IC Engines and Gas Turbines
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Lecture – 31
Open Cycle Gas Turbine Power Plant

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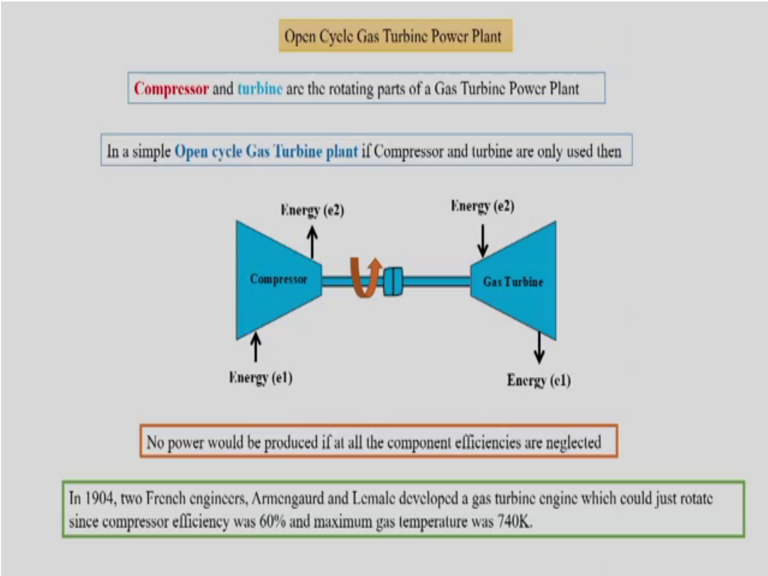

Welcome, to the second lecture. In today's lecture we are going to see about the Open Cycle Gas Turbine Power Plant. But, just as a recapitulation in last lecture we had seen the basics of turbo machines what do we mean by turbo machine, what are the different components of turbo machines like over how to classify the turbo machines based upon fluid used we classified them as steam based or hydro based turbo machineries or in case of a gas we classified them as and gas based turbo machineries.

Further, we have also classified them based upon the energy interaction. So, in case of a some machines if energy is coming from the rotor to the fluid then we call them as the work absorbing machines. Or in some machines if we have work transfer or energy transfer from the fluid to the rotor then we have called them as work producing machines. So, such classification was done in last class.

Then, we compared all these classes of turbo machines with the more prevalent or more conventionally used machines which are positive displacement machines and then we found that there are certain advantages of turbo machines. And then there are certain issues with a positive displacement machines. But, then again in case of positive displacement we had seen that they are not just the reciprocating kind they can be rotary kind and so.

Further we found out what are the components of the different turbo machines like compressor, like turbine in case of compressor we have first rotor and then we have diffuser, but for in case of turbine we have first nozzle and then we have rotor. So, this classification was seen and then we had seen one difference between impulse machines and we have seen the difference its difference with the; a reaction machine, also we have seen the difference between axial flow machines and radial flow machines.

So, having this classification done for various aspects of turbo machines and its comparison with other complementary or contemporary machines now, we are starting with the gas turbine power plant which is of open cycle types. So, obviously, when we say that there is a open cycle gas turbine power plant there would be a closed cycle gas turbine power plant and the subject of closed cycle power plant will be for the discussion in the next class, but this class is mainly for open cycle gas power plant.

We have seen that as a gas power plant is a turbo machine, the compressor and turbine are the two rotating parts of the gas turbine and these two elements are again there in the open cycle gas turbine power plant. And, now if I pretend and if I feel that suppose there is a compressor and there is a turbine and then they together would make a gas turbine power plant.

So, I will connect the compressor and the turbine. So, there is a compressor, there is a turbine and I connect it. So, what would happen in this case is that there is energy e1 at the inlet to the compressor then after the process of compression we know that compressor is a work absorbing machine. So, the work which is the energy which is in the rotor, it will be given to the fluid. So, fluid has some energy to start within the inlet of the compressor would get further increased to energy e2 at the outlet of the compressor.

But, since I have just connected compressor and turbine to form a gas turbine power plant I would pass this e2 energy to the gas turbine. So, gas turbine will have e2 energy at the inlet and we know again that gas turbine or turbine is a work producing machine. Since it is work producing machine it will extract the energy from the working fluid and since it is extracting energy from the working fluid working fluid after passing through the gas turbine will again have energy e1; obviously, my assumption over here is that I am assuming that both compressor and turbine have highest efficiencies or rather 100 percent efficiencies. They are very smooth frictionless devices, so, there are have they are ideal compressors and ideal turbines.

