Applied Thermodynamics
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Steam Power System
Lecture - 06
Thermodynamics aspects of Steam Power Plant – Efficiency and Work ration

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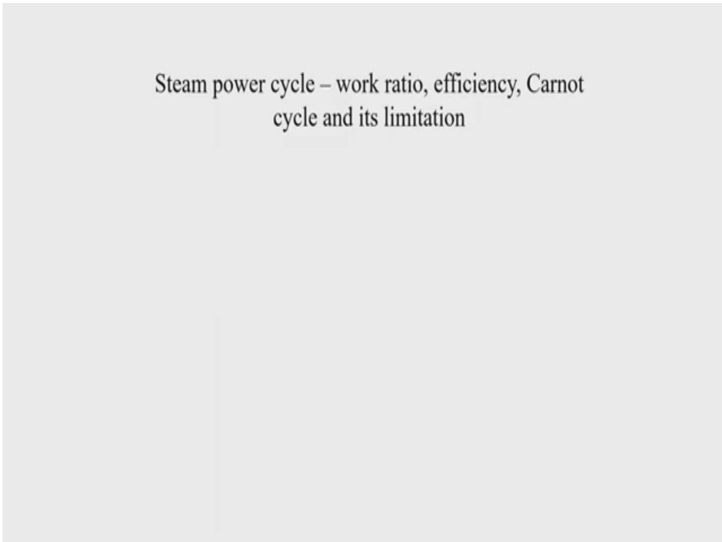

I welcome you all to the session of Applied Thermodynamics and we shall discuss today about the work ratio, efficiency, then we shall go to discuss about the cycle which are used to analyze the performance of the steam power cycle. So, if you try to recall in the last class we have just discussed about several components which are there in a steam power plant to be precise, though we did not discuss about the minor equipment, but still if we can recall we have discussed about the major equipment.

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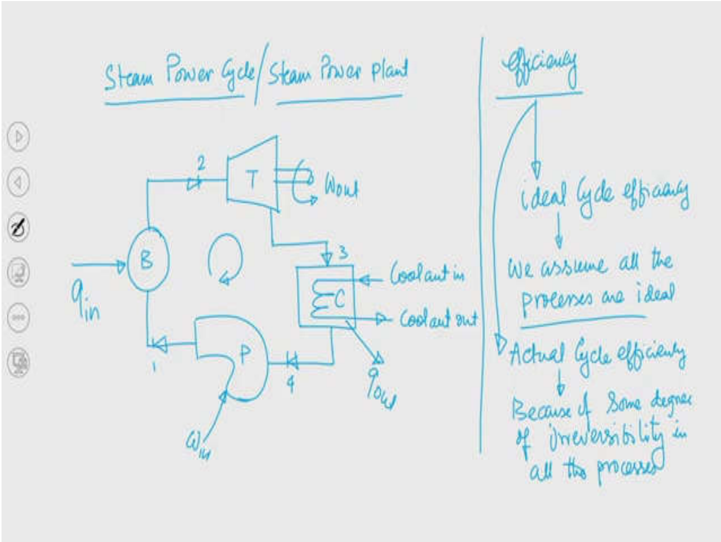

So, if we try to recall what are those equipment? So, if we write steam power cycle or I can write steam power plant briefly we will draw this line diagram which we have seen in the previous class. If we give the name this is 1, this is 2, this is 3 and this is 4, and this is the circuit or this plant is running in a cyclic manner.

So, this is what we are seen in the last class and we have discussed about the objective of several at least this four major equipment in this circuit. Now, what I would like to discuss today? We would like to discuss today a few index before I go to discuss about the Carnot cycle.

Now, this is the line diagram. This is the very simplest diagram to understand. Now, at least we have understood from the previous class is that the working substance for this particular cycle is steam water mixture.

Now, when the working substance is entering into a particular equipment and when it is coming out from that equipment there is a process and those processes we have identified. In a pump there is rise in pressure of the condensate which is collected from the condenser.

The purpose of the pump is having to develop pressure. Now in a boiler when the liquid water is allowed to go to the boiler upon receiving heat from the external source that is what is shown over here by this q_{in}. Water will be converted into steam and that steam will be again taken to the turbine, not directly to the turbine, but before steam enters to the turbine it will flow through the nozzle. Those are known as flow nozzles.

We shall discuss on this particular topic, but I did not show those nozzles over here. And, while steam is expanding in the turbine you can understand that you know this is turbine and this is condenser C. Now, you can understand though it is schematic depiction, but the turbine shape is kind of diffuser.

So, you can understand that while steam is flowing through the turbine it will expand. And, while it is expanding it does work on the wheel of the turbine and then we are getting work output and finally, after doing some work, steam is collected to this particular equipment which is known as condenser wherein, the coolant is circulated through this coil and over the coil steam is allowed to pass and by virtue of heat exchange, the steam is getting condensed into water. We will definitely have different pressure and temperature and that condensate is again collected at the bottom of the condenser and pump back to the boiler. So, this is the cycle.

