

Simulation of CO₂ Absorption and Desorption in Packed Columns

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ABSTRACT

This paper presents a research work on the simulation of a simultaneous gas absorption-desorption in the packed columns using computer software to obtain the maximum amount of absorbed carbon dioxide (CO₂) into the water, the optimum L/G ratio for absorption, the optimum airflow rate for desorption, and make-up water for desorption. Simulations were carried out using the Aspen HYSYS program, with Sour SRK (Soave-Redlich-Kwong) 'fluid package'. A Solteq gas absorption-desorption column unit (column diameter of 80 mm, glass raschig ring packing with an effective height of 1,500 mm) were used for the analysis, with an operating pressure of 1 bar, absorption temperature of 25°C, water flow rate (L) of 1.5 L/min, L/G 10-150 (kg/kg), and desorption temperature of 40°C. The model successfully predicts CO₂ absorption with water, including a maximum solvent capacity of 1.176 g CO₂/kg H₂O at an optimum L/G ratio of 50. For the simultaneous absorption-desorption process, the airflow rate needed of 0.0016 LPM but required quite a big amount of make-up water, which is 24% of the freshwater flow rate. From those results, it was concluded that CO₂ absorption and desorption in packed columns utilizing water as physical absorbent is feasible.

Keywords: *Packed column, simulation, gas absorption-desorption, Aspen HYSYS, carbon dioxide - water system*

1. INTRODUCTION

Purification of biogas from impurities, such as CO₂ (carbon dioxide) and H₂S (hydrogen sulfide) gas is essential prior to usage as fuel. The CO₂ content in biogas can reduce the heating value, while H₂S is highly toxic and corrosive to the equipment. There are several technologies that can be used to separate CO₂, such as absorption, adsorption, cryogenic, membrane and microbial-based [1]. The technology most widely used to remove CO₂ from biogas is absorption with water solvent in packed columns.

Separation of CO₂ with water has been operated for a long time, due to the simple plant design, inexpensive solvent, and more environmentally friendly compared to the absorption using amine solvents. However, CO₂ absorption with water has a disadvantage of poor recovery due to low CO₂ solubility in water. The CO₂ absorption with water will be economical at a pressure of more than 3.5 bar [2]. Washing of CO₂ with water has then be replaced by chemical solvents (such as monoethanolamine / MEA) and physical solvents (such as methanol in the Rectisol process) which have a greater CO₂ absorption capacity than water. The disadvantage of amine-based chemical absorption for carbon dioxide are:

- High energy consumption during solvent regeneration,

- Large solvent losses under elevated temperature for regeneration,
- Usage of a single type of amine did not give optimum result, therefore, amine blends are needed
- Corrosion requires the use of both inhibitors and resistant materials in their application.[3].

Separation of CO₂ from biogas was carried out at an L/G ratio of 120-220 L water/m³ of raw biogas, at a temperature of 14-20 °C and pressure of 6.5-8 bar a [4]. Evaluation of water wash for CO₂ capture from flue gas that contains 37% of CO₂ using Aspen Plus obtained a significant removal efficiency of 86 %. The solvent circulation rate was ten times higher than that of the amine absorption process. At the best experimental setpoint using an absorber of 5 m height, the CO₂ absorption efficiency was 60%, while the modeling calculations provided a maximum efficiency of 75% [5]. CO₂ absorption in a packed column with a diameter of 6 cm and a height of 75 cm using methyl diethanolamine (MDEA) absorbent obtained optimum result at an L/G ratio of 150. This condition was able to reduce the initial CO₂ concentration of 40% to 17%, with a CO₂ gas mass transfer coefficient of 0.0535 mol/atm.min.L [6].

2. OBJECTIVE

The goal of this simulation was to give a figure of simple water-wash process performance for CO₂ absorption, followed by desorption of rich solvent using air under atmospheric pressure and room temperature, to obtain the maximum amount of absorbed CO₂ into water, optimum (L/G) ratio for absorption, the minimum airflow rate for desorption, and make-up water for desorption.

3. METHODOLOGY

The simulation was conducted using the Aspen HYSYS program, with Sour SRK (Soave-Redlich-Kwong) 'fluid package'. The operating condition was selected in order to be achieved by a Solteq gas absorption-desorption column unit (Figure 1).