So, what has happened that compressor produced a fluid which is at high energy and then that fluid is passed to the turbine. So, what would happen is, if they are connected to each other then no power will be produced. Since there is some power which will be required for the compressor to run and exactly that much power will be supplied by the turbines; so, net power produced will be 0. So, no net power will be produced. If it would have been producing a power then it at composition of compressor and turbine would be similar to that what we call it as pmm 1 without supply of any energy it would produce a workout and it is not correct. So, such composition to form the gas turbine power plant is not proper.

Similar effects would be seen if at all there are some other components connected, but if component efficiencies are too low and they are not in practice or the ideal components like compressor and turbine they will have efficiencies not 100 percent and lower than that. So, in 1940's two French engineers tried to develop a gas turbine power plant, but the efficiency of the compressor was just 60 percent and the temperature or the maximum temperature of cycle was 740 Kelvin. So, the lower energy input and low efficiencies of the components led to hardly small amount of power output.

So, what we have to think over here is to formulate a composition to device a gas turbine power plant such that we should supply large amount of energy to get more amount of power output.

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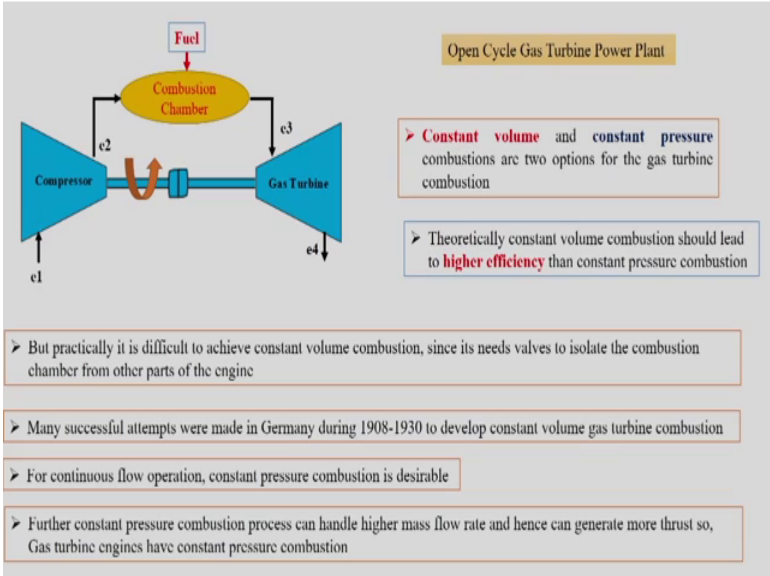

So, in case of open cycle gas turbine power plant a classical open cycle gas turbine power plant again has a compressor and a gas turbine, they are connected by a shaft. So, this arrangement is a single shaft arrangement where compressor and turbine are connected with each other and then they are again connected by a combustion chamber. In the combustion chamber we will have we will have fuel which is combusted. So, practically the fluid will enter the compressor, get compressed arises it is pressure head, then instead of directly going to the gas turbine it would go to the combustion chamber and in the combustion chamber we will have fuel burnt.

So, combustion will take place in the combustion chamber in the presence of fuel. So, chemical energy from the fuel will be used to increase the energy of the working medium this is an internal combustion approach which is happening in IC engines which are of our classical IC engines petrol engine and diesel engine. So, here we are supplying the fuel and that fuel is burning the air. So, classically in open cycle gas turbine power plant we are having air as the intake and the major concern or major advantage of air as the working medium is that air has oxygen and oxygen is a naturally available oxidizer.

So, we just need to burn the fuel in the; or we just need to put the fuel in the combustion chamber. So, we have high pressure, high temperature air which has passed through the compressor and reach the combustion chamber will burn the fuel which is injected or which is available in the combustion chamber. Thus elevated energy high temperature and high pressure fuel will get had working fluid will be passed to the gas turbine and then gas turbine would rotate and wrap. So, this is how a classical open cycle gas turbine power plant look like. At the exit of the gas turbine the working medium will be exhausted to the atmosphere; so it would not complete its cycle. So, at the intake we take air from the atmosphere and at the exhaust we let the gas go outside directly to the atmosphere. So, this is how open cycle gas turbine power plant operates.

