Steam Power Engineering
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Lecture-10

Feedwater heaters

So this is how we can calculate different quantities which are performance parameters or the thermodynamic quantities of different corners of the cycles using these basic equations which are related with energy conservation and mass conservation for close feed water heater in steam power plant.

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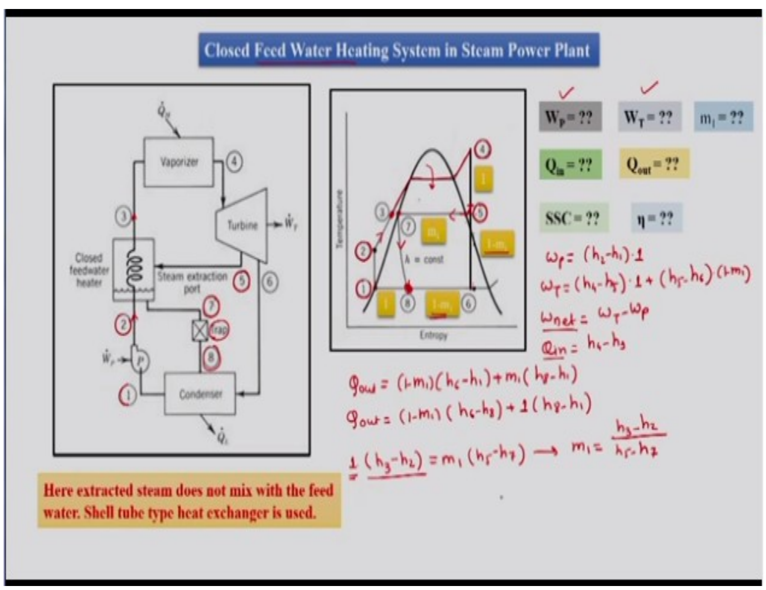

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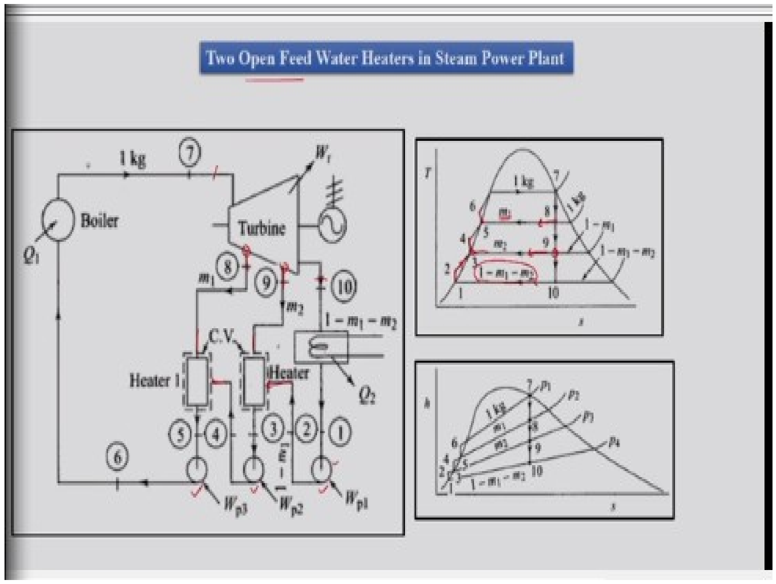

Now moving ahead, we might have an arrangement where we are having 2 open feed water heaters. So we are basically having a condition where we have expansion of steam taking place from state 7 till state 10. But in between we have 2 states 8 and 9 from where we are taking bleed from the turbine and this bleed is as it is said that it is a open type of feed water heater. This bleed is directly mixed with the water and then this mixture is pumped once and pump twice and then it is supplied to the boiler.

We would have understood a point over here by this time that if we are having closed feed water heater then like last case. Then we do not have to have multiple pumps or which are also called as drip pumps the pumps which are small in size which are basically the pumps which are supposed to handle the small amount of mass of the steam will be called as drip pumps. But in case of open feed water heater, so we need big pumps which will handle large amount of mass.

And as many feed water heaters are there plus 1 condenser pump, so if since we have 2 feed water heaters, so 2 feed water heater plus 1 condenser, so we need 3 pumps if we are operating with open feed water heater ok. So in case of closed as what we have seen last time here since we are sending the steam back with or not needing any pump apart from the pump or the condenser.

Then the cycle would look like this where we have our usual pump from 1 to 2 then we will have steam extracted from 9 which is coming with reduced enthalpy or which is reducing it is enthalpy since it is in mixing with water from 2 and then resultant state is 3. Then from 3 we are pumping it to higher pressure then at 4 this there is a drip from 8. So this mass of water is mixing with mass of steam is mixing with water then resultant state is 5.

Then we are having again pump till 6 and then we are adding heat into the boiler from 6 to 7. Then there is expansion from 7 to 8 for the complete mass in the turbine but later we will take drip of m_1 mass. So we will have only $1-m_1$ mass expanding from state 8 to state 9, then we have drip at 9 for m_2 mass. Then we will have expansion of the steam from 9 to 10 for mass $1-m_1-m_2$ and the same steam is passed to the condenser, so condenser attains the mass $1-m_1-m_2$ for condensation.

So practically what is happening, in this case we are having lesser mass to be entered into the condenser so lesser condensation is required so we actually have reduced load of the condenser when we are using with open feed water heater, this is HS diagram for the same thing.

