Power Plant Engineering
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Lecture - 20
Problem Solving - II

Hello, I welcome you all in this course on Power Plant Engineering, today we will solve some numericals based on the lectures on the previous weeks. So, we will start with in numerical on the gas turbines ok.

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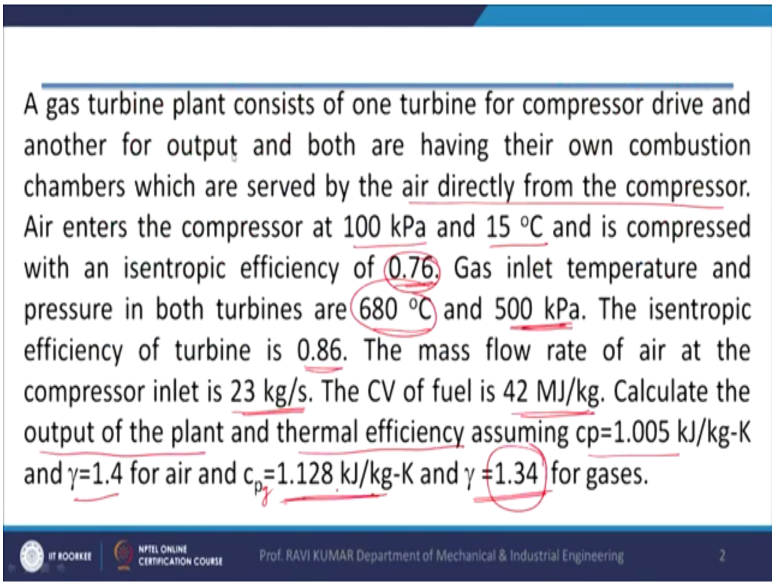

A gas turbine plant consist of one turbine for compressor drive and another for output, it means there are two turbines.

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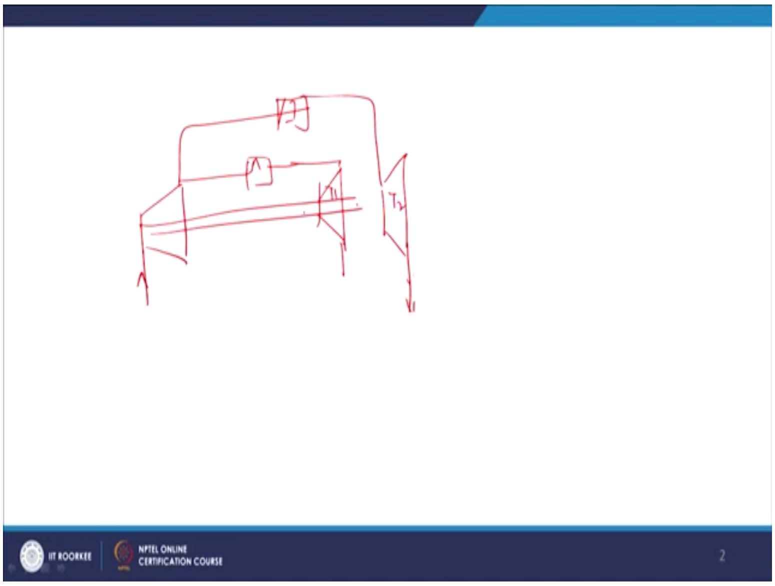

So, there is one compressor air is coming from here, after getting compressed it has two turbines. One turbine is exclusively driving this compressor, another turbine is producing the output right, so and both are having their own combustion chamber.

So, this combustion chamber one combustion chamber is here right, and another combustion chamber is also there, and from this turbine we are getting the output. Output is attained from turbine 2, and T 1 is specifically used for driving the compressor right. So, output of T 1 is going to the compressor, output of T 2 is been used by the consumer.

One combustion chamber which are served by their air directly from compressor, so the air for both the turbines or both the combustion chamber is directly coming from the combustion chamber right. So, air is getting compressed in compressor, then air is divided in two parts; one part is going to combustion chamber of turbine which is driving the compressor.

Another part of the air is going to separate combustion chamber which is driving the turbine which is giving output. The air enters the compressor at 100 kilo Pascal close to the atmosphere pressure and 15 degree centigrade temperature. Air is compressed with an isotropic efficiency of 0.76 I mean the efficiency of the compressor is 76 percent.

Gas inlet temperature and pressure in both turbines are 680 degree centigrade 500 kilo Pascal; it means at the entry level for both the turbines the temperature is same right. But, one turbine is producing only that much output which is sufficient to drive the compressor, so mass flow rate in both the turbine is not same it is different.

