Engineering Thermodynamics

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Lecture 38

Energy and second law efficiency

Welcome back. We are going to start new topic and it's on Exergy and we will examine the performance of engineering devices.

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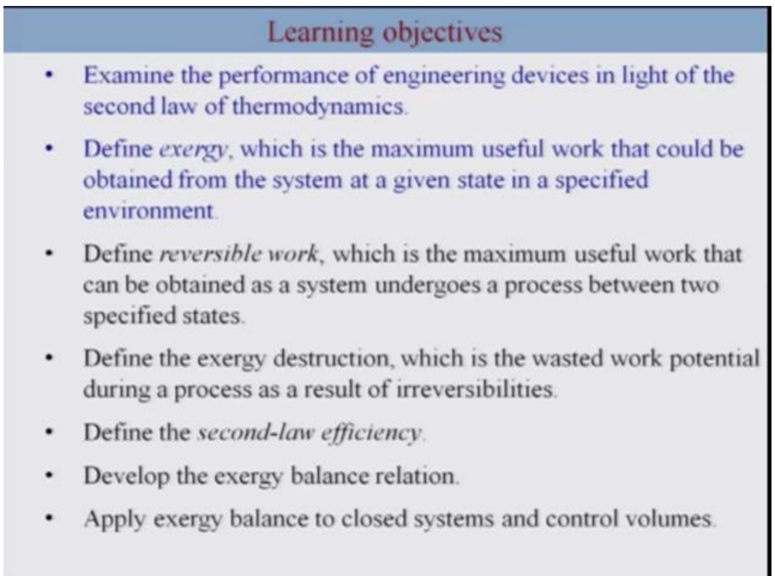

Now, as we have already discussed this fact that first law of thermodynamics is concerned with the quantity of the energy. On the other hand, the second law of thermodynamics is (many) deals with the degradation of the energy during the process or particularly concerned with the irreversibility or lost opportunity to work.

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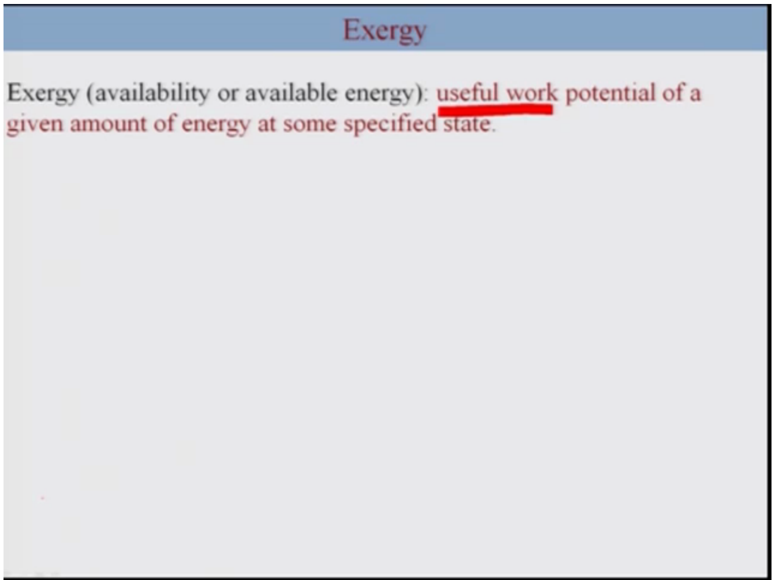

So in another word, if we describe a system and ask a question that what is the maximum of the work which we can extract out of the system then we need to do certain analysis and in order to do that, we will define a term called Exergy. So our practical interest would be to find out the maximum (ene) work which we can extract from a given system having certain specific state.

Okay as we know that heat cannot be completely converted to work hence there is a certain limitation and thus we would be able to analyze this limitation with the help of second law in particular with the help of Exergy or Exergy balance, so what is Exergy? Exergy is nothing but the availability or availability of energy is nothing but useful work potential of a given amount of energy at a given... at certain specified state.

