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Onboard Carbon Capturing Technology in Maritime Transportation

Harshit Singh[1], Ishan Vikrant Sharma[2], S. M. Puranik[3]

[1,2,3]Indian Maritime University, Navi Mumbai Campus T.S.Chanakya, Nerul, Navi Mumbai 400706.

Abstract.
In this paper an attempt is made to highlight causes for carbon and GHG emission particularly from the shipping transportation across the globe. Shipping transportation is expected to increase by more than 2% during 2024 and 2028 as per reports of UNCTAD. More rises in transportation means more carbon emission globally. Without action, emissions could reach 130% of their 2008 levels by 2050. Total de-carbonization, zero GHG emission should be a target for the maritime nations to curb the carbon emission. There are many methods available for carbon capturing at the source to reduce carbon emissions from shipping industry. In this paper various methods of on-board carbon capturing are discussed. Use of four stroke engine to reduce emission in place of two stroke engine has also been discussed.

Keywords: carbon capture, GHG, net-zero carbon, maritime.

1. INTRODUCTION

As per reports published by climate.gov [1], the amount of carbon dioxide in the atmosphere (pink line) in the Fig.1 has increased along with human emissions (blue line) since the start of the Industrial Revolution in 1750. Emissions rose slowly to about 5 gigatons—one gigaton is a billion metric tons—per year in the mid-20th century before skyrocketing to more than 35 billion tons per year by the end of the century. Along with industrial Revolution, Shipping transportation has also increased rapidly across the globe.

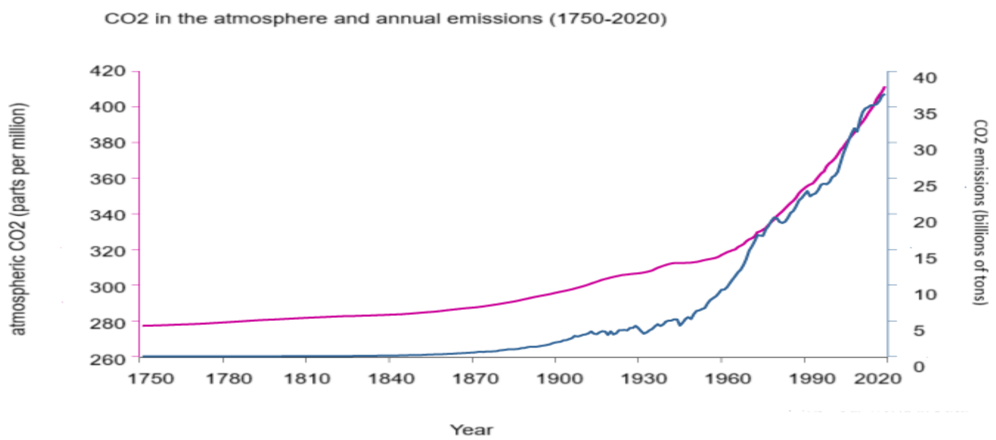

Figure. 1

With rapidly increasing shipping industry and shipping transportation, carbon emission from shipping industry is also going to be increase which may add more greenhouse gases globally. As reported by transport and environment [2] [3], at the present growth rate shipping could represent some 10% of global greenhouse gas emissions by 2050.

As per report published by Ian Tiseo [4] on statista site (GHG emission in India, in Feb.2024), India's greenhouse gas emissions increased by more than five percent in 2022, to four billion metric tons of carbon dioxide equivalent ($GtCO_2$). Since 2015, GHG emissions in India have risen by 17 percent. As per Sinay [5], a maritime data solution, in 2022, international shipping alone accounted for nearly 3% of the world's greenhouse gas emissions. The transportation sector, including shipping, is responsible for about 20.2% of the world's total CO_2 emissions, making it the second-largest contributor to global carbon pollution. It is observed that most of the carbon due to burning of heavy Fuel oil in ships emits carbon which flows towards land masses due to wind direction and thereby adding more carbon in most of the countries.

Most of ships run on two stroke engine mechanism and uses heavy fuel oil which emits black carbon in the atmosphere which adds to GHG emission. This emission can be reduced to greater extent by the use of four strike engine which runs on petrol and May emits very less black carbon. However, four stroke engines are less efficient but emit very less carbon in the atmosphere, which means reduction in GHG.

