Steam Power Engineering
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Lecture -07
Examples of Rankine cycle

Welcome to the class. Today we will talk about the examples related to steam power cycle which is actually Rankine cycle for us.

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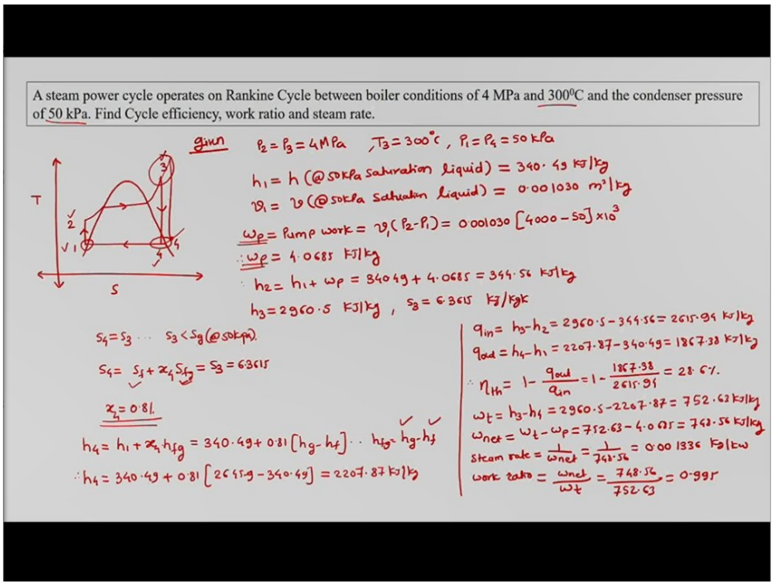

A steam power cycle operates on Rankine Cycle between boiler conditions of 4 MPa and 300⁰C and the condenser pressure of 50 kPa. Find Cycle efficiency, work ratio and steam rate.

given $P_2 = P_3 = 4\,MPa$, $T_3 = 300^\circ C$, $P_1 = P_4 = 50\,kPa$

$h_1 = h$ (@ 50kPa saturation liquid) $= 340.49\ kJ/kg$

$v_1 = v$ (@ 50kPa saturation liquid) $= 0.001030\ m^3/kg$

$w_p =$ Pump work $= v_1(P_2 - P_1) = 0.001030\,[4000 - 50] \times 10^3$

$\therefore w_p = 4.0685\ kJ/kg$

$\therefore h_2 = h_1 + w_p = 340.49 + 4.0685 = 344.56\ kJ/kg$

$h_3 = 2960.5\ kJ/kg$, $s_3 = 6.3615\ kJ/kgK$

$s_4 = s_3 \quad \because s_3 < s_g$ (@ 50kPa).

$s_4 = s_f + x_4 s_{fg} = s_3 = 6.3615$

$x_4 = 0.81$

$h_4 = h_1 + x_4 h_{fg} = 340.49 + 0.81\,[h_g - h_f] \quad \because h_{fg} = h_g - h_f$

$\therefore h_4 = 340.49 + 0.81\,[2645.9 - 340.49] = 2207.87\ kJ/kg$

$q_{in} = h_3 - h_2 = 2960.5 - 344.56 = 2615.94\ kJ/kg$

$q_{out} = h_4 - h_1 = 2207.87 - 340.49 = 1867.38\ kJ/kg$

$\therefore \eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{1867.38}{2615.94} = 28.6\%$

$w_t = h_3 - h_4 = 2960.5 - 2207.87 = 752.63\ kJ/kg$

$w_{net} = w_t - w_p = 752.63 - 4.0685 = 748.56\ kJ/kg$

Steam rate $= \frac{1}{w_{net}} = \frac{1}{748.56} = 0.001336\ kg/kW$

work ratio $= \frac{w_{net}}{w_t} = \frac{748.56}{752.63} = 0.995$

So, the first example says that, a steam power cycle operates on Rankine Cycle between boiler conditions of 4 mega pascal and 300 °C and the condenser pressure of 50 kPa. Find cycle efficiency, work ratio and steam rate. We will first draw the Rankine Cycle for our reference and then we would note all the numbers, this is 1, this is 2 this is 3 and this is 4. So, this is the Rankine cycle for us. So as for the given conditions $P_2 = P_3 = 4\,MPa$ .so it is given.

Then $T_3 = 300\,°C$ and $P_1 = P_4 = 50\,kPa$. We are supposed to find out cycle efficiency and work ratio and steam rate. So, in view of this we can proceed with the example and here we need to first go the steam table and then find out what are the properties at different stations. What properties we can find out from the steam table. We can find out definitely the property 3.

Okay, and property 3 would correspond to, if I go to the steam table for the 50 kPa. So, steam table we have discussed that there would be different sections and initially we would have a section where based upon saturation temperate, we can find out the enthalpy, entropy, internal energy, specific volume. In other section we had seen that we can find out the same parameters based on the saturation pressure.

But, after these two sections there would be superheated where we would be given with saturation pressure and different superheat temperatures. For each case there will be same parameters as entropy, internal energy, specific volume would be mentioned. So, one state corresponds to the saturation liquid so we can go to the 50 kPa condition in the same table and find out what is the enthalpy at state 1.

So, if we say h_1 which corresponds to enthalpy at 50 kPa saturation liquid is equal to 340.49 kJ/kg. Then we will also mention specific volume at state one which again corresponds to specific volume corresponding to 50 kPa saturation liquid and this specific volume in turn have be double zero one zero three zero-meter cube per kg. We would also need entropy since process one to two is isotropy.

But we do not need entropy since we can find out state 2 using the assumption of few to be in compressible and then we can find out the work input. So, for that we can find out W_P which is pump work and we know we have use formula for $W_P=v_1(P_2-P_1)$ .So, using this formula we can mention 0.001030 into meter cube, into 4000 kPa which is 4 MPa- 50 so this is into 10 to the power 3.

So, we can get pump work to be around 4.0685 kJ/kg. So, we can find out $h_2=h_1+W_P$. h_1 is known to us 340.49, pump work is 4.0685 so we get $h_2=$¿ 344.56 kJ/kg. Now we need to find out state 3. So, for finding out state 3 we need to go to this steam table in the initially the part which deals with the saturation pressure for 4 MPa. We have to see what is the saturation temperature and we have to compare that saturation temperate with our given saturation temperature.

If our given saturation temperature is basically more or if our given temperature is more than the saturation temperature then we have to go to the superheated part. So, we will obviously go the superheated part in the present case and then we will find out what is h_3 from the steam table. And h_3 from the steam table is 2960.5 kJ/kg. But here we would also mention as 3 which is entropy at is 3 and this is 6.3615 kJ/kgK this our entropy at station 3.

Now, we can find out the state 4 but for finding out state 4 we just first have to compare the fact that $S_4=S_3$. Now, how should we proceed here, we will go to the steam table we will go to the first the part the pressure part of the steam table where we are told that the condenser pressure is 50 kPa. So, we will find out what is saturation fluid entropy or saturation vapor entropy for the 50 kPa case.

And now if our $S_3$is greater than that then we would understand that 3. 3 is in the superheat part. But if our S_3 is less than S_g then we are in the wait dome as it is shown over here. So, we might sometimes if 3 is somewhere here then we might end our 4.4 over here. So, in this case we will have to go to the superheated part corresponding to 50 kPa find out at what temperature in the superheated part corresponding to 50 kPa.

The entropy matches with the entropy as 3 and when it matches that state that temperature at 50 kPa is the state 4 condition. But here it would turn out that as 3 as 4 is basically equal to S_3 and $S_3>S_g$ at 50 kPa. So, we have to find out the granny's fraction at state 4. So, $S_4=S_f+xS_{fg}=S_3=6.3615$and then we can know what is $S_f$and what is S_{fg} which is the latent entropy required for phase transfer.