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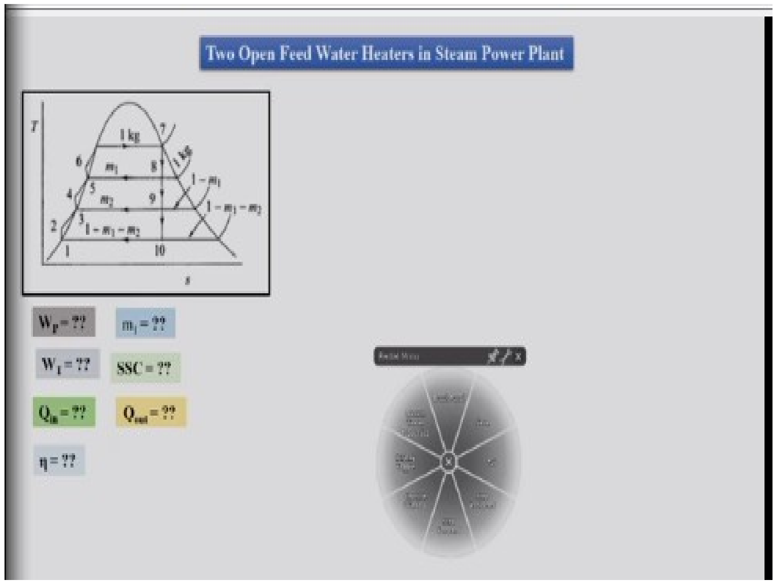

Then we are supposed to find out the same parameters as what we were expecting to find out in other case. So here as well we have to find out pump work.

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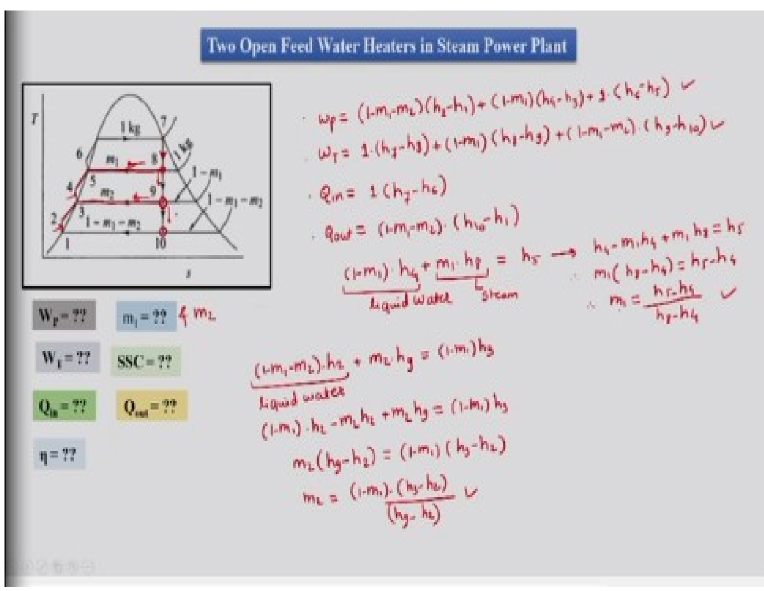

So we know pump work is, so W_P which is pump work and then we know that first pump handles mass $1-m_1-m_2$ this pump handles mass this and it rises enthalpy from h_1 to h_2. Then this pump it handles mass $1-m_1$ since m_2 is already mixed. And then we will have final pump which handles mass 1 and it rises enthalpy from h_5 to h_6. So

$W_P=(1-m_1-m_2)(h_1-h_2)+(1-m_1)(h_4-h_3)+1(h_6-h_5)$ this is what our pump work complete pump work then we have turbine work.

In case of turbine work it is exactly reverse first turbine handles mass 1 unit or 1 kg, it reduces enthalpy from $h_7 ¿ h_8$ then this is the first part of the turbine. Then second part of the turbine is here, so it deals with mass $1-m_1$when it expands from $h_8 ¿ h_9$ then third mass. Third part of the turbine handles $1-m_1-m_2$and it reduces enthalpy from $h_9 till\, h_{10}$, then this is complete turbine work $W_T=1(h_7-h_8)+(1-m_1)(h_8-h_9)+(1-m_1-m_2)(h_9-h_{10})$

We have basically now Q and this $Q_{¿}$ is for complete mass 1 and it is in the boiler we are having enthalpy risen from 6 to 7. $Q_{¿}=1(h_7-h_6)$. But then we have to find out Q_{out} and $Q_{out}$is in the condenser where we are handling mass $1-m_1-m_2$ and enthalpy is decreasing from $h_{10} ¿ h_1, Q_{out}=(1-m_1-m_2)(h_{10}-h_1)$. So these are different work and heat interactions for the power cycle, but now we are supposed to find out m_1 and also we have to find out m_2.

So how to find out m_1, m_2, so we know that we first have to find out m_1 and the equation for $m_1$is between these ok. So we know how to write, here we are try it like the mass $1-m_1$ at enthalpy h_4 mixes with mass m_1 this is mass of liquid water mixes with m_1 mass at enthalpy h_8. This is for steam and then we get resultant 1 kg of mass at h_5, so using this we can find out $h_4-m_1 h_4+m_1 h_8=h_5$, so we have $m_1(h_8-h_4)=(h_5-h_4)$ so we have $m_1=\frac{h_5-h_4}{h_8-h_4}$, so then we would have found out this m_1.

Now our topic is to find out m_2, so for finding out m_2, m_1 is known to us. Then here the equation is between along this line where we can as well write $1-m_1-m_2$ mass of liquid water mixes with m_2 mass of wet steam at h_9 and then we get $1-m_1$mass of h_3 of the mixture. And then we can put

m_2 over here and m_1 over here and then we can find out, so we can say that $(1-m_1)h_2 - m_2 h_2 + m_2 h_9 = (1-m_1)h_3$.

