**Steam Power Engineering**
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**Lecture - 19**
**Practice Examples**

Welcome to the class. Here we will see one example of regeneration which we had not seen yet. This example says that a steam power plant has steamed with 90 bar and $500^o C$ at the inlet of the turbine.

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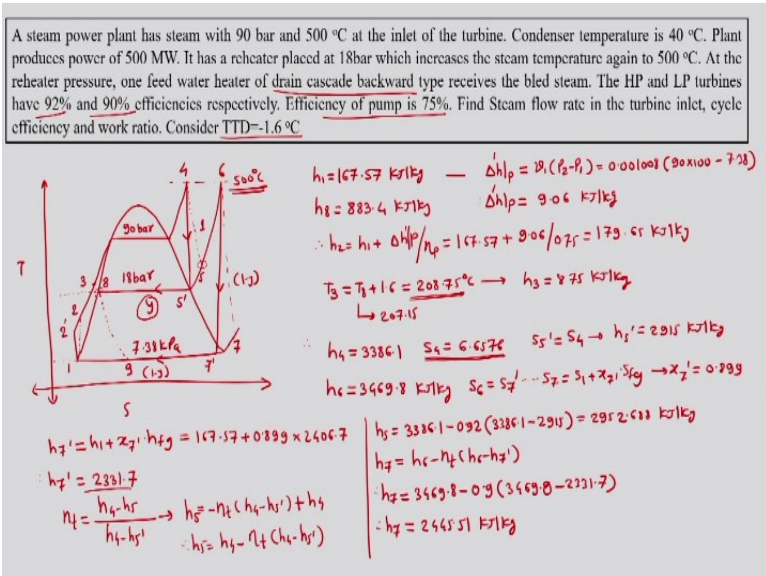


Condenser temperature is 40°C. Plant produces power of 500 MW. It has a heater placed at 18 bar, which increases the steam temperature again to 500°C. At the reheater pressure one feed water heater of drain cascade backward type receives the bled steam. The HP and LP turbines have 92 and 90% efficiencies respectively.

Efficiency of pump is 75%. Find the steam flow rate in the turbine inlet, cycle efficiency, and work ratio. Consider TTD to be 1.6°C. Having said this, this example specifically is chosen for the fact that it deals with drain cascade backward type. So let us not the T-s diagram for this example and number our usual notations. So this is T-s diagram.

Then we have one and then, so here it is cascade backwards means steam is sent back to the lower pressure through throttling. So we will put 1, $2^{'}$, but it is not the ideal pump so it will be 2. And then similarly this is not the ideal turbine. So we will have 3 here since it is 1.6 $°C$ extra. So this is 4, this is $5^{'}$, this is 5 and this is 6, this is $7^{'}$,, and this is 7, then this is 8 and this is 9.

So we have this as 90 bar, this suppose we will say $y$ mass of steam. So this is $(1-y)$, $(1-y)$here, 1 here and this is 18 bar. This is it is told that it is 40 °C. So if we see into the steam table and find out the saturation pressure corresponding to 40 °C and this it turns out to be 7.38 kPa. So these are the given things with us. So we can find out from steam table for this $h_1$. And $h_1$ is 167.15 kJ/kg.

Similarly, we can find out at 18 bar what is $h_8$; $h_8$ is the saturation enthalpy of liquid since it is told that the steam condenses there in the feed water heater. And then $h_8$ at 18 bar liquid saturation enthalpy is 883.4 kJ/kg. Now we can find out for $h_2$what is $\Delta h$or pump and that $\Delta h$ for pump is $v_1(P_2-P_1)$. So specific volume is $0.001008(90\times 100-7.38)$.

So we get $\Delta h$ for pump which is rather ideal $\Delta h$ for pump so we will put dash. And this turns out to be 9.06 kJ/kg. So we have $h_2=h_1+\Delta h^{'}P$. But pump has efficiency so it should be divided by pump efficiency. So it will be 167.57 plus 9.06 divided by pump efficiency is 75%. So we get it as 179.65 kJ/kg. Now we can do find out$T_3$. It is told that TTD is -1.6 °C.

So it means that the difference between this saturation temperature of feed water heater and the outlet temperature is - 1.6. So it means that $T_3=T_8+1.6°C$. So $T_3$ happens to be 208.75 °C since $T_8$is 207.15. Having said this we can go into the steam table and find out the enthalpy corresponding to 208.75 °C and then in that case we will get $h_3$= 875 kJ/kg.

