Steam and Gas Power Systems
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Module No # 06
Lecture No # 29
Condensers

Hello I welcome you all in this course on the steam and gas power systems today we will discuss on condensers are a very important component of any steam power generation system
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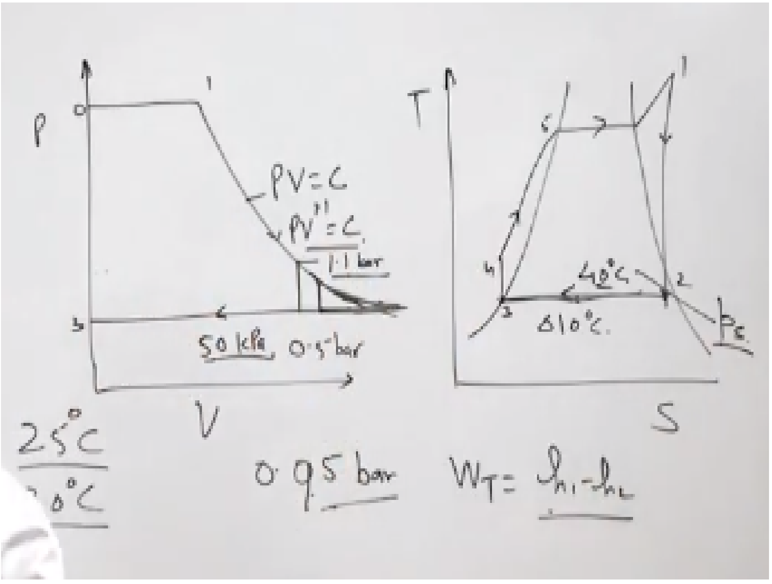

Which works on rankine cycle if i draw this steam power generation on Rankine cycle 1, 2 expansion 1 to 3and 3to 4 and 4 to 5. If you remember this diagram that 1 to 2 at state 2 the steam enters the condenser and the condensate is removed at state 3. Now for the steam power generations there are two devices one is steam turbine and another is steam engine.

If we draw the PV diagram of steam engine it is something like this state one to state two to three and 3 to 0 the ideal PV diagram for steam engine. If you look at this side this process is PV = cos 10 or PV is bar 1.1 is cos 10. If you look at the fair end of the this is a reciprocating machine the steam engine is the reciprocating machine .So if you look at the fair end of the in fact this curve is much flatter on this side.

So it you look at the fair end if we mention the vacuum let us say vacuum of 50 bar 50 kilopascal or 0.5 bar in that case this part or the stroke will generate very little amount of energy and this power loss due to fiction will be substantial. So that is why in the steam engines normally the condensers are not used the steam is come steam comes out of under at a slightly higher pressure that is approximately 1.1 bar or 1.1 atmospheric.

So that it can go to the atmosphere however in the case of a steam turbine because the steam turbine is a rotary machine and it is used for high power generation the atom of power generation is very low in case of a steam generation comparing with the steam turbine .So in the steam turbine if you can maintain the vacuum in the condenser more power can be generated because the work of turbine is nothing but H1 – H2.

We keep on increasing the sorry we keep on decreasing the pressure in the condenser. We will be getting more power here. But the issue is to what extent we can reduce the pressure can we go absolute vacuum that is not possible or even say vacuum of 0.05 or .09 bar that is also not possible. Because in the condenser heat has to be removed and normally in condenser heat is removed with the normal water which is available at the site and the water temperature is normally.

Approximately we can say up to 25 degree centigrade or 30 centigrade. Right and for heat removal at least temperate difference of 10 degree centigrade has to be maintained I am giving just approximate values so the steam temperature should not be less than forty degree centigrade corresponding to that pressure saturation pressure we can expand the steam right.

And definitely in a plant improves the efficiency because we are getting more power right. So output is increased.

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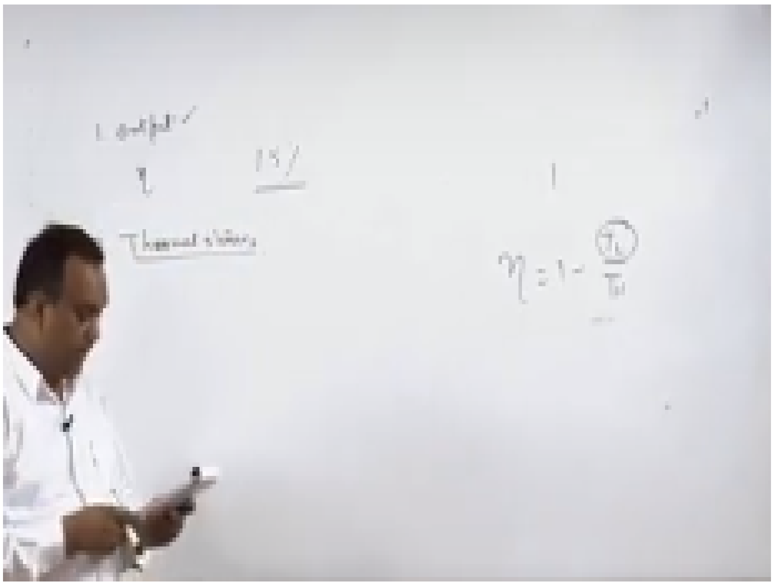

Efficiency is also increased if you look at the current efficiency it is 1 - TL over TH. So while putting the condenser we are reducing the TL lower temperature. So efficiency is also increased efficiency of the cycle is also improved once output is increased a steam consumption is reduced for the same output less amount of steam will be required in the system.

