Clean Coal Technology

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Week-11

Lecture-54

Hi, I, Professor Barun Kumar Nandi, welcome you in NPTEL online certification course on clean coal technology. We are at module 11, discussing coal-based power generation. So, we are discussing details about the coal-based power generation in coal-fired thermal power plant. and Rankine cycle-based power generation system. So, we will continue with the previous lectures in this lecture also.

So, let us start lecture 4 on coal-based power generation. Now, in the previous lecture, we have discussed the role of the economizer super heater etc. So, in this lecture we will discuss the remaining section of the coal based thermal power plants and their role in the power production or in the Rankine cycle. So, in the Rankine cycle the condenser is also a major unit used in steam cycle that the purpose of this condenser is to recycle back the working fluid. As we have seen in the steam turbine cycle that water is used as the working fluid.

Now this working fluid, this water is almost of pure H2O. It should not have any other impurities and etc. So, this purification of water is very much costly and that entire process is too much costly so that no impurities and other materials is present in this water. So always this water is recycled back in the system so that the same water recycled in the system and some amount of excess water whatever is required from the leakage or other that is used as the makeup water. So major purpose of this condenser is to recycle back the working fluid that steam is released in the turbine blades and from the turbine blade whatever is exhaust steam is there having less amount of heat energy and others so that steam or that liquid water is collected it is condensed to convert it from vapor phase to the liquid phase that is major objective is to convert this to vapor phase to liquid phase it also remove the unused heat whatever heat was sent to the turbine but some amount of heat will not be used so that unused heat from the steam must be removed and so the condenser does this job with the help of either cooling tower or by nearby water body so whatever the waste heat is there that this entire waste heat is released to the environment to the cooling tower or maybe nearby any big water body like river or other as per the design that unused steam whatever is there that must be condensed immediately to increase the efficiency as well as the pressure difference across the turbine so that it rotates at the high speed now if we see the turbine blades it will have three blades like if we see this one now from this side if it is coming at high velocity And from this side it is the downstream. So typically, in any of the such turbines this is called the upstream where the velocity of fluid like steam is significantly on the higher side.

This is called the downstream where after raising the kinetic energy over the turbine plates remaining amount of air or that wind or the steam it is passed to the downstream. Now this entire rotational speed of these turbines depends on the velocity at the upstream as well as the downstream. So, if in the downstream there the steam is stagnant that it is not removed then not more quantity of steam will be able to pass through this turbine. so it is always required that from the downstream whatever the steam is there whatever the other fluid is there that must be immediately removed if this steam is stagnant here it will prevent for any further entry of the newly coming steam so as a result the turbine blades and turbine rotational speed will fall and its efficiency will fall so to maintain the desirable turbine speed, it is always required that the out whatever the upstream velocity is there and in the downstream this velocity should be nearby to zero it should be ideally we should be zero so that it is always rotates at the highest speed but it is not practically be possible to make it zero so these two for steam purpose of or to make this downstream velocity zero so that the entire vapor from the downstream must be immediately removed. If we can immediately remove this vapor from the downstream, upstream velocity will be more and entire kinetic energy of the upstream steam, it will be released over the turbine blades. So, that is the job it is being done by the condenser in the condenser water is converted from the vapor phase to the liquid phase so water is coming here as the vapor and if it is converted to the liquid phase here in such case it may have 200 bar but here it is pressure will be zero. So immediately then it will get the pressure difference or delta p difference of 200 bar. It is the effective high-pressure difference it can get and turbine blades can rotate at high speed. But if it is not condensed suppose this speed is even at 40 bars. In such case their effective driving force is the 160 bars.

