

**Integrated Energy Efficient CO₂ Removal System via
Alkali-based Sorbent with Isopropanol System**

A Thesis

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Abstract

Traditional carbon dioxide (CO₂) capture technologies use amine-based sorbents that are very energy-intensive and result in secondary environmental pollution originating from amine degradation. In this work, a low temperature, energy-saving, and environmentally friendly CO₂ capture method has been investigated using potassium bicarbonate-alcohol-H₂O mixtures as sorbents. The addition of alcohol, particularly isopropanol, to the potassium bicarbonate solution can significantly increase CO₂ desorption and capture capacity. The absorbent containing 40 wt% (~72 g) isopropanol, ~20 g potassium bicarbonate, and ~108 g H₂O proved to be the most effective for capturing CO₂. The IPA-H₂O solution resulted in 2.09 mmol of CO₂ desorption within 1000 s and a total of 19 mmol of CO₂ desorbed by the end of the experiment, which was higher than the other alcohols investigated. This research demonstrates a catalytic CO₂ capture route with the potential to be economical, environmentally safe, and energy-efficient.

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List of Abbreviations

Nomenclature	Abbreviation
CO ₂	Carbon Dioxide
H ₂ O	Deionized Water
O ₂	Oxygen gas
N ₂	Nitrogen gas
DEA	Diethanolamine
MDEA	Methyl Diethanolamine
MEA	Monoethanolamine
CaO	Calcium Oxide
KHCO ₃	Potassium Bicarbonate
Na ₂ CO ₃	Sodium carbonate
MeOH	Methanol
EtOH	Ethanol
IPA	Isopropanol
TiO(OH) ₂	Titanium Hydroxide

Chapter 1: Background

Carbon dioxide emissions from the combustion of fossil fuels are a significant factor in climate change [1]. The current low price of fossil fuel energy is subsidized in part by unpriced CO₂ emissions, which take advantage of the natural atmosphere and ocean degradation. Even while the argument over climate change is ended, an effort to reduce CO₂ emissions has only just begun. Capturing CO₂ produced during combustion and storing it in a suitable location is one step toward lowering CO₂ emissions. Carbon capture and storage (CCS) has the potential to reduce global energy-related emissions by 20% in the future. Fossil fuel burning provides over 85% of the energy for industrial activity and is consequently the primary source of greenhouse gas emissions. As part of a 57% increase in CO₂ emissions, coal is on track to contribute 28% of world energy by 2030 [3]. Although current CCS technologies are still in the experimental stage, the fundamental goal is massive: by 2050, all coal and gas power stations will be equipped with CSS, reducing global CO₂ emissions from energy by 20% [2]. CO₂ emissions from fossil fuel combustion at large single sources, such as power plants, are stripped out, purified, and concentrated using CCS. The captured CO₂ is compressed to 70 bars after leaving the power plant, generating a liquid that can be transferred to a storage site and injected into rock crevices deeper than 800 m below the surface [4,5]. For tens of thousands of years, good storage sites will keep CO₂ without significant seepage. CCS can be used in a variety of major industrial settings, including refineries, steel mills, fertilizer plants, ethanol fermentation, and cement manufacturing. [1]

Chapter 2: Overview of CO₂ capture technologies

There are a variety of technology solutions that are generally compatible with CCS activity, but only a few have acquired any sort of industrial recognition. Post-combustion CO₂ capture employing amine solvents, oxyfuel combustion, and calcium looping technologies are three technology choices that are widely acknowledged as being acceptable for commercial implementation in the near to medium term. In amine-based CO₂ capture, the CO₂-rich gas stream is contacted with an aqueous amine solution. The amine solvent reversibly combines with CO₂, creating water-soluble salts. The oxyfuel combustion process involves the combustion of nearly pure O₂ (usually greater than 95 percent purity) and CO₂, with the latter being recycled from the process exhaust [1]. The fact that this method creates a flue gas that is primarily CO₂ and H₂O is its key selling point. Condensation efficiently removes the H₂O content, producing a pure CO₂ stream that may be compressed, transported, and stored. In the solid looping technology, Calcium oxide (CaO) and CO₂ are reversibly reacted to generate calcium carbonate (CaCO₃). This method is like traditional amine-based absorption procedures in that CO₂ is captured in one vessel, the carbonator, and then the "laden" sorbent material, CaCO₃, is sent to a second vessel, the calciner, where it is regenerated, resulting in a pure stream of CO₂ [1]. The rest of the chapter will be focused on an in-depth review of the three technologies. Currently, amine-based absorption is the leading CO₂ capture technology in the industry [3]. Among the various aqueous alkanolamines, including DEA and MDEA, MEA is the foremost capture solvent because of its high absorption capacity, low solvent cost, and low regeneration energy requirement. However, this state-of-the-art technology (i.e., MEA mixtures) has a few shortcomings, including a high energy requirement [4]. The CO₂ desorption step also makes the process uneconomical. Based on the results reported by Lin et al. the desorption energy of MEA was 1.93 GJ/ton CO₂ whereas the desorption energy of