The isentropic efficiency of turbine is 0.86. The mass flow rate of air at compressor inlet is 23 kg per second, so it is possible out of this 23 kg 7, 8 kg is going to the turbine which is driving the compressor remaining 15, 16 kg per second is going to another turbine which is giving the output. Calorific value of fuel is 42 mega Joules per kg or 42000 kilo Joules per kg. Calculate the output of the plant and thermal efficiency; we have to calculate 2 things.

Output of the plant and thermal efficiency assuming its specific heat of the air this is specific heat of the air specific heat ratio for air. This is you can see here the specific heat of few gases spg this is specific heat of the gases. So, this is 1.128 it is higher than the specific heat of the air, because here after burning the fuel is also mixed with the air and gamma for this is also 1.34 right.

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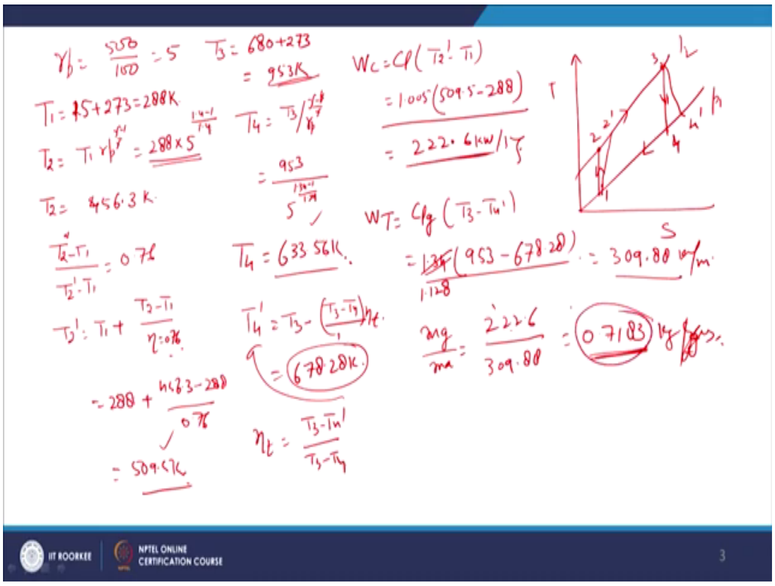

So, first of all we will draw the ah temperature entropy diagram at two pressures; pressure 1 and pressure 2; state 1 to state 2, state 2 to state 3, and 3 to 4 right. Now, the pressure ratio is pressure ratio is given they at least from enters as compressed isentropic efficiency just 500 kilo Pascal.

So, the pressure ratio is 500 divided by 100 it is equal to 5, because r p we are going to often use. Inlet temperature T 1 is 2's sorry 15 plus 273 is equal to 288 Kelvin right. Now, we will find the value of T 2, T 2 is going to be equal to T 1 r p raise to power gamma minus 1 over gamma.

T 1 is 288, r p is 5, gamma minus 1 is 1.4 minus 1 divided by 1.4, so if we solve this we are going to get the value of T 2 as 456.3 Kelvin. This is the temperature of gases at state 2, but it has certain efficiency compressor has certain efficiency of 0.76.

So, we will use the formula T 2 minus T 2 dash sorry T 2 T 2 minus T 1 divided by T 2 dash minus T 1 is going to be equal to 0.76 or T 2 dash is equal to T 1 plus T 2 minus T 1 divided by efficiency that is 0.76. T 1 is known to us 288 plus T 2 minus T 1, this is T 2 minus T 1 that is 456.3 minus how much? 456 minus 288 divided by 0.76. And this will give us that T 2 dash is 509.5 Kelvin, so T 2 dash we have got this much.

Now, T 3 is known to us now T 3 is given here 680 degree centigrade, so 680 plus 273 it is going to be equal to 953 Kelvin. Now, we have temperatures at the state 1, state 2 dash state 3 right. Now, for a state 4 pressure T 4 again T 4 is equal to T 3 divided by r p raise to power, now gamma here the gamma will come for the gamma for few gases.

So, gamma minus gamma minus 1 over gamma and T 3 is 953 divided by 5 raise to power here gamma is 1.34, so 1.34 minus 1 divided by 1.34 right. And this will provide the value of T 4 as 633.56 Kelvin, this is quite it high if you compare with the 2 dash it is quite high 509 and 633.56.

