Applied Thermodynamics

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Steam Power System
Lecture - 18
Boilers and Condensers

I welcome you all to the session and today, we shall start discussing about Boilers and Condenser. In fact, if you try to recall in the last lecture, we have discussed about the nozzle efficiency. So, before going to discuss about these two important components of steam power plant, let us briefly draw the schematic depiction of the steam power plant.

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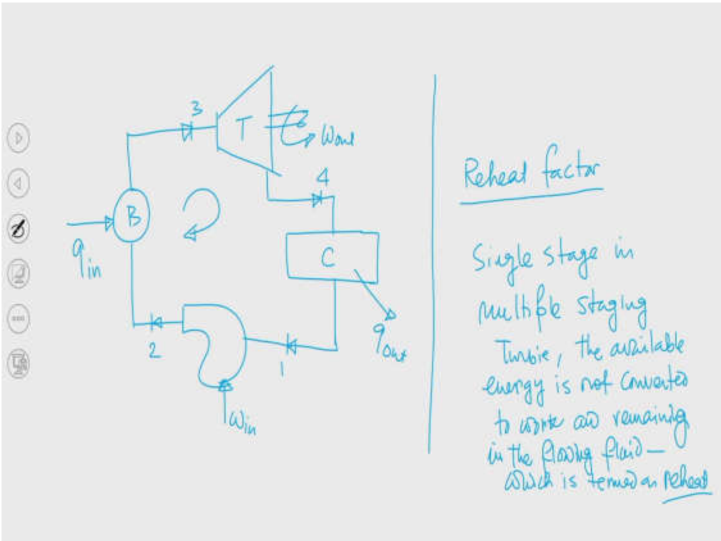

So, we have this is boiler where heat is added and finally, heat is getting rejected from the condenser. To have the cyclic process from this plant, we must have a heat source and one heat sink and that is to satisfy the second law of thermodynamics.

Now, what we can see in this schematic depiction is that; we have discussed about the cycles, then we have discussed about the turbine, also we have discussed about another important component that is not shown over here that is in this diagram is called flow nozzle. Today, we shall briefly discuss about boiler and then, condenser.

To have the cyclic process, we must have heat source and heat sink. So, if we look at the schematic depiction, heat source is basically the boiler here and heat sink is condenser. So, this is the place where heat is rejected from the system into the surroundings, and this is the place where heat is added to the system from the surroundings.

Now, how we are going to supply heat whether by burning coal or by burning diesel or by exploiting these nuclear reaction so, these are different issues altogether, but question is we must have a heat source and heat sinks and in this particular plant, heat source is the boiler.

In the last class we have discussed about nozzle efficiency and by having the analysis when steam is flowing through the nozzle, we could establish the nozzle efficiency. So, today, we shall briefly discuss about one important term that is called reheat factor.

So, heat is added into the system in the boiler, out of this heat we are getting work output from the turbine, but this amount of work that we are getting is not equal to the amount of energy in terms of the amount of heat that is added in the system and that is why we must have this rejection.

So, if we can look at this that a portion of the energy which is supplied in the system in the form of heat will be utilized to convert in work and we are getting from the turbine, remaining portion of the energy is not getting utilized and that is rejected from the system and knowing fully that energy must be rejected from the system, still we are having this component essentially to run all the processes in a cyclic manner.

So, we are supplying energy in the form of heat and that heat energy is getting converted into another form of energy that is work in the turbine, but that work output is always less than this heat energy. So, all heat cannot be converted into work. So, from there you can understand that the grading of energy.

So, that amount of energy supplied to the turbine, even out of this energy some portion of the energy is not getting utilized because of different losses. If you would like to utilize the energy inside the turbine, we need to go for multi-staging. We have seen multi-staging is done essentially from the operational point of view that if we allow all the enthalpy to drop from the boiler outlet to the condenser in a single stage, perhaps the design point of view because of the centrifugal stress and radial stress, it cannot be consumed in one stage and multi-staging is done.

