# Clean Coal Technology

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**Week-08**

**Lecture-38**

Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on clean coal technology. We are in module 8, discussing various emission control strategies for combustion utilities. So, in this module, we have already discussed SOx and NOx control strategies during and post-combustion. Now, in this class, I will be discussing oxy-fuel combustion. So, let's start lecture 3 on oxy-fuel combustion.

So, if we see, what is the purpose or what actually is oxy-fuel combustion? Typically, oxy-fuel combustion is the process where coal or any similar fuel is burned in an oxygen-rich environment and almost zero-nitrogen condition. So, if we see, the main purpose of this oxy-fuel combustion is that any fuel like coal—it can be any gaseous fuel like acetylene, natural gas, or methane—whatever it is, if it is burned in any condition where oxygen concentration is on the higher side, so it is the oxygen-rich environment, and there will be almost zero nitrogen. That means whatever the gas medium or whatever the air medium will be used for the combustion purpose, in such air or oxygen, there will be almost zero percent nitrogen. That means it is almost nitrogen-free—maybe trace amounts of nitrogen are there, or maybe they are, but theoretically, we can say it is like a zero-percent nitrogen condition. And if we avoid or if we eliminate nitrogen from the air, as this nitrogen present in the air causes NOx formation at high temperature, and there are many other issues with the nitrogen if it is available from the air.

So, there are many other issues also there, which we will be discussing here. So, all these problems we can eliminate if we do the coal combustion or fuel combustion in an oxygen-rich environment and zero-nitrogen condition. So, in such a case, the first thing is that we will eliminate or reduce the probability of NOx formation from the combustion utilities. Now, how will this NOx formation be reduced, as there is no nitrogen from the air?

So, whatever the nitrogen is available only from the fuel side that may form some of the NOx compound during the combustion process. So, we can eliminate the probability of NOx formation in the combustor. So, if we can eliminate the NOx formation, whatever the heat required for this conversion, like we have seen that this N2 plus O2, this reaction, N2 plus O2, which form NOx, there most of them are in the endothermic reaction. That means they need heat or they need heat from the combustion chamber which will they will utilize to do this reaction as this reaction is endothermic in nature it needs additional heat supply so whatever the heat was supplied or generated from the fuel by burning it or by combustion process some part of the heat will be utilized to carry these reactions for NOx formation. So, if there is no nitrogen in the air, so these reactions will not be happening. So, whatever the energy was utilized for this NOx formation, that amount of heat energy will be present in the combustor as well as the temperature of the combustor will get increased. So, that is the first purpose if we can avoid any NOx formation.

Second is that even if nitrogen was not doing any of the NOx formation reaction till if we see the condition of air, it enters at approximately 300 degrees centigrade if it is the preheated or it enters around 330 degrees centigrade if it is the preheated. normal air or atmospheric air. So, in such case, this air will exit at higher temperature, maybe at 1000 degree centigrade. So, whatever the sensible heat was required to convert or to heat this nitrogen gas from 300 degree to 1000 degree centigrade, that corresponding to MCP delta T, that amount of heat will not be consumed in the system. So that amount of heat will also be available in the system, so overall thermal efficiency of the system will get significantly increased if we can avoid this air with zero means if we can utilize air with zero nitrogen. So, there are many other similar issues if we eliminate nitrogen gas from the air and if we go for oxy-fuel combustion. So, in such a case, the flue gas released from the combustor will be rich in CO2 and H2O, meaning since there is no nitrogen present, only Carbon will be converted to carbon dioxide, hydrogen will be converted to H2O, and if sulfur is present, it will convert to SO2. Since nitrogen is not converting anything, we can get a pure mixture of carbon dioxide and H2O, and maybe some sulfur dioxide if sulfur is present. So, it will be rich in carbon dioxide and water. Since water can be separated by condensation, we can get almost pure carbon dioxide.

So, whatever carbon dioxide is produced from such combustion, like oxy-fuel combustion, it will be almost pure. 90% or 95% purity. Such high-purity carbon dioxide can be utilized as a source of chemicals in various other chemical industries where carbon dioxide gas is used to produce many more products. This type of high-concentration carbon dioxide can be captured easily in cylinders or maybe in liquid phase or other phases, where it can be supplied to nearby chemical industries that use carbon dioxide as a reagent for their chemical processing.