Now, if this is this the cycle at least we should know the cycle efficiency, right. Why? Because you can understand we are supplying energy in the form of heat here. Now, this cycle is there even for the nuclear power plant. So, this heat energy for the thermal power plant is supplied by burning coal. If it is diesel fired plant then definitely the energy will come from the diesel from the fuel.

So, whatever may be the case whether it is coal fired plant or it is diesel fired plant, so, in a thermal power plant this heat energy is coming from the combustion of the coal. Now, that means, we are supplying heat energy and at the cost of that heat energy you are getting work output and that is why we need to calculate efficiency.

So, we can understand that this part is there because we need to run this cycle in a cyclic manner and as I said in the last class that second law of thermodynamics puts a restriction that we should have a place wherein heat must be rejected and that is why this condenser is there. So, what we can understand from here is that we are supplying some amount of energy to the circuit and at the cost of that energy you are getting some amount of work output, but that is not equal to the energy that we have supplied. So, some part of the energy is getting rejected.

So, considering this aspect we need to know what will be the efficiency because where we are having energy conversion we need to have efficiency.

May be efficiency can be defined from different perspective, but question is efficiency what we have understood that we need to define one index by which we will be able to understand the performance of the plant.

So, basically at the cost of that energy what is the output we are getting? So, input energy is there. So, out of this input energy what fraction we are getting as the output energy.

So, now, I am talking about efficiency that is very important. So, if we talk about efficiency, efficiency of the thermal power plant. This is very important when we analyze cycles; so, this is a steam power cycle. As I said you in the last class that there are two different cycles either gas power cycle or steam power cycle.

So, that depends on the working substance whether it is steam power cycle or gas power cycle; we analyze the cycles because our objective is to predict the efficiency. What I said that there is a pumping process: process inside the boiler, also there is a process inside the turbine and finally, in the condenser. So, all these processes constitute together to form the cycle.

So, eventually if we consider the all these processes will be recovered to calculate the efficiency of the plant. So, when we are trying to calculate the efficiency of a plant what we assume we assume all the processes are ideal.

So, basically what we do normally we consider we assume all the processes which are there in the circuit are ideal processes. If all the processes are ideal, the corresponding efficiency is called as ideal cycle efficiency.

So, one is called ideal cycle efficiency. So, here we assume all the processes are ideal, but again we have understood from the basic thermodynamics course that in a process some degree of irreversibility is there.

So, though we have just now discussed that to calculate the efficiency of the plant we assume all the processes are ideal that is pumping process is ideal, boiling inside the boiler that is also ideal, expansion of the steam inside the turbine that is also ideal and finally, condensation of the steam or rather condensation of vapour and that is also the ideal process. But, this is not the case in reality.

In practical scenario some degree of irreversibility will be there in all the processes. If we take those irreversibilities into account, so, some degree of irreversibility is there in the pumping process; some degree of irreversibility is there in the boiling process that is boiling of liquid; some degree of irreversibility is there in the expansion process of the steam inside the turbine.

And some degree of irreversibility is there in the condensation that is the condensation of vapour into the liquid. So, basically if we consider all these irreversibilities, so, the ideal cycle efficiency will not be the ideal one. So, we are we will be getting actual cycle efficiency here and that is what we have learned from basic thermodynamics course as well as you have learned from the fluid machines that is hydraulic turbine and pump.

So, basically another efficiency that is also known as actual cycle efficiency and this actual cycle efficiency is coming into the picture because of the thermodynamic irreversibility that is there in all the processes which we have discussed till now. So, this is because of some degree of irreversibility in all the processes.

Now, basically we can see that there are two different efficiencies – one is ideal cycle efficiency that we can understand, but considering the thermodynamic irreversibility we also need to define another efficiency that is actual cycle efficiency. Now, the ratio of these two efficiencies, that is the ideal cycle efficiency to the actual cycle efficiency that is known as relative efficiency.

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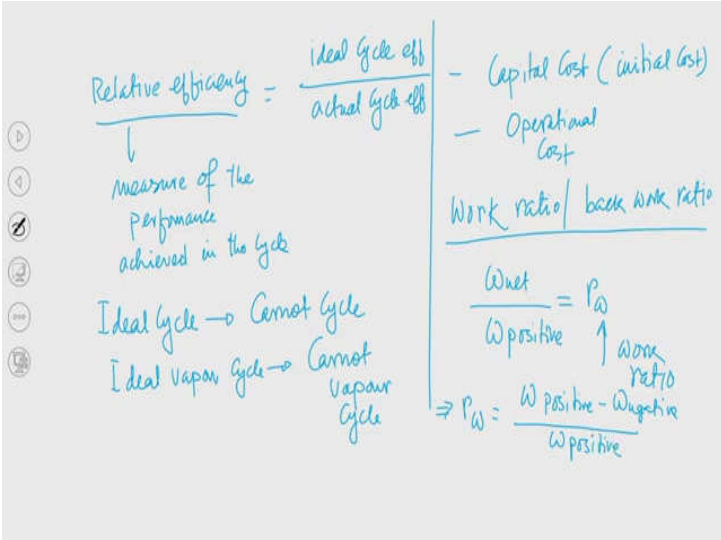

So, basically I am telling for the sake of completeness that till now we have discussed about two different efficiencies. So, relative efficiency which is nothing but the ratio of the ideal cycle efficiency to the actual cycle efficiency. Now, why we need to define this? So, if this relative efficiency is defined; that means, this relative efficiency is a measure of the performance of different cycles of the plant. So, basically this relative efficiency is a measure of the performance achieved in the cycle right.