Number three is thermal stresses in the boiler are also reduced because if the boiler takes the water from available at the site which is at 25 or 30 degree centigrade and in another case the boiler is getting water at higher temperature 40 or 45 degree centigrade definitely temperature differential will reduce and that will reduce the thermal stresses in the boiler itself.

And it is also helpful in economy of the water softening plant because this water is circulated. So softening plant will be less frequently because it will be required only for the make off water make off water is approximately 1.5 % of the water circulated in the cycle. So the load on the water circulated plant is also reduced normally water pool condensing unit is used for power plants so it consist of a closed vessel.

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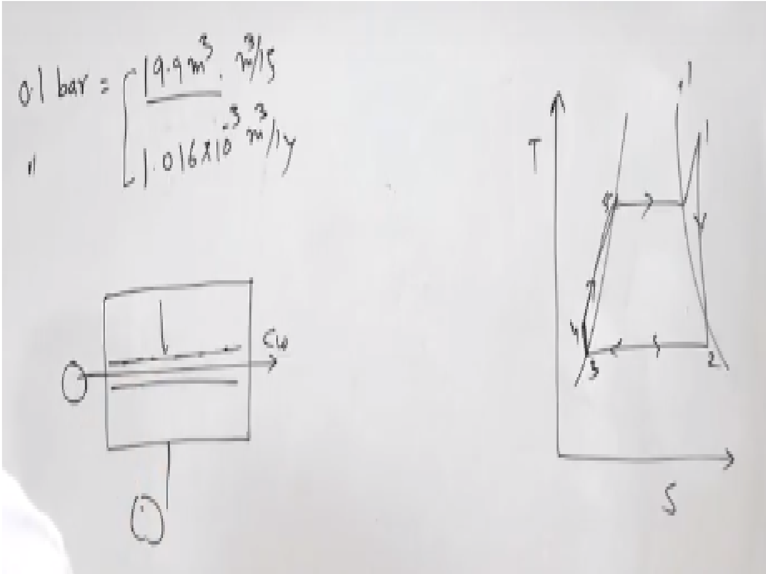

The condenser is a closed vessel and it is a sort of heat exchanger normally (()) (06:24) type of heat exchanger is used in the power plants in (()) (06:28) type of heat exchanger there is a big shell and it is fitted with a bundle of tubes cooling water is circulated in the bundle of tubes when high temperature steam when evolve at one tube but there is a bundle of tube when high temperature in steam comes into the contract into the surface of this tube heat is subsequently transmitted to the cooling water. Which is flowing inside the tube and steam.

Get condensed and it is removed and the volume of steam is drastically reduced. So at 0.1 bar i will give you some figure 0.1 bar the specific volume of the steam is 19.9 meter cube per kg but when it is condensed it is reduced to 1.016 into 10 to power - 3 meter cube per kg. So there is a drastic reduction in the volume itself and the volume is reduced a small pump fitted at the outlet of the condenser will increase the pressure because in the lengthened cycle.

If you look at a pressure entropy the 3 to 4 this is compassion of water and because it is a liquid water is a liquid state or condenser in a liquid state the change is volume is insignificant and the pressure is increased and this high pressure water is sent to the boiler for heat exchange. So that is another benefit now another component of say this is one. So there is a cooling water pump in a condenser.

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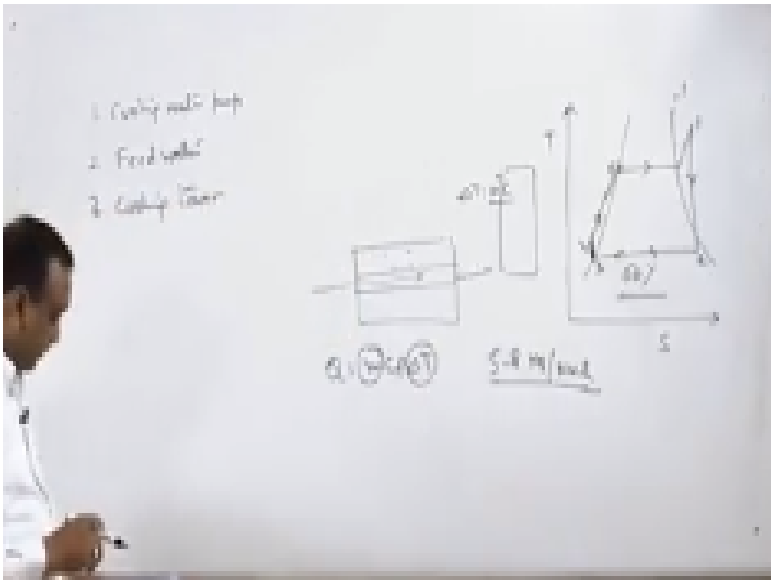

Number one cooling water pump which is used for circulation of cooling water in the vessel there is a tube .So for circulation of cooling water the cooling water pump in a condenser number two there is a feed water pump feed water boiler so another pump is connected to the condenser is feed water pump (()) (08:52) is cooling tower cooling tower is required because this water either we have one sue system.

