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CO_2 Absorption Using Potassium Carbonate as Solvent †

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Abstract: One of the main sources of global warming is greenhouse gasses; the most important of which is carbon dioxide. Reducing CO_2 emissions, and its utilization or storage, is a global challenge to tackle climate change. In this work, the operating conditions of the pilot CO_2 capture unit are studied using the ASPEN PLUS® software. This study describes the methodology of the simulations and the main results. The unit consists of one scrubber and one stripper. For carbon dioxide absorption from gas streams, the aqueous solvent K_2CO_3 is used. The effect on the absorption of CO_2, and regeneration of carbon dioxide and potassium carbonate were studied by varying parameters of pressure, temperature, and concentration of solvent. For each parameter, three values were evaluated with the following ranges: pressure 0.3–1 bar; temperature 80–100 °C; and concentration of potassium carbonate 15–25 wt%. The optimum operating conditions of the pilot unit are pressure of 0.3 bar, stripper temperature of 100 °C, and solvent concentration of 15 wt%. Under these conditions, 99.91% CO_2 capture and 85.46% CO_2 regeneration were achieved. The present research aims to find the optimal operating parameters of the pilot plant to validate the model with the experimental data. In this way, the model parameterization can be used to design large-scale CO_2 capture units.

Keywords: CO_2 capture; absorption; potassium carbonate

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1. Introduction

The combustion of fossil fuels produces a large amount- of carbon dioxide, one of the main greenhouse gases, which impacts global warming. Tackling climate change requires reducing CO_2 emissions either through the use of alternative fuels or through the use of carbon capture technologies [1–3]. One of the most well-known CO_2 capture technologies is chemical absorption in an amine-based solvent (mono-ethanolamine (MEA), methyldiethanolamine (MDEA), etc.) followed by desorption. Amines are widely used, mainly because of their reactivity with CO_2 under mild temperature (absorber: 40–65 °C; stripper: 100–120 °C) and pressure (1–2 bar) conditions [4,5]. However, amines are corrosive and cause equipment problems and, through their easy degradation by oxidation reaction, can be potentially toxic to the environment [5–8]. Additionally, another major drawback of amines is the high reboiler heat duty for desorption. An eco-friendly carbon capture process has been proposed to replace the amines with potassium carbonate (K_2CO_3). Potassium carbonate is less toxic and less corrosive than amines, and is considered a particularly attractive wet chemical absorbent as it has fewer energy requirements for its regeneration [9].

In this study, the absorption of CO_2 using potassium carbonate solution is investigated as well as its regeneration. ASPEN PLUS® software is used to evaluate the operating parameters of the CO_2 capture pilot unit.

2. Materials and Methods

In this study, the CO_2 capture pilot unit using the K_2CO_3 solution was simulated using the ASPEN PLUS® V11 software.

2.1. Rate Based Method

CO_2 capture can be modelled in Aspen Plus®, either as a thermodynamic model or as a rate model. In this study, the methodology for a rate model is used. The rate of absorption and desorption is determined by two mechanisms, mass transfer and chemical reaction, which, when combined with mass and energy balance equations, determines the concentration and temperature along the column [10,11].

Specifically, in this work, the electrolyte NRTL method is chosen for computing liquid phase properties and RK equation of state is chosen for computing vapor phase properties. CO_2, H_2S, N_2, O_2, CO, and H_2 are selected as Henry-components, to which Henry's law is applied, while the activity coefficient basis is aqueous. All the data are retrieved from Aspen Plus® databank and chemical equilibrium is assumed [12,13].

In post-combustion capture applications, the absorber is operated close to atmospheric pressure, which is similar to the input stream of flue gas. When CO_2 is absorbed into K_2CO_3 solvents, particularly at high concentrations of K_2CO_3, both physical reactions and chemical reactions occur [14,15]. The summary of the reactions for the absorber and stripper specifications are:

$$CO_2 + 2H_2O \leftrightarrow H_3O^+ + HCO_3^- \tag{1}$$

$$HCO_3^- + H_2O \leftrightarrow H_3O^+ + CO_3^{-2} \tag{2}$$

$$2H_2O \leftrightarrow H_3O^+ + OH^- \tag{3}$$

$$H_2O + H_2S \leftrightarrow HS^- + H_3O^+ \tag{4}$$

$$H_2O + HS^- \leftrightarrow S^{-2} + H_3O^+ \tag{5}$$

$$KOH \rightarrow K^+ + OH^- \tag{6}$$

2.2. Simulation

The specifications and operating conditions are presented in Table 1. A schematic flowsheet developed in this study is presented in Figure 1.

