Technologies for Clean and Renewable Energy Production

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Lecture 04
Conventional Route for Energy Production from Coal

Hi friends now we will discuss on the topic conventional route for energy production from coal. In the introductory module we have discussed that coal can be used through different routes like say combustion, gasification or direct liquification for the production of energy. Out of these routes the most conventional one is combustion based thermal power plant. So, in this module we will be discussing what is the flow sheet and what is the mechanism for the production of electricity in a thermal power plant? What is its efficiency? What are the thermodynamic cycles and what types of reactors are used?

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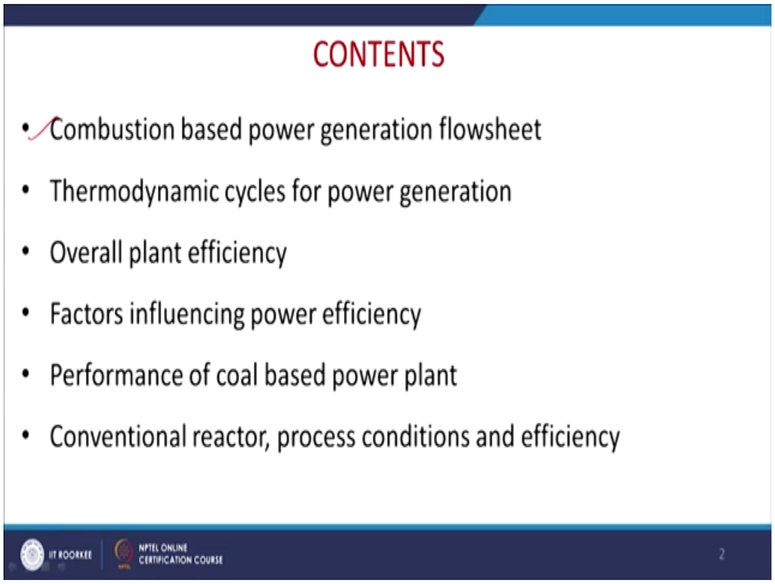

And the contents of these are combustion based power generation flow sheet then thermodynamic cycles for power generation, then overall plant efficiency, factors influencing power efficiency, performance of coal based power plant and conventional reactor process conditions and efficiency. Now we will see the flowsheet, the conventional flowsheet.

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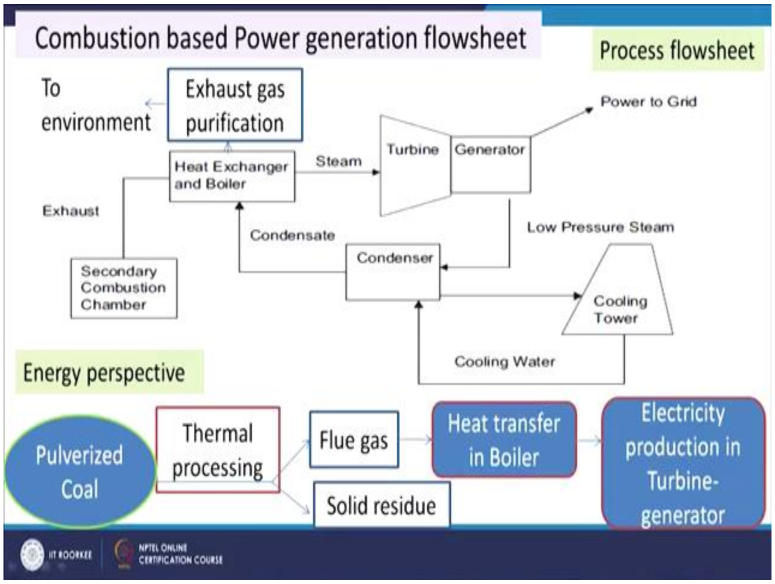

Here we have combustion chamber from which the flue gas goes into heat exchanger or boiler where combustion takes place. So, heat is released, high temperature flue gas goes to heat exchanger then from heat exchanger water comes and it forms steam. So, steam goes to turbine, steam turbine coupled with generator so power to Grid that is one way we get the electricity. And this flue gas which is going into the boiler after exchanging the heat it will go to the environment as exhaust gas.

And the steam which is coming out from turbine that will be of low pressure, that steam is condensed and condensed water is used for the production of steam again or some part of it can be sent to the process in a cooling tower and heat recovery can be possible. So, this is conventional process. And on energy perspective if we think, then pulverized coal we have thermal processing then we get flue gas and solid residue then flue gas heat transfer in boiler and steam and electricity production.

Now we can use gas turbine also or we can use the heat of the flue gas for the production of heat only by heat exchanger for heat application or we can produce steam only or we can produce electricity only or we can do the combination of these things. So, we may have some options; coal combustion then boiler, the flue gas is going to boiler, it can give a steam and steam to electricity that is one route.

