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Decarbonizing the future: Understanding carbon capture, utilization, and storage methods

Anvita Abhijit Bhate * and Elizabeth Biju Joseph

Department of Chemical Engineering, Thadomal Shahani Engineering College, W.P.G. Kher Marg, 32nd Road, Off Linking Road, TPS III, Bandra West, Mumbai, Maharashtra, India, 400050.

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Abstract

Carbon capture refers to the removal of carbon dioxide from the atmosphere, or directly at the source of its emissions. The latter employs chemical engineering to design capture systems for industries. Aqueous amine scrubbing makes use of amine based solvents to capture carbon dioxide from flue gas streams. The carbon, once captured, is compressed and redirected for either reutilisation or storage. In enhanced oil recovery, the CO_2 is injected into oil and gas reservoirs to increase their extraction. Carbon storage methods work to remove the carbon from the atmosphere, and aid mitigation against carbon emissions from industry, thereby reducing the contribution to global warming and ocean acidification. This paper aims to provide the readers with an understanding of the technologies involved in the above processes.

Keywords: Carbon Capture; Carbon Sequestration; Uses of CO_2; Sustainable; Green Technology

1 Introduction

In 2021, the chemical industry added 36.2 gigatonnes of CO_2 via emissions. The link between increasing CO_2 emissions and increase in global temperatures is well known and accepted and so we deliberate upon a way to control these numbers and avert the extreme effects of climate change. Energy efficiency, fuel switching, combined heat and power, use of renewable energy, and the more efficient use and recycling of materials are some of the methods to reduce emissions. However, many industrial processes have low-emission alternatives and will require carbon capture and storage to reduce emissions over the long term.

2 Carbon Capture

Carbon capture is best performed directly at source, in industries that produce large quantities of CO_2 emissions. Examples include biomass or fossil fuel energy plants, natural gas electric power stations, natural gas processing assets, synthetic fuel plants, and fossil fuel-based hydrogen production plants.

2.1 Pre-combustion capture

In this method, the fossil fuel is partially oxidised before combustion. This creates a syngas, which reacts with added steam, to give CO_2 and H2. The CO_2 can then be captured from a comparatively pure exhaust stream, while the H2 can be used as fuel without any CO_2 emissions. Pre-combustion capture is typically used in the fertiliser, chemical, gaseous fuel, and power generation industries.

* Corresponding author: Anvita Abhijit Bhate
Department of Chemical Engineering, Thadomal Shahani Engineering College, W.P.G. Kher Marg, 32nd Road, Off Linking Road, TPS III, Bandra West, Mumbai, Maharashtra, India, 400050.

2.2 Post-combustion capture

This process involves the capture of carbon dioxide from flue gases released after combustion or other processes. The technology for this capture method can be retrofitted to existing power stations as well as being built into new build plants.

2.2.1 Amine Scrubbing for CO_2 Capture

In this form of post combustion carbon capture, the exhaust streams are passed through a packed absorber column (amine scrubber) containing a 25–30% aqueous amine solution at high pressures. Amine absorbs carbon dioxide to form a carbamate species in the case of primary and secondary amines, and bicarbonates in the case of tertiary amines. Flue gas exiting the top of the absorber is water washed to reduce the entrained solvent droplets and then vented to the atmosphere. Following the absorption process, the rich solvent (high content of carbon dioxide reaction product) passes through a stripping column operating at higher temperature than the absorber in order to release the carbon dioxide in high purity (over 99%) which may be later compressed for commercial utilisation or storage.

2.2.2 Other Solvents

An alternative to amine-based solvents is sodium carbonate (Na_2CO_3). A sodium carbonate slurry is used to provide a basic environment in which CO_2 is absorbed as bicarbonate followed by sodium bicarbonate formation. The $NaHCO_3$ precipitation enhances the bicarbonate formation and, hence, the CO_2 capture capacity of the solvent is improved.