So, in such case efficiency of the turbine blades will fall. So, the turbine blades. does this job by immediately condensing these 40 bars to make it to zero. So, if this condenser works very smoothly, very efficiently from the downstream there will not be any amount of steam is available. So, whatever the steam is released over the turbine blades, the turbine blades can rotate very smoothly and it will rotate even at very higher speed because of we are making the downstream velocity zero, turbine blades or the condenser does this job if condenser takes lot of time to condense the exhaust steam then efficiency of the turbine blades will fall so this is the typical plots available in the textbook see if we see that if the input temperature is 470 degree centigrade now if the exhaust steam or the condenser side downstream that pressure is about 25 mm mercury the downstream pressure in the condenser should be nearby zero so if it is immediately condensed back there will not be 76 mm mercury it will be less than that so it will be less than atmospheric pressure or almost similar to the vacuum condition so in such case if it is the 25 mm hg or very less pressure is there Given at where degree centigrade in such case the efficiency will be significantly on the higher side where we can see if the pressure is increased from 20, 40, 60, 80 etc. So, in such case efficiency will be on the highest side. So, if contents are work very smooth because the downstream velocity or downstream steam pressure is almost zero or very less, in such case overall efficiency of the Rankine cycle is significantly improved. But if the condenser is not working smoothly, it is keeping the downstream steam pressure of 75%. mm which corresponds to the temperature about 36 degree centigrade in such case overall efficiency of the cycle will be much less so even if we consider that it is working at suppose it is working at this 80 bar so at this even of 80 bar here in such case it will efficiency at 39 percent nearby but in such case we can get efficiency of 42 percent for the Rankine cycle similarly if we go for the higher temperature of 140 bar and this pressure. In case of 140 bar, normal efficiency may be 41 percent, but here efficiency can be 43 percent.

So, that is the purpose of placing the condenser there. That condenser immediately removed the vapors by condensing it back to liquid. So, the downstream pressure across the turbine blade is zero or it is very less as a result turbine rotates at much higher speed at much higher efficiency so energy transport happens it much more efficiently as a result overall ranking cycle efficiency increases significantly two to three percent efficiency increase is higher side now as some amount of water vapor is lost as the condenser or there may have some other type of leakage also the steam can come out of the condenser across the turbine blades where some amount of air can also get mixed with these turbines so always some amount of makeup water is required to maintain the desired amount of water so that is done by continuously water purification units in the upstream process so as team with minerals like if we see that naturally water contains always some quantity of TDS which is known as the dissolved salt it can have different type of chemicals available it can have different type of organic compounds available so these all these material can be corrosive in nature particularly at high temperature as this water is collected for the power plant is from the nearby water bodies like a river or very big lake or pond so this naturally available water will always having some quantity of dissolved salt so this dissolved salt quantity can be available like 50 ppm or maybe thousand ppm in case of river water or other or other source of water so this TDS is extremely corrosive to the turbine blades because this TDS will go there along with the water so this during vaporization at the This TDS material will not vaporize. So only the water will get vaporized.

So, whatever the salt is there that will remain in the evaporator and the superheater stage. So, this they will continuously deposit across the steam tubes. So as a result, overall heat transfer coefficient of the steam tubes will be reducing. Its thickness will get continuously increased as the layer of this dissolved salt is significantly higher side. So, after some time that will create or that will cause a problem in the heat transfer across the boiler tubes because the metallic part will increase or decrease in its size as per the temperature. But the dissolved salt or TDS whatever is dissipated over the tubes they will not have same amount of thermal conductivity. so, as a result the boiler tubes will face thermal stress and its lifespan will get decreased and after certain time these boiler tubes must be replaced or must be cleaned properly so to avoid such complication in thermal power pen water of almost zero TDS is used that's why it is called like an pure water H2O so this quantity or this quality of water must be used there So, remove any type of dissolved salts. Similarly, if naturally water like river water or other, they may contain some different type of organic chemicals, pesticides, insecticides and other type of chemicals that can be dissolved in water. So, those are also corrosive to the entire steam cycle, different equipments like turbine blades, condenser as well as the boiler tubes they must be removed similarly any type of organic compound is present in the water they must be removed so to achieve all these things Because they can be damaged, they can be dangerous for the steam turbine as well as they can be very much corrosive to the other equipment particularly at the high temperature. So, water is purified at its best. So, there is a separate water purification unit or water handling unit is there which purifies water from river water. from atmospheric the condition to remove all the material as well as TDS chemicals organic compounds and other material even any dissolved oxygen do also that is also removed so there is a separate specific water purification unit or water treatment unit is there which makes naturally available water to purified at its best making it almost pure H2O and containing zero TDS and other material So there is always need a separate water treatment plant is always required which takes care about all these jobs. So, in a thermal power plant this unit is also there where the water which will be collected from the river that will be purified, that will be cleaned to remove all such impurities and then only that water can be entered to the steam turbine cycle. As this water consumption is there is always needs a water body. Similarly, whatever the condenser heat is there, condenser heat is released like this condenser heat or whatever is there. This condenser heat is released to the nearby to the cooling tower to the nearby river and others, so there is always a need of very big water body that water body must be having sufficient amount of water to operate the plant continuously because in plant always large amount of water is required for either cooling tower as well as for the water turbine cycle and as well as for the other units to operate to make the environment dust free and others. So, large quantity of water is always required. So, all these thermal based power plant, thermal power plants are installed or they should be installed to any river or nearby river as they need Continuously large amount of water.