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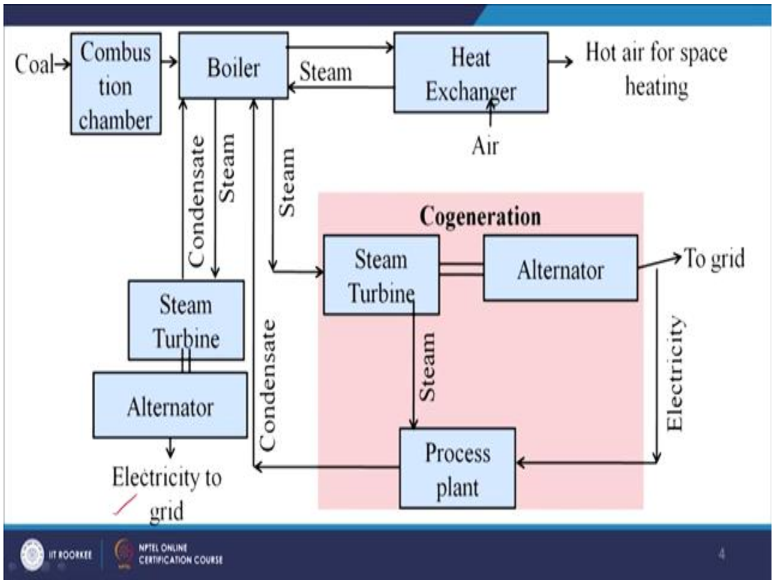

Another is steam to heat exchanger then hot air for space heating. There is also one option, this is our combination of both, heat and steam then electricity. So, steam is coming to steam turbine, we are generating electricity and supplying it to grid and this steam is also used in the process for heating purpose. So, this is called co-generation when we are using both electricity as well as heat in a plant.

Now this steam turbine can also be replaced by gas turbine, air after coal combustion, it can go to gas turbine and gas turbine to exhaust of the gas turbine, it can go to heat exchanger and then it can increase the temperature of air which can be used as a preheated air also and then it goes to vent. And when the turbine runs then it is connected with generator and produces electricity. So, number of possibilities are there; we can use for the production of electricity or other type of energy for its application.

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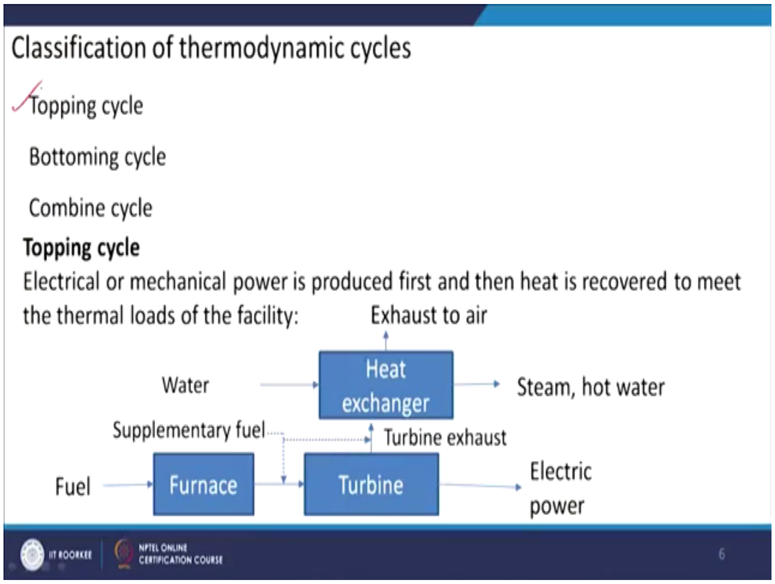

On the basis of these different possibilities we have different types of cycling, that is thermodynamic cycles, that is topping cycle, bottoming type cycle and combined cycle. What is the topping cycle? We have fuel, air then we are using it in furnace and flue gas is produced at high temperature then it is used in turbine for electric power generation then the exhaust from the turbine is further added with some supplementary fuel and that is combusted and temperature of this stream is also increased and then it is used in heat exchanger for steam generation.

So, in this case at first we are getting mechanical energy then heat recovery so that is why it is called topping cycle. But for bottoming cycle we are producing heat here then that is first heat recovery taking place in the first case whether you are using water to produce steam and then the turbine then electricity so this is called bottoming cycle. Now in combined cycle it is a hybrid cycle and contains both topping and bottoming cycles.

Now how the cogeneration helps? cogeneration means we are producing electricity as well as we are producing steam for different types of applications. So, in that case we can reduce the loss of energy and we can get more efficiency of the process.

