Applied Thermodynamics

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Exergy analysis of a steam turbine, Numerical Problems on Stream Power Cycle
Steam Power System
Lecture - 20
Exergy Analysis of a Steam Turbine

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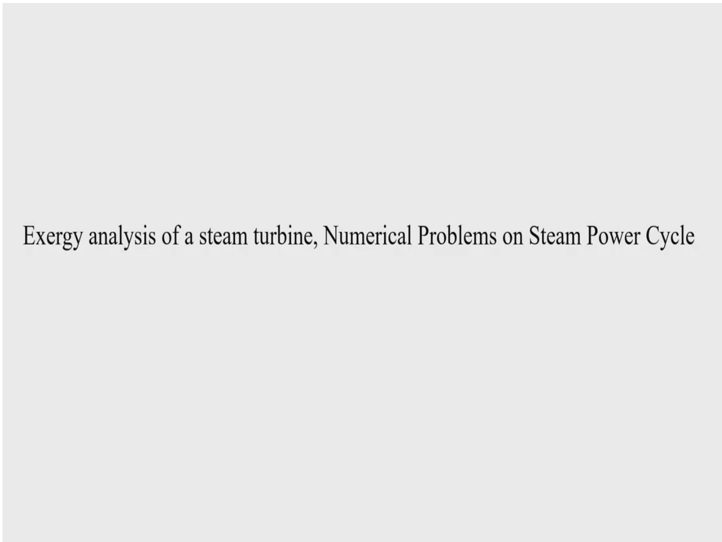

We shall start our discussion today on the Applied Thermodynamics. In particular the topic of our today's discussion is the Exergy Analysis of Steam Turbine and then finally, we shall try to solve two problems from the steam power cycles. In fact, instead of having only the exergy analysis of the steam turbine; it would be wise to have the exergy analysis of the steam power plant itself or the power cycle itself.

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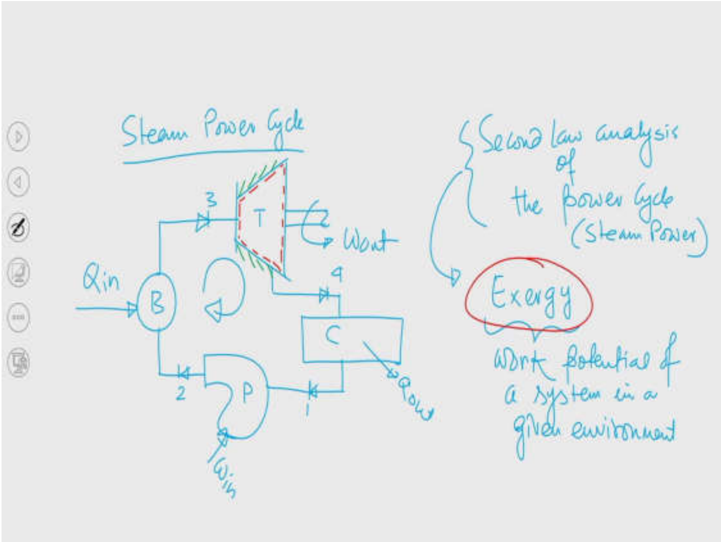

Now, if we try to recall that the component of the steam power cycles; so this is the schematic we have discussed many times. So, now question is; why do we need to go for the exergy analysis or second law analysis of the steam power cycle. Now you have studied about first law of thermodynamics, second law of thermodynamics in your thermodynamics course.

So, first law of thermodynamics talks about the conservation of energy. It does not provide the direction of any energy transfer. Second law on the other hand came only to address the limitations of the first law of thermodynamics. So, the limitation of first law of thermodynamics is that it talks about the conservation of energy, but it does not provide the direction of energy transfer.

So, second law not only provide that but also it provides the concept of entropy. Now the source of entropy generation is essentially due to the irreversibilities of the processes. And when there is irreversibility, entropy will generate and because of this generation of entropy the expected output from any particular device or cycle will be reduced. So, second law analysis is important in the context of steam power cycle essentially to understand the availability rather work output.

So, basically you can see from this schematic depiction is that we have boiler, turbine, condenser and pump. Now overall efficiency of the plant will be eventually determined by the efficiency of the individual component.

So, these four components constitute all the processes to operate in a cycle. As I told you that if you do not have this condenser it is very difficult to have the processes in a cyclic manner. The second law puts a restriction that it is not possible to have a cyclic process when it is working with a single temperature thermal reservoir.

