Direct Air Capture: A Review of Carbon Dioxide Capture from the Air

A. A. Okesola, A. A. Oyedeji, A. F. Abdulhamid, J. Olowo, B. E. Ayodele, T. W. Alabi

National Agency for Science and Engineering Infrastructure (NASENI), Idu Industrial Area. PMB 391 Garki, Abuja
Corresponding Author: yomiokesola@yahoo.com
Mobile No: 08188229756

Abstract- The level of carbon dioxide as well as other noxious gases in the atmosphere has been on the increase and this has caused a lot of issues relating to the effect of these gases to human and animal health. A process for capturing carbon dioxide directly from the atmosphere will go a long way in making the world a safer and healthier place for the entire inhabitant. Different methods and processes have been postulated and promoted by various researchers to mitigate climate change by reducing the amount of carbon dioxide in the atmosphere. This paper aims to consider a process to capture the carbon dioxide directly (Direct Air Capture) from the atmosphere at a cheap, sustainable and affordable way. The process aims to capture the carbon dioxide, concentrate it and pressurize it for storage or further usage. This is a deviation from the process of carbon capture from point source such as power plants, industries etc. The process focusses on capturing carbon dioxide that have found their way into the atmosphere through other smaller sources such as automobile exhaust, domestic power generators, fossil fuel burning equipment and many other sources not reported or captured in the international data base. A summation of the above-named sources will amount to a huge impact on the environment and a method to remove the contaminant at a cheap, affordable and sustainable way will be of immense benefit worldwide most especially developing countries in tackling climate change.

Keywords: carbon dioxide, carbon capture, mitigate, climate change, DAC, sustainable

1. Introduction

The growth in world economies attributed to the emergence of new technologies has brought about environmental problems along with it. With problems such as global warming, acid rain formation, smog formation, etc mentioned in areas where they were never mentioned before. Among all these problems, global warming, resulting from the emission of greenhouse gases mainly carbon dioxide, is considered as the most serious one.

The Carbon dioxide (CO2) which is the major constituent of the greenhouse gases can be produced from various sources, such as fossil fuel combustions (in cars, trucks, power generators), biomass energy facilities, large power plants in industrial processes, etc. And this is due to the increasing consumption of fossil fuels by humans as needed for industrialization. Carbon dioxide concentration in the atmosphere has increased from 270 ppm in pre-industrial period to nearly 400 ppm at present [1]. This increase in carbon dioxide concentration has led to numerous health concerns and increased cost of removing the pollutant from the atmosphere. To remove the carbon dioxide generated by heavy fossil fuel burning industries, the released carbon dioxide is capture and stored, but this has not taken care of the carbon dioxide released from smaller sources scattered all over to the atmosphere, this has led to a new approach of capturing (or removing) the carbon dioxide directly from the atmosphere.

The process of capturing waste carbon dioxide from large point sources such as fossil fuel power plants, transporting, storing and depositing it where it will not be allowed to enter back into the atmosphere like an underground geological formation is known as carbon capture and storage (CCS) [2]. The major reason for CCS is to prevent the release or emission of large quantities of carbon...
dioxide into the atmosphere as a result of burning fossil fuel to generate power and in other industrial uses. On the other hand, carbon dioxide removal (CDR) from the air is different from reducing emissions. Capturing waste carbon dioxide from large point source decreases the inlet of carbon dioxide to the atmosphere while carbon dioxide removal produces an outlet of carbon dioxide from the earth’s atmosphere. CDR is a different approach to removing carbon dioxide from the stack emissions of large fossil fuel point sources, such as power stations. Capturing waste carbon dioxide can only reduce the level of emission to the atmosphere but will not have any control over the amount of carbon dioxide already present in the atmosphere. Carbon dioxide removal (CDR) creates negative emission by removing carbon dioxide from the atmosphere, cancelling out the emissions from small and dispersed point sources such as domestic heating systems, domestic power generation, airplanes and vehicle exhausts.