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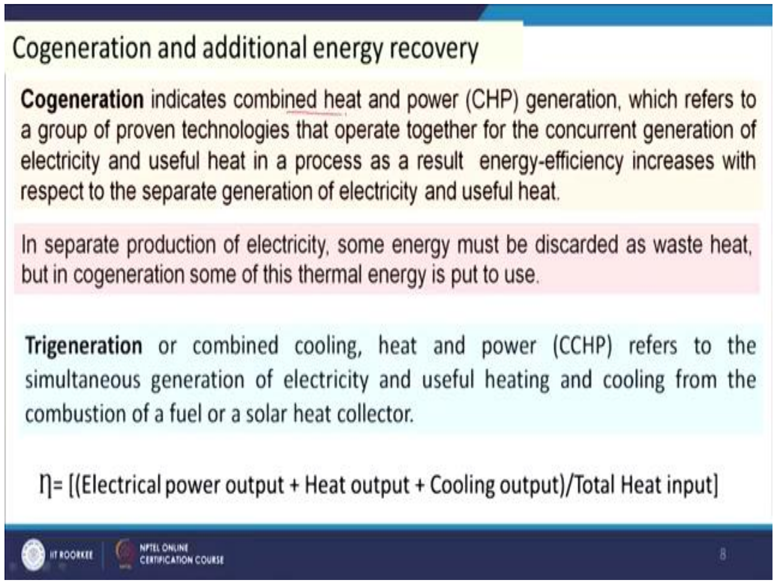

cogeneration indicates combined heat and power generation and tri generation concept is also developed that is combined cooling heat and power, heat application cooling applications and electricity generations so by that way the people have seen that the efficiency can be improved. Now this efficiency is equal to in this case electric power output plus heat output plus cooling out divided by total heat input so, that way we can calculate the efficiency.

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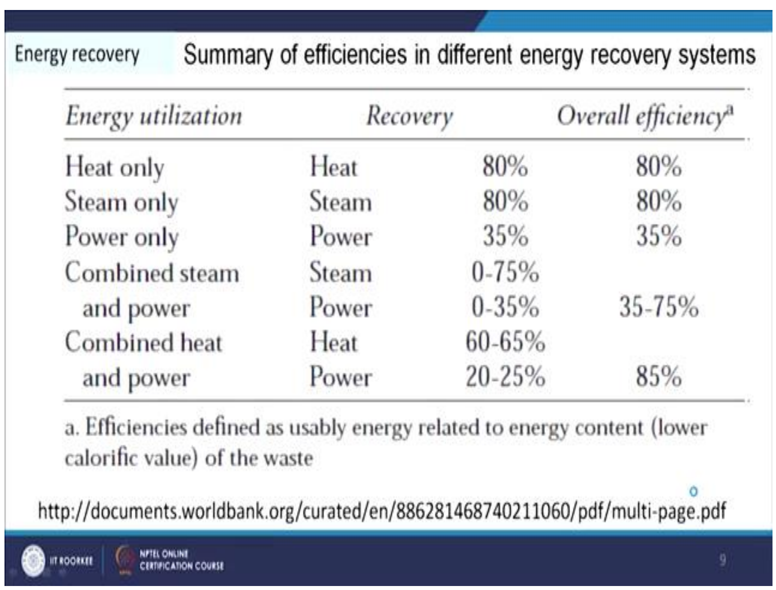

Now this table gives us some example. That how we can get overall efficiency, higher overall efficiency by using suitable combination of different types of energy utilisation. If we use it for heat only application then recovery is 80% and overall efficiency 80% steam only there is also 80% power only 35%. So, power is the most usable form of energy so that is our major concern but here our efficiency is less 35%.

But if we combine these power applications with steam application or steam + power + cooling application then we will see that this 35% can be increased to 35 to 75% or in some cases it is 85%. So, that is why the cogeneration and tri generation concepts are being implemented. Now on the basis of this discussion it is clear to us that we can use steam turbine or we can use gas turbine or we can use both turbines for the production of electricity from the coal. So, for the steam turbine is governed by the thermodynamic cycles that is called Rankine cycle.

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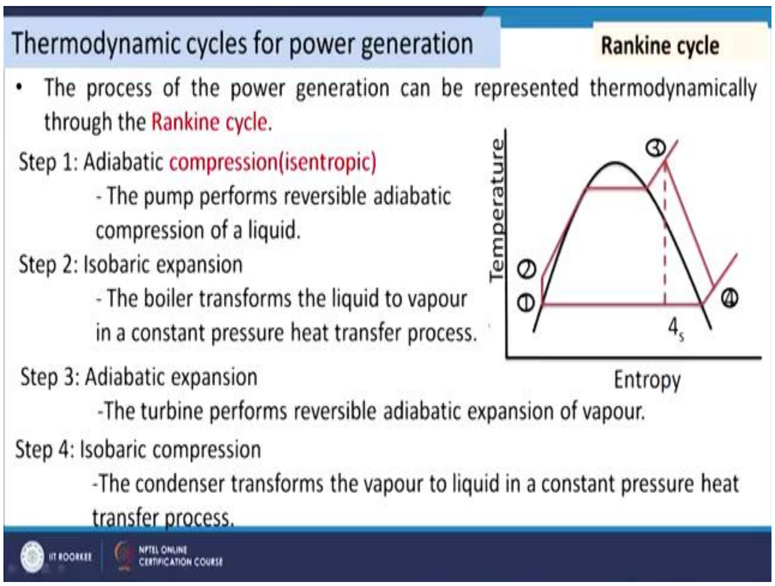