Water is entering from this side drain from that side then fresh water is entering from this side then huge water will be required i will give you the idea that 60% of the heat is reacted here it is huge 60% heat of the cycle is rejected in the condenser and water cooling. Water requirement is approximately 5 to 8 kg per kilowatt hour then you can imagine the quantity of water required for 1 mega watt or 100 mega watt plant.

So therefore the water has to be circulated right. So one the heat is taken away from the water it goes to the if heat is taken away by the water from the steam it goes to a cooling tower right in cooling tower temperature of water is reduced but cooling tower also has limitations i mean in normally when we design a cooling tower it is designed for delta T = 7 to 10 degree centigrade.

So water flow rate because Q = MCP delta T for water so the mass flow rate should be adjusted in such a way that delta T does not exit ten degree centigrade .So that is why huge water is required in condensers for a power plant now types of condensers there are mainly two type of condensers one is jet condenser another one is surface condenser. So there are two types of condensers.

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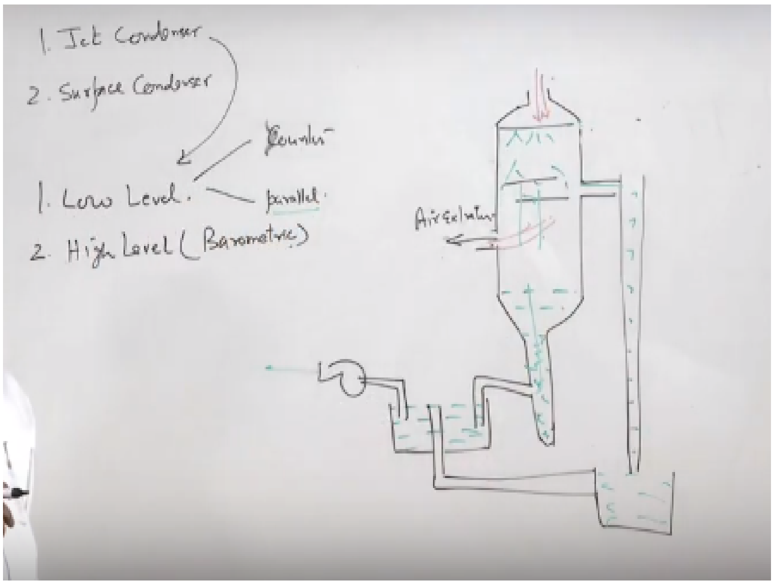

Jet condenser and another type is surface condenser but i was explaining to you was a is about surface condenser but in jet condenser mixing of cooling water with the steam takes place. So when the fresh water is available or clean is available are known as only this places are only those sides the jet condensers can be used now jet condensers are further classified low level jet condenser and number two is high level jet condenser or barometric jet condensers.

That condenser again there are classified turbine flow counter flow and then parallel flow. So surface condenses classified broadly classified into two classes low level sorry jet condenser and surface condenses and jet condenser are further classified as low level counter flow and parallel flow or high level baro metric condenses now for a low level condenser there in the container shall and at the top air suction pump is required air suction.

Right and it has an converging section then there is a lac ok i will reduce the height. So there is a converging section then there is a line which is and this is filled with water this area is filled with water and from here the condensate is sent to a tank in tank certain level is maintained certain level of water is maintained so that there is no over flow in order to maintain a water level a pipe is provided like this.

So whatever over flow is there it goes to the pipe and then from pipe it goes to the cooling point there is a cooling point it goes to the cooling point from here the water enters to this container and from here again it is pumped to the boiler right now regarding the steam the steam enters from this side. So steam enters form this side right and from here the water goes enters in the shell it is by thermo section only it was described here.

So the water level rises and it enters the shell from here and water spray takes place from here the water spray takes place and there are number of trays for breaking the water droplets and steam enters from the bottom steam comes in the contact with water this is steam which is entering from the bottom in the contact with the water coming from the top and the mixture goes to the lack of the jet condenser and subsequently sent to the boiler.

This is a counter flow type of low level jet condenser because steam and the water they flow in a opposite direction certain amount of air is always dissolved in water so this air is set by air suction purpose now in counter flow the things are different in counter flow steam enters from the top there is only change in arrangement. So now we will discuss about the parallel flow in parallel flow the steam enters from the top instead of water suction there is entry of steam from the top right and water is not injected from here.

It is injected somewhere here and they flow in a parallel direction this is a stop this is not there only this is for extraction of air extraction so in counter flow constructed from here in parallel, flow air was extracted from here and mixture of air and sorry mixture of a steam and water they flow in the same direction that is why it is known as parallel flow type of arrangement but the counter flow type of arrangement is more efficient then the parallel flow type of arrangement.