So, now as these are the major components; irreversibility associated with the process which is occurring in a particular component upon sum will lead to total irreversibilities of the cycle. And when there is irreversibilities, the expected work output from the cycle will be less than maximum work.

So, now from the second law of thermodynamics, unlike entropy there is another important proper that is called exergy; what do we mean by exergy? So, this is basically potential to do work of a system in a given environment.

Why I am telling given environment? Because we are supplying heat into the water which is passing through the boiler by burning any fuel; be it coal, be it diesel. Now the performance of the condenser essentially will depend on the temperature of the water or coolant which will be supplied to reduce the temperature of steam. So, that also will depend on the environment in which this power plant is installed.

So, this is nothing but the potential of a system in a given environment. Say, this is the turbine; so when steam is entering into the turbine and finally, after doing some work it is leaving from the turbine. So, if we focus on the working substance that is steam, the state of that steam is getting changed as it passes through the turbine. So, when steam is passing through the turbine the thermodynamic state is getting changed and at the cost of that change of the thermodynamic state, we are getting work output.

So, if we consider that this is as the control volume system because this is flow process. So, this is not the control mass system because we are having inlet and outlet. So, now, if we focus our attention on this control volume system we can understand the working substance of the system is changing. I mean state of the system is getting changed from the inlet to the outlet and that is why we are getting work. So, work is delivered by the system as the state changes from inlet to outlet through a reversible process.

Because, all the processes; constant pressure heat addition inside the boiler, isentropic expansion when steam is passing through the turbine, constant pressure heat rejection in the condenser and finally, the reversible adiabatic work input; all these processes are assumed to be internally reversible, but we cannot promise all the processes to have the external reversibility. So, we can assume that all the processes are internally reversible, but at the same time we cannot promise that all the processes will be having external reversibility because we will be having heat transfer to the working substance due to finite temperature difference. If we are unable to maintain the finite temperature difference, heat transfer will not be efficient. So, as long as efficient heat transfer is ensured external reversibility will be there.

Similarly though we are providing kind of insulation on the turbine casing, but some amount of heat loss will be there. Not only that you know steam is passing through the turbine blade as we have discussed that steam will impinge, so frictional effect will be there. So, though internally reversible of the processes, we cannot ensure that the processes will be externally reversible.

So, if we assume this is the control volume system, work delivered as the thermodynamic state changes from state 3 to state 4 and the processes is occurring reversibly then the work output will be the exergy.

So, work delivered as the state of the system changes from state 3 to state 4 reversibly and the system is coming to the dead state. So, basically if you allow steam to expand reversibly and the work that will be delivered if I allow system to change its states from 3 following a reversible process up to the dead state, that is nothing but the measure of exergy.

So, basically it is work potential of the system in a given environment and in a way I can tell you that maximum work that is obtainable from the system when the system is coming into the dead state equilibrium with the surroundings. So, though you have learned on this particular topic in a greater detail during your thermodynamics course, but just to have a brief recapitulation I have discussed this part. So, we know second law of efficiency; what is second law of efficiency? Second law of efficiency is nothing but the actual work obtainable from the system to the reversible work.

So, if we focus on this particular part, maximum or reversible work that is obtainable from the system is not equal to the actual work that we are getting. And that is because of the thermodynamic irreversibilities. So, fluid friction a will be there, mechanical losses will be there. Considering all these losses the actual work obtained from the system is not equal to the reversible work that is obtainable from the system and the ratio of these two work is nothing but the second law of efficiency.

So, because of the friction and mechanical losses, we will not be able to get the maximum obtainable work and that is the exergy destruction will be there. So, exergy is the basically work potential of the system in a given environment, but because of the thermodynamic irreversibilities there will be exergy destruction.

So, why exergy destruction is there? Because of the thermodynamic irreversibilities; which are the factors producing thermodynamic irreversibilities: friction, mechanical losses, heat transfer due to finite temperature difference. So, this factor leads to entropy generation and simultaneously also leads to exergy destruction.

So, the factors which lead to the entropy generation also lead to the exergy destruction. So, the friction, heat transfer due to finite temperature difference here in the condenser, heat transfer due to finite temperature difference in the boiler, all these factors lead to the entropy generation that means, they are inviting irreversibilities into the system.