So, if we use oxy-fuel combustion, there are many more advantages we can gain. If $CO_2$ is not utilized for this purpose, it can still be captured and stored below the earth's surface as part of carbon dioxide capture, which we will discuss in our next classes. So, oxy-fuel combustion is an emerging approach to post-combustion $CO_2$ capture. If we use oxy-fuel combustion, we can get almost pure or highly enriched carbon dioxide gas in the flue gas, which can be easily stored, utilized, or has many more applications since it is pure carbon dioxide.

so, if we go for air fuel combustion this advantage will not be there but if we go for the oxy fuel combustion this advantage we can easily get and another advantage of this oxy fuel combustion is that as there is no nitrogen present in the input gas like if we see the air it has about 80% nitrogen and 20% oxygen so effectively it has 80% nitrogen and about 20% oxygen. So, whatever the volume of the air we are using, like if we are using 30 liters of air, so out of these 30 liters, 80% corresponding to nitrogen. But if we are using pure oxy fuel combustion, we have to use only, that means we have to only use 6-liter oxygen. So accordingly, the volume of air utilized in the combustor chamber, that will be decreased significantly. That means if we go for an air fuel combustion we have to utilize a reactor which can handle 30 liters of air which contains 24 liters of nitrogen roughly and 6 liters of oxygen. but if we use pure oxygen fuel combustion then only six liter capacity reactor will be enough to do the reaction so entire combustion we can do in a small size reactor or small size combustor where we can have much more better control over the combustion process heat losses and equipment design all these things we can be better managed if we are able to do it in a small size reactor like if we are using a bigger size reactor whatever the heat insulation cost like refractory material cost heat insulation thickness of the heat insulation all these things needs to be done for a 30 liters volume reactor but if we use a pure oxygen reactor here the volume is only 6 liter so overall insulation cost will be much less and the amount of refractory material and other materials will also be less and eventually we can have much more better heat loss control that means heat loss we can minimize much more efficiently if we use a small size reactor if we use a very big size reactor we may not be able to control heat losses from all the sides as it will have higher amount of surface area available for heat loss all the convection heat loss conduction heat loss will be much more higher side but if we can reduce the size of the reactor We can reduce this conduction and convection heat loss tremendously as well as the surface area to be covered is less. Even we can use some much more efficient or costly insulator, much more efficient insulator which can eliminate further damage. heat loss from the system so effectively if we can use that oxy fuel combustion in such case the volume of the reactor will be significantly smaller that means almost one-fifth will be the size of the reactor in such case we can efficiently do the combustion reactions in much more better way with much more energy efficient much more low cost and all these things so if nitrogen is not present Input gas volume for both input gas and product flow gas is significantly reduced.

So, it is useful in many aspects when we design a combustor. And if we want to obtain pure oxygen, we have to use a suitable air separation unit, which will separate nitrogen gas and oxygen gas. So overall, if we see, oxy-fuel combustion is advantageous in many more ways compared to air-fuel combustion, particularly if we consider that it produces only pure CO2 and there is no NOx formation. Effectively, the heat loss caused by nitrogen gas—both in terms of sensible heat loss and the chemical reaction heat loss required for NOx formation—can be eliminated. So, we can easily achieve much higher temperatures, meaning that in oxy-fuel combustion, achieving temperatures in the range of 1500 to 2000 degrees Celsius is much easier, whereas it is very difficult in normal air-fuel combustion.

Typically, cryogenic temperatures, like if we reduce the temperature of the air to about minus 200 degrees Celsius, that is the temperature—or nearby—where cryogenic separation occurs, where one gas will be in the liquid phase and another in the gaseous phase. So, using this cryogenic separation, which is typically used to obtain pure nitrogen as well as pure oxygen gas, is the conventional method for refilling oxygen cylinders. for different purposes, as well as refilling nitrogen cylinders for industrial applications. Most cryogenic separations are used to separate nitrogen and oxygen before feeding the oxygen to the furnace, where it is used to burn coal. That means if we want to use oxy-fuel combustion, we have to install another plant nearby to separate nitrogen and oxygen using cryogenic separation. Although, at present, many other techniques are also being developed, such as membrane separation using selective membranes, and some adsorption techniques exist, cryogenic separation remains the most widely used method in industrial practice to obtain pure or highly enriched oxygen and nitrogen gas. So, that is the additional cost involved if we opt for oxy-fuel combustion—in coal or fuel combustion units, we have to set up another plant to produce pure or highly concentrated oxygen through cryogenic separation.

So, in cryogenic separation, almost all the nitrogen is removed from the air, and we can achieve oxygen concentrations of about 95 percent or more. Effectively, we can obtain 95 percent pure oxygen, which can be used for combustion purposes. Another important aspect of oxy-fuel combustion is regulating the flame temperature and other related combustion issues. If we consider using pure oxygen gas or even 95 percent pure oxygen gas, effectively, the feed concentration of the reactant is increased. As we see, C plus O2 produces CO2.

