Steam and Gas Power Systems
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Module No # 07
Lecture No # 31
Gas Turbine Cycle

Hello I welcome you all in this course in steam and gas power systems today we will start with the gas turbine cycle now in a gas turbine the working fluid is a gas it can be air also but normally the working fluid is gas. So far we have analysed the steam turbines where the steam is the working fluid in the gas turbines because we are using gas and phase change does not take place during the entire cycle.

In steam power systems there is a phase change since there is a phase change mass flow rate less mass flow rate is required in those type of systems because during the phase change a lot of I mean heat reaction or absorption takes place right. So heat interaction is more when there is a phase change but still in the gas turbines the entire cycle works taking gas as a working fluid so there is no phase change in the cycle.

It is single phase cycle that is why the sensible heat transfer takes place in all the processes of the gas turbine. Due to this fact the mass flow rate in the gas turbine is high or large volume has to be handled in the gas turbine that is why centre fuel and axial fuel compressors are used in the gas turbines which can handle the large volume large bulk of the working fluid.

Now it works on the steam power cycle works on the rankine cycle the gas power cycle works on joules or Brayton cycle.

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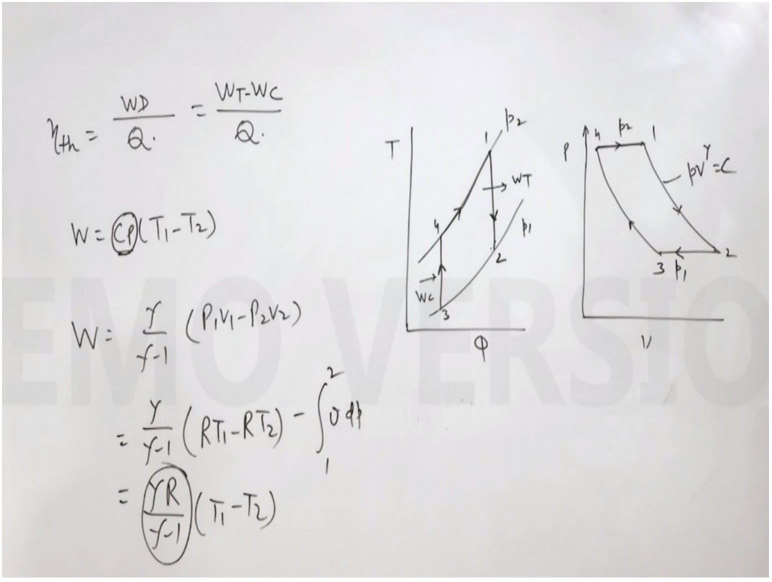

So if i draw the joule cycle on pressure and volume diagram it is going to be like this starting from 1 to 2. Now isotropic extension in gas turbine state 1 to state 2. Then 2 to 3 is cooling or if it is open cycle gas turbine in that case air is taken from the outside the compressor disk this process takes place inside the compressor normally central fuel or axial flow compressor are used in gas turbines.

And when the state four is attained the constant pressure heat edition is D1 inside the combustion chamber. There is a separate comp1nt and in all these processes unlike engines IC engines at an combustion angles in gas turbines all these processes that too take place in different components. Expansion in turbine then compression in a separate compressor then heat edition in a separate combustion chamber this is a separate dedicated combustion chamber for adding heat to the working fluid.

If we transform this on temperature entropy diagram then these processes now this is pressure 2 and this is pressure 1 this cycle works between 2 pressure and pressure 1 right and process 3 to 4 is isotropic process. So 3 to 4 is isotropic compression which takes place inside a compressor 4 to 1 is constant pressure heat edition we get 1.

And after stage 1 again expansion takes place inside the gas turbine that is state 1 and 2 that is were for us. You study state 1 to state 2 expansion in gas turbine because this produces the output. Now part of this output is used for reading the compressor and these lines are not parallel lines they are diverging lines right and the constant pressure lines. And this power generated in during expansion from state 1 to state 2 is part of the power is used to run the compressor to compress the gas.