So, e1 is the energy at the inlet, e2 is the energy at the outlet; as we have added the combustion energy took the working medium, e3 is the energy at the inlet to the gas turbine and e4 is the energy which is at the outlet of the gas turbine. So, there are some approaches which people have tried for having combustion in the combustion chamber and obviously, if we have some prior acquaintance with the automobile engines. We know that there are two types of engines; one is the petrol engine and other is the diesel engine thermodynamically if we try to see petrol and diesel engines. Then, we know that in case of petrol engine the combustion is takes place at constant volume sense, but in case of diesel engine the combustion place under constant pressure sense.

So, here as you can this open cycle gas turbine power plant being an internal combustion type we also can think of constant volume and constant pressure combustions. Theoretically speaking, if we try to attempt constant pressure constant volume combustion then constant volume combustion were; obviously, for the given pressure ranges would lead to maximum efficiency or higher efficiency in comparison with constant pressure.

But, there are some problems with constant volume combustion to achieve in a machine, in a engine, in the power plant like gas turbine power plant as we know in case of petrol engine we have constant volume combustion where we have valves to the internal combustion engine. We have a inlet valve from which the charge which is a mixture of air and the petrol comes into the combustion chamber or enter the cylinder and then inlet valve gets closed. And, then we compress the charge, and then we have sparking, and which leads to further to the combustion.

So, what is happening over here is that the inlet valve gets closed after having intake slope and at the same time exhaust valve is also closed. So, the process of combustion is possible with the arrangement of valves to take place in the constant volume sense. So, we need we feel to have the need of the valves to arrange constant volume combustion, but it is difficult in case of a continuous flow machine like the gas turbine. The internal combustion engine of petrol kind is not a continuous operating machine as we know that there are four strokes or piston moves up and down four times in one cycle out of which only one stroke or one motion produces the power, for rest of the three that power partially will get consumed. But, in case of gas turbine we are having continuous mass of fluid which is coming in getting combusted and going out from the turbine. So, it is not possible to have valves or rather it is difficult to have valves in case of a gas turbine power plant.

However, many successful attempts were done in the period of 1908 to 1930 in Germany to build a gas turbine power plant with constant volume combustion. However, constant pressure combustion is desirable to have a continuous flow machine. There is one more advantage of constant pressure combustion and that advantages that we can handle large amount of mass flow rate of the working medium in case of constant pressure combustion. So, constant pressure combustion since can deal with continuous operation and also can handle large amount of mass flow rate it is a desirable option among the two as what we say a constant volume combustion and constant pressure combustion.

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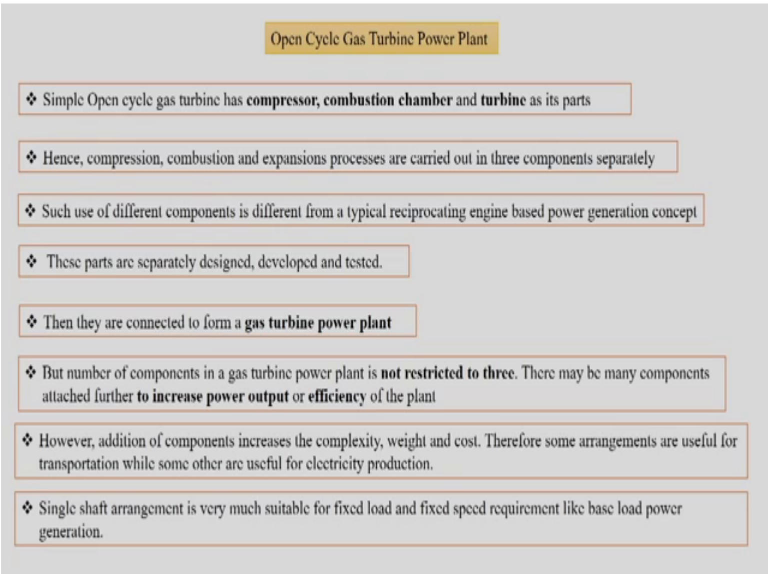

So, the open cycle power plant now is comprised of a compressor a combustion chamber and a turbine. So, these are the three entities of a open cycle gas turbine power plant and we have seen that among these three entities compressor and turbine at turbo machines, but combustion chamber is a stationary part of the simple open cycle gas turbine power plant. Here one should clearly see a big difference that the process of compression takes place in the compressor, process of combustion takes place in the combustion chamber and process of expansion takes place in the turbine. So, these three processes take place in the three separate components of the power plant.