So we have $m_2(h_9 - h_2) = (1-m_1)(h_3 - h_2)$, so $m_2 = \frac{(1-m_1)(h_3-h_2)}{h_9-h_2}$. And then since we know m_1 we could put over here and we can find out m_2, so this is how we would do the mass and energy balance for open type of feed water heater.

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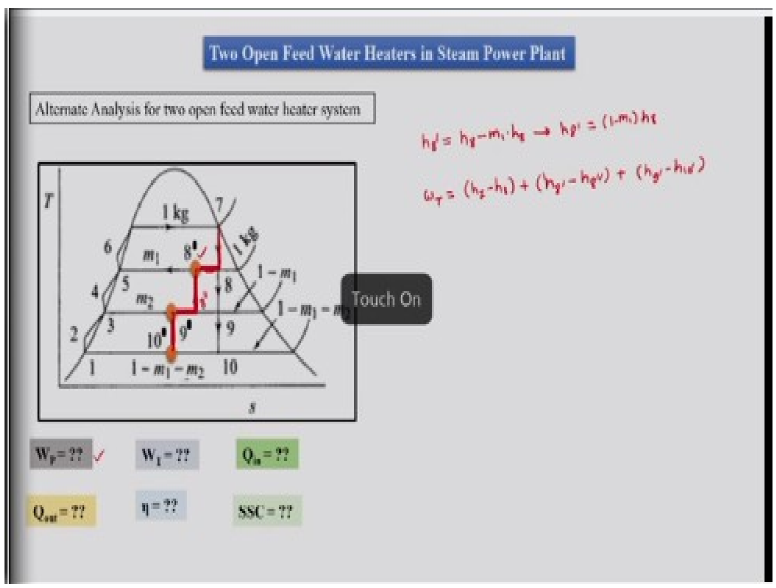

Then next is we can have 2 types of open feed water later as what we have said here this is one way where we are basically doing mass balance. And we are saying that there is complete 1 kg of steam but m_1 goes in this direction, so in this direction we have $1-m_1$. Then we say that m_2 go over here then we have $1-m_1-m_2$. Then instead of that we can have an alternative arrangement where we can say that ok steam got expanded from 7 to 8.

But there is some loss of enthalpy from 8 to 8' such that $m_1 h_8$ this and that which is lost is subtracted from h_8 and then we can get $h_{8'}$. So practically $h_{8'} = h_8 - m_1 h_8$. So we have $(1-m_1)h_8, so\, h_{8'} = (1-m_1)h_8$, so then this is $h_{8'}$. That is why we known we say that we are coming here, then we are going in this direction, then we are expanding again, then we are coming in this direction, then we are expanding.

Then here in this manner if we try to consider then the representation becomes simple where we can say that turbine work is $W_T = (h_7 - h_8) + (h_{8'} - h_{8''}) + (h_{9'} - h_{10'})$ here will say 8', 9'. Then here we will say 8''and then this is 10'ok. Then this is expansion from 7 to 8, 8 to 8'' and then we have expansion from 9' till 10', so this is our turbine work and rest of the quantities would remain unaltered whatever way we found out.

And then this is an alternative way by which we can understand we will understand here that the turbine is completely always dealing with complete mass and then for that this turbine line is getting shifted to towards the left hand side which otherwise in Bolivia's case turbine line was like this but for mass balance we were sending m_1 or m_2 must over the feed water heater, so this is one more way to understand

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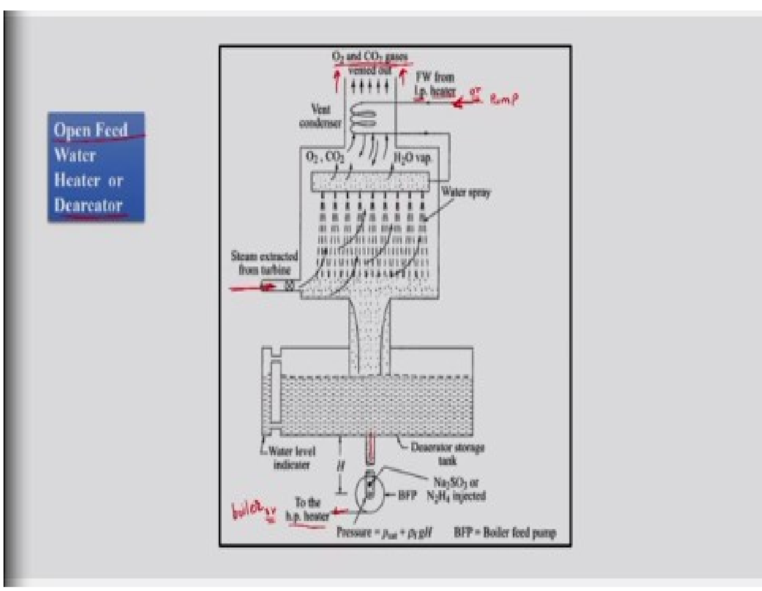

The next is open feed water heater, it is the configuration of open feed water heater as we know in the feed water heater we have liquid water which is coming and then we have steam bleed liquid water which is coming from the pump and we have steam which has come bleed from the turbine. Then these 2 are mixing in open feed water heater and then the resultant mixture is pass to the high-pressure heater or maybe to the boiler. So for that all we have steam coming from the turbine this is the path from which team will come.

And then this is the path where we have feed water heater feed water coming this feed water heater or at this feed water it is coming either from low pressure feed water heater or from pump, it can come from anyway. And then it will get sprinkled in this manner a jets this steam will interact with this water and then in this phase steam will get condensed due to heat loss water will get heated but either of them will come down and settle.

And then this water which is a saturated water would be pass to the high-pressure heater or to the boiler this is or to the boiler. In this space we can see that the unwanted gases are going out from the water which is coming from the pump. So these gases would have actually caused problem to the turbine. So open type of feed water heater helps to remove the unwanted gases from the liquid water and that is why rather 1 open type of feed water heater is suggested to be there into the steam power plant.