So, these factors lead to the irreversibility generation and also lead to the exergy destruction. So, exergy destruction is nothing but due to the irreversibilities of the system and which you know from your thermodynamics knowledge this is nothing but the entropy generation.

So, higher the entropy generation which is nothing but the higher degree of irreversibilities, higher will be exergy destruction. So, higher the irreversibilities of the system, higher will be entropy generation and which in turn will lead to the higher exergy destruction.

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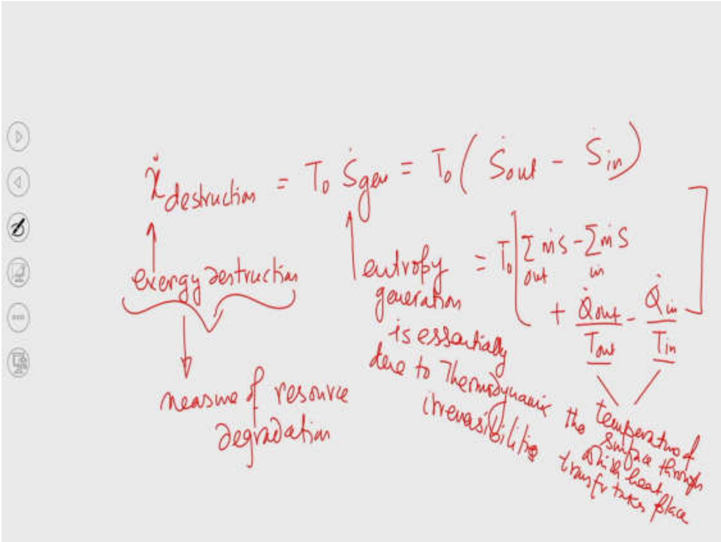

So, if we try to write what is exergy destruction? I have writing in the rate form so this is nothing but $T_0 S_{gen}$. So, we will be focusing on the exergy destruction of the cycle itself. I mean you can calculate exergy destruction of the turbine, condenser, boiler as well as destruction of pump and if you sum them up, you will be getting exergy destruction of this cycle. So, this is nothing but $T_0\left(S_{out} - S_{in}\right)$. So, this is what you have studied in thermodynamics. So, this is nothing but entropy generation.

So, this entropy generation is essentially due to is essentially due to thermodynamic irreversibility ok. So, if you allow the system to operate in such a way that you are going to invite higher degree of thermodynamic irreversibilities, entropy generation will be more. If you have higher entropy generation you will be having higher exergy destruction, higher the exergy destruction that is degradation of the useful work. So, basically efficiency of the cycle will be reduced drastically.

So, this exergy destruction is nothing but a measure of measure of resource degradation. So, basically we are trying to get work output from the turbine, but because of this exergy destruction which is nothing but the entropy generation which is again nothing but the thermodynamic irreversibilities, we are going to have degradation of the work output.

So, you know that all are flow process this is not control mass system. So, we are having continuous flow, heat addition, heat rejection. So, there is no heat addition and heat rejection over here, but heat transfer due to finite temperature difference, fluid friction mechanical losses, mixing; all these factors lead to the entropy generation. So, if I try to write for this flow process. So, it will be $T_0\left[\sum_{out}\dot{m}S-\sum_{in}\dot{m}S+\frac{\dot{Q}_{out}}{T_{out}}-\frac{\dot{Q}_{in}}{T_{in}}\right]$.

So, if we now focus on this particular device. When steam is entering into the turbine we are having entropy into the system. Steam is coming out from the system, so the entropy out.

So, in this particular device there is no heat addition and no heat rejection, so the entropy transport will be on nothing but the $\dot{m}S_{exit}-\dot{m}S_{in}$. So, entropy out minus entropy in that is nothing but the entropy generation.

For this case, again in addition to that we will be having heat transfer due to finite temperature difference, here we will be having heat rejection due to finite temperature difference. So, this T_{out} and T_{in} are the temperature of the bounding surface through which heat transfer takes place and these are the entropy transfer into the system and out from the system.

So, if we go one step further and if we try to write per unit mass and if we consider there is single entry, single exit and for the steady state steady flow processes. Because previously we have seen by applying steady state steady flow energy equation, we could find the enthalpy change. That is if I apply steady state steady flow energy equation to the process which is occurring inside the boiler, turbine; then we can find out work output, heat transfer etc.