Now, what I need to discuss that in the previous slide we have discussed about ideal cycle efficiency, all the processes are ideal. Now, you will be knowing that in many places, so far we have studied fluid mechanics, heat transfer and also thermodynamics, if we talk about the subjects from the thermal fluid sciences. Now, you have seen in all subjects we do analyze the ideal cases, ideal efficiency.

For example, for the hydraulic turbine again if you can recall we do analyze the ideal efficiency. For the heat transfer case, for the fin efficiency that is again ideal fin efficiency. So, the word ideal we consider so, why do we need to consider this particular term though we are very much you know familiar that in real practice the efficiency output what we will be getting those are not the ideal, those are the actual.

So, knowing a-priory that the efficiency output everything will be actual. So, that output will be always lesser than that predicted by any equation that is the ideal one, but we always study this. So, the purpose is to study the ideal efficiency is to compare the performance of the actual one.

So, basically that is there everywhere. Even in a class for the relative grading system if you would like to give grades to the students whose performance is not very good, but always we need to standardize, we need to compare the performance of a student with the performance of the student who is the topper in the class. So, always we do that.

So, basically here also though it is very difficult to achieve ideal efficiency in practice, but still we do analyze the ideal cycles. The sole purpose is to compare the efficiency of the actual cycles. So, how close we can reach. So, basically if we consider the actual cycle in real practice so, our objective should be to optimize the cycles, different processes in the cycle so that we would not be able to meet the ideal cycle efficiency, but at least we can reach closer to that. So, that is why the concept of ideal cycle efficiency is there. Now, when we talk about any cycle; so, basically for the ideal cycle we must understand the ideal cycle efficiency and this is done only to compare the efficiency of the actual cycles.

We have studied in classical thermodynamics that there are many ideal cycles, but the Carnot cycle is considered first and then other cycles are considered. Accordingly, among the ideal cycles Carnot cycle is considered first. So, if we now consider the ideal vapour cycle or ideal steam cycle then again Carnot steam power cycle or Carnot vapour power cycle will come first.

So, now if we try to compare that ideal, so, the Carnot cycle is considered first and similarly, ideal steam power or vapour power cycle. So, basically this is the cycle which is steam power cycle, but sometimes it is also known as vapour power cycle.

So, basically if the Carnot cycle is considered first then ideal vapour cycles should be Carnot vapour cycle. We shall discuss on this about the cycle, but at least before I go to discuss about the cycle, but just only recapitulate whatever we have learned I will discuss.

Now, before I go to discuss this topic it is essential to know that we are talking about ideal cycle efficiency. So, basically if we consider rather if we think that there will there is a steam power plant. So, basically if you like to know what will be the efficiency of the plant, there are two different aspects. One is the capital cost or which is also known as initial cost and other is the operating cost.

So, basically you can understand when we talk about efficiency, we understand operating cost; that means, you can understand we need to supply energy. So, we need to burn coal. So, for that, that is the operating cost. We need to supply coolant to condense to reduce the temperature of the steam which is coming out from the turbine. So, in all these cases we are having operating cost.

So, all these costs should be you know combined together to understand what is the operational cost. So, operational cost is an indirect measure of the efficiency that we are talking about. So, to operate the system here we are having input energy, here we are having circulation of the coolant, we are also having work input to the pump.

So, basically I mean a cost which is associated with the operation of this pump, operation of this condenser, operation of this turbine, operation of the boiler. So, operational cost is there. Also, the capital cost or initial cost is there. So, initially we need to install pump, install boiler, install turbine, install condenser. So, depending on the size of the plant you know how much work output we need from this particular plant, this capital cost or initial cost will depend.

So, basically when we will consider under a particular cycle then this choice depends on two important aspects. One is called capital cost or initial cost, other one is called the operational cost. So, now, that is very important. So, we have understood what is capital cost and what is operational cost. Now, we should again understand that there are indices which are used to you know define the cost that will be associated with the capital one and the operational one.

So, we have understood that if you would like to get output from a steam power plant depending on the amount of work that we get from this plant, size of the plant will depend. So, capital cost is depend on the size of the plant. So, size of the plant will dictate the capital cost and once it is there, then to operate it we have discussed that another cost will be there and that is the operational cost. So, basically these two costs we have understood.

