Steam Power Engineering

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Lecture - 13

Examples of Regenerative Rankine Cycle

Welcome to the class. We will solve some examples on regeneration. So we are practically going to consider the Rankine cycle with regeneration or regenerative Rankine cycle during these examples.

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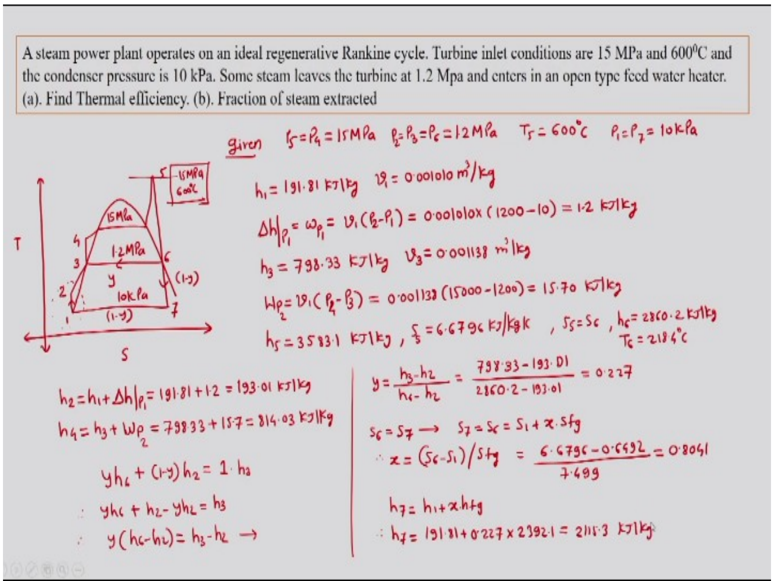

So first example reads as a steam power plant operates on an ideal regenerative Rankine cycle. Turbine inlet conditions are 15 MPa and 600 °C. Condenser pressure is 10 kPa. Some steam leaves the turbine at 1.2 MPa and enters in an open type feed water heater. Find thermal efficiency and fraction of steam extract. So we will start with the given things.

So in this we will first draw the Rankine cycle for us. We have to remember that this is an open type of feed water heater and in the open type of feed water heater, there will be two big pumps and then, so this is 1, 2, 3, 4, 5, 6 and 7. So we will say that y is given in the feed water heating. So we will have 1 – y in the rest of the turbine and 1 - y in the condenser. So given things for this example are $P_5 = P_4 = P_3 = 15\,MPa$.

Then $P_3 = P_6 = 1.2\,MPa$. Further T_5 is said as 600 °C and here $P_2 = P_3 = P_6$. Further $P_1 = P_7 = 10\,kPa$. Now in this example, we will first go into the steam table corresponding to 10 kPa and find out h_1. So h_1 will be the enthalpy which is liquid saturation enthalpy at 10 kPa. So its value is 191.81 kJ/kg.

Similarly, we will keep on writing about v_1 which is specific volume and this will be 0.001010 m^3/kg. Then, we can find out here $\Delta h/P_1$or which we will also call it as specific pump work (w_{P1}) and this specific pump work we have to remember that what we are calculating here it is specific pump work since in the process one to two there is only 1 – y mass in the component pump. So it is not multiplied with mass.

So it will be the$w_{P1} = v_1 (P_2 - P_1) = 0.001010(1200 - 10)$ and this gives us value of 1.2 kJ/kg. So this is value of $\Delta h/P_1$. Then we can find out h_3 from the steam table. And h_3 is liquid saturation enthalpy at 1.2 MPa. This is 10 kPa and this is 15 MPa.

So at 1.2 MPa we can find out h_3 and h_3 will be 798.33 kJ/kg and specific volume at the same station can be also seen which is 0.001138 m^3/kg. And this would be helpful for us to find out the pump work in the second case and so that is actually W_P which is pump work since here this y is going to mix with 1 – y and that will be total mass. So this will be total mass, so total pump work.

And then that total pump work is $W_P = v_1 (P_4 - P_3)$. So specific volume is known ¿$0.001138(15{,}000\,kPa - 1200\,kPa)$ and this gives us 15.70 kJ/kg as the second pump work. Now we can go into the steam table and find out h_5 which is the enthalpy at station 5 and that h_5 is 3583.1 kJ/kg. We know at 5 we have 15 MPa pressure and 600 °C.

So we should go into the superheated part of the steam table and find out what is the h_5. But parallelly we will keep it also noted about S_5. So S_5 and S_5 will be 6.6796 kJ/kg K. Now we know $S_5 = S_6$. So we can go into the steam table and then find out at what temperature we will have at 1.2 MPa same entropy as S_6 and it happens to be a superheated zone at 1.2 MPa as well.

So we can get $h_6 = 2860.2\, kJ/kg$ and here we basically get $T_6 = 218.4\,°C$. We should also keep it in mind that we might not get if we are using steam table then we might not get exactly same entropy then we have to interpolate between two entropies and find out one intermediate value. And then we would go back and then find out basically $h_2 = h_1 + \frac{\Delta h}{P_1}$.

And we get $h_2 = 191.81 + 1.2$ and this gives us $h_2 = 193.01\, kJ/kg$. Similarly we will find out $h_4 = h_3 + W_{P2}$ or we can also say it as $\frac{\Delta h}{P_2}$, but this is actual pump work. So this is W_{P2}. So h_3= 798.33 + 15.7. So it gives us 814.03 kJ/kg. So once we know now this, we can find out our required mass, which is y1 through the energy balance.

And for that we can use the equation which says that y amount of mass at state 6 mixed with the 1 – y amount of mass at state 2 to give one unit of mass at state 3. So we know it is $y h_6 + h_2 - y h_2 = h_3$. So we have $y(h_6 - h_2) = h_3 - h_2$. And this gives us $y = \frac{h_3 - h_2}{h_6 - h_2}$. And then we know all enthalpies. So $h_3 = 798.33, h_2 = 193.01$ and then we have $h_6 = 2860.2, -h_2 = 193.01$. And this gives us y as 0.227. So this is the mass fraction.