PZ/DETA/MeOH/ H₂O was 1.10 GJ/ton CO₂ at 120 °C. The addition of organic alcohol (MeOH) reduced the desorption energy by 43% hence proving the high energy requirement of MEA [5]. As shown in Figure 1, amine-based absorption is split into two steps, absorption and desorption. Firstly, the flue gas from the power plant which contains CO₂ enters the absorber. During the absorption step, the CO₂ readily and selectively bonds to the separating agent, amine. Secondly, the rich MEA solution containing the CO₂ is then sent to the desorption column where CO₂ from the absorber is extracted from the solution. This involves breaking the bonds to recover the separating agent during the desorption step which is a prolonged process. Substantial energy is often required to accelerate the process, resulting in a reaction temperature exceeding 100°C [6]. The high temperatures can also decompose amines, resulting in loss of sorbent followed by toxic emissions of the decomposition by-products [7].

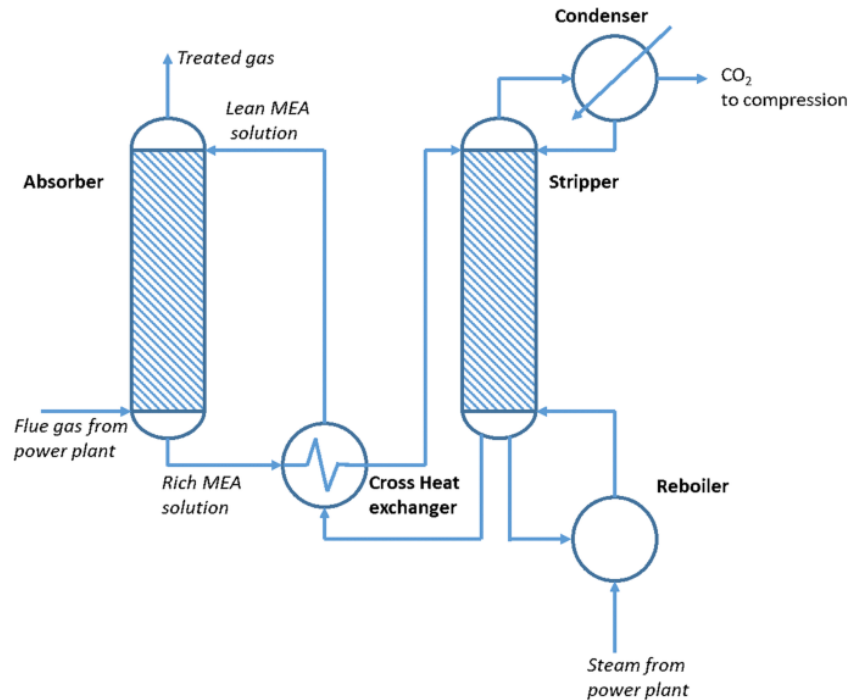


Figure 1. Process Flow Diagram of Post-combustion CO₂ capture [9]

As shown in Figure 2, Oxyfuel combustion involves three steps which include oxygen production (air separation unit [ASU]), the oxy-combustion boiler (fuel conversion [combustion] unit), and CO₂ purification. With these components, oxy-combustion systems can be constructed in a variety of ways, resulting in a variety of energetic and economic results. Instead of air, an oxy-combustion process uses a pure or enhanced oxygen stream for combustion. Almost all the nitrogen in the air is eliminated in this process, resulting in a 95% O₂ stream. As a result, the volume of flue gas produced by oxy-combustion, which is approximately 70% CO₂ by volume, is approximately 75% less than that produced by air-fired combustion. The decreased gas volume also makes it easier to remove contaminants from the flue gas (sulfur oxide [SO_x], nitrogen oxide [NO_x], mercury, and particulates). Another advantage is that NO_x production is considerably reduced because nitrogen is removed from the air. On the other hand, the biggest disadvantage of oxyfuel combustion technology is that the extraction of oxygen is a very energy-intensive process making oxyfuel combustion uneconomical to reduce carbon emissions [2].

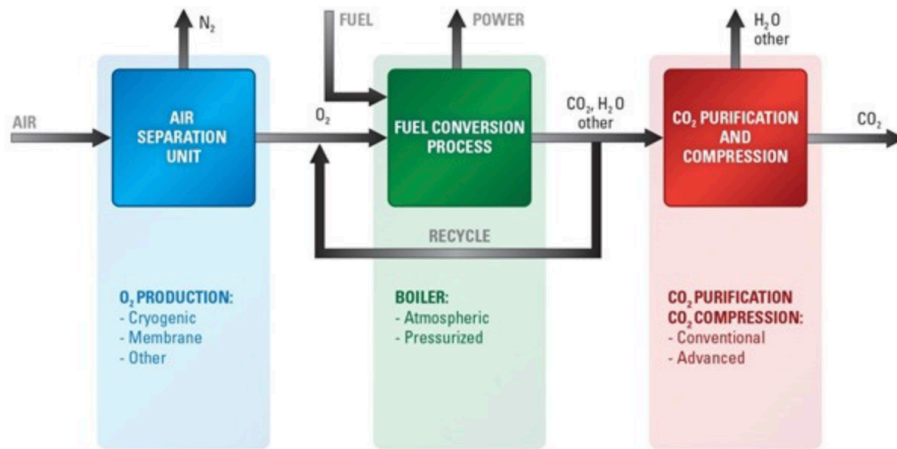


Figure 2. Process Flow Diagram of Oxyfuel combustion [2]