If any river faces water shortage particularly in summer season and other then plant faces difficulty in running the entire plant operation. Similarly, if we see, there are the fly ash is produced from the flue gas. In the flue gas, different type of fly ash particles will be there. It can have some amount of SOX gases; nitrogen gases and other gases can be there. So, accordingly, as per the environmental guideline, different type of units is used. Like initially, that is, dust particles are captured by the cyclone separator, then followed by the ESP, as we have discussed in our previous modules of the environmental engineering part there. So, there will be a cyclone separator and ESP will be there. Typically, a back filter is not there because the temperature is on the higher side. So, these two units take care of all the fly ash capture and others, and whatever ash is produced, either through this fly ash as well as the bottom ash. There is a separate ash handling section which takes care of whatever ash is generated, depending on the particle size, their chemical characteristics, and others.

And this air handling section takes care of all these things along with the different types of pollution control measures that are also there, so that this flue gas doesn't contain any sulfur oxides and others. So, suitable amounts of flue gas desulfurization units and other units are also there as part of environmental pollution control units. Now, if we come to the efficiency of the Rankine cycle-based power plants, this efficiency of the Rankine cycle is decided by the thermodynamics or the operating parameters of the plant. So, the basic efficiency of the Rankine cycle is initially decided by the thermodynamics of the plant, like what is the amount of input heat and output heat or what is the amount of input energy and output energy in the Rankine cycle-based plant. Typically, this varies from 42 to 46%, depending on the steam turbine, high pressure, ultra-high pressure, or what condition this particular turbine is working in. And there can be other types of losses for which this efficiency further falls down. So, if we see the overall efficiency of any of the steam turbine-based power plants. It has some of the boiler efficiency because coal is burning there, and some amount of heat is wasted through the flue gas, so whatever the heat energy is input from the coal. Not the entire 100 percent amount of energy is transferred to the boiler. Some 60 to 70 percent energy will be transferred to the boiler or similar thing, and some quantity of heat will be wasted and that will be going out through the flue gas. So, to reduce this heat loss, there are different types of waste heat collection methods there. Where the primary air is preheated from the flue gas to transfer the heat, and similarly, the waste heat is also used to preheat, or we can say it is the primary economizer section where the high-pressure water is heated. From the liquid phase to the vapor phase in the economizer section.

So, there is an efficiency in the boiler also which can be suppose it is about 92% efficiency if boiler is working. That means whatever the heat energy is available from the coal 92% of the energy is transferred to the steam remaining 8% amount of energy is wasted to the environment to the flue gas and other medium. And there is the efficiency for the Rankine cycle, which can be 42% to 44%, 46% as per the steam pressure and temperature. If we are using high pressure steam or high temperature steam, then amount of energy transported significantly higher. In such case, efficiency will be on the higher side, maybe a 44%, 46%. If we are operating it at what temperature, 100 bar or 120 bar typically which happens in case of fluidized bed combustor so in such case cycle efficiency will be of the lower case so if you are using pulverized coal combustor unit in such case efficiency is go significantly higher side but if we go for the fluidized bed combustor at the temperature in the FBC unit are much less around 900 degrees centigrade that's the steam condition cannot be and extremely high temperature and pressure. So, in such case cycle efficiency is less than 44%. Now further there is also an efficiency factor for the turbine.

