Applied Thermodynamics
Dr. Pranab Kumar Mondal
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Steam Power System
Lecture - 19
Condensers and Second law Analysis of Steam Power Cycle

We shall start our discussion today on Condenser and then we will try to discuss about Second Law of the Steam Power Cycle. In the last class we have discussed about steam generators, that is boilers and we have seen the classification of different types of boiler, and the problem associated of each type in the context of the operation of the steam power cycle.

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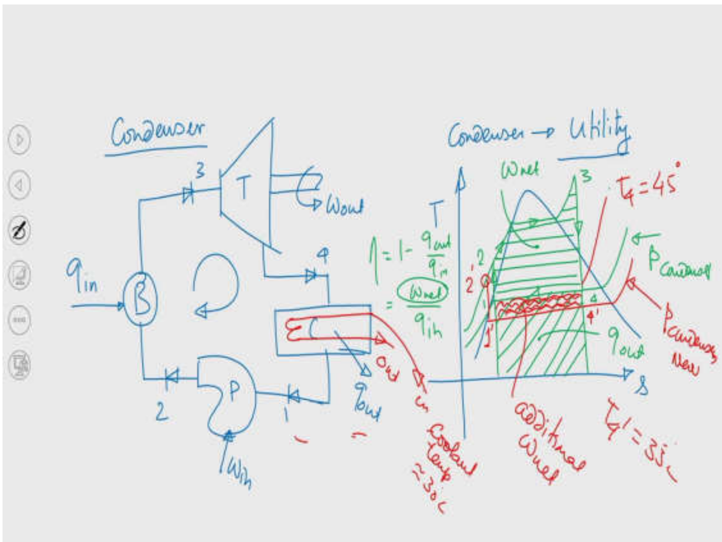

So, today we will discuss about condenser first and then we will discuss about the second law. So, this is boiler then steam is expanding and after doing work, steam is taken to this.

Now, we have discussed about the power cycle first, then we have discussed about turbine. And, yesterday we have discussed about the boilers that is steam generators. And, today we shall discuss about condenser.

So first of all if we try to discuss about the necessity of having this equipment in this cycle. If, we look at this diagram, we can see that this condenser is an important component for this cycle. Now, what is the need of condenser? We know that we are supplying heat into the boiler and upon receiving heat, water is getting converted into steam and that steam is allowed to expand in the turbine and from there we are getting work output.

After doing some work, steam is allowed to go through the condenser, wherein we are having heat rejection. So, question is we are supplying heat by burning coal or burning fuel? If it is coal fired boiler, then this energy will coming from the coal combustion. If it is diesel fired boiler then energy is coming from the diesel combustion.

Now, at the cost of that input energy we are getting some work output. And, we have discussed in the last class that the work output is not equal to the heat that is being added into the system. And from there we can classify that work is high grade energy and heat is low grade energy.

Because the amount of heat added into the system is not getting converted equally into the same amount of work. So, we can classify rather we can grade the energy, that is work and heat in different forms.

So, what is important that, the work output is not equal to the heat input and some amount of energy is getting rejected in this condenser. So, why do we need to have this particular equipment? Knowing fully that energy is added out of this energy either by burning coal or by burning diesel. So now, at the cost of that input energy, why we need to have this amount of heat rejection.

So, the condenser utilities second law of thermodynamics; second law of thermodynamics puts a restriction that if we need to run the system in a cyclic manner, after extracting the maximum amount of work, we could have directly discharged that steam into the surroundings.

But, in that case it would not have been possible to operate the system in a cyclic manner. So, to operate the processes in a cyclic manner we must have a sink where in heat should be rejected and that is second law of thermodynamics. It is impossible to construct a engine or device, which will operate in a cycle while exchanging heat with single temperature thermal reservoir.

So, maybe you were having this source that is one temperature reservoir from where we are supplying heat into the system, upon receiving that amount of heat we are getting work output. But, to satisfy the second law of thermodynamics there must be a heat sink and that is why this condenser is used.

So, the necessity of this condenser is that knowing fully that we are going to have rejection of certain amount of energy. Though that energy was added into the system by burning coal or burning fuel, still we are going to reject this, why? Only to have the cyclic process.

Now, this is the T s diagram; that means, we have been able to map the processes which are there in this cycle in this thermo dynamic plane. The process 4 to 1 is the condensation process. So, this is $P_{condenser}$. So, this area in T-s plane will essentially signify this as q_{out} and this is the area which is the w_{net}. Our objective should be to increase the efficiency of the plant, now the 4 to 1 is the condensation process that occurs at a constant pressure. So, heat will be rejected from the steam.