Now we will discuss about how high level of jet condenser in high level jet condenser there is a vessel

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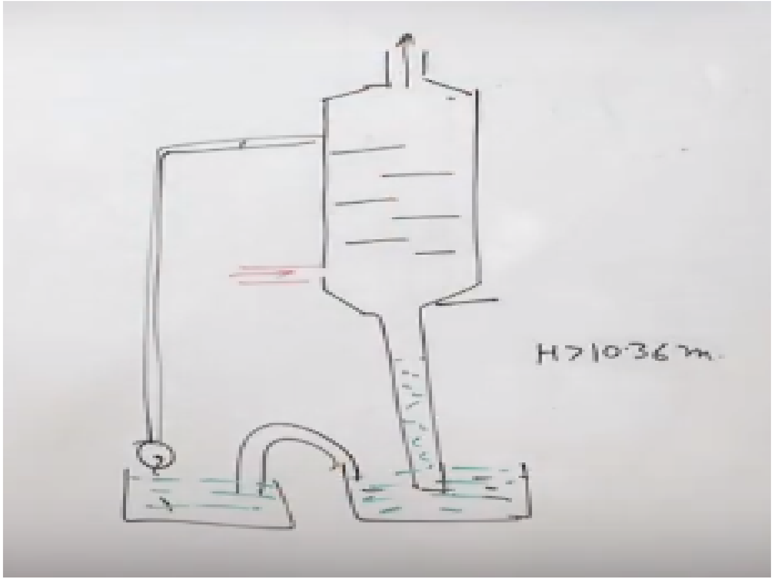

And the tail of this vessel or this led the height of the leg is more than the water column equal lent to 1 baro pressure that is the height is approximately more than 10.36 meters it is equal lent to 1 bar pressure so when it is put into the sump ok what when it is put into the sump water does not rise up to here. So it rises up to normally it rises up to the height of approximately 9 meters approximately up to the height of 9 meters and vacuum is here.

So the benefit of the vacuum is that it entire system works on a very low pressure. So more rigid can be extracted when it is connected to the turbine and from here it goes to the water goes to the slump and from this slump there is a pump which pushes water into this vessel earlier in previous case in low level there was no pump pump was not required to transmit water into the shell but here a pump is required to transmit water which is available here into the shell and when the water is trans mitted to the shell.

So there are baffles right baffles are used for proper mixing of steam enters from his side. So it is basically a counter flow arrangement steam enter from this side in the shell and air is removed from the top pressure arrangements are seen so this is a schematic arrangement of high level of this jet condenser but normally in the power point surface condenser are used in surface condenser normally shallot tube type of condenser are used in shallot tube condenser.

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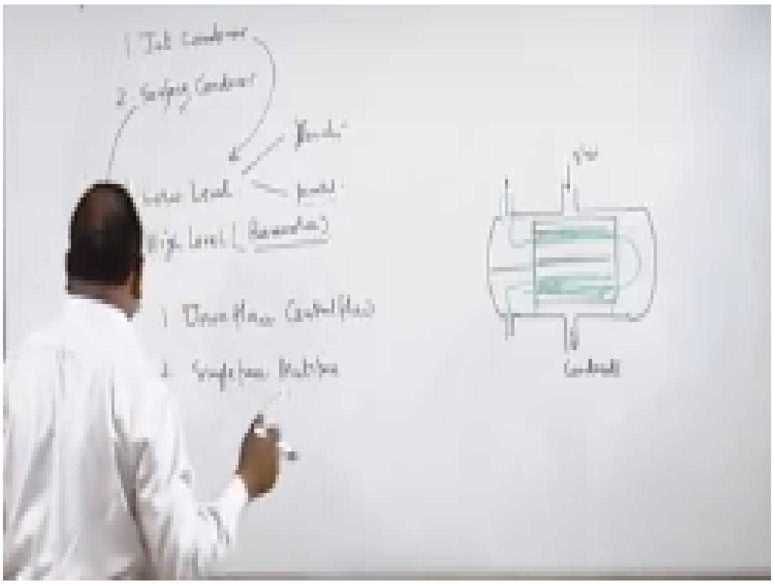

As i explained earlier there are I mean if you classify shallot tube surface condenser then there is down flow down flow type central flow type condenser and inverted flow type or number of passes single pass or multi pass it can be two pass three pass four pass we call it multi pass.

So in a shallot tube type of condenser necessarily there is a shell right and it has bundle of tubes this is end cover of the shell and there are chambers water sorry steam enters from the top steam and it leaves on the bottom condensate right and there are number of troops here and water flows inside the tubes.

The bundle of tubes and cooling water enters from the side this is of the air tubes so cooling water enters from this side right pass through this tubes takes a turn and then pass again passes through this tubes and leave from this side .So it is a two pass surface condenser right and this cool end which is coming out of the condenser it again goes to the cooling tower and get condensed gets cooled down there is always dissolved air in the steam.

