

**Clean Coal Technology**  
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**Week-11**  
**Lecture-53**

Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on Clean Coal Technology. We are in module 11, discussing coal-based power generation. So, in this module, we are discussing an introduction to coal-based power generation and the Rankine cycle. So, we will continue with this. In later classes, we will discuss gas turbines and combined cycle power generation IGCC.

So let us start lecture 3 on coal-based power generation. So, in our previous class, we discussed the coal handling section and how electricity is induced in the electric generator. So, these two parts we have already discussed. So, in this lecture, I will be discussing more about the superheater, economizer, condenser, and other major parts or sections of the plant. Now if we see what happens inside the actual boiler, our main objective is this furnace where coal is burned in the presence of air.

It will produce heat and high-temperature flue gas, so the purpose of this flue gas is to produce high-temperature steam. Now, the input in this boiler is high-pressure liquid-phase water, so it will be high-pressure water, which is done by this pump, and this water It will be at a lower temperature. So, this needs to be heated from approximately 30 degrees centigrade to here, maybe at 600 or 560 degrees centigrade, whatever the condition of steam is required. So, this is the final condition required, maybe 560 or 600, whatever. So, this condition may be like that: 560 degrees centigrade, 150 bar, or whatever. So and here this is the pressure is also our higher side. So, this entire heating of this water it happens in three different stages. First stage is called the economizer where water is heated to its about 100 degrees centigrade where it will reach to the vapor phase or it will convert it to the almost 100 degrees centigrade but it will be in the liquid phase. So, this is the purpose of this economizer which will particularly give the water, it will bring the water from liquid phase 30 degree centigrade to liquid phase 100 degree centigrade. So basically, this is the part where waste heat from the flue gas is used to heat this water.

So, the boiler tubes are placed such that whatever the waste heat is going out of the flue gas, exit gas which is going to the stack for ESP and other, before that it will have lower temperature. So, some amount of heat is used or received or you can say collected or recovered from the waste heat, that flue gas. Which will use to heat the water from 30 degree centigrade to 100 degrees centigrade in the liquid phase. That is the purpose of this economizer. Basically, it works on the waste heat recovery units from the flue gas.

Next part is that. evaporator where temperature of the water is remain constant but water will convert it from liquid phase to the vapor phase so in the evaporator water will evaporate will convert it to the steam so it will be 100 degree centigrade liquid water it will be converted to 100 degree centigrade vapor by collecting or by receiving the latent heat for vaporization so that is the section of the evaporator and after this steam is formed then it will go to the superheater where this steam will be superheated to desirable temperature and pressure and here most of the heat is required to superheat the steam from 100 degree centigrade to 560 degree centigrade as well as at the high pressure and this particular condition of 560 degree centigrade 150 bar or 160 bar it depends on the entire steam table data or water enthalpy data because if we increase the temperature steam will the liquid water will convert it to the steam but if we again increase the pressure as pressure is increased some of part of the steam will convert it back to the liquid phase so this is done by following the steam table data at what condition what pressure how much amount of energy is required. So accordingly, this heating is done. Now overall if we see that the superheated temperature zone is typically on the higher side. So, in this zone temperature will be on the highest part because there needs the high temperature heat. So, this super heater section will be placed inside the boiler where the temperature of the furnace or boiler is at the highest that is around 1200 to 1300 degree centigrade. The highest temperature zone in that section only this super heater will be placed.

Then intermediate temperature zone where temperature may be on the lower side that zone evaporator will be placed and the section where the temperature is at the lowest in such section economizer section will be there so as this heat transfer occurs between the temperature difference or driving force for the heat transfer is the temperature difference so superheated zone temperature is already 560 degree centigrade so superheated zone in a boiler it will be placed at the highest temperature zone then only this heat transfer is possible so similarly the medium temperature zone where temperature can be 400 500 or 600 degree centigrade that temperature can be placed or used for the evaporation of the water and where the flue gas temperature is 100 or 150 degree centigrade and that zone only economizer are placed so these