Just without going into the physical aspects or physics of this, if we try to look at the T s plane; so, our objective should be to increase the area that is w_{net}. So, if we get higher w_{net} efficiency will be high because $\eta = 1 - \frac{q_{out}}{q_{in}} = \frac{w_{net}}{q_{in}}$. So, if we increase this quantity efficiency of the plant will increase. So, what we can do, this condensation process is occurring at a constant pressure that is $P_{condenser}$, we can reduce the pressure at which condenser is operating.

Try to understand if we allow the condenser to operate at that pressure that is P condenser new, perhaps this is the amount of w_{net} we are getting additionally. So, I have shaded this portion using red color. So, this is the extra amount of work that we will be getting if we allow a condenser to operate, at a pressure which is less than the previous pressure.

So, heat is getting rejected at the condenser by suitably operating the condenser, we can control the heat or that amount that will be rejected from the system into the surroundings. And, we may get higher work output. Since, this much amount of additional w_{net}, then we can have relatively higher efficiency of the plant.

So, now, I will be coming to the question that the condenser is a component wherein we will be having heat transfer. Though, we can assume that all the processes are internally reversible, but transfer of heat from the steam into the water needs to be understood.

So, we are supplying coolant that is water from the nearby lakes, ponds. And, that coolant is supplied. Now, from that coolant when the steam is coming out from the turbine, either coolant will be allowed to mix with the incoming steam, so that temperature of the steam can be reduced and eventually the condenser that will be collected will be pumped back to the boiler.

Now, in direct contact type, this coolant will be allowed to mix directly with the incoming steam from the exit of the turbine. In that case, again it should have a kind of device in which the amount of steam that we are getting out of the turbine exit, that equal amount of condensate will be pumped back to the boiler. And, remaining amount will be transferred back to some places.

Now, if it is indirect type that coolant is coming through the pipe and steam is allowed to pass over the pipeline. In that case also we will be having heat exchange phenomenon. And, because of this we can reduce the temperature of the steam and that condensate will be again pumped back to the boiler.

So, whether it is direct type that is coolant is allowed to mix directly with the steam or if it is indirect type that is coolant is allowed to pass through the pipe and steam is allowed to pass over the pipe. In both the cases we will be having heat loss. And, this heat loss is due to finite temperature difference and it will lead to the external irreversibility of the system.

So, though all the processes are internally reversible, heat gained into the system due to finite temperature difference is externally reversibility. It is not necessary that the coolant temperature will be fixed always, if we maintain the coolant temperature at 30°C and if we can make sure that the heat transfer will be due to finite temperature difference. Then, steam temperature will be relatively higher. If, I allow steam to expand up to this 4`; then the steam temperature at the exit of the turbine will be 35°C.

If I consider T4 say 45°C and if I supply coolant which is having temperature 30°C, then heat transfer will be due to 45 - 30, so, 15 degree temperature difference.

If, I allow steam to expand further; that means, I am trying to extract more amount of work output. In that case temperature at the exit of the turbine will be 35 and that will lead to the temperature difference smaller as compared to the previous case. If we can reduce the temperature difference, we will be in a position to reduce the irreversibility.

So, you can see at the cost of that reduction in irreversibility, work output from the system will be more which in turn will increase the efficiency of the system. Now, question is if we allow steam to expand further up to point 4`, the corresponding saturation pressure will be less. Say, if it is a $P_{condenser}$ in first case and if it is atmospheric pressure, the saturation temperature corresponding to atmospheric pressure is 99.9. In that case, if the coolant temperature is 30 degree so, high degree of irreversibility will be there. So, to account for that particular aspect, condensers are allowed to operate at a reduced pressure that is at a low pressure than the atmospheric pressure.

So, when we are allowing the steam to expand further and further. So, you can see the P condenser new is again less than P condenser. Question is if I allow the condenser to operate at a pressure, which is significantly less than the atmospheric pressure, chances will be there that air might leak through different parts into the condenser. So, air leakage problem would be there.

So, what we can do to summarize see, we are allowing steam to expand further and further. It is because of this reason we can have higher thermal efficiency. But, we are also going to invite one problem, that if we allow turbine to expand turbine further, the temperature at the exit of the steam will be say close to 40 degree. In that case, because of this difference in temperature between coolant and the steam exit temperature at the turbine, the degree of irreversibility can be minimized.