Now, to quantify these two cost again there are indices which are used. One is known as work ratio or back work ratio. So, these two term will be defined. We will define now. What is work ratio and then what is back work ratio.

See, just if you look at the schematic, you can see that we are getting work output at the cost of this heat input that is given to the boiler. Now, this workout is not only the work output right. So, the net work output is something else because a part of the work output is getting or is consumed by this pump. So, we are getting work output from the turbine a part of which is getting consumed by the pump. So, the net work output is not the w_{out}.

So, the net work output is something that we will discuss, but in the circuit what is the positive work? So, if we think that this is the positive work we are getting, but this work can be viewed as the negative work that is being supplied to the cycle.

So, this is the amount of work we are getting from the cycle, while to get this work output we also need to give this work as the input work to the cycle. So, this work can be viewed as the negative work. So, that means, total work the net work by the positive work is known as work ratio r_w. So, this is work ratio.

So, that means, this work can be viewed as the positive work; that means, we are getting from the cycle by doing this and also by running this plant we are getting this amount of work that is the positive work. So, this work is not the positive work. So, this is the work we are getting as a positive work, but this is not the net work. So, this is the positive work this is the negative work. So, the net work by positive work is known as work ratio.

So, basically you can understand this r_w can be written as $\frac{w_{positive} - w_{negative}}{w_{positive}}$.

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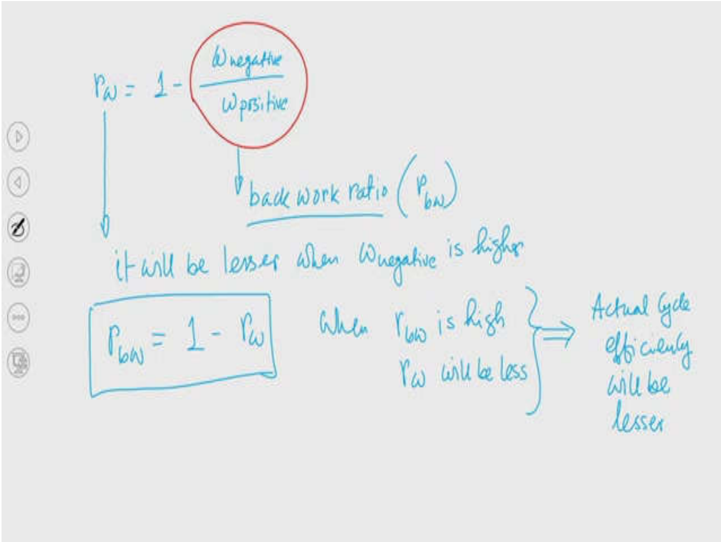

So, this work ratio $r_w = 1 - \frac{w_{negative}}{w_{positive}}$. So, this is the work ratio. You can understand that the ratio of negative work to the positive work is a decisive factor for the efficiency of the plant. So, we are supplying energy at the cost of this energy you are getting work output, but that work output but this is not the net work output. Though it is positive work, but this is not the net work.

So, work which you are getting from the turbine though it is the positive work because we are getting from the cycle itself and this is the negative work because we are giving to the cycle. So, basically though it is positive, but that is not the net.

So, basically what we can understand from this that ratio of negative work to the positive work which is the decisive factor for the efficiency of the plant. Now, the ratio of this quantity is also known as back work.

So, now I would like to discuss two important points for this particular case that if the work which is being supplied to the pump for the operation of the cycle is a significant part of this positive work, then definitely what will happen?

This quantity will be high and then the efficiency of the plant will be lesser. So, basically you can understand if $w_{negative}$ is a significant part of the positive work, then r_w will be less. So, basically if $w_{negative}$ is high that is significant part of the positive work so that back work ratio will be high. So, cannot we write that as back work ratio or r_{bw}.

So, we can write back work ratio $r_{bw} = 1 - r_w$ that we can write from this expression. So, if this amount is significant part of this positive work, work ratio will be less if this becomes higher work ratio will be less back work ratio will be high. So, that is quite obvious. So, work ratio is less back work ratio will be high. Now, if work ratio is less then you can understand what will happen? Efficiency of the plant will be lesser.

Now, you will be understanding that ideal cycle efficiency. So, this negative work will be a significant portion of this positive work if the irreversibility associated to this pumping process is very high.

So, if some degree of irreversibility will be there when the pump is executing the process. then we need to provide more work input.

So, the $w_{negative}$ will be definitely a significant part of the positive work when degree of irreversibility associate to the pumping process is very high. Now you can understand that when we talked about ideal cycle efficiency and actual cycle efficiency. Ideal cycle efficiency when we have defined we did not take into account the degree of irreversibility.

So, if we consider the degree of irreversibility then actual cycle efficiency is there. Now, that too depending on the degree of irreversibility actual cycle efficiency will depend. So, if the degree of irreversibility is more, actual cycle efficiency will be less. So, what we what we have understood that when these back work ratio is more, that is negative work is a significant portion of this positive work.

