Power Plant Engineering
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Lecture – 18
Steam Condensers

Hello, I welcome you all in this course on Power Plant Engineering. Today we will discuss about the Steam Condensers.

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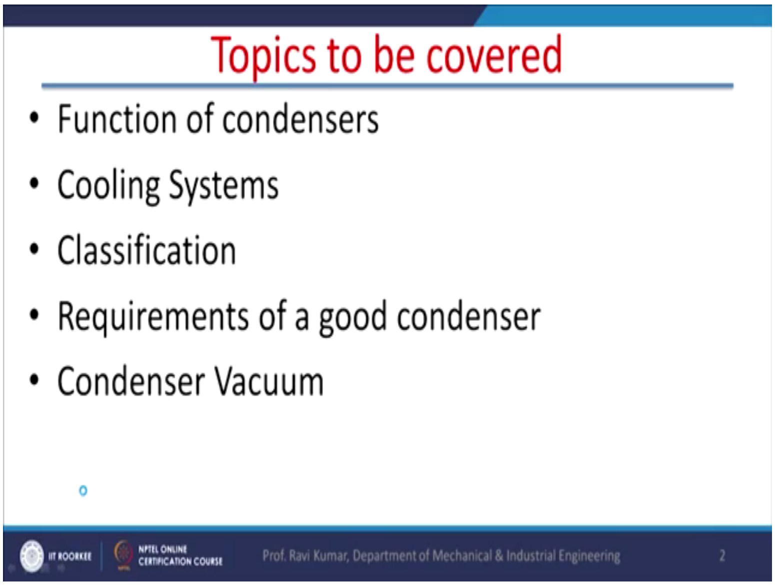

Topics to be covered today are the function of condensers, cooling systems, classification, requirements of a good condenser, condenser vacuum.

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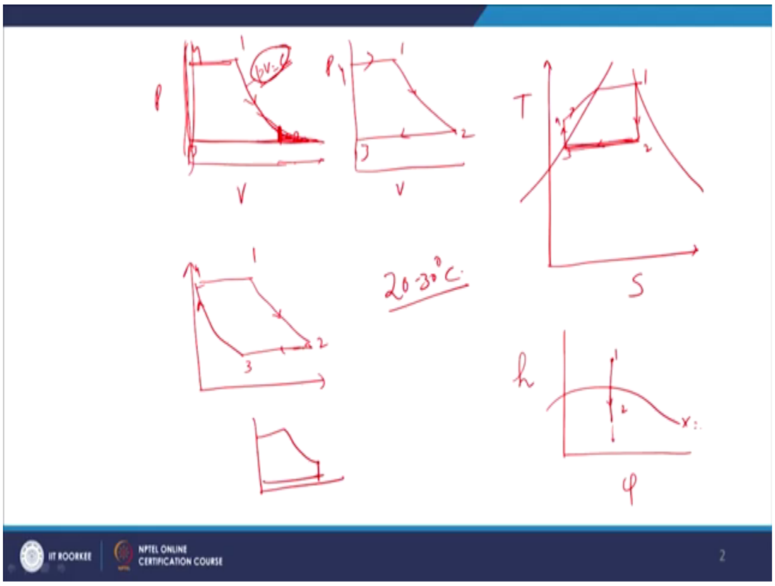

Now, the function of condensers as you know in a if you draw again the Rankine cycle on temperature entropy diagram, then again it is 1, 2; this is expansion in the turbine and 2 to 3 is condensation of the steam, then 4; 3 to 4 is pumping and 4 to 1 is boiler. Now, this steam is condensed in a condenser where the process 2 to 3 takes place. As we know if we keep on reducing this pressure right we will be getting the more energy; more output. If we draw this process in enthalpy entropy diagram, this is saturation line x is equal to 1.

So, if we keep on expanding this constant entropy process; if we keep on reducing the pressure, we will be getting the more output. If you compare the, this P V diagram of a reciprocating compressors; reciprocating steam engine, it is like this. Hence, if you draw the on a P V; on the P V pressure and volume diagram if you draw the diagram for this steam turbine it is also like this; pressure and volume right.

Now, this is an ideal diagram. Actually we have not shown in reciprocating compressor I have not shown any clearance here. In fact, there has to be clearance between the piston head and the cylinder wall cylinder head.

In that case there always be a cushion of the steam and the ideal diagram is going to be like this; this is 1, 2, 3 and 4; 1, 2, 3 and 4; ideal diagram is going to be like this for the steam engine 1, 2 3 and 4 right. But it is none of the concern here; here the concern is if you keep on reducing the pressure this back pressure in the steam engine or in a turbine the exit pressure of a turbine; we will be getting more power because the area of P V diagram will increase. But here in the steam engine, we do not do this because if you look at the later part, it is a parabolic process, p v is equal to c; it is not I mean constant temperature process, this expansion process is parabolic process p v is equal to c and the expansion goes like this.

So, in the fag end if you look at this end, we are getting very less power output and maybe this output may be compensated by the frictional loss in the engine reciprocating engine. So, normally the output is not; expansion is not taking up to here it is taken up to here; so the diagram is like this.

