Clean Coal Technology

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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 emission control from combustion utilities. So, in this lecture 4, I will be discussing carbon dioxide capture and storage. So, if we see the gases released from coal combustion or coal-fired utilities, there are SO2, NOx, and other harmful gases which can be captured by different methods, as we have discussed earlier. But the main gas or primary product gas from any coal combustion utilities or any fuel combustion is the generation of CO2 gas.

Now, as we all know, CO2 is a gas that can increase the temperature of the atmosphere and may cause global warming. So, to avoid this global warming, nowadays there is a great awareness about the CO2 released from plants and how we can utilize this CO2 for different purposes or how we can capture this CO2 so that whatever carbon is released into the environment does not cause global warming or other consequences caused by carbon dioxide. So, if we see the role of CO2 and why CO2 capture and utilization are nowadays required for thermal power plants as well as other coal combustion utilities and fossil fuel combustion utilities, it is because CO2 is produced whenever we burn any fossil fuel, which typically means we are adding carbon from below the Earth's surface which is stored below the Earth's surface, and we are bringing it into the atmosphere. So, if we take a global scenario like this: this is the Earth, and this is part of the atmosphere. Any fossil fuel is stored at this position below the Earth's surface, so it is not in the atmospheric condition.

So, whenever we burn any fossil fuel, whether natural gas, liquid fuel like petrol or diesel, or solid fuel like coal or lignite, all these bring carbon into the atmosphere. So, whenever we burn any fossil fuel, we add some amount of carbon dioxide or carbon-rich compounds, whether carbon dioxide, carbon monoxide, or unburned hydrocarbons, to the atmosphere. So, as a result, by burning fossil fuels, we are effectively increasing the amount of carbon dioxide or carbon-related compounds in the atmosphere. That's why they are called carbon-positive compounds or carbon-positive fuels. Whenever we burn any fossil fuel, it is like a carbon-positive system;

we are adding carbon to the atmosphere which is already stored below the earth's surface in different form, and we are adding it to the, bringing it to the environment, we are doing some carbon positive activities. Whereas if we see any of the biomass or biofuels, these carbons are available in the atmosphere. During photosynthesis reaction, this carbon makes some fossil fuel, and during utilization, we again bring this carbon to the atmosphere. So overall whenever we utilize any of the biofuel-based system like using any of the biogas or biomass utilized for the coal combustion or other purpose effectively we are using that same amount of carbon which was available in the atmosphere. few months or few years back and particular the trees and plants they converted or they captured it we are utilizing it. So effectively we are not adding any carbon externally whatever carbon was present in the atmosphere maybe few days back or few months back that same amount of carbon we are returning to the atmosphere. So as a result, whenever we utilize any of the biomass or biofuel they are carbon zero, not the carbon negative, they are the carbon zero compound. So, typically whenever we discuss about the carbon credits, carbon positive, carbon neutral, in such case all the fossil fuel ever we use, they are the carbon positive materials, carbon positive fuel, whereas the biofuels, they are the carbon neutral fuel. We are not adding any other additional carbon which is not in the atmosphere. That carbon which was there in the atmosphere, we are bringing back to the atmosphere.

So effectively, whenever there is a concern about this carbon positive, carbon credit, carbon neutral, so all the plants have to go to this carbon neutral cycle as per the environmental guideline and maybe in near future we have to go for this that no plants or no utilities will be allowed to release carbon dioxide and operate their plant in carbon positive way rather they should operate on the carbon neutral way. So, in such case if we want to go for the fossil fuel utilization or fossil fuel combustion like coal combustion we have to capture this carbon dioxide whatever is being released to the atmosphere that means whatever the carbon dioxide we are releasing to the atmosphere, we should capture it and store it anyhow or use it in any other purpose so that from the combustion utilities. We are not adding any excess amount of or any additional amount of carbon to the atmosphere. So, this is the main background or concept why Nowadays there is a concern and there is an increase in concern or awareness about the carbon dioxide capture. So, this carbon dioxide capture is required to make the plant or utilization of fossil fuel to make it or to move forward towards carbon neutral fuel.