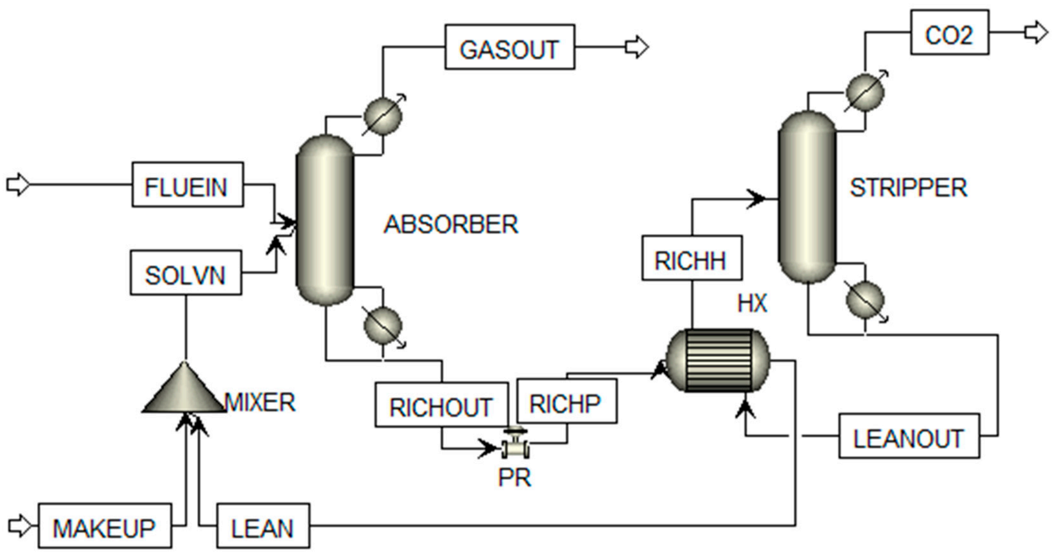

Figure 1. Aspen Plus flowsheet of CO_2 capture.

Table 1. Simulation parameters.

Parameters	Values
Absorber Temperature (°C)	35
Absorber Pressure (bar)	1
Stripper Temperature (°C)	80, 85, 100
Stripper Pressure (bar)	0.3, 0.7, 1
Gas flow rate (slpm)	1
Solvent flow rate (slpm)	0.1
Concentration of K_2CO_3 (%v/v)	15, 20, 25
Concentration of CO_2 (%v/v)	15

Two main streams were specified: the solvent stream named "SOLVN", and the flue gas stream "FLUEIN". The flue gas was considered to be composed of CO_2 and N_2 while other components, such as H_2O, O_2, and SO_2, are neglected. A solvent makeup stream was added to the recycled stream before entering the absorber in order to compensate for the solvent loss during the absorption and stripping process. The solvent was added at atmospheric pressure and at a temperature of 35 °C. From the absorber, a gas stream containing almost no carbon dioxide is released. Meanwhile, the liquid stream, which is rich in solvent, leaves the absorber and is pressurized and heated before entering the stripper. From the stripper, a gaseous stream of CO_2 is produced, while the liquid solvent stream is recycled back to the absorber.

An analysis of variance (ANOVA) was performed to estimate the influence of parameters on the absorption of carbon dioxide, and the CO_2 regeneration with independent parameters: (a) stripper temperature; (b) stripper pressure; and (c) concentration of solvent.

3. Results

The results of the ANOVA analysis are presented in Tables 2 and 3. All 27 cases were simulated based on the Aspen Plus flow sheet (Figure 1) for two responses: absorption of CO_2 efficiency, and regeneration of CO_2 efficiency. The CO_2 absorption efficiency for all cases exceeded 99.8%, and the simulation results for CO_2 recovery efficiency are shown in Figure 2.

Table 2. Effects of parameters on regeneration of CO_2 efficiency.

	Sum of Squares	Mean Square	F Value	*p* Value
Stripper pressure	1.6902	0.8451	101.3366	7.9357×10^{-12}
Stripper temperature	0.3185	0.1592	2.0396	1.5562×10^{-5}
Error	0.1835	0.0083		

Table 3. Effects of parameters on absorption of CO_2 efficiency.

	Sum of Squares	Mean Square	F Value	*p* Value
Solvent concentration	2.1473×10^{-6}	1.0736×10^{-6}	20.0785	7.5094×10^{-6}
Error	1.2833×10^{-6}	5.3472×10^{-8}		