The CO₂ was removed from the feed gas mixture by counter-current absorption (column diameter of 80 mm, glass raschig ring packing with an effective height of 1,500 mm), operating pressure of 1 bar, the temperature of 25°C, water flow rate (L) of 1.5 L/min, and L/G ratio of 10-150 (kg/kg). The rich solvent was regenerated by heating and stripping with air in the desorption column with a temperature of 40°C. The resulted lean solution was then reused for scrubbing. The simulation process flow diagram for simultaneous absorption-desorption operation is shown in Figure 2. The process was simulated using two main equipment, absorption column (T-100) and desorption column (T-101).

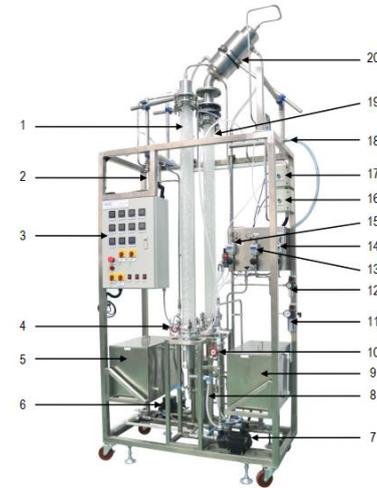


Figure 1 CO₂ Absorption-Desorption Equipment Set

Table 1 CO₂ Absorption-desorption equipment part list

Number	Component
1	Absorption Column, K1
2	Preheater, W2
3	Control Panel
4	Water Flowmeter, FT04
5	Sump Tank, B1
6	Pump, P1
7	Pump, P2
8	Heat Exchanger, W3
9	Sump Tank, B2
10	Water Flowmeter, FT05
11	Air Pressure Regulator, PR02
12	CO ₂ Pressure Regulator, PR01
13	Air Flowmeter, FT02
14	Air Flowmeter, FT03
15	CO ₂ Flowmeter, FT01
16	Outlet CO ₂ Analyser, QT02
17	Inlet CO ₂ Analyser, QT01
18	Vent
19	Desorption Column, K2
20	Condenser, W1

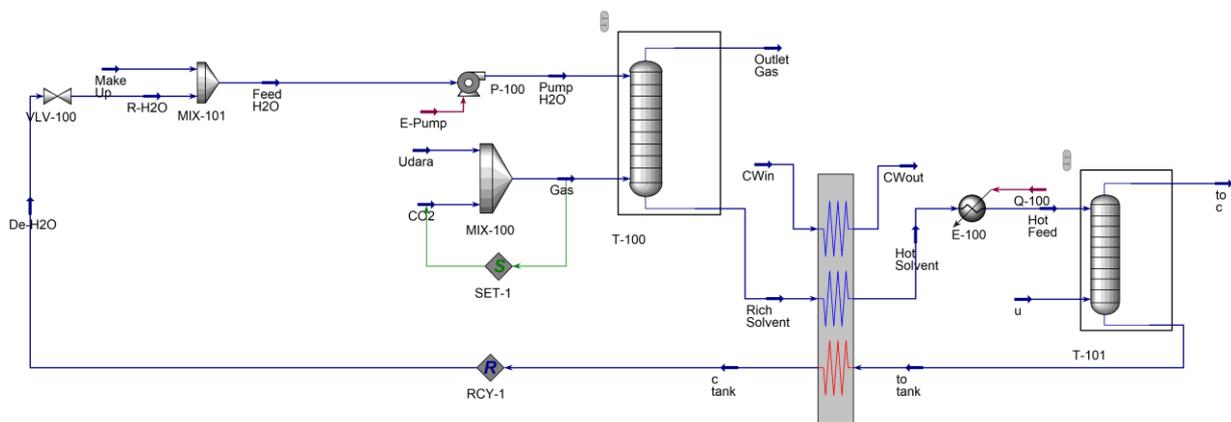


Figure 2 Simulation Process Flow Diagram

4. RESULTS AND DISCUSSION

The effect of CO₂ concentration in feed gas on absorbent capacity was conducted with an L/G ratio of 10-150 kg/kg, and gas flow rate, G = 47 L/min (figure 3). It was observed that, for feed gas with low CO₂ concentration the absorbent capacity was low. The greater the CO₂ content in the feed, the greater the increase in CO₂ levels in the absorbent. The enhancement trend of CO₂ levels in the absorbent was greater with an increasing L/G ratio. At an L/G ratio of more than 50, the improvement decreased, where the enhancement of absorbent capacity was less significant. The highest CO₂ solubility (absorbent capacity) was achieved at