Both processes (carbon dioxide removal and carbon dioxide capture) works towards achieving the same net effect in the long run but to achieve carbon dioxide concentration levels below the present level, carbon dioxide removal using the direct air capture process is very important. Carbon dioxide capture from the air is becoming more popular as it shows signs of providing the only possibility to fill the gap between the needed reductions to meet expected mitigation targets and global emission trends in higher concentration levels.

The objective of the carbon dioxide removal (CDR) process is to remove carbon dioxide from the atmosphere on large scale bases [3]. There are several technologies captured under the CDR process, some of which are; bio-energy with carbon capture and storage, biochar, ocean fertilization, enhanced weathering and direct air capture when combined with storage [2].

2. Direct Air Capture (DAC)

It is possible to remove carbon dioxide from the air through chemical processes. The captured carbon dioxide can then be sequestered, stored and possibly re-used. The rate of increase of atmospheric carbon dioxide concentration can be slowed down by the traditional modes of carbon capture such as pre-combustion and post-combustion CO2 capture from large point sources. However, only the direct removal of carbon dioxide from the air, or direct air capture (DAC) can actually reduce the global atmospheric carbon dioxide concentration if combined with long term storage or usage. Work in this area of research is still not well developed. [4]

Some of the main technologies proposed for direct air capture are; causticization with alkali-earth hydroxides [5], carbonation [6] and organic-inorganic hybrid sorbents consisting of amines supported in porous adsorbents.

Several scientists, engineers and researchers have proposed different methods for direct air capture. One of these methods is the use of artificial trees [7][8]. This method aims to create artificial trees around the world which can suck up more carbon dioxide from the air than the natural trees. The carbon dioxide will be captured in a filter, removed and stored.

Another method proposed can be carried out at temperature of only 40 oC, this method uses a polymer based ion exchange resin, which takes advantage of changes in humidity to prompt the release of the carbon dioxide captured from the air instead of using a kiln for the release process, thereby reducing the energy requirement for the process.[9]. Sodium hydroxide-based chemistry is used in different variants to achieve the direct air capture of carbon dioxide in all the literatures reviewed above.

This review introduces the use of Temperature Swing Adsorption (TSA) system of capturing carbon dioxide from the atmosphere directly using the most suitable adsorbent for optimum performance. The choice of the process is due to the objective of achieving the direct air capture of carbon dioxide at low temperature and at affordable cost.

3. Methodology

Temperature swing adsorption uses temperature to regenerate the adsorbent. At low temperatures, adsorbents can retain significant amounts of water while at temperatures above 200°C, adsorbents hold almost no water. By swinging the temperature from low to high, it is possible to adsorb large
quantities of moisture at low temperature, such as 40°C, and release it at high temperature. The adsorption and desorption curve will be analyzed to determine the rate at which the system functions and used for further optimization.

The software, Labview can be used to optimize the process to determine the optimum condition of the adsorbent to be used and at what conditions/parameters the best results will be obtained before deploying the equipment to capture the carbon dioxide from the atmosphere. In the search for the ideal adsorbent, the selection will be based around materials with high carbon dioxide adsorption capacity, high adsorption selectivity towards carbon dioxide (as opposed to other gases in the atmosphere), low energy requirements for regeneration, stability to prolonged adsorption-desorption cycling and tolerance to the presence of moisture.

A very large volume of data will be generated as a result of carrying out the research work in direct air capture that will ultimately lead to creating awareness within the populace within Nigeria and Diaspora. This paves way for a better mitigation method to climate change rather than the adaptive method currently popular in Africa.

4. Conclusion

The project is very relevant to current events in the mitigation against climate change and environmental degradation. The data and results from the work will not only help in understanding the process of removing carbon dioxide from the atmosphere better but will increase the knowledge in the general area of removing dangerous gases from the atmosphere.

The research work is of paramount importance to Nigeria as a country at this particular time. Claims have been made by researchers estimating the average number of homes with generating sets in Nigeria to 60 million\(^{10}\). We can imagine the enormous amount of carbon dioxide that will be pumped into the atmosphere with such a huge number of fossil fuel burning generators.

With the projected increase in the expected amount of carbon dioxide released into the atmosphere by 2060, the world needs a better means of removing the gas out of the atmosphere as fast as possible.

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