So, here we will see the Rankine cycles, how the entropy and temperature changes as per the Rankine cycle. And here it has the 4 steps the steam turbine has four steps, the step 1 adiabatic compression, what happens in this case? the pump is used to compress the water in the boiler. And then step 2 isobaric expansions, that the pressure is constant and then we produce the steam here. And then adiabatic expansion, the steam is going to the turbine and expansion is taking place, the adiabatic process.

And then isobaric compression, after that that is condensed, condensed air is sent to condenser and this transform vapour to liquid in a constant pressure heat transfer process. So, these are the four processes of steam turbine and Rankine cycle is shown here. So, what we see from this? we see that an ideal condition can be achieved when no fluid friction and heat loss is considered so this is the case dotted line.

But this is the ideal one but this does not happen in reality because of loss due to the friction. So, friction, fluid frictions in the boiler and pipe lines etcetera reduces the energy and we need to provide additional energy to maintain it.

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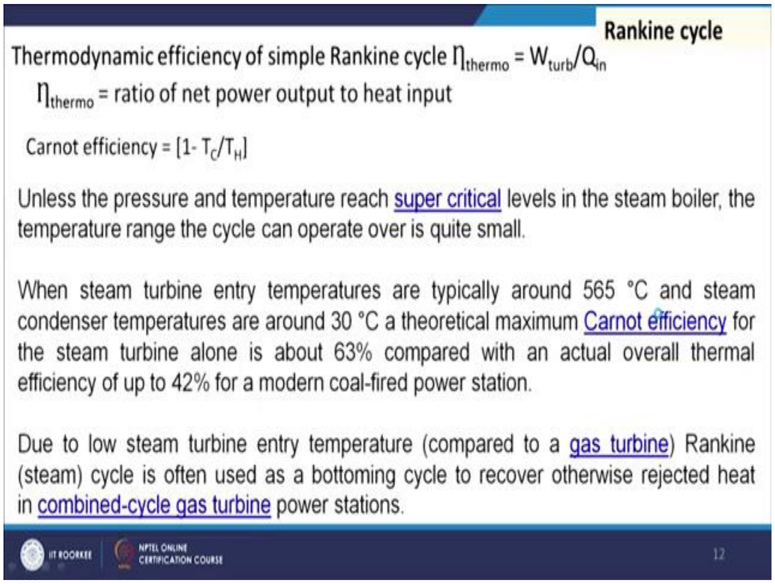

Now as per this Rankine cycle efficiency, thermodynamic efficiency is equal to ratio of net power output to heat input and Carnot cycle efficiency is 1 minus cold temperature by hot temperature TC = 1 - cold temperature / hot temperature. Now if we increase the temperature hot temperature then the efficiency is more that we have discussed in the introductory module also that supercritical conditions if we can use then we can enhance the efficiency.

But how much? that is guided here if we use steam turbine NT temperature is typically around 565 degree centigrade and steam condenser temperatures are around 30 °C then Carnot efficiency is 63%. But actually overall thermal efficiency up to 42% is available it is possible with modern coal-fired power station. In the previous slide I have shown you it is 35% subcritical conditions but the supercritical conditions which may be increased.

So, thermal Carnot cycle efficiency is 63% that is a maximum but so far there is no turbine with the steam turbine with this much of efficiency this is up to 42% as you put it here. Now we will see the Brayton cycle who did used to explain the gas turbine.

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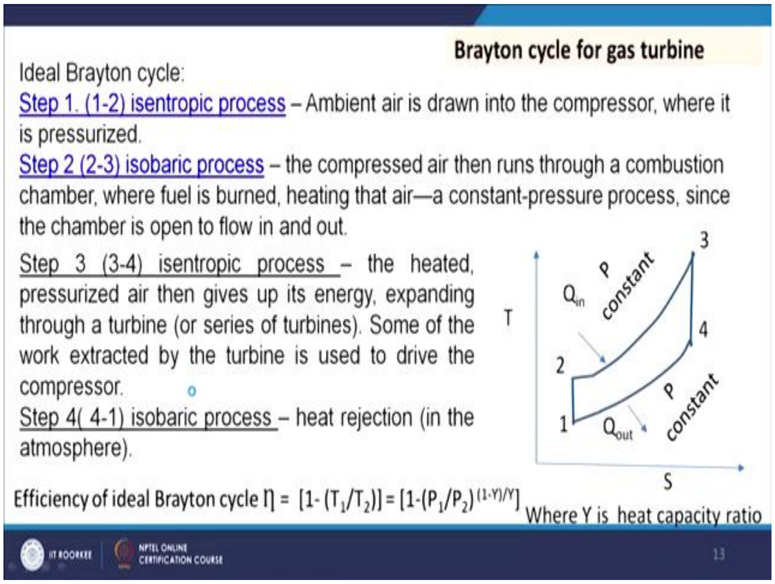