But in the steam turbine, we can keep on expanding because a rotary machine right; we can keep on expanding up to absolute vacuum or absolute pressure is 0, but that we normally do not do. Even we restrict this pressure to a certain value in turbines, the reason being the cooling is done by the water and the water is taken from some river or some from some water body right. And this water is at the normal temperature; I mean temperature may vary from say 20 to 30 degree centigrade.

So, this water is used for the cooling purpose; for the extraction of heat. So, if the steam temperature is lower than this in fact, the steam will be getting heated rather than extraction of heat is taking place. So, the temperature of the steam has to be higher than this value and at least 10 degree centigrade higher than this value.

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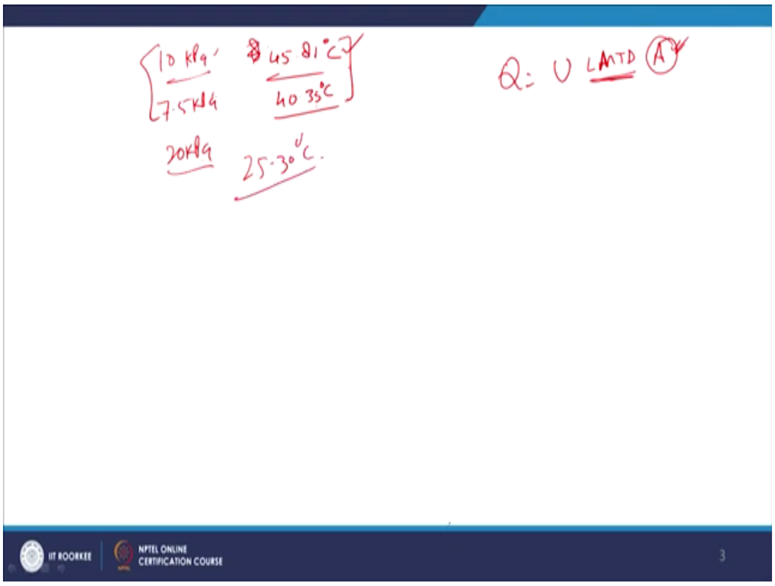

So, if you look at the values; if you take 10 kilo Pascal pressure, suppose pressure in the condenser is 10 kilo Pascal, corresponding saturation temperature is 45.81 degree centigrade. If the pressure is 7.5 kilo Pascal, the temperature is 40.33 degree centigrade, this is just to give you physical idea about the quantities right.

So, the pressure normally pressure in the condenser of this order only. Now, if I increase this pressure if I increase this pressure I take it to 20 kilo Pascal. So, actually this temperature will shoot, but when we increase this pressure in that case output of the turbine will reduce right; at the same time size of the condenser will also reduce because LMTD will increase; Q is equal to U; LMTD or AMTD whatever is applicable here; LMTD or AMTD multiplied by area; right.

So, when this LMTD is increasing because we are condensing at higher temperature right, area will reduce for the same amount of heat extraction. And if we reduce this it means we come to 40, when come to 40 or we reduce further reduce the pressure; the output of the turbine will increase, at the same time area has to be increase, LMTD will reduce area has to be increased enormously right.

So, the fixed costs of this system will increase and beyond a certain value; it is not possible at all, we cannot go beyond 7.5 or a 10 kilo Pascal because our cooling water is available at 25 to 30 degrees centigrade right.

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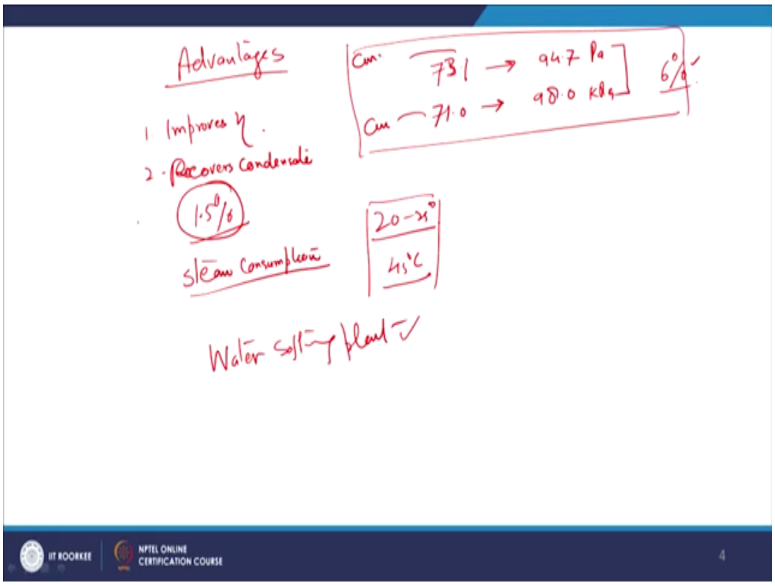

Now, we will talk about the advantages of condensers; this is the importance of condenser, I have explained to you in the system. Now, advantage of the condenser it improves the efficiency; efficiency of the system right, recovers the condensate; recover condensate, it means there is a closed loop.

