

Science Education Collection

# Solving for the Mass Transfer Coefficient of a Gas Absorber

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## Overview

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Gas absorbers are used to remove contaminants from gas streams. Multiple designs are used to accomplish this objective<sup>1</sup>. A packed bed column uses gas and liquid streams running counter to each other in a column packed with loose packing materials, such as ceramics, metals, and plastics, or structured packing<sup>1</sup>. The packed bed uses surface area created by the packing to create a maximum amount of efficient contact between the two phases<sup>1</sup>. The systems are low maintenance and can handle corrosive materials with high mass transfer rates<sup>1</sup>. Spray columns are another type of absorber, which uses constant direct contact between the two phases, with gas moving up and liquid being sprayed down into the gas flow<sup>1</sup>. This system only has one stage and poor mass transfer rates, but is very effective for solutes with high liquid solubility<sup>1</sup>.

The goal of this experiment is to determine how variables including gas flow rate, water flow rate, and carbon dioxide concentration affect the overall mass transfer coefficient in a gas absorber. Understanding how these parameters affect CO<sub>2</sub> removal enables contaminant removal to be optimized. The experiment uses a randomly packed water counter-flow gas absorption column. Eight runs with two different gas flow rates, liquid flow rates, and CO<sub>2</sub> concentrations were used. During each run, the partial pressures were taken from the bottom, middle, and top of the column unit, and the equilibrium partial pressures were calculated. These pressures were then used to find the mass transfer coefficient, and the mass transfer coefficients were compared to theoretical values.

## Principles

A gas absorption unit (Figure 1) uses contact with a liquid to remove a substance from a gas mixture. Mass is transferred from the gas mixture to the liquid via absorption.



**Figure 1: Typical gas absorption column.**

The overall mass transfer coefficient is the rate at which the concentration of one species moves from one fluid to the other (Equation 1).

$$K_G = \frac{G_s}{a \cdot x \cdot z} \int_{Y_{A2}}^{Y_{A1}} \frac{dY_A}{(p_{AG} - p_A^*)} \quad (1)$$

In equation 1,  $G_s$  is the gas molar flow rate per cross-sectional area of the column,  $p_{AG}$  is the partial pressure of  $\text{CO}_2$ ,  $p_A^*$  is the pressure in equilibrium with  $p_{AG}$ ,  $a$  is the interfacial area/volume or "effective area" (a function of column packing),  $z$  is the height of the packing, and  $K_G$  is the overall mass transfer coefficient in mols/(pressure x interfacial area x time). Mass transfer depends on the mass transfer coefficients in each phase and the amount of interfacial area available in the absorber. Henry's Law or Raoult's Law is applied to approximate the partial pressures. They are two laws that describe the partial pressure of a component in a mixture, and are used together in order to fully describe the behavior of the mixture at the limits of the vapor-liquid equilibrium relationship. The objective of a gas absorption column is to control the effluent partial pressure of contaminant. A liquid solvent flows counter-current to the gas stream to remove the contaminant through convective mass transfer. The overall mass transfer of a water counter-flow packed column is measured in this study to determine the effects of water flow, gas flow, and  $\text{CO}_2$  gas concentration. The coefficients will then be compared to theoretical values.

## Procedure

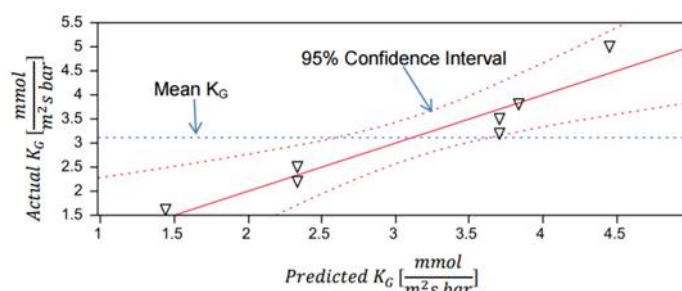
The experiment uses a randomly packed water counter-flow gas absorption column. The column is packed with 34 cm of 13 mm berl saddles with  $465 \text{ m}^2/\text{m}^3$  surface (effective) area. The pressure entering the system is about 1.42 bar with a temperature of about  $26^\circ\text{C}$ , and valves at the entrance and exit of the column allow gas to escape. An "Oxy Baby" Infra-red spectrometer, directly connected to the unit at various locations, measures gas composition, and tanks of pure gas are used for calibration.