We can as well find out this enthalpy from liquid tables and then these enthalpies would almost be similar. So for that fact we have now $h_4$which is this and we know it is 500 °C. So for that$h_4$ = 3386.1. We will keep also noted $s_4$which is 6.6576. So we know that $s_{5^{'}}=s_4$ . So we can get $h_4$okay. So $h_{5^{'}}$.

And that $h_{5'}$ we will see at 18 bar what would be the value at which we will get the entropy as $s_4$ So $h_{5'}$ for us will be to 2915 kJ/kg. Similarly, we can see it for $h_6$ which is at 18 bar and 500 °C. So we have $h_6$ = 3469.8 kJ/kg. We will keep also noted $s_6$ and then $s_6$ will be equal to $s_7$ and then from that fact we can find out $s_7$ basically is equal to $s_{7'}$. $s_1 + x_{7'} s_{fg}$ okay.

So this gives us $x_{7'}$ and the value of $x_{7'}$is 0.899. So from that we can get $h_{7'}$ which is equal to $h_1 + x_{7'} h_{fg}$ So it is 167.57 plus 0.899 into 2406.7. So we have $h_{7'}$= 2331.7. Now we can find out basically $h_5$where we know that turbine efficiency is equal to actual work which is $h_4 - h_5$ divided by ideal work which is $h_4 - h_{5'}$

And this gives us hint to find out $h_5$ which is turbine efficiency into $h_4 - h_{5'}$ and then it will have minus sign and then we will have plus $h_4$ So $h_5 = h_4 - \eta_t (h_4 - h_{5'})$ So we have $h_4$ for us is 3386.1 minus turbine efficiency. This is high pressure turbine. Its efficiency is 92%. So it is 0.92 into 3386.1 minus $h_5$ and $h_5$ rather $h_{5'}$ 2915 .

And this gives us 2952.688 kJ/kg. Similarly, we can find out $h_7$ by knowing the fact using the same formula $h_6 - \eta_t (h_6 - h_{7'})$. So we have $h_6$which is 3469.8 minus turbine efficiency. For low pressure turbine efficiency is 90%; $h_6$is 3469.8 minus $h_{7'}$ is 2331.7. So we get $h_7$. From here as 2445.51 kJ/kg.

Having said this, we can move ahead and then we can find out basically the mass fraction$y$ using the energy balance. Here the energy balance would say that the mass $y$ is losing its enthalpy from 5 to 8 where one minus, here it is complete mass one unit is gaining its enthalpy from 2 to 3.

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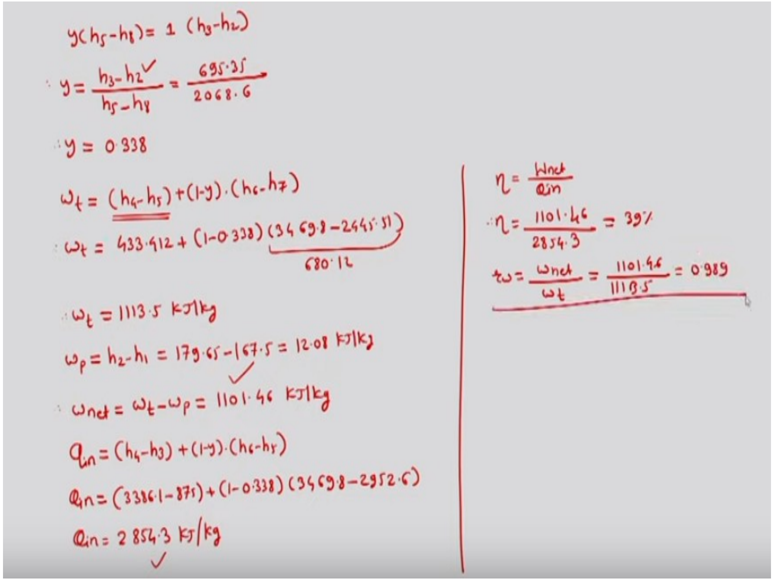


So we will write down as $y$ mass is losing its enthalpy from $h_5$ to $h_8$ and one unit of mass is gaining its enthalpy from 3 to 2. So we can write down $y = \frac{h_3 - h_2}{h_5 - h_8}$. So it turns out to be $y$ is equal to 695.35 the numerator based $\Delta h$ and denominator based $\Delta h$ is to 2068.6. So we will get $y$ as 0.338. So this is the mass fraction which is extracted for the process of drain cascade backward.