Otherwise maybe in near future we will not be allowed or we cannot utilize any of the fossil fuel in the power plant or any other utilities as this is a carbon positive system. So, carbon dioxide capture is required and it is nowadays an essential or maybe in near future it will be compulsory for all the plants to go for the carbon capture technologies. So, these are the different methods which can be utilized or which can be used to capture carbon dioxide released from the flue gas in different methods. Like we can capture carbon dioxide using different type of organic and inorganic solvents. There are different types of organic solvents inorganic solvents are available which typically does some chemical reactions or they are the reversible chemical reaction under certain temperature pressure and other condition, they easily react with carbon dioxide or sometimes they physically absorb this carbon dioxide in their own structure. So, this is one of the methods using different type of organic or inorganic solvents. We can use the carbon dioxide capture and whatever the after recovery of carbon dioxide we can utilize in different plants and other as a source of chemicals. We can go for the adsorption method; there are different type of absorbents are their solid absorbents are there which can store carbon dioxide. So, from the flow gas if we keep some of this if we allow this adsorption process going on. So, whatever the carbon dioxide it is from the plant that can be absorbed in this absorbance There are some membranes separation-based method which is nowadays getting popular.

There are some selective membranes which can selectively separate carbon dioxide from other gases. So, this membrane separation is a not nowadays new it is already 20 to 30 years old technology nowadays and almost an established method where different type of selective membranes is used which will selectively separate the desired gases like if we want to separate hydrogen gas if we want to separate carbon dioxide gas if we want to separate methane gas or other gases there are selective membranes available. So those type of selective membranes can be used to separate carbon dioxide from the flue gas stream so that we can get almost pure carbon dioxide which can be utilized in different purpose and there is also cryogenic based separation is there by reducing the temperature of the system making it around 200 minus 200 degrees centigrade where one gas will be in the liquid phase and another gas will be in the gaseous phase. So, these are the different methods which can be used to separate carbon dioxide from the flue gas and many more technologies are coming in day by day also. So solvent based capture systems typically they rely on the chemical or physical adsorption methods like they do some physical or chemical adsorption by which that carbon dioxide get captured or trapped in the particularly solvent into the flue gas that is the solvent will be the liquid carrier which is typically done in an suitable type of or suitable design of absorption column and once it absorbed typically during this absorption, once this gas is CO2 is absorbed this liquid carrier is transported to a second column. So, in the first column This CO2 will get absorbed into the liquid and in the second column this liquid will be sent and there some reversible reaction condition will be allowed so that like either temperature will be modified or pressure will be released or some different thing has to be done by which we can do the reversible chemical reaction and we can regenerate the carrier for another round of CO_2 absorption. Typically, different type of amines is mostly used in such applications and they are relatively mature technology and nowadays even available in commercial scale compared to some of the other approaches. So, if we see what is done in the CO_2 capture during the absorption method, like from this flue gas, it has contained higher amount of CO_2.

So, this flue gas contains CO_2. This is sent to this absorption column. So, in this absorption column, some amine-based solvents are placed and they are allowed to spray from this top. So, from this top side, these amine-based liquids are sprayed. They are spread using a suitable either packed bed column or other design.

So, these overall an absorption tower. There are different designs available in the absorption tower which increases the mass transfer from that means CO_2 will get absorbed to the liquid medium. So, there are different ways to increase the mass transfer as per the different design of the absorption column. So as a result, what will happen this CO_2 molecules are here, they are entering in this system and they will come contact with this red color here. It is showing as the absorption column. So once this they get contact, so what will happen this co2 will get absorbed in this system which is shown in this blue dot which is considered like an CO_2 rich solvent. So as a result, it has selectively or this liquid will selectively absorb only. CO_2 because they have affinity that CO_2 has affinity to this liquid and only CO_2 will get absorbed in this system any other gases like nitrogen excess oxygen or other gases they will not be captured this and they will be released at the other gases from the absorption column.

So, whatever the CO_2 will be there that will get trapped by reversible chemical reaction here and we will get the CO_2 rich solvent. Now this CO_2 rich solvent is sent to a different tower or a second tower where this CO_2 rich solvent will be used to do the reversible reactions. here the temperature and pressure will be set in a different way not in the same way, so as the temperature and pressures are different, so that these reversible reactions can occur. So, in the reversible reaction this occurs this is known as the stripping tower or the desorption column. So, in the desorption tower or stripping tower. So here this CO_2 resolvent will be sent and this is allowed to go for expansion so that or increase in higher temperature so that the solubility of the CO_2 gas in that liquid is different or we can decrease the pressure so that again the solubility can be different So, by this method, what we can get it that we can easily recover back the solvent here, which will be again go for the next round and we can get the captured CO2 or release the pure carbon dioxide gases.