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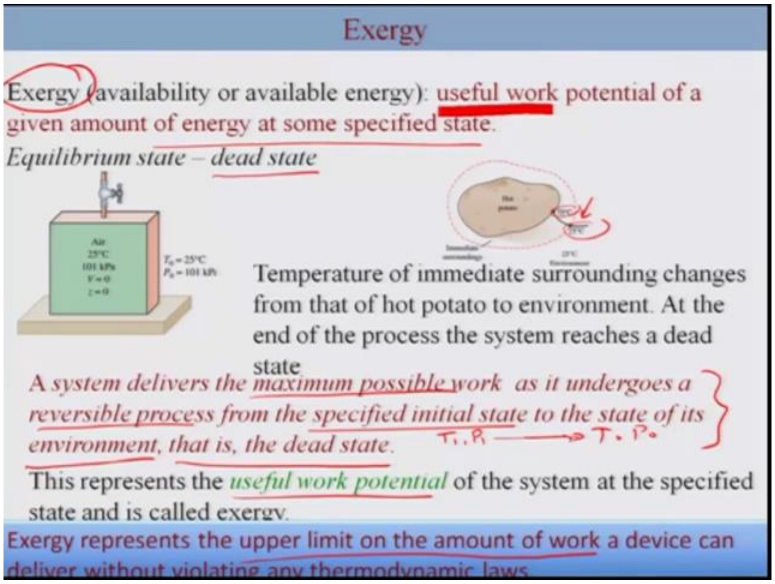

Okay so let us consider a system here. A system is nothing but a hot potato and let's say at the boundary of the potato, you have 70 degree Celsius temperature and immediate surroundings. There will be a drop in the temperature until it reaches the temperature corresponding to that of its environment so at this condition, the system reaches an equilibrium with the environment and this particular state would be called a dead state.

So essentially or the gradient of temperature is 0 and in particular it reaches an equilibrium so thus for a equilibrium state or if a system is at equilibrium with the surrounding, this would be defined as a dead state and later you would realize that this dead state is indicative of the fact that this particular system has no specific value in terms of work it can generate.

We have already discussed this this aspect earlier that the system delivers the maximum possible work as it undergoes the reversible process from the specified initial state to the state of environment and that's what we are going to reflect now is that earlier we had just discussed about the reversible process, we will deliver the maximum possible work.

But now we are bringing this fact that the system undergoes transformation from the initial state to the state of its surrounding that is the dead state so that changed from certain temperature pressure to T0 P0 essentially is the maximum possible or this path would lead to the maximum possible work and that is a system can deliver that okay.

So this particular would be a useful work potential during this process and this we would be calling as Exergy. Okay so the Exergy in another work represents the upper on the amount of the work, a device can deliver without violating any thermodynamic law.

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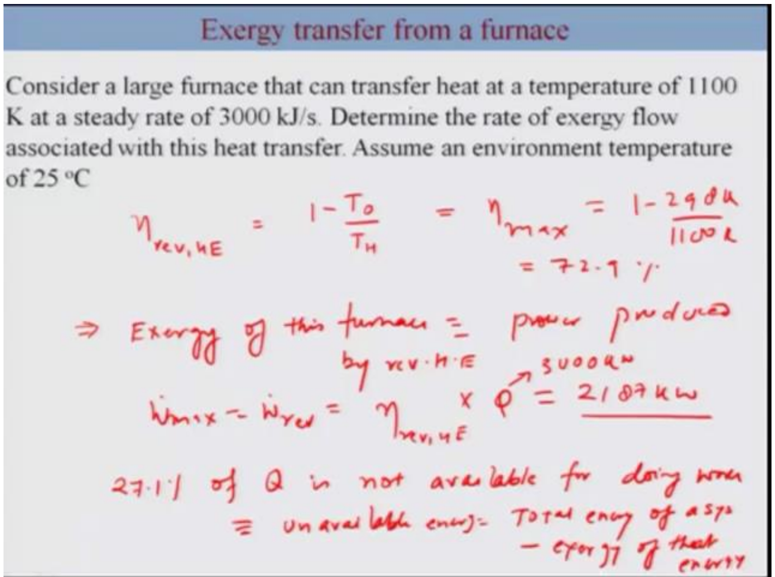

Okay so we will discuss this aspect more in detail. So let us first look at the specific example to understand the maximum possible work for a given system. So this is about furnace which transfers heat a temperature of 1100 kelvin at a steady rate of 3000 kilo Joules per second or kilowatt and what we need to find out is the rate of Exergy flow associated with this heat transfer.