Now, compressor work, because compressor work has because T 4 is been taking place in two different turbines. Because, pressures are same that is why I have shown in single process otherwise this process T to 3 to 4 physically is taking place in 2 different turbines.

So, now the work of the compressor work of the compressor is for 1 kg of air we are considering only 1 kg of air. It is CP T 2 dash minus T 1 CP is 1.005 for air, and T 2 dash is 509.5 minus T 1 is 288,this is work of the compressor.

And the work of the compressor is 222.6 kilowatt per kg. Now, we will go for the work of turbine, work of turbine is CP CP gas T 3 minus T 4 dash. Now, CP of gas is 1.34 T 3 is 953 minus T 4 dash is T 4 dash you are not calculated sorry. This is calculated at T 4 dash if you calculate T 4 dash is equal to T 3 minus T 3 minus T 4 divided by T 3 minus T 4 multiplied by efficiency of the compressor right.

So, this T 4 dash is going to be678.28 Kelvin here also we have taken, because for this formula we have taken we are taken efficiency of the turbine is equal to T 3 minus T 4 dash divided by T 3 minus T 4. Because, here CP g will be cancelled out otherwise it is enthalpy at 3 minus enthalpy at 4 dash because, CP gd is getting cancelled out.

So, efficiency of the turbine is T 3 minus T 4 dash divided by T 3 minus T 4. So, we have just manipulated here as T 4 dash as efficiency of the turbine T 3 minus T 4 T 3 minus T 4 multiplied by efficiency of the turbine and we have got this value 678. So, 678.28 Kelvin we have taken here and this gives the work of the turbine as 309.88 kg per minute, this is also per kg right.

So, mass of the gas multiplied by the mass of the air it is going to be 222.6 divided by 309.88 is equal to 0.7183 kg and this is gas this is gas. It means instead of because see the output of gas this turbine which is operating between 3 to 4 per kg of gas is this much, output of input to the compressor per kg of air is this much.

So, it means we do not have to provide the flow rate of 1 kg per second in the turbine, it has to be less than that how much less? Then we have taken the ratio. Now, if you multiply this by this one you will get this one. So, mass flow rate of the gas has to be this much, mass flow rate of the gas if you multiply this by 309 point; obviously, you are going to get this one and this much of the energy required.

So, this much amount of gas is required 1 kg of air is entering from here now what is the quantity of gas which is available at state 3? Now, quality of the gas just a minute it is it depends upon the air fuel ratio how much fuel is burnt into the?

Student: CP g 1.128.

[FL].

Student: The CP g work out turbine is equal to specific heat of gas turbine (Refer Time: 12:29).

[FL].

Student: 1.

1.128 [FL], now here there is a correction this is this is gamma the CPg is 1.128 right this the 1.34 is gamma. So, now we have to find how much mass of fuel is being burnt per kg of air? Once you know the mass of the fuel is burnt we will get how much mass total air and mass of the fuel available at state 3 right.

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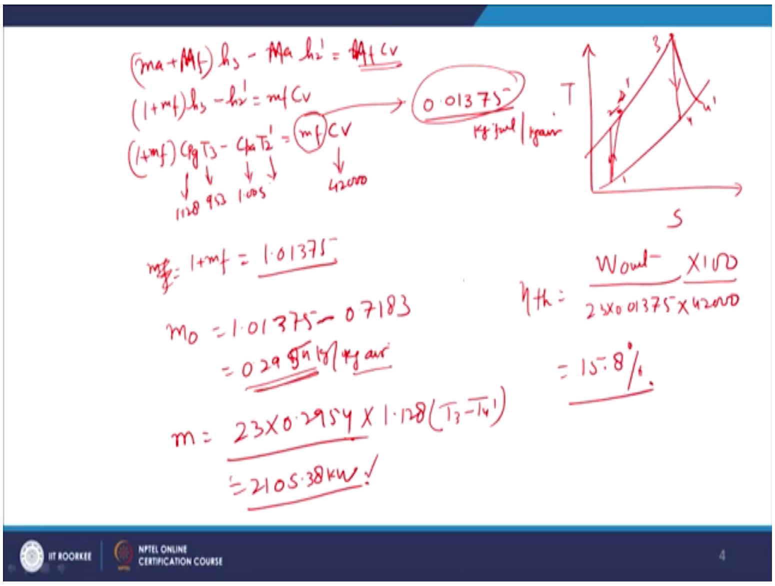

So, we will write a an energy balance equation, it is mass of the air plus mass of the fuel h 3 minus mass of the air h 2 dash is equal to mass of the C v. Because, again if you draw the temperature entropy diagram right, so mass of the fuel and mass of the fuel burnt here which is available at 3 right and mass of the air.