So, knowing S_f, knowing S_{fg} from the steam table we can find out x. So, here we get $x=0.81$. So, this is granny's fraction at state 4. So, knowing this granny's fraction, we can find out h_4 as h_1+x_4 which is basically this x_4h_{fg} and then we know $h_1=340.49+0.81\,h_{fg}$if h_{fg} is given otherwise we can make is as h_g-h_fwhich is basically saying that $h_{fg}=h_g-h_f$ this saturation enthalpy vapor and this is saturation enthalpy liquid.

So, knowing this we can find out $h_4=340.49+0.81\left(h_g-h_f\right)=340.40+0.81\left(2645.9-340.49\right)$ this gives as $h_4=2207.87\,kJ/kg$. Now, we know enthalpy at 1 enthalpy at 2 enthalpy at 3 and enthalpy at 4. We also had find out what is pump work. So, now we can proceed and find out other work interactions. So, we can find out what is basically initially $Q_{¿}$ which is added which is $h_3 - h_2, h_3 = 2960.5 - h2 = 344.56$ and this gives us H delta h or $Q_{¿}$ 2615.94 kJ/kg.

We can also find out Q_{out} and $Q_{out} = h_4 - h_1$ so, h_4 is known to us $2207.87 - h_1 = 340.49$ this gives us $Q_{out} = 1867.38\,kJ/kg$. So, we can find out thermal efficiency of cycle as $\eta = 1 - \frac{Q_{out}}{Q_{¿}}$ so it is $1 - \frac{1867.38}{2615.94}$ and this us efficiency as 28.6%. So, we can find out also turbine work and turbine work is $W_T = h_3 - h_4, h_3 = 2960.5, h_4 = 2207.87$ and this give us turbine work as 752.63 kJ/kg.

Pump work is already found out so we can get W_{net} and $W_{net} = W_T - W_P$ so 752.63 is turbine work - pump work as 4.0685 so we get net work as 748.56 kJ/kg. Knowing this we can find the last thing which is work ratio and steam rate. So, we can find out steam rate, steam rate is equal $SSC = \frac{1}{W_{net}} = \frac{1}{748.56}$. So, it is 0.001336 kg per kilo weight. Then we can find out work ratio and that is $\tau = W_T / W_{net}$ so $W_{net}$is 748.56 and $W_T$which is turbine work 752.63.

So, we get it as 0.995. So, this is how we can solve the example. Here we have to also remember one more point. That suppose in a case in the present case we need to find out the condition at 3 from the steam table. And then in the steam table if $300°C$ superheat temperature is not available corresponding to 4 MPa and if we have 350 and 250 temperatures given and then we can interpolate and find out the condition at our required desired condition of $300°C$.

So, we need to practice for the fact that if some data is unavailable from the given data we should extrapolate or interpolate to get the conditions required.

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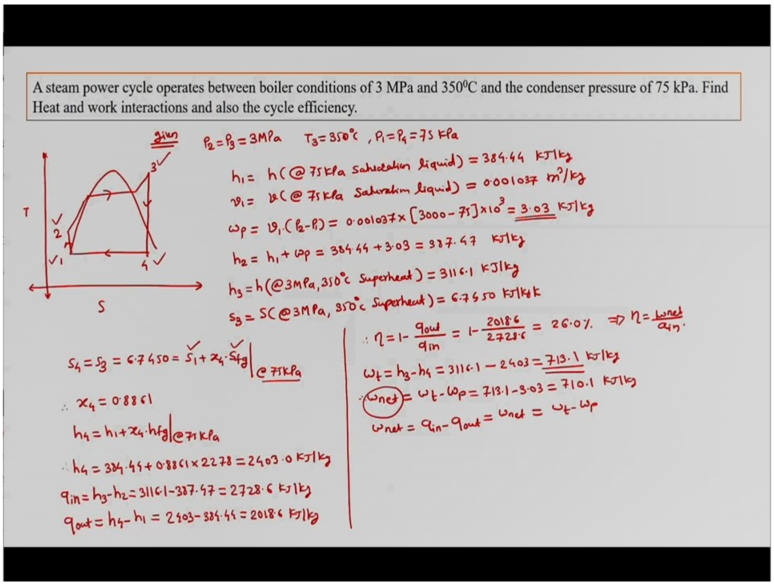

A steam power cycle operates between boiler conditions of 3 MPa and 350⁰C and the condenser pressure of 75 kPa. Find Heat and work interactions and also the cycle efficiency.

given $P_2 = P_3 = 3 MPa \quad T_3 = 350^\circ C, \; P_1 = P_4 = 75 \; kPa$

$h_1 = h(@ 75 kPa \text{ Saturation liquid}) = 384.44 \; KJ/kg$

$v_1 = v(@ 75 kPa \text{ Saturation liquid}) = 0.001037 \; m^3/kg$

$\omega_p = v_1 \cdot (P_2 - P_1) = 0.001037 \times [3000 - 75] \times 10^3 = \underline{\underline{3.03}} \; KJ/kg$

$h_2 = h_1 + \omega_p = 384.44 + 3.03 = 387.47 \; KJ/kg$

$h_3 = h(@ 3MPa, 350^\circ C \text{ Superheat}) = 3116.1 \; KJ/kg$

$s_3 = S(@ 3MPa, 350^\circ C \text{ Superheat}) = 6.7450 \; KJ/kgK$

$s_4 = s_3 = 6.7450 = s_1 + x_4 \cdot s_{fg} \Big|_{\underline{@ 75 kPa}}$

$\therefore x_4 = 0.8861$

$h_4 = h_1 + x_4 \cdot h_{fg} \Big|_{@ 75 kPa}$

$\therefore h_4 = 384.44 + 0.8861 \times 2278 = 2403.0 \; KJ/kg$

$q_{in} = h_3 - h_2 = 3116.1 - 387.47 = 2728.6 \; KJ/kg$

$q_{out} = h_4 - h_1 = 2403 - 384.44 = 2018.6 \; KJ/kg$

$\therefore \eta = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{2018.6}{2728.6} = 26.0\% \Rightarrow \eta = \frac{\omega_{net}}{q_{in}}.$

$\omega_t = h_3 - h_4 = 3116.1 - 2403 = \underline{\underline{713.1}} \; KJ/kg$

$\therefore \boxed{\omega_{net}} = \omega_t - \omega_p = 713.1 - 3.03 = 710.1 \; KJ/kg$

$\omega_{net} = q_{in} - q_{out} = \omega_{net} = \omega_t - \omega_p$

We will move ahead the next example which state that steam power cycle operates between boiler condition of 3 MPa s and 350° C and the condenser condition of 75 kPas. Find Heat and work interactions and also cycle efficiency. Example, for practice is almost similar we are given that we are having now boiler condition as 3 MPa s so state 2 and 3 pressures are given. $P_2 = P_3 = 3 MPas$.

And $T_3 = 350\,^\circ C$we are told that $P_1 = P_4 = 75\,kPas$. Again, as what we did in the first example, we have to go to the steam table and then find out enthalpy corresponding to 75 kPa saturation liquid. And this would have value as 384.44 kJ/kg. Here, we also need to find out specific volume at 75 kPa saturation liquid specific volume and this will be 0.001037 meter cube per kg.

Then we can do one thing we can find out first pump work and pump work is $W_P = v_1 (P_2 - P_1) = 0.001037 (3000 - 75) \times 10^3$. So, we will have pump work as 3.03 kJ/kg. Hence, we can find out h_2, $h_2 = h_1 + W_P = 384.33 + 3.03$ and this us $h_2 = 387.47\,kJ/kg$. So, we know now state 1 and state 2.

So now we need to find out state 3. So, we will go to h_3 and obviously as expected we will coMPare the we will first see what is the saturation temperate corresponding to 3 MPa s and it out that our given temperature is 350° C is more than that. That is why $h_3$we are seeing in steam table in the 3 MPa and 350° C superheat for enthalpy and this gives us value of an enthalpy as 3116.1 kJ/kg.

