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Reboiler duties at ultra-high CO_2 capture rates with MEA and CESAR1

Benas Mockus[a], Diego Morlando[a], Hanna K. Knuutila[a]*

[a]*NTNU, Gløshaugen, Sem Sælands vei 6, Trondheim 7034, Norway*

Abstract

Introduction

Growing global temperatures and human population lead to a constant increase in energy demand (Smit et al., 2014). Even with the growing energy supply from renewable sources, consumption of fossil fuels is inevitable in the future (Khaleel et al., 2022). Therefore, we should focus on technologies tackling CO_2 emissions and transitioning towards net-zero carbon emissions by 2050 (Feron, 2016). Post-combustion CO_2 capture (PCC) using absorption has emerged as the most mature technology to capture the emitted CO_2 (Smit, 2016). Monoethanolamine (MEA) has been considered for many years as the benchmark solvent for its effective absorption capacity and low material cost (Bui et al., 2018). An aqueous blend of 3 M 2-amino-2-methyl-1-propanol (AMP) and 1.5 M piperazine (PZ) was found to outperform MEA in terms of energy performance and degradation stability (Feron et al., 2020; Morlando et al., 2024). Therefore, it has been proposed as the new benchmark solvent for this technology (Feron et al., 2020).

With the need to capture all emitted CO_2 from power plants to meet net zero emission requirements (Dixon et al., 2022), the performance of PCC at ultra-high CO_2 captures (up to ~99.8%) must be studied. The aim of this work is to investigate MEA and CESAR1 energy performance at different CO_2 capture rates going up to ~99.8%. Energy penalty will be the main performance indicator for solvent comparison. However, we also aim to present a techno-economic comparison that takes into consideration other aspects such as solvent loss by degradation and emission.

Results and discussion

In the evaluation three different CO_2 wet concentrations in the flue gas were considered: 4 vol%, 12 vol% and 18 vol%. Here results for 30 wt% MEA at 12 vol% are discussed. However, we have results for all concentrations and both solvents already completed.

Figure 1, presenting the specific reboiler duty (SRD) as a function of liquid to gas (L/G) ratio for 30 wt% MEA at 12% CO_2 wet concentration, shows some preliminary results. It is seen that increasing CO_2 capture from 90.0% to 99.0% at 25m absorber height led to only a little increase in SRD from 3.7 to 3.8 MJ/kg CO_2. The optimal liquid to gas ratio (L/G), increased with higher capture rate since larger amount of CO_2 was captured.

* Corresponding author. Tel.: +4773594119
E-mail address: hanna.knuutila@ntnu.no

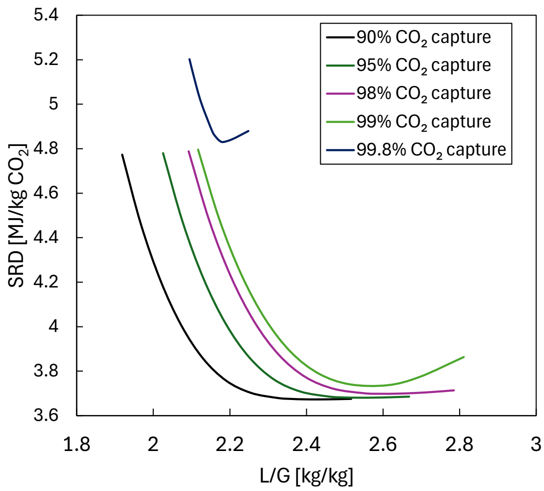

Figure 1. SRD vs L/G performance of 30 wt% MEA at 90.0-99.8% CO_2 capture with 25m absorber.

For the net zero emission case (99.8% CO_2 capture), it is clearly seen that the lowest SRD of 4.8 MJ/kg CO_2 is higher by more than 30% in comparison to other capture rates. This is caused by temperatures in the absorber reaching over 75°C leading to lowered driving force of mass transfer and temperature pinching in comparison to 90.0% CO_2 capture as shown in Figure 2. In addition, Figure 2 shows that the net zero case also required stripping the solvent to significantly lower lean loadings (0.10 mol CO_2 / mol MEA) compared to the other cases to provide driving force for CO_2 depleted hot flue gas at the top of the absorber. Implementation of absorber intercooling would reduce the reboiler duties significantly. In this work, absorber intercooling was used only for net zero case.