Since it is removing unwanted gases, so it is also called a deaerator, so open feed water heater or direct contact type of feed water heater where steam and water are directly touching with each other. So there are 3 names for this feed water heater one name is open feed water heater, second name is deaerator and third name is direct contact type feed water heater.

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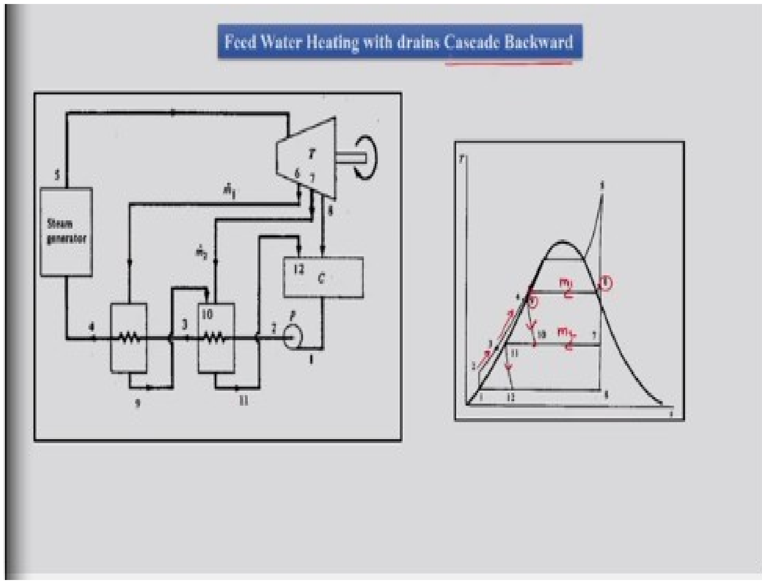

Now going back we can see that in case of closed feed water heater there are 2 types as what we had seen earlier. In the previous case the type what we had seen is called as drain cascade backward, so this is called as drain cascade backward. Here backward means low pressures, so we are taking some brand some we are taking some bleed at state 6 of mass m_1 then we are taking bleed of mass m_2, this bleed is getting enthalpy loss or energy loss due to heat transfer and it is coming to state 9 from 6.

And then from 6 it is sent back to the low pressure, so this bleed is coming back to the low pressure and in the low pressure this is used to heat further the liquid water and in this space it will transfer it is enthalpy to the liquid water such that water we go from state 2 to 3. Here when it came from state 6 to 6, 9 state 9 water went from 3 to 4. So this kind of arrangement where steam after transferring the energy to the water it is sent back to the low pressure side or low pressure field water heater, then such arrangement is called as drains cascade backward.

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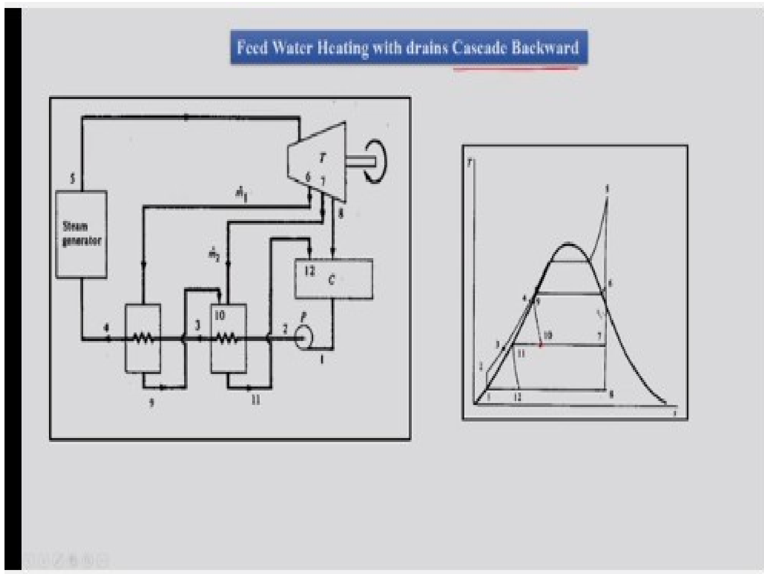

It is not that difficult to calculate the properties over here and then we can find out properties for drain cascade backward.

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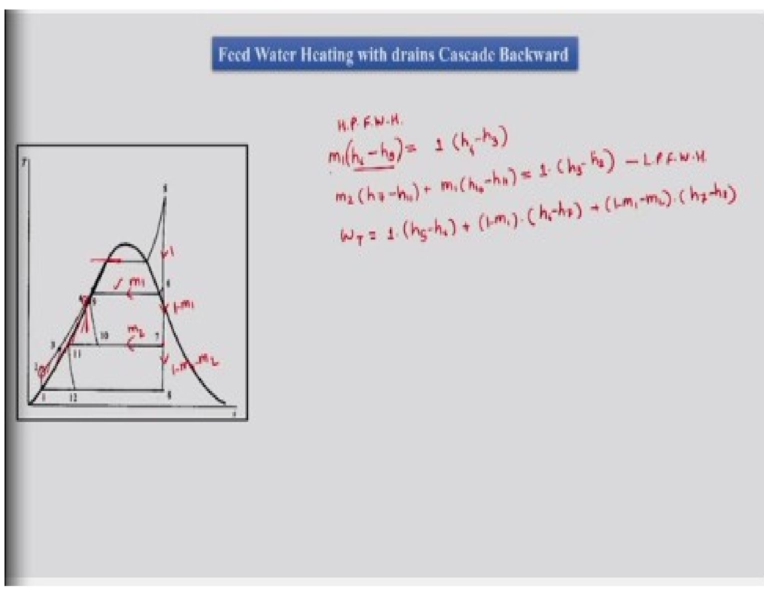

And those properties are basically related with mass m_1 and mass m_2, so here we have 1, here we have $1-m_1$, here we have $1-m_1-m_2$. So first we will write for the high pressure feed water heater which is this for this we are having m_1 mass at h_6 enthalpy is losing it is enthalpy to h_9, m_1 mass is losing enthalpy from h_6 to h_9. But this is getting helped to raise the enthalpy from h_3 to h_4, so this is for 1 unit of mass.