So, after the condensation again it can put the boiler and I mean closed loop the system can work, but still due to some leakage or barrier because in condenser also the steam is vented out in order to remove air, I will discuss it later on. So, compensating water is required and it is 1.5 percent; make up water is approximately 1.5 percent of the total water requirement right.

Now, it reduces the steam consumption also; from the steam, suppose power requirement is same power requirement is same if per cycle output is more; per cycle output is more definitely we will have to use less amount of the steam. For example, suppose 73.1 corresponding to 73.1; this is 94.7 and 71.0; it is 98.0 kilo Pascal pressure. 73.1 is centimeter of mercury; centimeter of mercury, if we change pressure from this to this; we can increase output by the 6 percent. This is simple a I mean rough calculation to have some idea about the pressures.

So, slightly variation in pressure; slight variation in pressure may affect the efficiency or the output of the entire system. Now, if there is a close'; loop say water is already always under heated stage right; if you compare with the water which is fresh water which is coming at 20 or 25 degree centigrade and the water which is available with the closed loop is available at 45 degree centigrade.

So, this will also reduce the thermal stresses in the system right. So, in a closed loop; the thermal stresses in the system also it is reduced and closed loop is attained by using a condenser. And water softening plant because if you use a water softening plant which is require plant because we cannot just simply put the water in the inside the system because scaling will take place in that case.

So, in order to remove the water softening plan is used. If we are using fresh water for entire process, then the size of the water softening plan will increase or the load of this water softening plan is increased because in this case when it is a closed loop using condenser the make-up water is only 1.5 percent right. So, this cost will also increase in a power plant.

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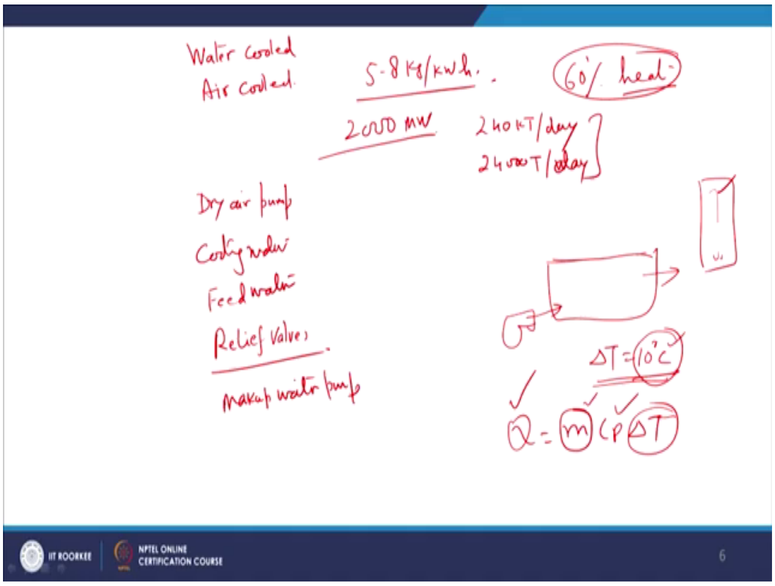

So, the condensers they are two types; water cooled and air cooled condensers. Air cooled condensers are also there when there is a scarcity of the water; air cooled condenser are also used, they are direct type and indirect type, they are different type of air condensers.

So, if it is water cooled condensers; if you remember that in a thermal power plant, 60 percent of the heat is taken away in the condenser because heat is added in the boiler; expansion in the turbine and in the condenser approximately 60 percent of the heat is taken away. The water consumption I just want to tell you the magnitude of the water consumption in the power plant it is approximately 5 to 8 kg per kilowatt hour. This is the amount of water consumption is water is required in a thermal power plant or suppose there is a 2000 megawatt thermal power plant. In this power plant we require 240 kilo tons of water per day or 24000 tons of water per day.

So, water requirement is huge in thermal power plant right and at the same time heat rejection is huge in the steam condenser. And they are different elements of in of a condenser; one is dry air pump. This is used to this pump is used to remove air from the condenser because air does enter the condenser because it is operating at some atmospheric pressure. There may be some leakage through the cracks or air also comes with the water make up water in the condenser; so air has to be removed right; so dry air pump is used.

Now another is cooling water pump because water has to go inside the condenser. So, there will not be any gravity flow pump has to be used, a pump house is there which pumps the water into the condenser for the cooling purpose. And while designing a condenser, it has to be ensured that the temperature rise of the water should not be more than 10 degrees centigrade. Because this heat because this also is a closed loop; we do not have infinite amount of water, cooling water is also the finite, the working fluid is also finite.

So, what happens? This water which is emerging from the condenser right; it goes to a cooling tower and where the cooling of water takes place by natural process and during this process; the maximum temperature drop is considered to be 10 degree centigrade; I mean this is for the designing purpose right.