So, when there are multiple stages, I mean we can write that even for the single stage in multiple staging turbine, the available energy is not converted to work and remaining in the fluid which is termed as reheat. So, if we consider a single stage in multiple staging turbine, the amount available for the conversion of heat into work is not getting converted and it is remaining with the flowing fluid and it is known as reheat.

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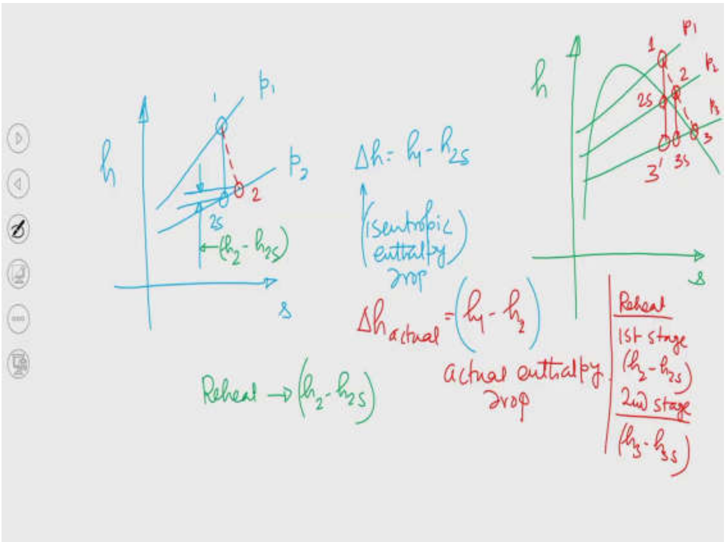

So, if we try to draw h-s diagram and if we try to draw say this is one stage so, this is p_2 and this is p_1.

Now, if we try to draw the enthalpy drop. So, in a stage say suppose this is point 1 and this is point 2. So, $\Delta h = h_1 - h_{2s}$ in a single stage. If it is a single stage, we can see the enthalpy will drop from 1 to 2s so, this is isentropic enthalpy drop.

But in real practice because of some losses, the actual enthalpy drop will be like this, so, this is say 2 and actual Δh will be $h_1 - h_2$. So, we can see that this amount of enthalpy, loss will be there. As I told you in the last class, we really cannot ignore the fluid friction and as a result of which that instead of having the isentropic enthalpy drop, we will be getting actual enthalpy drop and that is $h_1 - h_2$.

So, because of this effect, we can see that this quantity is h_2 - h_{2s} and this is known as reheat. So, if we have multiple staging, every stage we are having reheat except in the last stage. So, let me draw the at least two different stages.

So, if we consider multiple stages turbine, if we allow enthalpy to drop; so, this is p_1, this is p_2, this is p_3. So, actual drop will be like this. So, try to understand that in every stage, we will be having reheat. So, if I drop the steam from 1 to 3\` and we have only 1 stage, the enthalpy isentropically will drop from 1 to 3\`, but having these two different stages we are have this enthalpy drop from 1 to 2s that is isentropic, but actually will be from 1 to 2, but in the 2nd stage, again it should be 2 to 3s as that is isentropic, but actual should be 2 to 3.

So, if I write reheat in the 1st stage reheat equal to h_2 - h_{2s}, 2nd stage we will be having reheat that $h_3 - h_{3s}$. So, in every stage, you are having reheat that is nothing but the energy which is not getting converted in the previous stage and that will be cumulatively added.

So, we can write very important line that whatever amount of reheat in a particular stage is there, that is available to do work in the next stage and since the constant pressure lines diverge, for the same pressure drop, reheat per stage will increase. So, the reheat available for the 1st stage is not equal to the reheat available for the 2nd stage.

