Steam and Gas Power Systems
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Module No # 01
Lecture No # 05
Problem Solving (Rankine cycle)

Hello I welcome you all in this course on steam and gas power systems today we will solve a numerical based on vapor power cycle

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In a regenerative steam cycle employing two closed feed heaters the steam is supplied to the turbine at 40 bar pressure and 500 °C temperature. Condenser pressure is 0.035 bar. The intermediate bleeding pressure are 10 bar and 1.1 bar. Find the amount of steam bled at each stage, output of plant/kg steam and the cycle efficiency.

This numerical is based on regenerative steam cycle and the statement of the numerical is in a regeneration steam cycle implying to pose feed water heaters. Feed water heaters are used for feeding or used for heating the water which goes to the boiler and that is known as feed water. So it has the steam supplied to the turbine at 40 bar pressure.

So steam at the inlet of the turbine is 40 bar temperature is 500 degree centigrade temperature. Condenser pressure is 0.03 bar approximately it is it is exactly 3.5 kilopascal then intermediate bleeding pressure and 10 bar and 1.1 bar find the amount of the steam bled at each stage output of the plant per KG of the steam and efficiency of the cycle.

Now here in this case as I stated earlier the feed water heating is done with the help of the steam this can be done in two ways one is we pass the feed water through the casing of the steam turbine but that process is not the very practical process. So instead of that the steam is tapped from the steam turbine at various locations.

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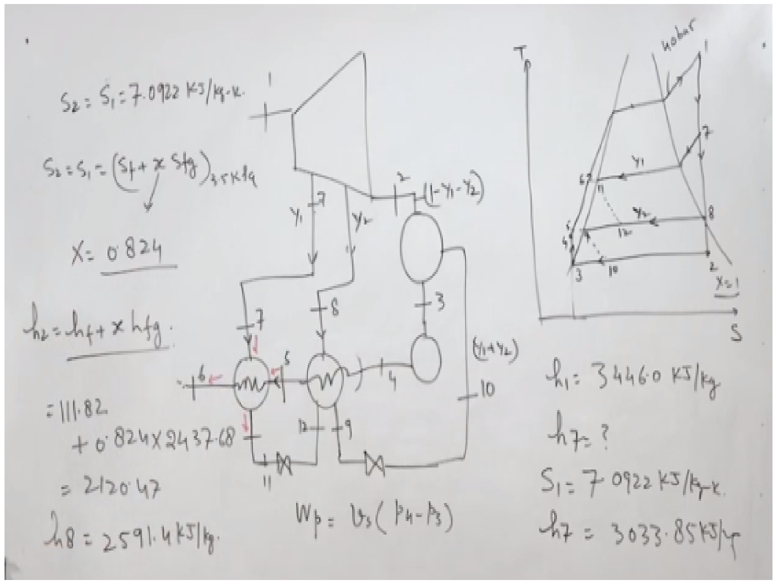

Suppose it is steam turbine steam will be tapped from various location and this steam will be used for heating the feed water going into the boiler. So first of all we will draw a temperature entropy diagram for the processes then physical we will draw the schematic diagram and then we solve it very well. Now this is temperature and entropy X = 0 and here X = 1.

Now steam is at 40 bar pressure and 500 degree centigrade pressure if we look at this steam table at 40 bar pressure this is 40 bar pressure the saturated temperature is 250.35 degree centigrade. Therefore the steam is superheated so state 1 is superheated steam this is state 1 now after state 1 it is expanded to state 2 with the turbine.

No during expansion process the steam is tapped at two location and after the expansion it goes to the condenser where complete condensation of the steam takes place this is vapor power cycle. And then I will shift this line otherwise create confusion so here 3 to 4 process taking place in a pump and after the pump it goes to the boiler and in the boiler super heating of the vapor takes place.

This is the normal rankine cycle for power generation with the facility of super heating. Now for okay now here steam is being tapped because during this process 1 to 2 the expansion of the steam is taking place and steam is step at two points as stated here at 10 bar pressure and 1.1 pressure per bar pressure.

So a ten bar pressure steam is tapped perhaps the steam will remain superheated in this state ok and the super heating takes place and then complete condensation of vapor takes place and this heat is transmitted to the feed water because the tap is steam from here is used for heating the feed water right. So my state let us say six we get 6 here and this is state 7 and this is state let us say this is 11.