Then, the degree of irreversibility associated with the pumping process is high and then definitely it is not the ideal cycle. So, degree of irreversibility is there, that is definitely actual cycle and that too if the degree of irreversibility is high, actual cycle efficiency will be less.

So, basically what I would like to conclude is that higher the back work ratio, actual cycle efficiency will be less. It does not matter whether the ideal cycle efficiency is less or high. I hope you have understood. So, what I would like to tell you when the back work ratio is very high work ratio will be less.

So, when r_{bw} is high, r_w will be less then consequence is actual cycle efficiency will be lesser. So, basically that is the case. So, if back work ratio is high, work ratio will be less; actual cycle efficiency will be less. Now, we have written here the actual cycle efficiency will be laser, but we did not talk about whether the ideal cycle efficiency will be lesser or higher. So, it does not matter whether the ideal cycle efficiency will be lesser or higher, our objective should be to always obtain higher work ratio and lesser ideal cycle efficiency.

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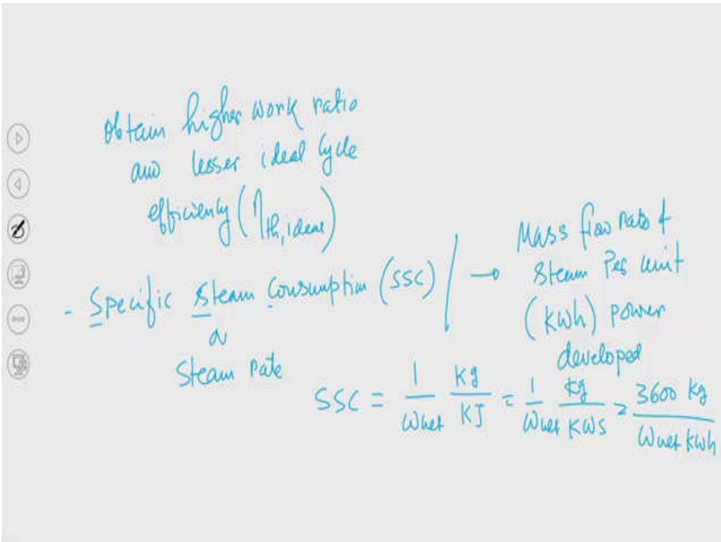

So, our objective should be to always obtain higher work ratio. For that whether the ideal cycle efficiency is less or high that we should not have botheration rather we should only be careful to obtain higher actual cycle efficiency. If you would like to have higher actual cycle efficiency we should have higher r_w. So, that is the work ratio should be higher.

So, this is one index to compare to see the performance of the plant. So, as I said that ideal cycle efficiency and actual cycle efficiency, but at least to quantify those there are these two different indices one is the work ratio and back work ratio that we have already defined another is known as you know as specific steam consumption SSC.

So, this is another important index which is used for the comparison of the steam power cycles is this specific steam consumptions or sometimes specific steam rate. So, basically what is specific steam consumption SSC or steam rate? So, this is another important index which is used to compare the performance of the steam power cycle. What is this?

So, this is nothing but mass flow rate of steam per unit kWh power developed. So, this is basically mass flow rate of steam per unit power developed.

So, if we write this SSC that is specific steam consumption that is nothing but $\text{SSC} = \frac{1}{w_{net}} \frac{\text{kg}}{\text{kJ}}$. So, that is mass flow rate of steam per kilowatt of power developed. So, this is $\frac{1}{w_{net}}$. Now, if we can write what is kilo Joule? That is kilo watt second.

Now, $\text{SSC} = \frac{1}{w_{net}} \frac{\text{kg}}{\text{kJ}} = \frac{1}{w_{net}} \frac{\text{kg}}{\text{kWs}}$, but this is the specific steam consumption. So, mass flow rate of steam, but we have to define per unit power which is kilo watt hour not kilo watt second so, that is nothing but $\text{SSC} = \frac{3600}{w_{net}} \frac{\text{kg}}{\text{kWh}}$.

So, we have to define mass flow rate of stream per unit power, but in the form of kilo watt hour. So, from this at least we have been able to arrive here that is nothing but $\text{SSC} = \frac{3600}{w_{net}} \frac{\text{kg}}{\text{kWh}}$. What we can see from this expression? As I said this is again another important index which is used to compare the performance of the steam power cycle.

So, you can understand higher the SSC less will be w_{net}. If w_{net} is less, then what will be the consequence? Consequence will be the efficiency will be less. So, if we get w_{net} is less then work ratio will be less. If work ratio is less efficiency will be less. So, that means, higher the SSC that means mass flow rate of steam will be high. Again, I am telling, if you need to ensure that the work output that means, the electricity that we demand from this particular plant should be very high, then plant size will be high. The plant size will be very high which in a way indicates that the SSC will be high.

So, if SSC is very high, then we have seen that w_{net} should be less. So, if you would like to have bigger plant, higher capital cost, then w_{net} will be very small and efficiency will be less. Now, if SSC is very small, w_{net} will be very high. So, you can understand this is an important index which governed both the capital cost as well as the operational cost.