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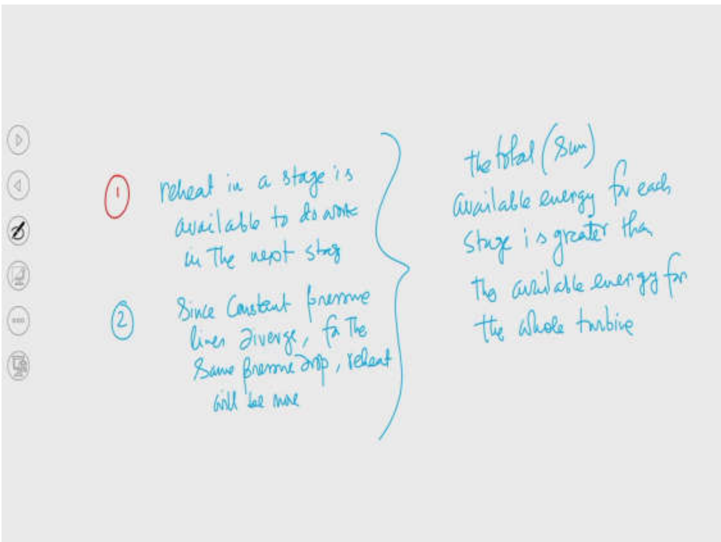

So, reheat in a stage is available to do work in the next stage and for the same pressure drop, enthalpy drop will be more; so, reheat will be more. So, because of these two, sum of total available energy for each stage is greater than the available energy for the whole turbine.

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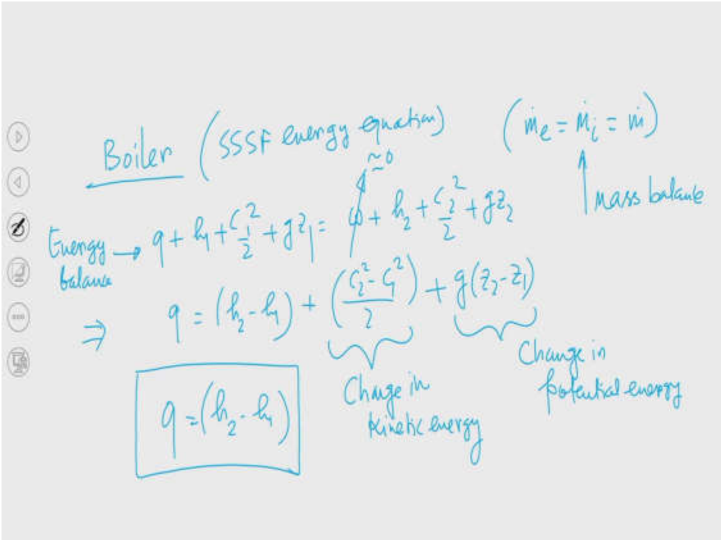

So, with this little bit of introduction about the reheat, now let us go to discuss about the boiler. So, boiler is a heat interacting device upon receiving heat, water is getting converted into steam.

Now, if we apply steady state steady flow energy equation in the specific form $q + h_1 + \frac{C_1^2}{2} + gz_1 = w + h_2 + \frac{C_2^2}{2} + gz_2$. So, we can write, there is no work done; so, work interaction is 0. So, you can write $q = (h_2 - h_1) + \left(\frac{C_2^2 - C_1^2}{2}\right) + g(z_2 - z_1)$.

See this is change in kinetic energy and this is change in potential energy. These are specific quantities and we are assuming that mass flow rate at the inlet equal to mass flow rate at the exit equal to m; so, this is from the continuity.

Now, if we can assume that the change in kinetic energy and change in potential energy is negligible, we can write $q = (h_2 - h_1)$.

So, the amount of energy required for the conversion of phase that is water should be converted into vapor, it is nothing but enthalpy change. So, basically we can estimate what is the amount of heat needed to supply to the boiler for the conversion of steam. If we know the mass flow rate then we can easily calculate heat added. Try to understand it is not that the absolute value of kinetic energy and absolute value of potential energy rather we are neglecting the change of these two you know energies.

