

Clean Coal Technology
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Week-08
Lecture-40

Hi, I am Professor Barun Kumar Nandi, welcoming you to the NPTEL online certification course on clean coal technology. In Module 8, we will discuss various emission control strategies for coal-fired combustion utilities. So, in this module, we have already discussed SO_x and NO_x control strategies during combustion and post-combustion from coal-fired utilities. Oxy-fuel combustion and carbon dioxide capture have also been discussed. So, in this Lecture 5, I will discuss carbon dioxide storage and its utilization.

So, let's start Lecture 5 on carbon dioxide capture and storage. If we observe the amount of carbon dioxide produced or released from coal-fired utilities, its volume is extremely large. So, when this large quantity of carbon dioxide is released from any plant or industry, we must ensure that the entire amount of carbon dioxide can be utilized in various other applications. Accordingly, the utilization strategies vary based on the amount of carbon dioxide that can be captured and stored.

While small quantities of carbon dioxide can be used in different small-scale applications, for large volumes of carbon dioxide, we must find large-scale utilization as well as storage or disposal solutions. So, there are different technologies or methods currently available where we can utilize pure carbon dioxide or carbon dioxide-rich flue gas in various applications. First, the major utilization for carbon dioxide is in enhanced oil recovery and enhanced natural gas recovery, where carbon dioxide is used or injected into the oil, to extract crude oil as well as natural gas.

So here, carbon dioxide can be sent there or injected there, which typically improves the recovery of natural gas as well as crude oil. The same carbon dioxide can also be used in different plastics and chemical industries, as carbon dioxide is one of the raw materials for making different types of plastics, carbonates, and polycarbonate-type plastics and chemicals. Some of the carbon dioxide can also be used in biomass or biomass growth, similar to bio-algae growth. to improve their bio-algae growth, as carbon dioxide is the feed material for the

photosynthesis process. So, in the presence of enriched carbon dioxide, the growth of such algae is increased, and they can be utilized there.

A smaller quantity of carbon dioxide can also be utilized in the production of soft drinks, but we consume it daily or on some particular days in a year. In the production of soft drinks, typically, carbon dioxide is mixed with water to make it soluble. So, in those applications, we can use pure carbon dioxide, at least food-grade carbon dioxide. Similarly, this carbon dioxide in its liquid phase can also be used for the extraction of different types of oils and other chemicals, which may be utilized in the solvent extraction process. And this can also be used as a cleaning material. So here, a suitable solvent is required.

Liquid carbon dioxide can also be used as a refrigerant. In different cooling applications where carbon dioxide is cooled and can act as a very good refrigerant, replacing conventional materials. Carbon dioxide is also used as a fire suppression material or inerting agent, which creates an inert atmosphere that prevents combustion and fire in extreme conditions. To extinguish the fire or prevent it from continuing. So, in such cases for fire suppression, carbon dioxide gas is also used. So, some quantity of carbon dioxide can also be stored in this type of fire suppression container and may be used when required.

And there are other applications like this; dry ice is also used in our daily life for different purposes. So dry ice is typically the solid phase of carbon dioxide. Similarly, some quantity is also used during sandblasting, some medical oxygen, great oxygen where the oxygen is very pure, highly pure; some quantity of carbon dioxide is also added to avoid or reduce the purity of oxygen so that humans can take it. It can also be used as an aerosol propellant material. And after all these uses, whenever we find some excess amount of carbon dioxide, it can also be stored in a suitable location below the Earth's surface, like any location where carbon dioxide can be stored geographically in a deep saline reservoir or maybe in an oil or gas reservoir where it may be below the Earth's surface at 1 km or 5 km; any suitable locations, we can store this carbon dioxide also. So, if we discuss one by one, Typically, in enhanced oil recovery, nowadays carbon dioxide is widely used. The main purpose of enhanced oil recovery or terminology is that typically in normal crude oil extraction or natural gas recovery, hot water is sent to the oil, and this hot water typically reduces the viscosity of the crude oil and increases the flowability, also forcing that crude oil to come out through a pipeline. Now, by this process, some of the crude oil cannot be extracted as this steam cannot go to every point at every location. So, there is always some unexpected crude oil and natural gas there, which is very

difficult to extract by the conventional method. So, if we want to extract this additional amount of crude oil from the conventional method, that is called enhanced oil recovery. So, in enhanced oil recovery, we give some additional effort and try to recover the additional amount of oil as well as the natural gas which is not recovered by the conventional method. So, in this method, typically high-pressure carbon dioxide in the supercritical stage, in the supercritical state, this high-pressure carbon dioxide is injected in an oilfield typically below the 2000 feet of the well along with hot water and steam. So, in this method, typically carbon dioxide is injected in the well along with the conventional hot water as well as steam. As such, CO₂ is miscible with crude oil. Typically, crude oil is highly miscible with carbon dioxide. So, miscibility between crude oil and carbon dioxide is on the higher side. So, carbon dioxide, whatever is injected from the external source, gets easily miscible with the crude oil, and it's The result is that it reduces the viscosity of the oil.