So by this formula $m_1(h_6-h_9)=1(h_4-h_3)$we can find out m_1, then we can find out for m_2, for m_2 it is little tricky since we can mention that m_2 mass is losing it is enthalpy from h_7 to h_{11}. But we also have h, m_1 mass in enthalpy h_{10} it is decreasing to h_{11}, but these 2 enthalpy decrements are used to heat the gas water of unit mass from h_2 to h_3. So this$m_2(h_7-h_{11})+m_1(h_{10}-h_{11})=1(h_5-h_6)$ is what the mass and energy balance means combined equation would look like power the low pressure feed water heater and that is how we can find out m_2.

Here then we can use this to find out turbine work, turbine work is $W_T=1(h_5-h_6)+(1-m_1)(h_6-h_7)+(1-m_1-m_2)(h_7-h_8)$. We can understand here that due to such bleed m_1 and m_2 we arose the enthalpy of water from 2 to 4 and we went very close to the boiler pressure saturation condition. So we reduced this much amount of sensible enthalpy or sensible heat which we would have otherwise added. So this is how we reduced the external irreversibility and we improved the mean temperature of heat addition.

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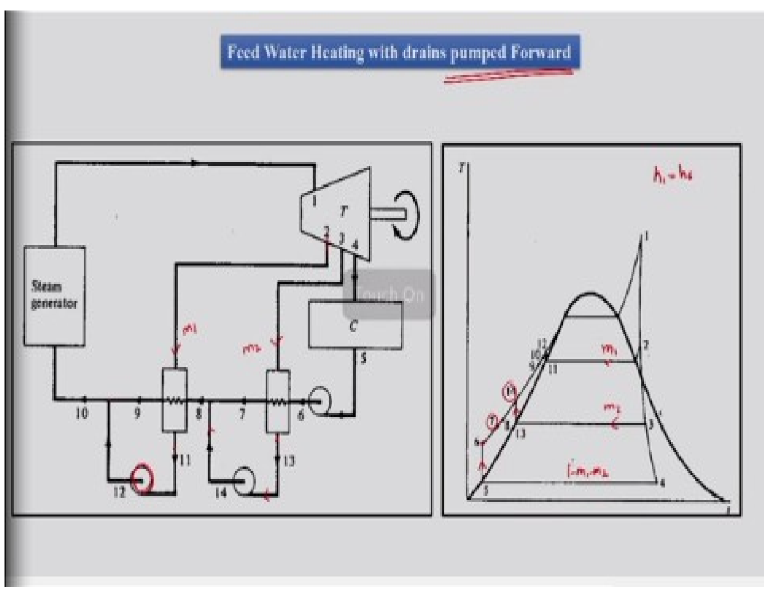

Then instead of that there is one more arrangement and it is called as drain pumped forward. So now here we are not putting the water which is saturated water which is obtained after heat loss of the steam to the feed water. That water instead of putting it back it will be pumped forward, forward means from low pressure to high pressure and such pumps are called as drain pumps.

So we can see that from 2 and drain is coming and then this drain of mass m_1 is losing it is enthalpy. But after losing the enthalpy it is coming over here it is a dry saturated liquid and this liquid is pumped using the drain pump. Such that it will attain the boiler pressure same thing we have m_2 mass bleed and this bleed is having reduction in enthalpy. And then it will become dry saturated liquid and this dry saturated liquid will be pumped from low pressure feed water heater to the pressure of high pressure feed water heater.

So the diagram as what we can see, this is the initial part of turbine 1 to 2 but at 2, m_1 mass will be coming out. At 3, m_2 mass will be coming out and then at 4 for the condenser we have $1-m_1-m_2$ mass what will happen is this. This $1-m_1-m_2$mass will get pump to the boiler pressure 6,$P_1=P_6$, it is a boiler pressure. So water will be at boiler pressures from 6 it will get heated and then it will come to state 7, it is like that. But it is going to get mixed with the pumped water at 14 and then we have state 8 and that is how it is getting little complicated for finding out enthalpies.

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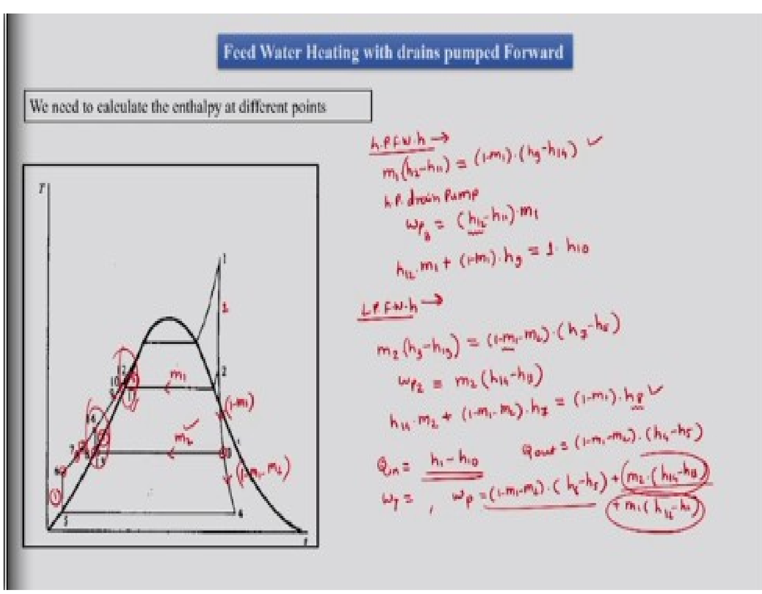