In the turbine steam goes there. Steam by the action of the steam it will rotate the turbine and the exhaust steam is released to the condenser. Now in this turbine not that entire amount of steam they releasing energy to the turbine blades. Some amount of energy is also available to the downstream steam part of the steam where this energy is removed by the condenser so depending on how much amount of energy is removed by the condenser your turbine will have some amount of efficiency if that efficiency is typically like 95 percent that means five percent of the energy whatever is available in the steam that five percent of energy is not being converted to the rotational energy so it will turbine will also have some efficiency

And further, the electrical generator where electricity is induced by Fleming's left-hand rule will also have some efficiency factor, maybe around 93 percent. Note that if the turbine is rotating, the entire amount of energy will be converted to electrical energy. Some amount of energy will be converted to heat energy. That's why the turbine armature cables or armature coils get heated. So, there will also be some amount of heat loss due to overheating of the electrical cables and other equipment.

So overall, it can have 93% efficiency. So overall, if we summarize, the boiler can have an efficiency of 92% here. Rankine cycle efficiency of about 44%, turbine efficiency of 95%, and generator efficiency of 93%. So, if we summarize the overall efficiency that can be achieved, 92% into 0.4 into 95 into 90 and another aspect is there: the auxiliary power consumption. This auxiliary power consumption is whatever is required to run the different equipment in the power plant. As it is, the coal handling section is there, with different types of crushers, grinders, and conveyor belts. So, the entire coal handling section needs a significant amount of electrical energy to run the plant. So, they also consume some amount of electrical energy. So, they will also have some amount of efficiency. If that efficiency is 95%, the overall final efficiency we can get is about 34%. That's why in any thermal power plant; it can operate around 34% to 35% efficiency. That means the remaining 65% of the energy is wasted and released into the environment in different forms, either as part of flue gas energy loss or as part of Rankine cycle energy loss to the condenser, as well as the heat energy loss in the generator. So, whenever we calculate the entire efficiency of the plant, it is based on this. Now, whenever we calculate the amount of coal required or coal fire needed, we have to use this 34% factor in the coal consumption calculation. For example, if we want a 500-megawatt power plant, we have to convert 500 megawatts to kilocalories per hour.

It will be converted to kilocalories per hour, as we have discussed. Then it will be adjusted for the 34% efficiency. And so, we can get the actual amount of energy required from the coal in the boiler. Based on the GCV of the coal, we can calculate the amount of coal feed rate required. This calculation process has been discussed in our previous lectures.

If we see how the efficiency of the Rankine cycle is calculated, the overall efficiency of the Rankine cycle is based on the total amount of energy available or heat energy available and how much energy has been converted to electricity by the turbine. These depend on different factors like Q1, Q2, Wt, and Wp, where Q1 is the heat transfer to the working fluid—how much heat is transferred from the boiler to the working fluid. And how much energy this working fluid actually transfers to the turbine. That means the Q2 amount of energy is wasted in the condenser. The working fluid receives Q1 amount of heat, and Q2 amount of heat is wasted in the condenser. The remaining amount, Q1 minus Q2, is actually transferred to the turbine blades. There, it will contribute to the individual work transfer from the working fluid and work transport into the working fluid. That is the amount of energy we are considering there. So, the overall efficiency can be determined based on this factor , Wt minus Wp by Q1: what is the total amount of heat energy transferred to the working fluid? So, in this way, we get the formula that is 1 minus Q2 by Q1, where Q2 is the amount of heat rejected. So, if this Q2 amount is there—that amount of heat rejected in the condenser is significantly on the higher side—then the efficiency will fall. If the Q2 quantity is very less, then this efficiency is very high. So, it entirely depends on the turbine blades and the entire operation—how much amount of energy or efficiency can be there.