CO₂ capture via high-temperature solid sorbents has recently gotten a lot of attention in the scientific community. Calcium oxide (CaO), which can be generated from natural limestone, is a particularly attractive solid sorbent option. As shown in Figure 3, calcium looping is divided into two steps, carbonation and calcination. The carbonate or calcium looping process makes use of the reversible gas-solid reaction between calcium oxide (CaO) and CO₂ to produce calcium carbonate (CaCO₃). The carbonation process between CO₂ and solid CaO separates CO₂ from a gas mixture, such as coal-combustion flue gas, in one vessel, the carbonator, resulting in CO₂ capture by the creation of solid CaCO₃. The CaCO₃ is then moved to the calciner, a second reaction vessel where it is heated to reverse the reaction, releasing CO₂, and regenerating the CaO-sorbent, which is then recycled back into the carbonation vessel [8]. Carbonation is an exothermic reaction that takes place at temperatures around 650 °C. The calcination reaction is a single-step endothermic reaction that takes place at 750°C. However, if the goal is to produce a pure stream of CO₂, thermodynamic constraints necessitate that calcination is carried out at 900–950°C at a high CO₂ partial pressure (90 vol%). To attain this relatively high temperature, it is widely assumed that additional fuel must be combusted in pure O₂ in the calcination vessel, necessitating the use of an air separation unit. The energy cost associated with air separation is partially compensated by heat recuperation in the form of hot CaO and CO₂ streams, as well as heat created by the combustion process [1]. There are a couple of downsides to the use of solid looping technology. Firstly, the calcination reaction is a very energy-intensive process (temperatures ranging from 900-950°C) making solid looping an uneconomical way to capture carbon. In addition, the metal particles are like sand, and the CO₂ gas created blows them between the combustion furnace and the oxidation reactor. As the metal or metal-oxides

complete their loop, all the particles are extremely abrasive, and the plant equipment is virtually sandblasted internally.

The chemical looping plant must be made of expensive metals that can endure the repeated abrasion of the metal particles, which is a big engineering difficulty. Currently, a chemical looping plant is significantly more expensive to build than other carbon capture technologies [1].

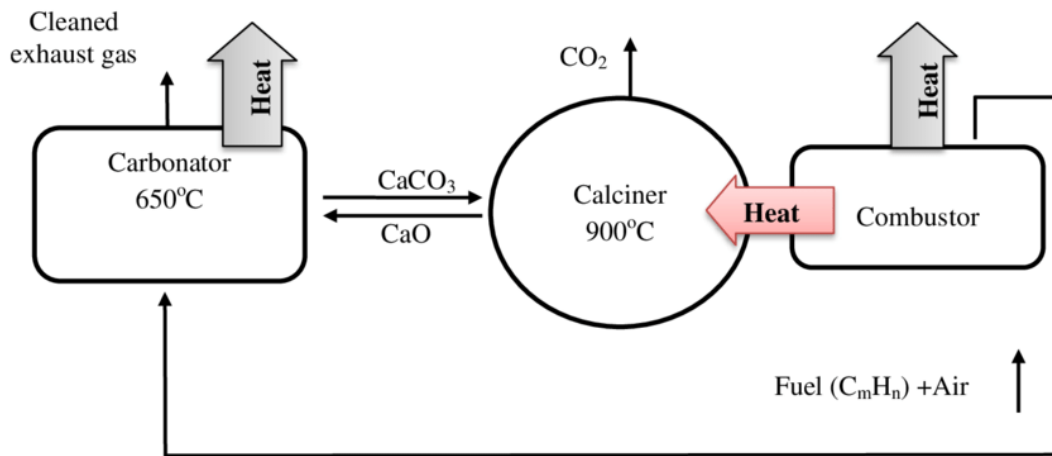


Figure 3. Process Flow Diagram of Calcium looping [10]

Chapter 3: Integrated Energy Efficient CO₂ Removal System via Alkali-based Sorbent with Isopropanol System

3.1 Introduction

Emissions of greenhouse gases (GHG) have increased substantially since the start of the industrial revolution. The rising levels of carbon dioxide (CO₂) in the atmosphere have received significant attention due to increased global temperatures and noticeable climate change [3]. CO₂ capture and storage (CSS) or utilization technologies reduce GHG emissions in the atmosphere to minimize their warming effects and fight climate change. Post-combustion capture removes CO₂ from flue gas (composed primarily of CO₂, H₂O vapor, O₂, N₂, trace gases, and fly ash) after burning fossil fuel. At present, conventional coal-fired power plants combust primary coals to generate power directly [12]. Thus, post-combustion capture is the most viable choice for existing coal-fired power plants.