Maritime sector should go for use of four stroke engine instead of two stroke engines. For the global environment health, net-zero carbon emission is far more important than engine efficiency ships speed.

IMO has given various time line to cut the emission from ships and draft outline of an "IMO net-zero frame work" for cutting GHG emission from international shipping [6].

According to IEA reports [7] in 2022, emissions from the international shipping sector grew by 5%, continuing the rebound from the sharp decline in 2020, and are now back to 2017-2018 levels.

Innovation is vital to ensure that zero-emission oceangoing vessels are made commercially available by the mid-2020s. Now that the IMO´s greenhouse gas (GHG) emissions targets have been made more ambitious, the stringency of existing policies, such as operational emissions intensity standards, needs to be increased accordingly to ensure significant emission reductions and to encourage the adoption of low- and zero-emission fuels and technologies for oceangoing vessels.

The process of carbon capture has been ongoing naturally since the beginning. The plants, oceans and soils are natural carbon sinks which remove carbon dioxide from the atmosphere and store it underground, underwater or in tree roots and trunks. Without human interference, the vast amount of carbon in oil, coal and other fossil fuels would have been left untouched, but, unfortunately that is not the case.

As the situation stands, it is like watering your garden, where water is carbon dioxide and your garden is the natural mechanisms to capture carbon. Even though the plants would absorb the water, but it is only a matter of time before they are unable to absorb anymore or the rate of absorption is less than the rate of water incoming. This will eventually lead to flooding of the garden which will happen in real life as well. With more carbon in the atmosphere it might even become the reason for the cease of existence of humans and all species.

2. Methods of on-board carbon capturing

The Onboard carbon capturing system helps in reducing carbon emission onboard which has an effect on the amount of greenhouse gases in the atmosphere resulting in climate change and global warming. This will also help in achieving the net zero carbon emission by 2050 that was initiated at COP26 meeting at Glasgow and will be a significant contribution by the maritime industry. The captured CO2 can be further utilized in other facilities such as agriculture, production of graphene, carbonated drinks, plastic production, carbon battery, carbon rods, activated carbons etc. It can mainly be utilized as an alternative fuels (e-fuels) which can be used in vehicles.

There are various methods available for on-board carbon capturing. Basically there are two methods, namely pre-combustion and post-combustion [8]. In the pre-combustion method, ships fuel converts into gas and captures Carbon before combustion. The post-combustion captures the carbon from the ship's exhaust and captured CO2 is stored onboard either as a liquid in high-pressure tanks or as a solid in mineral form such as limestone. Both these methods are termed as on-board carbon capture storage (OCCS).

1. In **OCCS**, carbon capture technology removes existing carbon dioxide from the atmosphere or that catches carbon before it is released into the atmosphere. While there are many different types of carbon capture technology, the most common method is amine-based CO2 capture.

This process involves routing emitted exhaust or "flue gas" through ducts into a cooling tower in order to reduce the temperature. Once the gas has been cooled, it is moved to an absorber, which runs the gas through a chemical solution made up of compounds called amines. The amines bind to the CO2 and keep the CO2 in the absorber while the remaining carbon-free exhaust is vented into the air. The pure CO2 is finally converted from a gas to a fluid and is then ready to be transported for underground storage or further utilization. The process is illustrated in the figure 1. [9]