There itself we will see entropy at state 3 and entropy at state 3 will again be at 3 350 °C superheat and then this will have entropy as 6.7450 kJ/kg kelvin. Now, again we have known that we have $S_4=S_3$ which we will see that if this $S_3>S_g$ at 75 kPa or $S_3<S_g$ at 75 kPa and accordingly we will see which part of steam table should be seen.

So, our case S_3 remains less so we will see such steam table in the saturation part and then we are not in the superheated part. So, then we need to find out the granny's fraction. So, it turns out that, S_3 is know which is $S_3=6.7450=S_1+x_4S_{fg}$ and S_{fg} at 75 kPas. So, we will see in this steam table what is the liquid saturation enthalpy at what is the liquid saturation entropy at 1 and what is the latent and entropy as S_{fg} corresponding to 75 kPas.

And from that we will get x_4 and x_4 turns out to be 0.8861. Knowing this we can find out $h_4=h_1+x_4h_{fg}$ at 75 kPas. So, this gives us suppose h_{fg} is given so we first know h_4 which is 384.44+ x_4 is 0.8861 and h_{fg} it would be known to us from the steam table it is 2278 so this gives us h_4 as 2403.0 kJ/kg. Now we know all enthalpies at all corners of the cycle. Now we can find out what is $Q_{¿}$ and Q_{out}.

So, $Q_{¿}=h_3-h_2=3116.1-387.47$and this gives us $Q_{¿}=2728.6\,kJ/kg$. Similarly, $Q_{out}=h_4-h_1=2403-384.44\,, so\,Q_{out}=2018.6\,kJ/kg$ and this gives us the all the numbers required to find out thermal efficiency of cycle which is $\eta_T=1-\frac{Q_{out}}{Q_{¿}}$ so which is $1-\frac{2018.6}{2728.6}$ and thermal efficiency would be 26%.

So, this is the value of thermal efficiency for the given example. Then we can find out wt which is turbine work as $W_T=h_3-h_4=3116.1-2403$ and this gives us $W_T=713.1kJ/kg$. So, we have network as turbine work - pump work this turbine work and we have found this as pump work so we have 713.1 - 3.03 and this gives as net work as 710.1 kJ/kg.

This W_{net} we would also have got if we do $Q_{\text{¿}} - Q_{out}$is equal to basically W_{net} which is $W_T - W_P$. Similarly, we would also have got if efficiency by saying $\frac{W_{net}}{Q_{\text{¿}}}$. So, this would be different ways by which we can find out different parameters which are asked in the question.

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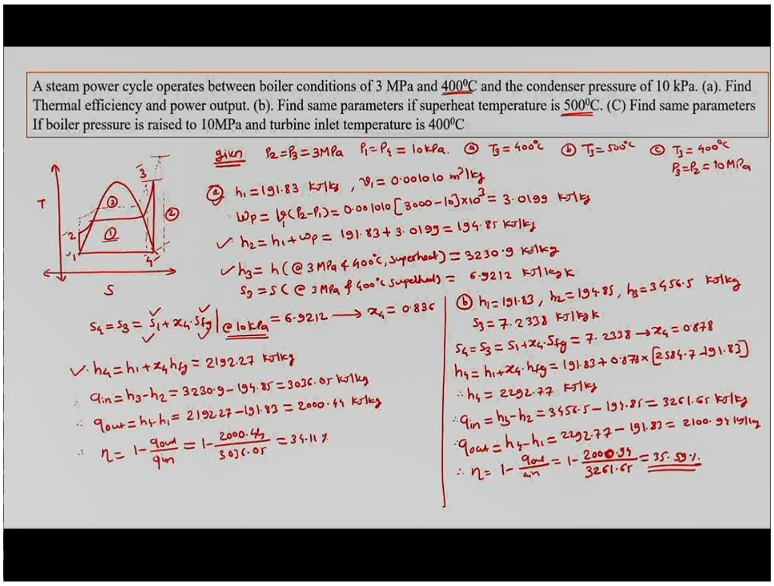

A steam power cycle operates between boiler conditions of 3 MPa and 400⁰C and the condenser pressure of 10 kPa. (a). Find Thermal efficiency and power output. (b). Find same parameters if superheat temperature is 500⁰C. (C) Find same parameters If boiler pressure is raised to 10MPa and turbine inlet temperature is 400⁰C

given $P_2 = P_3 = 3\,MPa$ $P_1 = P_4 = 10\,kPa$. ⓐ $T_3 = 400°c$ ⓑ $T_3 = 500°c$ ⓒ $T_3 = 400°c$
$P_3 = P_2 = 10\,MPa$

ⓐ $h_1 = 191.83$ kJ/kg , $v_1 = 0.001010\ m^3/kg$
$w_P = v_1(P_2 - P_1) = 0.001010[3000 - 10]\times 10^{3} = 3.0199$ kJ/kg
✓ $h_2 = h_1 + w_P = 191.83 + 3.0199 = 194.85$ kJ/kg
✓ $h_3 = h(@\,3\,MPa\ \&\ 400°c,\ \text{superheat}) = 3230.9$ kJ/kg
$s_3 = s(@\,3\,MPa\ \&\ 400°c\ \text{superheat}) = 6.9212$ kJ/kgK
$s_4 = s_3 = s_1 + x_4 \cdot s_{fg}\big|_{@\,10\,kPa} = 6.9212 \longrightarrow x_4 = 0.836$
✓ $h_4 = h_1 + x_4 h_{fg} = 2192.27$ kJ/kg
$\therefore q_{in} = h_3 - h_2 = 3230.9 - 194.85 = 3036.05$ kJ/kg
$\therefore q_{out} = h_4 - h_1 = 2192.27 - 191.83 = 2000.44$ kJ/kg
$\therefore \eta = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{2000.44}{3036.05} = 34.11\%$

ⓑ $h_1 = 191.83$, $h_2 = 194.85$, $h_3 = 3456.5$ kJ/kg
$s_3 = 7.2338$ kJ/kgK
$s_4 = s_3 = s_1 + x_4 \cdot s_{fg} = 7.2338 \rightarrow x_4 = 0.878$
$h_4 = h_1 + x_4 \cdot h_{fg} = 191.83 + 0.878 \times [2584.7 - 191.83]$
$\therefore h_4 = 2292.77$ kJ/kg
$\therefore q_{in} = h_3 - h_2 = 3456.5 - 194.85 = 3261.65$ kJ/kg
$q_{out} = h_4 - h_1 = 2292.77 - 191.83 = 2100.94$ kJ/kg
$\therefore \eta = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{2100.94}{3261.65} = 35.59\%$

We will go ahead with the next example and it states that steam power cycle operates between boiler conditions of 3 MPa s and 400°C and condenser condition of 10 kPas. Find thermal efficiency and power output. Find same parameters if superheat temperature is 400°C, find same parameters if boiler pressure is raised to 10 MPa s and turbine inlet temperature is 400°C.

So, basically there are three examples in the same example so let us see what to do for the first part. So, for the first part we will first draw T-s diagram. So this is for the first part. In second we would have told that the temperature is raising. So, we have to find out new condition. In the second part or in the third part we are told that boiler pressure and boiler temperature both are increased. So, this will be three condition. This is 1 this 2 and this is 3.

So, having said that these are the general numbers. So, for in the given case present case we have $P_2 = P_3 = 3\,MPa$ and we also have $P_1 = P_4 = 10\,kPa$. In example A $T_3 = 400°C$, in B, T_3 is equal to 500 °C and in C we have T_3 is equal to again 400 °C but $P_3 = P_2$ is having raised value of 10 MPa s.