So, whatever the carbon dioxide gas was absorbing this, those carbon dioxide gas will be released through this. path. So, from this path what we can get is that we can get pure carbon dioxide gases other gases which was released which was present in this flue gas, they have already get released in this system. So at this system at this location particularly we will get pure carbon dioxide gases and these carbon dioxide gases can be utilized in different other chemical production or plant utilization whatever so we will get a pure carbon dioxide stream from here that can be put it in some cylinder compressed form and sell it to the market or maybe to given to nearby other industry who utilize carbon dioxide for their processing of different type of chemicals so overall by this process and this Method this amine based method.

This is an oil nowadays well matured technology which can be utilized and efficiently remove or you can say they can easily separate carbon dioxide from the flue gas and they can be utilized in separation of flue gas to extract the carbon dioxide and which can be captured and stored in different other locations. So, for this purpose we need typically the amine as the solvent. In most of the cases the amine-based solvents are mostly used although there can be other type of solvents can be there or other type of liquids can be there like calcium potassium hydroxides or sodium hydroxides-based solvent also can be used. But in most of the cases, amine-based sorbents are much more efficient as their reaction is easily reversible. That means they can easily do the absorption and desorption cycle by only changing the pressure and temperature of the system.

So typically, different type of amines is used and these do the reversible chemical reactions and they are much more selective towards the CO2 compared to any other liquids or inorganic liquids. So, mostly these amines are used and these amines can be like monoethanamyl, methyl diethanolamine and many more type of amines are there which has different type of separation efficiency and they have different type of cost also. Their mass transfer coefficient is different. So, these are the different type of amines are mostly used. and if we see the process the as these amines are the organic compounds or organic chemicals there is some significant amount of amines are there that means these amines are not easily available so if we go for a very large scale plant the availability of large higher amount of amines is sometimes doubtful that means if we want to use like 5 liters 10 liters or 100 liters of means we can easily get but if we want to run a very big power plant where maybe million liters of amines is required. So, in such case the availability of amines is also under doubtful as it is a very costly is there. So this technology is very efficient in small scale plant where availability of amines is not a challenges but if we want to utilize it in a very big plants like 500 megawatt or 1000 megawatt or 2000 megawatt plant this technology is cannot be may be not really visible and these amines are also environmentally toxic as these amines are the organic compounds, they have some nitrogen this compound, they are always some toxic nature is there. So, if by the process if there are some minor losses in the amines are there like even there if someone percent loss in the system these amines come along with the CO2 as in the flow sheet we can see that these amines are getting contact with the other gases. So, depending on the temperature and pressure of the system, so if amines are released at this point or any of the amines are get vaporized and released at this point. So these all these amines can come to the environment along with the flue gas and they can get give some corrosive environment and they can also be challenges to further remove these amines from the flue gas typically this is the main challenge availability in large volume is also the challenge to get large volume of amines for the industrial practice or industrial plant is also a very challenging part that we will not may not be able to get large volumes of payments and if we see that significant amount of energy is also required to run solvent based process as this process needs some pump or some compressor to compress and to create the pressure in the system some energy is consumed also in the desorption or in the stripping column some amount of energy is required as we have to increase the temperature of this amine and which may need some further cooling at this point So, this will be an energy intensive process also for separation of carbon dioxide here. So, this may not be feasible in all the cases as the significant amount of energy is involved there. Now, if we see the overall technical feasibility as well as the financial feasibility of the process as the cost of amines are significantly higher and its regeneration cost is also significantly higher and in the cycle even if there is some Very minor quantity of amine loss is there.

We also have to add some makeup amines in the liquid so that the quantity of amine remains the same in the system. So, all this involves some cost to the plants. And this cost typically comes from whatever profit the plant makes by utilizing fossil fuel and generating electricity and other outputs. So, it will also affect the plants or enter the plant operation, technically or financially, making it unfeasible to operate such a cost-intensive process.