Now, here you can see mass of the air is available here if this process fuel is also added. So, enthalpy at 3 mass of the air plus mass of the fuel, mass of the air here is equal to this much heat liberated by the fuel or if you divide by mass of the air because you are assuming 1 kg of air.

So, 1 plus mf this will write it M, so it will be from small letter 1 plus mf h 3 minus h 2 dash is equal to m f C v. Now, h 3; now h 3 will be going to is going to be equal to CP g T 3 minus

CP a T 2 dash is equal to mf C v; CP g is known to us it is 1.128. So, this is 1.128 T 3 is also known to us; now the T 3 is we calculated here somewhere here no 953 right 953 Kelvin.

This is Cp a is 1.005 T 2 dash also we calculated earlier, C v is known to us 42000 kilo joules, because we are dealing in kilo Joules and kilo watt. So, 42000 kilo Joules per kg from this equation we can always find the mass of fuel burnt per kg of air. So, mass of the fuel burnt per kg of air is 0.01375 kg fuel per kg air ok.

Now, this fuel is burnt for the per kg of air, so air, so fuel few gases available for the power output. Now, this per kg of air this amount of fuel is getting mixed, so total amount of few gases is going to be 1 plus mf is going to be equal to 1.01375 mass of the few gases.

And in previous previously we have already calculated this point 7183 of few gases will be used for power generation right. So, therefore, the mass available for output is 1.01375 minus 0.7183 is equal to 0.2984 kg per sorry 54 kg per kg of air, now we are just focusing on per kg of air right. Now, if you multiply this by the total quantity of air supplied that is 23 kg per second that is the amount of air which is sort by the compressor right.

In that case we will get the mass of the total mass of the fuel gases which are used for power generation that is 23 multiplied by 0.2954 right. And power output is going to be equal to multiplied this mass multiplied by CP that is what is that what we are supposed to find calculate the output of the plant and thermal efficiency.

So, output is going to be the this multiplied by the CP g that is 1.128 T 3 minus T 4 dash. This is the output of the second turbine and this output is 2105.38 kilo Watt or approximately 21 mega Watt. So, in this system if there is one compressor there are two turbines; one turbine is driving the compressor another turbine is driving giving the output and the output of the turbine is this much.

For finding out the thermal efficiency this output has to be divided by input, input is 23 into 0.01375 this is mass of the fuel burnt. And multiplied by 42000 this is the calorific value of the fuel and this thermal efficiency multiplied by of course 100, and this efficiency is coming out to be 15.8 percent.

So, in the nutshell what we have done we have simply take the system is like this the compressor has taken the air. Air is the splitting one compressor is driving the is producing sufficient power to drive the compressor one turbine is producing sufficient power to drive the compressor another turbine is giving the output.

In this system the efficiency is coming out to be 15. 8 thermal efficiency is coming it is quite low. But, this is not I mean because the thermal efficiency is coming low because the maximum temperature is going up to 650 degree centigrade. If you further increase the temperature efficiency will improve, because efficiency is the gas turbine is strong function of the maximum temperature.

In any thermodynamic cycle it is a function of maximum temperature, if you look at because all the cycles are compared with the Carnot cycle. So, Carnot cycle minimum and maximum temperature that is taken into the account. So, if you keep on increasing the and in gas turbines we can go temperature higher than the steam turbines. And with the facility of pooling of modern I mean arrangement of pooling of blades very high temperature can be attained in a gas turbine right.

So, next numerical is about the leakage we have discussed in one of the lectures. So, this is the numerical as numerical are here not to just to check your computational scale it is just to give you the idea about the physical values right.

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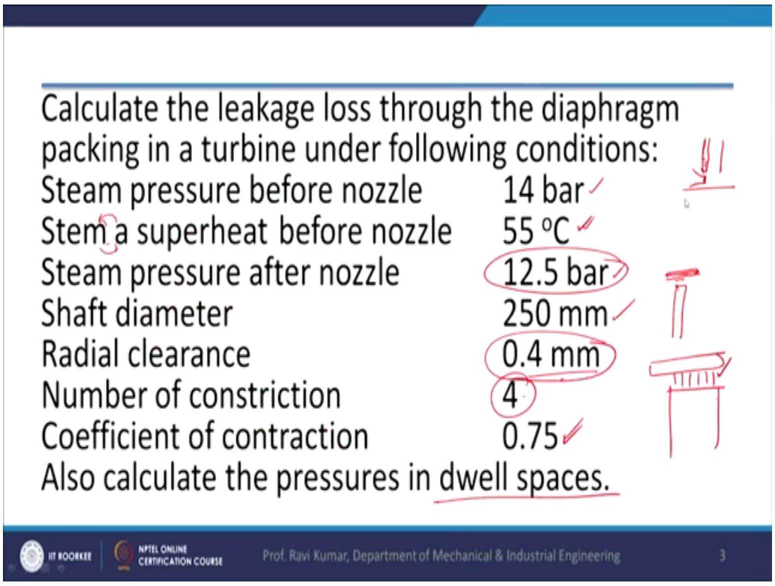