So, we will solve first A, for A we have to find out h_1 and h_1 turns out to be 191.83 kJ/kg. Similarly, $v_1 = 0.001010\, m^3/kg$. So, we have $W_p = v\left(P_2 - P_1\right) = 0.001010\left(3000\, kPa\, s - 10\, kPa\, s\right)$. So, pump work will be 3.0199 kJ/kg. So $h_2 = h_1 + W_p$ so we have 191. 83+ 3.0199 and this gives us 194.85 kJ/kg.

This is our h_2 so we have to go into the steam table and note down what is h_3 and in case of 3 MPa , so at 3 MPa and 400 °C super heat condition, we have h which is h_3 as 3230.9 kJ/kg. Similarly, as 3 at 3 and 400 °C super heat $S_3 = 6.9212\, kJ/kgK$. So, we have $S_4 = S_3$and then again mind the fact we will write it as $x_4 S_{fg} + S_1$ at 10 kPas.

So, we will get these two things at 10 kPa we can find out in the steam table where this is liquid saturation entropy this is latten entropy and then we know it is equal S_3 which is 6.9212 and this gives us x_4 as 0.836. So, we have $h_4 = h_1 + x_4 h_{fg}$. This helps us to find out what is the enthalpy and so enthalpy is equal to 2192.27 kJ/kg. So now have everything, h_4, h_3, h_2, h_1. All corners are known for the example number 1. So, we have $Q_{¿} = h_3$ - h3 and that $Q_{¿}$ is 3230.9 and 194.85.

So this is 3036.05 KJ/kg. $Q_{out} = h_4 - h_1 = 2192.27 - 191.83$so we will get $Q_{out} = 2000.44\, kJ/kg$.

So, thermal efficiency is equal to $\eta_T = 1 - \frac{Q_{out}}{Q_{¿}} = 1 - \frac{2000.44}{3036.05}$ so we get 34.11% efficiency for the first case. We can go ahead and do the calculation for the rest of the cases in the similar way. So, we will go ahead and for part B we can write down the enthalpy h_3, it should be remembered earlier that for part B we are not changing the boiler conditions.

If we are not changing the boiler inlet condition in h_1 it's same and h_1 is 191.83, h_2 its same 194. 85 but h_3 is not the same. We have to go back into the steam table, see in the superheated part corresponding to 3 MPa s and lastly we had seen for 400. But now we have see for 500°C and we have to mention h_3 as 3456.5 KJ/kg. Similarly, we will mention here S_3 also. And S_3 will be 7.2338 kJ/kg knowing this we can again say $S_4 = S_3 = S_1 + x_4 S_{fg} = 7.2338$ and this gives us x_4 as 0.878 so we can find out $h_4$and $h_4 = h_1 + x_4 h_{fg}$.

So, we know that it is $191.83+0.878\,h_{fg}$ in case if it is not given we can make it as $h_{fg}=h_g-h_f$ so it is 2584.7 - 191.83 and this gives us $h_4=2292.77\,kJ/kg$. So, we can find out $Q_{¿}=h_3-h_2=3456.5-194.85$and this gives us $Q_{¿}=3261.65\,kJ/kg$. So, we have $Q_{out}=h_4-h_1=2292.77-191.83$ and this gives us $Q_{out}=2100.94\,kJ/kg$.

So, efficiency is equal to $\eta_T=1-\frac{Q_{out}}{Q_{¿}}$ and we know $¿1-\frac{2000.94}{3261.65}$ and this gives us efficiency as 35.59%. So, we can compare two efficiencies and in the first case we had efficiency 34.11% and for 34.11% Turbine inlet temperature was 400 °C, but now we solved the same example for turbine inlet condition of 500 °C.

It should be remembered here that if we increase the turbine inlet condition for the same condenser condition then we will have more temperature of heat addition which will lead to increase in efficiency of the cycle. So we have third part remained in the same example so here we know that in C part we have h1 will be same and it is 191.83 but now we have to work out the 10 MPa pressure.

So $h_2$we have to find out for 10 MPa condition where we know, we also written down $v_1=001010$, so we can find out $W_p=v(P_2-P_1)$, So it is 001010 into we have now 10 MPa so 10,000 kPa and we have only 10 kPa for the condenser pressure so it 10 to the power 3. So, we have pump work as 2, so the pump work turns out to be 10.08999, so we have $h_2=h_1+W_p$ and h_2 over here that's why it will be 201.92 kJ/kg.

So we now know 2 corners, we have to find outh_3 from the steam table and h_3 enthalpy at 10 MPa and in the example temperature is given as 400 °C and 400 °C super heat in that enthalpy h_3 would be 3096.5 kJ/kg and here we remember that we have to also find out the entropy corresponding to 10 MPa, 400 °C superheat and at this entropy is 6.2120 kJ/kg K.

So, we have $S_3=S_4=6.2120=S_1+x_4S_{fg}$ This gives us the idea for the value of x_4 and then this is 0.742

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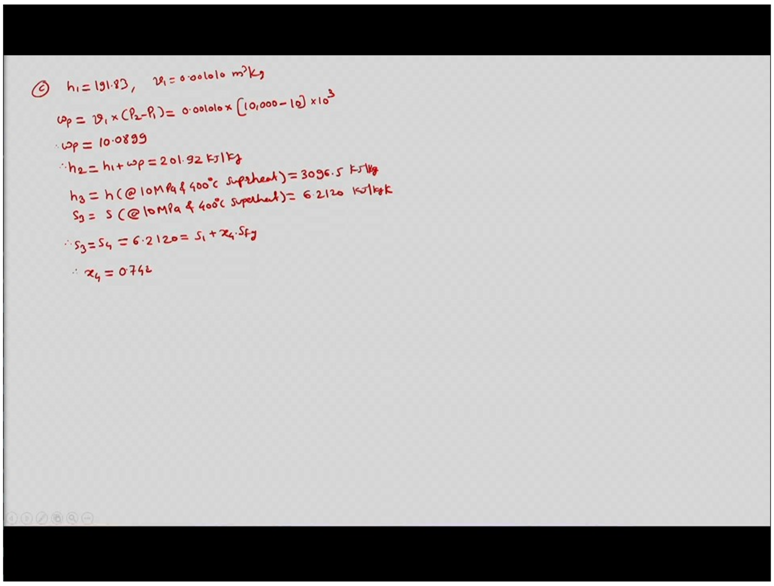

Ⓒ $h_1 = 191.83$, $v_1 = 0.001010\ m^3/kg$

$w_p = v_1 \times (P_2 - P_1) = 0.001010 \times [10{,}000 - 10] \times 10^3$

$\therefore w_p = 10.0899$

$\therefore h_2 = h_1 + w_p = 201.92\ kJ/kg$

$h_3 = h(@10MPa\ \&\ 400°C\ \text{superheat}) = 3096.5\ kJ/kg$

$s_3 = s(@10MPa\ \&\ 400°C\ \text{superheat}) = 6.2120\ kJ/kgK$

$\therefore s_3 = s_4 = 6.2120 = s_1 + x_4 \cdot s_{fg}$

$\therefore x_4 = 0.742$

Now, we should remember here that as we have plotted over here

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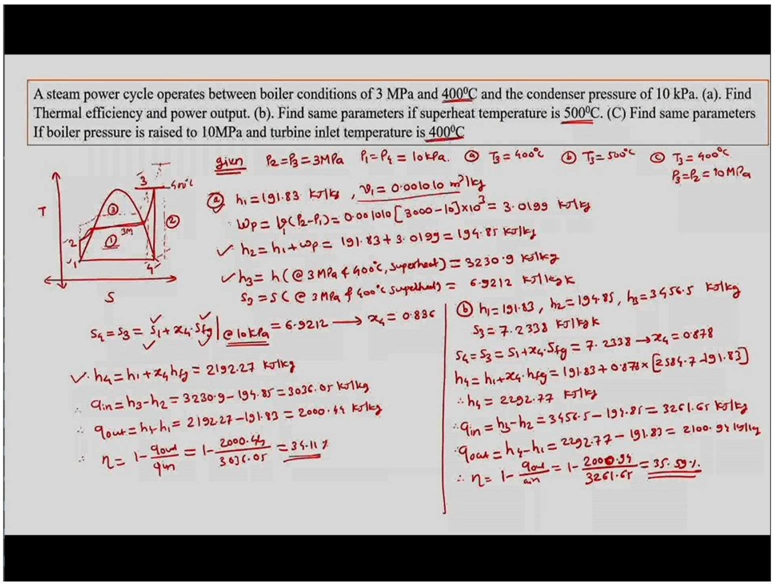