So from 7 to 11 condensation of superheated vapor takes place this superheated vapor comes from the tapping and this vapor is used for increasing the temperature of feed water heater. Another tapping takes place this may be superheated or let us say it is close to the saturation. So here again the tapping takes place and again condensation takes place somewhere here.

So this state is 8 and after 8 by steam the steam tablet it may be superheated or that will find out while solving the numerical right. So this is steam again condensed and heating from 4 to 5 takes place in second heat exchanger and ok this point is nine right. So this is entire arrangement I am repeating this is a rankine cycle. In rankine cycle from the turbine they are two tapping and this tappings are to feed to heat the feed water because now when the feed water is heated now the heat required at the boiler will be only H1 – H6.

Earlier without feed water heat arrangements the energy required in the boiler was H1 - H4. So this much heat is coming from the tablet if suppose the tapped esteem is Y1 here Y2 here okay 1 KG of the steam is calculated. Y1 of the steam is tapped here and Y2 fraction of the steam is tapped here right. So Y1 let us say Y1 tapped here and Y2 is tapped here and will make the cycle like there is a boiler right and from the boiler the steam is going to the turbine so it is state 1 right.

Now after state 1 it is going to state 2 this is state 2 from state 2 it is going to the condenser it is going to the condenser process 2 to 3 is taking place. Now after process two to three it is going to the pump right and pump three to four this process takes place two to four inside the pump. So after the pump it goes to two different heaters feed water heaters there are two different feed water heaters as shown here after the pump it was to the first feed water heater.

And then second feed water heater so first water heater using vapor fraction of his team okay and Y1 it is fraction of it is team is entering at state 7 this is state 7 right and it is leaving the feed water this is a feed water heater and this is leaving it at state 11 each team is getting condensed from state 7 to state 11 right. And steam entering from here is .5 and getting heated up to state 6 they are not getting fixed indirect heat exchanger there is a I mean there is a no mixing at all.

So 5 to 6 the steam the water feed water is getting heated in a closely heater am repeating the steam tab at state 7 right. And it is cool to state 11 this energy is used for heating the feed water from the state 5 to state 6. So state 5 to state 6 the feed water is heated at state 6 is going to the boiler it is going to the boiler and from 6 to 1 the heating is taking place inside the wall.

Now in first feed heater the second heater steam is again depth Y2 from here and this steam at state 8 right and after state 8 where it is going it is reducing to 9. Now one thing we have to see here that steam available at this pressure is 10 bar and this is 1.1 bar because once the arrangement is clear to you so all know numerical is not a big issue but in the generative heating one has to understand the arrangement of the feed water heater and the energy transfer right.

So here pressure is 1.1 bar yet pressure is at a stand bar so what should we do now in this case expansion devices are provided at both the places. So this 10 bar pressure is reduce to 1.1 bar only then we can mix this fluid with this fluid right. So expansion takes place okay and this expansion we get state 12 and this also gets expanded and we get state ten because students are often condensed why this expansion is taking place this expansion is taking place otherwise we cannot mix this water with this water.

Because after condensation also the enthalpy is quite high at 11 also the enthalpy is high this enthalpy can further be used for heating this feed water. So now they are connected right and this is state well and all the heat is imparted to this feed with this feed water moving in this pipeline and this goes to back to the condenser how the condenser is at again state then.

So pressure at 10 = pressure at 6 because pressure balancing is very important otherwise there will be a reverse flow if the fluid and everything will be theoretical state. Now here in this arrangement now let us look at the mass fluid. Y1 has been tapped from here Y2 has been tapped for here.

So here is repeating only 1 - Y1 - Y2 right the mixture or the condensing which is going from here to here at state 10 this is Y1 + Y2 and they are mixing in the condenser and then they are getting pumped to the boiler. So this is the entire arrangement for this problem now we can do the energy balance the rest of the things are like simple numerical on the vapor power cycle we can start with H1 enthalpy at one state 1.

Now we have to find enthalpy at all the state what is remaining finding out enthalpy at all the states and value of Y1 and Y2 that is it. If we have these values we can always find the value of everything find out then steam bled at each stage output of per KG of steam and cycle efficiency. Now actually it is superheated steam so we will have to refer the table for superheated vapor.