So, it is; so this is a restriction in designing of the surface condenser that the mass flow rate or the size of the condenser. So, how it will be compensated? Q is equal to m C P delta T right this is the; so certain amount of heat has to be carried away, delta T we have fixed C P is also fixed; so we have to monitor the mass flow rate. Mass flow rate means how many number of tubes are required, what should be the size of the condenser right; this has to be decided by this.

So, that is we were talking about the cooling water pump, then feed water pump; feed water pump is there, cooling power or a spray is there; this is an integral part, there are certain relief valve and there is a make-up water pump. Relief valves are to be in any machine I mean whether I mean it is pressurized any pressurized machine two relief valves have to be provided. And here also there is a relief valve for removing air, I mean sometimes air has to be removed as I said earlier the relief valve is used, it is not a safety valve, it is simply a relief valve which is provided in the condenser. Now, there are jet condenser which are known as the direct contact condenser.

So, I mean there are two types of condenser where coolant and the fluid they do not come into the contact like surface condenser. There are certain condensers where fluid and the coolant they get mixed; they are known as jet condensers or direct contact type of condensers right. [FL] Then again, we can classify down flow condensers, invert flow condensers; they are I mean this is about the surface condenser.

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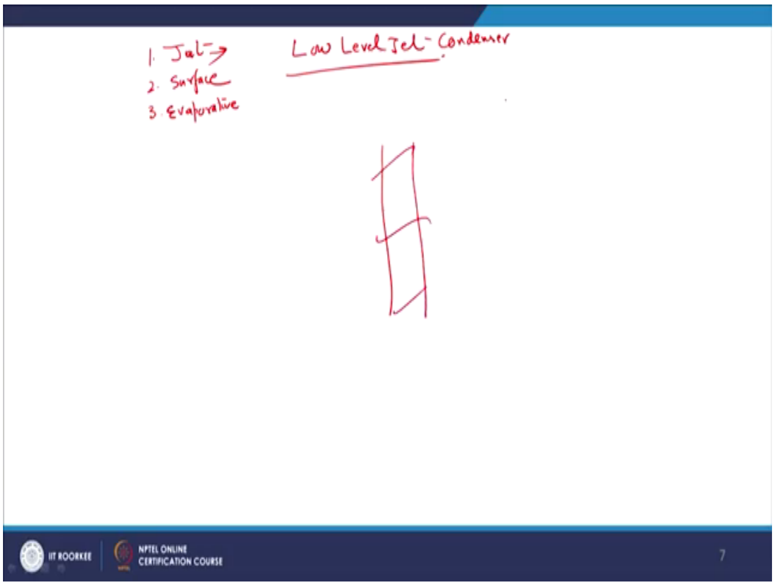

So, normally they are jet condensers and they are surface condensers and evaporative condensers are also there right. So, in jet condensers there is a direct contact of coolant and the steam which is coming from the turbine.

So, in jet condenser we will talk about the low level jet condenser; low level jet condenser right in low level jet condensers there is a column.

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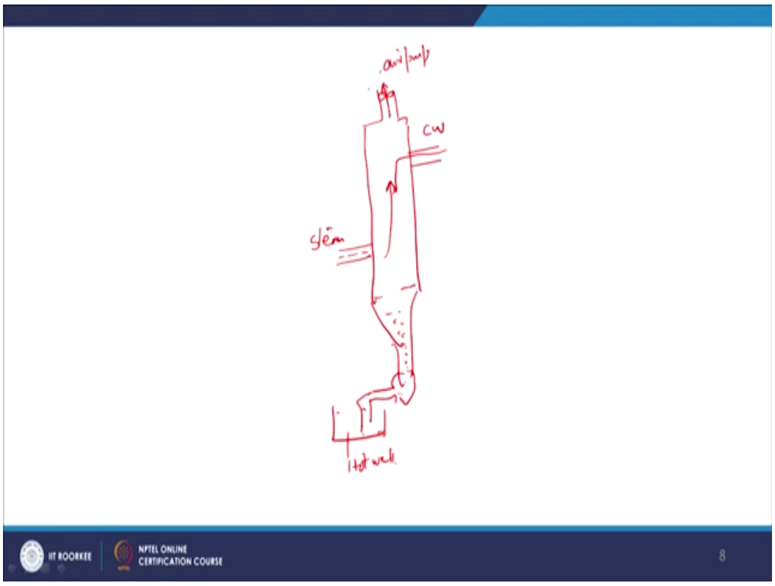

In low level jet condenser; there is a column right and at the bottom, there is a condensate pump; which put the condensate into the hot well right and because we are talking about the counter flow type, so, the cooling water; cooling water enters from here and steam enters from here. So, if steam is entering from the bottom and it is moving in the upward direction, cooling water is coming from here it is moving in downward direction.

So, mixing takes place and finally, what happens because cooling water thermal capacity is quite high; the latent heat of the steam is taken away and they get condensed and accumulated at the bottom of jet condenser. And subsequently it is pumped to the hot well for the further use right and air which is just coming with the steam because steam when it is expanded as I said earlier, by certain means the air managed to enter into the system. So, this air is liberated and this air is sent to the outside with air pump.