an L/G ratio of 150 and pure CO₂ feed gas, namely 1.176 g CO₂/kg H₂O, which equal to 78.4% of the maximum solvent capacity (solubility of CO₂ in the water at 25°C, 1 atm is 1.5 g CO₂/kg H₂O).

In absorption operation, it was well agreed in various studies that a higher liquid flow rate led to a higher CO₂ removal efficiency. For biogas upgrading which CO₂ content of 35-50 % this result is equivalent to 25% of absorbent capacity, which meant that utilization of water as physical absorbent is feasible. This fact is in accordance with the theory that physical absorption is suitable for the absorption of feed gas with high impurities.

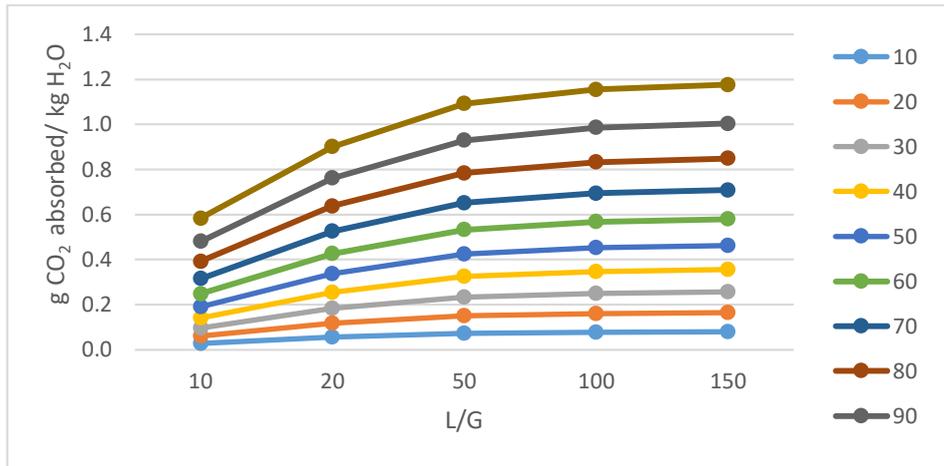


Figure 3 Effect of L/G at various % CO₂ in Feed on Absorption Capacity of Water

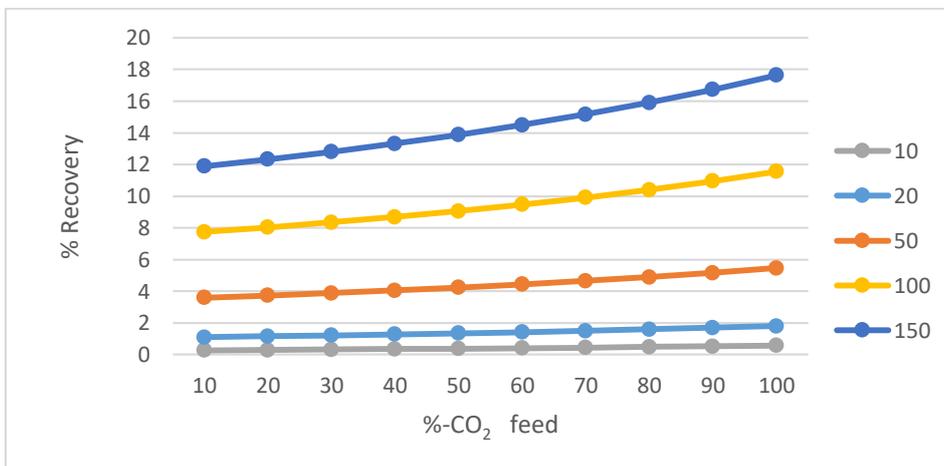


Figure 4 Effect of %CO₂ at various L/G Ratio on % Recovery

The review on CO₂ recovery was carried out by varying the CO₂ content in the feed at various L/G values of 10-150 kg/kg. The result was presented in figure 4. It was observed that, at a low L/G ratio there was no effect of the feed gas CO₂ concentration on CO₂ recovery. The greater the L/G ratio, the greater the enhancement in CO₂ recovery. At an L/G ratio of more than 50 the improvement increased. For CO₂ content in the feed of 40% and L/G ratio of 150 kg/kg, the obtained CO₂ recovery was 13.3%. CO₂ absorption using methyl diethanolamine (MDEA), with CO₂