Then we can find out here since we have m_1 mass of bleed m_2 mass of bleed, we can write down for high pressure feed water heater, we have m_1 mass of bleed at enthalpy h_2 is mixed is giving it is heat to the water and it is losing enthalpy is to h_{11}. And that water is basically $1-m_1$ mass of water is rising it is enthalpy from h_{14}¿h_9 ok. But then there is a high-pressure drain pump, so we have a high-pressure drain pump which has pump work.

We will say this is pump 1, this is pump 2 and this is from 3 $W_{P_3}=(h$¿¿$12-h_{11})m_1$¿ but now we have liquid at 12 at boiler pressure. This liquid at 12 of mass this is handling mass m_2, h_{12} of mass m_1 is getting mixed with $1-m_1$mass at h_9. And resultant you need mass we will be formed at 10, so the 10 is the state where we are having low temperature feed water getting mixed with the high temperature drain.

And then we can go to the low pressure feed water heater and in case of low pressure feed water heater where we are having m_2 amount of mass. We can write down here the energy equation m_2 amount of mass is losing enthalpy from 3 to 13. In this case water is getting enthalpy risen from 6 to 7, so we have $1-m_1-m_2$mass of water rising it is enthalpy from $h_6, h_7 . m_2(h_3-h_{13})=$¿($1-m_1-m_2$¿(h_7-h_6)

Here m_1 is known to us using this formula, we will put m_1 over here and then we can find out m_2 . But then we have to find out state 8 also, how state 8 is obtained we are saying that there is a pump which is 2, it is a drain pump which is handling mass $1-m_1-m_2$ sorry it is handling mass only m_2 it is a drain pump. And this drain pump since it is handling mass m_2, it is rising the enthalpy from 13 to 14. $W_{P_2}=m_2(h_{14}-h_{13})$

Then this enthalpy 14 of mass m2 is mixed with $1-m_1-m_2$mass of liquid water at enthalpy 7 and then we have $1-m_1$ mass at enthalpy 8. So this is what energy balance we can obtain, so this is how we have to obtain point 8 and then we can state that $Q_{¿}$amount of heat added is(h_1-h_{10}), Q_{out} would be very simple $(1-m_1-m_2)(h_4-h_5)$. And W_T is as usual $W_T=1(h_1-h_2)+(1-m_1)(h¿¿2-h_3)+(1-m_1-m_2)(h_3-h_4)¿$.

So this is how we have expansion to find out W_T then we can find out $W_P, W_P=(1-m_1-m_2)(h_6-h_5)$. But then we have m_2 amount of mass at low pressure feed water heater which is getting enthalpy risen from $(h¿¿14-h_{13})+m_1(h_{12}-h_{11}).¿$ So these all are pump works and then we can find out W_{net} and then we can find out the efficiency, this is how we can proceed for the drain pump forward case.

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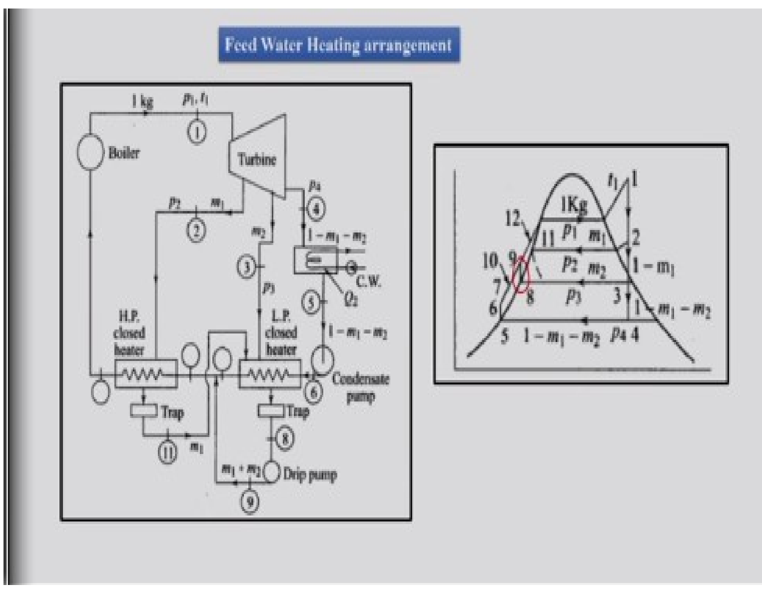

This is the typical feed water heating arrangement, in the typical feed water eating arrangement we have basically 1 pump which is open type of feed water heater as we have suggested. Under it is the necessity of this open type of feed water heater it will mix directly the steam.