Now, if the concentration of this oxygen is increased, in such a case, the reaction will always go in the forward direction. So, as one of the reactant concentrations is increased, if we are using the normal air, their concentration is less because the partial pressure of oxygen in oxy-fuel combustion is on the higher side. Since it has 95 percent or 96 percent oxygen, the partial pressure is high, and the concentration of oxygen is high. Thus, the overall reactant concentration is on the higher side, so the reaction will always proceed in the forward direction, which means the rate of combustion of coal or the rate of combustion of fuel will increase significantly if we opt for oxy-fuel combustion. As a result, it may be possible that the flame temperature increases significantly.

For instance, if we want to maintain a temperature of 1200 to 1300 degrees centigrade, it will be very difficult because the rate of combustion is very high. So, unless we regulate the fuel very precisely, there will be a very high temperature in the combustor. And that high temperature may or may not be a desirable condition. So, to control or regulate the temperature better—just like if we want exactly 1300 degrees centigrade without it rising even to 1350 degrees centigrade— in such cases, mostly the flue gas is recycled back into the combustor.

This is a common design and control technique: the flue gas released from the combustor is sometimes sent back to the reactor or furnace so that there will be a much more efficient heat balance in the system. Additionally, any excess oxygen provided can be recycled back, as we have discussed in our previous classes. This is a very common design—recycling flue gas back into the system—so that there will be much better temperature control in the system. So, it is one of the process control parameters to regulate the temperature of the combustor. If the temperature of the combustor exceeds a certain threshold, it can damage many other pieces of equipment, and there can be other consequences, such as ash fusion and other issues. The advantages of this include a lower flue gas volume so if we go for the oxy fuel combustion we can also have to handle lower amount of flow gas volume as there is no nitrogen present and high degree of combustion efficiency is there as oxygen concentration is always on the higher side so all the coal will get completely burned or all the fuel will get completely burned so effectively its combustion efficiency will be significantly improved even at it is showing some higher temperature in addition whatever the oxy fuel the CO2 generated from the oxy fuel it will be relatively pure and can be easily separated from the steam by cooling as the generating

$CO_2$ and $H_2O$. So, $H_2O$ can be later separated by simply cooling down as it will condense in the liquid phase and we can get pure $CO_2$ and if we use the oxy fuel combustion we can see that there is no nitrogen present, so it will be about 70 to 80 percent less amount of flue gas will be generated. So, if flue gas quantity is very less we can efficiently put some cyclone separator some ESP some bag filter we can manage it in much better way much more efficient way if flue gas volume is less This lower flue gas volume also makes it easier for removal of any other pollutant like sulfur emission or mercury, fly ash, etc. Even that means if the flue gas volume is very less, we can utilize very much more efficient design to capture SOX.

If any NOX is there, any mercury or any other heavy metals which may be available in the fly ash solution. or coal combustion utilities. So, whatever even in present days there is some concern about the presence of chlorine fluorine bromine these type of metals elements in the coal and they are also oxidized during combustion they also are very harmful to the environment. So all this pollutant also can be easily managed easily controlled if we use low volume flow gas as we are using oxy fuel combustion and as there is no nitrogen this NOx production is almost zero or it is almost eliminated and if we go for your oxy fuel combustion power production involves three major component like it needs an oxygen production unit it needs an oxy fuel combustion units and it needs and $CO_2$ purification and compression units so that whatever the $CO_2$ is produced that can be compressed to a liquid phase that can be marketed as a value-added product That is then byproduct of the plant which can be sold to the nearby chemical companies who use $CO_2$ for different purpose.

Oxy fuel combustion system can be configured differently with these components resulting in different energetic and economical performances. So, overall, if you see the different challenges for this oxy-fuel combustion is that one is the capital cost. There is a significant amount of capital cost involved, particularly if we want to install any of these gas separation unit. As it is, if we can get pure oxygen as free of cost, the process is very much efficient. But in this process, as we have to installed a separate plant or separate facilities from which we can separate air to get pure oxygen. So that involves some cost and that is the major operating cost for this plant and particularly for the thermal power plants. So that is the main challenge to get this capital cost as well as the operating cost for this air purification unit its energy consumption as in cryogenic separation large amount of electricity will be consumed to compress and reduce the temperature. So, there is some energy consumption is also there and there are many more other operational challenges as we are going for a normal air purification unit. So that is the main hurdle to make this cost competitiveness of this oxy fuel combustion. So overall if we see that oxy fuel combustion method is very good but it has many more technical challenges, energy consumption challenge and finally it is the economical and profitability parameters which decide whether oxy fuel combustion should be used or not as there is some major cost involved in the generating pure oxygen or getting pure oxygen from the air. Typically, oxy fuel combustion system performances can be improved by Two means that is if we can reduce the cost of oxygen to the system.