A steam power cycle operates between boiler conditions of 3 MPa and 400⁰C and the condenser pressure of 10 kPa. (a). Find Thermal efficiency and power output. (b). Find same parameters if superheat temperature is 500⁰C. (C) Find same parameters If boiler pressure is raised to 10MPa and turbine inlet temperature is 400⁰C

given $P_2 = P_3 = 3MPa$ $P_1 = P_4 = 10kPa$. ⓐ $T_3 = 400°C$ ⓑ $T_3 = 500°C$ Ⓒ $T_3 = 400°C$, $P_3 = P_2 = 10MPa$

ⓐ $h_1 = 191.83\ kJ/kg$, $v_1 = 0.001010\ m^3/kg$

$\therefore w_p = v_1(P_2 - P_1) = 0.001010[3000 - 10] \times 10^3 = 3.0199\ kJ/kg$

✓ $h_2 = h_1 + w_p = 191.83 + 3.0199 = 194.85\ kJ/kg$

✓ $h_3 = h(@3MPa\ \&\ 400°C, \text{superheat}) = 3230.9\ kJ/kg$

$s_3 = s(@3MPa\ \&\ 400°C\ \text{superheat}) = 6.9212\ kJ/kgK$

$s_4 = s_3 = s_1 + x_4 \cdot s_{fg} \big|_{@10kPa} = 6.9212 \longrightarrow x_4 = 0.836$

✓ $h_4 = h_1 + x_4 h_{fg} = 2192.27\ kJ/kg$

$\therefore q_{in} = h_3 - h_2 = 3230.9 - 194.85 = 3036.05\ kJ/kg$

$\therefore q_{out} = h_4 - h_1 = 2192.27 - 191.83 = 2000.44\ kJ/kg$

$\therefore \eta = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{2000.44}{3036.05} = 34.11\%$

ⓑ $h_1 = 191.83$, $h_2 = 194.85$, $h_3 = 3456.5\ kJ/kg$

$s_3 = 7.2338\ kJ/kgK$

$s_4 = s_3 = s_1 + x_4 \cdot s_{fg} = 7.2338 \rightarrow x_4 = 0.878$

$h_4 = h_1 + x_4 \cdot h_{fg} = 191.83 + 0.878 \times [2584.7 - 191.83]$

$\therefore h_4 = 2292.77\ kJ/kg$

$\therefore q_{in} = h_3 - h_2 = 3456.5 - 194.85 = 3261.65\ kJ/kg$

$q_{out} = h_4 - h_1 = 2292.77 - 191.83 = 2100.94\ kJ/kg$

$\therefore \eta = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{2000.94}{3261.65} = 35.59\%$

So, we kept the same turbine inlet temperature as 400 degrees but increase the boiler pressure from 3 to 10 MPa. From 3 to 10 MPa we can see that we got decrement in granny's fraction. In the first case we had granny's fraction where we found out x_4 and x_4 was 0.836 and in the last example, for the same boiler pressure when we increased turbine inlet temperature we should see the dryness fraction increased later we got x_4 as 0.878, so we can make a small conclusion over here in the first if we compare example A and B, then x_4 we got increased since T_3 increased.

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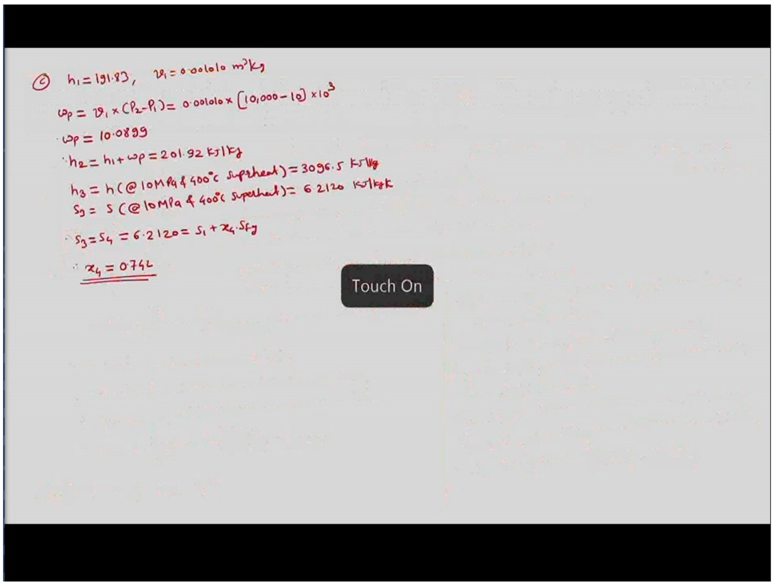

ⓒ $h_1 = 191.83$, $v_1 = 0.001010\ m^3/kg$

$w_p = v_1 \times (P_2 - P_1) = 0.001010 \times [10{,}000 - 10] \times 10^3$

$w_p = 10.0899$

$\therefore h_2 = h_1 + w_p = 201.92\ kJ/kg$

$h_3 = h(@ 10MPa\ \&\ 400°c\ \text{superheat}) = 3096.5\ kJ/kg$

$s_3 = s(@ 10MPa\ \&\ 400°c\ \text{superheat}) = 6.2120\ kJ/kgK$

$\therefore s_3 = s_4 = 6.2120 = s_1 + x_4 \cdot s_{fg}$

$\therefore \underline{\underline{x_4 = 0.742}}$

And now if we coMPare here and make a small conclusion that if we comp$a$re A and C then x_4 decreased for the case that we increase $P_2 = P_3$ and this is increased or same P_3.

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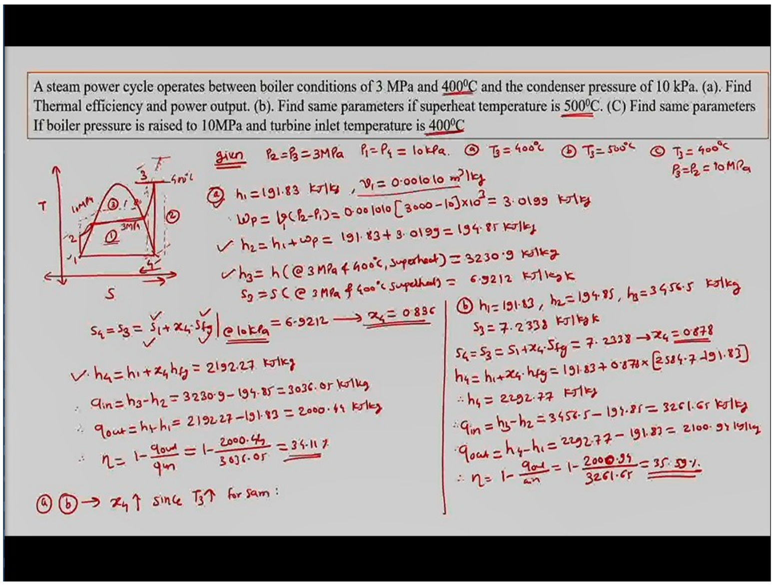

