Energy Conservation and Waste Heat Recovery
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Lecture – 12
Entropy (Contd.)

Hello everyone, again we are back in our lecture class of energy conservation and waste heat recovery, if you recall, we were discussing thermodynamic principles which are very essential for the design of waste heat recovery system and particularly we have completed the discussion on first law, we have introduced second law of thermodynamics and also define the property which is of unique importance entropy and then in the last class, I have also shown you how to calculate the change in entropy during a process, when we are considering the change of state of a solid or a liquid or change of state of an ideal gas.

For other cases which are also important I think one should refer a book of thermodynamics because we cannot go into much detail then we have to compromise with what we want to do in waste heat recovery well.

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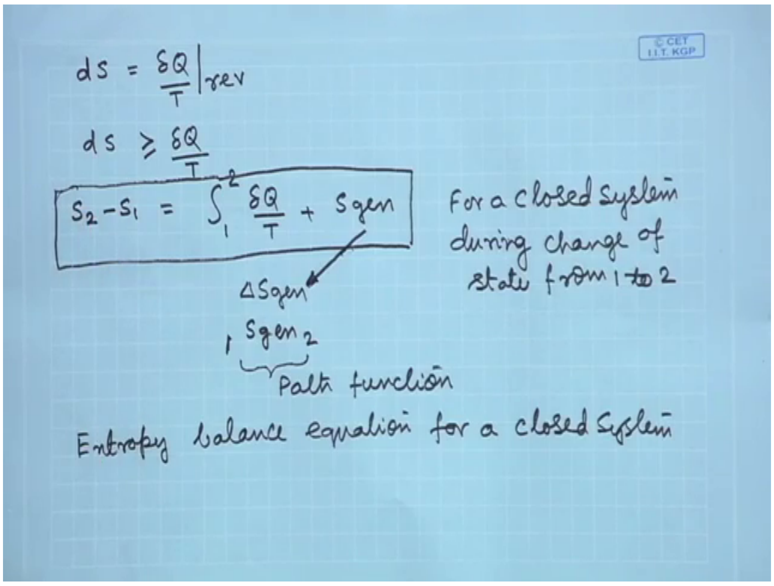

So, the basic equations of entropy or basic definitions of entropy which I have given and let me write it once again.

DS is equal to dQ by T reversible and from there we get dS should be greater than equal to dQ by T, if we consider any kind of process both reversible and irreversible; then by integrating 1 can write S 2 minus S 1 is equal to 1 to 2 dQ by T plus S gen or delta S gen because this is an integration process.

So, this equation I like you to have give some attention this is a very important equation, this is change of entropy for a closed system during change of state from 1 to 2. So, you see what we have written here, S 2 minus S 1 entropy being a property of the system it is a point function S 2 is the value of the entropy at the end of the process that is at State 2. S 1 is the value of the entropy at the beginning of the process and then this change is given by the integration of dQ by T from 1 to 2, we have to remember this will be dependent on the path and then there is S gen because if the process is not a reversible one, if it is irreversible process then there is some amount of entropy generation.

So, this is 1 concept again a very unique and we should pay due attention to this concept, that when whenever there is a process, there will be entropy generation if there is any irreversibility. So, entropy generation S gen, again one can write it as I have proved it is an integration process, one can write it delta S gen or more correctly one can write it S gen 1 to 2, during process 1 to 2 whatever generation of entropy is there that is your S gen and from this one can easily appreciate because this concept is familiar to us this is a path function. It depends on the path from 1 to 2 if the process has taken a path fully reversible, then S gen will be 0; if it has taken some sort of a path where there is irreversibility is there we will get a specific value of S gen, if it has selected another path with different kind of irreversibility then we will get another value of S gen.

So, this is a very important equation and this equation is called entropy balance equation for a closed system, so this is very important. So, for a closed system what we can see that change in entropy that is on the left hand side that is equal to or that comes from that generates sorry, that comes from the change of the change of entropy of the system that results from heat transfer process and that results from the irreversibility which generates entropy; one thing again I like to stress upon I have shown dQ by p integration dQ by T from 1 to 2, it indicates that there is only 1 heat transfer, but it is not. So, there could be heat transfer from different parts of the system at different temperature. So, when we will proceed it will be clear to us with this let us go to some.