So, it also has 4 steps in this case what happens now air is used and compressed so then it is sent to the furnace for the heat exchanger to heat it up and then basically the combustion chamber so it is the isobaric process so it expands. So, expansions and then we are going for step 3 that is isentropic process, the heated and pressurized air then gives up its energy in the turbine blade so that is the case expanding to the turbine.

And then isobaric process, heat rejection in the atmosphere so these are the steps of the gas turbine cycles and efficiency is = $1 - T_1/T_2$ just like Carnot cycle efficiency or T_1 by T_2 can be replaced by P_1/P_2 the power $1 - \gamma/\gamma$ already we have discussed we studied this in thermodynamics subjects and here gamma is the heat capacity ratio. So, what we can guess from this relationship? If we can increase the temperature then we can get more efficiency. But how much?

We are using the air in a combustion chamber and then in the combustion process the material which you are using that that will be having some resistance power so maximum is a 1500 to 1800 °C can be used or we can convert the pressure ratio change the pressure ratio P_1/P_2.

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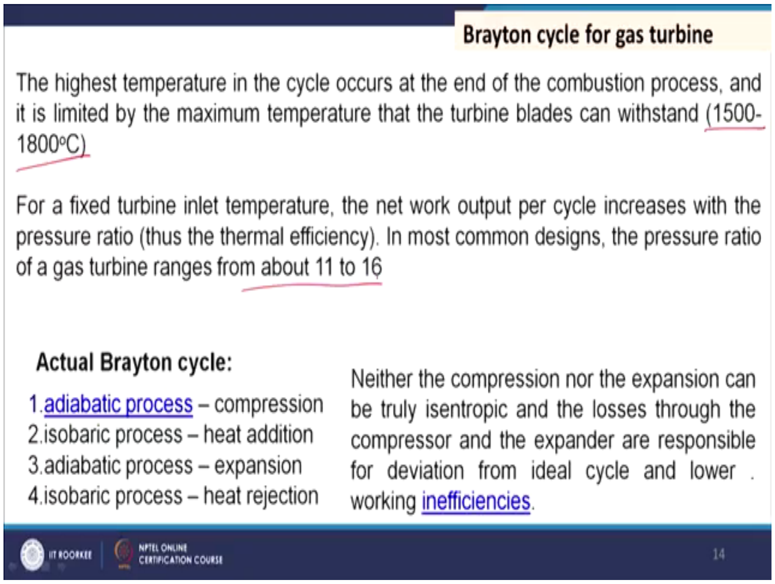

By pressure ratio change we can change the efficiency of it and it has been reported that the pressure ratio of gas turbine ranges from 11-16. So, pressure ratio as well as operating condition temperature both influence the performance of the gas turbine. But in actual case the Brayton isentropic process is not applicable we get adiabatic process, adiabatic that is compression then isobaric process heat addition and adiabatic process expansion in turbine and then isobaric process heat rejection.

So, these are the different steps of the thermodynamic cycles of steam and gas turbines. Now we will see now what is a performance of a coal based power plant how can we define it and how this will be influenced by other factors obviously we are using coal.

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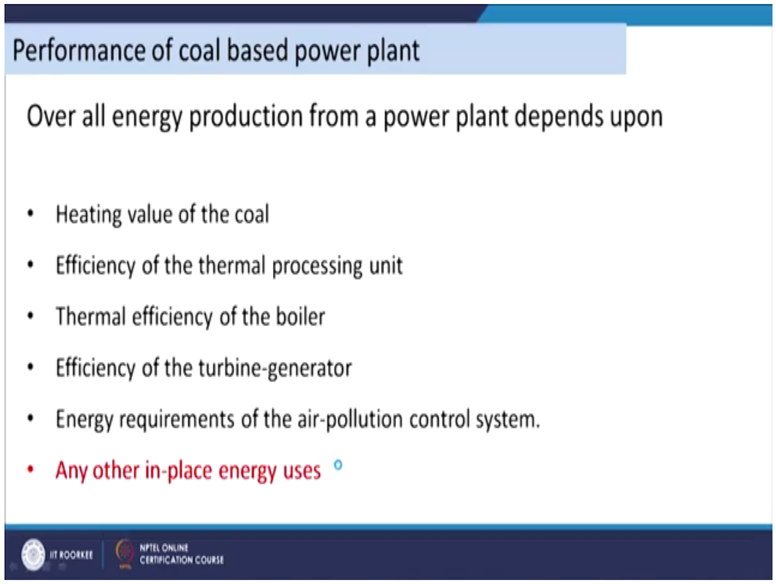