Now we know this mass fraction, we can now calculate actual pump work also in the first pump by multiplying it to 1 - y. But further we can find out state 7 where we will take $S_6 = S_7$. So we go into the steam table and we will see at what temperature or at what condition we will have the entropy at state 7 equal to state 6. And so it happens in this case that we are inside the dome.

That means S 6 is lesser than the vapor, saturation vapor entropy at 10 kPa. So $S_7 = S_6 = S_1 + x\,S_{fg}$. Here this will helpful for us to know it is $\frac{S_6 - S_1}{S_{fg}}$. So we can get this as $\frac{6.6796 - 0.6492}{7.499}$. And this gives us S_7 or rather $x = 0.8041$. So this is the dryness fraction at state 1. We will move here onwards and find out what is the amount of heat added and what is amount of heat rejected.

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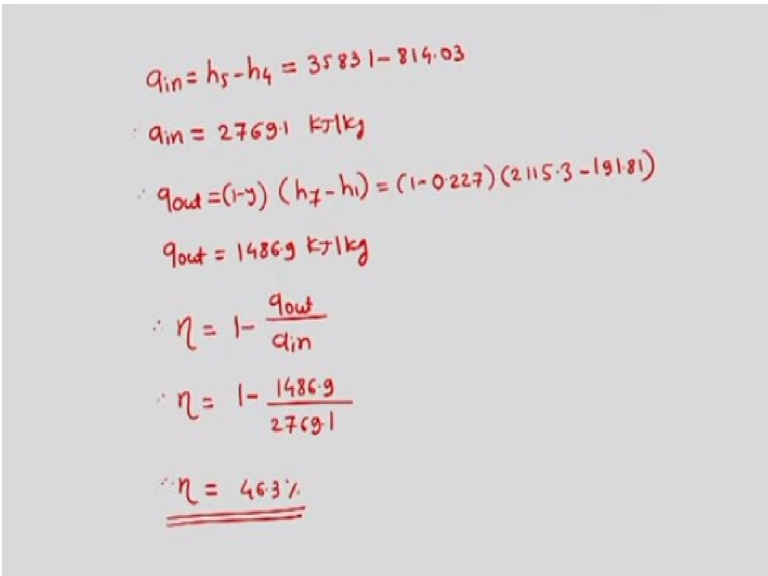

So amount of heat added $q_{in} = h_5 - h_4$. We know 3583.1 – 814.03. So this gives us $q_{in} = 2769.1\,kJ/kg$. Similarly, $q_{out} = h_7 - h_1$. But this is not for one unit of mass, this is for 1 – y kg of mass. So this will be $q_{out} = (1 - 0.227)(2115.3 - 191.81)$. Here, knowing the dryness fraction, we would have calculated $h_7 = h_1 + x\,h_{fg}$.

Basically this $h_7=191.81+0.227\times 2392.1$ and this gives us 2115.3 kJ/kg. So this h_7 is used over here to find out q_{out} and we get q_{out} to be 1486.9 kJ/kg. So efficiency $\eta=1-\frac{q_{out}}{q_{¿}}$. So $q_{out}=1486.9\wedge q_{¿}=2769.1$ and this gives us efficiency as 46.3%.

So here, we have to remember one point that we are using different masses, which are present in the different components of the circuit to find out individual interactions and this we would not have to forget in the case of regeneration examples. So we will proceed with next example and next example states that there is a steam power plant based on regenerative cycle steam enters the turbine at 400 °C and 3 MPa state while the condenser pressure is 10 kPa.

Find cycle efficiency and mass fraction extracted at 0.6 MPa for open type of feed water heater.

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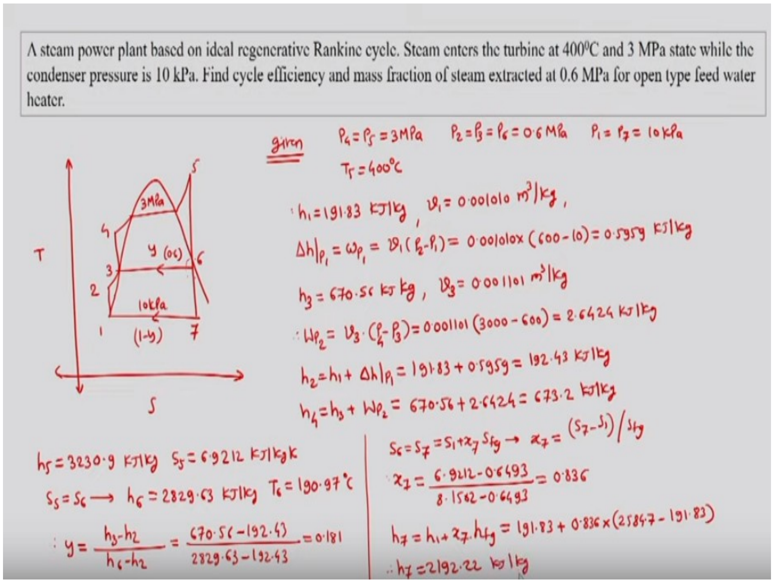

So we are given again in this example that there is open type of feed water heater. So we will again put the same diagram where we have all the time whenever we draw diagram this is an intuition based diagram. This diagram would get corrected based upon the answer. For the example this point, this point 6 we are having at this moment inside the dome. But this might be inside or might be outside the dome.

So this is y, this is 1 - y. So this is 3 MPa. This is 0.6 MPa and this is 10 kPa. Knowing this we can say what is given in this example and in the given thing we have $P_4 = P_5 = 3\,MPa$. We have $P_2 = P_3 = P_6 = 0.6\,MPa$. We have $P_1 = P_7 = 10\,KPa$. Further T_5 is given as 400 °C. So we will start. We will find out h_1 which is liquid saturation enthalpy at state 1 which is 10 kPa and h_1 happens to be 191.83 kJ/kg specific volume at state 1 is 0.001010 m^3/kg.