So, it is very important that we should understand. So, higher the SSC less will be w_{net}; if less is the w_{net} efficiency will be less. So, if you need to maintain the same efficiency, then operational cost will be high. So, basically I mean if if we provide the same heat input, but thermal efficiency will be less.

So, for this particular case we have understood that this parameter is very important. It governs both the capital cost as well as the operational cost. So, for the same heat input if this is bigger, then what will happen? This will be less. So, this will be less; that means, thermal efficiency will be less. So, this is very important to understand.

Now, at least we have discussed about work ratio and efficiencies and we have understood that there are two indices, one is work ratio and SSC specific steam consumption which governs both the capital cost as well as the operational cost. Now, we shall quickly discuss about the Carnot cycle.

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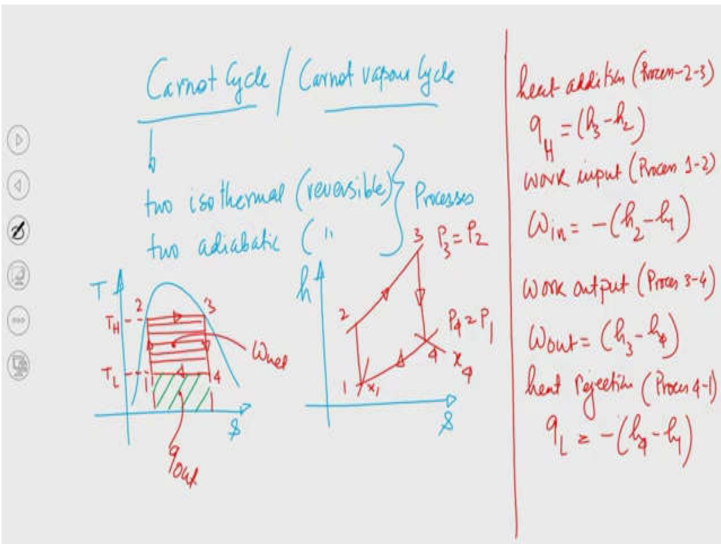

So, as I said this Carnot cycle to be precise Carnot vapour cycle. So, as I said that there are two efficiencies; one is ideal cycle efficiency, other is the actual cycle efficiency we have seen. But, again I am telling though it is difficult to achieve the ideal cycle efficiency in practice, but still we need to analyze it because we need to compare the performance of all actual cycles. If you would like to compare actual cycle at least we should have one index by whom we can compare with.

So, basically to compare the actual cycles at least we should have one cycle and that is the ideal cycle and for that we should understand this. Though you have studied this in thermodynamics, but I am trying to recapitulate. What is Carnot cycle? That is the ideal cycle considered first. So, there are two isothermal and adiabatic processes. So, two reversible and two adiabatic processes are there.

So, the cycle is having two isothermal of course reversible and two adiabatic reversible processes. So, if we try to draw the T-s and h-s diagram. If you now try to map all these processes corresponding to this particular schematic diagram in these two planes. So, now, if we consider this T-s diagram if we try to understand 1 to 2 that is we can see the constant pressure.

So, now you have understand this is constant pressure boiling. So, pressure is remaining constant, but temperature increases from T_1 to T_2. So, here you can see that the temperature increases from this T_1 to T_2 and this is isentropic process that is reversible.

So, basically two reversible isothermal, reversible adiabatic. So, you can understand two reversible isothermal process 2 to 3 and 4 to 1; constant temperature heat addition and constant temperature heat rejection that is what we have studied.

So, this is basically q_{out} and this is basically W_{net}. Here we have shown the point 2 and 3. The points 2 and 3 are shown on the saturated liquid line and saturated vapour line, but for the sake of generality these two points could be shown to be inside the vapour dome. So, now what is the h-s diagram? So, you can understand that this is x_4,

So, this is the h-s diagram you can understand. So, this is $P_3 = P_2$ and this is $P_4 = P_1$. You have studied two reversible isothermal, two reversible adiabatic processes which are shown in this T-s and h-s plane.

Now, I have shown the points 2 and 3 on the saturated liquid line and saturated vapour line respectively, but now at least we should discuss. So, if we consider then it can be shown that efficiency of the plant can be written in terms of the $1-\frac{T_l}{T_h}$; So, if you try to discuss about the efficiency of the plant. So, this is x_1. Again, I am telling just I have tried to represent all the processes which are there in the cycle in the T-s and h-s plane. So, 1 to 2 this is the process in which heat is added. So, 1 to 2 that is the heat addition.

So, if I try to write per unite mass that is $q_h = h_3 - h_2$. So, work input process 1 to 2. So, this is W_{in}. So, $w_{in} = -(h_2 - h_1)$. So, I have given negative work that is given into the system. Now, work output process 3 to 4 that is $w_{out} = h_3 - h_4$ and heat rejection that is process 4 to 1 $q_l = -(h_4 - h_1)$. So, again this is rejected.