So, if we have high heating value then the performance will be higher and the thermal conversion units which we are using, the combustor in some cases, the combustion or the furnace and boiler are combined in some cases, 2 are different units. So, there are variations in the technology and the heat recovery is also different. So, that way the efficiency of the thermal processing unit will also influence the overall efficiency of the process.

And then thermal efficiency of the boiler, the thing as I already discussed, and then efficiency of the turbine and generator, in the boiler we are getting steam and then that steam is used in turbine and generator. So, all those units' turbines and generators have their own limitations and efficiency so that will also be considered into the overall efficiency of this, it will influence. Then energy requirements of the air pollution control systems as I have shown after the heat recovery from the flue gas it is allowed to go into the atmosphere the exhaust gas.

So this exhaust gas temperature at which temperature we are releasing it and what type of fluids we are using for the heat exchanger purpose all those things will be influencing the performance of the power plant as just we have discussed, that if we use the cogeneration or tri generation then I have sensible increase. So, all those factors influence the performance of the thermal power plant, coal based thermal power plant.

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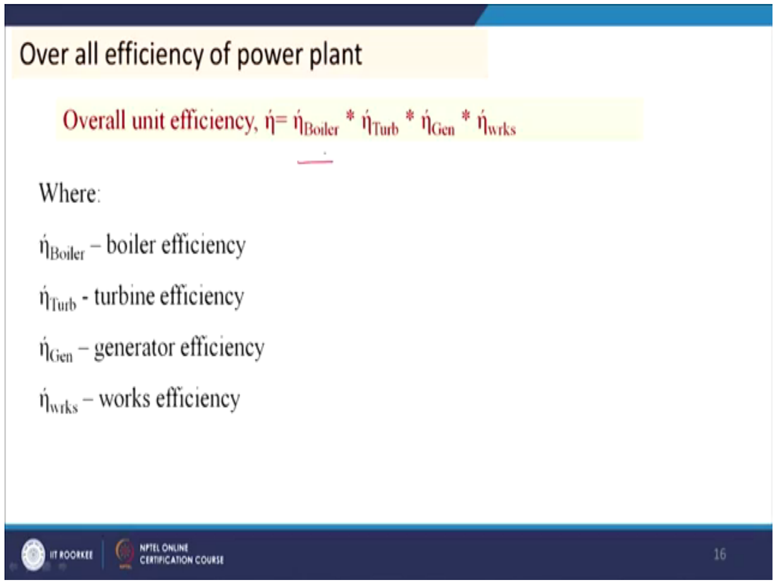

And overall efficiency can be expressed as that is efficiency of boiler efficiency of turbine efficiency of generator and emissions of works; works efficiency. Now it is found that full heating value and what is the size of the plant that will influence the economy or the performance of the process.

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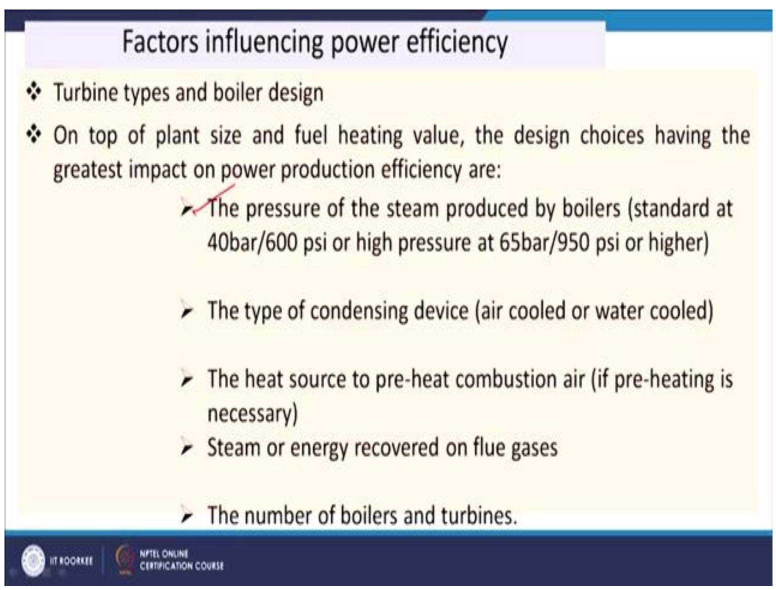

Apart from this, notice the pressure, the steam is produced that will also influence just we have discussed, the pressure ratio. So, pressure it is used that will also influence the performance. The type of condensing device air or water so heat transfer coefficient is different so more the transfer coefficient more efficient to the heat transfer or recovery, so that also influence the performance of the process in the heat source to preheat combustion air that will also if we are using recovering some amount of energy or not.