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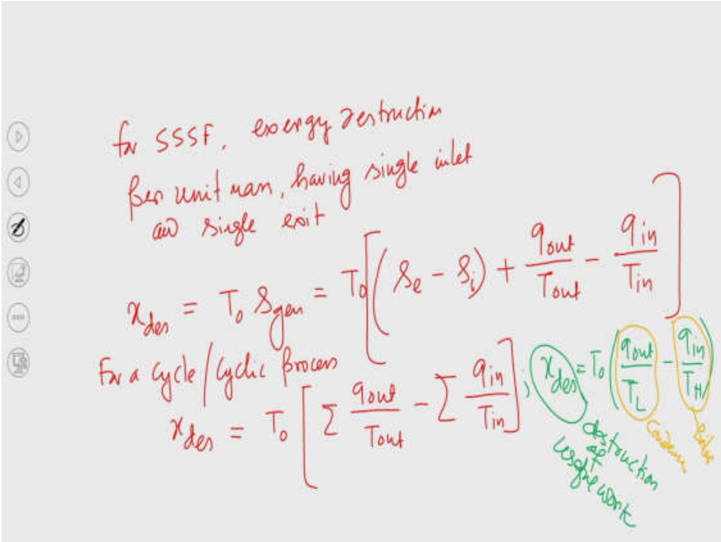

So, for steady state steady flow processes, exergy destruction per unit mass having single inlet and single exit can be written as $x_{des} = T_0 s_{gen} = T_0 \left[\left(s_e - s_i \right) + \frac{q_{out}}{T_{out}} - \frac{q_{in}}{T_{in}} \right]$.

So, we have written all terms in specific form. So, this is basically exergy destruction. So, now if it is applied for the cycle, that entropy exit - entropy in term will not be there. Because this is cyclic process, so whatever entropy is exiting and that is equal to inlet. So, for a cyclic process $x_{des} = T_0 \left[\sum \frac{q_{out}}{T_{out}} - \sum \frac{q_{in}}{T_{in}} \right]$.

Because we really do not know how many surfaces are there through which heat is added to the system; how many surfaces are there through which heat is rejected from the system? So, this is the heat transfer from the system, this is heat transfer into the system. So, since we really do not know how many surfaces are there, so, it is written in a generic form.

Now, for the present case, this is considered that the surface is insulated. So, there is no heat interaction, only heat exchange takes place in the boiler as well as in the condenser between the working substance and the surroundings. So, this is also not a device through which heat exchange takes place. So, for this particular cycle if we try to write the exergy destruction is nothing but $x_{des} = T_0\left[\frac{q_{out}}{T_L} - \frac{q_{in}}{T_H}\right]$. So, this is destruction of the useful work. So, for this particular case where we are having only one surface through which heat is added to the system that is $\frac{q_{in}}{T_H}$. So, this is high temperature thermal reservoir that is in the boiler and this is low temperature thermal reservoir so, $\frac{q_{out}}{T_L}$ that is in the condenser.

So, this is basically exergy destruction. If we know the exergy destruction that is destruction of the useful work, we can find out what will be the minimum obtainable from the system. So, knowing the magnitude of destruction of the useful work, we can predict what will be the minimum work that is obtainable from the system. And from there we can quantify the second law of efficiency.

So, to summarize todays discussion you know that we had started discussion using the second law analysis of the steam power cycle. Though we wanted to have discussion of the exergy analysis of the turbine, but in a steam power plant there are several other components not only the turbine.

So, instead of just having the exergy destruction analysis only for the turbine it is better to have the generic expression of exergy destruction for the cycle. Because there are many other components in addition to turbine which constitute together to form the steam power plant.

And because of all these components it is possible to have all the processes in a cyclic manner. So, that is why instead of having only the exergy analysis of the turbine we have discussed about the exergy destruction of the power cycle itself.

And we have found that for the cyclic process where s_e - s_i is not there; we can write destruction of available work is nothing but $\frac{q_{out}}{T_L} - \frac{q_{in}}{T_H}$. So, if we can reduce the heat transfer due to finite temperature difference inside the condenser perhaps we can reduce the exergy destruction.

So, if we reduce the T_L, the surface through which heat is rejected to the coolant inside the condenser, also if we reduce the Q_{out} that is amount of heat that will be rejected to the coolant in the condenser, we can reduce the exergy destruction. And if we can reduce the exergy distraction that will eventually ensure the higher efficiency of the plant.

So, with this I stopped here today and in the next class we shall be solving a few numerical problems from the power cycles.

Thank you.