And, this fact of having three different thermodynamic processes taken care by three different components of a power plant is making gas turbine power plant distinct from the conventional internal combustion engines of petrol and diesel kind. Since as we know in petrol and diesel kind of engines we have a piston cylinder arrangement and a piston cylinder arrangement itself is used for the compression and there only we will have combustion and then we have expansion. So, compression combustion and expansion takes place in the same entity in case of petrol and diesel engine. But, in case of gas turbine we have three separate entities compressor, combustion chamber and turbine.

So, we have to design three different parts for designing the components for three different processes and it is again unlike in case of IC engines which is petrol and diesel kind. So, have to design three different parts, we have to test this three different parts and then we have to assemble three different parts of the gas turbine power plant to form a gas turbine power plant for necessary or necessary objective of power so, it may be electricity production or it may be for propulsion or transportation application.

So, there is one more thing that as we say that open cycle gas turbine power plant has three component, but it is not that it can have only three component it can have multiple component more than three and this need comes from the fact that we need to have more power output or for a given constraint of having energy source available or atmospheric constraints or design we want a maximum efficiency. So, we want maximize the efficiency or we want to maximize the power output. So, in these cases we have to add on some extra components to the gas turbine power plant so as to have higher power output and higher efficiency of the power plant.

So, we can think of having additional component, but addition of each component leads to addition of weight, leads to addition of cost. So, the added or modified gas turbine power plant becomes bulky and it may become costly as way. But, there is need in certain cases where we have to improve the power output or we have to improve the efficiency. In general, single shaft kind of arrangement as what we had seen earlier to constitute a gas turbine power plant is very conventional used for electricity generation where fixed load and fixed speed are the requirements.

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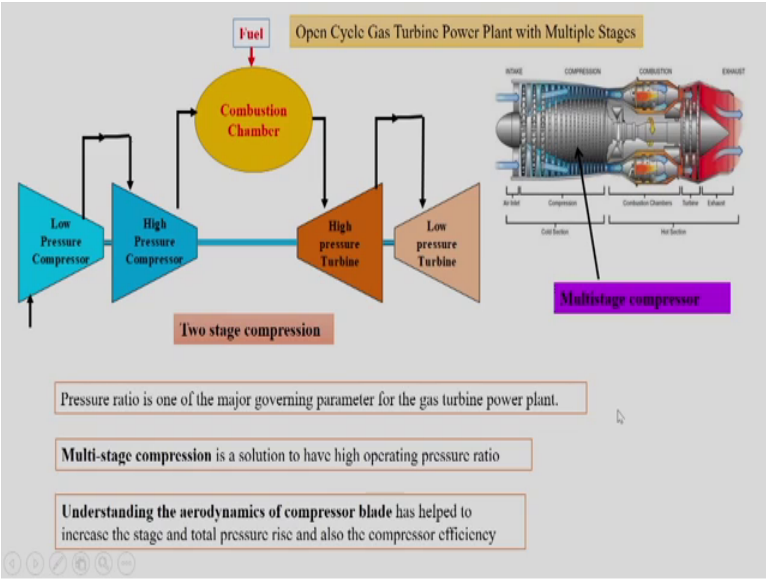

So, we have seen that we can attach different components to increase the power output and to increase the efficiency. So, but for a given composition of our a given availability we can think of increasing the efficiency of the power plant by having higher pressure ratio of the cycle. Here cycle pressure ratio we can roughly design at this moment of our course as the pressure ratio which the compressor has rise in the pressure; means initial pressure is p 1 at the entry to the compressor outlet pressure is p 2 at the outlet of the compressor. So, p 2 by p 1 is a driving pressure ratio for the gas turbine power plant.

So, if we increase the driving pressure ratio of the power plant it can increase the efficiency. So, if we want to increase the pressure driving pressure ratio so we obviously, we have to increase the compression amounts. So, we have to use multiple compressors for this aspects. So, multistage compression is preferred in case of increasing the cycle pressure ratio. And, initially it was difficult to have very high pressure ratio maybe 9, 10 to achieve in the early stages of the development of gas turbine power plant, but with evolution of the aerodynamics of the compressor blades now it has reached a state that we can reach the compression ratios or the cycle pressure ratios of the order of 30, 40 so that we can get higher and higher efficiency of gas turbine power cycle.