## 1. Operating the Gas Absorber

1. Turn on the master switch and close the adjusting valve used to control the amount of water in the column
2. Open the air flow valve completely and the adjusting valve for column pressure.
3. Set the air flow rate to the desired level (use a minimum of 20 L/min and increase as needed), and set the column pressure to ~ 1.4 bar and 25°C using the adjusting valve for pressure.
4. Start the carbon dioxide flow rate at ~ 4 L/min.
5. Set the water flow at ~ 75 L/h, and adjust the water level to maintain a constant height. Tweak if necessary while running to ensure constant height.
6. Sample the CO<sub>2</sub> partial pressure at the base, center and head of the column using the pressure taps and the infra-red spectrometer.
7. Perform eight different runs, using two different gas flow rates, liquid flow rates, and CO<sub>2</sub> concentrations. This will enable determination of the most important variables.
8. Allow the system to achieve steady-state when any flow rate is altered. This typically takes 30 - 45 min.

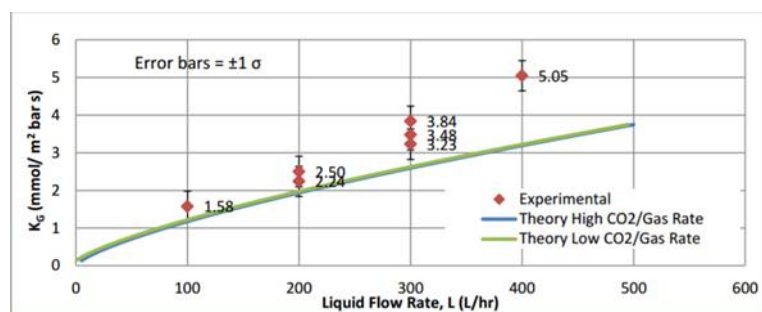
## Results

Partial pressures were taken from each trial run. Mass transfer coefficients were calculated from these and compared to predicted values (Figure 2). The predicted values arise from the calculated operating line for the absorber (see reference 2 for an in-depth discussion of the operating line). Solid lines represent the values calculated using the operating line, while triangles represent the experimental mass transfer coefficient values. Confidence intervals for the model values and the mean mass transfer coefficient were plotted with dashed lines. These values were compared to determine how the experimental parameters (liquid flow rate, gas flow rate, and CO<sub>2</sub> partial pressure) affected the overall mass transfer coefficient. Under these operating conditions, only liquid flow rate had a statistically significant effect on mass transfer when compared to the confidence interval. The results showed that gas flow rate and feed composition had little to no effect on the mass transfer coefficient.



**Figure 2: Model of the predicted and actual values of the mass transfer coefficient.**

Theoretical  $K_G$  values for a high (30 L/min) and low (20 L/min) were calculated from mass transfer coefficient correlations and are shown as blue and green lines, respectively, in Figure 3. The experimental  $K_G$  values at a variety of liquid flow rates were plotted against the theoretical values and showed similar trends, verifying the dependence of  $K_G$  on liquid flow rate. The theoretical values showed some variation from the experimental values, attributable to minor experimental error.



**Figure 3: A graphical depiction of experimental value compared to theoretical values.**

## Applications and Summary

The goal of this experiment was to use factors of gas flow rate, water flow rate, and carbon dioxide concentration to determine the overall mass transfer coefficient in a gas absorber. The experiment used a randomly packed GUNT CE 400 water counter-flow gas absorption column. Eight runs with two different gas flow rates, liquid flow rates, and CO<sub>2</sub> concentrations were performed. Partial pressures were taken from the bottom, middle, and top of the column unit, and these pressures were then used to find the mass transfer coefficient.

Under these operating conditions, only the liquid flow rate had a significant statistical effect on mass transfer when compared to the confidence interval for the given conditions. The process is liquid-phase mass transfer controlled. Gas-related factors such as CO<sub>2</sub> concentration and gas flow rate will have little to no significance.

Gas absorption is an important mechanism for safety in the production of chlorine<sup>3</sup>. During normal operation, gas absorbers treat any consistently occurring leaks. The start-up of a chlorine operation must be treated until it produces a gas-free product. In the event of a breakdown in the process, absorbers must be used to treat the gas that has been produced. Additionally, when new leaks form, the main emergency response unit is the standby gas absorbers. Treatment units are vitally important in these operating conditions, as they help create a safe environment when dealing with a dangerous product<sup>3</sup>.

When refining natural gas, absorption towers are used to remove natural gas liquids from the gas phase<sup>4</sup>. An absorbing oil with an affinity to natural gas liquids removes the liquid from the gas phase, purifying the product. The oil with natural gas liquids is then further purified to recover the liquids, such as butane, pentanes and other molecules. The oil can then be used again for treatment.

Absorption is also used to remove the major impurities CO<sub>2</sub> and H<sub>2</sub>S from wellhead natural gas, converting it to pipeline gas. The process uses aqueous amines or glycols as solvents at low temperatures (typically <40 °C)<sup>5</sup>.

## References

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