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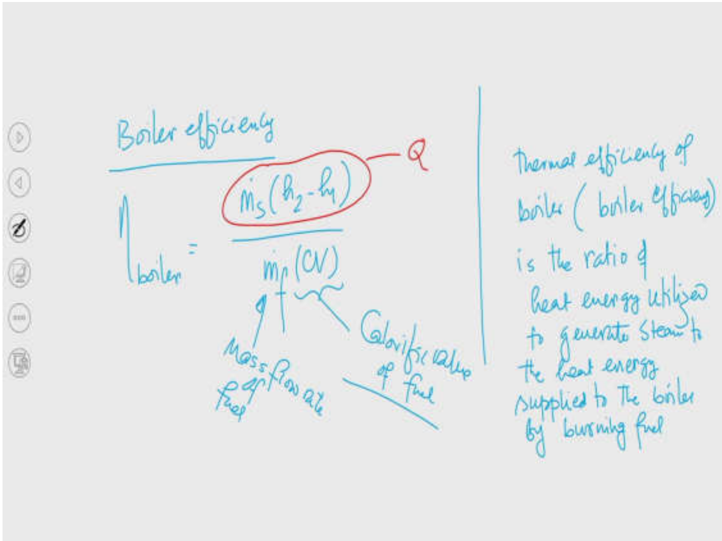

Now, having established this, we can understand what boiler efficiency is. For the conversion of water into steam; for this phase change, amount of energy required is $h_2 - h_1$. If we try to write total heat, it will be $\dot{m}_s\left(h_2 - h_1\right)$.

Now, this is the energy required for this conversion that is a phase change, but we are supplying energy to the boiler that is mass flow rate of fuel into calorific value of fuel. So, mass flow rate of fuel multiplied with the calorific value of the fuel is the input energy, out of this input energy, this much amount of energy will be utilized to convert water into steam and ratio of these two energies is nothing, but the boiler efficiency.

So, the boiler efficiency is defined is the ratio of heat energy utilized to generate steam to the heat energy supplied to the boiler by burning fuel. So, this is basically the concept that the amount of heat energy that we are supplying and out of that energy, how much energy is utilized to generate steam, ratio of these two energies is known as the boiler efficiency or thermal efficiency of the boiler. $\eta_{boiler} = \frac{\dot{m}_s (h_2 - h_1)}{m_f (\text{CV})}$

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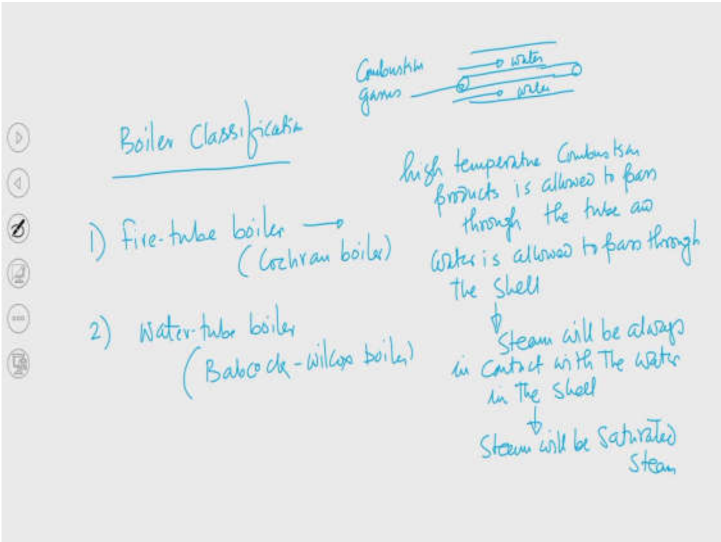

So, now briefly discuss about the different types of boiler. There are two different types of boiler, one is known as fire tube boiler and other is water tube boiler.

So, when water is allowed to pass through the boiler and definitely, the energy which is supplied in the form of heat; heat will be supplied to the boiler by burning fuel. So, when water is allowed to pass through the boiler, it may be allowed to pass through the tube or it may be allowed to the pass through that shell.

So, you have studied in heat transfer subject that is called heat exchanger, shell and tube heat exchanger. Rather if we allow water to pass through the shell, whereas the fire that is flue gas will be allowed to pass through that tube, this is known as fire tube boiler. So, in this boiler, water is allowed to pass through the shell wherein the combustion product, the fire is allowed to pass through the tube and that is why it is known as fire tube boiler.