Now, the suppose there is the numerical on leakage calculate the leakage loss through a diaphragm packing in a turbine under the following condition. Steam pressure before nozzle is 14 bar steam, steam super heat steam super heat before nozzle 55 degree centigrade. Steam pressure after nozzle 12.5 bar, shaft diameter this is shaft diameter is 250 mm.

Radial clearance between the blades and the shaft is 0.4 mm, because some clearance has to provided. So, it is not blade not blade between blade in the shaft it is housing and the blade, blade edge and the housing right. Number of constrictions as I said earlier in the previous, lecture constrictions are provided just to prevent the loss of a steam or pressure loss of a steam in it is a sort of sealing.

And constrictions are made of soft material, so that a damage of the constriction does not take place. Suppose there is a accidently there is a contact between the blade and the constriction the damage of the blade not the constriction takes place. Sorry, the damage of constriction takes place and blade is prevented.

Now, coefficient of constriction is 0.75, the coefficient what is the coefficient? Coefficient is if you magnify this figure it is going to be like this. So, steam is passing through the restricted place space, and here also a Vena Contracta is formed. So, actual cross section area available for the transmission of fluid is less then it is only less then 75 percent right, so also calculate the pressure in dual spaces ok.

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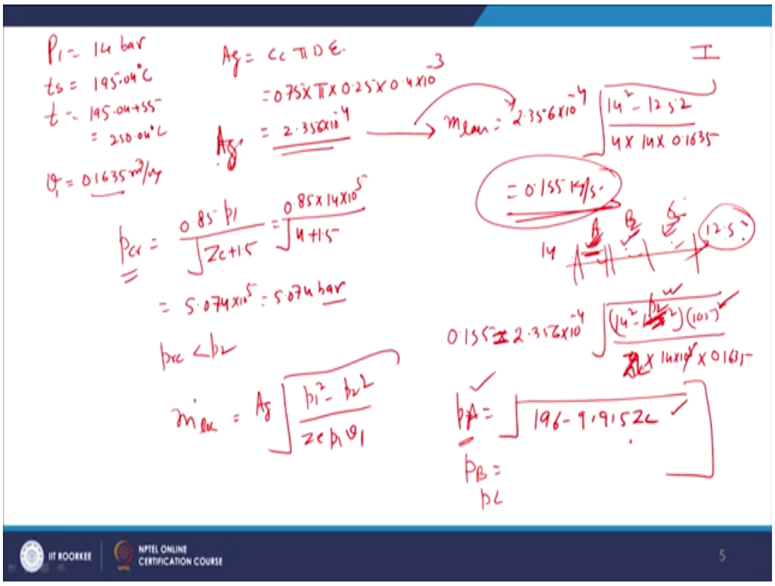

So, the pressure is 14 bar right, according to this pressure the saturation temperature is 195.04 degree centigrade this we can take simply take from the steam table. Now, the superheating is 55 degree centigrade, so T is equal to 195.04 plus 55 is equal to 250.04 degree centigrade right.

Now, at this temperature we look at the super heated table and we get the specific volume also that is 0.1635 meter cube per kg. Now, area available for steam to pass that is we say it is Ag it is C c pi D epsilon naught, epsilon naught is the clearance and here the epsilon naught is 0.4 mm right.

So, we will take the value of C c as 0.75 it is already given pi into diameter is 0.25 meters in this is 0.4 into 10 to power minus 3. And from here we get the area as 2.356 into 10 to power minus 4 this is the value of A g right. Now, we will calculate the critical pressure in the last stage, so critical pressure is 0.85 p 1 divided by under root Z c plus 1.5.

Now, Z c what is the value of Z c here? The value of Z c is 4 and p 1 is 14 bar. So, it is 0.85 into 14 into 10 to power 5 let us convert into the Pascal. Now, we may not, because in that case we will be getting values in Pascal otherwise if you remove this then will be getting values in bar.