In other words, what is the maximum useful work which we can extract from this furnace. We have assumed this environment temperature to be 25 degree C1elsius so we already talked about the fact that your maximum possible work is for the reversible process in another word, we will considering this furnace as a heat reservoir that supplies heat indefinitely at a constant temperature and the temperature is 1100 Kelvin okay. So we can model this particular system as a reversible heat engine and as a question what is its efficiency?

So this can be written as 1 minus T0 by TH okay and this is going to be your maximum thermal efficiency. So you can put down the values here to 298 Kelvin divided by 1100 Kelvin and this turn out to be 72.9% okay. That means this particular reversible heat engine can convert 72.9%

of heat in from this furnace to a work.

Okay, which essentially means that Exergy of this furnace is nothing but is equivalent to the power produced by this particular by this particular reversible heat engine okay or Wxmax is W dot reversible which is going to be this efficiency of this reversible heat engine multiplied by Q and this Q is already given to us as 3000 kilo joules per second. This turns out to be 2187 kilo watt. Okay.

Okay so this particular maximum work is basically the amount of work that a reversible heat engine operating between the furnace and the environment can produce okay. So in another word, the remaining 27.1% of Q is actually not available for doing any work so this would become unavailable energy which is nothing but total energy of the system okay of the system.

Let's say in this case furnace or whatever the energy being supplied here minus of system they specified it minus the Exergy of that energy okay which essentially means that the amount of energy available is not 100% and certain, for example in this case out of 3000 kilo joules per second only 72.9% is available for doing work okay and rest of them are unavailable and that's what this analysis demonstrates that exercise and this is based on the reversible heat engine efficiency which we have used okay assuming the furnace becomes the source or furnace was used as a reservoir to supply the heat to the reversible heat engine okay.

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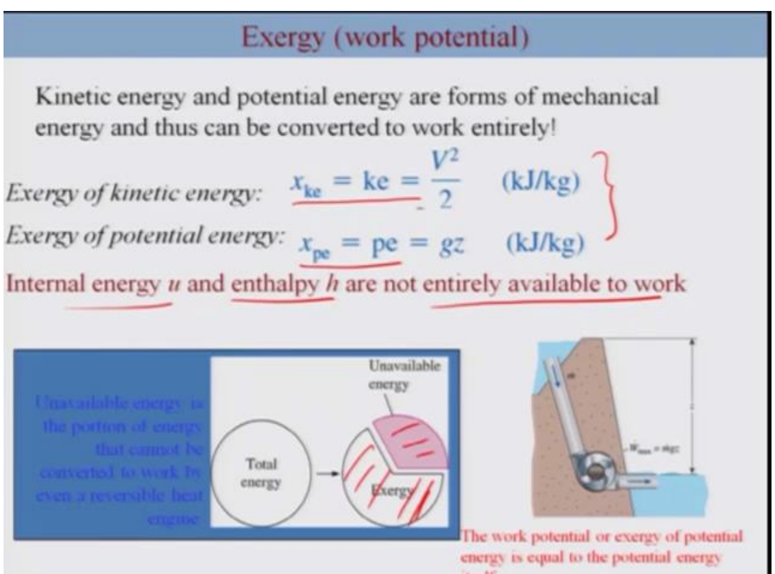

So let's continue and ask the question that what about the Exergy of let's say kinetic energy or potential energy which are the forms of mechanical energy and as we know from our past exercises that the kinetic energy and potential energy can be converted to work entirely and thus Exergy of kinetic energy is simply the kinetic energy okay and Exergy of the potential energy is simply the potential energy. Okay.

So however this is not true if we consider internal energy and enthalpy okay which are microscopic molecular level microscopic energies okay and they are not entirely available to work okay so internal energy and enthalpy are not entirely available to work. On the other hand, mechanical energy such as your kinetic energy or potential energy are entirely available to work and thus Exergy is directly related to the corresponding energies okay and this is your schematic representation of total energy and the only part which is available would be your Exergy. The rest would be unavailable energy, useful work.