So we can write down now turbine work. So turbine work is equal to $(h_4 - h_5) + (1 - y)(h_6 - h_7)$. So turbine work is basically equal to $h_4 - h_5$ is 433.412, 1 – 0.338 and then we have 3469.8 - 2445.51 and then this basically is 680.12. So we have turbine work is equal to 1113.5 kJ/kg. We have pump work as $h_2 - h_1$. So which is 179.65 – 167.5. It gives us 12.08 kJ/kg.

So we have net work is equal to $W_t - W_p$ and that is equal to 1101.46 kJ/kg. Here we have $q_{¿}$ which is heat input to the cycle and that is $(h_4 - h_3) + (1 - y)(h_6 - h_5)$. Here heat is added into two phases $h_4 - h_3$. This heat is added in the boiler. And $h_6 - h_5$ heat is added in the reheater. So we can keep all these numbers. So $Q_{¿}$= (3386.1 – 875) + (1 – 0.338) into h 6 = (3469.8 – 2952.6) and this gives us $Q_{¿}$ = 2854.3 kJ/kg.

And then we can find out from here efficiency which is equal to $\frac{W_{net}}{Q_{¿}}$. So efficiency $W_{net}$ we have found out which is 1101.46. $Q_{¿}$ we found out 2854.3. This gives us efficiency as 39%. Work ratio $r_w = W_{net} / W_t$. So we have $W_{net}$ as 1101.46 and turbine work is 1113.5 and then this gives us 989 as the work ratio. So we have to keep this point in mind.

So we will have to solve this example of drain cascade backward specifically for the concept that we are putting the steam blade which is taken out exactly back to the condenser or maybe to the lower pressure feed water heater. So we end the example over here. So we go ahead with the next example. This example says that a cogeneration plant produces 5.6 MW and also supports 1.163 MW heating load.

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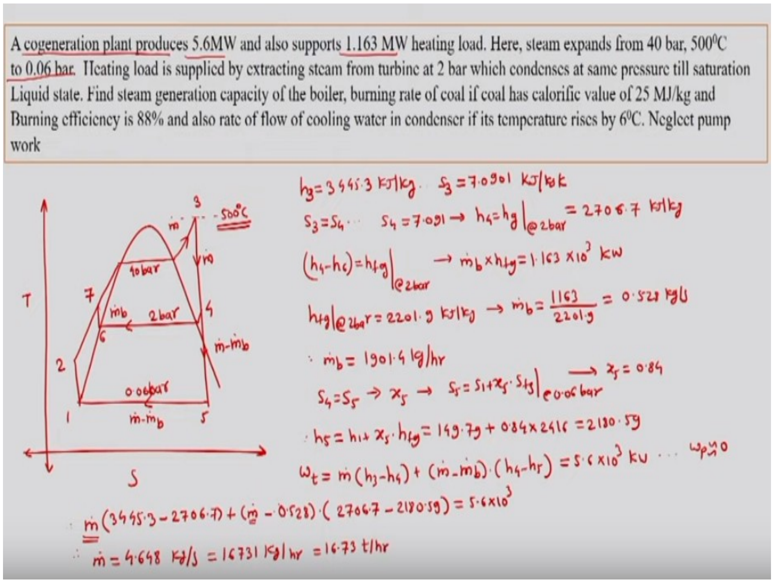


So this is the work produced and this is the heat load. We have to understand that this is a cogeneration plant. Here steam expands from 40 bar and 500°C to 0.6 bar. Heating load is supplied by extracting steam from at 2 bar which condenses at same pressure till saturation liquid state. Find steam generation capacity of boiler, burning rate of coal if calorific value is 25 MJ/kg.

Burning efficiency is 8% and also rate of flow of cooling water in condenser if its temperature rise is 6°C. This example for cogeneration is nothing but the example for Rankine cycle. This example is similar to the one what we work for the regeneration case, where we have some steam extracted from the turbine at certain pressure and given to heat the water in the economizer.