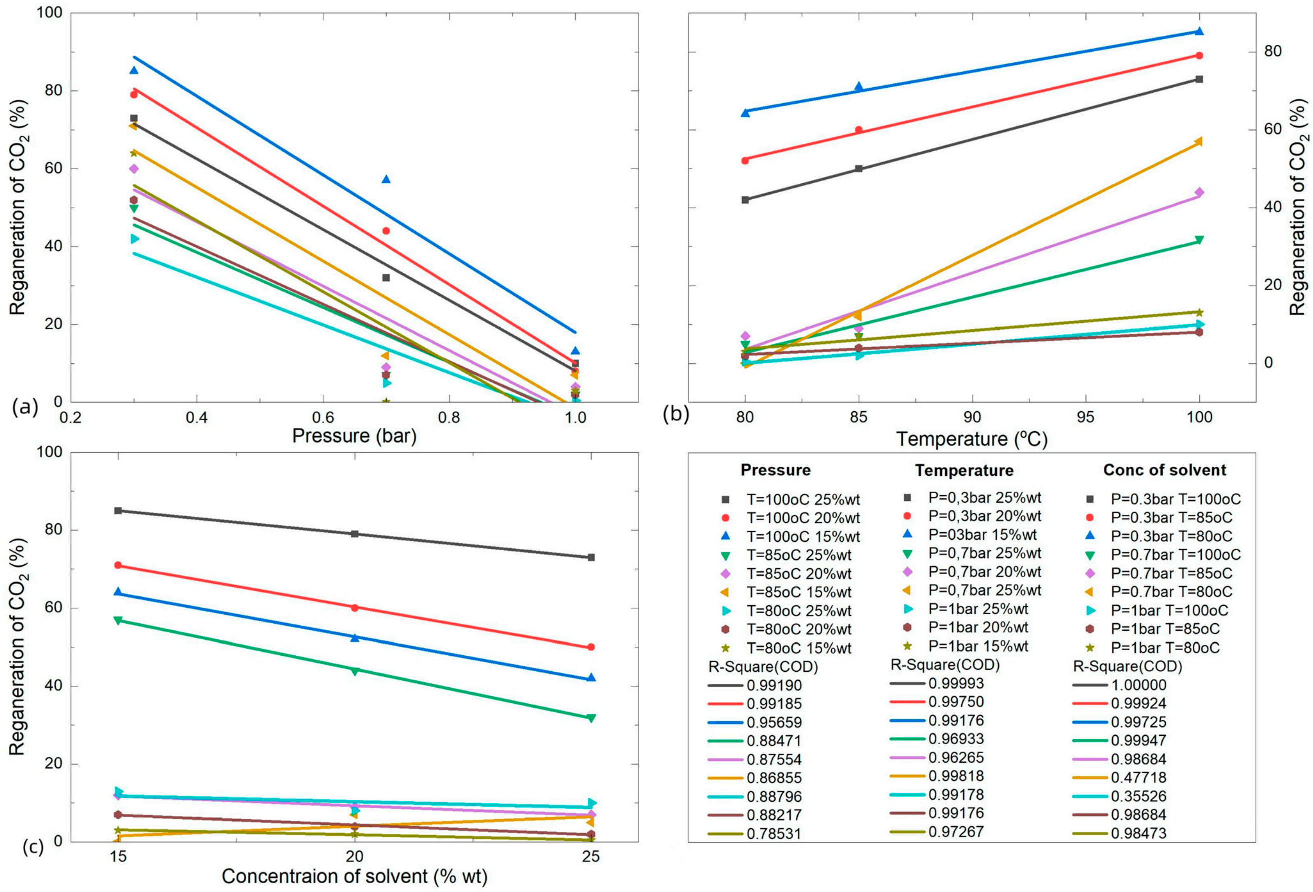

Figure 2. Regeneration of CO_2 for each case.

4. Discussion

ASPEN PLUS® software was used to find the optimal operating conditions of the CO_2 capture pilot unit. The parameters studied were stripper pressure, stripper temperature, and solvent concentration. The CO_2 absorption in all cases exceeded 99.8%. The increase in potassium carbonate solvent has a subtle decrease in absorption of CO_2. This is inconsistent with the parametric analysis of K_2CO_3 concentration conducted by Ayittey [16]. This differentiation is due to the small variation in CO_2 absorption values. The regeneration of CO_2 showed a large variation of values depending on the stripper operating conditions. Figure 2a shows that reducing the pressure of stripper significantly increases CO_2 recovery with a fine linear correlation ($R^2 > 0.785$). Greater regeneration of CO_2 is observed when the stripper temperature is higher, as confirmed in Figure 2b. There is a perfect linear correlation of stripper temperature with regeneration of CO_2 ($R^2 > 0.963$). The concentration of potassium carbonate in the liquid absorber is not expected to affect the regeneration of carbon dioxide (Figure 2c).

An analysis of variance (ANOVA) was conducted to estimate the influence of parameters on the absorption of carbon dioxide and the CO_2 regeneration. Stripper pressure and stripper temperature were chosen as independent variables, as they were suggested to influence CO_2 recovery. The results of two-way ANOVA analysis were evaluated for CO_2 recovery as the p-value and F-factor. As shown in Table 2, the statistically significant parameters for the regeneration of CO_2 are the stripper pressure and the temperature of the stripper, with a p value lower to the level of 0.05. In addition, a one-way ANOVA analysis showed that the concentration of K_2CO_3 is statistically significant for the absorption of carbon dioxide (Table 3).

5. Conclusions

An eco-friendly carbon dioxide capture process is studied in this research using ASPEN PLUS® software. The capture and recovery of CO_2 were simulated in an absorption and a desorption column using potassium carbonate. The parameters examined were the concentration of K_2CO_3, and the temperature and pressure of the stripper. Stripper pressure and stripper temperature influence the regeneration of CO_2, as shown in the analysis of variance (ANOVA).

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Data Availability Statement: Data available in a publicly accessible repository that does not issue DOIs. Publicly available datasets were analyzed in this study. This data can be found here: https://co2coccus.gr/en/ (assessed on 1 December 2022).

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Conflicts of Interest: The authors declare no conflict of interest.

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