So when the steam gets condensed the air is liberated right and it is accumulated close to the tubes of the container normally so air has to be removed frequently from the condenser so air electric pumps are used. So there are two types of arrangement dry type of vacuum arrangement and wet type of vacuum arrangement wet type of vacuum arrangement the steam or steam is also set along the air or the condensate is also set along the air but in dry type of arrangement only air is sent out of the condenser.

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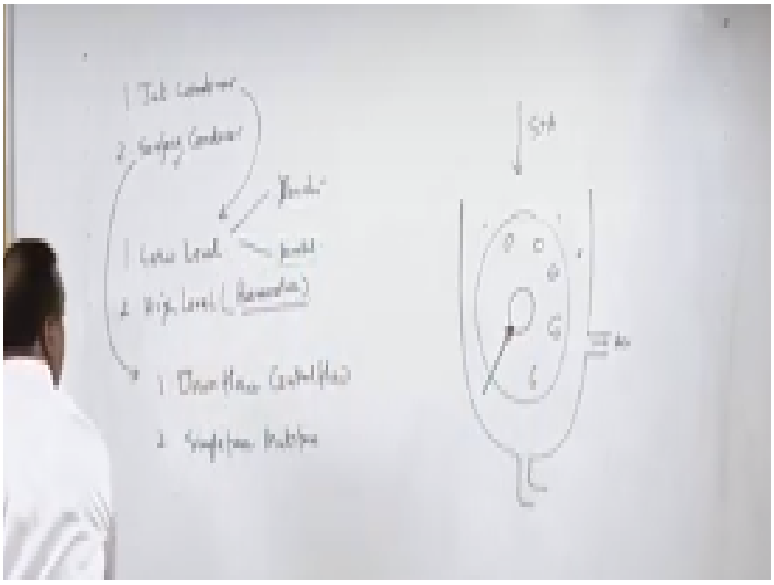

So a dry vacuum type of surface condenser if i want to show schematically is going to be a vessel consisting of number of tubes exhaust steam plus air coming from the top right getting condensed and removed from the bottom in this type of condensers baffles are provided for suction of air. So this is a dry type of dry type of vacuum system here only air is sent out of the condenser vessel in centre flow system there is a centre flow system where there number of tubes and steam flows radially invert and air is sent from the centre of the bundle ok.

So this type of arrangement is known as centrally central flow type of surface condenser now in a condenser there is always a mixture of air and water right and as per the Dalton's law the total pressure is the partial pressure of water and partial pressure of air that is Dalton's law for non-reactive mixtures.

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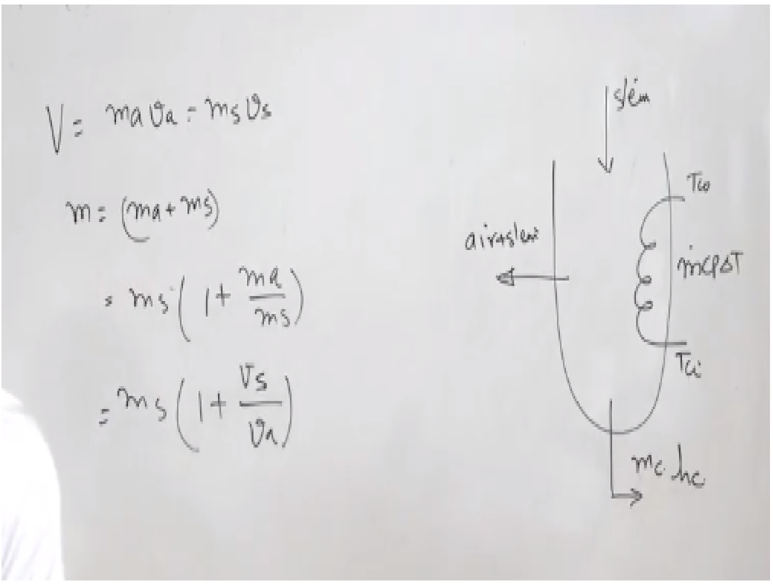

But volume of the shell is equal to mass on the air specific volume of the air is equal to mass of the steam. Specific volume of the steam right total mass in the vessel is mass of the air plus mass of the steam is equal to mass of the steam one plus mass of the air divided by mass of the steam is equal to mass of the steam one plus specific volume of the air mass of the steam mass of the air. So specific volume of steam by specific volume of air right.

Now in a condenser if you do the heat balance steam is coming from the top it out on the total heat of the steam part of the heat is taken away by the cooling water TCI TCO and this certain mass florate. So it is MCP delta T right and part of the heat is going with the condensate mass of the condensate right and enthalpy of the condensate right here pressure steam are also ejected from the condenser because air has to be sucked out.