So, high temperature combustion product is allowed to pass through the tube and water is allowed to pass through the shell. As if fire is passing through the tube and the tube is placed in a shell and outside the tube there is water.

Since the steam which is getting produced will be in contact with the water because you cannot isolate that steam from the water as a result of which steam that will be produced from the fire tube boiler is always saturated steam. So, steam will be always in contact with the water in the shell. Hence steam will be saturated steam.

So, it is very difficult to have superheated steam from a fire tube boiler. If you would like to have, you have to collect the steam and that collected steam will be again allowed to pass through several arrangements to obtain the superheated steam. The steam which will be produced will be in contact with the water so, it is quite expected that steam will be saturated steam.

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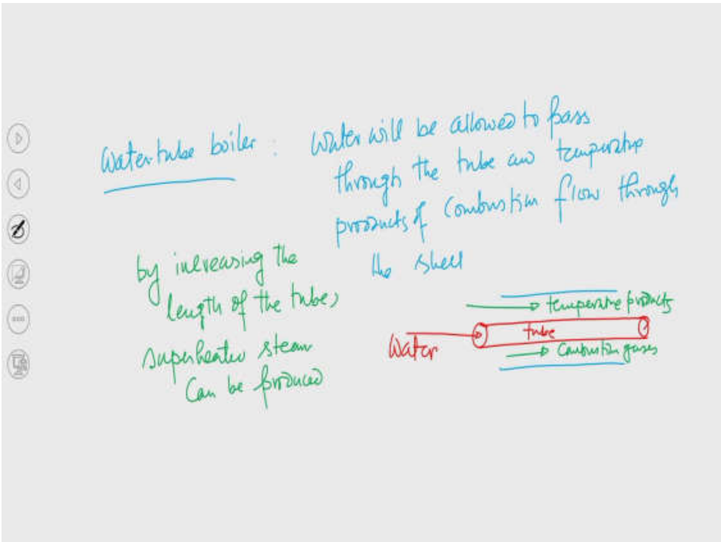

Fire tube boiler example is Cochran boiler and example of water tube boiler is Babcock-Wilcox boiler. See in water tube boiler, the name itself suggest that water will be allowed to pass through the tube and product of combustion flows through the shell.

So, if we try to draw the schematics say this is a shell and we are having say multiple tubes. So, if this is the tube and through the tube, water is allowed to pass while through the shell, combustion gases or temperature product is allowed to pass over the tube. And while these two streams are passing, because of this heat exchange phenomenon, water will be converted into steam, one important thing that I would like to discuss over here is that since water is allowed to pass through the tube, by increasing the length of the tube, you can generate superheated steam.

So, maybe initially steam produced will be in contact with the water, but if we can increase the length of the water tube, then at the end of the tube, we will be getting superheated steam.

So, maybe 50 percent of the length, water and steam will coexist. So, if water and steam coexist, then the steam will be saturated steam, but in the remaining length of the tube, only we will be getting superheated steam. So, in this case, by increasing the length of the tube, superheated steam can be produced.

So, if you would like to summarize today's discussion, we have talked about what is reheat and then, we have started discussing about boiler, from this steady state steady flow energy equation, we have seen that if we supply energy by burning fuel, amount of energy required for the generation of steam to the energy supply to the boiler can be considered as the boiler efficiency.

And then, we have discussed about two different types of boilers which are used in different power plants that is fire tube and water tube boiler. In fire tube boiler, we have seen the name itself suggests that the thermal products of combustion will flow through the tube and the water will flow through the shell. Since water will be allowed to pass through the shell, always steam which is getting produced will be in touch with the water and as a result of which we will be getting saturated steam.

On the other hand, in case of a water tube boiler, as the name suggests water will be allowed to pass through the tube while the combustion gases will be allowed to pass over the tubes and while these two streams are passing, because of these heat exchange phenomenon, the water will be converted into steam, but by increasing the length of the tube, we can generate superheated steam.

So, this is an important aspects of this type of boiler. Since if we can generate superheated steam, we do not require extra or additional arrangements to have superheated steam from the boiler.

So, with this I stop here today. In the next class, we will be discussing about condenser.