CO₂ capture has been tested using different methodologies, including solid sorbents, solvents, and membranes [10]. Inorganic sorbents such as CaO, KHCO₃, and Na₂CO₃ have been recognized as potential adsorbents for CO₂ capture. Membrane capture technologies [7] and solid sorbents [1] were implemented and studied on a large scale, but these technologies were determined to be uneconomical and inefficient. This research focuses on aqueous-phase sorbent technology, which was first used in the 1930s to separate CO₂ from natural gas in oil fields [10,20]. The two main types of CO₂ capture sorbents are organic and inorganic. Organic sorbents cannot be used due to their toxicity and high decomposition rates, which render them uneconomical. According to the Benfield process, inorganic sorbents are economically preferable candidates for CO₂ capture [19,20].

CO₂ capture using KHCO₃ is divided into two steps, absorption and desorption. The absorption involves the capture of CO₂ into the solution which contains KHCO₃, organic alcohol, and DI

water. Furthermore, the desorption step involves extracting the CO₂ absorbed in the solution. However, the desorption step for inorganic sorbents has a very high energy requirement. One of the methods to increase the CO₂ desorption rate while maintaining low temperatures is reduce the amount of H₂O in CO₂ capture system. H₂O reduces the CO₂ desorption rate due to high molar enthalpy of vaporization resulting in high energy requirement making the process uneconomical. Therefore, the one solution to increase the CO₂ desorption is to replace the H₂O with other solvents. Previous research was performed using a mixed solvent made using MeOH and DI water. Lin et al. reported that the combined solvent of water and MeOH would prevent the absorbent from rapidly increasing in viscosity after absorbing CO₂. The increase in viscosity of the sorbent reduces the CO₂ capture capacity of the solvent hence reducing the amount of CO₂ desorbed making the process uneconomical. Other than that, high energy requirement for solvent regeneration is the other limitation which prevents the implementation of large scale carbon capture technology. MeOH has a lower molar enthalpy of vaporization and a lower boiling point than water, despite being more volatile. As a result, the regeneration energy penalty can be decreased while absorption performance is maintained [22]. Therefore, based on the results of Lin et al. this research was conducted using different organic alcohols to analyze the effect on CO₂ desorption. It's not surprising that alkaline metal carbonate solids have received a lot of interest in recent years for CO₂ capture applications due to their high sorption capacity and inexpensive cost. Alkali metal carbonates can be used to treat flue gases at temperatures below 200 °C making them potentially relevant for CO₂ capture from current fossil-fuel-fired power plants. This research opens a new avenue for energy savings and the reduction of secondary pollution [21]. This research focuses on using KHCO₃ with a combination of different organic alcohols to analyze the effect on CO₂ desorption.

3.2 Experiment

3.2.1 Materials

Ethanol (Sigma-Aldrich, $\geq 98\%$), isopropanol (Alliance Chemical, $\geq 99\%$), methanol (fisher chemical, ACS grade), 1-butanol (fisher chemical, ACS grade), H₂O, KHCO₃ (Chem-Impex Int'l Inc., 100.15%), mixed gas (10% CO₂, 10% O₂, 80% N₂ molar concentration), and pure N₂ gas were utilized without further purification. Bottled air was used to simulate atmospheric air, and N₂ was used as a purge gas. All gases were purchased from Praxair (Danbury, CT, US). Vögtlin (Monterey, CA, US) RED-Y mass flow controllers were used to control the flow of gases from the gas cylinders to the reactor. A CAI ZPA gas analyzer (Orange, CA, US) was used during the process to monitor gas levels being absorbed, and a Monarch DataChart 2000 (Amherst, NH, US) was used to collect and read the data.

3.2.2 Methods

CO₂ capture and desorption tests were performed using the setup shown in Figure 1. Each trial run started with 200 g of solvent solution. Blank trials were prepared with 20 g KHCO₃ and 180 g H₂O. Tests with and without the addition of different alcohols were performed to evaluate the effect of alcohols on desorption. Thus, the remaining trials were prepared with 20 g KHCO₃, 90 g H₂O, and 90 g alcohol.