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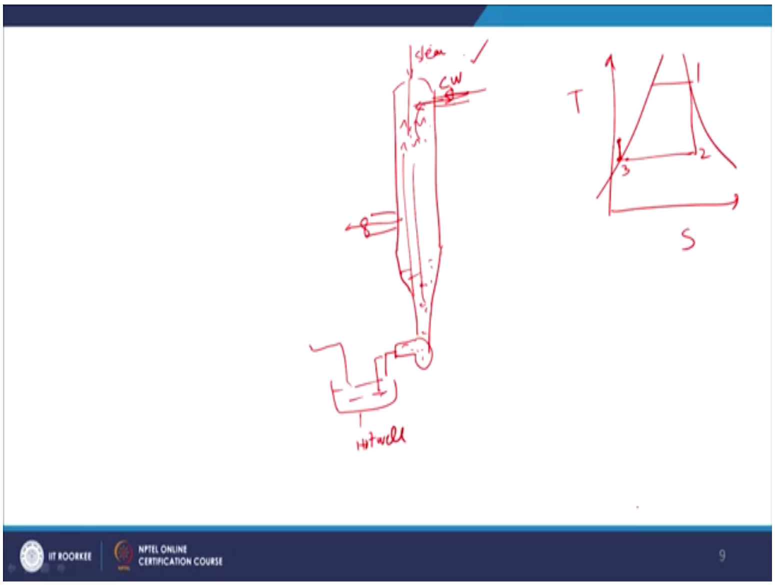

So, this is about the jet level condenser which is counter flow type. Now, if you want to look at the parallel flow type of jet condenser; in that case steam and water move, they move in the same direction; so that is parallel flow. So, the geometry remains almost same at the bottom, there is a pump; it goes to a well and the hot well and from definitely from hot well the water will go to the boiler because after the condenser water goes to the boiler.

Now, here the cooling water; cooling water enters from here and steam enters from the top. In previous case, the air was hot air was leaving the from the top; here the steam is entering the top, cooling water has lateral entry, there are certain taps here which allow the proper mixing of; in previous case also which allow the proper mixing of steam and cooling water right. After coming here there is a again; there is a pump which removes the air and the steam the condensate is collected at the bottom through a pump, it goes to the hot well and from hot well, it goes to the boiler.

So, jet condenser, it does not require any pump right; sorry it does not have any under cooling of water it is designed in such a way because under cooling of water in any condenser is not required. In condenser it is required only that the latent heat is removed why?

The reason being; suppose there is a; if again we will go for this temperature entropy diagram 1, 2, 3; now, we want a steam at only a state 3. Because when we will increase the pressure; it will automatically become sub cooled, but if the steam is left here; it is a two phase mixture that will drastically reduce the efficiency of the pump or in fact, two phase pumps are not available, pumps are designed for single phase that is water.

So, if it is left here; it will drastically reduce I mean it will become very difficult to operate the plant. So, we have to ensure that entire steam is condensed; some under cooling will be there practically right, but it has to be been minimized because anyway when we are compressing the steam, we are compressing the water saturated water; it is coming down into the sub cooled water.

So, so sub cooling is not required here; so it should not be. So, a good condenser design ensures that only latent heat of the steam is taken away, not the sensitivity. So, here also in the parallel flow; it is collected and it is sent to the boiler, but here you see we need extra water.

So, water has to be plenty; in addition to the condense I mean other purposes here; plenty of the water is required for the purpose of condensation. Now, regarding the efficiency as you know the counter flow processes are often more efficient than the parallel flow processes. So, here also the parallel flow type of jet condenser is less efficient than the counter flow type of jet condenser. Now these are the low level jet condenser.

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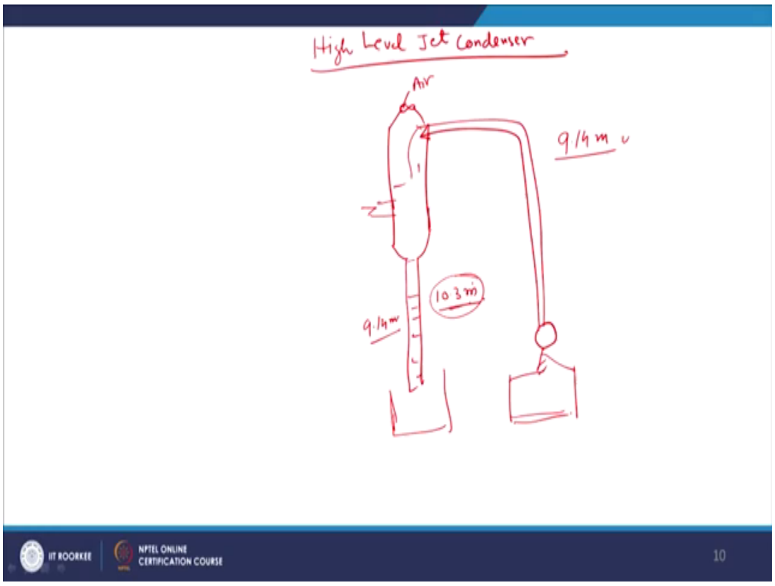

Now, there is one which is known as high level jet condenser; it is also known as barometric condenser. Now, in this condenser it is almost like a parallel flow sorry counter flow condenser where there is a air pump which is at the top air pump right and there is a leg.