So, in case of multistage compression we have low pressure compressor which is connected which gets the air and then it compresses the air for initial rise in pressure and the air which is coming out from the outlet of the low pressure compressor will be supplied to the high pressure compressor. And then high pressure compressor supplies the high pressure air to the combustion chamber where we will have fuel combusted into the high pressure and high temperature combustion chamber and then we have the outlet of the combustion chamber connected to the high pressure turbine. So, then outlet of the high pressure turbine will be connected to the low pressure turbine.

Here as we see the multi staging is not just for the compression, but it is also for the turbine. So, we have multi staging concept for compressor for getting the higher and higher pressure ratio and here we are having separate turbines to dial separate compressors. So, this is there is multistate compression and there is multistage expansion. So, this is a open cycle gas turbine power plant with multi stages. So, this is an example we are having multiple compressors over here; so multistage compression here, so as to achieve the higher pressure ratio.

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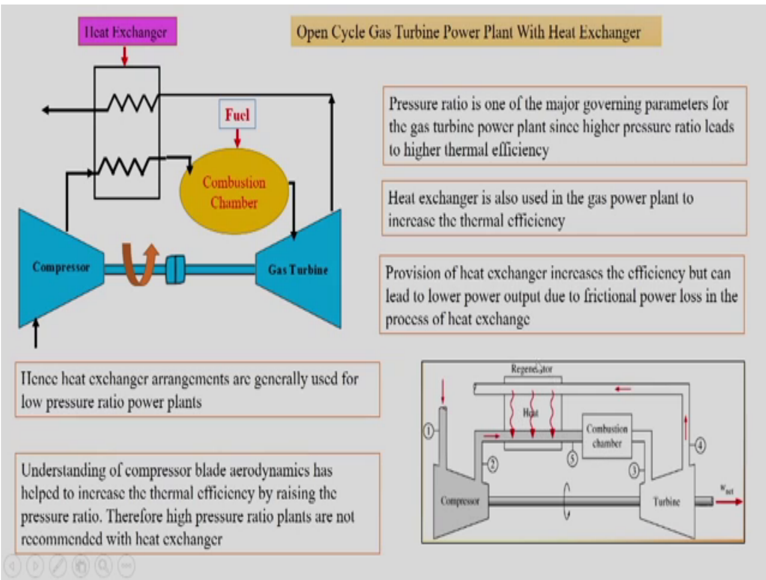

So, we have now come to a point that we want to increase the efficiency. One way what we have said that we can increase the efficiency by increasing the pressure ratio of the cycle, but there is one more way by which we can increase the efficiency of the cycle by introducing a heat exchanger. This concept is there in steam power plant cells we will see it how it is executed over here. So, compressor will get the air at the intake and that is connected to the combustion chamber where fuel burns it is passed to the turbine. But, here turbine will not directly exhaust the air or the gas to the atmosphere, but it is connected to a heat exchanger where heat transfer will take place between the hot exhaust gas turbine gas with the inlet to the combustion chamber.

In the inlet of the combustion chamber we have comparatively much lesser temperature and after the burning of the fuel we enhance the temperature of the gas. So, what we achieve practically over here is that we will loss of fuel, since the temperature of the gas which supplied to the combustion chamber will be partially raised by the heat exchanger. So, heat exchanger job over here in this context is to raise the temperature of the gas which is supplied to the combustion chamber.

And, then we are having higher efficiency in the presence of heat exchanger attached with a gas turbine power plant. We are going to revisit this when we come back or when we come to the thermodynamic cycle. As what we have said that pressure ratio is one of the governing parameters for higher efficiency, but we again can have heat exchanger to improve the efficiency. There is a problem with a heat exchanger here when we are transferring heat between the high temperature exhaust of the gas turbine with to the low pressure, low temperature not low pressure low temperature gas which is going into the combustion chamber.

