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Modeling MEA Solvent Degradation in CO_2 Capture: A Comparison Applied to the Steel Manufacturing Process

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ABSTRACT

Certain industrial processes, such as steel production, inherently emit CO_2 due to the decomposition of raw materials, independent of energy sources. For these sectors, CO_2 capture technologies play a critical role in achieving carbon reduction goals. Among the mitigation technologies, the absorption-regeneration process with amine solvents like Monoethanolamine (MEA) is widely used, though challenges remain. MEA undergoes both thermal and oxidative degradation during absorption-regeneration cycles, which reduces process efficiency and complicates solvent management. This study examines CO_2 capture using Aspen Plus software, focusing on MEA-based processes for a steel manufacturer, with CO_2 concentrations reaching 8 vol-% and with a capture capacity of 21.2 t/h. By incorporating degradation kinetics in process models, the study evaluates energy requirements, emissions of degradation products, and MEA reactivity loss. Results show MEA losses of 0.2 kg/ton CO_2 captured at a 90% capture rate, aligning with pilot plant measurement at WtE plant Amager Bakke [1].

Keywords: MEA, Degradation, Process modelling, CO2 capture.

INTRODUCTION

CO_2 capture processes

In terms of CO_2 capture processes, more and more technologies are becoming commercially available. However, the absorption-regeneration process using amines, especially ethanolamine (MEA), is one of the most mature technologies and it serves as benchmark process for CO_2 capture. Many pilot units have already been built and have been running for hundreds of hours [2]. A lot of efforts are made to decrease the energy demand of such processes, but a remaining challenge is to deeper understand the effects behind MEA degradation.

Solvent Degradation

MEA degradation is caused by different factors such as the presence of O_2, the presence of pollutants such as SOx, NOx..., but also the high temperature of regeneration (~120-130°C). In this paper, the oxidative and thermal degradations are considered to highlight their impact on critical parameters such as reboiler duty (GJ/t CO_2) and solvent loss. Indeed, based on previous experimental results, some degradation species, as well as their kinetic of formation, have been extracted. The following modelled process then uses Léonard's model for oxidative degradation [3] and Braakhuis's model for thermal degradation of MEA [4].

CO_2 CAPTURE PROCESS MODEL

Base case (Case 1)

In **Figure 1**, the CO_2 capture process modelled in ASPEN Plus starts with a cooler, followed by a blower to overcome system pressure drops. The gas then enters the absorption-regeneration loop, consisting of an absorption column, a lean amine pump, a desorption column, a lean-rich amine heat exchanger, and another cooler to reduce the lean amine temperature to 40 °C before recycling. Cleaned flue gas is washed to reduce amine losses before being discharged safely into the atmosphere. The process uses a 30 wt.-% MEA aqueous solution. Flue gas enters the absorption column at the bottom, where it interacts with the solvent to separate CO_2 from the other gases. The exothermic reaction raises the column temperature to about 75 °C. CO_2-rich solvent leaves the column at the bottom and is then pre-heated before entering the stripper where a reboiler heats the solvent to 120 °C for the desorption of the CO_2. The condenser, at the top of the desorption column, removes water and impurities like NH_3 and MEA droplets.

This study is based on emission coming from natural gas fired reheating furnaces in a steal manufacturing process in Belgium. The emission related to the process is close to 150 kt/year. The different parameters of the flue gas are shown in **Table 1**.

Table 1: Composition of the flue gas from the reheating furnaces.

Parameters	Units	Value
Flowrate	[Nm³/h]	150 000
Temperature	[°C]	260
Pressure	[atm]	1
H_2O concentration	Mol.-%	15
CO_2 concentration	Mol.-%	8
O_2 concentration	Mol.-%	4
N_2 concentration	Mol.-%	73

Results

The CO_2 capture process applied to the steel manufacturing case leads to a consumption of 3.86 GJ/t of captured CO_2 with a capture rate fixed at 90 %. But, when MEA degradation is included (**Case 2**), this energy consumption achieves **3.88 GJ/t**, an increase of around 0.5%. The stripper temperature was 123.1 °C in both cases, as well as the solvent flowrate fixed to 435.7 m³/h.

A deeper analysis on the effect of O_2, as well as CO_2 concentrations on solvent degradation and process performances is undertaken to visualize how they impact degradation and the subsequent consequences on regeneration energy consumption. It's important to notice that the MEA loss calculated the evaporation losses in the MEA, as well as the degradation.

Table 2: Simulation results for the CO_2 capture model

Parameters	Case 1	Case 2
Energy consumption (GJ/t CO_2)	3.86	3.88
Captured CO_2 (t/h)	21.2	21.2
Apparent [MEA] (wt.-%)	30.04	30.03
MEA loss (kg/t CO_2)	10^{-4}	0.189

Based on these two cases, it is not possible to assert that degradation would lead to higher energy consumption. There is also a slight difference in terms of MEA concentration, which has an impact on energy consumption at the reboiler.

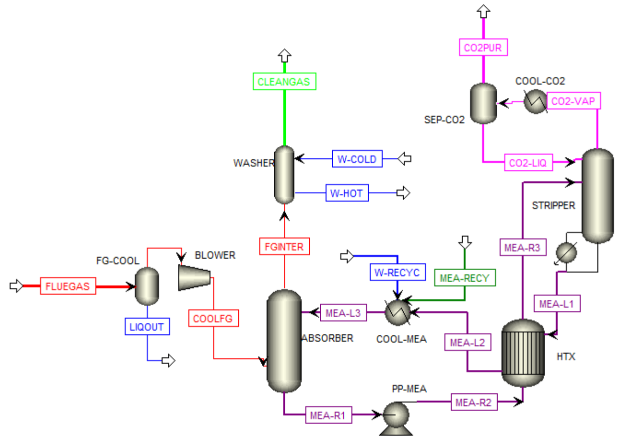

Figure 1. CO_2 capture process modelled in ASPEN Plus

The consistency between modeling results and pilot plant data represents a significant step forward in understanding CO_2 capture by MEA absorption-regeneration processes.

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