But here instead of heating the water this steam is used to heat the components or heat the product or heating the processes. So this heat from the steam is used for the other purpose. So that is what this plant produces electricity through turbine and also gives the hot steam as a heat source. So we can go ahead and then plot the T-s diagram. Our T-s diagram says this.

So this is 1, this is 2, this is 3, and this is 4, this is 5, and this is 6, and this is 7. We know this is 40 bar. This is we are bleeding steam $\dot{m}_b$. Here we say that there is $\dot{m}$ amount of mass and so here is $\dot{m}-\dot{m}_b$. And here also $\dot{m}-\dot{m}_b$. And this bleed is taken at 2 bar, here it is 0.06 bar. And pressure we know. This temperature is 500 °C. So this data is given to us.

With this data, we will go ahead and find out different corner properties. First, we will note $h_1$ corresponding to 0.06 bar or we can first find out $h_3$ so that we can find out different flow rates. So for that, let us denote $h_3$and $h_3$is found out at 40 bar and 500 °C in the superheated part of the steam table and this gives us 3445.3 kJ/kg.

We will also not $s_3$at the same time such that we would have equated it for the other corners of the cycle. So $s_3$ = 7.0910 kJ/kg K. We know that $s_3=s_4$ and this gives us $s_4$ and $s_4$ happens to be the superheated part. Or $s_4$ happens exactly on the practically on the liquid saturation line. And so we have basically $s_4$ = 7.091 and this gives us $h_4=h_g$ at 2 bar. And this value is 2706.7 kJ/kg.

So knowing this we can further go ahead and then find out what is the heat given. So for that we should know $h_6$ and $h_6$ is liquid saturation enthalpy corresponding to 2 bar and value of $h_6$ is equal to we can go ahead and find out the mass flow rate of the bled steam since we know that $h_4-h_6$is given as a heat load. So it is completely $h_{fg}$ and in that we should know at 2 bar and then that is $\dot{m}_b$ mass of bled steam into $h_{fg}$.

This is given to act for the heat load and that heat load is 1.163 MW. And then we can take it as into 10 to the power 3 KW. So we know $h_{fg}$and $h_{fg}$at 2 bar is equal to 2201.9 kJ/kg. So we can get $\dot{m}_b$ is equal to 1163 divided by 2201.9 and this gives us $\dot{m}_b$ as

0.528 kg/s. We can also find out $\dot{m}_b$ in terms of kg per hour. So it will be 1901.4 which is kg per hour. We can convert it into the tons per hour as well.

Having said this we can then find out as $s_4 = s_5$.. So this gives us $x_5$. Since we know $s_5 = s_1 + x_5 s_{fg}$ at 0.06 bar and we get $x_5$ = 0.84. So we can know $h_5 = h_1 + x_5 h_{fg}$ and then that gives us $h_5$ as 149.79 which is $h_1 + 0.84 h_{fg}$ is 2416. And then that gives us 2180.59. So this is $h_5$.

Now we can find out the turbine work. Since we know turbine work is equal to $\dot{m}(h_3 - h_4) + (\dot{m} - \dot{m}_b)(h_4 - h_5)$. But turbine work is known to us as $5.6 \times 10^3$ KW. Here we are neglecting $W_p$ and making it close to 0. So we know $\dot{m}$is not known and then $h_3$, we know $h_3$; $h_3$ is the enthalpy at the entry to the steam turbine 344.3 minus $h_4$and $h_4$ enthalpy is equal to 2706.7 plus $\dot{m}$minus now$\dot{m}_b$.

We have found out $\dot{m}_b$as 0.528 into $h_4$, 2706.7 minus $h_5$, 2180.59 is equal to $55.6 \times 10^3$ . In this equation, only unknown is mass flow rate which is the total mass flow rate of the steam or mass flow rate of the steam in the boiler. So we can get from here, which is $\dot{m}$ and $\dot{m}$comes out to be 4.648 kg/s, which is equal to 16731 kg/hr. So which is equal to 16.73 tons/hr.

So this is what we have got from the mass flow rate for the steam power plant which is used as a cogeneration plant. Now we will go ahead and we have to work for the cold, which is the total fuel supplied for the cycle.