So, in a way we can get higher work output, but at that temperature the saturation pressure will be significantly less than the atmospheric pressure. So, when the condenser is operating at a pressure which is significantly below the atmospheric pressure, the leakage of air into the condenser that problem will be there.

So, the designer will be in trouble to design such a component which will be operating at a pressure which is significantly less than the atmospheric pressure. Not only that the air leakage into that condenser.

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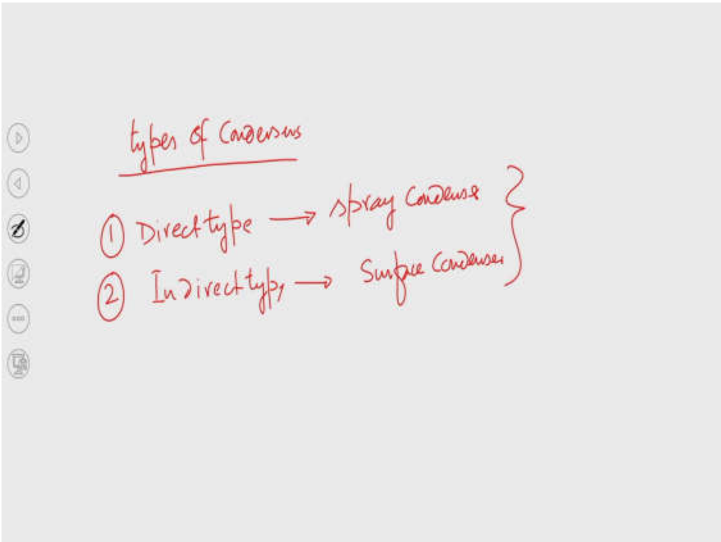

So, let me discuss about the different type of types of condenser. 1) direct type; 2) indirect type. So, direct type is spray condenser, and indirect type is surface condenser.

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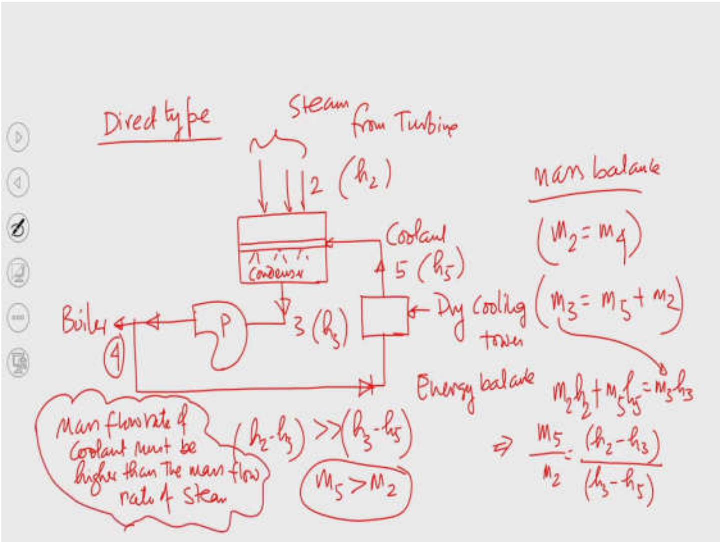

See, if I try to discuss about direct type. What is done? So, we will be having coolant and, steam will be allowed to spray on this coolant. Coolant is allowed to pass through the pipe and in the form of a spray steam is coming from the top and so these two streams will mix together and, the collected condensate will be pumped back to the boiler to boiler.

So, the coolant will be allowed to mix with the steam. So, the amount of condensate that we will be getting is higher than the mass flow rate of working substance in the cycle. So, we know the mass flow rate of working substance in the cycle, but since we are externally supplying coolant. So, this externally added coolant will increase the mass flow rate. So, we need to ensure that when it is pumping, the required quantity is going to the boiler. Remaining quantity will be taken to the dry cooling tower, why? Because, it is the coolant which is coming out it is not dry. So, as long as it is allowed to go again through the condenser, then the efficiency will reduce. So, we need to ensure that the coolant before going into the condenser it should be dry.

So, now, what is the mass balance? See $m_2 = m_4$. So, the amount of condensate will be supplied to the boiler is equal to the steam mass flow rate that is taken into the condenser and $m_3 = m_5 + m_2$. What about energy balance?