So part of the heat is also going with the air plus steam coming out of here right. So initially we will consider air only so suction is talking place and air is coming out of here. If we do the energy balance that this is stage one let us say this is stage one so

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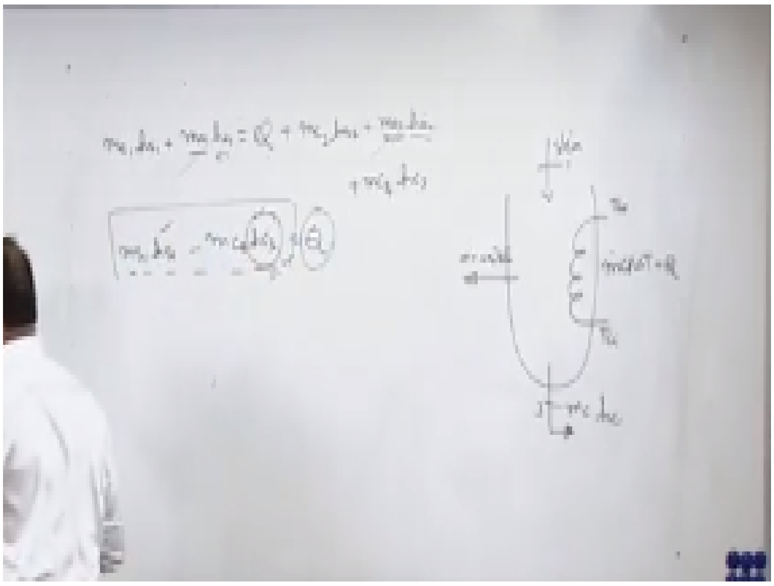

Mass of the steam at state 1 H of the steam is state 1 + mass of the air state 1 enthalpy of the air state 1 there is a total energy which is entering the vessel right is equal to heat transfer Q + this is heat transfer Q + mass of the steam 2 enthalpy of the steam 2 + mass of the air 2 enthalpy of air 2. This is air plus steam right now remaining part is going with the condensate mass of the condensate and enthalpy of condensate three.

It is three this is the total energy balance now mass of the air whatever mass is entering it is leaving the vessel temperature of air is also constant because steam is getting condensed it is getting condensed at constant temperature .So both are equal they can be cancelled out because while doing the analysis it is often asked why you have not considered the air the heat carried away by the air or heat coming with the air in the vessel.

So they are cancelled out so mass of the steam enthalpy of the steam minus mass of the condensate enthalpy of the condensate is equal to Q right. So this heat which is taken away by the cooling water is the enthalpy difference of this steam entering from this side and condensate leaving from this side air does not come into the picture. Now we can further say that this enthalpy it is a condensate can be in a liquid state or sometimes.

It is a sub liquid also but for properly designed condenser a condenser has to be i mean should not have any sub liquid inside a condenser should not that is called the poor design of the condenser condenser should take away only latent heat from the condensing vapour right. So this HC 3 can be calculated the all these things can be taken from all these properties can be taken from the steam table and we can find the value of Q.

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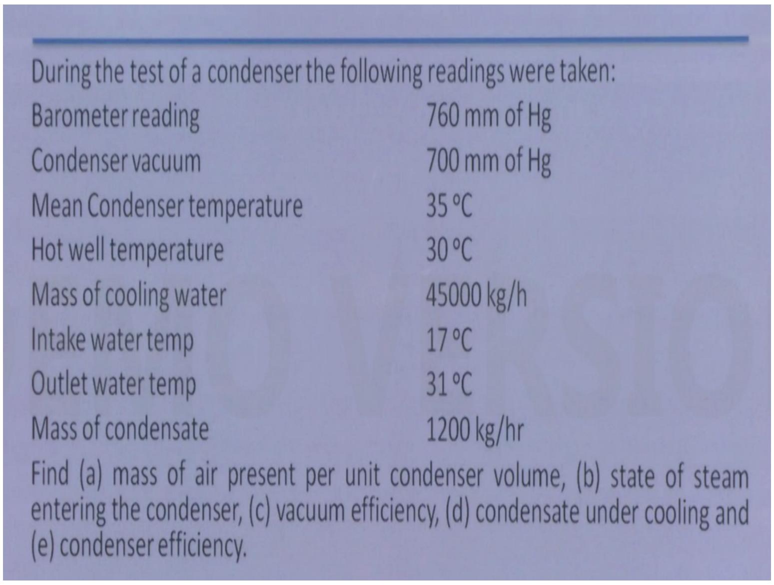

Now regarding this we will solve one numerical that will give us clear idea about this now in this numerical the barometric reading is 760 millimetre of mercury is the pressure at the site is the atmospheric pressure and vacuum in the condenser is 700 millimetres of mercury vacuum is 700 meters of mercury means the pressure below the atmospheric pressure.