The height of this leg is equal to or more than 10.3 meters which is equivalent to the; I mean one atmospheric pressure or 10.3 meters, we can say it is something like if you can physically want to; physically realize physically realize it is a height of a let us say 10 storied building; not 10 storey, 3 storey building. So, because normally ceiling height is 10 feet or 3.3 something meters; so we can comfortably say it is 10.3 meter is the height of a 3 storey buildings; so this has to be ensured.

Then there is a hot well here right; now cooling water is coming from the separate well through a pump and from the pump it enters; the process is same it enters the condenser, here steam is coming from the exhaust, they get mixed and they are drained oh, but here pump is not required; in this case pump is not required that energy can be saved here.

And normally water column is not more than 9.14 meter; for the most efficient jet type of high level jet type of condenser, water level is here is normally 9.14 meters but it still we take it more than 10.3 meters. After this jet type of condenser, there is another type of condenser which is known as ejector condenser.

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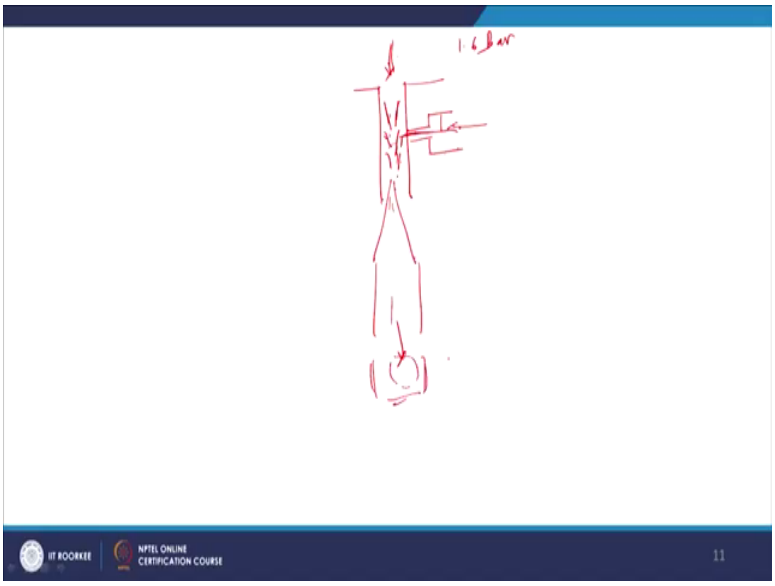

Now, in ejector condenser; the cooling water enters from the top and the cooling water pressure is which is approximately 1.6 bar; slightly higher than the atmospheric pressure. And when it enters their nozzles which increase the velocity of the water right and here on this side;

there is an ejector system having a non return valve; non return valve is a valve which allows the flow of the fluid in one direction only.

If there is a reversal of flow; it will stop the flow. Non flow of type of valve is provided here so that in case of reverse flow the; the steam the water does not enter the engine or does not enter the turbine. So, nonstop valve is provided here; this is the extra system and after that there is a diverging part and after diverging part, there is a collection of fluid.

So, the water enters from this side with a very high velocity, the number of nozzles are provided which further increase the velocity of water. Injection system is here from through which system the steam enters it get mixed with the water. Subsequently, the latent of this heat of this steam is sent to transfer to the water which increases the sensible heat of the water; both of that get mixed and they are condensed in a pump ok.

This is the steam ejection system; now we will come to the most popular condensing device that is surface condenser.

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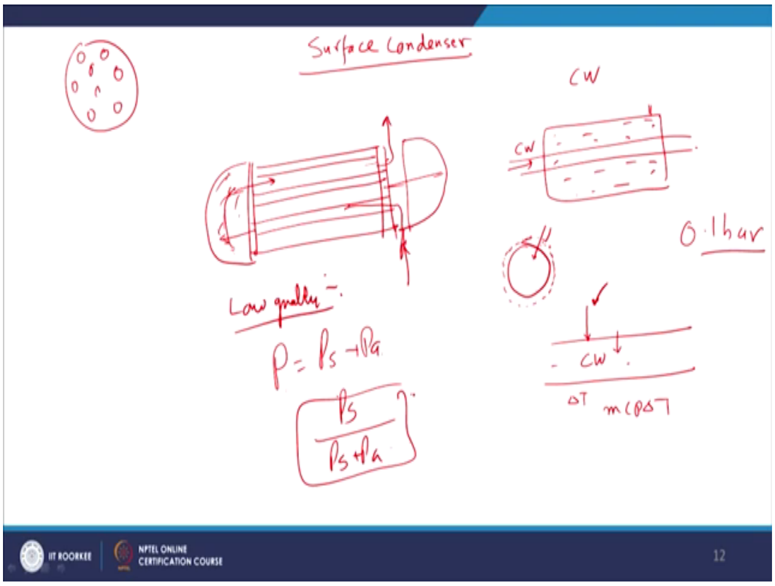

Now, surface condenser; there is a shell in the surface condenser, there is a shell and shell has number of tubes right and cooling water it flows inside the tube. The tubes; the cooling water flows inside the tube and shell is filled with that steam right.