content in the feed of 40% and L/G ratio of 150 (kg/kg), obtained CO₂ recovery was 57% [6]. This means that the effectiveness of CO₂ absorption with water is 75 % lower than that of MDEA.

Based on Figure 4, for feed with a CO₂ content of 37%, L/G ratio of 128 at 1 Bara and 30 °C obtained removal efficiency of 11%. Suomalainen’s simulation of CO₂ absorption with similar CO₂ contains an L/G ratio, at 10 Bara and 14 °C resulting in removal efficiency of 86% [5]. It means that the efficiency of our work is 87% lower than Suomalainen’s. It

showed that the absorption process will be better at a higher pressure and lower temperature.

The review on the gas mass transfer coefficient was carried out by varying the CO₂ content in the feed at L/G values of 10-150 kg/kg. The result was presented in figure 5. For CO₂ content in the feed of 40% and L/G ratio of 150 kg/kg, the gas mass transfer coefficient (kG) obtained was 0.0108 mol/L.min.atm. CO₂ absorption using MDEA obtained kG of 0.0535 mol/L.min.atm [6]. This means that the effectiveness of CO₂ absorption with water is 80 % lower than that of MDEA, in terms of gas mass transfer coefficient. Stripping of CO₂ content from a rich solvent was conducted by heating the solvent (flow rate of 1.5 L/min) to 40°C and flowing the air counter currently. The simulation of CO₂ desorption from a rich solvent was conducted for a concentration of 0.27 g CO₂/kg H₂O, which was the maximum absorption using a water flow rate of 1.5 L/min. The result showed that increasing airflow rate gave higher

CO₂ reduction in water. For the airflow rate of more than 8×10^{-4} L/min, the curve turns to a lower slope. The CO₂ was totally released from the air with a flow rate of 1.6×10^{-3} L/min (Figure 6). The air required for desorption was small indicated that heating of solvent to 40°C was effective for stripping of CO₂.

Heating of rich solvent results in water evaporation. In order to maintain a constant solvent flow rate, the water losses need to be replaced by makeup water. Based on figure 7, it was obtained that increasing gas flow rate or lower L/G ratio resulting in larger make-up water requirements. The effect of the L/G ratio on make-up water requirement is more significant than temperature enhancement. Solvent heating to 40 °C at L/G ratio of 50 required 360 mL/min make-up water, which means 24% of solvent flow rate.