entire boiler tubes are placed accordingly based on the temperature profile inside the boiler so these are their individual role so if you see inside the boiler water is converted to steam at three different section economizer evaporator and superheater In economizer heat is used to increase the feed water temperature from 30 degree centigrade to about 100 degree centigrade using the low temperature heat available inside the boiler. Mostly waste heat is used to heat this economizer heat from the flue gas. The evaporator in this zone water is vaporized from liquid phase to the vapor phase here most of the cases the only latent heat is required which is the highest amount of heat required for phase conversion from 100 degree centigrade liquid phase to 100 degree centigrade vapor phase so this phase transformation occurs in this evaporator so it is the in this case significant amount of latent heat is required Then the sensible heat is required from only heating the water from 30 degree centigrade to 100 degree centigrade. In the economizer zone, the temperature requirement is only the sensible heat whether as the evaporator zone. temperature requirement is the latent heat. And in the superheated zone, in this zone, steam is superheated from about 100 degree centigrade to the desirable temperature and pressure condition as per the requirement of turbine so if it is the normal turbine it can work even up to 120 bar if it is the high pressure turbine or if it is the super thermal power plant ultra super thermal power plant based on the turbine condition and plant design this pressure is sometimes higher and temperature is also higher so this varies from the plant to plant if it is the older plant this pressure is maybe 150 or 120 bar but if it is the newly installed plant because The metallurgical or high grade metal has been used in manufacturing all these boiler tubes and turbine. There this pressure is also on the higher side. So high temperature flue gas approximately 1300 degree centigrade in the pulverized coal combustion units is used in this purpose. now overall if we see what is the actual role of this steam or what is the actual role of the water as we have discussed in our previous lecture we need any fluid that is it can be any gas it can be any vapor or it can be any liquid we need high temperature or high kinetic energy containing fluid so in this steam turbine we are using water vapor or steam as the working fluid so this is required as working fluid with the following quality parameters. Now what fluid or what medium we can use for steam turbine or in the Rankine cycle power plant. First condition is that it must be having higher amount of heat transport capacity. The major role for this steam or this water in the steam turbine is that it transports the energy from the boiler or the combustor to the turbine blade. So it must have very good heat transport capacity so that in one cycle it should transport highest amount of energy from the flue gas or from the combustor to the turbine grid so it should have higher amount of heat transport capacity that is from the boiler to the turbine so if any fluid or if any liquid has lower energy transport capacity that means if

its latent heat is less as well as sensible heat is less than that is not suitable because in one cycle it will only transport very smaller amount of energy but in case of water or steam even for 100 degree centigrade liquid to 100 degree centigrade vapor it takes significant amount of latent heat which is on higher side compared to other similar liquid available similarly at 100 degree centigrade one atmospheric steam to 560 degree centigrade 200 bar steam there is significant amount of energy or enthalpy is required for this conversion so This steam or water transport large amount of heat from the boiler to the turbine. So suitable liquid must have high specific heat capacity CP value. Like this CP value means how much energy it can transport if temperature difference is 1 degree centigrade.

If any fluid has lower amount of this specific heat capacity CP value, then only after 10 calorie or 20 kilocalorie or 30 kilocalorie heat, it will change its temperature from 100 degree to 200 degree or 300 degrees centigrade. So, temperature will rise. but it will not absorb higher amount of heat but in case of water this specific heat capacity is on the higher side both in the liquid phase as well as in the vapor phase that's why this particular fluid should have higher amount of specific heat capacity cp similarly higher amount of latent heat is required when it converts from the liquid phase to the vapor phase or similar phase transformation because latent heat amount if it is on the higher side within the same temperature it will absorb higher amount of heat from the boiler and this same amount of heat it will be released to the turbine so that particular liquid or particular fluid medium should have mandatorily higher amount of specific heat capacity lambda or latent heat so that they can transport large quantity of heat from the boiler to the turbine So these value must be higher so that with low temperature difference they can carry much higher quantity of heat.

Second criteria are that that particular liquid or particular fluid must be easily available. That means to meet the plant demand. In thermal power plant amount of liquid required is on the much higher. 1000 kiloliters or 2000 kiloliters or whatever this quantity is on the higher side so that much quantity of fluid or liquid must be available in theoretically there are many fluid is there or many liquid is there which still contains higher amount of cp value and higher amount of lambda value that means there are many more fluids or liquids are available which meet the criteria this criteria that it has higher heat transport capacity so many liquids has this capacity but they are not easily available if we see water is available everywhere it can be collected in rivers or others and if we see the similar other liquid like if we see the heavy water D2O that is not easily available at every location.

So, not all the plants can operate on the heavy water D<sub>2</sub>O or any other organic liquid. They are not available to a higher extent. They can be available in smaller capacity. They can be available, but they are not available in higher extent. That's why general water H<sub>2</sub>O is used in most of the plants. Like 99% plants, they use this water very rare cases any other fluid is used only in case of nuclear thermal power plant they only they use the D<sub>2</sub>O also in objective to other purpose to control the rate of nuclear reactions and other so major objective or major criteria for this fluid should have that this would be easily available in higher quantity it should be cheap because for power plant if the operating fluid cost is significantly higher than the entire installation cost of the plant will be significantly higher so if we are using any other organic liquid any other liquid matter etc. they are not cheap neither they are easily available so they are not suitable although they may be suitable for fast criteria but they may not be cheap and some of the material can be also be non-toxic in nature particularly there are several organic liquids are there we can use different type of organic liquids for the same turbine cycle but they are toxic in nature that means if some quantity of this organic liquid is released in vapor phase to the environment there have severe environmental pollution issues so they must be environmental friendly That they will not create any pollution.