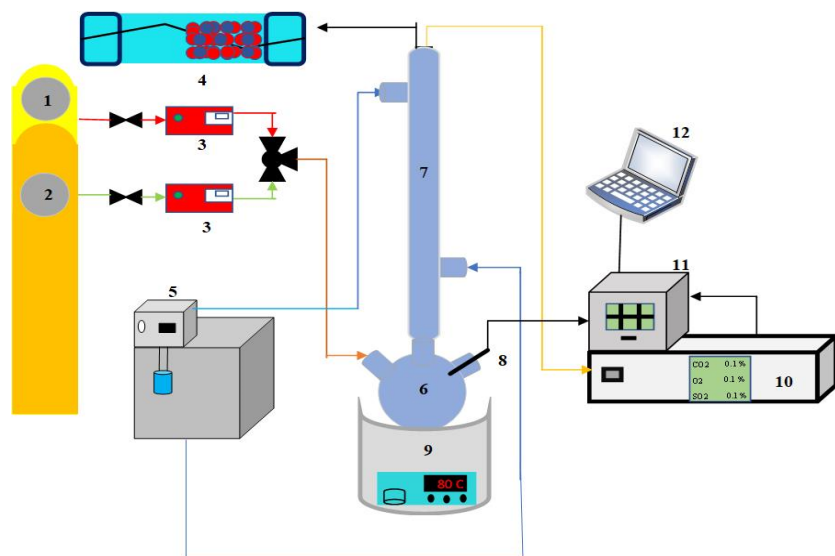


Figure 4. CO₂ capture experiment setup. 1) N₂ cylinder, 2) mixed gas cylinder, 3) mass flow controller, 4) desiccator, 5) thermostatic bath, 6) 500 mL reactor, 7) condenser, 8) thermocouple, 9) heater/stirrer, 10) gas analyzer, 11) Monarch DataChart, 12) Laptop.

The mixed gas reactor feed percolated into the solution through a muffler, and the outlet gas CO₂ concentration was measured to determine the capture capacity of the absorbent. Pure N₂ (1) was used during the CO₂ desorption step to flush out residual gas at the end of each desorption experiment. The mixed gas (2) was also used to calibrate the equipment twice per week to obtain accurate results. Mass flow controllers (3) were used to regulate the gas feed rates.

The CO₂ capture and desorption steps were performed in a 500 mL reactor (6) surrounded by an adjustable electric heater (9). The gas absorption step was conducted at a constant laboratory room temperature of 25 °C. A cooling liquid at 5°C from the thermostatic bath (5) was circulated through the condenser (7) to return vapors to the reactor. A desiccator (4) was used to trap any fugitive water vapor.

The CO₂ desorption experiments were performed by shutting off the mixed gas feed, then heating the spent sorbents to 80°C. A flow of 500 mL/min of N₂ was used to desorb CO₂ gas from the sorbents, then analyzed for CO₂ content. The desorption step was conducted for 40 minutes. Each trial run was replicated to validate the results. The reactor apparatus was then cooled and cleaned with deionized (DI) water before performing the next experiment. The desorbed solvents from the CO₂ desorption experiments were analyzed using Raman spectroscopy.

In the case of Raman analysis, sample spectra (20 g of KHCO₃ with a 180 g solution of 50 wt% H₂O (90 g) and 50 wt% IPA (90 g), and the blanks with 20 g of KHCO₃ with 180 g of H₂O as a control system, were collected in 5 min interval with a Horiba MacroRAM Raman spectrometer (Irvine, CA, US) with a 785 nm excitation.

3.3 Results and discussion

3.3.1 Effects of different alcohols on CO₂ capture

Table 1 summarizes the effects of alcohols on the CO₂ desorption conditions at 80°C under 2400 s. “CO₂ maximum desorbed rate” is the maximum amount of CO₂ desorbed per second during the whole desorption experiment. “CO₂ loading” is the amount calculated by dividing the number of moles of CO₂ by the number of moles of KHCO₃. “CO₂ capacity” is the amount calculated by dividing the number of moles of CO₂ by the mass of solvent (alcohol +water).

It was expected that alcohols would promote an increase in CO₂ desorption rate, as seen in previous work [8]. As shown in Table 1, KHCO₃-H₂O-alcohol sorbents show increased amounts of CO₂ desorption within the 2400 s period. Similarly, our results demonstrate that adding alcohols, especially MeOH, EtOH, and IPA, to the sorbent increases the CO₂ desorption rate. According to

Table 1, IPA-H₂O has the highest CO₂ loading and the highest CO₂ capture capacity as compared to the other combinations.

The CO₂ desorption trials were conducted in five distinct experiments, as previously described. One experiment involved running a blank trial with a solution of 20 g KHCO₃ and 180 g of H₂O to establish a baseline. The four other experiments used 20 g KHCO₃ mixed with 50 wt% H₂O (90 g) and 50 wt% alcohol (90 g). From these experiments, a trend of the effects on the desorption rate of the alcohols was established. At least two trials of each method were performed to use the average values of desorption during data analysis. Figure 5 shows the cumulative CO₂ desorbed during the desorption experiments. As shown, the addition of alcohols increased the amount of CO₂ desorbed. EtOH-H₂O, MeOH-H₂O, and butanol-H₂O solutions desorb approximately 6.98, 2.93, and 0.036 mmol of CO₂, respectively. However, the IPA-H₂O solution resulted in 2.09 mmol of CO₂ desorption within 1000 s and a total of 19 mmol of CO₂ desorbed by the end of the experiment. The boiling points of MeOH, EtOH, and IPA are 64.7 °C, 78.37 °C, and 82.5 °C. The reaction temperature is 80 °C. During the experiment, MeOH and EtOH evaporate due to the boiling points lower than 80 °C. Whereas, IPA has a boiling point higher than the reaction temperature hence IPA results in the highest amount of CO₂ desorbed throughout the whole experiment. As mentioned earlier, the organic alcohols work as a catalyst in the CO₂ capture. The organic alcohols aid more with CO₂ desorption close to their boiling points. Since the boiling point of IPA is higher but close to 80 °C, IPA does not get consumed (evaporate) in the reaction, hence allowing IPA to be present in the solution throughout the experiment therefore maintaining the low activation energy resulting in an increase in the amount of CO₂ desorbed. Furthermore, it is also observed that there is barely any desorption taking place in the KHCO₃-H₂O-Butanol

combination. Since the reaction temperature does not get close to the boiling point of butanol, no desorption takes place.