And then we have actually delta h pump one or specific pump one work $w_{p_1} = v_1 (P_2 - P_1) = 001010(600\,kPa - 10\,kPa)$ and this gives us the specific pump work for station for first pump which is 0.5959 kJ/kg. So this is the first pump work. Now we can find out h_3 which is liquid saturation enthalpy at state 3 or 0.6 MJ/kg and this is h_3 = 670.56 kJ/kg.

Similarly, specific volume at state 3 is $v_3 = 0.001101\,m^3/kg$. So we can find out second pump work W_{P_2}which is also specific, but here we are handling complete mass which is one unit and this is equal to$W_{P_2} = v_3 (P_4 - P_3) = 0.001101(3000\,kPa - 600\,kPa)$. So this gives us second pump work as 2.6424 kJ/kg. Now we can use this two pump works or specific pump works to find out other enthalpy.

So $h_2 = h_1 + \Delta h \vee P_1$. So $h_2 = 191.83 + 0.5959$ and this gives us $h_2 = 192.43\,kJ/kg$. And h 3 is already found out So $h_4 = h_3 + W_{P_2}$ and this is basically 670.56 + 2.6424 and then this gives us h_4 as 673.2 kJ/kg. So now we can go into the steam they will find out HPU at three mega Pascal and 400 °C. So we have table, find out h_5 at 3 MPa and 400 °C.

So we have $h_5 = ¿3230.9$ kJ/kg but we will also note down S_5 and S_5 happens to be 6.9212 kJ/kgK. After this we will find out state 6 where we have $S_5 = S_6$ and then for that we will have to go into the steam table, find out at what temperature of 0.6 MPa we will have same entropy as that of S_5. So we can get from here h_6 basically, and h_6 turns out to be 2829.63 kJ/kg. So for this T_6 is 190.97 °C.

Keep this point in mind that we might have this T_6 point inside the dome, if we would have the vapor saturation entropy to be higher than S_5 or S_6. In that case 6 would have been inside the dome. But at this moment, we have vapor saturation entropy to be lower than S_5. So point 6 is in the superheated zone. Then we got everything necessary, which is required to find out the mass fraction.

We can know now directly use the formula $y=\frac{h_3-h_2}{h_6-h_2}$. So this gives us $\frac{670.56-192.43}{2829.63-192.43}$ and this gives us 0.181. So mass fraction is found out. Upon that we will find out state 7 where we know $S_6=S_7=S_1+x_7 S_{fg}$ if we have entropy at 6 is lower than the vapor saturation entropy corresponding to 10 kPa and which happens to be the present case.

So $x_7=\frac{S_7-S_1}{S_{fg}}$ and then this gives us $x_7=\frac{6.9212-0.6493}{S_{fg}} which\, is\, S_{fg}=S_g-S_f=1502-0.6493$ and this gives us x_7 as 0.836. Now this will be helpful for us to find out $h_7 \wedge h_7=h_1+x_7 h_{fg}=191.83+0.836(2584.7-191.83)$ and so h_7 turns out to be 2192.22 kJ/kg.

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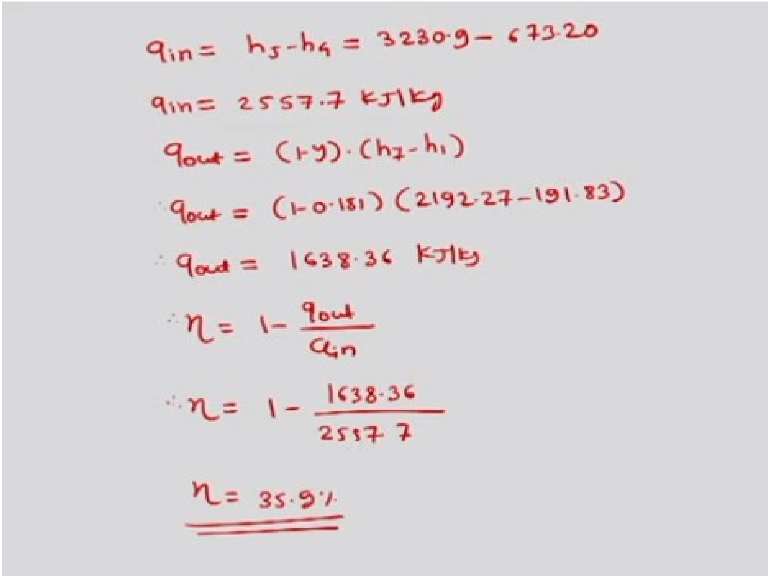

Now we can find out efficiency of the plant and so for that we need to find out $q_{¿}$ and $q_{¿}=h_5-h_4=¿$3230.9 – 673.0. We should remember here the heat added is in between these two states, which are h_5 and h_4 where h_5 is the enthalpy at the outlet of the boiler and h_4 is the enthalpy at the inlet to the boiler. So h_5 we had already found out which is 3230 and h_4 also was already found out as the 673.2.

Knowing this we can get $q_{¿}$ and that $q_{¿}=2557.7\, kJ/kg$ and q_{out} is basically as what we did in last time $q_{out}=(1-y)(h_7-h_1)$. So we know $q_{out}=(1-0.181)(2192.27-191.83)S$

o we get $q_{out}=1638.36$. So we can say efficiency is equal to $\eta=1-\frac{q_{out}}{q_{¿}}$. So $1-\frac{1638.36}{2557.7}$. So this gives us efficiency as 13.9 percentage. And then this has helped us in finding out the parameters which were asked like mass fraction and efficiency of the cycle.