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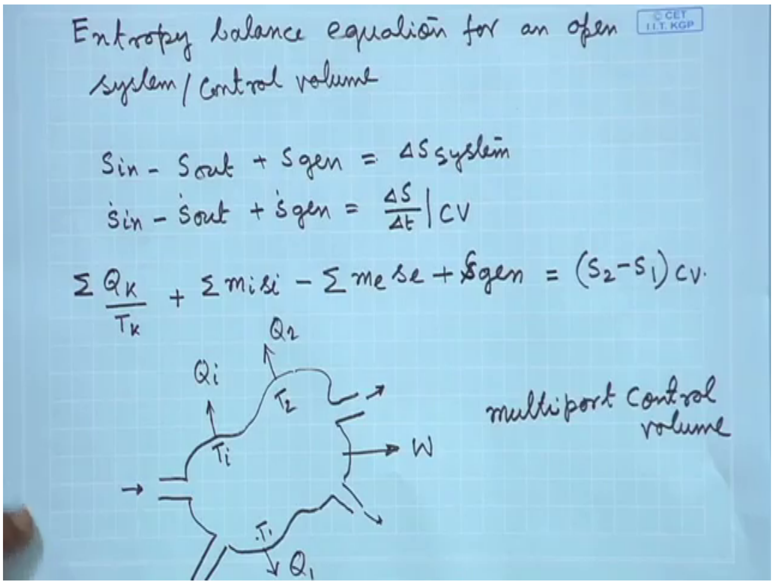

Next what we can do we can write entropy balance equation for an open system or control volume for an open system or control volume. So, how should we do it you see the concept of entropy balance can be done like this, S in minus S out plus S gen that is equal to delta S of the system

Let us say during a process during a time, let us say it is open system or control volume. So, we can understand it during a particular time. So, during that particular time S in amount of entropy has entered the control volume, his out amount of entropy has gone out of the control volume, S gen that is the amount of entropy generated within the control volume; so, summation of all these that will give the accumulation of entropy within the system or change of entropy for the system during this period.

So, in terms of time if I divide it divide both the sides by some delta T, where delta T denotes the duration. So, 1 can write S in this is rate S out plus S gen that is equal to dS dt or delta S delta T we can write it control volume cv. So, this is basically the top one I have written system which is nothing, but which we can write for an open system and also for a closed system, but now we are considering for a control volume. So, let us write cv.

So, how entropy can enter this system, if it is a closed system then there is only 1 way of entering the system that is through heat transfer, but if it is an open system then there could be heat transfer and also true mass entropic and come in so far, is in what we can write Qk by Tk plus sigma mi si minus sigma me se that is equal to and plus S gen this should be S gen that is equal to S 2 minus S 1 of control volume.

Let me explain what I have written Qk by Tk to understand this thing, let us think of a control volume like this. So, I have schematically drawn the control volume which notionally having to inlet and 2 outlets, to indicate that there could be multiple number of inlets and multiple number of outlet. So, this is some sort of a multi port control volume, there are many examples in industry and there are many example from the domain of waste heat recovery, let us say we are considering some sort of heat exchanger. So, heat exchanger will have 2 inlets and 2 outlets.

So, this is a multi port control volume, mass is entering at through different entry ports, mass is leaving through different exit port and there is heat transfer at different points. So, here heat transfer is at a temperature T 1. So, this is Q 1 here heat transfer is at a temperature T 2 and the amount of heat transfer is Q 2 and here general some sort of a general mode of heat transfer has been shown temperature is T i and heat transfer is Q i.

So, shamming all these thing all the heat transfer Q k by T k, that I will get what is the entropy transfer due to heat transfer; for a certain duration again if Q k is the heat transfer for a temperature T k. Then Q k by T k is the entropy exchange between the control volume and the surrounding and the direction of exchange that will be decided by the direction of heat transfer. So, this is 1 part of input, another part of input there are number of input port, through the input port mass entering entropy is an extensive property it is associated with mass, so entropy is also entering.

So, m dot sorry mi si if that is the total amount of mi is the total amount of ma mass entering to a particular port si is the specific entropy of the mass entering through that port. So, mi si will give me the entropy that is entering into the control volume through that port, summation will give through all the port how much entropy has entered. Similarly, we can get me se S gen is the amount of entropy generated during this period S 2, is the S 2 I have written capital. So, it is taking care of the mass also. So, S 2 is the total amount of entropy at the end of our duration and S 1 is the entropy at the beginning.

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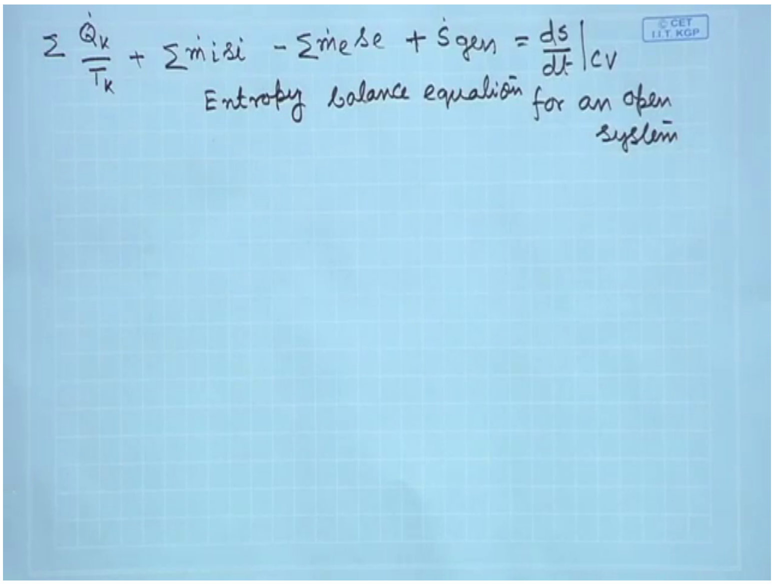

