Energy Efficient Method for Capture of CO_2 Directly from Air Using Phase Change Amines

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Highlights

- A continuous process for the direct air capture (DAC) of CO_2 using phase change amines (PCA)
- Energy and cost comparison of PCA-DAC with Solid-DAC, Liquid-DAC, and MEA-DAC
- PCA-DAC reduces the energy required for regeneration by 50-70% compared to conventional methods
- Cost of capture would be > \$100/tCO_2 at par with post combustion capture.

1. Introduction

Burning fossil fuels for power generation and transportation, producing cement, razing forests, farming, and numerous other anthropogenic activities all add to the pollution of CO_2. As a result, the global average CO_2 concentration in atmosphere has been gradually increasing since the industrial revolution (1750–1760), rising from 275 ppm to 421 ppm on May 2022, which has caused an increase in the average surface temperature of about 1.1°C as of the end of 2017 [1]. Consequently, emphasis is placed on CCS technologies, with absorption emerging as the most mature technology for post-combustion capture of CO_2 (PCC) from flue gas, using 20-30% aqueous monoethanolamine (MEA), that requires 120-130°C. The process demands 4-6 GJ/tCO_2 in energy and costs \$80-\$100/tCO_2. However, even if all CO_2 emissions from point source emissions were captured and sequestered, it would not be possible to achieve more than 60% reduction in CO_2 emissions. Therefore, it is equally important to reduce CO_2 emissions from non-point sources such as transport, agriculture, household etc., to meet the target of "Net Zero Emission".

Direct air capture (DAC) technology offers an option to address the emissions from non-point sources. Like PCC, conventionally DAC also used 20-30% MEA solution which required energy of 15-18 GJ/tCO_2 captured [2]. Currently two approaches are being used to capture CO_2 directly from the air: solid-DAC (S-DAC) and liquid-DAC (L-DAC). S-DAC is based on solid adsorbents (zeolite) operating at ambient to low pressure (*i.e.*, under a vacuum) and medium temperature (80-120°C) that requires energy of 7-10 GJ/tCO_2 captured and costs up to \$500/tCO_2 [3]. L-DAC relies on an aqueous basic solution (such as KOH, NaOH), which releases the captured CO_2 through a series of units operating at high temperature (between 300-900 °C) that requires energy of 6-9 GJ/tCO_2 captured and costs up to \$300/tCO_2 [3]. However, both these DAC techniques still suffers from high costs of CO_2 capture, high regeneration temperature/energy (in case of L-DAC) and low CO_2 uptake and capture rate (in case of S-DAC). Lately, a novel phase change amine (PCA) is emerging for DAC that has the potential to substantially reduce the energy required for regeneration by separating the CO_2 sorbed phase as precipitate from the solvent (lean phase as liquid), thereby reducing the cost of capture. Therefore, the current study investigates the feasibility of directly capturing CO_2 from air using novel phase change amine (PCA) and compare with the existing DAC technologies in terms of energy required for regeneration and cost of CO_2 capture.

2. Methods

Steady-state plantwide thermodynamic models are developed in ASPEN Plus for the existing MEA-DAC, S-DAC, L-DAC and novel PCA-DAC to understand the potential pay offs the innovative technology. 10 wt. % Isophorone-diamine in Decane (IPDA) is considered for PCA-DAC analysis.

3. Results and discussion

A comparative analysis of total energy requirements encompassing heat and power aspects, measured in GJ/tCO_2 is depicted in Figure 1. It is observed that the heat (for sorbent regeneration) and electricity (for blower, compressor, and pumps) required by PCA-DAC (2.3 GJ/tCO_2) reduces by more than 50% compared to existing DAC technologies. This significant energy efficiency enhancement in PCA-DAC can be attributed to its distinctive features, namely: (a) solvent separation prior to regeneration, (b) lower regeneration temperatures (60-80°C), (c) increased CO_2 uptake (1-1.2 moles of CO_2 per mole of amine) and (c) increased CO_2 capture efficiency (up to 99%). Figure 2 elucidates the variations in energy distribution among the distinct units of various DAC technologies.

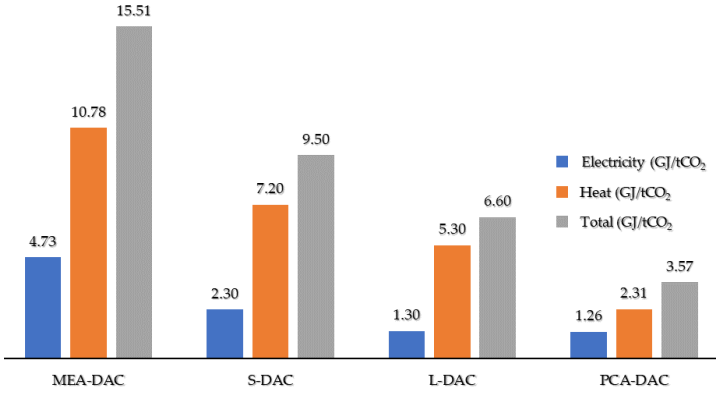

Figure 1. Comparative analysis of energy required for CO_2 capture using MEA-DAC, L-DAC, S-DAC, and PCA-DAC.

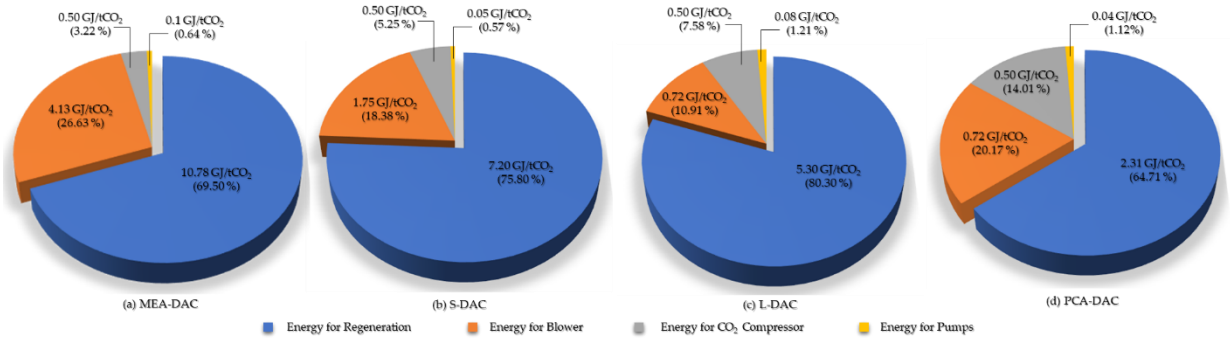

Figure 2. Energy requirements of major units for CO_2 capture using MEA-DAC, L-DAC, S-DAC, and PCA-DAC

4. Conclusions

The novel PCA-DAC technology has the potential to reduce the energy required for regeneration by 50-70% compared to the exiting S-DAC and L-DAC technology, thereby resulting in reduction in cost of CO_2 capture to less than \$100/tCO_2 which is at par with the existing MEA based PCC.

References

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Keywords

Direct Air Capture; Phase Change Amines; CO_2 capture; Absorption