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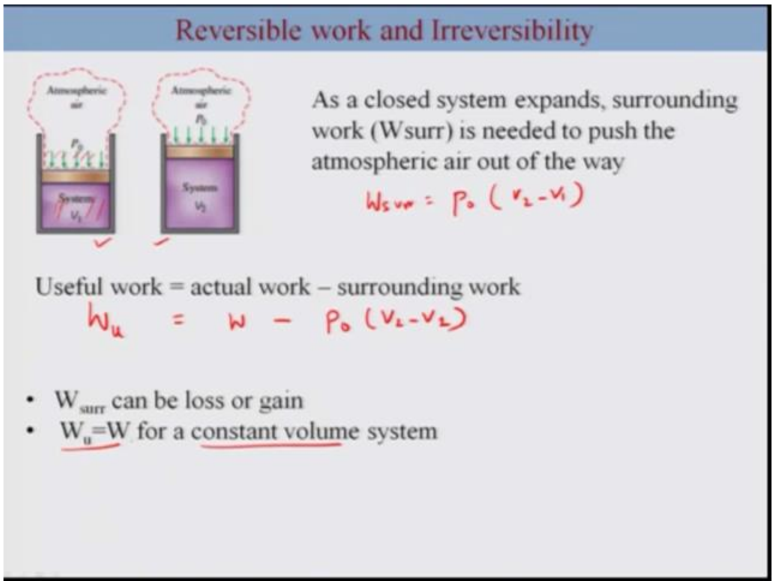

Okay so let's look at the reversible work and irreversibility by using this piston cylinder device and this is nothing but a closed system okay so both are closed system and if it is as this particular system expands, it has to push the air which is outside the system or just push the atmospheric air out of the way in order to push the piston outward and thus it has to do certain work okay.

So this work surrounding can be mentioned as the atmospheric pressure multiplied by the change in the volume of the system. Thus the useful work would be the actual work minus whatever work the system has to do on the surrounding okay in order to change the system volume to this is going to be double.

This could be a loss or gain. For the case of gain, one can consider when the system undergoes compression where the atmospheric pressure helps the compression process and thus W surrounding represent a gain. For a constant volume system okay your useful work which we would write like subscript U as simply as W okay so this that's why the definition of a useful work now will define reversible work now.

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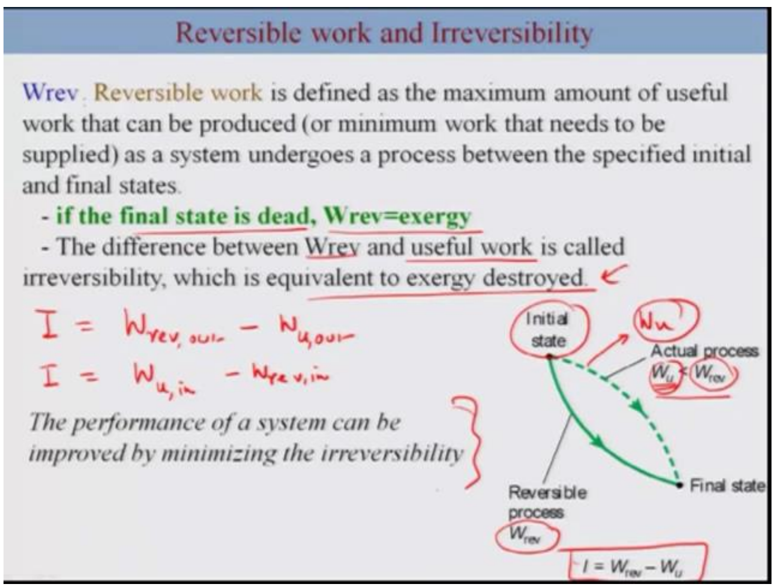

So the reversible work is defined as the maximum amount of useful work that can be produced for the work producing device or minimum work that needs to be supplied for the work consuming device as the system undergoes a process between the specified initial and final states. Okay so that would be the definition of reversible work.

So in another word, if the final state is dead as we already talked about earlier that Exergy which we are going to define is the maximum amount of work possible from a given state to the state where the system is at equivalent with the surrounding or which we say the dead state so definitely the reversible work would be same as energy when the final state is the dead state so that's about we emphasize there that W reversible is Exergy in case final state is dead okay.

And the difference between the W reversible and useful work is called irreversibility because this is nothing but equivalent to Exergy which is destroyed that means or the work which cannot be used okay that will be the corresponding Exergy destroyed okay so we can consider this. We are using this particular diagram that we have this initial state okay which follows the reversible process to undergo changes from initial state or final state.