So, what about the oil which was not being able to be extracted by the hot water or steam? So, that oil can be extracted by the Carbon dioxide. As carbon dioxide also reducing its viscosity and as it is a gaseous phase in the supercritical stage, so it can easily move at every pore or every porous structure, porous layer where water or steam may not be able to go there. So as a result, carbon dioxide can go at each and every point or each and every location of the well, which is where the oil is stored inside some of the rocks. So, each and every rock will be getting the carbon dioxide and from that location, easily the oil can come out as it has modified its viscosity and surface tension.

So as a result, crude oil easily gets out of the rock. So, purpose of this carbon dioxide injection is that that it will improve or it will help to get the oil out of the rock where in the inside the rock in the porous structure oil or natural gas are present. So crude oil will able to force them that could to come out of that rock and easily get mixed with the water and steam and that can come out below the earth surface easily. So, there will have a significant improvement in the oil production as compared to the only steam. So, if we inject only steam, their oil production capacity will be less.

But if we inject this carbon dioxide in high pressure, overall, the oil extraction capacity is or oil production capacity is significantly improved. So, enhanced oil recovery as the process is on the large scale we can utilize large volume of carbon dioxide generated from the thermal power plant easily. So, this is the best method or you can say in the method where large amount of carbon dioxide can be utilized. So, in this process some amount of carbon dioxide can come

out along with the oil, so about 20 to 30 percent of carbon dioxide may come out to the atmosphere along with the oil and which can be typically recycled inside the plant as this whatever oil and water mixture is coming, we can after recovery of oil we can send back the same water and same oil mixture inside the Well, to extract more.

So, this is the one type of recycle process. Although some amount of carbon dioxide may not be able to recycle, but most of the carbon dioxide can be recycled in this process. And maximum amount of carbon dioxide typically they stay inside the porous structure of the rock. So about 70 to 80 percent of the carbon dioxide, they can stay inside the rock for longer time as the pore size pore volume is matches with the carbon dioxide. So, they can stay trapped inside the rock for longer duration and they can do their suitable chemical reactions whatever is possible. So as a result, we can at least reduce or send some amount of carbon dioxide below the earth surface as a safe storage in some of the cases if it has some salty water also so salty water or sea water also can trap carbon dioxide by similar reactions. Second most utilization of the carbon dioxide is utilization in the chemicals and plastics typically there are different chemicals are available and for which manufacture the carbon dioxide is a raw material for their manufacturing so carbon dioxide is an raw material used in many chemical industries to manufacture many chemicals particularly carbonate and bicarbonate based inorganic salt as well as the some of the polymer and plastics So CO₂ can be utilized as a feedstock to make methanol, urea as well as other chemicals directly or into some chemical products. Similarly, from CO₂ we can produce urea. So, urea is also one of the products typically formed from the carbon dioxide. So, urea and its derivatives are also used in fertilizer, road, explosive, animal feed, food processing applications.

That means if we can utilize carbon dioxide to process some of the chemicals like methanol, urea and others, and those chemicals can further be utilized in different applications, either industrial applications or domestic applications or medical applications or road repairing applications. So, there are different applications where carbon dioxide can be utilized on regular directly or maybe indirectly. Like personal care product, pharmaceutical, flame proofing material, thermosetting resins. In all these different applications we use carbon dioxide derived product. So, we can send this carbon dioxide released from the thermal power plant to all such plants after purification.

So that is the reason why carbon dioxide needs to be purified by the method as we have discussed in previous classes, like membrane separation or any other using solvents or other

methods. So, it needs to be purified and enriched, and that carbon dioxide can be directly sent to these plants, so they can also buy it at some lower cost. A product or byproduct from one of the thermal power plants can be used as a raw material for chemicals and plastics as well as other industries. So, in this way, we can run a cyclic channel where carbon dioxide can be utilized. Other applications are bioconversion and byproducts.