Table 1. Summary of the effects of alcohol on CO₂ desorption with KHCO₃-based absorbents 10 wt% KHCO₃, 45 wt% H₂O, 45 wt% alcohol

KHCO ₃ Solvents	Maximum CO ₂ desorbed (mmol)	CO ₂ loading (mol CO ₂ /mol KHCO ₃)	CO ₂ Capture capacity (mol CO ₂ /kg solvent)
KHCO ₃ -H ₂ O	0.0070	3.50E-05	6.3E-08
KHCO ₃ -H ₂ O-MeOH	2.93	0.015	0.016
KHCO ₃ -H ₂ O-EtOH	7.00	0.035	0.039
KHCO ₃ -H ₂ O-IPA	19.00	0.095	0.11
KHCO ₃ -H ₂ O-Butanol	0.036	1.8E-04	2E-04

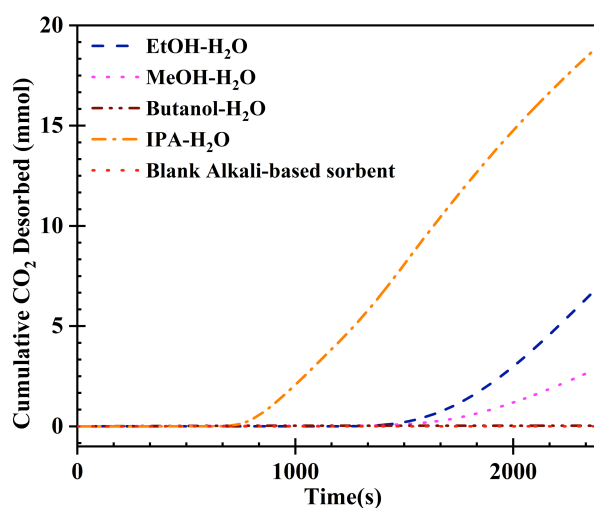


Figure 5. Effect of different alcohols on CO₂ desorption in KHCO₃ sorbent at 80 °C.

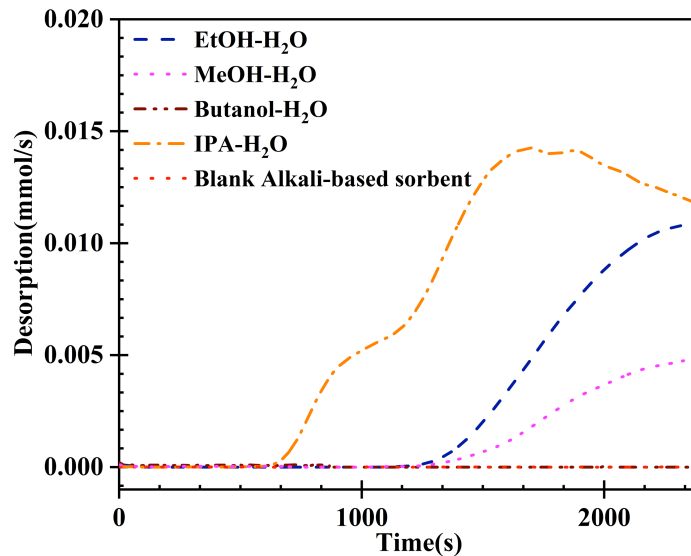


Figure 6. CO₂ desorption rates using KHCO₃ sorbent with and without alcohols at 80 °C.

Although the quantity of CO₂ desorbed is important, the desorption rate reflecting the CO₂ kinetics is more critical to applying the sorption-based CO₂ capture technology because it can affect capital and operating costs [8]. Figure 6 shows the desorption rates based on the type of alcohol used in the solution. As shown, the addition of alcohols resulted in varying CO₂ desorption rates. Specifically, EtOH-H₂O, MeOH-H₂O, and butanol-H₂O have desorption rates of 0.011, 0.0049, and 0.0005 mmol/s. However, the IPA-H₂O solution reaches a peak desorption rate of 0.014 mmol/s at 1690 s with an average desorption rate of 0.012 mmol/s. Therefore, it is concluded that the IPA-H₂O solution achieves the highest desorption when compared to the other alcohols used in the experiment. As a result, the isopropanol-H₂O solution was selected for further study.