Actually 60 to 80 degree centigrade, this temperature stream in the industries are very poorly utilized. So, if we can have some arrangement to utilize this heat then also increase the efficiency. And steam or energy recovered from flue gases, the number of boilers and turbines, that we have discussed whether it is a bottoming cycle, topping cycle or combined cycle. The combined cycle will give us more efficiency.

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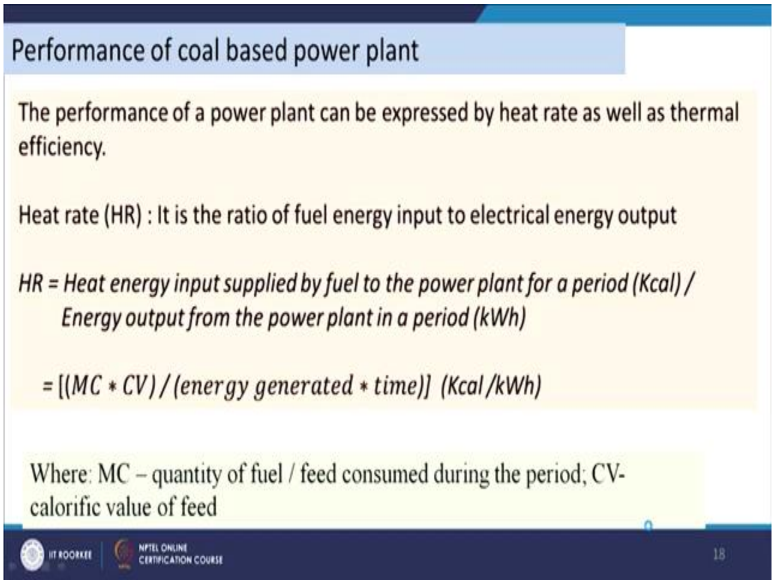

Now we will discuss the performance of coal based power plant. The performance of a power plant can be expressed by heat rate as well as thermal efficiency. So, what is heat rate? heat rate is nothing but it is the ratio of the energy input to electrical energy output. So, HR a heat rate is heat energy input supplied by the fuel to the power plant for a period so that we can calculate in kilocalorie divided by energy output from the power plant in that period that is kilowatt hour.

So, heat rate is this one the heat energy input supplied by the coal, that how much fuel you have used during this time and what is the heating value of it. So, MC how much fuel we have used and CV calorific value of it, that is the heat used and then how much we are getting that energy generated into time. How much time the plant is running and during this time how much energy is produced, that is kilowatt hour.

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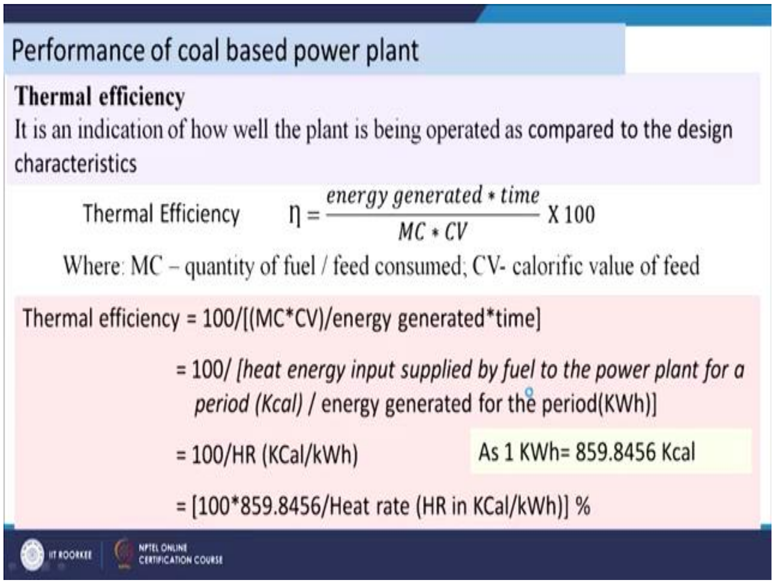

Now what is the thermal efficiency? Thermal efficiency is the inverse of this, your heat recovery that is 100/HR x kilo calorie/kilowatt hour. So, thermal efficiency is defined as the energy generated into time by amount of fuel used into the calorific value of the fuel. Now how much energy we're getting per unit amount of heating value of the fuel, that is an energy efficiency. So, thermal efficiency is equal to 100 divided by, we are getting MC into CB divided by energy generated into time.