In this process of heat transfer there is loss pressure loss due to the friction. So, this frictional pressure loss leads to the lower work output of the gas turbine power plant due to frictional power loss. And, then this puts a limit on use of the heat exchanger for the gas turbine power plant this frictional loss account would make us to use the heat exchanger best power plant only for low pressure ratio gas turbines. Actually what would happen in case of high pressure ratio gas turbine power plants is the with increase in pressure ratio we would have higher and higher loss in the heat exchanger. So, it is not good idea to have higher losses in the presence of heat exchanger.

So, we have low pressure ratio gas turbine power plants only which operate on heat exchanger basically heat exchanger is used here for increasing efficiency. But, as it is associated with frictional power loss we can bypass the use of heat exchanger in case of high pressure ratio gas turbine. Since increment of pressure is already sitting when we are telling that we are using high pressure gas turbine power plant. So, we have the compressor blades which can increase the pressure ratio to our desirable value and this higher pressure rise would automatically lead to higher efficiency.

So, this is one more schematic where we have exhaust of the turbine heating the inlet to the combustion chamber. Here the name is given to the heat exchanger as regenerator and this name is also given such name in steam power cycles. In steam power cycle also regenerator concept is used where steam is partially taken from the steam turbine and it is used to heat the water which is going towards the boiler or steam generator. This would reduce the energy input in the combustion chamber in case of gas turbine or energy put in the boiler in case of steam turbines. So, lower energy input requirement makes the power plant more efficient in case of heat exchanger.

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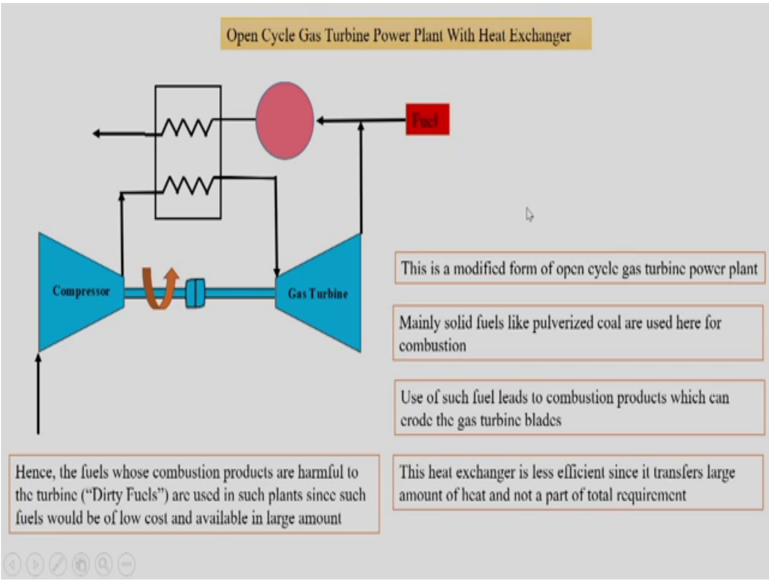

There is one more concern for having heat exchanger. As what we have seen in case of open cycle gas turbine power plant we were considering that fuel getting burnt in the combustion chamber and those fuels are mostly either gaseous fuels or liquid fuels. So, we have lesser chance to use solid fuels in the gas turbine power plant. So, as to accommodate solid fuels in the gas turbine power plant we have compressor, then it will take the air compresses it and then it will pass to the gas turbine, but in between it will have a heat exchanger where the air gets heated using the gas which is an outcome from the burning of the fuel; so there is a heat take instead. So, this heater or this heat exchanger is by passing the combustion chamber. So, this arrangement makes it a external combustion open cycle gas turbine power plant.

So, here combustion is taken place inside this externally to the power plant and those combustion products are used to heat the air which is then passed over the turbine. So, here we can use fuel of our choice burn it and then pass it through the heat exchanger so that heat transfer can take place this is a modified version of open cycle gas turbine power plant. Examples of fuel which we can use like pulverized coal and there is one more thing what we can think over here is the combustion products would not get mixed with the actual air when we are thinking open cycle gas turbine power plant where there is a combustion chamber combustion directly takes place in air.

So, having combustion taking place in air we have combustion products in the gas which is passing over the turbine. So, we have some combustion products which are harmful to the turbine having presence of those combustion product there is a chance that turbine blades get eroded, but with such an arrangement the air does not come into contact with the combustion products. So, we can have enhanced life of the blades or the gas turbine. Mainly the fuels which we can think for using in such an arrangement of heat exchanger is are the fuels which are titled as dirty fuels.