So, the entire Rankine cycle efficiency particularly depends on 1 minus Q2 by Q1. So, naturally, not that entire amount of steam energy will be transferred to the turbine blades—some amount of exhaust steam will be there in the downstream of the turbine. So, as a result, it will never have an efficiency of 100%. That is why this efficiency can be about 42 to 46% or whatever. And if we see the detailed methods—how this W1, W2 plays a role—we are burning this fuel, we are getting this air here, and so the furnace will have an amount of heat energy released—that is the calorific value into the mass of coal.

The amount of mass and calorific value—that amount of energy will be released to the furnace, and from that, some amount of exhaust flue gas will be there, which will take some amount of heat loss. So, after that, whatever heat is released from the furnace—some amount of heat loss is there to the flue gas—the remaining amount of heat is actually entered in the cycle or in the Rankine cycle-based steam cycle. So, out of this Q1 amount of energy, it initially converts in the boiler. It is converted in the first unit to convert this water into the gaseous phase.

So, the boiler converts water to the gaseous phase here. It does the first unit. It goes to the turbine. Here, the turbine at the T, if work is done to the shaft, it generates electricity. We get it and after the exhaust heat is there, it goes to the water as a condenser. That is in the condenser point, liquid water will go, and this water is then condensed. The water goes to the pump, which will again recycle the water, and that is why this pump also consumes some amount of energy to compress or pressurize this water, which is the WP. So overall, if we see, these are the four main energy factors: Qm is the amount of energy actually entered in the cycle, Qt is the amount of energy that is removed by the condenser, which goes to the river. So, Q1 minus Q2 is the actual amount of energy input there, and this work done by the shaft is there, and work done by the motor is also there. The pump is also there. So, we get accordingly the energy calculations. Now, if we discuss the other aspects, like auxiliary fuel. In regular thermal power plant operation, some amount of auxiliary fuel is always required, which is typically liquid fuel. The supplied coal may have variations in its calorific value as well as its combustion characteristics, which may not be the same every day because, in thermal power plants, coal is received from multiple sources, and not the same amount or type of coal is received every day. So, any minor variations in the coal properties, either in its calorific value or its combustion characteristics. So, that is made up by using liquid fuel, typically fuel oil is used. So, minor one or two percent energy is always provided by this liquid fuel so that the temperature profile inside the boiler remains constant, and the steam quality, whatever is required for the turbine, is maintained and also this liquid fuel is also used in the initial part when the plant is started where the boiler temperature is from atmospheric condition to the atmospheric condition at 25 degree centigrade 30 degree centigrade to the 1000 or 1200 degree centigrade, so that temperature rise is typically done by the liquid fuel firing and after the temperature of 1200 degree is achieved then the coal combustion started and liquid fuel supply is stopped. So, in this way always plant need some amount of auxiliary fuel like liquid fuel mostly fuel oil is used to make up this required amount of energy. There is always some amount of auxiliary power is also there that is electricity consumed in the entire plant operation. In the entire plant there are some control units, there are different type of compressor, pump. coal handling section everything is there so they always consume large amount of electricity even different type of office and other section is there they also consume ESP also consume some amount of electricity as handling section consume some amount of electricity water purification unit they also consume some amount of electricity. So all these energy or electricity consumption is called the auxiliary power consumption if this auxiliary power consumption in the higher side in the plant efficiency is less that means out of 500 megawatt electricity produce auxiliary power consumption if it is 30 or 40 megawatt that means 10 percent of the energy is consumed in the plant itself so it should be lower as lower as possible then there is some fly ash utilization section is also there in thermal power plant it has to think about this fly ash whatever fly ash is produced it is one type of solid waste it takes large amount of space in the plant to discharge at what location so typically they plant they transfer this fly ash to other consumer or the plants maybe cement plants or other companies buy these fly ash and use it for their different purposes maybe cement manufacturing or bricks manufacturing or land filling whatever so it is one type of solid waste for the plant they have to dispose it discard it to any other location and the final electricity is transmitted to the grid so there is always some section is there which will be always contact with the grid in depending on the amount of electricity to be produced based on the requirement of the grid because once coal is burned energy is released from the coal electricity is produced now electricity is produced whether we are consuming or not it will be wasted so coal will be wasted so power production must be done with correlating with the power requirement in the grid if our requirement is the grid is less than the power production should be controlled to some extent so that there is not wastage of energy and steam pressure for efficiency plot is important particularly for the steam turbine the steam pressure and efficiency very important if we increase the pressure of the steam some amount of steam will condense back so we have to add some more amount of heat to make it again to vapor phase. So, this steam pressure and efficiency plot is important and that is highest temperature and pressure of the steam is decided by the metallurgical limit of the plant. That means what is the material used in the manufacturing of boiler tubes, turbine blades and other. Up to what temperature, what pressure they can extend this condition.