So using irreversible process, the work corresponding would be W reversible. In case of our actual process, the corresponding work is useful work okay and so the useful work would be less than the reversible work because reversible work would be where there is no irreversibility and hence it's going to be more for work producing device on the other hand it is going to be opposite that means less for work consuming devices.

So here we are going to consider a work producing device where the maximum work is for the case of a reversible work or reversible process and hence your W reversible is greater than W useful, so the difference between them would be corresponding to the irreversibility okay and this is nothing but equivalent to Exergy destroyed, okay. That's your I which is the irreversibility would be your reversible work.

Now we will define out which essentially means it corresponds to work producing device minus the useful work which is out, okay so it is clear that if you want this performance of a system to be maximized then I should be minimum, okay or I should be minimized okay. For the case of a work consuming device, you can write this in a opposite way or you can write it in this following or you can write as WU in minus W reversible in.

Okay the reason why we have done this because the W useful in going to be more for work consuming device compared to the reversible okay or as I said the performance of the system can be improved by minimizing the irreversibility so certainly when I goes to 0 when the irreversibility goes to 0, the work approaches towards that condition of reversible process okay. Or useful work approaches to the condition of that reversible process.

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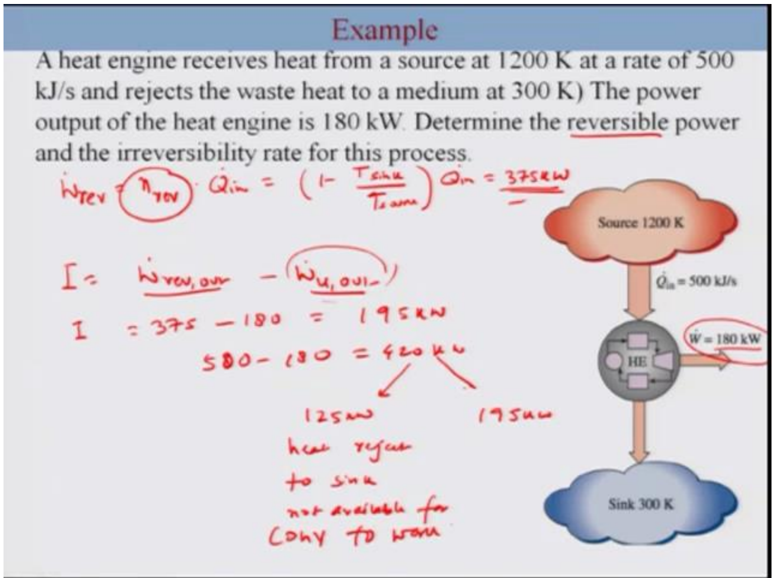

So let us try to analyze with further with an example okay this is an example of heat engine receiving heat from a source of 1200 Kelvin at a rate of 500 kilo joules and rejects the waste heat to a medium at 300 Kelvin. Power output of the heat is 180 kilowatt. Determine the reversible power and the (reversi) irreversibility rate for this process okay so this is a schematic representation so in order to find the reversible power, we simply have to make use of your thermal efficiency for the reversible heat engine.

Okay. Multiplied by Q in. now, this is given in terms of your sink. T source okay and multiplied by Q in. T sink is 300, T source is 1200, Q in is 500. This turns out to be 375 kilowatt, so now this is basically nothing but the maximum power that can be produced by the heat engine. That is, this is the available power for the condition of sink at 300 Kelvin so your I in would be your simply W reversible out minus W useful out. Okay.

Now, what is reversible out? Of course reversible out is this 375. What is useful out? That is what is for your system and this gives you 195 kilowatt so this is of course not maximized and this because this is not maximized because I is not minimized. I is the irreversibility, it turns out to be 195 kilowatt so there is a loss of 195 kilowatt due to irreversibility. Okay. Now, note that the input heat is 500 kilo joules per second that is 500 kilowatt thus your 500 minus 180 is 420.

Out of 420 kilowatt, 195 kilowatt is due to irreversibility and around 125 kilowatt is the heat which gets rejected to the sink so this is not available for conversion to work. Okay so this was the example of making use of a reversible heat engine and demonstrating the irreversibility. Now, let's look at little bit of analyzing the performance of realistic performance of devices based on second law of thermodynamics.