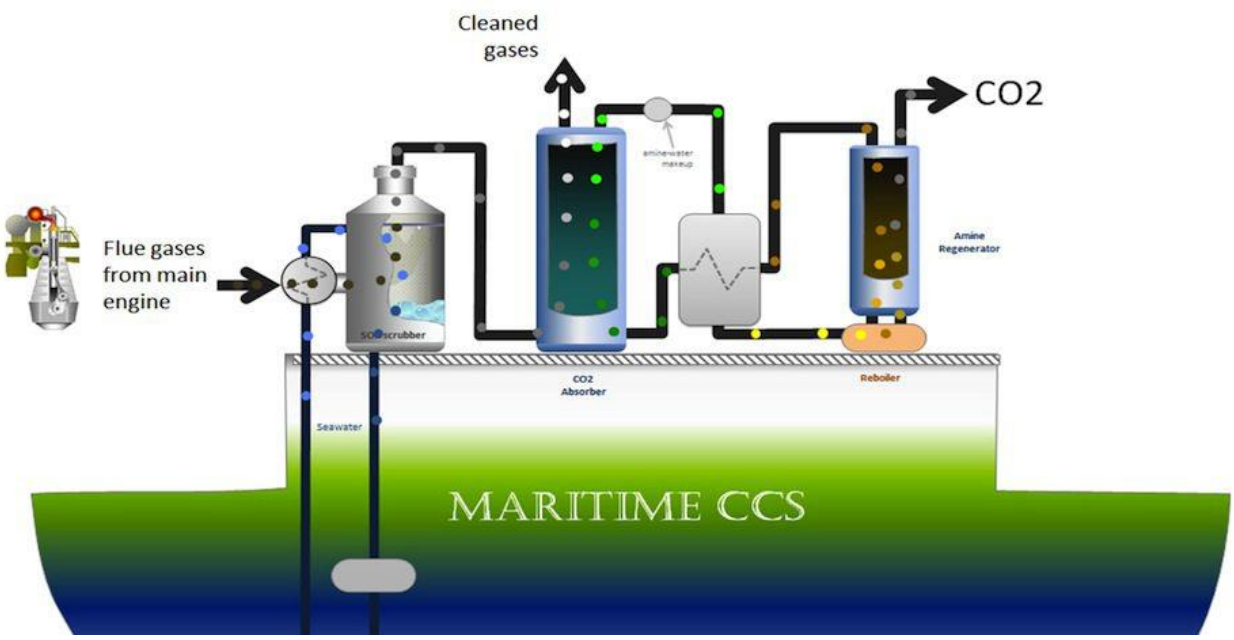

Figure 2.

2. In **solvent scrubbing method** [10] uses during the process of post combustion gases. This scrubbing process works like a normal scrubber does, feeding the flue gasses from below and using liquid form solvents to extract the CO2 from the current through an adsorption process, allowing the CO2-free current to exit on top, and separating the CO2-rich solvent current, which will be sent into a

separation unit, where the CO2 will be released from the solvent, which can then be reused. This process already well proven in absorption from flue gases on land.

3. **Molten carbonate fuel cells** [10] method works at high temperatures around 650^0 C using nickel-based electrodes and molten carbonates (of Li, Na and/or K) as electrolytes inside a lithium aluminate matrix. The high temperatures allow the electrolytes to stay fluid and move through the matrix as cations CO_3 2^-. Furthermore, the passage of CO $_3$ 2−, which becomes oxidized to CO2, allows the CO2 to be selectively separated from flue gas. This method is illustrated in the figure 3 below.

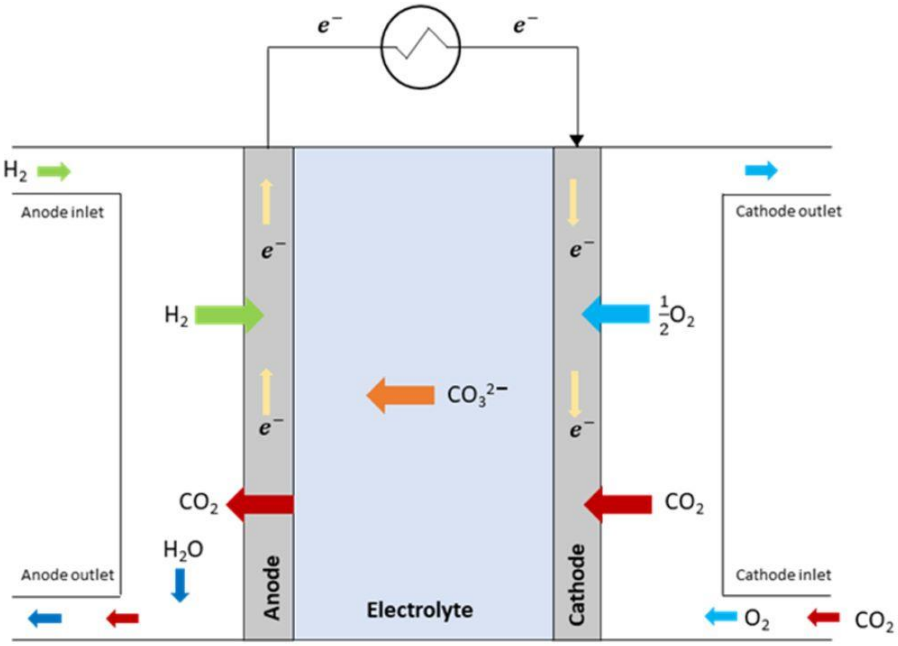

Figure 3.