So, here we see MC divided by energy generated by time is nothing but the HR so we can get 100 divided by HR, so this is kilo calorie per kilowatt hour. But this if we want to get in percentage then these two units have to be same. So, the unit conversion is indeed, we know that one kilowatt hour is equal to 859.846 kilo calorie so we can put this value here and this is a relationship for the determination of thermal efficiency in percentage.

So we will put the value HR in kilocalorie per kilowatt hour and multiply and we put this in numerator and denominator heat rate in kilo calorie per kilowatt hour then we will get the thermal efficiency in percentage. So, I will show you some example, if the average heat rate of a power plant in 2018 is 2611 kilo calorie per kilowatt hour then calculate the average efficiency of the plant. So, how we can do it? thermal efficiency we know 100 divided by MC into CV divided by energy generated into time.

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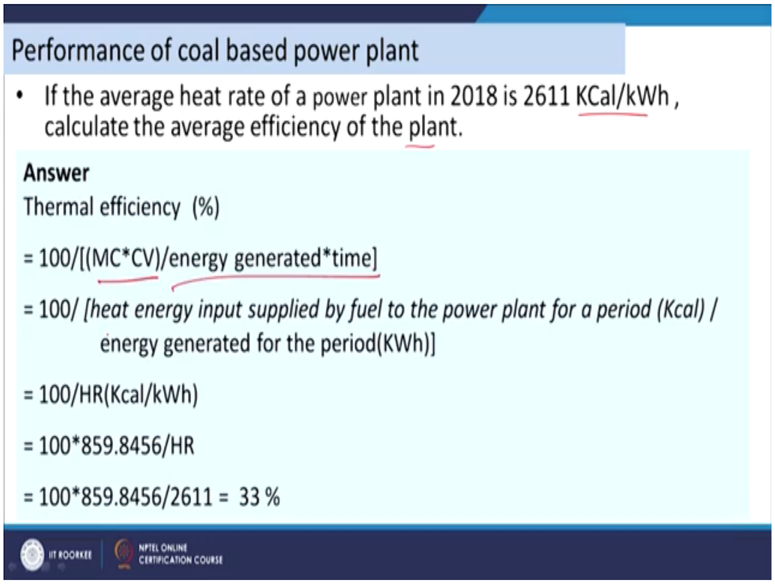

So, 100 divided by heat energy inputs applied by fuel to the power plant for a period by energy generated for the period. So, what is in our case? HR is given 2611 kilocalorie per kilowatt hour we will be using this formula 859.5856 divided by HR so 100 into 859.8456 divided by 2611 as given in the statement, it is coming to 33%. Now we will see whatever reactors are used for the production of electricity in a thermal power plant using coal.

The conventional reactor type is fixed bed type and in some cases we also get fluidized bed. so, fixed bed and fluidized bed , these are mostly used reactor type in thermal power plant.

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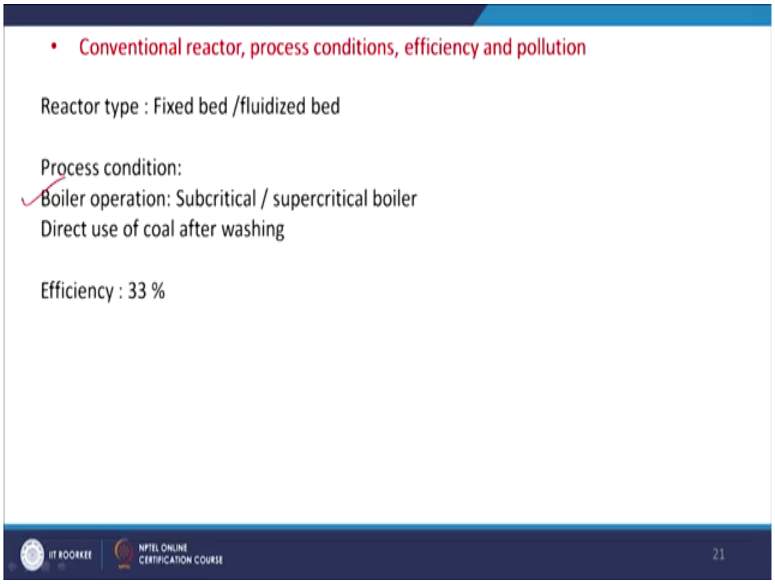

And in this case what is the condition of the boiler operation? it is mostly in sub critical conditions and some advanced plants are using supercritical boiler and also getting more efficiency than the subcritical boiler. And direct use of coal without washing so the coal is having high ash and sulphur content. If so we need to remove the ash by washing, after washing we will be using it for thermal power plant. And then in this case the efficiency is around 43%. So, up to this in this class thank you very much for your patience.