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kPa	deg. C	vf	vfg	vg	uf	ufg	ug	hf	hfg	hg	sf	sfg	sg
3.5	26.672	0.001004	39.465	39.466	111.82	2299.58	2411.4	111.82	2437.68	2549.5	0.39061	8.13049	8.5211
110	102.29	0.001045	1.548455	1.5495	428.72	2079.98	2508.7	428.84	2250.36	2679.2	1.333	5.9939	7.3269
1000	179.88	0.001127	0.193233	0.19436	761.39	1821.31	2582.7	762.52	2014.58	2777.1	2.1381	4.4469	6.585
4000	250.35	0.001253	0.048523	0.04978	1082.5	1519.2	2601.7	1087.5	1713.3	2800.8	2.7968	3.2728	6.0696

		1000 kPa		
C	v	u	h	s
179.88	0.19436	2582.7	2777.1	6.585
200	0.20602	2622.2	2828.3	6.6955
250	0.23275	2710.4	2943.1	6.9265
300	0.25799	2793.6	3051.6	7.1246
350	0.2825	2875.7	3158.2	7.3029

		4.0 MPa		
C	v	u	h	s
250.35	0.04978	2601.7	2800.8	6.0696
300	0.05887	2726.2	2961.7	6.3639
350	0.06647	2827.4	3093.3	6.5843
400	0.07343	2920.7	3214.5	6.7714
450	0.08004	3011	3331.2	6.9386
500	0.08644	3100.3	3446	7.0922
600	0.09886	3279.4	3674.9	7.3705

So I have taken out the properties of superheated vapor at 10 kilo pascal 10 bar it is 1000 kilo pascal. So at 1000 kilo pascal and 500 degree centigrade sorry it is not 10,000 it is 40 bar this is 40 bar. So superheated steam at 40 bar pressure and 500 degree centigrade the enthalpy is 3446.0 kilo joules per KG of steam right.

Now how to find S7 because we need S7 also how to find S7 in order to find S7 this process 1 to 7 is isentropic process right. So entropy at state 1 how much entropy at state one at 500 degree centigrade the entropy is 7.0922 kilo joules per KG kelvin S2 at 10 bar is same.

But if you look at the saturation properties at ten bar pressure the entropy is 6.585 it means the vapor at state 7 is superheated right. So we will take the vapor as superheated and in this case at 10 bar we will have to find we will have to do interpolation between 25 and 300 degree centigrade because entropy will lie 7.0922 entropy will like between these two between these two temperatures and between these two enthalpies right.

So this we have done and the value of H7 is 3033.85 five kilo joules per KG right. So it is lying between these two right similarly we will find the enthalpy at state two in order to find somewhere here S2 again is how much is equal to S1 = 7.0922 kilo joules per KG kelvin right. Now if we look at the thermo physical properties or properties of steam at 3.5 kilo pascal.

The entropy 8.5211 it means entropy of the gas 8.52 this 8.5211 it means after expansion or its state two the vapor is wet it is quality is less than one right. And S2 = S1, S1 = SF + XSFG at 3.5 kilo pascal and this tunes out to be and this will give you the value of X and S turns out to be +0.824.

Values can be taken out from here it is there all the values are given in the steam table and with the help of this X we can find the value of H2 it is HF + X HFG and this is going to be = 11.882 +0.824 into2437.68 = 2120.47. Now what is remaining eight similarly we can find the value of enthalpy at 8 so we can have enthalpy at state 1, state 7, state 8 and state 2.

Assuming that the proper the entropy during this process remains constant okay after finding the values these values now H eight I have calculated the H8 is 2591.4 kilo joules per KG right. So now we have enthalpy of all the states these enthalpies we can always take from steam table right now what is remaining.

Now here in this case we can neglect the power and if you want to find the net from work then work of the pump is specific volume at 3 multiplied by P4 – P3 in kilopascal that will give you pump work in kilowatt and specific volume at 3 is specific volume of liquid at 3.5 kilo pascal that is going to be this much right.

Now after now what is remaining now remaining is the value of Y1 and Y2 if we have the value of Y1 and Y2 we can find the rest of the things right. So in order to find Y1 and Y2 will have to make heat balance here and here in both these two heaters heat balance we heat how much heat is coming to the heater. How much heat is coming to the heater and how much heat is leaving the heater or enthalpy for the fluid leaving the heater enthalpy of the fluid coming to the heater.

Now in order to do that we will do that energy balance that is energy of the fluid available here is Y1 at 7 Y1 S7 is energy coming from here right. This is heater one this is okay plus fluid entering H5 enthalpy of 5 is equal to how much energy of the fluid leaving the heater that is H6 + Y1 H11 is it clear because this this you have to understand very clearly that the energy which is enthalpy which is coming to the heater enthalpy of sum of the enthalpy of incoming fluid is equal to sum of the enthalpy of outgoing fluid.