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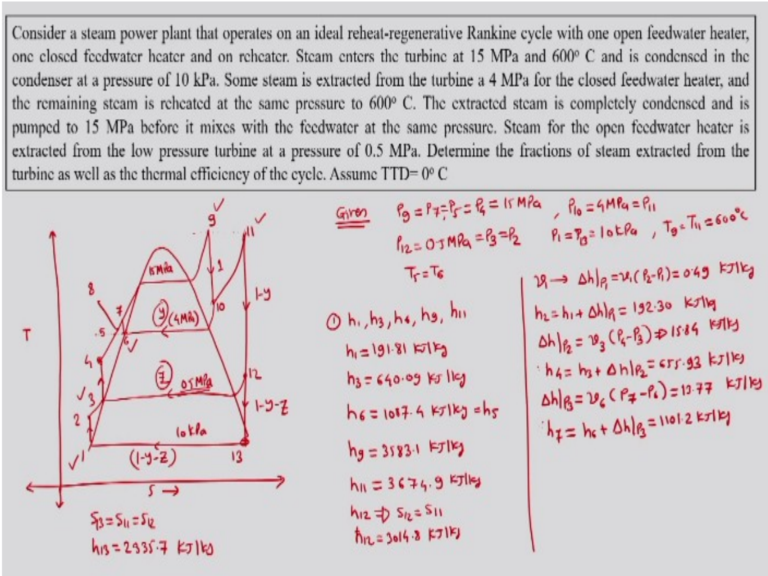

So we will move to the next example. Next example reads that consider a steam power plant that operates on an ideal reheat regenerative Rankine cycle with one open feed water heater, one closed feed water heater and one reheater. Steam enters the turbine at 15 MPa and 600°C and condensed in the condenser at pressure 10 kPa.

Some heat is extracted from the turbine at 4 MPa from the closed feed water heater and the remaining steam is reheated at the same pressure to 600°C. The next example reads that consider a steam power plant that operates on an ideal reheat regenerative Rankine cycle with one open feed water heater and one closed feed water heater and one reheater.

Steam enters the turbine at 15 MPa and 600°C and is condensed in the condenser at a pressure of 10 kPA. Some steam is extracted from the turbine at 4 MPa for closed feed water heater and the remaining steam is reheated at same pressure to 600°C. The extracted steam is completely condensed and is pumped to 15 MPa before it reaches mixes with the feed water at the same pressure.

Steam for open feed water heater is extracted from low pressure turbine at a pressure of 0.5 MPa. Determine fractions of steam extracted from the turbine as well as thermal efficiency of the cycle and then assume TTD at 0°C and this is for the closed feed water heater. So we will first plot TS diagram for the power plant which is given to us and as per this we will have one.

So this is first pump, this is condenser 1 to 2, 2 to 3, 3 to after the closed feed water heater we will have 3 to 4 and then TTD at 0°C, so 5 will be at same temperature as here. So this is 6 to 7 and then in between there will be 8. And then we will have 9. Then we have 10 here. We have 11 then 12 then 13. So we will pretend that here y steam is extracted and here z steam is extracted.

So here 1 kg of steam is expanded, here 1 – y kg of steam is expanded, here 1 – y – z kg of steam is extracted. And then both the temperatures are same. So $T_9=T_{11}$. So in this example, we need to go first into the steam table and note all the enthalpy whatsoever given as per their state values. Like as per their pressures and as per their temperatures. So first we will go into the steam table. First given things.

And as per the given things, we have $P_9=P_7=P_5=P_4$ and everything is 15 MPa. Then we are having P_{10} = 4 MPa. So P_{10} is 4 MPa and then we have which is also is equal to P_{11}. So but P_{12} is 0.5 MPa and then that is why it is equal to P_3 and that is equal to P_2 and similarly $P_1=P_{13}=$¿ 10 kPa. So this is what the conditions. Here we are having 15 MPa. Here we are having 4 MPa. Here we are having 0.5 MPa.

Here it is 10 kPa. Having said this, now we can proceed further and then the given things are further $T_9=T_{11}$ = 600 °C. Since TTD is zero, we are also told that $T_5=T_6$. So with this, we will note we will first find out all the enthalpies at the different corners from the steam table. So which enthalpies we can find out first? We can find out the enthalpies which are $h_1, h_3, h_6, h_9, h_{11}$. We can find out this.

So here we will get $h_1=191.81\,kJ/kg$. This is corresponding to 10 kPa condenser condition. Then we have $h_3=640.09\,kJ/kg$. Then we have h_6 and $h_6=$¿ 1087.4 kJ/kg.

Then we have h_9 and h_9 is turbine inlet and h_9 is the enthalpy which is 3583.1 kJ/kg and then that is equal to h, temperatures are same, so $h_{11}=3674.9\,kJ/kg$. Now we know enthalpy 1, 3, 6, 9, and 11.

Basically, since TTDs are same, we can as well take the enthalpy of state 5 as enthalpy of state 6. This is the one condition what we can do. So we can say $h_5=h_6$. So the state 5 is so close to the state 6. So we can make an assumption for TTD zero as $h_5=h_6$. This is one way to solve the example where we can just make use of steam table.

And then we can go ahead and we can monitor few more things, where we will monitor specific volume at state 1 and this will be helpful for us to find out $\Delta h \vee P_1$ which is the change in enthalpy in pump 1 and that is $\Delta h \vee P_1=v_1(P_2-P_1)$ and we get it as 0.49 kJ/kg and this gives us $h_2=h_1+\Delta h \vee P_1$ and we get h_2 as 192.30 kJ/kg.

Then we can find out what is $\Delta h \vee P_2=v_3(P_4-P_3)$ and this gives us the 15 MPa minus 0.5. So 500 kPa into specific volume. So we will get $\Delta h \vee P_2$. We can carry forward from here and we can get $\Delta h \vee P_2$which is 15.84 which will be helpful for finding out $h_4=h_3+\Delta h \vee P_2$and this gives us h_4 as 655.93. Now, we have h_4.

So knowing all these things now we can move ahead and then find out h_7 also. So for that we can get $\Delta h \vee P_3=v_6(P_7-P_6)$ and this gives us value of $\Delta h \vee P_3$is equal to 13.77 kJ/kg. So knowing this we can find out $h_7=h_6+\Delta h \vee P_3$and so we get h_7 as 1101.2 kJ/kg. Now knowing all this, we can find out now y and z. So for this we can go ahead and write down the expression for y. For y we know that we can use the energy balance.