They will not corrode the pipeline, steam turbine etc. If that liquid corrodes the pipeline, turbines and other plant infrastructure, then that liquid is not suitable. And if boiling temperature matches the heat transfer requirement and turbine profile, like it is the low temperature profile or high temperature turbine. In the turbine section, there are two, three different types of turbines are used, which operates at the low temperature zone, medium temperature zone, high temperature zone. In actually multiple cycle power plant. Two three different power cycles are run which in one cycle high temperature is used to get most of the energy then the exhaust heat is used to produce run another cycle which can be operated at the lower temperature and even very low temperature cycle at 100 degree centigrade is also possible where different type of organic liquids can be used of lower capacity so That boiling temperature range must be matching with the heat transport requirement that that particular liquid will get vapor phase in 50 degree centigrade and it will transport higher amount of energy. So that boiling temperature matching also should be there as per the requirement at the turbine profile if it is the high temperature turbine or low temperature turbine as well as the medium temperature turbine. So, overall considering all these aspects, in most of the cases, pure water like pure H<sub>2</sub>O is used in thermal power plant at normal cycle. As water is available at cheap rate almost free of cost, so any nearby water bodies like river, very big lake or similar,

location that is used to supply the water to this plant that's why this water is mostly used at present 99 percent plant they use water and in some cases in earlier times like before 50 years or 100 years in the 19th century mercury liquid mercury was also used in some of the thermal power plant Liquid mercury can be used in this thermal power plant in Rankine cycle, as this liquid mercury has an excellent heat transport capacity, its specific heat capacity is significantly higher, it can evaporate, it can operate even at higher temperature, around 1000 degree centigrade it can operate. So, in earlier or very initial days of Rankine cycle-based power plant, they operate on the mercury. that the overall efficiency of the Rankine cycle based power plant was significantly higher now it is around 42% but if you are using mercury it can even cross 50% or 60% because mercury can transport large amount of heat from the boiler to the turbine but major drawbacks for this mercury is that mercury is not available at large quantity so very smaller quantity of mercury is available so whatever mercury is available that can be used to run only one plant or two plants but if we want to operate thousand number of plants across the world that amount of mercury is not available worldwide because it is the limited amount of liquid metal available not available in large quantity also this mercury has different type of environmental issues environmental pollution it is sometimes corrosive in nature also that's why During the initial days of Rankine cycle based power plant mercury was used earlier but at present days mercury has been abandoned. It is not used nowadays because it is now neither available cheaply not it is an environmentally it is very much environmentally polluting metal as we all everyone knows. Some of the organic liquids that also can be used in the low temperature Rankine cycle in case of combined cycle or dual cycle plants where different type of organic liquids also can be used to run a smaller capacity low temperature Rankine cycle where temperature of the cycle is around 100 degree or 150-degree centigrade different type of organic liquids can be used. But obviously it is in the rare case or in the very smaller quantity of this organic liquid can be used theoretically.

In real time very few plants or neither we can say no plant use such Rankine cycle-based plants where low temperature cycle is run. As water can transport more heat. as steam at high temperature and pressure so corresponding to the steam table enthalpy data so high pressurized water is fed to the boiler typically the high pressure water it is fed to the boiler so that the pressure of the water is already on the higher side so that it can absorb large quantity of heat when it is heated either in the evaporator as well as in the super heater that is the reason initially some pump is used which actually pressurize the water to high pressure if we pressurize the steam at high pressure it is very difficult to pressurize the steam and it will again condense back