So, this is what I can write and dividing by time, I can get some sort of rate equation and the rate equation what I can have is this sigma Q dot k T k plus sigma m dot I si minus sigma m dot e se plus S gen, this is also rate that is equal to dS dt control volume. So, this is our entropy balance equation for an open system, very useful in engineering practice and also for waste heat recovery. Here let me point out a few things, I like to bring the diagram of the multi port control volume which I have drawn sometimes back.

So, here you see these are basically inlet mass flow rate, these are outlet mass flow rate; these are different heat interaction this is working interaction in our entropy balance equation, all the things which I have drawn. So, that has been put here which are relevant, but you can see that there is no contribution of the work transfer term. So, this is important is you have to also keep in mind that, due to transfer of work there is no change on the entropy; it is implication we will understand later on.

Another point I like to stress upon that is the entropy generation. So, entropy generation as I have discussed earlier that it is related to the irreversibility of the process. So, if we can calculate entropy generation. So, we should have some idea regarding the reversibility, during the process we incur the irreversibility that we will be able to calculate with the help of S dot gen term and then this is 1 way of knowing how good is the transfer process for an equipment if we do this we can have some idea regarding the design of the equipment. Both for the design of the equipment or for the design of the process S dot gen or S gen those is very important term and there are ways of calculating it in for waste heat recovery, if we want to analyze the system this term is very useful.

Let us take up a problem and with the problem let us try to understand, how we can utilize S gen the concept of S gen and know whether a pa typical process for waste heat recovery is good or not.

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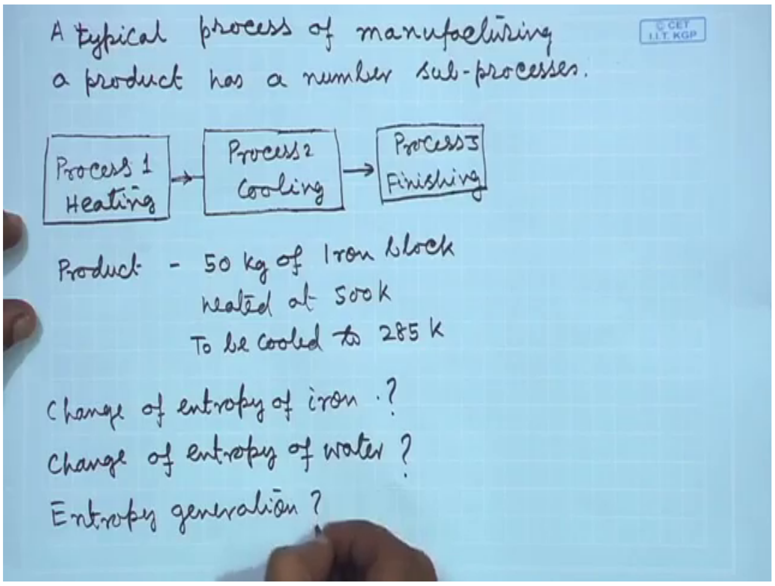

Let us take an example; let us say we have got a typical process. So, of manufacturing a product, so a typical process of manufacturing a product has a number of sub processes. So, let us say the process one heating so we have to heat an object and then process 2 after heating, let us say we will have some sort of a goal; that means, we can achieve some material property, heating could be a part of the manufacturing process. But after that process is over process 2 this is cooling and once this is cooled, so it goes to process 3 this is finishing.

So, let say some metal object we are manufacturing in the first process we are heating it, maybe to achieve certain material property or say part whatever it may be then we have to cool it because during finish finishing a process we cannot allow the hot object. So, let say this is what we want to do and let us take a very typical example, let say a 50 kg of iron block product let say the product. What is the product? This is 50 kg of iron block and this is during the process of heating it is heated at 500 Kelvin and then it has to be cooled to 285 Kelvin. So, now our focus is on the cooling process, just to explain the entire thing how it may fit in industry, I have described all this thing, but our focus is on the cooling process.

So, let say in the existing plant the cooling is done by showing this piece of iron in a large tank, that is how the cooling is done and then the tank is so large that we can assume that, the tank temperature tank is filled up with water and the tank temperature does not change while the iron get coo gets cooled, but the tank temperature does not change. Now what we have to determine here that; what is the change of entropy of the iron block? What is the change of entropy of the water in the tank and what is entropy generation. So, this is what we have to find out?