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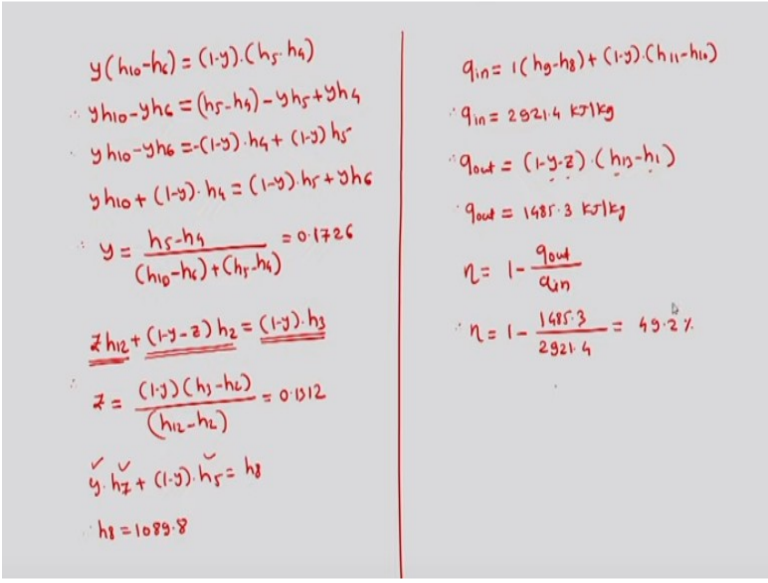

So keeping this in mind first we can find out y and for y we know that y amount of mass at enthalpy 10. If we go back we know that y amount of mass at enthalpy 10 it loses its enthalpy till 6 such that 1 - y amount of mass at enthalpy 4 rises its enthalpy till 5. So $y h_{10} - y h_6 = (1-y)(h_5 - h_4)$.

So this was giving us $y h_{10} - y h_6 = (h_5 - h_4) - y h_5 + y h_4$. So we can have $y h_{10} - y h_6 = (1-y) h_5 - (1-y) h_4$. We can rather put it in this way. So we will have it as $y h_{10} + (1-y) h_4 = (1-y) h_5 - y h_6$¿.. Further if we rearrange all the terms we will get

$$y = \frac{h_5 - h_4}{h_{10} - h_6 + h_5 - h_4}.$$

So if we put all the enthalpies we will get y = 0.1726. Then we can find out z and this z can be found out from again the fact that that we have the z amount of mass at enthalpy 12 loses its enthalpy to 3, where 1 – z, 1 – y - z amount of mass will raise its enthalpy from 2 to 3. So we can write down the same thing in terms of z where we will have $z h_{12} + (1 - y - z) h_2 = (1 - y) h_3$.

So z amount of mass at h_{12} is again having it exchange of heat with $(1-y-z)h_2$ such that we will get 1 – y at 3. So knowing this we can write down for $z=\frac{(1-y)(h_3-h_2)}{h_{12}-h_2}$. And this gives us z to be 0.1312. So here we would have found out h_{12} basically h_{12} with the constraint that $S_{12}=S_{11}$ and we would go to the 0.5 MJ pressure.

We will go to the superheated part and see at what temperature we will have S_{11} matched with S_{12} such that we would have $h_{12}=3014.8\,kJ/kg$. Similarly, we would also keep it noted for 13 where we will have $S_{13}=S_{11}=1$. We will go to 10 kPa pressure and see at what condition we will have same entropy. So from that we can get h_{13} and h_{13} will be 2335.7 kJ/kg.

Thus we know all enthalpies. Now we can do rest of the calculations where we just need to know one more thing that we need to know what is enthalpy at 8. So for that we know enthalpy at 5 mass at 5. We know enthalpy at 7 and mass at 7. And that we can do here. So we know y amount of mass at 7 is mixed with 1 - y amount of mass at 5 to give h_8. So $y\,h_7+(1-y)h_5=h_8$

So h 8 knowing y, h_7, h_5 we can get h_8 and h_8 remains to be 1089.8. Now knowing all the enthalpies we can find out q in. And q in is basically in the h 9. There are two cases where we are having heat addition. So here from 8 to 9 we are having heat addition in the boiler and from 10 to 11 we are having heat addition in the reheater. But 10 to 11 we are having only 1 - y amount of mass but in the boiler we have 1 amount of mass. So it is $1(h_9-h_8)+(1-y)(h_{11}-h_{10})$.

If we put all the heat, all the enthalpies and y we will get $q_{¿}$ as 2921.4 kJ/kg. Similarly we can find out $q_{out}=(1-y-z)(h_{13}-h_1)$. We know $y, z, h_{13} \wedge h_1$ we can find out q_{out}

and it turns out to be 1485.3 kJ/kg. So it is helpful for us to find out efficiency which $\eta = 1 - \frac{q_{out}}{q_{in}}$. So 1- 1485.3/2921.4. So we get efficiency of the cycle as 49.2%.

So this is what we are trying to calculate. Here, we used the concept of TTD where we made us steam table to find out h_5. It is not necessary we have to use steam table. We can as well use water table to find out enthalpy at 5.

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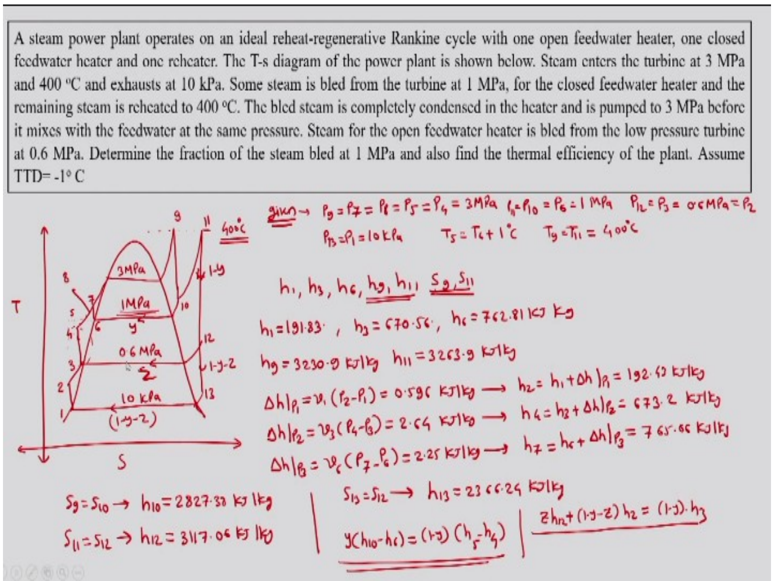

We will move to the next example. This example state that there is a steam turbine power plant which operates on an ideal reheat regenerative Rankine cycle with one open feed water heater, one closed feed water heater and one reheater. The T-s diagram we will draw. Steam enters the turbine at 3 MPa and 400°C and exhausts at 10 kPa.

