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CO_2 Capture Performance of Amine-Infused Resin for LNG-Fueled Ship Emissions

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Abstract

Global warming is accelerating worldwide, leading to critical environmental issues such as rising sea levels and the loss of biodiversity. Among the various greenhouse gases, carbon dioxide (CO_2) is considered the most significant contributor to global warming. In response, the International Maritime Organization (IMO) has introduced measures such as the Energy Efficiency Design Index (EEDI) and aims to reduce CO_2 emissions from the shipping industry to zero by 2050 (IMO 2023). The main source of CO_2 emissions is the use of fossil fuels. Consequently, technologies have been developed to either reduce CO_2 generation by replacing fossil fuels with alternative energy sources or to capture emitted CO_2 for mitigation. One of the most promising alternative fuels is liquefied natural gas (LNG), which is composed primarily of methane liquefied from underground deposits. Compared to conventional fossil fuels, LNG emits fewer harmful substances like sulfur oxides (SO_x) and nitrogen oxides (NO_x), and it also produces less CO_2 upon combustion. Due to these advantages, LNG is increasingly being used as a transitional fuel in the shift toward carbon-free alternatives. According to Det Norske Veritas (DNV), the number of LNG-fueled ships increased from 63 in 2015 to 1,034 as of May 2024, making LNG the most widely adopted eco-friendly fuel in shipping (DNV 2024).

Although LNG-fueled ships are generally considered environmentally friendly, the methane-based nature of LNG still results in some CO_2 emissions. As the adoption of LNG-fueled ships increases, there is a growing need for technologies to reduce CO_2 emissions from these ships. Among the various available CO_2 reduction technologies, amine-based absorption remains one of the most widely used methods. Amines such as monoethanolamine (MEA) and diethanolamine (DEA) are utilized across multiple industries for CO_2 capture (Dutcher et al., 2013; Meng et al., 2022; Aghel et al., 2022). These amines absorb CO_2 chemically in liquid form, and recently, a new form of hybrid adsorbent, known as Amine-Infused Resin, has emerged by combining amines with resins to achieve both chemical absorption and physical adsorption, thereby improving capture efficiency.

In this study, a gas mixture simulating the exhaust of LNG-fueled ships—composed of 5% CO_2 and 95% N_2—was used as the feed gas. This concentration is lower than the typical 15% CO_2 found in post-combustion flue gas from fossil fuel combustion, allowing for performance comparison under low CO_2 conditions. The amines used were

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MEA and DEA, and the adsorbents were in the form of amines combined with resin. The CO_2 concentration of the emitted gas was measured using gas chromatography, and the total reduced CO_2 mass was quantified. CO_2 loading was then determined by dividing the total captured CO_2 mass by the mass of the adsorbent used. The experimental setup is shown in Figure 1, where the gas is controlled to meet the desired conditions before passing through the reactor. The reactor, which contains the adsorbent, is equipped with a heating band for temperature regulation. During adsorption, the feed gas, stored in the buffer tank, flows into the reactor with the flow rate controlled by the Mass Flow Controller (MFC), while the pressure is regulated by the back pressure regulator placed behind the reactor. After the reaction, the gas flows directly into the gas chromatograph for measurement. During regeneration, nitrogen gas is used for the regeneration process.

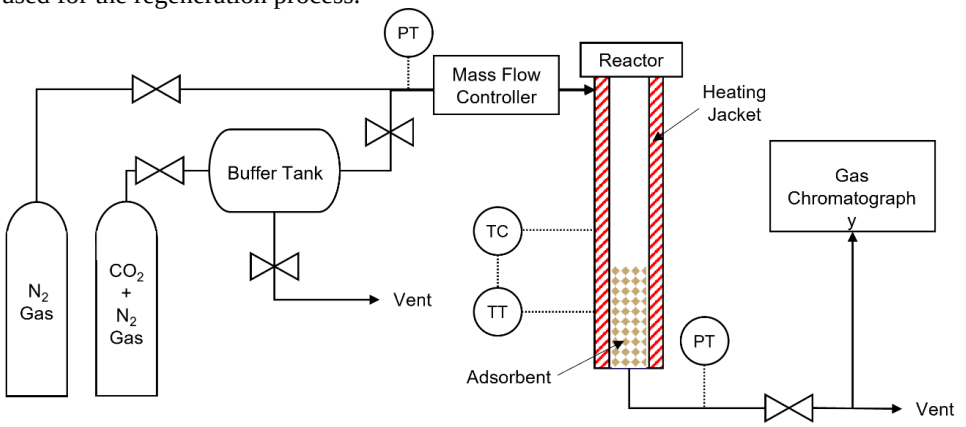

Figure 1. Schematic Diagram of the Experimental Setup

As shown in Figure 2, in the first cycle, both MEA-based resin and DEA-based resin rapidly adsorb CO_2 at the beginning. During this period, DEA-based resin shows a higher maximum CO_2 adsorption compared to MEA-based resin. Furthermore, while MEA-based resin's adsorption decreases significantly after the first 5 minutes, DEA-based resin maintains its maximum adsorption until 30 minutes. In terms of CO_2 loading, DEA-based resin shows 3.24 wt%, while MEA-based resin shows 0.91 wt%, indicating that DEA-based resin exhibits superior performance. Additionally, degradation over cycles shows that, for DEA-based resin, the CO_2 loading in the first cycle is 3.24 wt%, and by the fourth cycle, it is 3.08 wt%, showing little degradation. In contrast, MEA-based resin's performance declines significantly from 0.91 wt% in the first cycle to 0.27 wt% in the fourth cycle. Therefore, it appears that DEA-based resin shows superior performance compared to MEA-based resin.

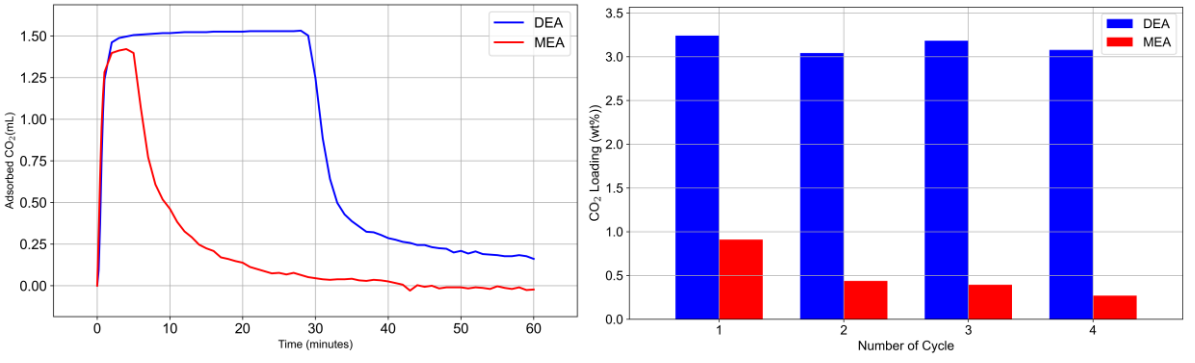

Figure 2. (Left) Time-Dependent CO_2 Adsorption Performance of MEA and DEA in First Cycle, (Right) CO_2 Loading of MEA and DEA according to the number of Cycles.

Through this research, we aim to identify more suitable adsorbents for low CO_2 concentrations and expand the range of potential adsorbents. Furthermore, this work could contribute to the selection of adsorbents for Direct Air Capture (DAC) applications.

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