See, if we consider this as h_2 enthalpy, this is h_5 and this is h_3. See if we do the energy balance applied to this particular component according to SFSS, then we can write that $m_3 h_3 = m_5 h_5 + m_2 h_2$. By simple algebraic step and you will be getting $\frac{m_5}{m_2} = \frac{h_2 - h_3}{h_3 - h_5}$.

What you know from this equation is that, $h_2 - h_3 \succ\succ h_3 - h_5$, that means the mass flow rate of coolant will be much higher than the mass flow rate of steam. So, if we try to have efficient cooling essentially to allow the system to run smoothly, the mass flow rate m_5 will be much larger than steam flow rate. So, mass flow rate of coolant will be much higher than the rate of steam.

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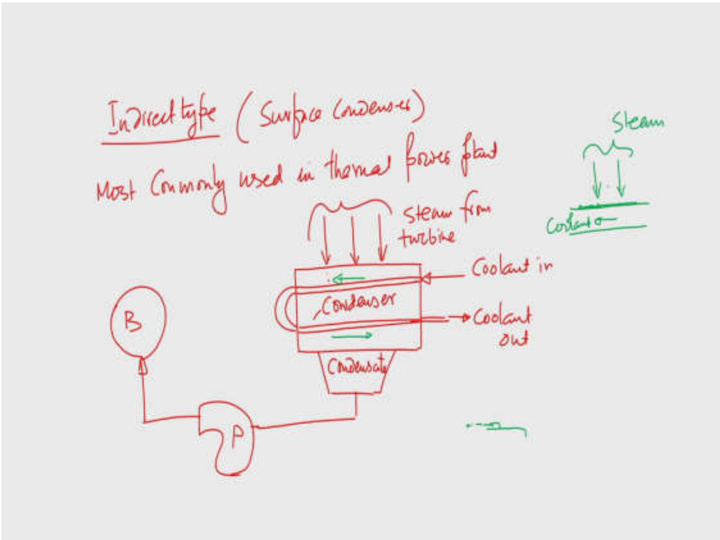

Next we talk about indirect type, which is commonly used in most of the thermal power plant. So, indirect type is surface condenser. Since it is indirect type, steam will be coming from the exit of the turbine and, coolant will be allowed to pass through the tube. So, this is coolant out and this is coolant in.

So, this is steam from turbine. So, steam will be allowed to flow over the turbine and we will be collecting the condensate and it will be pumped back to the boiler. So, this is condensate and this is condenser. So, this is pump and it will go to boiler.

So, this is the indirect type. Why it is called indirect type? If I try to write, this is the water flow direction and this is the steam direction. So, coolant is coming from the cooling tower, it is not a case that always coolant is taken from the nearby lake ponds.

From the environmental constraint, you are not allowed to directly discharge this coolant into the lakes, ponds, instead what is done? This coolant is taken in a cooling tower and the cooling tower is again a heat exchanger. Wherein by supplying air the coolant is again cooled down and temperature of the coolant is reduced and that is again taken into the condenser.

So, in this indirect type, the coolant is coming into the condenser, it is allowed to pass through the tube and steam is allowed to pass over this tube. And, when steam is passing over the tube by releasing heat it will condense and that is collected in this chamber and this condensate is again pumped back to the boiler. So, this is how cycle is completed.

Question is that you may have multiple pass or single pass. It is sometimes depending on the capacity of the plant, depending on the mass flow rate of steam that is coming from the turbine, size of the condenser, you may require to go multiple pass condenser wherein coolant will be allowed to pass multiple times. So, I mean it is up to the designer.

But, the idea is that steam will be allowed to pass over the tube through which coolant is flowing and because of this heat exchange, steam will release the temperature to the coolant and that heat will be taken away by the coolant. And, when steam is releasing heat it will condense and that condensed steam will be collected in this condenser chamber.

Question is as I told you that condensers are normally operated at a pressure which is sufficiently less than the atmospheric pressure. So, chances of air leakage through the condenser is not quite unexpected. So, rather it is expected that air will leak into the condenser.

So, steam will be getting condensed, it will form a drop. Now, as air leakage is quite expected; so, when steam is getting condensed that air film will create and that film will disturb the transport of heat.