So, I am writing following the convention of the first law of thermodynamics, I have written this is a negative sign. So, I have straightaway written this equation perhaps Professor Sahoo has discussed about the basic laws to describe to the content of the subject.

So, if we apply steady state study flow equation applied to the boiler, condenser, turbine and pump as I said you in the beginning in the last class that all these devices either heat interacting or work interacting devices. So, if we apply the steady state steady flow process applied to the you know boiler, pump, turbine and condenser we will be getting we can write this expression.

So, my objective is to calculate the efficiency. Since it is ideal cycle so, efficiency that will be getting by from this exercise again that will be the ideal cycle efficiency. So, you can understand from the T-s plane itself; so, the area which is shown by this hatch portion shown by the green color that is the q_{out}.

So, the hatched portions shown by this red color is the w_{net}. So, we can calculate that is w_{net} by q_{in} that is the efficiency.

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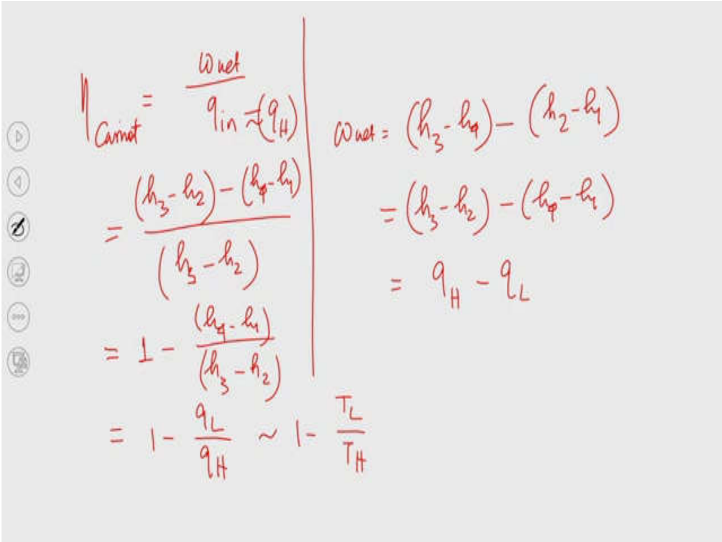

So, if we try to calculate the efficiency, thermal efficiency of the Carnot cycle $\eta_{carnot} = \frac{w_{net}}{q_{in}}$. Now, what is w_{net}? w_{net} will be equal to work output minus work input. So, $w_{net} = (h_3 - h_4) - (h_2 - h_1)$.

So, we can write this is as $w_{net} = (h_3 - h_2) - (h_4 - h_1)$. Why I am doing this? Now, you can understand this $h_3 - h_2$ that is q_h and $h_4 - h_1$ that is q_L so, this is nothing but $w_{net} = q_h - q_l$. So, now, what we can write that $\eta_{carnot} = \frac{(h_3 - h_2) - (h_4 - h_1)}{(h_3 - h_2)}$. So, this q_{in} for this particular case equal to q_h.

So, we can write $\eta_{carnot} = 1 - \frac{(h_4 - h_1)}{(h_3 - h_2)}$. So, this is the expression of the Carnot cycle efficiency. Now, you can understand $h_4 - h_1$ that is q_L. So, this is nothing but $\eta_{carnot} = 1 - \frac{q_l}{q_h}$. So, $\eta_{carnot} = 1 - \frac{(h_4 - h_1)}{(h_3 - h_2)}$.

So, you can understand, this process is basically these two processes are isothermal process. So, we can write this is $\eta_{carnot} = 1 - \frac{T_l}{T_h}$. So, you have studied from the thermodynamics course. So, that is the ideal cycle efficiency.

Now, in this particular case as I said you that these points 2 and 3 are shown on the saturated liquid line and saturated vapour line respectively. Now, as I told that for the sake of generality these two points could be shown to be inside the vapour dome. Now, what we can see from this process 2 to 3? That is there a phase change, right. So, saturated liquid is getting converted into saturated vapour.

So, when there is a phase change also you can see from point 4 to point 1. So, there is a phase change in a vapour cycle in two different processes – one is process 2 to 3, another is process 4 to 1. So, these two processes are isothermal processes. These two processes are easily attainable as the internally reversible process.

So, again try to understand when there is a phase change following this particular cycle, that processes 2 to 3 and 4 to 1 there is a phase change in the vapour per cycle. These two processes which are the reversible isothermal processes are easily attainable as the internally reversible cycle.

But, to convert saturated liquid into saturated vapour we had to supply heat that is transfer of heat externally for this boiling as well as we had to take out heat from point 4 and that is why this condensation takes place. So, heat transfer externally to the system from the system, for the boiling and for the condensation are highly irreversible process. So, basically though these two processes are internally reversible phase change process, but they are not externally reversible that you have studied in thermodynamics.

Now, very quickly I will discuss a few you know important points and that is known as limitation of the Carnot cycle.