That means if we can get oxygen or pure oxygen at much lower cost. So, in such case the oxyfuel combustion is can be utilized in many more plants and if we can improve the overall efficiency of this plant so that the overall combustion efficiency or overall, the plant efficiency if it is increased significantly in such case whatever the cost involved in this oxygen purification and other that can be taken care. If we go for the oxyfuel combustion, this is the main pathways what we have to get. Either we have to get pure oxygen at low cost or there should have significant improvement efficiency in the plant by different design or different operational modifications. So, strategies to improve the oxy-fuel combustion system efficiency at reduced capital cost that offsets the challenges of the oxygen production.

So, that is nowadays the main challenge, how we can utilize this oxy-fuel combustion in much better way without any major improvement or major increase in the operating cost and how we can improve the performance of the combustor. So these are the different advantages like what we can get from the oxyfuel combustion like what we have discussed that reduce the volume of the reactor or combustor as 80 percent volume of the air is eliminated that is the great savings in the design and size of the reactor can have better thermal efficiency if it is a lower size reactor it will have lower heat loss better control space saving low investment and maintenance cost enriched oxygen is also used in combustion, so rate of combustion improved hence complete combustion coal may takes place and easily we can reduce the unburned carbon monoxide etc. and as we are getting pure carbon dioxide from the flue gas that can be used as an chemicals from other industries also and the last more part which is nowadays an upcoming method when we Think about the carbon dioxide utilization methods.

Like if we see that carbon dioxide is produced from the coal-fired utilities, and this amount of carbon dioxide released is significantly high. So, although we can go for oxy-fuel combustion, carbon dioxide will still be released, and if carbon dioxide is not utilized in any of the plants. So, typically if we go for oxy-fuel combustion, high-concentration carbon dioxide will be released from the plant, and such high-concentration oxygen can also be dangerous to nearby localities, as oxygen and carbon dioxide are heavier than air. So, it will easily come down and settle down, and there will be a shortage of oxygen as carbon dioxide density is higher; its molecular weight is 44 compared to air or nitrogen and oxygen, which are around 28 and 32.

So, carbon dioxide is heavier. So, if we do not utilize this pure carbon dioxide released from the oxy-fuel combustion utilities, it can have many more challenges. to the environment, as it is actually a threat to the environment if we are not using this oxy-fuel combustion-released carbon dioxide. So, this carbon dioxide must be captured and used in any other chemical production or chemical plants. So that we should not release this high-concentration CO2 into the nearby atmosphere.

So, one of these methods is that nowadays people are thinking or people are adopting, which is going for the coal-to-chemicals method, particularly for the production of methanol and other compounds for the production of different types of organic compounds. So, in all these organic compound productions, CO2 is the raw material to be used. by the Fischer-Tropsch reaction to convert it to methanol. So, this is nowadays a new challenge, and many plants are opting for a similar process.

How can we convert this CO2 into methanol production so that the high-concentration CO2 released from oxy-fuel combustion can be used to produce valuable chemicals? Now, with the increase in solar energy in this way, CO2 can be converted into methanol using solar energy or other energy sources so that we can utilize this CO2 more efficiently and avoid releasing it into the atmosphere. These fields are emerging, and industries are exploring them for methanol production from CO2. Overall, if we consider oxy-fuel combustion,

To summarize, oxy-fuel combustion is a highly efficient technique that benefits thermal power plants and combustion utilities by reducing flue gas volume and particularly lowering NOx emissions. Additionally, chemical looping combustion and other emerging technologies will adopt oxy-fuel combustion to reduce NOx emissions. By implementing oxy-fuel combustion, we can achieve high temperatures. A real-world example is gas cutting or welding, where pure oxygen from cylinders generates temperatures of 2000 to 2500 degrees Celsius as needed. At that rate, the burning or combustion rate of the fuel improves significantly. We can achieve a much higher heat release.

Through oxy-fuel combustion, we can effectively achieve very high temperatures and combustion rates, reducing NOx emissions as well as other combustion-related issues in the plant, such as unburned carbon, unburned hydrocarbons, carbon monoxide generation, etc. This is a highly effective technique, but the main challenge is the cost associated with obtaining pure oxygen or separating oxygen from air, which is the primary technical hurdle for oxy-fuel combustion. Additionally, if the released $CO_2$ and byproducts are not utilized properly, they pose an environmental threat, as $CO_2$ concentrations in nearby areas could rise significantly, affecting nearby populations and creating other environmental challenges.

So, this $CO_2$ must be captured or utilized in a much more efficient way so that we can get the advantages of oxy-fuel combustion from coal-fired utilities.

Thank you.