A steam power cycle operates between boiler conditions of 3 MPa and 400⁰C and the condenser pressure of 10 kPa. (a). Find Thermal efficiency and power output. (b). Find same parameters if superheat temperature is 500⁰C. (C) Find same parameters If boiler pressure is raised to 10MPa and turbine inlet temperature is 400⁰C

given $P_2 = P_3 = 3MPa$ $P_1 = P_4 = 10kPa$. ⓐ $T_3 = 400°c$ ⓑ $T_3 = 500°c$ ⓒ $T_3 = 400°c$, $P_3 = P_2 = 10MPa$

ⓐ $h_1 = 191.83\ kJ/kg$, $v_1 = 0.001010\ m^3/kg$

$w_p = v_1(P_2 - P_1) = 0.001010[3000 - 10] \times 10^3 = 3.0199\ kJ/kg$

✓ $h_2 = h_1 + w_p = 191.83 + 3.0199 = 194.85\ kJ/kg$

✓ $h_3 = h(@ 3MPa\ \&\ 400°c, \text{superheat}) = 3230.9\ kJ/kg$

$s_3 = s(@ 3MPa\ \&\ 400°c\ \text{superheat}) = 6.9212\ kJ/kgK$

$s_4 = s_3 = s_1 + x_4 \cdot s_{fg} \Big|_{@ 10kPa} = 6.9212 \longrightarrow \underline{\underline{x_4 = 0.836}}$

✓ $h_4 = h_1 + x_4 h_{fg} = 2192.27\ kJ/kg$

$\therefore q_{in} = h_3 - h_2 = 3230.9 - 194.85 = 3036.05\ kJ/kg$

$\therefore q_{out} = h_4 - h_1 = 2192.27 - 191.83 = 2000.44\ kJ/kg$

$\therefore \eta = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{2000.44}{3036.05} = \underline{\underline{34.11\%}}$

ⓐ ⓑ → $x_4 \uparrow$ since $T_3 \uparrow$ for sam :

ⓑ $h_1 = 191.83$, $h_2 = 194.85$, $h_3 = 3456.5\ kJ/kg$

$s_3 = 7.2338\ kJ/kgK$

$s_4 = s_3 = s_1 + x_4 \cdot s_{fg} = 7.2338 \rightarrow \underline{\underline{x_4 = 0.878}}$

$h_4 = h_1 + x_4 \cdot h_{fg} = 191.83 + 0.878 \times [2584.7 - 191.83]$

$\therefore h_4 = 2292.77\ kJ/kg$

$\therefore q_{in} = h_3 - h_2 = 3456.5 - 194.85 = 3261.65\ kJ/kg$

$q_{out} = h_4 - h_1 = 2292.77 - 191.83 = 2100.94\ kJ/kg$

$\therefore \eta = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{2000.94}{3261.65} = \underline{\underline{35.59\%}}$

and here also it is for same $P_2 = P_3$ for same $P_2 \vee P_3$ we got this conclusion,

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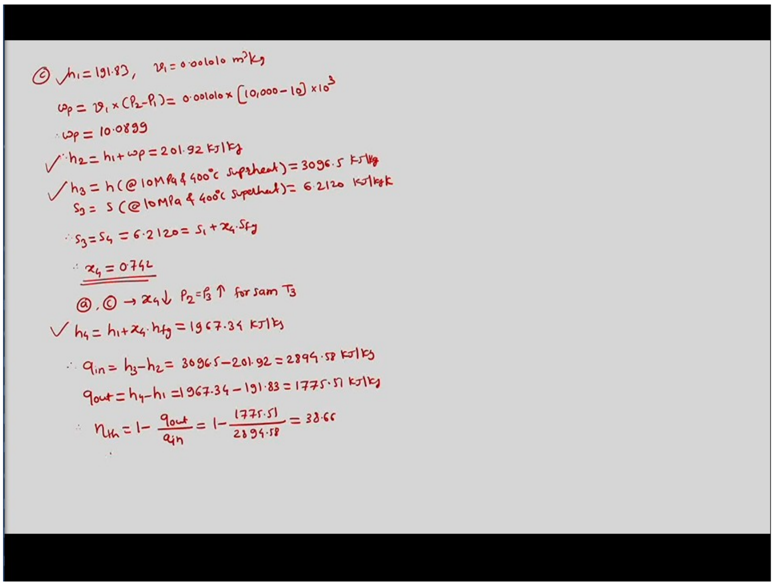

ⓒ ✓ $h_1 = 191.83$, $v_1 = 0.001010\ m^3/kg$

$w_p = v_1 \times (P_2 - P_1) = 0.001010 \times [10{,}000 - 10] \times 10^3$

$\therefore w_p = 10.0899$

✓ $\therefore h_2 = h_1 + w_p = 201.92\ kJ/kg$

✓ $h_3 = h(@10MPa\ \&\ 400°c\ \text{superheat}) = 3096.5\ kJ/kg$

$s_3 = s(@10MPa\ \&\ 400°c\ \text{superheat}) = 6.2120\ kJ/kgK$

$\therefore s_3 = s_4 = 6.2120 = s_1 + x_4 \cdot s_{fg}$

$\therefore \underline{\underline{x_4 = 0.742}}$

ⓐ, ⓒ $\rightarrow x_4 \downarrow$ $P_2 = P_3 \uparrow$ for sam T_3

✓ $h_4 = h_1 + x_4 \cdot h_{fg} = 1967.34\ kJ/kg$

$\therefore q_{in} = h_3 - h_2 = 3096.5 - 201.92 = 2894.58\ kJ/kg$

$q_{out} = h_4 - h_1 = 1967.34 - 191.83 = 1775.51\ kJ/kg$

$\therefore \eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{1775.51}{2894.58} = 38.66$

so now we can move ahead and find out $h_4 = h_1 + x_4 h_{fg}$ and this gives us value as 1967. 34 kJ/kg. So, we can then know now everything $h_1, h_2, h_3 \wedge h_4$, So $Q_{¿} = h_3 - h_2 = 3096.5 - 201.92$ and $Q_{¿} = 2894.58\, kJ/kg$ and $Q_{out} = h_4 - h_1 = 1967.34 - 191.83$ so it is 1775.51 kJ/kg. So, we have thermal efficiency as $\eta_T = 1 - \frac{Q_{out}}{Q_{¿}}$ which is $1 - \frac{1775.51}{2894.58}$ and this gives us efficiency 38.66, so this is our efficiency.

Here as well we can make a small conclusion when we compare example A and C, we can see that thermal efficiency has got increased from the value of 34.11 to 38.66 for same T_3 and increase in P_3, since here as well mean temperature of heat addition has got increased

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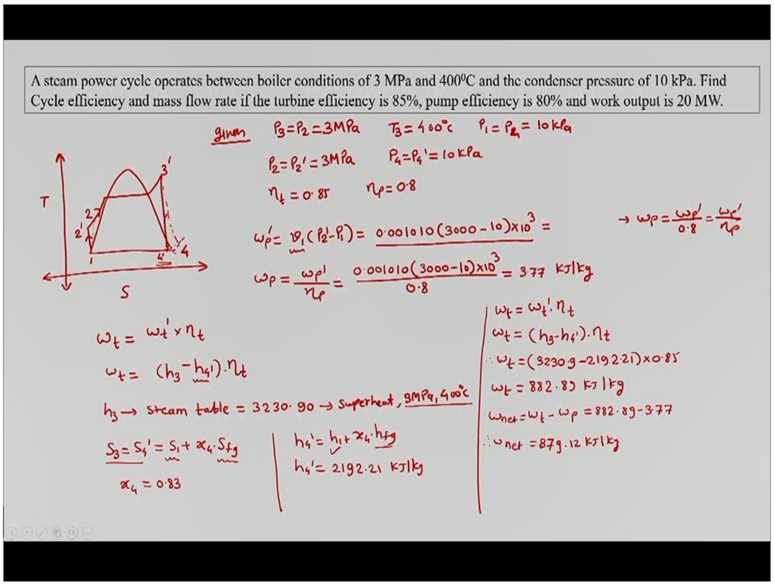