So, it is an extension of double pipe heat exchanger; double pipe heat exchanger, there is a single tube; in surface condenser there is a bundle of tubes. Now, what happens; due to leakage as I mentioned earlier, due to leakage from any joint or from any valve because this entire condenser is at very low pressure is at very low pressure.

It is approximately at 0.1 bar pressure right or from jet or from this compensating water or make of water; the air happens to enter in the condenser. When air enters the compressor what happens the steam what is what is happening here if this condenser surface condenser the cooling water is flowing inside the tube.

It is surrounded by the steam when steam; hot steam is coming into the contact with the surface which is at lower temperature, it transmits heat to the surface and this is a copper tube and the from the surface; it goes through the cooling water and temperature of cooling water raises or it is m C P delta T.

Obviously and this is this comes from the latent heat of condensing the steam. Now, if the air is mixed with these steam air will not condense what is going to happen air will envelop this tube. So, this; this is the tube, a thin layer of air will envelope this tube because there is a lowest pressure zone in the entire system. In the condenser itself the vicinity of the tube is the lowest pressure zone in the condenser.

So, here the thin layer of cloud a cloud of air will be formed around the tube. Now, this cloud of air will prevent the heat transfer or it will hamper the heat transfer. If that is not sufficient heat transfer in a condenser, the pressure of condenser will rise there are many reasons in the rise of the pressure of the condenser. Suppose, cooling water flow rate is low in that case also the condenser pressure is high. If the air is mixed with the steam in that case also the condenser pressure will rise right.

So, this is a; I mean we will discuss it later on. So, here as per the construction of the surface condenser, there is the bundle of tubes right and the tubes are connected to the tube plate. So, if you look at the end view; the end view is going to be like this, there is a plate and there are a number of tubes which are embedded in the plates right. There is a water box on this side, there is a water box on this side as well right and water is entering from let us say from this side. First of all it will not go to this side, there is a partition.

So, water will go in this direction from the bottom right; then this is filled with water right and then water will take a U turn and it will again flow in this direction. And after taking heat from all the tubes; it will leave from here right this is a up flow, this is up flow. If you invert the flow it will become down flow water is entering from here and leaving from here.

It will become down flow right. So, in this condenser the advantage is pure condensation is possible; I mean we can easy easily design a condenser where only phase change of steam to water is taking place. Low quality of cooling water can be used in surface condenser and high vacuum efficiency can be maintained high vacuum efficiency what I mean to say total pressure in the condenser will be pressure of the steam plus pressure of the air right. So, ideally it should be the pressure of the steam.

So, total pressure should be pressure of the steam because air has been added so the pressure as I said condenser has increased. So, if the; if you take the ratio of these two pressure of the steam divided by pressure of the steam plus pressure of the air, this will give you the vacuum efficiency of the condenser. If the pressure of the air is 0; then vacuum efficiency of the condenser is 100 percent. Now, there are certain disadvantages also for the surface condensers; first of all large area is required large volume; volume of water.

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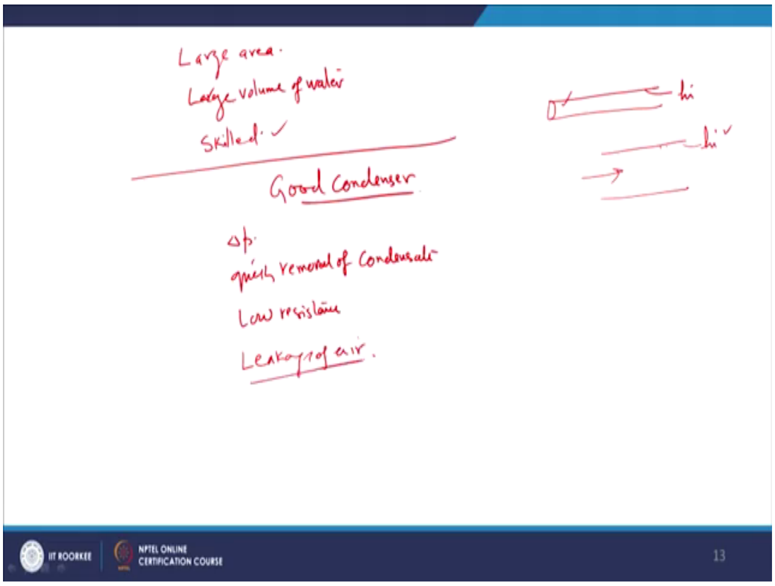

So, large volume of water is required; if you compare with a direct contact or mixing type of condenser. Construction is also not simple; I mean it is a complicated construction skilled worker is required to operate a the surface condenser. Maintenance cost is also high for surface, but still apart from these disadvantages; the surface condensers are used in a power plant so when we design a condenser, the minimum requirement for a good condenser.