So the maximum operating temperature and pressure are limited typically by the metallurgical limit of these boiler tubes, turbine blades, and these circuits. And to improve the efficiency of the plant, to improve the mass, a greater quantity of steam can be utilized. Because in only one cycle, not the total amount of steam is converted to electricity. There can be a requirement for different other low-temperature cycles; medium-temperature cycles are also there. So there can be different types of turbines also there.

In an actual power plant, there are always two or three different turbines there. One is operating at the high-pressure turbine. which gets the fresh steam, and the exhaust steam goes to the medium-pressure turbine; then that exhaust steam goes to the low-pressure turbine. So always three different turbines work at three different pressures. The first turbine will work at the highest condition, maybe 200 bar; the second turbine may work at 75 or 50 bar; the third turbine may work at 10 or 15 bar. So different types of turbines are used to improve the differential increase in efficiency. Like the first turbine may give 35% efficiency, the next turbine may produce some much more quantity of electricity, and the third may produce some much more quantity of electricity. So there are always different types of reheating cycles there to maintain the steam quality as per the low-pressure turbine, medium-pressure turbine, as well as the high-pressure turbine.

If we go for so many types of reheating cycles, then the plant complexity also increases. It is very difficult to maintain the actual steam condition, pressure, coal combustion, etc., so it is based on up to what extent we can make plant operation complex and up to what extent we can control this entire complex plant. Because if we go for such a complex plant, plant efficiency will be increased, but plant operation or maintenance of the individual units will be very difficult. So, it is based on that plant complexity; to some extent, it is required but not to a very higher extent. So, simplicity is desired if you see the process control aspect because the entire plant operation has to be controlled so that all the units operate at the same synchronization. So, some amount of complexity is there in terms of reheating cycles and other things, but the final decision is based on up to what extent our control system can accept and up to what extent we can operate the plant very smoothly. And in some of the plants, there is always some amount of cogeneration there.

This cogeneration typically occurs where, along with electricity, some amount of heat or steam is also used, as we burn coal, and from burning coal, we can produce heat. So, in the same plant, maybe some other unit is there which needs heat to operate or which needs steam to operate, producing some chemicals and others. So, in the same plant, we can simultaneously produce electricity as well as supply heat or steam to another plant. So, that system is called cogeneration. If we go for this cogeneration system, we can operate multiple plants, like one power plant and another chemical-producing plant or chemical synthesis plant, which will use waste heat or steam from this thermal power plant.

In such cases, the efficiency of the plant is significantly increased. So overall, if we go for this cogeneration part, waste heat or steam released from the power generation unit is transferred to the material processing section of another plant, as they utilize it in such plants where fuel is used for both electricity as well as cogeneration of heat and others, so overall. In such cases, efficiency is higher. In such plants, we call it cogeneration of heat. In this way, we can increase the efficiency of the plant by simultaneously producing heat. For other plants as well as the electricity for these plants. So, in this way, we can increase the efficiency of the plant from 35% to 40% or 45%, and we can also reduce the environmental impact or pollution from coal, efficiently utilizing coal in this way.

Thank you.