So, if we go for the other method, like the adsorbent method or any solid-based adsorbent method, here typically CO2 is captured on the surface of different types of adsorbents, such as pure carbon, porous carbon, which has very high porosity and almost all the pores are in the nano size, so that carbon dioxide can be stored there for a long time. There can be some zeolites that may have metal-organic frameworks or MOFs, so all these materials can also capture and be utilized to separate carbon dioxide from the flue gas. So, if we can use such materials, they can easily be used to separate carbon dioxide, and typically heat and pressure reduction are the main factors that enable the reversible action. Pressurizing the system will cause carbon dioxide to get absorbed in the structure of these carbons, zeolites, and others, and if we release the pressure, then in such cases, carbon dioxide will get desorbed and come out of this adsorbent structure. Similarly, if we apply lower temperature and higher temperature, adsorption capacity is lower, gas molecules will have a higher amount of Brownian velocity, so gas molecules will come out of the structure, whereas at lower temperatures, their Brownian activity or velocity will be less, so they will stay inside the adsorbent. So typically, heat and pressure are mostly used to perform pressure swing adsorption or temperature swing adsorption, specifically for carbon dioxide adsorption. In some cases, inert gas is also used to replace it. As these inert gases, like helium and neon, have very low molecular weight and low molecular volume, they can easily be used to replace the CO2 stored inside the solid adsorbent and can vacate the entire number of pores and adsorb CO2 from the zeolites or this adsorbent. So, they can be regenerated once again this adsorbent offer potential energy savings as these adsorbents are in the solid phase. Typically, there is no loss of the adsorbents as well as there is no major energy cost in this process. So overall although there is some amount of energy is consumed to change the modify the pressure and temperature but overall if we see the energy saving it is much more economical compared to the amine-based process and there is no as such waste is produced by this process and process is much simpler but they are maturity as the availability of these zeolites and carbons is not so much high. So there this technology is not yet completely mature. So that many plants can utilize so typically if you see the amine-based technology they are the mature technology and they are being utilized in the plant scale from last 10 to 15 years. So, they are almost in a mature technology whereas this adsorbent technology is still under the research and develop somehow matured but not to the large extent that it can be adopted or accepted to the plant scale typically the adsorbent durability that carbon zeolite or MOF whatever is used whether they will be stayed or their lifespan will be for longer time another. They are the major hurdles in this process. Their adsorbent capacity, whether they can absorb large amount of CO2 or only small amount of CO2 can be absorbed in a large volume of adsorbent. They are the major challenges and they are particularly selectivity over the CO2. It is possible that this CO2 whatever is released, this adsorbent can be also have selectivity to the other gases. So, we have to get some selective adsorbent which will only allow this CO2 to store there, not the nitrogen gas, not the oxygen gas, not the methane gas to be stored there. So, this is also a technical challenge and also the cost reduction, they are the most of the technical challenges in this process. and if we see the other methods like membrane based technology is nowadays almost a mature technology where we can use any permeable or semi-permeable selective material which will selectively separate carbon dioxide from the other gases like they can be made of metal polymer or ceramic they can be used to selectively separate that is the most important factor that they should have some selectivity to the carbon dioxide that this they will only absorb or they will only have the selectivity to the carbon dioxide not the other gases or if other gases is present they will only selectively absorb the other gases not the carbon dioxide. So, there should have very high selectivity, so that whatever adsorbent is used it is only trapped the only one gas not the all the other gases either the waste gases or the required co2 gas they should have selectivity in this way so their selectivity is required from to separate other gases like from hydrogen from the syn gas. Typically, this selectivity is the most important their permeability mechanical and chemical stability is also there. In some of the cases as this flue gas may have higher temperature 300-degree 400 degree centigrade. So, this metal particularly if they are the made of polymer they may not be able to withstand that high temperature whereas some metallic membrane as well as the ceramic membrane can be used again the selective layer Which separates the material. The selective layer also has to withstand this high temperature and high pressure. So, they should have a higher amount of mechanical as well as chemical durability and stability. They should have a lower pressure drop. There should be resistance to the corrosiveness of the flue gases, as the flue gas may contain sulfur dioxide and other gases. They should be able to meet all the required conditions; whatever is present in the flue gas.

So, these are typically the different technical challenges which are nowadays solved by the R&D units. So, this is, although membrane separation is now a mature technology, but obtaining much more selective membranes along with all these desirable characteristics is still a technical challenge, particularly for large-scale applications in thermal power plants. And if we go for the cryogenic-based separation, some gases are commercially purified or utilize this cryogenic separation to separate carbon dioxide, where the gas is cooled until a different constituent either becomes a liquid or a solid. So now, this cryogenic-based separation is the only solution.