Typically, it has been observed that CO₂-enriched air enhances the growth of microalgae. All these microalgae grow for the photosynthetic reaction at a much more rapid rate. Typically, the growth rate of all these algae is very high if they get some amount of sunlight as well as their desired conditions like pH and other factors. So, in all these processes, carbon dioxide is required as part of photosynthesis, and typically, this microalgae growth rate improves significantly if we supply CO₂-enriched air or carbon dioxide-enriched air along with other components at a desirable temperature. Particularly, the main advantage of this algae is that all these algae convert this CO₂ into suitable nearby bio-oil, like different types of vegetable oil, edible oils, non-edible oils, they all produce different types of oily or fatty products, fatty acid-based products, which are typically generated from microalgae. So, if we cultivate these microalgae on a regular basis at a large scale, that carbon dioxide will be absorbed, or it will enhance the growth rate of microalgae. For that, if we can extract this oil, which will typically be used for biodiesel production, then the same microalgae can also be used for biodiesel production and other chemicals, and even some pharmaceutical production. So, we can utilize this carbon dioxide, maybe in a diluted condition, even in the microalgae growth in the plant or thermal power plant itself, if that amount of land and facilities are available. That is one of the very good methods to utilize or trap carbon dioxide by naturally grown algae in a low-cost manner.

If the land or other facilities are available and from these algae after certain times we can extract biodiesel which also gives one of the profitable materials. So, this entire system can also be profitable also. We have already discussed that carbon dioxide is also required for the food and beverage processing that for a different type of soft drinks, beer and other materials they also use carbon dioxide for their carbonation process. So, some amount of pure carbon dioxide not mixed with any other impurities which can be harmful for making it a food grade material.

So, after purification of this carbon dioxide, we can utilize it to making different type of food and beverage. They also can be used as chemicals or reagents as carbon dioxide in liquid phase that can be a very good solvent for different type of chemicals so they can also be used in the

process of solvent extraction and as carbon dioxide easily get vaporized or converted to the gaseous phase so recovery of solvent will also be very much easy that's why carbon dioxide is also used as an extraction material as well as the cleaning agent in different industries they can also be used as a refrigerant like a dry ice and liquid carbon dioxide they are directly used in refrigeration and freezing applications carbon dioxide itself act as the working fluid in the refrigeration system they also can be used in suppression of fire and others so this is the typical structure how at present people are thinking about storing carbon dioxide below the earth surface. So typically, carbon dioxide can be stored geographically or geologically below the earth surface. So, from this top surface we can send or inject this carbon dioxide in a below the earth layer maybe one kilometer or five kilometers depth in a storage in between the rocks. So, these rocks are almost they are vacant or they may have some amount of groundwater. So, all these rocks can be filled with the carbon dioxide. So, carbon dioxide will get or remain there as in liquid phase or in the gaseous phase longer time and slowly it may react with the nearby rock and it can react with other material. So typically, it will again be going to the below the earth surface by this method.

So, some mineralization of carbon dioxide will occur after this longer time. So, in this way, we can send some about the or we can do the decarbonization of the plant, like we can make that plant. carbon from carbon-positive to carbon-neutral like after whenever we extract coal that we extract coal from below the earth's surface, we utilize it and whatever carbon dioxide is there, we can send it back to the earth's surface at a suitable location, at a suitable geographical location where below the earth's surface in some rocks and other materials are there where it can be sent. So, by this process, we can also make this process like a carbon-neutral process.

So, this is one of the methods nowadays being used. accepted or a month that means recommended by many of the scientists at present and even this can be done below the sea level also and it has also been observed that the seawater or salty water can also absorb some amount of carbon dioxide So, overall, by this process, carbon dioxide can be stored geographically in deep saline reservoirs, depleted oil and gas reservoirs, and any other formation, either of basalt rock, etc. So, in this way, we can also store a large volume of carbon dioxide below the earth's surface. This is nowadays recommended by many scientific agencies to store carbon dioxide here.

But one of the dangers of such a method is that if we store carbon dioxide below the earth's surface in this way and within a few years or within a short span of time, if any major

earthquake or similar activity happens, that can result in the entire carbon dioxide coming out immediately. So, whenever we do the site selection for this, we have to ensure that it is not earthquake-prone or similar will not happen in the near future so that whatever carbon dioxide we inject below the earth's surface does not come out within a short span of time. So, this is one of the concerns if we store carbon dioxide below the earth's surface. So, overall, if we summarize this chapter on carbon dioxide capture and storage, NO_x and SO_x pollution, oxy-fuel combustion, etc. Overall, if we summarize and if we conclude, typically for SO_x reduction, the best method is sulfur reduction or sulfur capture at the source control is the best method. That is, desulfurization of coal is the best method using a suitable technique, either physical coal cleaning or chemical coal cleaning or froth flotation or any other suitable method.