So, when steam is getting condensed, it will condense in the form of a drop and eventually it will come out and it will be collected in this condensate chamber. But, the the leakage air, that will also try to condense in the form of a film and that film will reduce the heat transfer rate. Because, thin film of air will not allow to receive that heat by the coolant from the flowing steam. So, maybe we can operate this condenser at a reduced pressure, but we must be careful that the condenser will be leak proof. So, that air leakage problem should be minimized.

So, now, finally, I will discuss about one important thing what do you mean by condenser efficiency.

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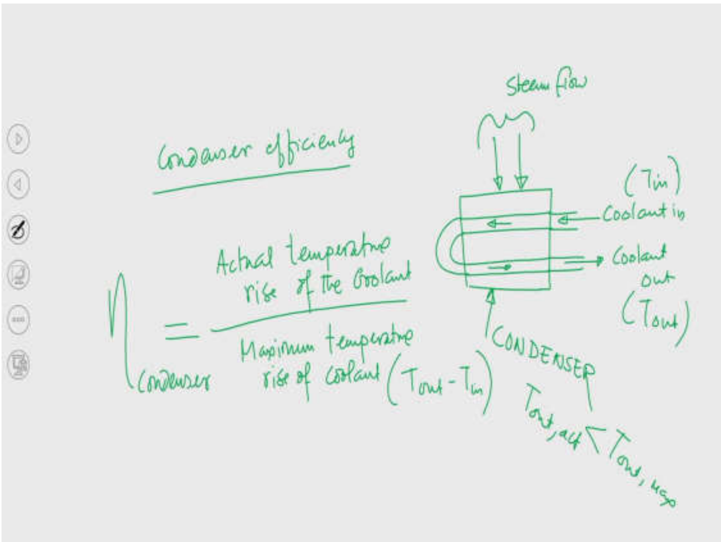

What do you mean by condenser efficiency? Let us say it is surface type condenser. The coolant is used to reduce the temperature of the steam. So, in the process of this cooling, temperature of the coolant will increase that is quite obvious. So, basically we can write efficiency as the actual temperature rise of the coolant to the maximum temperature rise of coolant.

When we are supplying coolant to this condenser and this device will be operating at a pressure which is less than the atmospheric pressure that is quite obvious. If we allow the condenser to operate at atmospheric pressure, then the saturation temperature corresponding to that pressure is 99.99 and; that means, steam temperature at the exit of the turbine should be 99.99.

So, when the steam temperature is 99.99 and coolant temperature is 30 degree. So, you can see the temperature difference between these two different steams and as a result of this finite temperature difference high degree of irreversibility will be there. So, accounting for that high degree of irreversibility, the efficiency of the plant will be reduced.

So, to increase the efficiency in a way which I have discussed that without going into that much thermodynamics details, that if I reduce the condenser pressure, we can increase the area that is w_{net}.

So, if we reduce the condenser pressure; that means, I am allowing steam to expand further and further. So, that $T`_4$ will be very close to this coolant temperature. So, lower the temperature difference, lesser will be the irreversibility and efficiency of the plant will be high.

Now, we have also seen that if I reduce the pressure at which condenser is operating, we cannot eliminate the air leakage problem. So, air leakage problem will be there because this is mechanical device. So, when air is getting into the condenser, the following problem will be there. So, when steam will condense in the form of a drop and the air which is there due to the leakage, that air will create a thin film. And, that thin film air will lay on the tube surface and this thin film of the air will reduce the heat transfer rate.

So, eventually if we design this condenser that this will be coolant in temperature T_{in} and this is the T_{out}. So, maximum temperature rise of the coolant is T_{out} - T_{in}.

But in reality we will not be able to get this amount of temperature rise of the coolant, why? Because the problem due to the formation of thin film of air heat transfer rate will be disturbed.

So, actual temperature rise of the coolant will be always less than the maximum temperature rise. So, basically designed T_{out} will never be reached. So, T_{out} actual will be always less than T_{out} maximum because of the poor heat transfer. And, if I take the ratio of this two quantities we can define efficiency of the condenser.

So, to summarize today's discussion we have talked about condenser, we have seen the necessity of having condenser in a steam power plant, we have also discussed about that why by operating the condenser at a suitable pressure, we can control the efficiency of the total plant.

Now, when we are talking about increased efficiency, if I allow the condenser to operate at a low pressure, we are also going to invite another problem of air leakage. And, this air leakage problem also will try to reduce the efficiency of the condenser.

So, with this I stop here today. And, in the next class I will be discussing about second law analysis of the power cycle and we shall try to solve one or two problems and then we will complete our topic.

Thank you.