The method is mostly used in plants to separate carbon dioxide, nitrogen, oxygen, and other gases. So overall, it has a large amount of energy consumption. So, this cost has to be brought down for large volumes of gases so that this can be operated at low temperatures and within a cost that can be affordable by the plants, and this technique can be feasible for very high concentrations of gases. So, as this cryogenic separation is very costly, it can only be applied where high concentrations of CO_2 are available in the flue gas, like in oxy-fuel combustion. If we see the oxy-fuel combustion, the concentration of CO_2 is significantly higher. So, their cryogenic separation can be efficiently applied as large volumes of CO_2 can be captured, then they can be marketed as chemicals. But if we see the air-fuel combustion, where large volumes of nitrogen are present and only maybe 5 to 10 percent carbon dioxide is there, the cost of the process will be offset by the large volume of nitrogen to be cooled down. So, in such cases, it needs to be feasible, and mostly it is applied with high concentrations of CO_2 streams. Apart from this conventional method, microalgae-based carbon dioxide capture is also getting popular. Typically, it has been observed that different types of microalgae are available.

They grow in natural ponds and other locations. They are like green, normal-type plants. They grow naturally in the presence of sunlight and atmospheric conditions. And particularly, their specialty is that during their photosynthesis reaction, they capture a large volume of carbon dioxide and convert it into different types of bio-oils stored in their bodies or in their plants. So, if we increase this microalgae culture or microalgae growth near thermal power plants, all these CO_2-rich flue gases can be sent to these microalgae-based plants, and this microalgae growth will be significantly higher. So, CO_2-enriched waste streams from flue gas can efficiently be captured, and plant growth will also increase.

They can also capture greenhouse gases like other gases. So, this microalgae-based method is nowadays also getting popular, as it effectively converts carbon dioxide into bio-oils, biodiesel, or other organic compounds with biofuels, which can be efficiently utilized for further energy extraction. So, this microalgae-based process is nowadays getting much more popular. Statistically, microalgae cultures can grow in closed reactors or open ponds, turning CO_2 into biomass for the production of food, animal feed, nutritional supplements, medicine, fuel, chemicals, etc. Numerous laboratory and pilot studies have been undertaken in the past 2-3 decades, and the kinetics or growth rate of algae is the only limitation—the growth rate of algae is not significantly high enough for them to be applied on a plant scale. The growth of algae is slower. So typically, that is the main technical challenge: although algae can capture CO_2 very efficiently, their growth rate is very slow. So, a large area of algae growth is needed, and the amount of CO_2 absorbed is very low. So that is the main technical challenge and limitation of this.

So, this typically this alga will not remove large amount of CO_2 from the waste stream quickly. It will take lot of time and in a compact space do other physical chemical approaches as required to capture this carbon dioxide. And these algae are also very much sensitive to the temperature, pH, salinity and other conditions as well as chemical and biological contamination. So, this algae growth is very much sensitive if the temperature is different, pH of the flue gas is different. If flue gas contains some other toxic gases, so their growth rate can be get modified or the algae growth can be stopped.

So, they are prone to other type of chemical contamination. And biological contaminants can affect the growth of algae and culture systems are processing can be long term process. It will take it may be very much difficult to control these culture systems, but resulting products can be high. So that entirely micro algae growth culture maintenance and their processing is very, very difficult. But whatever the biofuels can be obtained from these micro algae, they can be very much useful.

So, they can be done in a hybrid and novel concept. Like here we can utilize two or three different concepts like adsorption followed by absorption or adsorption followed by algae growth and others. So here we have to combine multiple characteristics, multiple technology or we have to explore some new process condition. We have to use some new materials so that we can easily capture this carbon dioxide as this only one method is not suitable or they may not be feasible for the large-scale application and further use of chemical looping combustion, where we can increase the combustion efficiency as well as obtain pure carbon dioxide. So overall, if we see that carbon dioxide separation from the flue gas is a really technical challenge. So, for normal thermal power plants that work on air-fuel combustion. In such cases, this carbon dioxide capture is really a challenge, whereas in oxy-fuel combustion, where concentrated CO_2 is produced, or in chemical looping combustion or similar methods where high-concentration CO_2 is produced. So those can be future technologies that can easily capture carbon dioxide and utilize it in different other plant activities whereas for common air-fuel combustion, it will be very difficult to adopt these CO_2-based capture technologies.

Thank you.