Since the dirty fuels are the fuels which produce harmful products can be obviously, accommodated in this gas turbines so that such fuels either have low cost or have large abundance can be utilized for our basic objective either to achieve basic objective and to reduce the cost. But, this heat exchanger is less efficient since this heat exchanger actually has large temperature gradient and this heat exchanger is actually passing the energy from the high temperature exhaust of the external combustion to the air and this large temperature gradient makes it a less efficient device as compared to the combustion chamber.

And, in the combustion chamber we have complete chemical energy maximum chemical energy getting absorbed in the working medium, but here we cannot absorb maximum working in a maximum energy of the gas. So, this arrangement would have lesser efficiency as compared with the other arrangement what we have seen in earlier slide.

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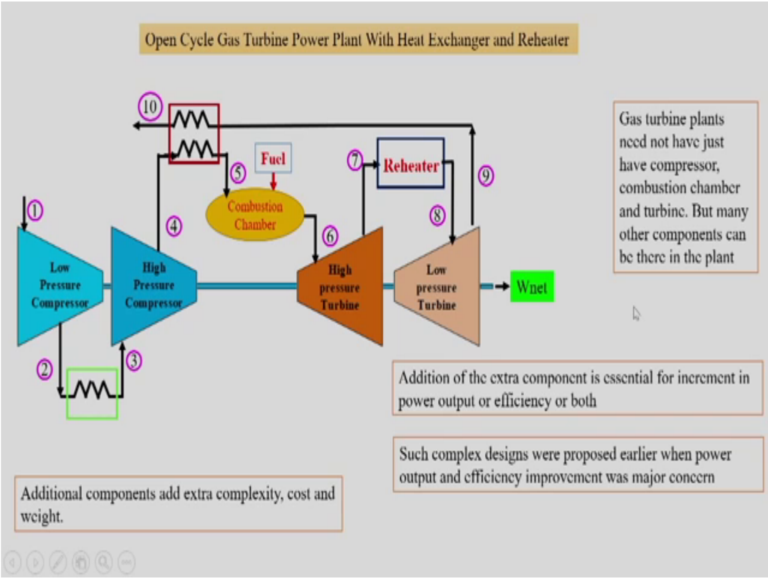

We have seen that there are multiple attachments which can be thought for the attaching to the gas turbine power plant to increase the power output or increase the efficiency. So, some are in one of the arrangements is we are seeing over here that gas turbine power plant with heat exchanger and reheater. So, in this case we have low pressure and then we have high pressure compressor. There is one more entity over here which is called as intercooler. So, basically what we are seeing is open cycle gas turbine power plant with intercooler heat exchanger and reheater.

Then, low pressure compression to high pressure compression in between has and intercooler. We know that or we are going to see again revisit again when you are going to see thermodynamic cycle we practically want to have compression process to be isothermal for lower and lower work input requirement. So, that can be achieved by the introduction of a intercooler. So, there is an intercooler which would take away the heat which would be take away the heat which otherwise would be sitting in the form of rise in temperature during the process of compression in low pressure compressor and then from high pressure compressor the fuel will be passed in the combustion chamber and air would get introduced into the combustion chamber.

After combustion chamber, then the gas would pass to the high pressure turbine and from the high pressure turbine it would not directly go to the low pressure turbine, but it would have a reheater; reheater which is used generally to increase the power output. Reheater is nothing, but a combustion chamber. Here we are having certain amount of oxygen left and then that oxygen would again be burnt in the reheater by introduction of the fuel. And, so, burning of the fuel into the reheater would again increase the temperature of the gas and that gas would be passed through the low pressure turbine. And, exhaust of low pressure turbine would be used to heat the gas or is the air which is getting passed to the combustion chamber.

So, this arrangement is what we can see is a mixture of all kinds of attachments what we can think for a gas turbine power plant. One, we have intercooler, other we have reheater, and then we have heat exchanger. So, these entities where thought in earlier days for having more power output and more efficiency as per the requirement. So, if we add as what we discussed an extra component in a gas turbine power plant and that extra component would lead to complexity in the design, it would lead to additional cost and it would also lead to the problems like what we have seen in case of heat exchanger but such things are required if we are interested in the increment in power output or we are interested in increment of the deficiency.