In the steam power system all the pump is required because when there is a face change the entire volume is converted into a very small volume or negligible volume right. So a small pump is required to just to increase the pressure of the feed water. But here because we are dealing with the gas the fluid is the gas state only so bulk of the fluid has to be handled. So if sustention part of this output is consumed by the compressor.

It is substantial part of the power generated or the energy generated during expansion process is consumed by the compressor. Now remaining part this is work of the turbine and this is work consumed by the compressor. Now first of all we will try to find thermal efficiency of the cycle that is the first thing we should do as we did in the case of vapor compression system sorry yes vapor power system.

Thermal efficiency means network D1 divided by the heat added so network D1 here is thermal efficiency is work D1 divided by heat added. Thermal efficiency work D1 this is not the work of the turbine but the network D1. So it is work of the turbine minus work of the compressor divided by heat added. Work of the turbine say because it is always it is an isotropic expansion process right.

So work of the turbine is CP T 1 – T2 but here pressure is not constant but we are taking CP this taking CP there is often confusion among students this taking this CP does not mean that the pressure is constant. In fact in isotropic process work is gamma over gamma - 1 P1 V1 - P2 V2. This is the expression for work D1 during expansion how we got about this work D1 expansion is? VDP from state 1 to state 2 right.

If you use this formula and work D1 is and for PV is to power gamma is equal to constant followed during this process adiametic process reversible adiametic isotropic process. So if you follow this use this equation integrate this you will be getting this expansion right. Once we have this expansion which is derived from this VDP - 1 to 2 right.

P1 V1 is because this fluid can be treated as an ideal gas then P1 V1 = P2 V2. Sorry right P1 V1 is because this fluid can be treated as an ideal gas and P1 V1 = P 2 sorry P1 V1 is RD1 and RT1 here PR it is a cycle it is a air stated cycle we are not analysing the gas turbine it is the joules Brayton cycle it is air stated cycle in air stated cycle the working fluid is assumed to be the air right.

So here we are finding the thermal efficiency of air stated cycle this is known as joule cycle or brayton cycle. So now we can take P1 V1 = RT1 so gamma over gamma - 1 RT 1 - RT 2 and this can be gamma R over gamma – 1, T 1 -T2 and if you further take this is nothing that CP right.

So CP is the expression for this it is nothing to 2 with the constant pressure process right.

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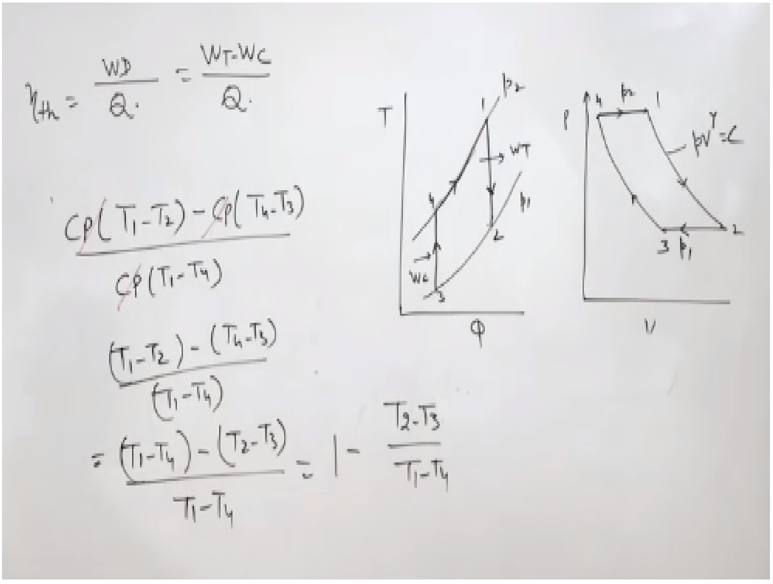

So work is CP delta T now here turbine work is T1 - T2 work d1 by the compressor work consumed by the compressor in fact or work D1 on the compressor is CP T4 – T3. So this much work will be taken out of this to run the compressor and net heat supplied is this is a constant pressure process C but this is also CPT1 – T4.