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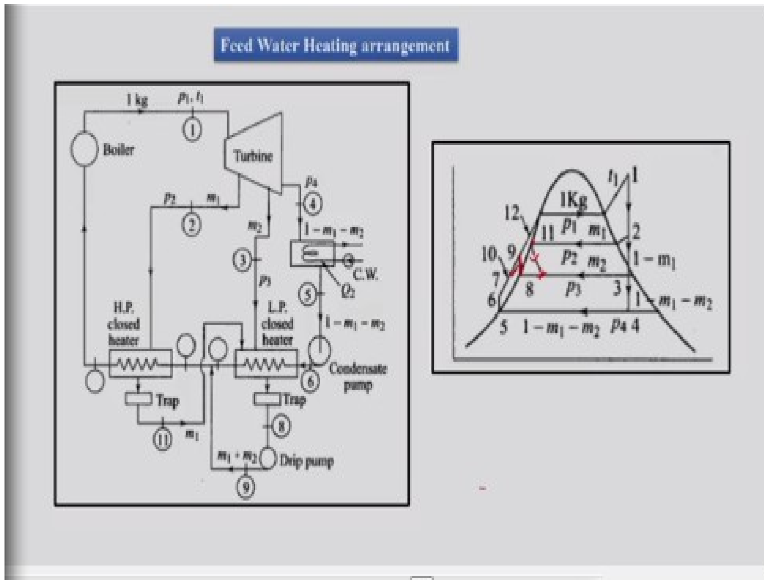

It will mix basically this is a closed feed water heater of open type and this is a closed feed water heater of drain cascade backward. But if we have multiple type of feed water heaters then we can use 1 feed water heater which is open type of feed water heater. But this diagram specifically suggest that we can remove the requirement of pump as what we can see lastly, we can see here that we are since using 2 feed water heaters.

We need 2 pumps 1 is low-pressure feed water heater pump and other is high pressure feed water pump. So these 2 pumps were required apart from the sorry this pump and this pump or in other way this pump and this form these 2 pumps were required if we are using drain pump forward case. But if we use drain cascade backward then we do not need any pump, we are having throttling process which is an isenthalpic.

So this mass is throttled to reach the same enthalpy but at lower pressure then by which we have avoided the use of one small drain pump. But lastly also we could have sent it back as a drain cascade backward, but if we sent like that then this will increase the requirement of the condenser. And by that means we need a bigger condenser since it will handle more amount of mass, so to avoid this instead of sending it backward last pump is last feed water heater open a closed feed water heater with pumped forward.

So before that we can use any feed water heater basically of type which is cascade backward. But last feed water heater lowest pressure feed water heater should be open type or which should be pump forward type. Open type of feed water heater 1 has to be there to remove the unnecessary gases from the water, but last feed water heater should be at least the drain pumped forward such that it will not reduce the load on the condenser, so we can find out the properties over here

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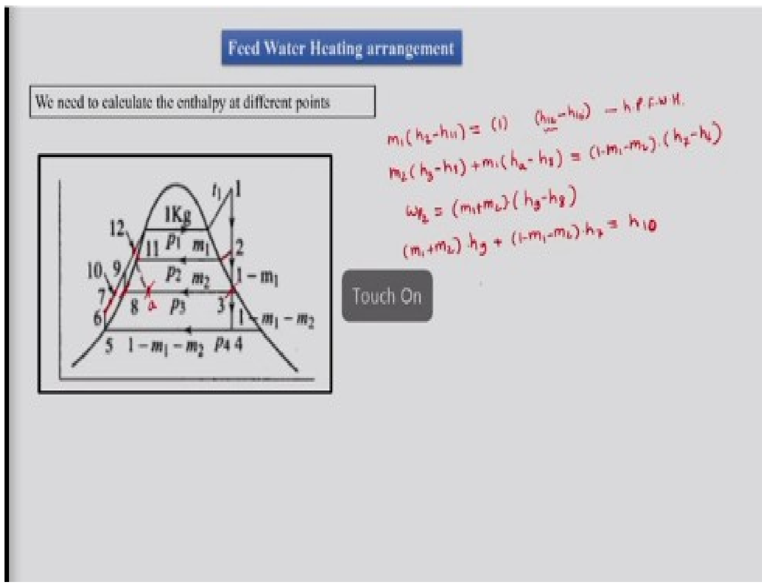

In the same manner as what we did in earlier case, in earlier case we used the energy balance and then from that we found out. So same way we have to do energy balance here as well to find out different states. So here for example we have steam coming from 2 and then it is coming over here and then it is state 11. So m_1 mass of steam from state 2 to state 11 is state 2 is losing enthalpy to 11 and across which we are having increment of enthalpy.

But this is for high pressure feed water heater, but for low pressure feed water heater we have m_2 mass is losing it is enthalpy from 3 to 8. And then across which $1-m_1-m_2$mass is gaining the enthalpy from h_6¿h_7 but it is not stopping the work of the low pressure feed water heater is not done. Then there is a drain pump which is W_{P_2}it is pumping it from low pressure for mass m_2 low pressure to high pressure where it is rising the enthalpy from 8 to 9.

Then m_2 mass of water at state 9 is mixed with $1-m_1-m_2$ mass of water at state 7 such that we have 1 - m1 mass of water at state 10 and this is what it is used over here. And this is how we can find out the different corners of the cycle or properties for the different corners. Here one more thing $Q_¿$ is basically $1(h_1-h_{12}¿$ and here ok there is one more thing here we have forgotten, we have to remember one thing that this is drain cascade backward.

So m_2 mass is losing it is enthalpy for low pressure feed water heater we have to state like this m_2 mass is losing it is enthalpy from $h_3¿h_8$. But there is m_1 mass that is also losing it is enthalpy from a point suppose to h_8 and these 2 are heating the water from of mass $1-m_1-m_2$ from the state $h_6¿h_7$. So this is rise of the enthalpy from here but here we are having 2 masses when is m_2 mass which loses enthalpy from here to here, and then m_1 mass which loses enthalpy from here to here.

And then we have to say that the pump W_{P_2} will be handling 2 masses which is m_1+m_2 and then it is basically pumping them from 8 to 9. And then we have m_1+m_2 at state 9 is mixing with $1-m_1-m_2$at state 7 and then we have h_{10} ok, this is how we will have to calculate.