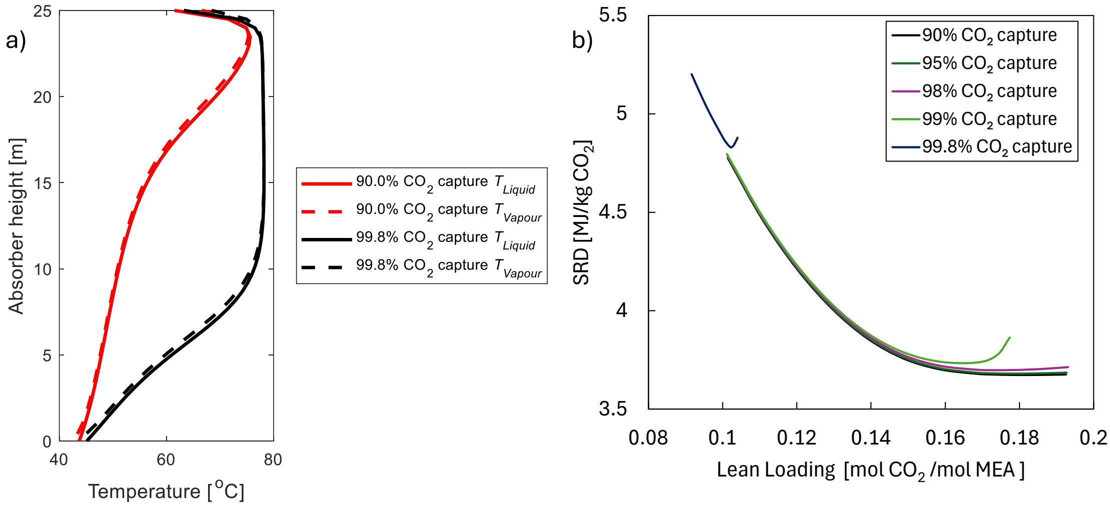

Figure 2. Reasons for high SRD achieved by 99.8% CO_2 capture at 12% wet CO_2 flue gas and 30 wt% MEA at 25m absorber height: a) Temperature profile at 90.0% (Red) and 99.8% (Black). Solid line used for liquid temperature profile, dashed for vapour; b) SRD vs Lean loading performance at 90-99.8% CO_2 capture.

All the preliminary SRD optimizations were performed with a 25 m absorber packing height. The SRD dependence on absorber height at fixed L/G was then studied. Following the approach of Nakao et al. (2025), the optimal lowest height was chosen when an increase in SRD between two heights was higher than 1% of the total SRD values at the chosen height. Based on Figure 3 for 30 wt% MEA, it is seen that increasing the amount of CO_2 captured leads to higher optimal height: 10/12/15/17 m absorber height for 90.0/95.0/98.0/99.0% CO_2 capture respectively. However, this is only a preliminary check, and a thorough techno-economic assessment will provide final conclusions on optimal absorber height.

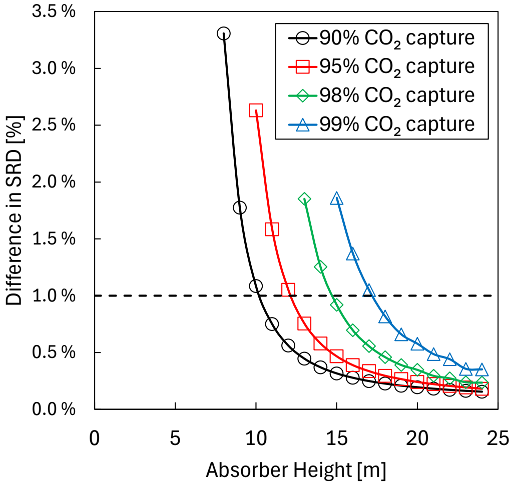

Figure 3. SRD vs Lean loading performance of 30 wt% MEA at 90-99.8% CO_2 capture with an absorber of 25m packing height.

In conclusion, we will present the energy performance of 30 wt% MEA and CESAR1 solvents. For both solvents, reboiler duty from 90.0% to 99.8% will be shown for 4, 12 and 18 vol% CO_2 concentrations. Further, the connection between absorber height and reboiler duty is discussed, and the techno-economic assessment provides results for the discussion of the impact of CO_2 capture on the total cost for these two solvents.

Keywords: MEA; CESAR1, ultra-high CO_2 capture; Post-combustion CO_2 capture; absorption.

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