. So, let us do delta S iron change of entropy of iron, change of entropy of water; we have to know it and entropy generation. So, this is our problem statement and then we will see what is it is implication in waste heat recovery, alright.

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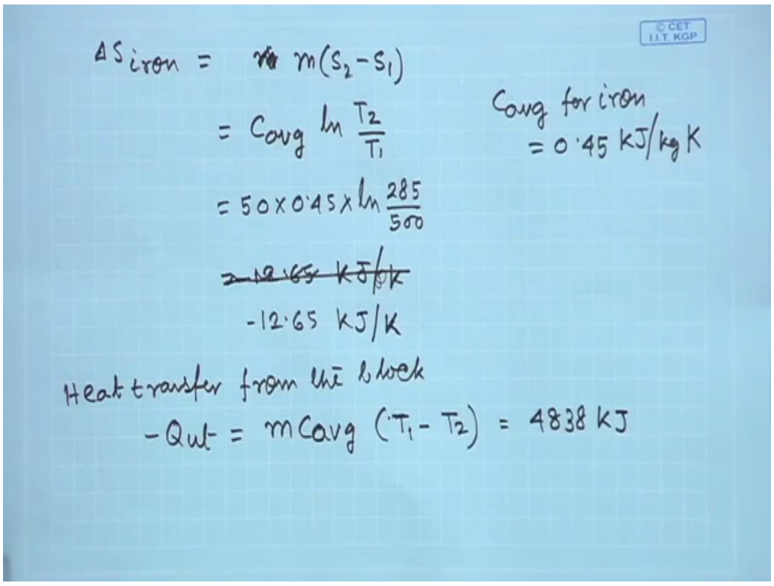

So, first let us try to find out delta S iron that is equal to how we can find out; already in my last class I have discussed and I have told how to calculate the change of entropy for a solid body.

So, it will be something like this, it will be m into m is the mass m into S 2 minus S 1, that is that is c average ln T 2 by T 1 and c average for iron is .45 kilo joule per kg Kelvin. So, from there what we get this is 50 into .45 into ln of 285 by 500. So, this will be equal to minus 12.65 kilo joule per this will be kilo joule sorry; it will be in not kilo joule per kg, it will be in kilo joule already. We have taken the mass into consideration. So, this will be kilo joule only. So, let me write it minus 12.65 kilo joule.

So, what is the heat transfer? So, this is the entropy change for the iron kilo joule per Kelvin this is the entropy change for iron. Now what is the heat transfer, heat transfer from the block so that will be minus Q out that will be m into c average T 1 minus T 2 and putting all these thing, you will get 4838 kilo joule. So, this is the magnitude for iron block it will be a negative quantity and this will be a positive quantity for the water in the tank.

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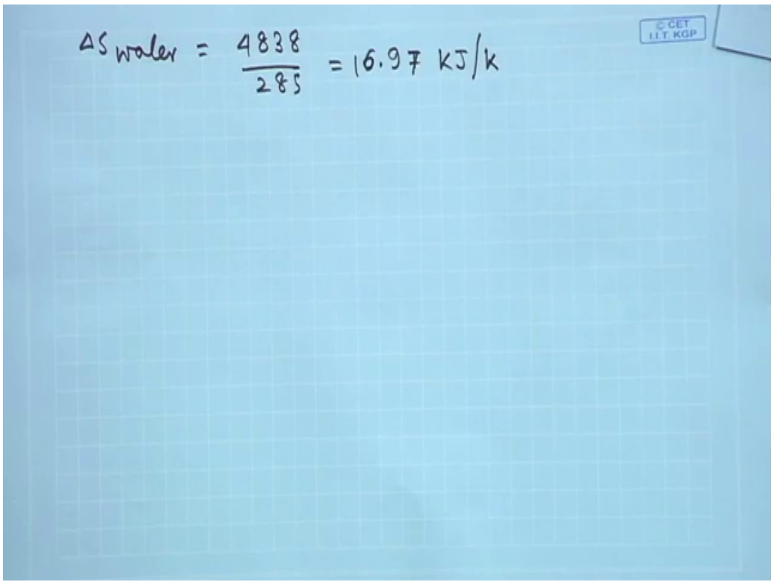

So, now very quickly if I calculate what is the delta S for water? So, we will have 4838 by 285 that is 16.97 kilo joule per Kelvin.

So, these are the values we will get from the entropy change of water. So, mind it heat is transferred to the water and that is why it is positive and entropy change of the water that will be also positive; that means, the entropy of the water will increase . So, we are not yet finished some part is left, some implications are left. So, we will start from here in our next class.