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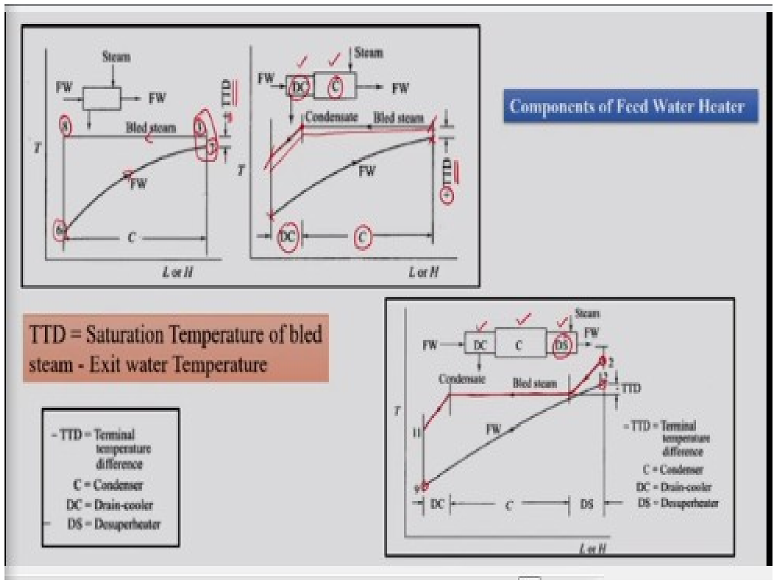

Now what are the different components of a feed water heater, there are different components of a feed water heater. If we are having a low pressure feed water heater, then in the low pressure feed water heater we initially will have only condensation process. So it will have only condensation, so this steam will lose it is enthalpy from one point to other point along the direction but water will gain it is enthalpy from one point to other.

These temperature difference which is termed as TTD and TTD is defined as **is** saturation temperature of bleed steam - exit water temperature. So if we are having low pressure feed water heater then this TTD is always positive. Since steam saturation temperature is more than the exit temperature of water. But if we go to some intermediate pressure level, then we might not just have condensation of steam but we would have drain cooling also the water would reach the saturation liquid state.

But further it has still higher temperature, so it gets cooled while losing the enthalpy to the feed water heater. So steam is losing his enthalpy from here to here where we initially have condensation and then we have sub cooling. But water will get rising it is enthalpy from here to here, so the part is one part is condenser one party drain cooler, but still here we are having TTD as positive.

However if we go to high pressure feed water heater then the feed water is rising it is enthalpy from here to here. But in this process we have bleed this steam from high pressure, so it is also at supersaturated state superheated state. So initially it will have to lose it is superheat, so it is a de-super heater initially steam will lose the superheat. So it is a de-super heater then usual condenser and then the drain cooler.

So it high pressures, so feed water heater will have 3 components this de-super heater condenser and drain cooler intermediate feed water heater will have 2 components condenser and drain cooler and lowest feed water heater will have only one component which is called a condenser.

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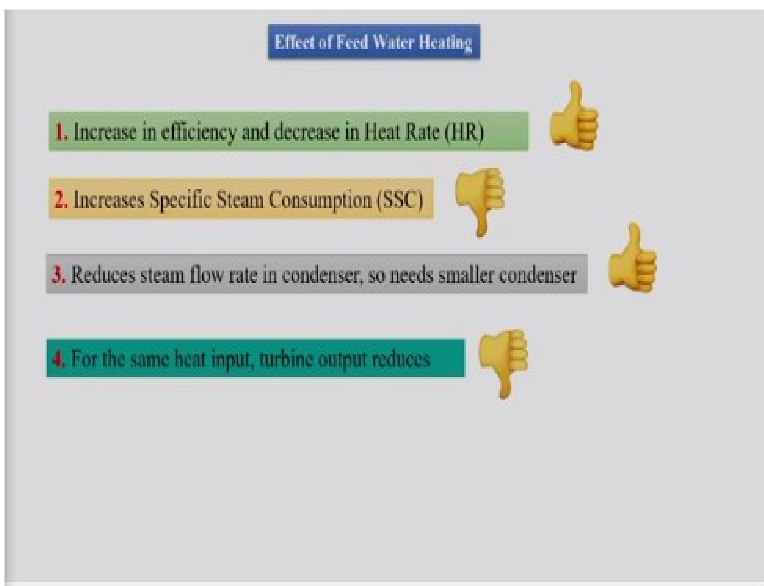

So effect of feed water heating, the primary effect of food what feed water heating as we can see since we are eliminating the economizer increase in efficiency and decrease in heat rate that is obvious in case of feed water heating. Then since our turbine work is reducing since we are taking some mass out from the turbine we have decrease in turbine work output. So we have increasing specific steam consumption.

Further good point of this feed water heating is we need smaller condenser since it is reducing the load on the condenser. Here we have one more thing for the same heat input, turbine work output reduces as what we have seen for the specific steam consumption. So this is odd we have talked about the case where we are having regeneration with feed water type of backward or type forward or closed or open type of feed water heating and these are the advantages of regeneration.

So here we end our discussion, initial part on Rankine cycle with feed water heating, we have seen that feed water heating has been opted to improve the efficiency of the cycle and that idea was fetched from the Sterling cycle. And in the Sterling cycle we were taking the heat from one part of the system and putting it into the other part, so this heat is not the external heat addition. The same concept we have seen that how to implement into the Rankine cycle by that means we are reducing the load on the economizer.

And we are putting the feed water's temperature or enthalpy close to the saturation enthalpy corresponding to liquid water at boiler pressure. This would reduce the heat added into the economizer and this will increase the mean temperature of heat addition and hence it will increase the efficiency. But it decreases the network let us see the rest part related to the regeneration in the next class, thank you.