4. **Calcium Hydroxide to Limestone Reaction method** [10] use the reaction of calcium hydroxide with CO2 to produces calcium carbonate or limestone. This stable solid product CaCO3 can then be discharged into sea without causing any harm. This method is under consideration as it has not having any environmental regulations.
5. **Membrane technique** is proposed for LNG-fuelled vessel [10] as the out coming flue gasses have the right amounts of CO2 and O2 for this system to work correctly. This has the huge advantage connected to the reduced dimensions and the cost, when comparing it to the ammine systems, which are in essence the most established Onboard Carbon Capture and Storage. This technology could be developed in two different ways: Membrane Gas Separator (MGS) or Membrane Contactor (MC). The first system is constituted by a dense membrane and the selectivity is determined by the membrane material, while the second one has a porous membrane and a solvent, used to absorb CO2, which characterized the selectivity. Figure 3 shows the schematic representation of the membrane-separation MC process. In maritime carbon capture MC is preferred over MGS due to its efficiency.

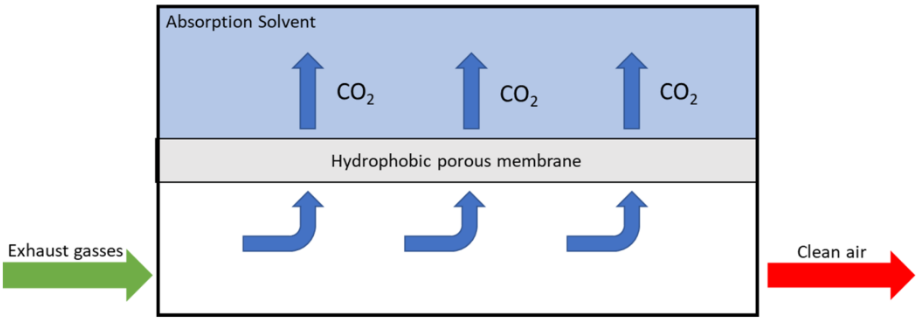

Figure 4. Schematic representation of the membrane separation MC process.

As shown in Figure 4 in MC, the membrane materials should be hydrophobic in order to avoid the wetting of the membrane. MC should have high chemical and thermal stability and high porosity. In addition, the liquid concentration affects the efficiency of CO2 absorption. The most common micro porous membrane from polymeric material is Poly Tetra Fluoro Ethylene (PTFE), Polypropylenes (PP), and Poly Vinyl De Fluoride (PVDF). The first one has better performance in terms of hydrophobicity than the other materials, but it is more expensive. PP is the cheapest material, but it is less hydrophobic than the other polymers. Ceramic materials have also been studied.

6. **Fixed Bed Adsorption and Desorption method** [10] uses potassium carbonate and seems to be a good alternative, as it can chemically bind the CO2 into potassium bicarbonate. This unit should be placed after the SO2 scrubbing that is necessary and already widely applied and can work at low temperatures (around 50 °C). Figure 5 represents both steps of the process below.

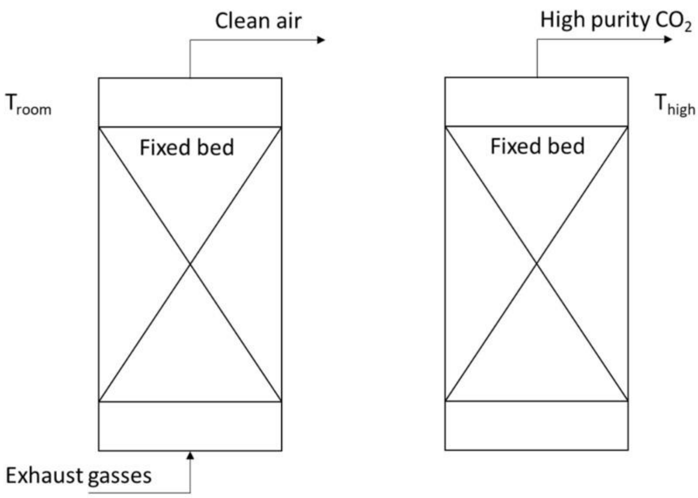

Figure 5. (Left) First step of the process, the CO2 exhaust gasses flow over the fixed bed and the CO2 is absorbed. (Right) Second step, the temperature is set higher, and the CO2 is released.