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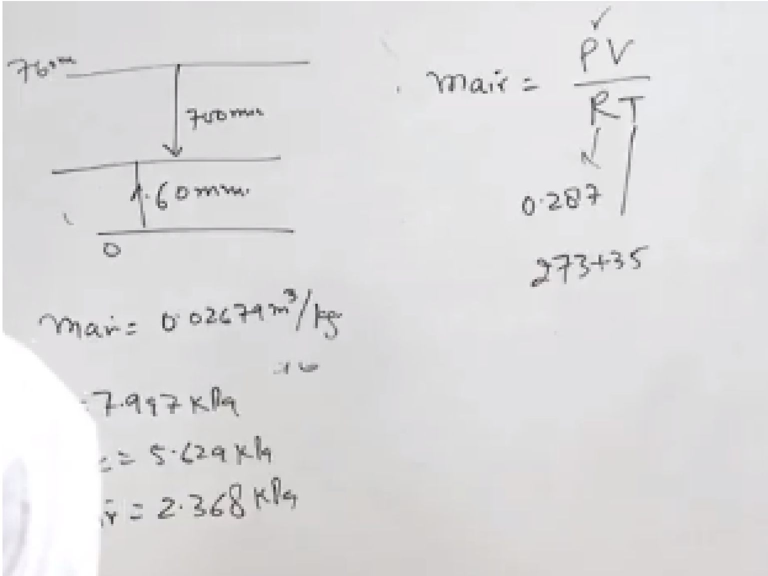

So this is above zero pressure this is atmospheric or 760 ML. So if the vacuum is 700 MM it is 700 below the 760 MM the absolute pressure is 70 MM of mercury right mean condenser temperature is 35 degree centigrade hot well temperature 30 degree centigrade mass of cooling water is 45,000 kg per hour intake water temperature is 17 degree centigrade outlet water temperature 31 mass of condensate 1200 kgs per hour.

Ok these are the figures so initially corresponding to 35 degree centigrade right corresponding to 35 degree centigrade saturation pressure is 5.629 kilo pa square. So there is a correction it is not seventy it is 60 MM because 760. So PS is this now corresponding to this seven into 1.013 divided by 76 it comes around 7.99 kilo pa square right.

So the pressure in the condenser is 7.997 kilo pa square saturation pressure corresponding to this is 5.629 kilo pa square right it is there is some air and partial pressure of air is difference of these two so partial pressure of air is going to be the difference of these two and it is going to be 2.368 kilo pa square because partial pressure of air partial pressure of a steam is equal to total pressure inside the condenser.

So mass of the air we can calculate is equal to PV over RT right volume. We can take one right pressure because pressure is pressure of the air we can take from here 2R for air is 0.287 kilo joules per kg Kelvin and temperature is 273 + 35 right and this will give the mass of the air as 0.02679 metre cube per kg right now steam is under pool to 29 degree centigrade or 30 degree centigrade ok.

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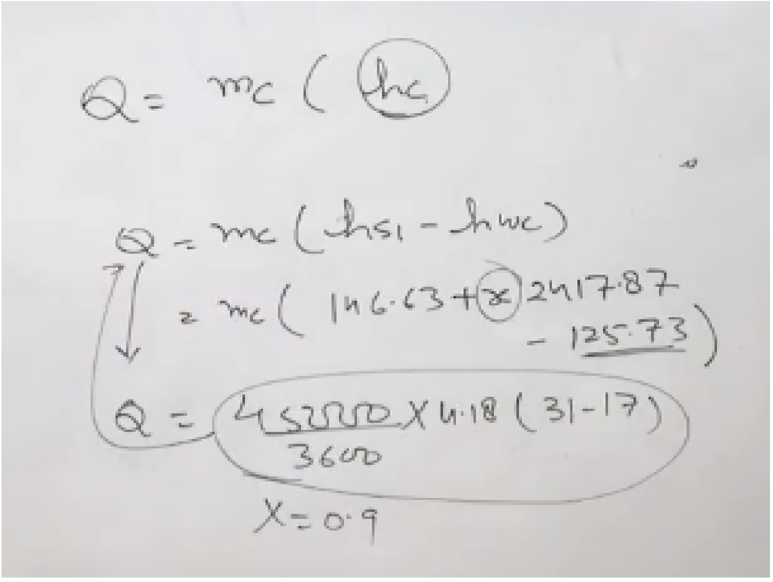

So Q is mass of the condensate and enthalpy of the condensate. So once we have the enthalpy of the condensate now we do not have enthalpy of condensate because we do not no the state of condensate because the vapour which is entering the condenser is a wet vapour.

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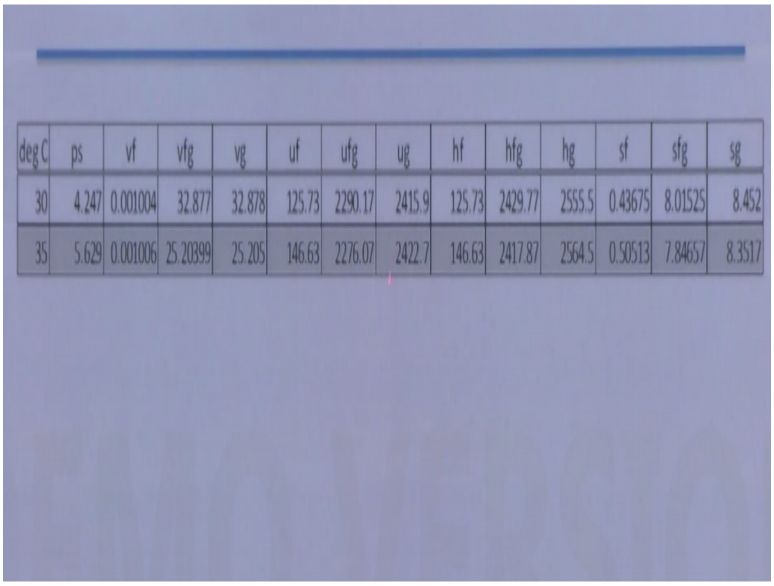