Now, we are going to see some extra arrangement of the gas turbine power plant and that arrangement is called as twin shaft arrangement. Till time what we were discussing was open cycle gas turbine power plant with one shaft, single shaft alignment, but now what we are going to see is a open cycle gas turbine power plant with twin shaft arrangement.

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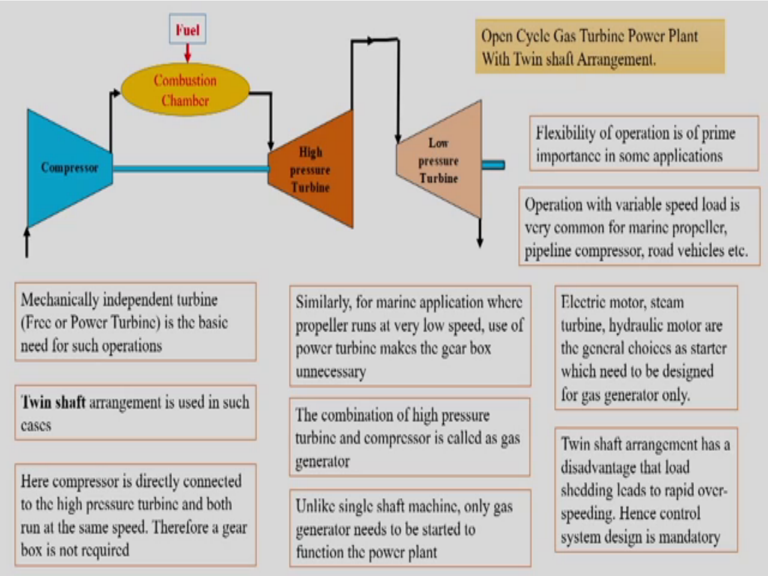

In case of twin shaft arrangement again we have compressor we have combustion chamber, we have turbine and turbine high pressure turbine and compressor they are connected by one shaft, but exhaust of this turbine is given to the low pressure turbine which is run by a separate shaft. So, there is a separate shaft for the low pressure turbine, but high pressure turbine drives the compressor. So, this is what called as the twin shaft arrangement of a gas turbine power plant.

What it is going to help us; how it is going to help us? Basically, in case of single shaft arrangement we are fixed with certain load and we are fixed with certain speed. But, here we can have flexibility of operation we need flexibility in many operations and those operations maybe something like we have marine propeller driving operation or we have pipeline compressor, we need road vehicles to be operated with variable load and variable speed condition and in such condition it becomes difficult if we have turbine and compressor they are mechanically connected operation.

Since turbine has to run at one speed and compressor would run at other speed, then we need a gearbox to match their speeds. But, if we have a twin shaft arrangement then the shaft is used for power production is a separate one which is not the one which is used to connect between the compressor and the turbine. So, this shaft or this turbine which is actually anchoring the power output is called as pre shaft or it is called as power turbine. And, power turbine is what used for the variable or flexibility in the operation and such an arrangement is called as twin shaft arrangement.

Here as we have seen that since compressor and turbine run at the same speed we are not in need of a gearbox. Similarly, similar requirement is there for marine propeller where marine propeller will have lower speed, but compressor has to run at higher speed. So, there would have been a need of a gearbox having propeller connected with the free shaft, we can bypass the gearbox requirement and then we can directly club it with the power turbine.

Then we have this arrangement which is combination of compressor and high pressure turbine and this arrangement is called as a gas generator. We have boiler or steam generator in case of steam power plant, where steam will be initially generated and that generated steam will be passed to the steam turbine. Here same thing exists here we have an arrangement where we want high pressure high temperature gas. So, that high pressure high temperature gas would be generated by an arrangement and that arrangement is called as the gas generator. So, power turbine runs on a gas generator, that has an advantage.

In single shaft arrangement, we need a starter to run the complete gas turbine power plant, but in this case having this shaft separate we need only starter for this gas generator. We do not need any starter for this power turbine since it runs on the exhaust of the gas turbine. Electric motor, steam turbine, hydraulic motor are the general choices for the starter.

There is one disadvantage of this twin shaft arrangement and that disadvantage is linked with the control. If there is a variation in load or load shedding at the power turbine then there is a speed up of the turbine shaft and that speed enhancement or decrement needs to be controls that has to be a control system devised in association with the power shaft or twin shaft.

So, here we complete today's lecture where we have seen how the arrangements are there in an open cycle gas turbine power plant.

Thank you.