Investigation of a lab-scale physicochemical CO_2 capture system

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In recent years, numerous countries face a significant challenge of environmental degradation due to uncontrolled carbon dioxide (CO_2) emissions resulting from increased industrialization and urbanization. This has led to a significant global rise in anthropogenic greenhouse gases, particularly CO_2, contributing to global warming and climate change. The current scenario of anthropogenic pollution and unrestricted greenhouse gas emissions poses risks of exacerbating global warming, causing adverse impacts such as ocean acidification, desertification, and altered weather patterns. Immediate consequences of climate change include challenges in food security, rising sea levels, intensified coastal storms, health concerns, migration, and economic burdens. Global CO_2 emissions due to human activities have increased by over 400% since 1950 and the high concentration of CO_2 in the atmosphere is predicted to continuously increase if the problem of CO_2 emission is not addressed (Yoro & Daramola, 2020).

According to the 2015 Paris agreement, the rise in temperature of Earth should be kept below 2°C in comparison to the preindustrial levels, and the increase in Earth's temperature should be limited to below 1.5°C. In order to achieve this goal, hundreds of tons of CO_2 should be captured and stored annually until 2030 and thus, various techniques for CO_2 capture such as adsorption, absorption, and membrane separation have been proposed and tested in the literature (Leung, 2014).

The mechanism of CO_2 capture in aqueous media includes the dissolution of the CO_2 gas molecules in water (equation 1) according to the Henry's equilibrium, the reversible conversion by deprotonation of the neutral $CO_{2(aq)}$ species (hydration) to form anionic bicarbonate species HCO_3^- (equation 2) according to a chemical equilibrium which is pH dependent, the transport of both the neutral and anionic aqueous CO_2 species, from the CO_2 capture side towards the CO_2 release side, by molecular diffusion inside the aqueous medium and/or by forced fluid circulation and the reverse process.

$$CO_2(g) + H_2O \leftrightarrow CO_2(aq) \quad (1)$$

$$CO_2(aq) + H_2O \leftrightarrow H^+ + HCO_3^- \quad (2)$$

The equilibrium constant of equation 2 is $K_a = 10^{-6.35}\ at\ 25^oC$. Therefore, if the pH can be maintained above the pKa value of 6.35 using a buffer, the formation of ionic HCO_3^- species is favored, while the concentration of neutral CO_2(aq) species remains fixed at the gas-liquid interface according to Henry's law. The solubility of HCO_3^- anions in water is much higher than that of the neutral CO_2(aq) species so a larger total CO_2 concentration can be dissolved in aqueous solution (Pierre, 2012).

To ensure efficient CO_2 scrubbing, it is crucial to design an exchange surface between the gas phases and the aqueous medium. This will favour the dissolution of CO_2(aq) species on the capture side and the release of CO_2 gas on the release side. In a wet scrubber, the contaminated gas stream comes into contact with the liquid through spraying, forcing it through a pool of liquid or some other method of contact so that the contaminants are removed. Some operating parameters that affect the scrubbing process are gas flow rate, liquid to gas (L/G) ratio, pressure drop, temperature and particle size distribution.

The aim of this study was to investigate the carbon dioxide capture in a lab-scale scrubber system by studying different types of buffers and pH, as well as different gas inlet flows and buffer volumes. The gas input is supplied from a commercial cylinder of a mixture of 80% atmospheric air (O_2, N_2) and 20% CO_2. The CO_2 capture is measured quantitatively in terms of the inorganic carbon contained in each solution inside the scrubber.

The experimental apparatus of the lab-scale scrubber includes inlet and outlet flowmeters for the measurement and control of the gas flow. Moreover, a pump is used in order to achieve recirculation of the liquid buffer and an outlet pipe is used for liquid sampling after the gas dissolution. The experimental set-up is presented in Figure 1.

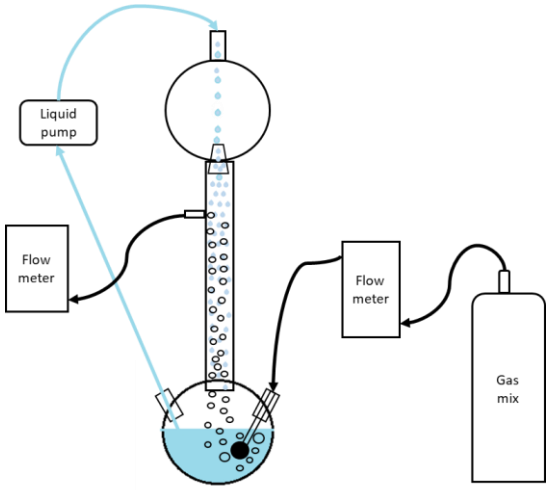

Figure 1: Overview of the set-up of the CO_2 capture system

After the gas flow has been launched, the required volume of buffer solution is added to the system and samples are taken at regular intervals (almost every 20 min). The pH, dissolved oxygen, inorganic carbon (IC), organic carbon, and total nitrogen concentrations are measured in sample. The parameters investigated are the pH of the buffer, using different buffer solutions (Na_2HPO_4/NaH_2PO_4, NH_3/NH_4Cl, $Na_2HPO_4/NaOH$, Na_2CO_3) in order to create a range of pH from 7 to 12, the initial volume of the buffer solution (400, 600, 800 mL) and the gas flow rate (0.1, 0.3, 0.5, 1.0 L/min) in order to control the L/G ratio.

The CO_2 capture percentage is determined based on the IC measurements in the liquid and the inlet CO_2 flow in the scrubbing system as explained (equation 3).

$$CO_2\ capture\ efficiency\ (\%) = \frac{total\ CO_2\ dissolved}{total\ CO_2\ input} 100\% \quad (3)$$

Some indicative results based on the parameters and the equation mentioned are shown in Figure 2.

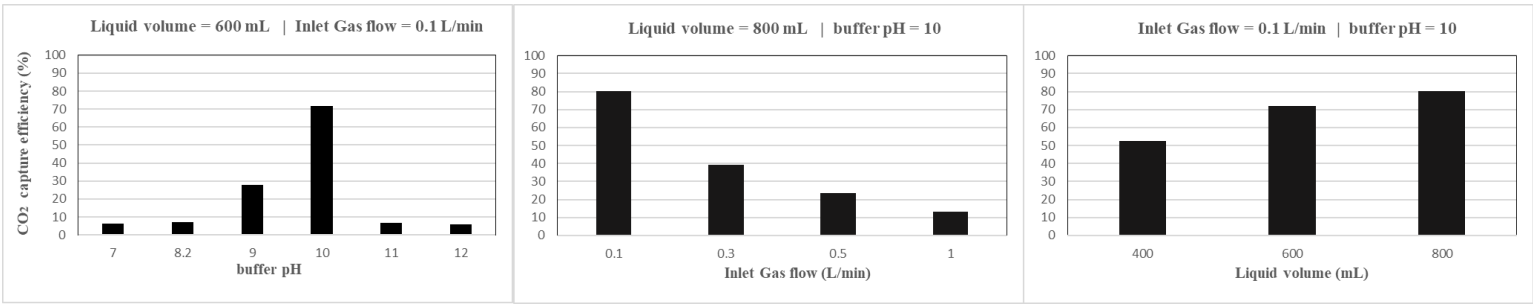

Figure 2: The CO_2 capture efficiency in relation to initial buffer pH, volume and inlet gas flow

As can be seen from the Figures above, CO_2 capture efficiency maximizes on pH 10 and it rises when inlet gas flow decreases and liquid volume increases. Thus, the CO_2 capture is more efficient with a higher L/G ratio.

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