deg C	ps	vf	vfg	vg	uf	ufg	ug	hf	hfg	hg	sf	sfg	sg
30	4.247	0.001004	32.877	32.878	125.73	2290.17	2415.9	125.73	2429.77	2555.5	0.43675	8.01525	8.452
35	5.629	0.001006	25.20399	25.205	146.63	2276.07	2422.7	146.63	2417.87	2564.5	0.50513	7.84657	8.3517

So at 30 degree centigrade we will refer the steam table at thirty degree centigrade we will take the properties of the steam there is HF + XHFG. So it is mass Q is equal to mass of the condensate HS 1 - HWC one HS1 is 146.63. We have taken from here 146.63 at 35 degree centigrade + quality 2417.87 that is latent heat – 125.73 that is the enthalpy of saturated liquid at 30 degree centigrade because the condensate is sub cooled to 30 degree centigrade.

Now from here we need to add the value of Q = 45,000 kg per hour right multiplied by 4.18 into 31 - 17 and this we can take 36 this is a Q is in kilo watts and CP delta T. Now once we calculate the Q from here we will put the value of Q here and we add the value of X right. Ok one thing more it is kg per metre cube not metre cube per kg ok mass of the air is kg per metre cube ok.

So Q is first of all what we have done Q is equal to heat taken away the in the condenser is mass of the condensate enthalpy of entering steam or sensible heat of leaving condensate right enthalpy of entering steam. We do not know right this sensible heat of condensate is known to us because it is the saturated enthalpy liquid at thirty degree centigrade Q is not with us Q we have taken from MCP already the heat is taken away by the cooling water and from here by putting this value.

Here we will get the value of X and the value of X is 0.9 right this is the state of steam which is entering the condenser now vacuum efficiency is defined as for

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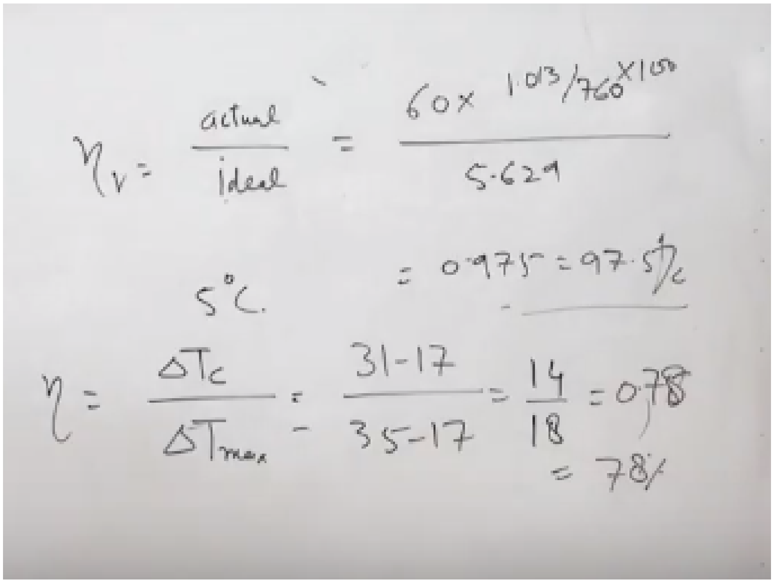

Any condenser is equal to vacuum divide by ideal vacuum. So actual vacuum divide by ideal vacuum right now actual vacuum is how much 60 millimetres of mercury or into 1.013 by 76 bar or multiplied by 100 then it is kilo pa square right divided by ideal and what is the ideal it is this 5.629 and this is 0.975 = 97.5 % this is the vacuum efficiency of the condenser under cooling condenser.

Under cooling is vapour is available at 35 degree centigrade and it is sub cooled to 30 degree centigrade. So it is sub cooling is 5 degree centigrade it is obvious from the data in the numerical and condenser efficiency now condenser efficiency is the temperature raise in the cooling water divided by maximum possible temperature raise. So temperature raise in cooling water is 31 - 17 and maximum possible temperature raise in cooling water cannot be more than 35 degree centigrade.

Because 35 degree centigrade is a temperature of condensing steam so it is 35 - 17 there is one more correction here this is 76 because this is in millimetre this has to be in millimetres right and now let us go back to this volumetric efficiency this is going to be 14 by 80. It is going to 0.78 or it is 78 %.

So efficiency of the condenser is 78 % volumetric efficiency we have calculated in 97.5 volumetric efficiency actual vacuum divided by ideal vacuum actual vacuum we have calculated from here 60 multiplied by 1.03 atmospheric pressure divided by 760 millimetre into 100 divided by ideal vacuum. Right and this all we got solutions for all the required parameters in this numerical. That is all for today. Thank you very much.