So, sulfur capture at the source is the most efficient method as it can trap the sulfur in the source itself and it can reduce many other consequences of transporting and utilizing sulfur at later as it can happen or it can result some acid rain and acid mine drainage and similar issues if we utilize this sulfur-rich coal or if we continue to mine this sulfur-rich coal so Typically, this sulfur reduction at source is the best process. If not possible, we should try to capture or we should try to react this sulfur with any other chemicals during the combustion or we can say during the utilization. So, this can be either combustion or gasification.

So, typically by this fluidized bed gasifier in the fluidized bed combustor in both the cases, typically sulfur is trapped or sulfur oxide is trapped using the lime and limestone. That is the method and even if it is that not possible in some of the combustion utilities like in pulverized coal combustion utilities. Typically, desulphurization unit or flue gas desulphurization units are the final method which is nowadays almost mandatory that all plants should go for this flue gas desulphurization units by certain timelines given by the ministry for all the power plants. So, this flue gas desulphurization in the final method to capture or to reduce the sulfur dioxide.

That means if we cannot able to control it at the source or during utilization. So, at the final stage, one unit must be there to reduce or to capture the any SO_x emission from the coal combustion utilities either in the cement plant or in a thermal power plant or any other utilities. Similarly, if it is in the coal gasification plants, suitable type of chemicals or process must be adopted to trap all the H₂S and sulfur rich gases released from those utilities. mostly these limestone are widely used as it is available as the raw material from the limestone mines so mostly at present limestone is widely used as a material as it can convert it to gypsum and this gypsum has some market value in terms of cement industry as well as other applications But

utilization of ammonia or ammonia-based chemicals is also preferred as ammonium sulfate produced from this flue gas desulphurizer unit can have some much more advantageous as it can recycle the sulfur to the growth of the vegetables and plants.

So, as ammonium sulfate is one of the major fertilizers used in the agricultural sector, the use of ammonia is also possible, but there will be some cost involved whenever we try to use ammonia, whereas the utilization of lime or limestone is not so costly, as lime is available in different mines. For NO_x generation, we can see that NO_x generation can be avoided only by controlling the combustion process. So, if we modify our combustor unit where the probability of NO_x formation is less, that is the best method. For example, controlling the combustion temperature so that NO_x formation does not occur or controlling the amount of nitrogen available for the reaction.

As happens in the case of oxy-fuel combustion. So, oxy-fuel combustion nowadays is almost the future of the combustion process, as NO_x emissions from different coal-fired thermal utilities, as well as other industries like automobile industries, are increasing day by day. So, oxy-fuel combustion will be the future if suitable technology is developed or if the separation of oxygen from nitrogen gas is made very cheap, easy, and accessible to all plants. Otherwise, we have to only go for controlling combustion temperature and combustion to avoid any NO_x generation. But if the separation of oxygen and obtaining pure oxygen on an industrial scale is really feasible, then oxy-fuel combustion is the best method, which actually improves the combustion efficiency of the fuel and reduces all other issues, such as unburned carbon, unburned hydrocarbons, and others. So, oxy-fuel can be used if the cost of oxygen generation is low. Otherwise, we have to control NO_x generation in the combustor by controlling temperature or adjusting the primary air, secondary air, and others. So, oxy-fuel combustion can eliminate many issues during combustion, but overall, it is a costly process. So, only in some high-cost processes or where the cost does not matter, such as gas welding or gas cutting, is oxy-fuel combustion typically used at present.

But once this cost comes down in the near future, many plants or industries will emerge where they will utilize oxy-fuel combustion. To avoid many more environmental issues faced during the combustion process, and if we consider CO₂, it can be captured or purified in the plant itself by different technologies, particularly with amine-based solvents, which are mostly used nowadays. However, their process is also costly, and the utilization of amines has some environmental drawbacks. So, perhaps in the near future, it will shift to zeolite or solid

adsorbent-based processes or membrane separation-based processes, which will be in the future, many plants may adopt this method, as this process is relatively cheap and easy to install in different plants. In terms of CO₂ utilization, most of the CO₂ can be used in enhanced oil recovery units, which improve the recovery of oil and natural gas. However, it has many pros and cons—meaning it has both negative and positive points. Particularly, if we store it below the Earth's surface, the selection of a suitable location, site, and rock type, along with other constraints, must be considered very carefully. This ensures that if an earthquake or any other natural phenomenon occurs, all the stored CO₂ does not escape from the storage. So, we must be very careful when storing carbon dioxide below the Earth's surface.

Thank you.