So, 4 plus one point 5 and that is going to be equal to 5.074 into 10 to power 5 Pascal or 5.074 bar that is the critical pressure. Now, critical pressure is greater than p 2 sorry less than p. So, critical pressure is less than p 2, p 2 is this 12.5, so it is less than p 2, so the steam leakage, so because you have different equations for the different conditions.

So, steam leakage will be determined by the equation is equal to A g under root p one square minus p 2 square divide by Z c p 1 v 1. But, A g is known to us A g is 2.356 into 10 to power minus 4 we have taken from here this value here A g. Under root T 1 is 14 bar this is 12.5 bar divided by Z is 4 p 1 is 14 and v 1 we will take from here 0.1635 right and this mass of the leakage is going to be 0.155 kg per second.

So, this is this amount of steam which is getting leaked through the grinds right, because in when we want to improve the design in any design the estimation may be may be a rough estimation. But the estimation of all the quantities only then we can improve upon it, so here we can find 0.155 kg per second that is the amount of a steam which is been leaked out through the constrictions.

So, number of the dwell space is because they are 4 constrictions, so number of the dwell spaces is 1 2 3 3 dwell spaces, and now we have to find the pressure in each dwell spaces. So, we will use the same formula because they are all in series, so mass flow rate is going to be remain in all same in all the dwell space. Now, let us take first dwell space, so if you take the first dwell space the leakage is 1 you will use the same formula 155 to 1.5 is equal to 2.356 into 10 to power minus 4 right. Under root 14 square minus 12.5 square and 10 to power 5 square we will take out divided by ah.

Now, this is Z c is equal to 1, so Z c is equal to 1, so where you are this is not 12.5 this is not 12.5 this is p 2, because p 2 12.5 is here and 14 is here 14 bar is here 12.5 is here. So, this is p 2 pressure here, so this is not 12.5 this is p 2 and Z c is 4 p 1 is 14 into 10 to power 5 and v 1 will take from here 0.1635 right and from here we will get the value of p 2.

Because all are known only p 2 is unknown and this 10 to the power 5 will be cancel with this. And here we will get the value of p 2 when we are putting the Z c is equal to 4 no sorry this is Z c. So, p 2 is equal to under root 196 minus 9.915 Z c constrictions right. Now, we wrongly we had put 4 here we will not put 4 here, so there two unknowns p 2 and Z c. Now, I am repeating this we have use the same formula to find the pressure inside the first constriction.

Now, pressure in the first constriction is not known 12.5 is the pressure in the last and Z c is n is equal to 1 Z c is 1 for here, 2 for this, 3 for this and mass leakage is known to us. So, we have found the pressure in terms of function of Z c. Now, if you put Z c is equal to 1 we will get p 1 this is p let us say ABC, so we will get p A dwell space this is known as dwell space. Now, if we put p B if you put Z is equal to 2 here we will get the value of p B if you put Z is equal to 3 here we put we will get p c right this is how we can get the pressures in all 3 dwell spaces.

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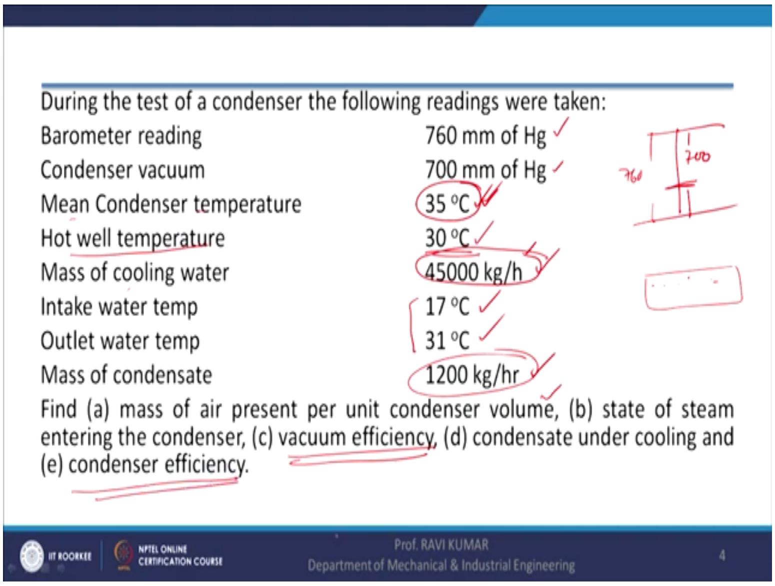

Now, there is a one short numerical on the condensers these on the condensers. During the test of the condenser the following readings were taken: barometric reading 760 it is atmospheric pressure, condenser vacuum 700 mm it means the pressure below the atmospheric pressure. So, this is 760 suppose, so pressure is somewhere here this is 700, so 760 minus 700 is the absolute pressure in the condenser, mean condenser temperature 35 degree centigrade right.