Now CP will be cancelled out sorry T1 – T4 ok because here we are taking air as a working fuel but in actual gas turbines what happens when the air is compressed? The air is compressed combustion takes place and fuel gas is the burned fuel is also mixed with the gases right the specific heat change that we will discuss later on right now we are discussing on air standard cycle.

So thermal efficiently is T 1 - T2 - T4 – T3 divided by T1 – T4 or if we can realize these T 1 - T4 - T2 - T3 divided by T1-T4 or = 1 - T2 - T3 by T 1- T4 ok.

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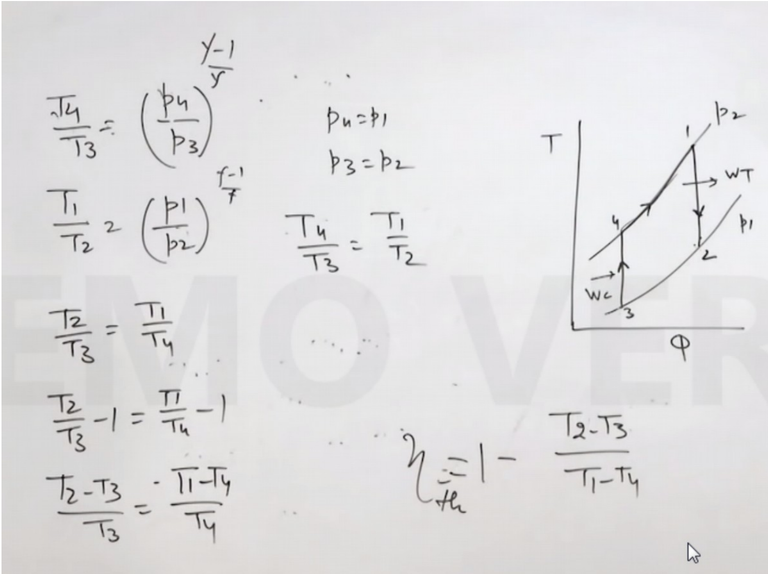

Now what we will do we will take T4 by T3 = T4 by T three raise to power gamma -1 to whole gamma T 1 by T2 = T1 by T2 raise to power gamma - whole gamma where P4 = P1 and P3 = P2. So both the expressions are same it means T4 by T3 = T1 by T2 right.

Or T2 by T3 - T1 by T2 right T 2 by T 3 – 1= T 1 by T4 - 1. T2 - T three divided by T 3 = T 1 – T4 divided by T4 or T 2 - T3 divided by T 1 – T4 = T3 by T4or =T 2 by T 1. Now we will be putting this here and we will be getting thermal efficiency as = 1- T3 by T4 right.

Now T3 by T4 is nothing but 1 - 1 over R raise to power gamma -1 gamma. Where R is P 2 by P 1 for here yes P2 this is P2 and this is P1 pressure ratio. So R is P 2 by P 1. So thermal efficiency of air stated gas turbine cycle is 1 - 1 upon R pressure ratio raise to power gamma - 1 by gamma right but this is for air standard cycle.

In air standard cycle also this is ideal air cycle when it comes to the actual brayton cycle. Here we have not considered any kinetic energy of gas to total energy includes the kinetic energy also we have taken only enthalpy change in enthalpy CP delta T right but say here in the entire process the velocity of the gas is quite high. So kinetic energy we have not considered second thing is there are losses in the processes.

So this is no longer isotropic process compressor will require more energy for compression that is 4 dash right. So actual work in the compressor is CP T4 dash – T3 right similarly during expansion it is not a vertical line it is an inclined line. So it is 2 dash so the work of the turbine is CP T1 - T2 dash third is in the chamber also in the pressure drop due to flow resistance.

And pressure is no longer P2 it is slightly less than it is the expansion to start up here. So that also we are not taken in count. So the actual cycle deviates quite substantially from the ideal cycle. But we need this air stated efficiency or the purpose of comparing the performance or we should have the base value of the efficiency only that we can compare the value of efficiencies of different turbines.

So it is essentially required but the actual thermal efficiency of the turbine will differ. Further if we use the cycle for gas turbine power generation then heat edition we have taken CP T1 – T4.