3.3.2 Effects of different isopropanol concentrations on CO₂ capture

KHCO₃-based sorbents (~20 g KHCO₃) with IPA concentrations ranging from 20 to 50 wt% were used to investigate the effect of IPA concentration on CO₂ capture. As shown in Figure 7, there was a significant difference in the amount of CO₂ desorbed by the 20 and 40 wt% IPA solutions. The 20 wt% solution has a desorption capacity of 2.61 mmol, and the 40 wt% solutions have a desorption capacity of 15.16 mmol. Figure 7 indicates the increase in desorption capacity as the concentration of the IPA-H₂O sorbent increases, while Figure 8 illustrates the improvement of IPA-H₂O desorption kinetics when 0 to 40 wt% IPA solutions are used. 20 and 30 wt% IPA solutions yielded desorption rates of 0.004 and 0.006 mmol/s, respectively, while 40 and 50 wt% IPA solutions yielded desorption rates of 0.01 and 0.011 mmol/s, respectively. The 40 wt% IPA solution desorbed roughly the same amount of CO₂ as the 50 wt% IPA solution. As shown in Figure 4, the 40 wt% IPA solution had the highest desorption rate compared to the other IPA concentrations. Therefore, we conclude that a higher alcohol concentration increases the desorption amount. Still, if the alcohol concentration is too high (>40 wt%), precipitation of KHCO₃ in the solution could reduce the amount of CO₂ desorbed. Based on the results presented in Figures 4 and 5, 40 wt% IPA solution was selected for further study.

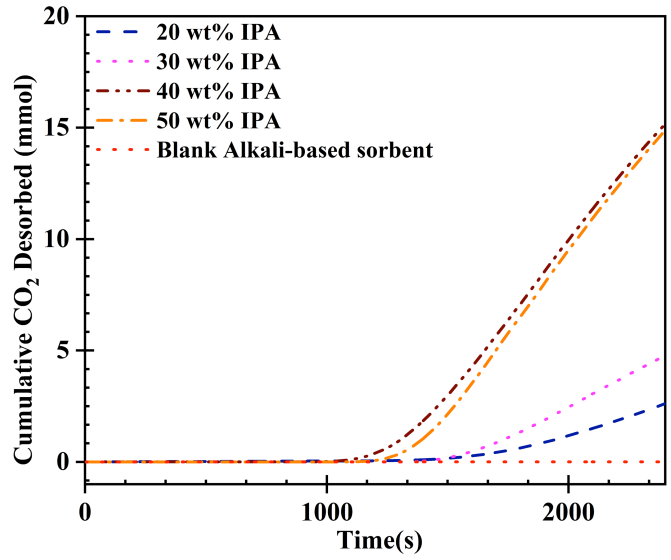


Figure 7. Effect on IPA concentration on CO₂ desorption in KHCO₃ sorbent.

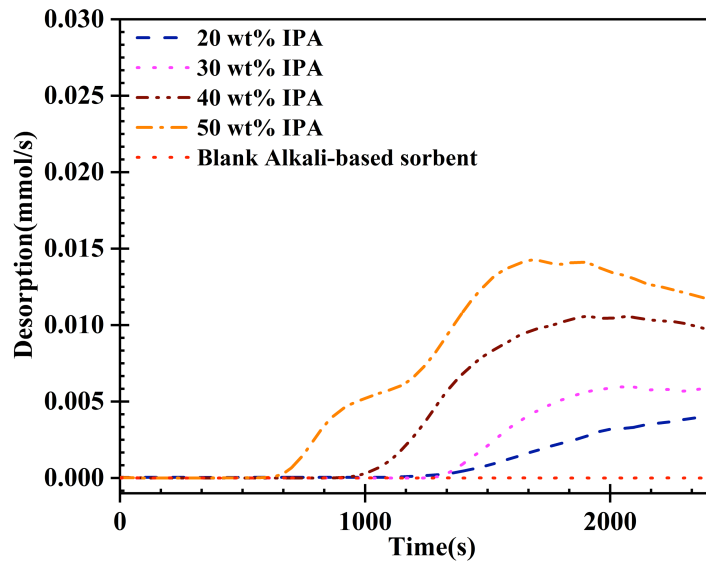


Figure 8. CO₂ desorption rates using KHCO₃ sorbent with different IPA concentrations.

Table 2. Summary of the effects of different wt% IPA on CO₂ capture with KHCO₃-based sorbent.

KHCO₃ Solvents	Maximum CO₂ desorbed (mmol)	CO₂ loading (mol CO₂/mol KHCO₃)	CO₂ Capture capacity (mol CO₂/kg solvent)
KHCO ₃ -H ₂ O	0.0070	3.50E-05	6.3E-08
KHCO ₃ -H ₂ O-20 wt% IPA	2.62	0.013	0.015
KHCO ₃ -H ₂ O-30 wt% IPA	4.79	0.024	0.027
KHCO ₃ -H ₂ O-40 wt% IPA	15.17	0.078	0.084
KHCO ₃ -H ₂ O-50 wt% IPA	19.00	0.095	0.11

CO₂ desorption data from KHCO₃ solution with varying amounts of alcohol are shown in Table 2. The rate of desorption observed for 40 wt% and 50wt% are significantly higher than the rate for 20 and 30 wt%. These experiments were performed to see the effects of different concentrations of IPA on CO₂ desorption. According to the results, CO₂ desorption varies depending on the concentrations of IPA used hence proving those different concentrations of IPA affect the CO₂ desorption. According to Figure 8, 40 wt% IPA is likely the best option for CO₂ capture with KHCO₃. According to the data, even though 50 wt% results in a slightly higher amount of CO₂ desorbed, 40 wt% has a higher desorption rate as compared to 50 wt%. As a result, 40wt% IPA solution is the optimum concentration for the experiment. Therefore, further experiments were performed on a 40 wt% IPA solution.