Hot because in condenser also why it is mean condenser temperature? Because inside the condenser the value temperature changes and it depends upon the presence of air with different parts of the condenser. Hot well temperature 30 degree centigrade, mass of cooling water 45000 kg per hour, intake water temperature 17 is cooling water which is used for the condensers. Mass of condensate if this much of steam is getting condensed, mass of air present per unit condenser volume right. Now, for this we will start at 35 degree centigrade.

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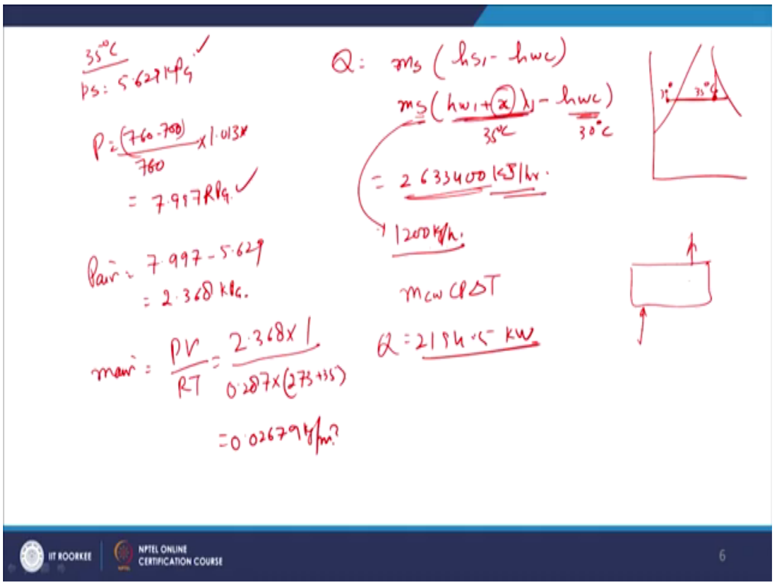

What is the value of pressure? That is 5.629 kilo Pascal that is the temperature inside the condenser, so it should have this much of absolute pressure. Now, we will calculate what is the absolute pressure inside the condenser. 0074hat is 760 minus 700 divided by 760 multiplied by 1.013 into and it is going to be 7.997 kilo Pascal.

So, this pressure is greater than this one, it binds the total pressure is the partial pressure of vapor this is this plus pressure of air. So, pressure of air partial pressure of air can be found out by taking these two difference between these two. So, difference between these 2 means 7.977 minus 5.629 and this is going to be 2.368 kilo Pascal. Once the pressure of air is known air is saturated, so not air is saturated steam is saturated, so mass of the air is equal to PV over RT.

So, now because pressure is known it can always be considered as a ideal gas. So, 2.368 into volume we can say 1 specific value R 0.287 this the value for R for air, and 273 plus 35 that is the temperature and we get 0.02679 kg per meter cube of air. Now, steam, steam is at this is hot well temperature 30 degree centigrade right.

So, here Q is equal to mass of the steam mass of the steam hs 1 minus hwc, now mass of the steam this is hw 1 plus x lambda 1 minus hwc. Now, this is at 35 degree centigrade and this is at 30 degree centigrade, you can see here the mean condenser temperature 35, hot well temperature 30 degree. It means if you look at this condensation process, so it has condensed and it is further condensed this is thirty degree centigrade hot well temperature.

From here the pump will suck the water and inside it to the boiler and this is the condenser steam temperature this is 35 degree centigrade. So, we have taken the mixture because after expansion we will get the mixture of vapor and liquid. So, we have taken property for 35 degree centigrade here and property that 30 degree centigrade here. And if you take the difference are putting the value we will be getting 2633400 kilo watts, because mass flow rate is how much 45000 kg per hour.

So, it is going to be kilo joules per hour, so it is kg per hour, so it is going be the this much kilo joules per hour. So, this is mass of the condensate this is not 45000; 45000 is mass of the cooling water, mass of the condensate is 12000.

