the reversible case. So thus considering insulated the only thing which is being is your W reversible in and thus your X in that is W reversible in is going to be simply is the change in the Exergy so which can be written in this form. Considering it is a the change in the volume is 0 so you can calculate this. It turns out to be 1 kilojoules for the case of air considering at this.

Okay so this is the reversible work which is required but if you apply your energy balance because your energy balance would yield the other work motor or this work, paddle wheel work is simply equal to change in internal energy and that is going to be 20.6 kilojoules okay so W reversible work is something which is coming out to be 1 kilojoule.

So this can be realized by considering that this whole operation can be represented in this form where the reversible pump is making use of the ambient condition at 20 degree Celsius which has 19.6 kilojoules and it does a work of 1 kilojoules and thus your final energy change is 20:6 kilojoules which is supplied to the air which changed temperature from 20 degree Celsius to 54 degree Celsius.

Okay so that means the same effect on the insulated tank can be accomplished by a reversible heat that consume only 1 kilojoules of work okay so that was that is something the analysis of this based on Exergy.

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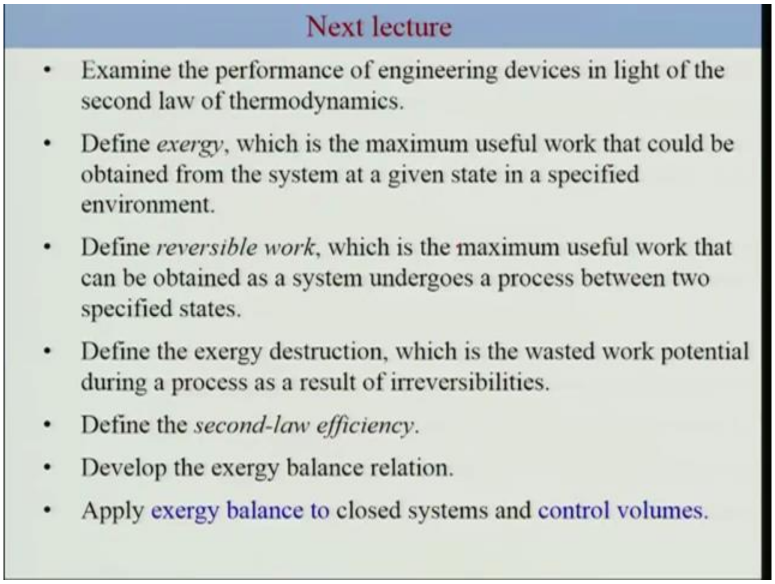

So this would be the end of this particular lecture. In the next lecture we will be taking this exercise to Exergy balances for control volumes followed for few examples so see you in the next lecture.