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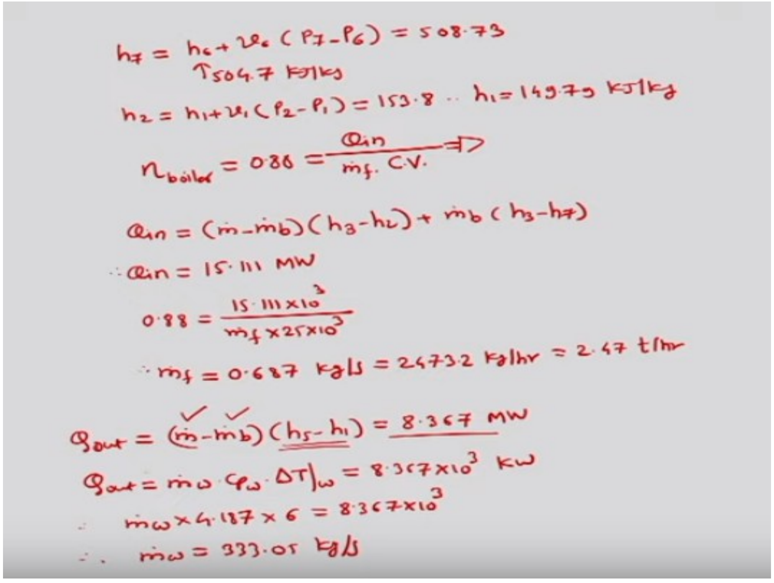


So for that, we will first find out$h_7$; $h_7 = h_6 + v_6 (P_7 - P_6)$and this turns out to be 508.73 where $h_6$ is at the bleed pressure which is 2 bar the liquid saturation enthalpy and we know this as 504.7 from the steam table. We can also find out $h_2$ which is equal $h_2 = h_1 + v_1 (P_2 - P_1)$and this gives us 153.8 since we know$h_1$ is equal to 149.79 kJ/kg.

Now this is useful for us to find out the fuel related data. So boiler efficiency is given as 88% which is basically $Q_{¿}$ divided by mass flow rate of fuel into its calorific value. And we had found out $Q_{¿}$ basically, we have to find out $Q_{¿}$ over here. So let us find out $Q_{¿} = \dot{m} - \dot{m}_b$, which is the mass flow rate of the bleed and this is the mass of the steam and this is getting heated from 2 to 3.

And then only $\dot{m}_b$ gets heated from 7 to 3. It means that the pump actually deals with $\dot{m} - \dot{m}_b$ and supplies to the entry to the boiler. So $\dot{m} - \dot{m}_b$get heated in this complete path from 2 to 3. But $\dot{m}_b$ joins over here at 7. So $\dot{m}_b$gets heated from 7 to 3. So this is what it is written over here. So from here, we get $Q_{¿}$ as 15.111 MW.

So we can put this $Q_{¿}$and then it becomes $15.111 \times 10^3$ divided by mass of fuel into its calorific value. And calorific value is given to us as 25 MJ/kg. So this is 25 $\times 10^3$. So we get $\dot{m}_f$is equal to mass of the fuel 0.687 kg/s, which is equal to 2473.2 kg/hr and which is also equal to 2.47 tons per hour. Now having solved for the fuel we have to work for the cooling water which is used in the condenser.

So we are losing the mass, losing the heat as the mass m minus $\dot{m}$passes in the condenser from 5 to 1. So $\dot{m}-\dot{m}_b$ loses its enthalpy from 5 to 1 and then that is used to be a source for the cooling water where cooling water gets that and gets heated. So we can known that and that can be evaluated first and it will turn out to be 8.367 MW.

Since we got $\dot{m}$ now $\dot{m}$basically, we know $\dot{m}$ from here, we know $\dot{m}_b$ from earlier calculations of our. So $\dot{m}$ is known, $\dot{m}_b$ is known, $h_5$ is known and $h_1$ is also known. So knowing this we just found out the $Q_{out}$. So $Q_{out}$for us is equal to mass flow rate of water into $C_p$ of water into $\Delta T$ of water. So this is equal to 8.367 $\times 10^3$KW.

So $\dot{m}$ water into $C_p$ of water is 4.187 into 6 °C or Kelvin as rise is equal to 8.367 $\times 10^3$ . So this gives us mass flow rate of water to be 333.05 kg/s. So this is how we would have solved the example for the cogeneration plant where we have to find out the work as electricity output and also the work or the heat transfer in the form of heat load. We would see the rest of the concept in the other class. Thank you.