7. **Value marine filtree system** [11]. In this system Carbon can be stored in high pressure tanks either as a gas or in a liquefied form. The system stores the captured carbon in CO2 batteries, which for the context is a groundbreaking technology built by a company called 'Energy Dome' which can store CO2 for a long period of time while also offering cost effectiveness and being a better option than the traditional lithium batteries. This unique system cleans both air and water from all ship types

8. (SOx Scrubber).
Such filtree system of value marine carbon captured technology has been installed on an Eastern Pacific Shipping (EPS) managed tanker from Dutch start up value marine. The installation which in 2017 and was recently completed on a chemical tanker Pacific Cobalt. Value Marine's Filtree System is installed in the funnel of the vessel and is expected to filter sulfur and 99 percent of particulate matter. Value Marine's Carbon Capture & Storage (CCS) module added to the system can capture up to 40 percent of CO2 emissions from the vessel's main and auxiliary engines. In 2021, Mitsubishi working with Japan's "K" Line success fueled tested the first small unit installed aboard an ocean-going vessel.

3. Discussion

There are number of methods available for carbon capturing. But most suitable and effective method for on-board ship is yet to be found out. Cost of making of on-board OCC system and its effectiveness is also a matter of concern.
Modern ship has to be designed with On-board Carbon Capturing set up to achieve the net-zero carbon emission targets to reduce GHG from maritime sector. However, for existing ships most feasible methods needs to adopted to reduce carbon emission as per IMO regulations.
In is seen that most of marine diesel engines are two stroke types. All the engine steps such as induction, compression, combustion (power stroke) and exhaust gas removal occur with the help of piston strokes within one revolution. Therefore two stroke engines provide higher power-to-weight ratio, more efficient, greater stability and easy construction. In most of the marine ships these engines operate with heavy fuel oil, resulting more black carbon emission.
On the other hand four stroke engines takes two complete revolutions of the crank shaft for one power stroke. The four engine steps of induction, compression, combustion (power stroke) and exhaust gas occurs in four separate steps. Therefore these engines are more fuel efficient and required less lubrication and proved to be more eco-friendly alternative as they emits less carbon. But these engines run with gasoline, diesel fuel and petrol fuel. This makes them more expensive than two-stroke engines.
However, more than the engine cost, the clean and green environment of our earth is far more important than anything else in the world. Therefore, future ships may go for four stroke engines.

4. Conclusion.

The maritime industry should adopt most suitable OCC techniques for on-board implementation depending upon type of the ship, size of the ship, amount of carbon emission from the ship and other related aspects.
In addition to the OCC techniques some other alternatives for the fuel such as ammonia, methanol, LNG, LPG, biofuel, biodiesel and hydrogen etc. may also be adopted to reduce carbon emission. It may also be possible to use existing fuel to start and propel the ship till it attains sufficient speed. Once the require speed is achieved, disconnecting the engine and start running it on either using the wind power or any one of the fuel as above.
Changing over the engine to other fuel system could reduce the speed, but rather than the ships speed what is most important is safety and lower carbon emission. Less speed means less fuel consumption and lower carbon emission. Maritime sector and every ship must be concerned about reduction of toxic gases in the atmosphere to reduce GHG and to achieve net-zero carbon emission as recommended by IMO by 2030.

All developing countries must be concerned about climate changes, GHG, ecosystem, forestation etc. If ecosystems totally ignore then our earth and we all human and living species, would be declared as endangered species. Earth is an ideal home for all living species and their survival. It should be underlined that it is responsibility of every country, policy makers, politician and common citizens to preserve and protect our only home, the Earth.

Time has come to minimize the emission of toxic gases such as sulphur oxide, nitrogen oxides. Particulate matters, black carbon emission etc. from maritime industry with the help all available technologies to reduce global carbon emission from shipping world.

Acknowledgements

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