So, this is 1200 kg per hour because mass of the steam that is mass of the condensate we have taken 12000 kg per hour that is how we are getting this value. Now, how much heat has been reviewed? That is mass of the cooling water m c p delta T, because in the condenser the heat suppose this is the surface condenser.

So, heat removed in the condenser is mass of the cooling water CP delta T mass of the cooling water is CP delta T and then mass of the cooling water is known to us. CP of water is known to us 4.2 and temperature delta T also known to us that is intake water temperature outlet water temperature. So, 31 minus 17 multiplied by specific heat of the water multiplied by 45000 divided by 3600 will give you the heat removal in kilo watts and that is coming around 2194 point 2194.5 kilo watt.

Now, this heat removal is enthalpy of this minus enthalpy at this right, and this comes out. So, from this energy balance this enthalpy at this minus enthalpy at this we will get the value of just a minute x [FL] we never knew the x here [FL].

Student: [FL].

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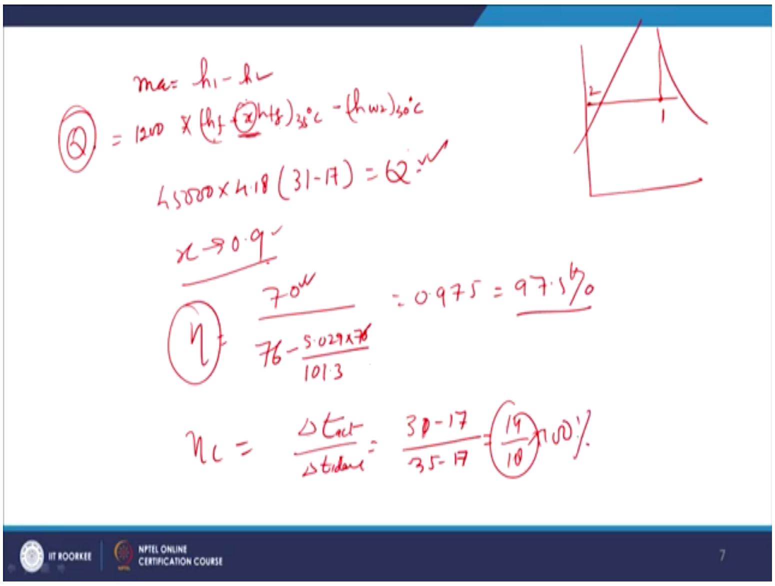

After getting the mass of the air mass of the air we will find how much heat as been extracted in the condenser right. So, this is condenser after expansion let us say this is state 1 and the water is getting sub-cool to state 2. Because state 1 the temperature is 35 degree centigrade hot well temperature is 30 degree centigrade right.

So, we will calculate h 1 minus h 2, h 1 is h f plus x h f g at 35 degree centigrade minus h w 2 at 30 degree centigrade. But, here the value of x is not known and this multiplied by 12000 you will get the total amount of heat transmission, but here the value of x is not known. But, the cooling water if you look at the temperature raise of cooling water that is 17 to 31 and mass flow rate of the cooling rate is also known 45000.

So, 45000 multiplied by 4.18 31 minus 17 will give us the heat transmission Q. Now, this value of Q if you put here we will get only unknown remains x, because these values we will get from the stream table this value will get from the stream table the only unknown remains x. And if you manipulate this values the value of x is 0.9 right, once the value of x is known.

Now, the next is we have to find is state estimating vacuum efficiency. If there is no air vacuum efficiency is 100 percent, when there is air then pressure the total pressure with the condenser is the sum of the partial pressure of air and the partial pressure of water right. So, in this case the vacuum efficiency is going to be equal to 70 divided by 76 minus 5.029 into 70 divided by into 76 divide by 101.3. What we have done? The actual vacuum and the ideal vacuum right.

So, ideal vacuum has to be more than actual vacuum ideal vacuum when there is no air actual vacuum vacuum when there is air present in the condenser in that case absolute pressure is high. If you manipulate this value you we will be getting 0.975 or 97.5 percent this is the vacuum efficiency of the condenser right. And then last one is condenser efficiency condenser efficiency is efficiency of the condenser is actual temperature difference ideal temperature difference.

Now, the actual temperature difference is ideal temperature difference is 31 minus 17 sorry 35, because the temperature of condensing this is 35. So, it is 35 and actual is 31 only, so switch it is going to be 30 minus 17 this is actual and this is 35 minus 17. So, we are getting this is 31, so we are getting around 14 divided by 18 multiplied by 100 this is going to be the efficiency of the condenser that is all for today.

Thank you very much.