So incoming fluid of enthalpy is Y1 S7 + H5 fluid is coming to the heater plus = S6 because this 1 - Y1 - Y2 + Y1 + Y2 will make 1. So the mass of the fluid mass of the water which is flowing in this pipe is 1 KG per second right. And Y1 and H 11 we have all the values and from this we can find the value of Y1 and Y1 here is 0.147.

It means 14.7% yes you may be wondering how I have taken S6 right because H6 and H11 are very close to each other. So they are very close to each other so we have taken the same value there is not much enthalpy difference practically right. So Y1 is 0147 now energy balance for this another heater which is at low pressure.

Now in this heater again the energy is coming or enthalpy of incoming fluid from state well enthalpy of incoming fluid from state 8 enthalpy of incoming fluid from state 4 and enthalpy of outgoing fluid.

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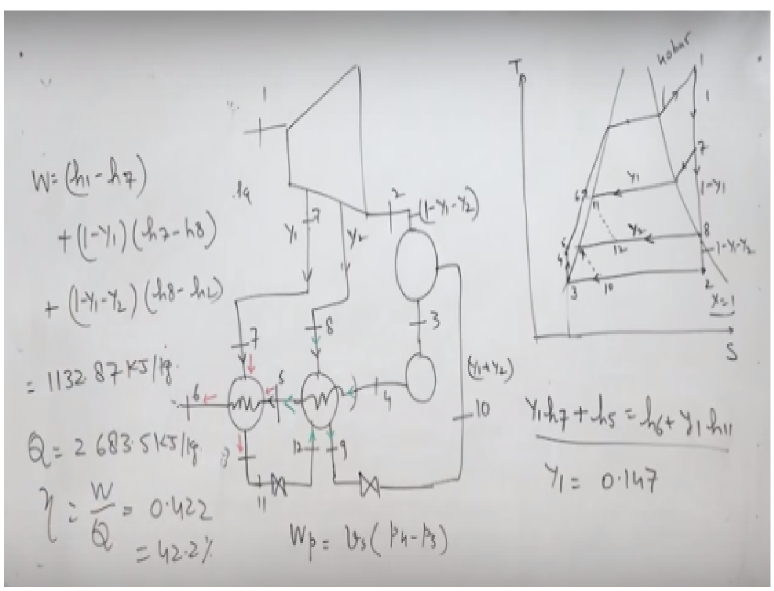

So they have to be balanced and the final equation is going to be and the final equation is going to be Y2 H8 this is enthalpy of fluid at 8 we have already calculated Y2 V + Y1 H12 this is Y1 H12 H11 it is only isenthalpic expansion. So H12 = H11, H4 is enthalpy at state 4 three pump after pumping we are getting state 4 = H5 + Y1 + Y2 X9 H 9 and H 10 both are same right is it clear because H5 is also this I did not show earlier this is also the outgoing heat right outgoing energy.

Now we have done we have 1, 2, 3, 4, 5 okay right. So now by Y1 is already with us the rest of the enthalpies are with us and this gives the value of Y2 is 0.124. So Y1 we are getting 14.147 or 14.7 % and then Y2 is 12.4 % here at state 8 right.

Now we have all the values in order to find the heat given to the system or heat transfer in the boiler that is going to be H1 - H6 right and what about the output? Output of the turbine now we will have to take output in three stages first stage is one to seven where the mass of the steam is 1 KG. Another state is seven 2 here mass of the steam is 1 = state 1 – Y1 8221 – Y1 - Y2.

So now if we have to calculate the value of output of the turbine for calculating of output of the turbine we have to take H1 – H7 + 1 – Y1, H7 – H8 + 1 – Y1 – Y2, H8 – H2. This will give us the output of the turbine once we have the heat giving to the system and output of the heat given in the cycle net heat given in the cycle and output of the cycle.

We can find the efficiency of the cycle what was to be found here find out the steam he amount of the steam played at is this stage we have already calculated. Output of the plant and out of the plant you do by yourself I am giving you the answer to this 1132.87 kilo joules per KG that is output of the plant. Heat given in the cycle for the boiler is 2683.5 kilo joules per KG right.

Efficiency will be this is W by IQ and that will turn out to be 0.422 or 42.2%. The rest of the things you can do by yourselves and you can match your results are you answers will be these answers that is all for today next class we will start with the steam generators