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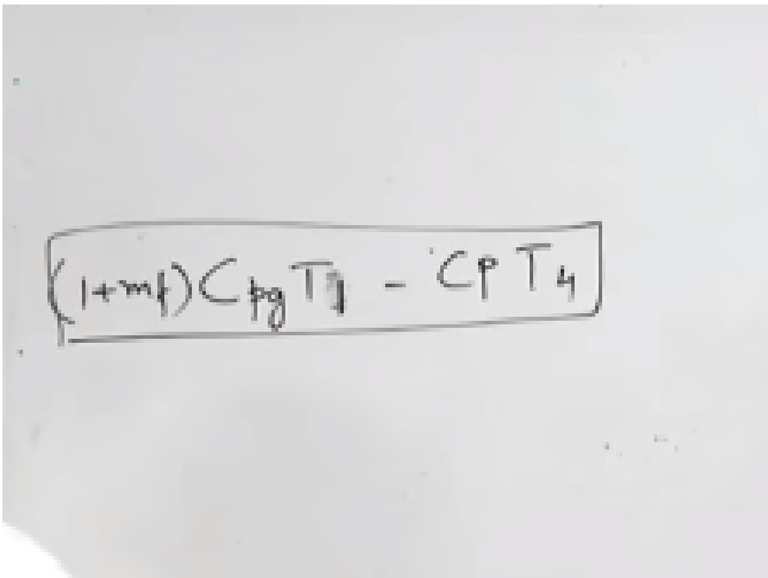

But actually edition will be CPG T4 - sorry T1 - CP T4 temperatures are in Kelvin right. And this also will include mass of the fluid mass of the fuel 1 kg of working fluid is here but here it is not 1 kg it is 1 kg plus fuel burned with 1 kg. So 1 + MF so these things will take down later on right now let us solve some worked example of gas turbines we have already taken into account Brayton cycle actual cycle.

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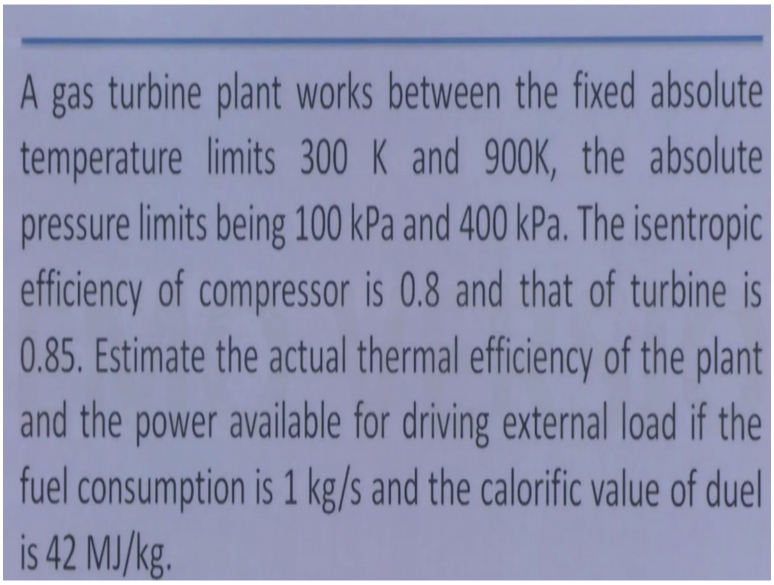

Now we will take the some numericals from this so starting with first numerical a gas turbine plant works between fixed absolute temperature limits 300 Kelvin and 900 Kelvin temperatures are already given in Kelvin. The absolute pressure limits being 100 kilo Pascal and 400 kilo Pascal so P1 and P2 are also given.

The isotropic efficiency of compressor is 0.8 or 80% and the turbine is 85 % or 0.8 right estimate the actual thermal efficiency of the plant and the power available for driving external load. So if the fuel consumption is 1 KG per second and the calorific vale of fuel is 42 mega joules per kg so first of all we will draw the temperature entropy diagram of actual cycle.