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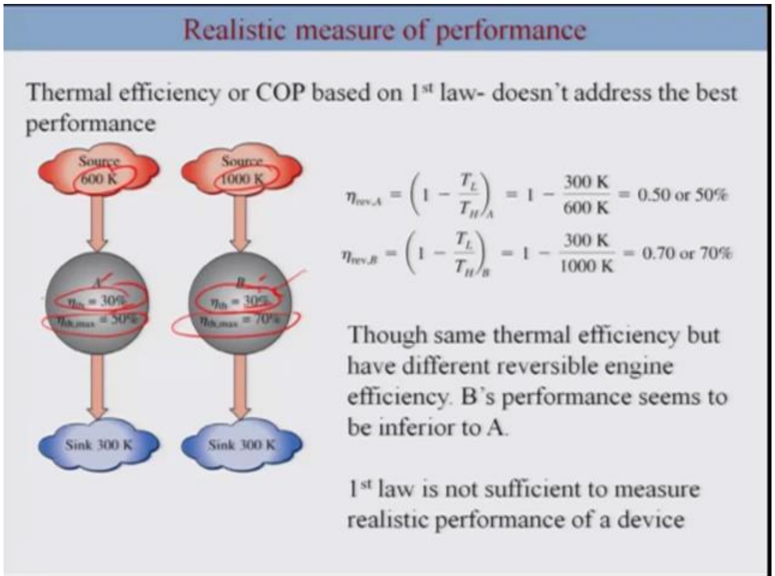

Now, thermal efficiency of COP based on first law does not address the realistic performance of the devices and this we can understand based on a simple (illus) illustration. So here for example, in this case, you have 2 particular device, A and B. Okay. Thermal efficiency both have 30% however source are at different temperatures. Assuming sink to environment at the same temperature okay so based on your reversible heat engine efficiency.

The maximum efficiency for A is 50%, for B is 70% so certainly it appears that the thermal efficiency of this is relatively performing much lower compared to its maximum ability so we need to come up with a better way to represent in order to show the thermal efficiency okay because this is certainly not giving us the indication of its performance considering that both have the same value but it has different corresponding maximum thermal efficiency okay.

Thus we need to come up with a better way to represent the performance of the devices so what we do is, we look at the ratio of this, the thermal efficiency with respect to reversible heat engines or the efficiency corresponding to reversible heat engine or corresponding to the maximum thermal efficiency and that's what we come with this particular second law of efficiency which we define at Eta 2, 2 stands for second law.

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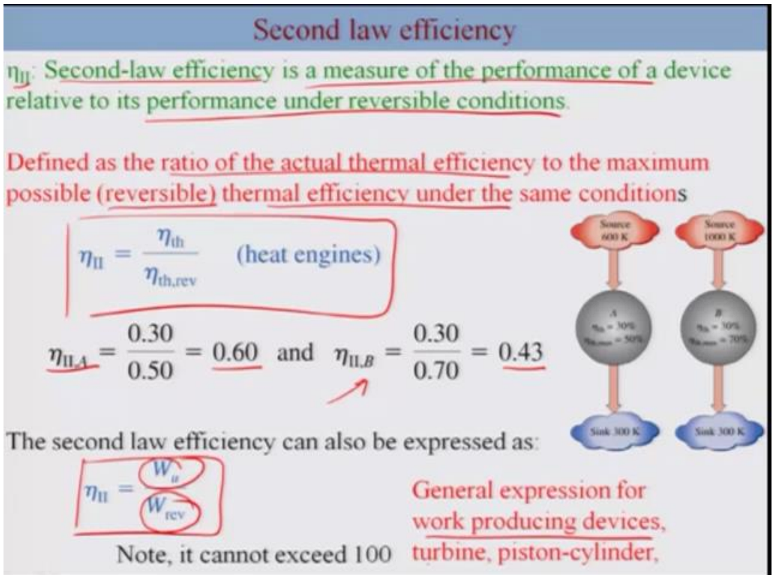

The second law of efficiency is a measure of performance of a device related to its performance under reversible condition okay so thus we simply take the ratio of the actual thermal efficiency to the maximum that is your reversible thermal efficiency under the same condition. Okay so this is what I was referring to so we can simply take this as a ratio. Now, with this we can go back and look at again the same 2 particular devices and clearly we can write Eta2A (is) becomes 0.6 and eta 2B becomes 0.43, clearly it indicates that the second device is performing inferior to your first device which is A, okay.