Some steam is bled from the turbine at 1 MPa for closed feed water heater and the remaining steam is reheated to 400 °C. The bled steam is completely condensed in the heater and is pumped to 3 MPa before it mixes with the feed water at the same pressure. Steam for the open feed water heater is bled from the low pressure turbine at 0.6 MPa pressure.

Determine mass fraction of the steam bled at 1 MPa and also find out thermal efficiency. Assume TTD to be -1 °C. So here we will first draw the steam the T-s diagram. So this is 1, 2, 3, 4 then we will say -1 °C. So this is above here. So this is 5, this is 6, this is 7, 8, 9, 10, 11, 12, 13. So these are the states.

So given in this example is basically this pressure is 3 MPa, this pressure is 1 MPa and this is 0.6 MPa and this is 10 kPa. So this is what it is given and then further given thing that this temperature is given as 400 °C. So for this, we can we mentioned the given things where we have $P_9 = P_7 = P_8 = P_5 = P_4 = 3\, MPa. Then\, P_{10} = P_6 = 1\, MPa$. And then we have this also equal to P_{11}.

Then we have $P_{12} = P_3 = 0.6\, MPa.\, P_{13} = P_1$. Here this is also equal to P 2. 10 kPa. Then we are told that $T_5 = T_6 + 1°C$. We are also told that basically, $T_9 = T_{11}$=400°C. So knowing this, we can proceed with this example. As we did earlier, we will mention all the known enthalpies which are $h_1, h_3, h_6, h_9, h_{11}. \wedge h_9 \wedge h_{11}$ we will also keep mentioned S_9 and S_{11}.

So we will have $h_1 = 191.83$. We will have$h_3 = 670.56$ and then we have $h_6 = 762.81\, kJ/kg$, all have same unit. And then we have $h_9 = 3230.9 \frac{kJ}{kg}, h_{11} = 3263.9\, kJ/kg$. So we have h_9 and h_{11} mentioned along with the their S. We will also keep mentioned S_9 and S_{11}. Knowing these enthalpies we can find out first $\Delta h \vee P_1 = v_1 (P_2 - P_1)$ and this turns out to be 0.596 kJ/kg.

This gives us $h_2 = h_1 + \Delta h \vee P_1$ and we get h_2 = 192.43 kJ/kg. Then $\Delta h \vee P_2$ that is the enthalpy rise by second pump is equal to $\Delta h \vee P_2 = v_3 (P_4 - P_3)$. So considering this we get it as 2.64 kJ/kg. This is helpful to find out $h_4 = h_3 + \Delta h \vee P_2$and this gives us h_4 as 673.2 kJ/kg. Then we can find out $\Delta h \vee P_3 = v_6 (P_7 - P_6)$.

And this gives us the value of h_7, $\Delta h \vee P_3$as 2.25 kJ/kg and we can $h_7 = h_6 + \Delta h \vee P_3$. So h_7 will be 765.06 kJ/kg. So we have got most of the enthalpies. Then we will also mention the other enthalpy as h_9 and h_9 is 3230.9 which is mentioned. So for this we can go and see for 1 MPa case at what temperature we have $S_9 = S_{10}$ and record the enthalpy at S_{10}which would come out to be 2827.38 kJ/kg.

Similarly, we can keep a track of $S_{11} = S_{12}$ and then mention S_{12} which will be 3117.06 kJ/kg. Similarly, we have as $S_{13} = S_{12}$. This also gives us h_{13} that is 2366.24 kJ/kg. So knowing this, we can find out the fraction of masses. As what we generally mention this is y, so this is 1 – y. This is z, so this is 1 – y – z. This is also 1 – y – z. So for this we can go ahead and do the calculations.

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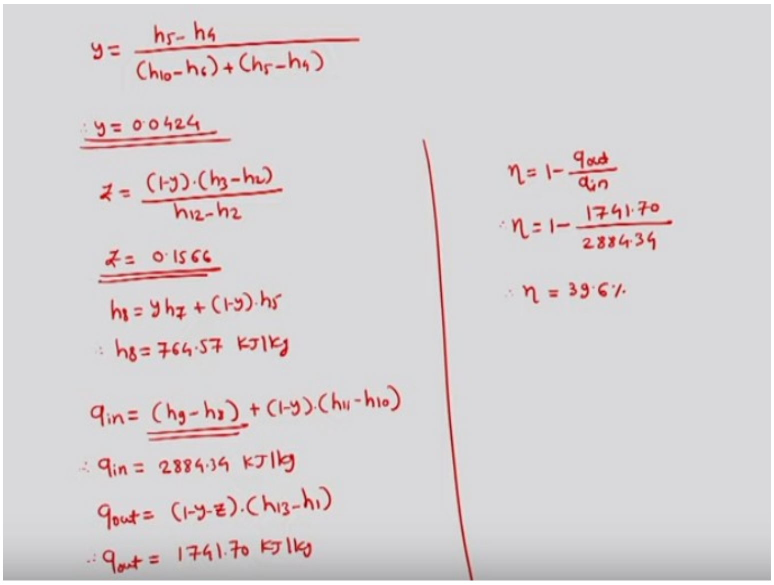

We know now formula for the $y = \frac{h_5 - h_4}{(h_{10} - h_6) + (h_5 - h_4)}$.We know how we are going at arrive at this formula. This is just the energy balance where we are saying that y amount of mass is losing its enthalpy from 10 to 6. So basically y amount of mass losing its enthalpy from 10 to 6 and this enthalpy is used to rise the enthalpy of 1 - y amount of mass from $h_4 ¿ h_5$. Basically it $is\, h_4 ¿ h_5 . So\, h_5 - h_4$. So this is the energy balance.