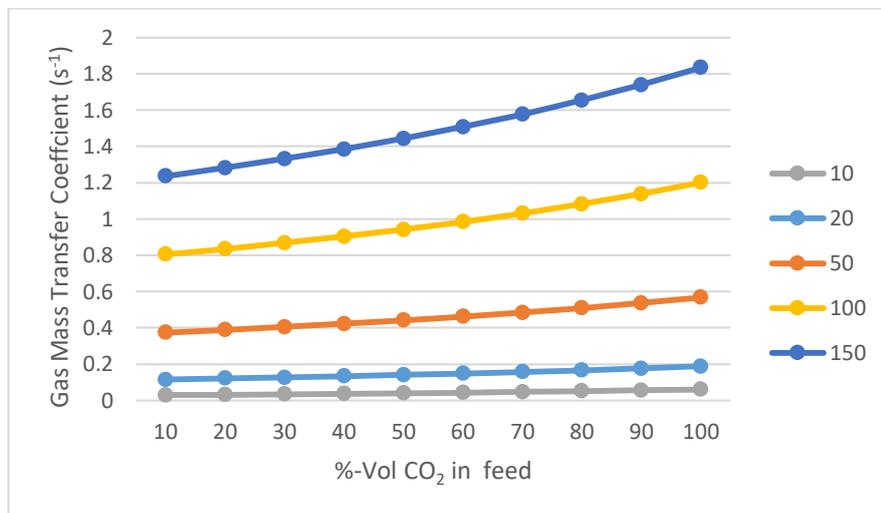


Figure 5 Effect of % CO₂ at various L/G Ratio on Gas Mass Transfer Coefficient

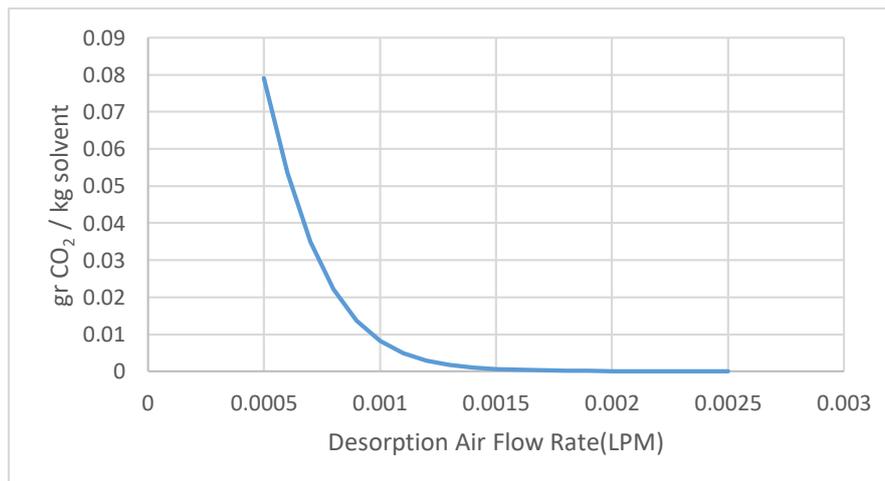


Figure 6 Effect of Airflow Rate on CO₂ Desorption

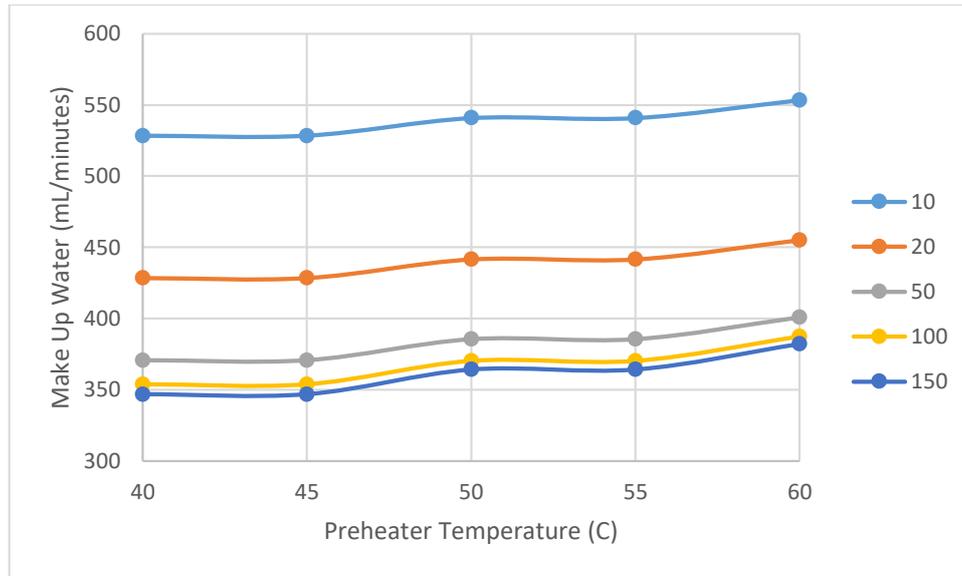


Figure 7 Makeup Water Consumption Correlation to Preheater Temperature at Different L/G ratio

5. CONCLUSION

The model successfully predicts all responses for the CO₂-water system, including the maximum solvent capacity of 1.176 g CO₂/kg H₂O, optimum (L/G) ratio of 50, minimum desorption airflow rate of 0.0016 LPM and quite a big amount of make-up water of 360 mL/min for a gas flow rate of 40 LPM at the simultaneous absorption-desorption operation. From those results, it was concluded that CO₂ absorption and desorption in packed columns by utilization of water as physical absorbent is feasible.

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