A steam power cycle operates between boiler conditions of 3 MPa and 400^{0}C and the condenser pressure of 10 kPa. Find Cycle efficiency and mass flow rate if the turbine efficiency is 85%, pump efficiency is 80% and work output is 20 MW.

given $P_3 = P_2 = 3MPa$ $T_3 = 400°c$ $P_1 = P_4 = 10kPa$

$P_2 = P_2' = 3MPa$ $P_4 = P_4' = 10kPa$

$\eta_t = 0.85$ $\eta_p = 0.8$

$w_p' = v_1 (P_2' - P_1) = 0.001010(3000 - 10) \times 10^3 =$

$\rightarrow w_p = \frac{w_p'}{0.8} = \frac{w_p'}{\eta_p}$

$w_p = \frac{w_p'}{\eta_p} = \frac{0.001010(3000-10)\times 10^3}{0.8} = 3.77\ kJ/kg$

$w_t = w_t' \times \eta_t$

$w_t = (h_3 - h_{4'}) \cdot \eta_t$

$h_3 \rightarrow$ steam table $= 3230.90 \rightarrow$ Superheat, 3MPa, 400°c

$S_3 = S_4' = S_1 + x_4 \cdot S_{fg}$

$x_4 = 0.83$

$h_4' = h_1 + x_4 \cdot h_{fg}$

$h_4' = 2192.21\ kJ/kg$

$w_t = w_t' \cdot \eta_t$

$w_t = (h_3 - h_{4'}) \cdot \eta_t$

$\therefore w_t = (3230.9 - 2192.21) \times 0.85$

$w_t = 882.89\ kJ/kg$

$w_{net} = w_t - w_p = 882.89 - 3.77$

$\therefore w_{net} = 879.12\ kJ/kg$

We will move to the next example, this example states that the steam power cycle operates between boiler conditions of 3 MPa and 400°C and condenser pressure of 10 kPas. Find cycle efficiency and mass flow rate if the turbine efficiency is 85% and pump efficiency is 80% and work output is 20 Megawatt. So, again we will do from the scratch where we will first draw T-S diagram for the cycle where we will denote on the points 1,2,3 and 4.

So, given things for us are $P_3 = P_2 = 3 MPa\,s$, $T_3 = 400°C$ and we have $P_1 = P_4 = 10\,kPa$ but now we are told that the pumps and turbine are not ideal. So, what we should do for ideal case we will mention them as dash and then really two will be hear and then 4 will be hear, this is 4 dash. So, practically $P_2 = P_{2'} = 3\,MPas$ and $P_4 = P_{4'} = 10\,kPa$, Turbine efficiency 0.85, pump efficiency is 0.8.

Now we will proceed, we can find out $h_1$which is h corresponding to 10 kPa and saturation liquid. So, this H for us, we can find out, we can get it from the steam table and then this H we can further use for the calculation of h_2 which is the enthalpy at the outlet of the turbine of the compressor. In this example, we will start with finding out the pump work. So, pump work which is ideal, we know it is$W_p = v(P_2 - P_1)$; $P_{2'} = P_2$ so we can use either.

So we can see v and this v is specific volume corresponding to saturation liquid at 10 kPa and this turns out be $0.001010(300\,kPa - 10\,kPa) \times 10^3$in terms of pascal and then this will give us turbine pump out put in ideal sense. But we want pump output in the real sense, so for that we can make use of the fact that $W_{P'}$which is pump out put W_P which is real pump output is equal to $W_P = \frac{W_{P'}}{0.8} = \frac{W_{P'}}{\eta_P}$

So we can say that $W_P = \frac{W_{P'}}{\eta_P} = \frac{0.001010(300\,kPa - 10\,kPa) \times 10^3}{0.8}$, so this gives us pump work which is real pump work and real pump work turns out to be 3.7 kJ/kg. Now, we can find out turbine work similarly real turbine work is equal to ideal turbine work into turbine efficiency. So ideal turbine work we know that, it is equal to h3 - h3, Ideal turbine work is $(h_3 - h_{4'})\eta_T$.

So, now we can find out h_3 from the steam table and go to the conditions 3 MPa will go into the superheated part and see the temperature at 400°C and we can get h_3. And this h_3 can be found out from steam table and this turns out to be 3230.90 and this superheated part corresponding to 3 MPa and 400 °C. Now, we need to find out $h_{4'}$. But $h_{4'}$ is inside the Doom, so we do not know what is the wetness or what is the dryness fraction for that $S_3 = S_{4'}$.

So we need to find out S_3 also from the steam table corresponding to 3 MPa s and 400 °C in the superheated part of the steam table and then we can write it as $S_3 = S_1 + x_4 S_{fg}$ where S_1 is the entropy of Liquid saturation corresponding to 10 kPa, S_{fg} is latent entropy corresponding to 10 kPa pressure. So knowing this on the main left hand side we can find out x_4 and $x_4$turns out to be 0.83.

Knowing this we can find out $h_{4'} = h_1 + x_4 h_{fg}$ where h_1 is the enthalpy corresponding to liquid saturation at 10 kPa and h_{fg} is again latent enthalpy at 10 kPa. So, having said this we can find out $h_{4'}$ and from all these numbers know and it turns out to be 2192.21 kJ/kg. Having said this, we can find out now turbine work as it was expected to be turbine work is equal to $W_{T'}$is equal of turbine efficiency.

So, $W_{T'} = \left(h_3 - h_{4'}\right) \times \eta_T = (3230.9 - 2192.21) \times 0.85$, so we will get turbine work at 882.89 kJ/kg. So, this is the turbine work, now we can find out W_{net} which is the network and that network is turbine work - pump work, so it is 882.89 - 3.77, so we know network in this case is 879.12 kJ/kg. Now we know this network we can find out the mass flow rate and also efficiency.

So for mass flow rate, we know W_{net} which is M into W_{net} and this is told to us as 20 megawatt so 20×10^3it is kilowatt. So we can say $W_{net} = \dot{m} w_{net}$so we have found out it has 879.12 is equal to 20 into 10 to the power 3. This is right hand side is kilowatt and left-hand side unit kJ/kg and $\dot{m}$ is in kg per second. So, we $\dot{m}$ as 22.75 per sec. So now for efficiency we need $Q_¿$ and $Q_¿ = h_3 - h_2$.

So h3 we have known to it 3230.9, $h_2 = h_1 + W_P$. h_1 can be found out corresponding to liquid saturation enthalpy at 10 kPa condenser condition we have found out the pump work we need to add that and then get h_2. h_2 turns out to be 195.59. So, $Q_{¿}$ for us is 3035.31 kJ/kg. So, efficiency of the cycle is $\eta_c = \frac{W_{net}}{Q_{¿}} = \frac{879.12}{3035.31}$ so efficiency turns out to be 28. 96%. So, we can find out the cycle parameters if at all we do not have ideal component of the cycle. We will move to the next example and this example reads that there is a steam power cycle in which boiler condition or turbine inlet condition are given as 15 MPa 600 °C as condenser pressure as 10kpa.