that's why from the beginning in the circuits the high pressure water is used in this plant which is shown in this what is the purpose of this pump this pump actually pressurize the water at normal liquid water it is pressurized it at high pressure so that this high pressure water goes to economizer and evaporator and it converted to the steam if we pressurized here then it is very difficult to compress this water so high pressurized or pressurization is done through this pump here only so in this case particularly the steam table and enthalpy data is very important if we increase the pressure of the steam it will condense back to the liquid phase and if we then in such case we have to again add some amount of heat so that the condensed liquid water is again converted to the steam that's why this steam temperature enthalpy data is very much important when to put design or when to we decide that what temperature we should use and particularly if the steam has higher amount of liquid droplets like if we continuously increasing the pressure of this steam so in such case some amount of steam will condense back that means it will be liquid water but at high pressure so that high pressure liquid water at high temperature it will extremely corrode the turbine blades and others so it is required that water must be at high pressure temperature to transport the desired amount of energy and not to damage the boiler not to damage the turbine blades any change in the steam pressure temperature can lead to the phase change of water from vapor to the liquid phase then it is highly undesirable condition it will damage the turbine in the turbine it is designed to operate for the water vapor or steam so if some amount of steam is converted to the liquid phase water then its density will be high then the kinetic energy disposed on the turbine blades it will be on the significantly higher side and then the turbine blades will immediately get damaged and it will get immediately needs replacement so it is always monitor what is the steam temperature and pressure to ensure that at least 88 or 90 percent of the water steam is going there it must be in the vapor phase some less or zero amount of this steam may be converted to the liquid phase but that is in the very rare cases more than 90 percent of this steam must be in the vapor phase not in the liquid phase And pump is used to pressurize this water and it is sent to the boiler. The purpose of this pump is to pressurize the water. After the condenser, water is going to the pump and here pump compress the water to pressurize it from atmospheric pressure to high pressure so that high pressure liquid water goes to the evaporator so that it is converted to the steam.

So, if we see the purpose of this turbine is that typically turbine converts kinetic energy available from the steam to the rotational energy so that the rotor containing armature electrical cables they rotate with the necessary magnetic field due to variations in the magnetic field electricity is induced in the armature coil or electrical coil and mechanical energy is converted

with the electrical energy. And once this electricity is produced, it is then step up is done as per the requirement of electricity transmission. So, in this case to reduce the transmission loss, electricity whatever is produced that is converted to high voltage so that we can reduce the electrical transport energy loss and that is done through the a separate step of transformer and another a separate complete electrical engineering section is there where the electricity is converted to the high voltage and it is further transported to the grid and purpose of this high voltage is that to reduce the current or ampere in this transportation because the most of the electrical energy loss is happens it mostly depends on the  $VI$  or  $I^2 R$  as the electrical transport is going on the resistance for the electrical wire it is constant we cannot change it depending on the length or distance the electricity travels from the power plant to the consumer it can be 50 kilometers it can be 500 kilometers so this  $R$  we cannot change.

As per the available material, electrical wires are made. So, resistance of these electrical wires is constant. We cannot change it, but we can change the  $I$ . That is current flowing through this. Overall electricity power is given as the  $V$  and  $I$ . Now, if we increase the  $I$  in such case electricity that heat loss or ohmic loss for this electricity transmission will be significantly on the air side so major purpose of this to increase this voltage is that to reduce the current if we reduce the current significantly then the entire ohmic loss during transmission will be less so this is done by this  $VI$  is constant. So typically, that  $V_1 I_1 = V_2 I_2$ . So, if we reduce this current significantly, we have to increase the voltage significantly. So, major purpose of this tape of transformer or the electrical section is that to increase the voltage significantly. So, this increase in voltage typically, although this generation electricity can be maybe of 1000 volts or nearby, but it is increased to here maybe at 132 kV or may be 266 kV so this kilo volt in this range electricity is step up so that there will be significant decrease in the current or ampere in the electrical transmission circuit so the ohmic loss or transmission loss is significantly less because in conventional power plant this transmission loss is a major loss that from thermal power plant if it travels around 500 or 1000 kilometer there can have 20 to 30 percent electricity is lost due to this ohmic loss to reduce this just at the exit point of the thermal power plant there will be one electrical transmission units where the electricity is induced or generated from the armature or the turbine it is converted using a step of transformer to make it significantly higher voltage as per the requirement of the grid So, a separate electrical power transmission unit is always there which takes care about all these jobs. So, overall if we see this transmission unit there. super heater evaporator economizer they collect heat from the furnace they transfer it to the turbine and whatever the turbine electricity is produced the

electricity is induced in this electrical generator but this electrical generator voltage is on the lower side as per the design of the electrical generator or the manufacturer but this voltage is on the lower side so this voltage is step up to significantly higher may be 132 kV or may be 266 kV.

So, the transmission loss from this unit is significantly less. So, from this output unit of the thermal power plant, it goes to the electrical transmission units. The electrical power transmission units are separate units which it uses. Step up, and further it is connected to the grid. Now, why is grid connectivity required? As we have already discussed, many thermal power plants can change their production capacity day to day or from season to season to maintain the overall load of the country. A separate network of all the thermal power plants is made so that any minor change in the power consumption or sudden increase in the power consumption can be absorbed by the bigger network. So, for this, I recommend that you please go through this power plant engineering book by Professor P.K.Nag. This is a very well-written book on this aspect and all the aspects of the power plant's different units. It has been well discussed in this book.

Thank you.