So for this energy balance, we would this formula for y we can put all enthalpies and get y as 0.0424. Similarly, for z we know the formula $z=\frac{(1-y)(h_3-h_2)}{h_{12}-h_2}$ and this again can be written in terms of energy balance as the z amount of mass is losing its enthalpy, is mixed at 12 enthalpy with (1 – y – z) at enthalpy 2 such that we will get 1 – y at 3.

So this is the energy balance for the other feed water heater. So knowing this we can as well find out z and z turns out to be 0.1566. So now this is how we have found out the mass fractions. So now, next turn is to find out what is the enthalpy at state 8. So for that we know that we can write down that 1 - y amount of mass at state 5 mixed with y amount of mass at 7.

So it is 1 - y amount of mass at state 5 mixed with y amount of mass at 7 to give h 8. So this we can use to find out h_8. So $h_8=y h_7+(1-y)h_5$ and we can get $h_8=¿764.57$ kJ/kg. This is required for us to find out $q_{¿}$. So $q_{¿}=h_9-h_8$ which is in the boiler plus in the reheater which is $1-y(h_{11}-h_{10})$. Putting all the numbers we get $q_{¿}$ as 2884.34 kJ/kg.

We can find out $q_{out}=(1-y-z)(h_{13}-h_1)$and we get q_{out} as 1741.70 kJ/kg. And this gives us efficiency which is $\eta=1-\frac{q_{out}}{q_{¿}}$. So it is $1-\frac{1741.70}{2884.34}$. So we get efficiency is equal to 39.6%. So this is how we saw that how to solve the examples which are for open feed water heater or closed feed water heater of forward type or regeneration plus reheat cycle.

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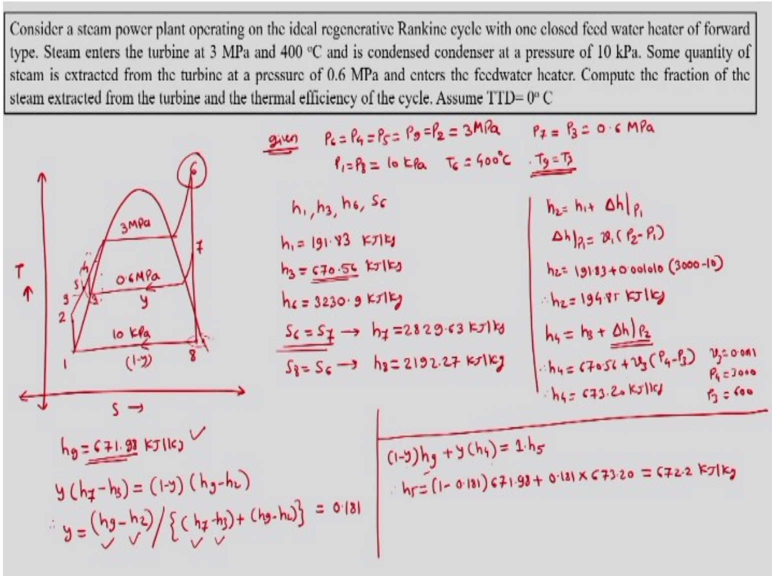

We will go to the next example, which reads that consider a steam power plant operating on the ideal regenerative cycle with one closed feed water heater. The steam enters the turbine at 3 MPa and 400°C and condensed in the condenser at a pressure of 10 kPa. Some quantity of steam is extracted from the turbine at a pressure of 0.6 MPa and enters into the open.

The example reads that consider a steam power plant example reads that consider a steam power plant operating on the ideal regenerative cycle with one closed feed water heater of forward type. Steam enters the turbine at 3 MPa and 400°C and is condensed in the condenser at a pressure of 10 kPa. Some quantity of steam is extracted from the turbine at a pressure of 0.6 MPa and enters the feed water heater.

Computer the fraction of the steam extracted from the turbine and find thermal efficiency of the cycle. Assume TTD to be 0 °C. For this again, we will first draw the T-s diagram. This is 1, this is 2, we will say this as 3, this as 4. So this is, after feed water heating we will reach at state 5 and then basically the state is 5 after mixing and feed water heating.

And then we have 6, 7, 8 and here we are saying that the feed water heating has led to the state 9. So in this case what is given and it is 3 MPa. This is 0.6 MPa and this is 10 kPa. So these are the things which are given. So $P_6 = P_4 = P_5 = P_9 = P_2 = 3\,MPa$. And we will have $P_7 = P_3 = 0.6\,MPa$. And we have $P_1 = P_8 = 10\,kPa$. $T_6 = 400°C$.

First will go into the steam table and again we will see some enthalpies which are directly obtainable from the steam table. So here first we will get enthalpies like h_1, h_3, h_6 and then we can get enthalpy. Along with that we can get entropy also. So h_1 would be here and then that h_1 is 191.83 which is liquid saturation enthalpy at station 1 corresponding to 10 kPa; h_3 is equal to 670.56 and then h_6 is equal to 3230.

All are in unit kilojoule per kg, 3230.9 kJ/kg. So knowing this, we can do one more thing, we can write down S_6 and S_6 would happen to be the entropy at station 6 and to find our state 7 we know $S_6 = S_7$. So from this constraint, we would have monitored S 6 into the steam table at state 6. So corresponding to 3 MPa which happens to be in the superheated zone.

Similarly, we will go into the 0.6 MPa case and find where we will have same entropy and then it happens to be at again superheated state and then that is why we get h_7 as 2829.63 kJ/kg. Now having said this, we can go ahead and find out same way $S_8 = S_6$ again and so from that we can get the enthalpy at state 8.