The minimum requirement of the good condenser is during the supply the pressure drop has to be minimum during the supply of water the pressure drop has to be minimum. Quick removal of condensate; condensate should not accumulate in the condenser shell because it will hamper the heat transfer; so quick removal of condensate right; low resistance in water tube, low resistance of flow in a water tube.

Now, here if you take tubes of the smaller diameter the resistance is more; at the same time inside tube heat transfer coefficient will also high. If you take large diameter tube, the distance will be less, but at the same time inside tube heat transfer coefficient will be low.

So, the designer has to designer has to always trade also; here also designer has to trade off what should it be the diameter optimum diameter of the tube. In this case surface condensers because they are not insulated often not insulated. So, the heat loss through the condenser wall where convection or radiation should be all convection and conduction should be minimum leakage of air is main issue.

So, air leakage has to be minimum; it has to be minimized in a surface in a surface condenser, but it cannot the possibility cannot be made as absolute 0 because air anyhow air will enter the condenser because it is running at a very high vacuum.

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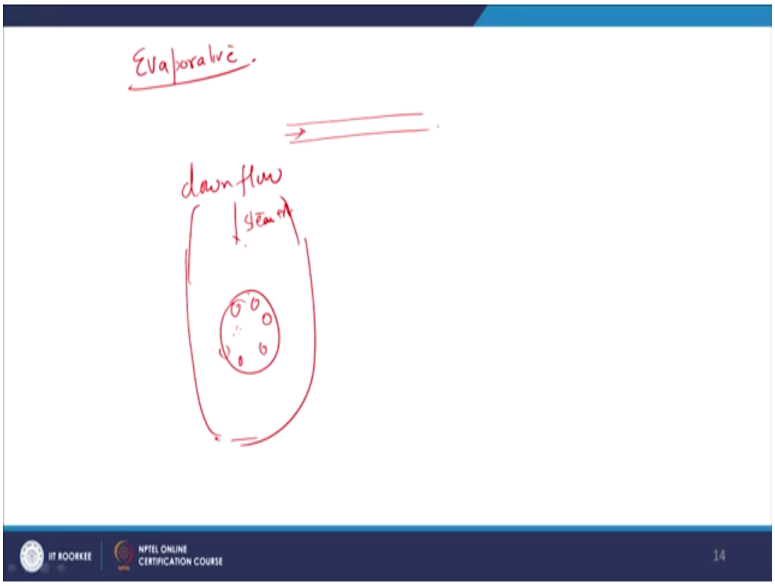

Now, there are certain condensers which are known as evaporative condenser. In evaporative condensers, the steam flows inside the tube and it is surrounded by the cooling water; it is reverse of surface condensers right.

So, there are two types of condensers; one is down flow; in down flow condenser there is a shell, there is a I mean bunch of tubes right and the steam and air; they enter from the top and steam and air they come from the top.

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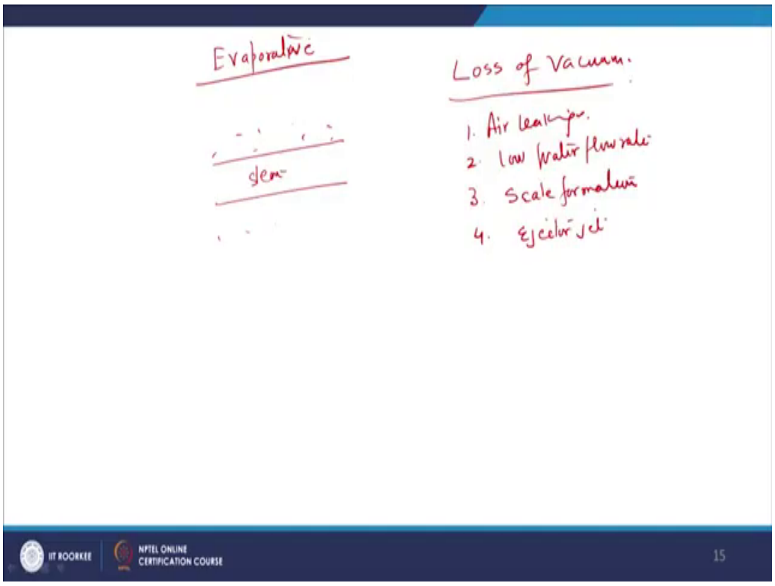

Another type of condenser is evaporative type of condenser right; in evaporative condenser, the steam flows inside the tube and it is surrounded by the water right. So, it is a reverse of surface condensers; now there is as I said earlier there is a loss of vacuum which is major concern in surface condensers.

So, loss of vacuum maybe due to air leakage; loss of vacuum maybe low water flow rate cooling water flow rate ok. Loss of vacuum maybe hamper in heat transfer due to scaling; scale formation; this will also hamper the heat transfer and may cause a rise in the pressure in the or if there is a ejector jet in a condenser.

So, if the purpose of the ejector jet is to periodically remove the air and steam mixture from the condenser. So, if periodically if it is jam or it is blocked in that case also the pressure in the condenser will rise that is all for today.

Thank you very much.