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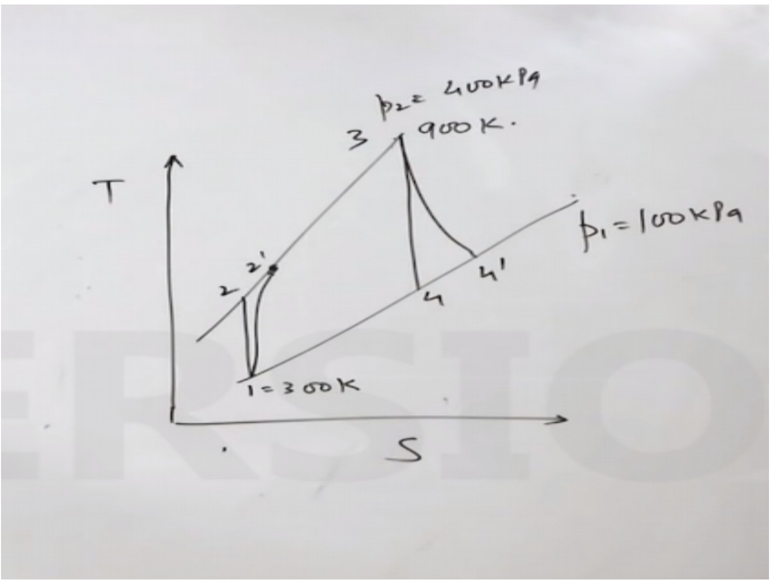

The two pressures P1 and P2 this P1 = 100 kilo Pascal and P 2 = 400 kilo Pascal. So starting from P1 1 to 2 but it is not an isotropic process as efficiency isotropic efficiency point eight it is 2 dash now 3 and this 4 and this 4 dash. Now isotropic efficiency of compressor now it has to be explained here.

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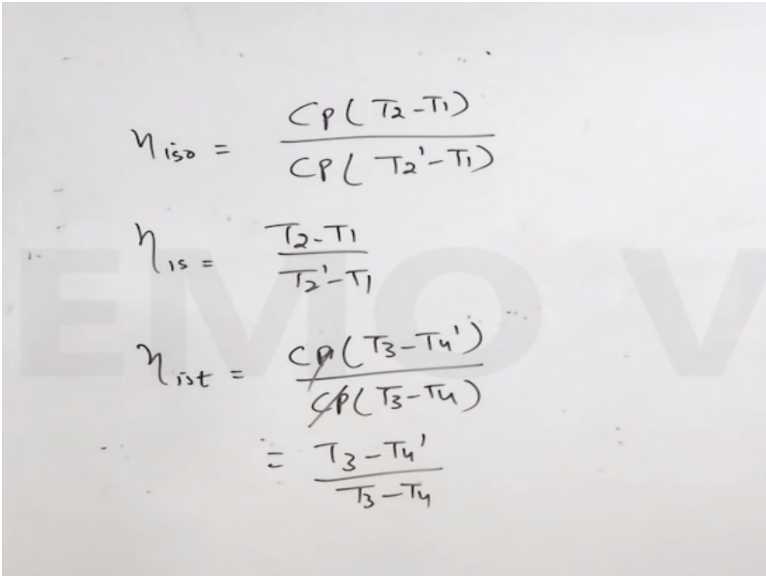

Isotropic efficiency of the compressor is actual work D1 and ideal work some actual work D1 is more. So ideally what should be the work D1 in compressing the gas that is CP T2 - T1 and actual work consumed is T2 dash - T1. So isotropic efficiency = T2 - T1 divided by T2 dash - T1.

Isotropic efficiency of turbine here turbine actual output is less here actual output is input is more than a ideal input here actual output is less than ideal output. So isotropic efficiency of the turbine is going to be CPT3 - T4 dash divided by CP T3 – T4 or it is going to be T 3 - T4 dash divided by T 3 - T4 right. So it is actual ideal, ideal actual now here the efficiency of the compressor is 8%.

Now the initial temperature limits means T 1 = 300 Kelvin and another limit is 900 Kelvin. So T3 is the highest temperature 900 Kelvin now if you want to have work in the compressor work consumed by the compressor we should have the value of 2 dash right. So first of all we will calculate the value of T2 so T2 is T1, T2 by T 1 raise to power gamma - 1 by whole gamma.