Here we again need to see whether this 8 point is having entropy higher than the gas vapor phase enthalpy or lower than the vapor phase and the saturation vapor phase enthalpy and accordingly we would have to calculate dryness fraction if it is lower, and then we ultimately need to find out h_8 and h_8 comes to be 2192.27 kJ/kg. So once this is done, then we can go and find out h_2.

For that, we can say $h_2 = h_1 + \Delta h \vee P_1$ where we know $\Delta h \vee P_1 = v_1 (P_2 - P_1)$. So we will have $h_2 = 191.83 + 0.001010 (3000 - 10)$. So we have h_2 = 194.85 kJ/kg. Similarly, we can find out h_4 and that $h_4 = h_3 + \Delta h \vee P_2$. Here we have to remember that we are extracting y mass of steam for the feed water heating. So this pump is forward type closed feed water heater.

So this is handling only y unit of mass. So we are logically saying that this is only. This $\Delta h \vee P_2$is not the pump work. So we have $h_4 = h_3 = 670.56 + v_3 (P_4 - P_3)$. So we can get h_4 = 673.20 kJ/kg. Since here, we will have v_3 and where v_3= 0.0011, $P_4 = 3000\, kPa \wedge P_3 = 600\, kPa$. So knowing all this, we would find out h_4. Now we have to find out h_9. So here TTD is given to be zero.

That means temperature at 9 is equal to temperature at station 3. So as what we know we could as well assume that $h_9 = h_3$ if we would like to use steam table or we will go to the liquid part or water part and in those tables, we can find out the value of h_9. So in this case we will write down the value of h_9 obtained from the liquid water table and that is 671.98 kJ/kg.

We can see here that $h_9 = 671$ and h_3 is basically equal to670. So this is almost similar. So knowing this now we can find out the mass fraction extracted. So here for mass fraction extracted, we know here what is happening that y amount of mass is losing its enthalpy from $h_7 ¿ h_3$ and giving it to (1 – y) unit of mass to gain its enthalpy from $h_2 ¿ h_9$.

So knowing this, we can write down the expression for y which happens to be $y = \frac{h_9 - h_2}{(h_7 - h_3) + (h_9 - h_2)}$. So here we can get we know now h_9 which is mentioned over here, h_2 is also known, h_7 is found out. So h_3 is also known. So we can find out y and y happens to be 0.181. So 0.181 fraction of 1 kg of mass is extracted for the closed feed water heating.

So knowing this we can go ahead and then we can do rest of the calculations. So in the rest of the calculations, in rest of the calculations, we basically have to find out what is the enthalpy at state 5. So for enthalpy at state 5 it is simple. We have to say here that (1 – y) of water at state 9 is mixed with y state of water at enthalpy 4 with y mass of water at enthalpy 4 to give 1 kg of water at state 5.

So we know now y, we know h_9, h_4. So using this we can find out our h_5. So $h_5 = 1-0.181(h_9-h_4) = 1-0.181(671.98-673.20)$. This gives us h_5 and which happens to be 672.2 kJ/kg. Now we know enthalpies at all stations. So we can go ahead and do the performance calculation.

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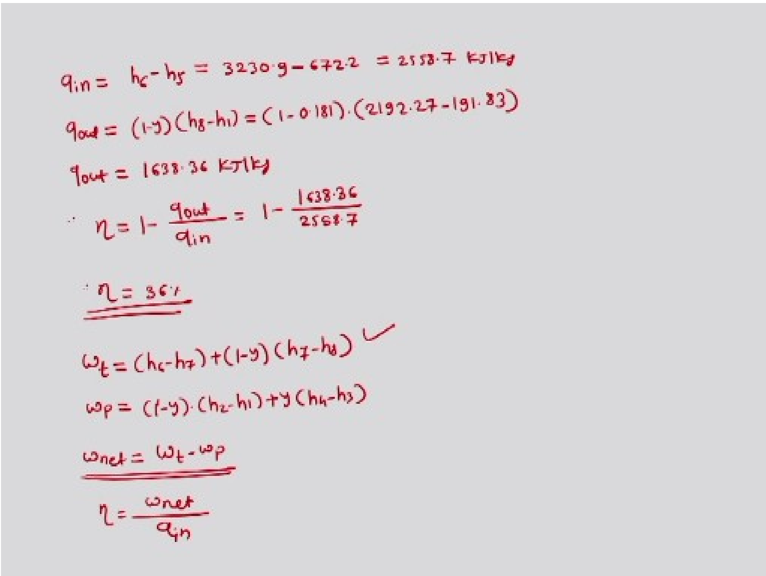

So for that we first need to find out what is q_{in} and q_{in} if we remember q_{in} is given from 5 to 6. So it is $q_{in} = h_6 - h_5$. So this is $q_{in} = 3230.9 - 672.2$ and this gives us 2558.7 kJ/kg. We also need to find out q_{out} which is $q_{out} = 1 - y(h_8 - h_1) = 1 - 0.181(2192.27 - 191.83)$. So we know that we found out h_8 here using the matching of $h_6 = h_8$.

So this gives us q_{out} and q_{out} comes out to be 1638.36 kJ/kg. So we can find out efficiency which happens to be $\eta = 1 - \frac{q_{out}}{q_{in}}$ and then that is $1 - \frac{1638.36}{2558.7}$. So efficiency comes to be 36%. We could as well found out efficiency. For that we would need it to find out turbine work. So turbine work we could have found out by saying that there is some 1 kg of mass getting expanded from h 6 to h 7. So it is $(h_6 - h_7) + (1 - y)(h_7 - h_8)$. So this is turbine work.

We would have found pump work. Total pump work is here plus here. Here we are handling $(1 - y)(h_2 - h_1) + y(h_4 - h_3)$. We know all enthalpies, we know y. We would have found out $W_{net} = W_T - W_P$. If we divide it by $q_¿$ we can get efficiency. This is how we would have found out efficiency in the present case.