The second law of efficiency can also be expressed in terms of your useful work so you can write this in terms of simply the amount of useful work for the particular device divided by the maximum possible amount which can extracted from the device. So this is the expression for work producing device such as turbine piston cylinder. certainly it cannot exceed 100%.

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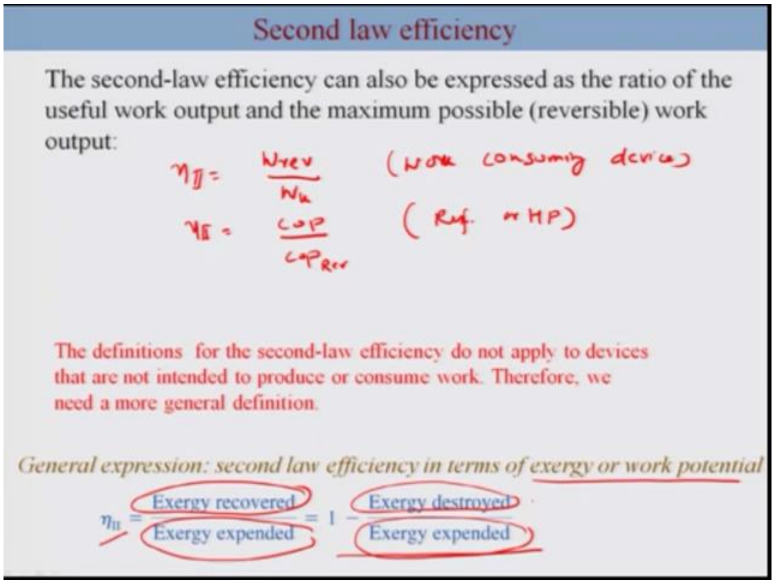

And similarly you can express this for your work consuming device where we put our reversible in the numerator and useful work in the denominator because of course this is going to be less than the W useful and since we want the efficiency not to be more than 100% and for the consistency, we consider this definition for the work consuming device okay.

Similarly for your refrigerator, we write this okay. So this is for the refrigerator or heat pump okay. So now this particular definition which we have made use of it clearly indicates that these are either for work producing device or work consuming device. However what we want to do is make use of a definition which is generic in nature that this is need not be just confined to the work producing device or work consuming device okay.

So therefore we need a more general definition and what we are going to make use of general definition, it will be in terms of Exergy or work potential, so Eta 2 would be Exergy recovered divided by Exergy spent okay or in other word we can write it in terms of 1 minus Exergy destroyed divided by Exergy expanded. Now we are going to spend more time on this definition and as well as making use of this efficiency in terms of Exergy in the later of this particular topic okay.

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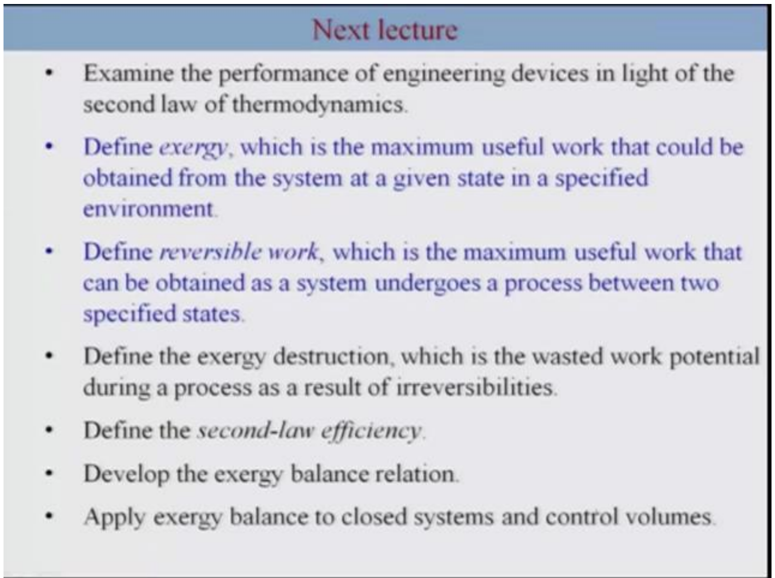

So here I will stop for this particular lecture. In the next lecture, we will discuss more of Exergy destruction and particularly more about Exergy. So here I will stop and I will discuss continue this Exergy discussion in the next lecture, so see you in the next lecture.