2.3 Oxyfuel Combustion Capture

Here the fuel is burnt in oxygen rather than in air, and then the cooled flue gas is recirculated and injected back into the combustion chamber to prevent high flame temperatures. This flue gas is mainly carbon dioxide and water vapour. Since the water vapour can be condensed by cooling, the process leaves almost pure carbon dioxide steam that can be captured.

3 Utilisation of Captured Carbon dioxide

The use of CO_2 as a starting material is feasible as it is inexpensive and nontoxic, and recycling CO_2 will produce a positive impact on global CO_2 levels.

3.1 As fuel

Carbon dioxide can be converted to fuels by reduction to methanol or methane. For this, an established industrial method involves the reaction of hydrogen and carbon dioxide using a ruthenium-based catalyst at temperatures of 300 to 400 degrees Celsius.

3.2 As chemical feedstock

The captured carbon can be utilised in the manufacture of acetic acid which is used in many household cleaning products, polycarbonate plastics and methanol, which is used in thousands of everyday products, including fuels, paints, adhesives, fertilisers and windshield fluid.

3.3 As Solvent

When CO_2 is substituted for an organic solvent, emission of toxic organics and proceed costs are minimised. Currently, supercritical carbon dioxide is used in manufacture of dimethyl carbonate, caffeine extraction, dry cleaning, and parts degreasing.

4 Carbon Sequestration

Carbon Sequestration involves injecting CO_2 deep into the earth to reduce its impact on the atmosphere.

4.1 Types of Carbon Sequestration

4.1.1 Geological

The CO_2 is pressurised until it becomes a liquid, and then it is injected into porous rock formations in geologic basins. This process is employed in the later stages of a producing oil well. The liquid CO_2 is injected into the geological formation bearing the oil, which reduces the viscosity of the oil and allows it to flow more easily into the oil well.

4.1.2 Biological

It is the natural ability of life and ecosystems to store carbon. Forests, peat marshes, and coastal wetlands are particularly good at storing carbon. Carbon can be stored in plant tissue, such as long-lived tree bark or in extensive root systems. Microbes break down plant and animal tissue through decomposition.

4.2 Limitations of CO_2 Sequestration

EOR systems require burning of fossil fuels to power the compression of carbon and its pumping into the oil wells, which is counterproductive to the cause.

The best way to remove carbon is by sequestering it in its natural sinks — forests, grasslands and soil. But for this method we would need to plant the equivalent of over a 100 billion trees to even try to combat the rate at which CO_2 is entering our atmosphere globally. Thus the creation of artificial sinks gains importance.

Carbon sequestration also does not justify the huge capital investment required for compression and transportation of the captured carbon, given the fear that after all this, the carbon can still leak out.

5 Conclusion

As the industry moves forward, it becomes more and more important to optimise processes and find economical ways to upscale sustainable technologies.

In the direct capture of CO_2 from air, the high dilution level of CO_2 in air (0.04%) increases the energy requirement and cost of the process compared to carbon capture from flue gases (with CO_2 concentrations around 15% for coal power plants). Thus investing in direct capture can have a more significant impact on emission reduction.

Pre-combustion capture typically is more efficient due to the more concentrated CO_2, but the capital costs of the base gasification process are often more expensive than traditional pulverised coal power plants. Amine scrubbing to remove carbon dioxide and converting it to fuel requires a fuel feedstock to supply energy, and this will in turn contribute to emissions. Hence a renewable source of energy can be used to optimise this process.

Carbon reutilization offers incentives to industry to invest in carbon capture technology as they profit from using their emissions as a feedstock.

The sequestration of carbon remains a debated topic given the difficulty of the process and cost, so it must be considered as a final carbon clean up method, with the focus being on reducing industrial emissions through overall process optimization and the principles of green chemistry. Hence our focus should be on reducing our overall emissions and reusing what we emit.

Compliance with ethical standards

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Disclosure of conflict of interest

All authors declare that they have no conflict of interest to disclose.

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