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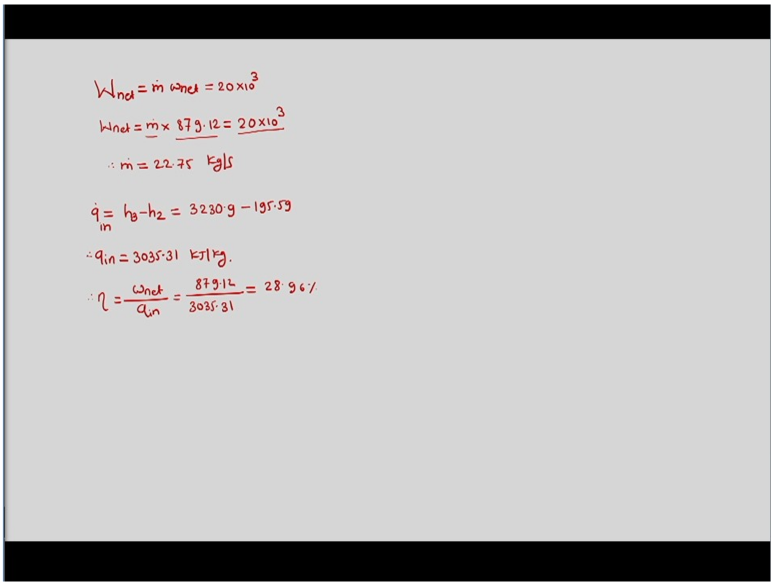

$W_{net} = \dot{m}\, w_{net} = 20\times10^3$

$W_{net} = \underline{\dot{m}} \times \underline{879.12} = \underline{20\times10^3}$

$\therefore \dot{m} = 22.75$ kg/s

$\dot{q}_{in} = h_3 - h_2 = 3230.9 - 195.59$

$\therefore q_{in} = 3035.31$ kJ/kg.

$\therefore \eta = \frac{w_{net}}{q_{in}} = \frac{879.12}{3035.31} = 28.96\%$

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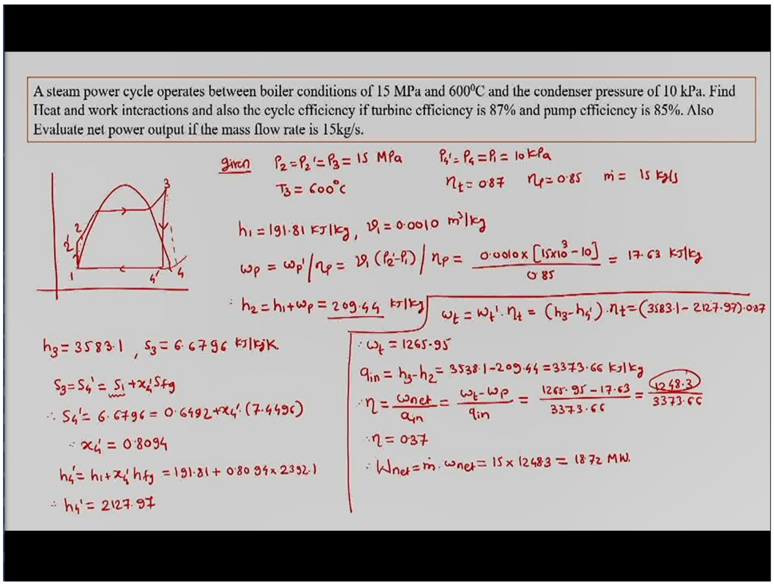

A steam power cycle operates between boiler conditions of 15 MPa and 600⁰C and the condenser pressure of 10 kPa. Find Heat and work interactions and also the cycle efficiency if turbine efficiency is 87% and pump efficiency is 85%. Also Evaluate net power output if the mass flow rate is 15kg/s.

$\underline{\text{given}}$ $P_2 = P_2' = P_3 = 15$ MPa $\quad P_4' = P_4 = P_1 = 10$ kPa

$T_3 = 600°C \quad \eta_t = 0.87 \quad \eta_p = 0.85 \quad \dot{m} = 15$ kg/s

$h_1 = 191.81$ kJ/kg, $v_1 = 0.0010$ m³/kg

$w_p = w_p'/\eta_p = v_1(P_2' - P_1)/\eta_p = \frac{0.0010\times[15\times10^3 - 10]}{0.85} = 17.63$ kJ/kg

$\therefore h_2 = h_1 + w_p = \underline{209.44}$ kJ/kg

$w_t = w_t' \cdot \eta_t = (h_3 - h_4')\cdot\eta_t = (3583.1 - 2127.97)\cdot 0.87$

$h_3 = 3583.1$, $s_3 = 6.6796$ kJ/kgK

$s_3 = s_4' = s_1 + x_4' s_{fg}$

$\therefore s_4' = 6.6796 = 0.6492 + x_4'(7.4996)$

$\therefore x_4' = 0.8094$

$h_4' = h_1 + x_4' h_{fg} = 191.81 + 0.8094\times2392.1$

$\therefore h_4' = 2127.97$

$\therefore w_t = 1265.95$

$q_{in} = h_3 - h_2 = 3538.1 - 209.44 = 3373.66$ kJ/kg

$\therefore \eta = \frac{w_{net}}{q_{in}} = \frac{w_t - w_p}{q_{in}} = \frac{1265.95 - 17.63}{3373.66} = \frac{1248.3}{3373.66}$

$\therefore \eta = 0.37$

$\therefore W_{net} = \dot{m}\cdot w_{net} = 15\times1248.3 = 18.72$ MW.

Find out heat and work interactions and also the cycle efficiency, if turbine efficiency is 87% and pump efficiency is 85%. Evaluate net power output if the mass flow rate is 15kg per second. This example is reverse, in earlier example mass flow rate was to be found out and total power output was given here we have to find out total power output and we are given with mass flow rate. So, we will start as in earlier case we will make this as 3 this as 4', 4, 1, 2'.

So, this is our cycle having said this given things are $P_2=P_{2'}=P_3=15\,MPa$. $T_3=600\,°C$. $P_{4'}=P_4=P_1=10\,kPa$. Turbine efficiency is 87% and pump efficiency 85% and $\dot{m}=15\,kg/s$. Now as expected, we should go and find out h_1 which is enthalpy corresponding to condenser and liquid saturation enthalpy which is 191.81 KJ/kg,

Similarly, specific volume at the same condition is 0010 m^3/kg. So, we can find out W_P. $W_P=W_{P'}=\frac{v_1\left(P_2-P_1\vee P_{2'}-P_1\right)}{\eta_P}$. So, we get pump efficiency from here $\eta_P=0010\times(15\times10^3kPa-10)/0.85$ and we get pump work at 17.63 kJ/kg. So, we can get $h_2=h_1+W_p$ and it is 209.44, that is kJ/kg.

Having said this, we can find out h_3 which is the superheated enthalpy at 15 MPa and 600 °C and this is 3583.1 will immediately note entropy at the same state and that entropy will be 6.6796 kJ/kgK. So, we know that, $S_3=S_{4'}=S_1+x_4S_{fg}$. So, we have $S_{4'}=6.6796=S_1$, again from steam table 6.492 corresponding to liquid saturation entropy at 10 kPas. S_{fg} is 7. 4496.

So, we get $x_4=¿0.8094$. Knowing this we can find out $h_{4'}$and $h_{4'}=h_1+x_{4'}h_{fg}=191.81+0.8094\times2392.1$. So $h_4$is equal to 2127.97. Having said this we can find out, basically here the turbine work in real is equal turbine work ideal into turbine efficiency so it is $\left(h_3-h_{4'}\right)\eta_T$. So h_3 is known to us, we have noted it as $(3583.1-2127.97)\times0.87$. So, we get real turbine work using this as 1265.95.

Then we can go ahead and find out $Q_{¿}=h_3-h_2=3538.1-209.44$. So $Q_{¿}=3373.66\,kJ/kg$. So, we can find out cycle efficiency which is $\frac{W_{net}}{Q_{¿}}$. So $W_{net}=W_T-W_P$,$\eta=\frac{W_T-W_P}{Q_{¿}}$. And this gives us W_{net}first as 1265.95 which is turbine work - pump work which is 17.63 divided by 3373.66. So W_{net} is $\frac{1248.3}{3373.66}$ and this gives us cycle efficiency as 0.37 or 37%.

And then total W_{net} is equal to $\dot{m}$ into specific W_{net} and $\dot{m}$is given to us as 15 into W_{net} is here 1248.3 and then is 18.72 megawatt. And this is how we can solve the example if we are having the cycle which has simple component or may be the components which are non ideal and this cycle examples are actually not dealing with any attachment. Thank you.