So T2 is 300 T2 by T1 is 400 divided by 100 raise to power 1.4 - 1 divided by 1.4.

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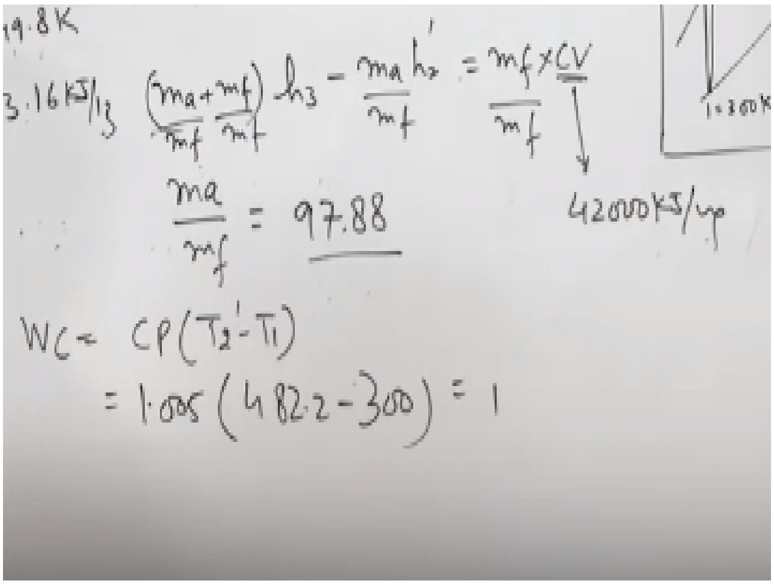

And this brings the T2 as 44 5.8 Kelvin now we have the efficiency 80%. So 0.8 = T2 - T1 divided by T 2 dash - T1 or T2 dash = T1 + T2 - T1 divided by 0.8.

We have the value of T2 T1 is already 300 Kelvin we will put the value of T2 and T1 here and we will get the value of T2 dash and this T2 dash is 482.25 Kelvin right. Now after getting T2 dash we can calculate in similar fashion we can get the value of T4 dash also because these temperature values will be required when we will calculate the efficiency.

So Similarly T3 by T4 = 400 by 100 this is T3 by T4 raise to power 1.4 - 1 divided by 1.4 and this gives the T4 as 605.65 Kelvin. So now we have the value of T1, T2, T2 dash, T3 and T4 dash.

Again efficiency of the turbine = T3 -T4 dash divided by T3 -T4 or T4 dash = efficiency of the turbine T 3 - T4 T3 - T4 dash. So T4 dash is T3 – T4 now we have the value of T3 at 3 is 900 Kelvin and T4 we have right now we have calculated and we will get the value of T4 dash and T4 dash is 649.8 Kelvin.

Now we have all the values of the temperatures and these values will help us in calculating the efficiency of the cycle. Now here it is stated that if the fuel consumption is 1 kg per second. So mass of the air plus mass of the fuel right H3 - mass of the air H2 dash = mass of the fuel into calorific value of fuel right .So here we can find mass of the air and mass of the fuel divided this by mass of the fuel.

So this is mass of the fuel calorific value is 42 mega joule per kg or this can be taken as forty 2000 kilo joule per kg because here we are dealing with the kilo joules right. Now this gives the mass of the air and the mass of the fuel ratio is 97.88 or fuel air ratio is here is 97.88 means per kg of fuel will require this much of air.

Now the work of the compressor is CP T2 dash - T1 right now CP is known to us 1.005 it is standard value for air T2 dash we can take from here 482.2. And T1 is 300 Kelvin and the work of the compressor is work of the compressor we will write here 183.16 kilo joules per kg after this we will calculate work of the turbine