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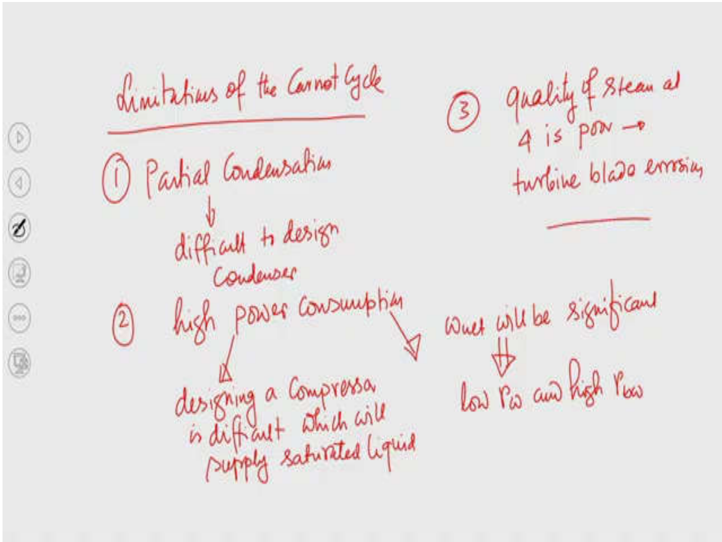

So, now this is the ideal cycle. Ideal cycle it is very difficult to implement in practice, it is very difficult to achieve in practice, but still we need to study it as because all the actual cycles will be compared with this ideal cycle. So, now at least time has come to understand what are the limitations, what are the drawbacks associated to this particular cycle.

So, you can understand one is that I told you that these processes are reversible though we have said, but maybe the these processes are internally reversible, but externally supplied heat from the external source to the system and heat transfer from the system to the surroundings because of the boiling and condensation; these two processes are not externally reversible.

First of all the condensation process starts from point 4 and it is getting terminated at point 1. So, it is very difficult that the amount of heat that should be taken away from this process that the condensation process will terminate at point 1 and that is called partial condensation. It is not that the liquid which will be getting saturated liquid. So, at point 1 it is 2-phase mixture; it is not the saturated liquid and that is partial condensation.

So, it is very difficult to design the condenser which will allow us to have this partial condensation and the condensation process will terminate at point 1. So, that is called number 1 is partial condensation – difficult to design condenser. Again, I am telling because this is not really achievable in practice, in practice we have to design condenser.

So, if we cannot design condenser which will work efficiently to have this partial condensation that is really difficult. This process 1 to 2 that is what we have seen from the schematic depiction that is pumping process, but pump cannot handle two phase mixture. So, we should have a compressor. So, pump cannot handle two phase mixture.

So, instead of a pump if you would like to design a steam power cycle following the Carnot cycle we must have a compressor. But, when we are designing a compressor to handle this two phase mixture power consumptions will be very high. So, the power consumptions will be very high; that means, the work input to this compressor will be a significant portion of the work output. So, eventually we will be getting high back work ratio, low work ratio, right. So, this is another important drawback.

So, that is high power consumptions and it is having two different problem, number 1 is designing a compressor, I will be discussing that too; another is high power consumption. So, w_{net} will be significant eventually we will getting low r_w and high r_{bw}. I did not write anything on this designing a compressor. So, basically till now we have understood that lower work ratio or high back work ratio.

Last point is that though we can run a compressor even compromising that efficiency of the cycle. So, low work ratio, high back work ratio; that means, efficiency will be very less. It is quite obvious because the power required to operate the compressor will be a significant portion of the work output. On the top of that it is again very difficult to design a compressor which we will take two phase mixture at it is inlet and it will give saturated liquid at the outlet.

So, you understand following the Carnot cycle if we design a compressor and the process will be 1 to 2, so, at the inlet to the compressor quality will be two phase mixture, but at the exit of the compressor, the liquid will be saturated liquid. So, again it is very difficult to design. Designing a compressor is difficult which will supply saturated liquid.

And, finally, let me write over here is that again if we try to design a steam power cycle following this Carnot cycle that is ideal cycle, the quality of the stream at the exit of the turbine is 4. So, it is again 2-phase mixture inside the vapour dome. So, if the quality of the steam is very poor. So, the steam which is coming out from the turbine is having high moisture content and that will lead to erosion or you know blade pitting of the turbine.

So, turbine blade pitting and turbine blade erosion; so, this is again very difficult. So, the quality of the steam at the exit of the turbine which is dictated by this point 4, so, this is the 3 to 4 that is the expansion process.

Now, for the poor quality, the moisture content of the steam at point 4 is very high which will lead to another important problem that is called turbine blade erosion. So, basically I am writing quality of steam at 4 is poor and it will lead to turbine blade erosion.

So, these are the different drawbacks we have identified and to overcome this drawback we need to have modification of the Carnot cycle and eventually we need to go to the actual cycle. So, those actual cycles we shall now discuss one by one and from the next class onward.

Thank you.