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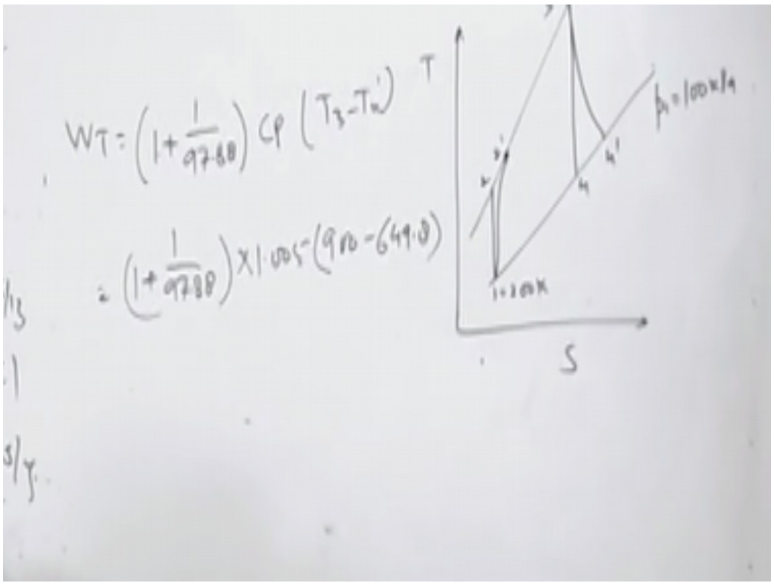

Work of the turbine now here mass of the fuel is also added at P mass of the air plus mass of the fuel. So for 1 kg of air the mass of the fuel will be what is the fuel ratio fuel air so the air fuel ratio was 97.88 is to 1 so 1 by 97.88 will be added here right and this is this will give CP T3 - T4 dash since CP of the gas is not given to us otherwise CP would have changed.

It would have increased but since CP of the fluid gas is not given to us we will assume CP of the air here so it is 1.1 by 97.88, 1.005 T3 is 900 – T4 dash is 649.8 Kelvin and this will give the work of the turbine as 254 kilo joules per kg nut this work is not available to us what is available for the use is difference of turbine work compressor so the network here so

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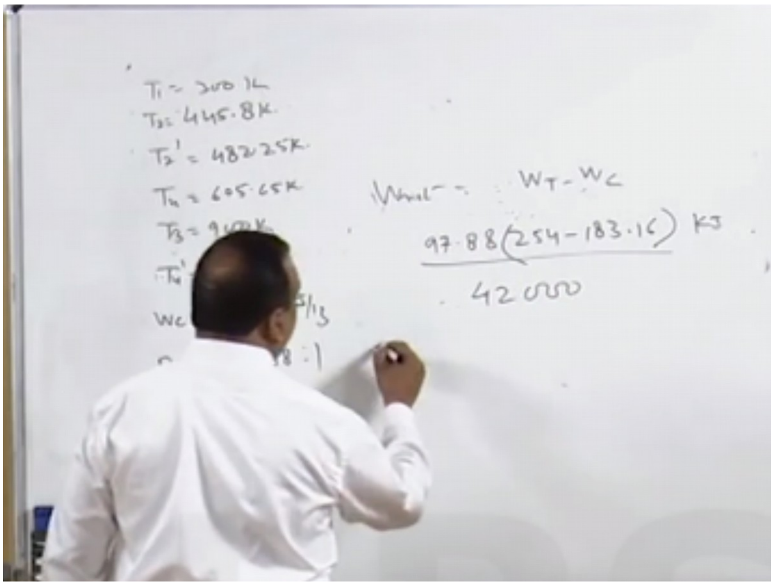

Net work is equal to work of the turbine minus work of the compressor that is 254 – 183.16 once we have net work with us and mass of air is also with us this is per kg of this is kilo joules per kg of air right mass of the air is also with us mass of the air is 97.88 for burning 1 kg of fuel and we have the calorific value of 1 kg of fuel that is 42 mega joules per kg right.

So this will be multiplied by in order to find net work this will be multiplied by mass of the air 97.88 and this will be in kilo joules divided by calorific value that is 42,000 when we take ratio the efficiency of the turbine comes around 16.5% so one thing what has to be remembered that mass circulated in actual gas turbine cycle is not constant.

Compressor is taken here but when the air enters the combustion chamber mass of the fuel is also added and both the mass the fluid gases the fluid gases consists on the air and the burned fluid it takes part in power generation in the turbine right. So that is all for today in the next class we will further discuss on gas turbines.