3.3.3 Effects of different inorganic sorbents on CO₂ capture

To determine if IPA also works for other inorganic sorbents, 40 wt% of a NaHCO₃-based sorbent was also tested. Different inorganic sorbents (~20 g of KHCO₃ and NaHCO₃) with an IPA concentration of 40 wt% were used to determine the effect of inorganic sorbents on CO₂ capture. All experiments used ~20 g KHCO₃ mixed with 40 wt% H₂O (72 g) and 60 wt% alcohol (108 g). As shown in Figure 9, desorption with KHCO₃ starts at approximately 1109 s, whereas desorption with NaHCO₃ starts at approximately 1403 s. Furthermore, the total CO₂ desorbed with KHCO₃ and NaHCO₃ was 15.10 mmol and 19.56 mmol, respectively. This is because KHCO₃ is more soluble than NaHCO₃ in water. This is because of the hydrogen bonding present in KHCO₃ due to the presence of a dimeric anionic structure. Whereas NaHCO₃ results in an infinite chain of ions hence reducing solubility in water. Based on these results, a higher desorption rate was observed using KHCO₃ as a sorbent, while a higher desorption amount was observed using NaHCO₃ as a sorbent.

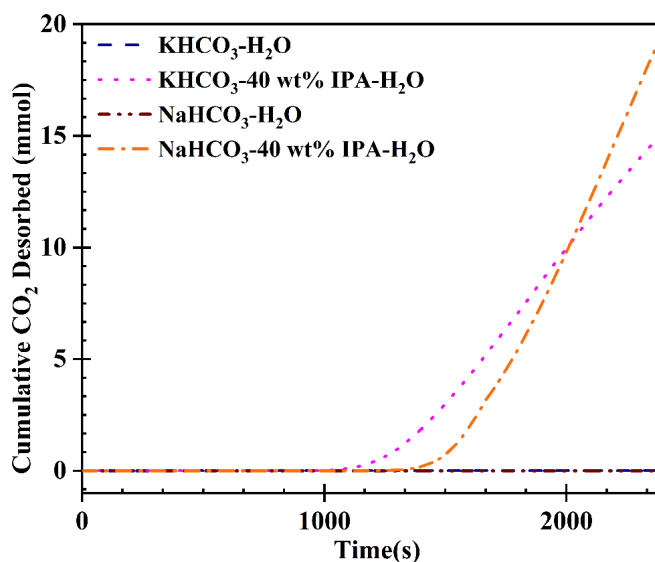
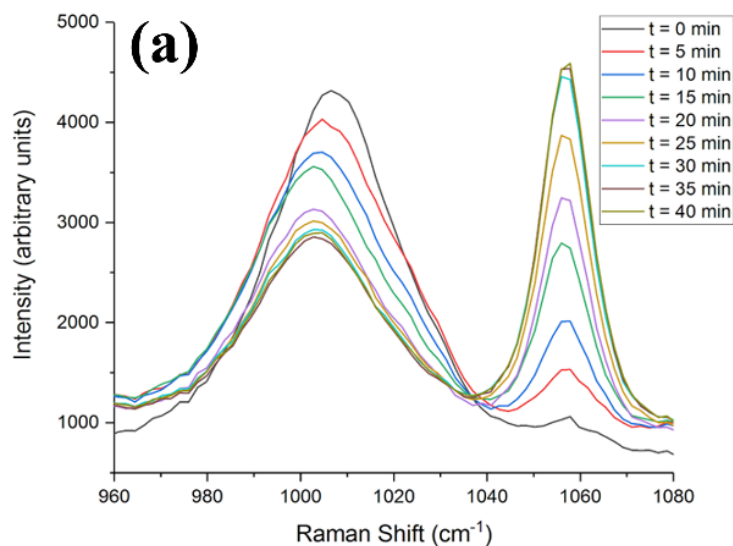


Figure 9. Average cumulative desorption using different amine sorbents.

3.4 Material analysis

3.4.1 Raman spectroscopy

Desorption improvements with IPA as a catalyst were tested through Raman spectroscopy (Figure 10). The readings were taken at five-minute intervals from time 0 min to 40 min of the desorption time. Figure 10 a contains KHCO_3 and D.I. water with 40 wt% IPA added at time 5 min. Figure 10 b contains KHCO_3 and D.I. water. The peaks at approximately 1005 cm^{-1} and 1060 cm^{-1} represent the presence of HCO_3^- and CO_3^{2-} respectively [6]. When comparing the peaks with and without catalysts, it can be determined whether the presence of IPA in the solution influences the rate of desorption. The intensity of the HCO_3^- peak at 1005 cm^{-1} with catalyst present decreases at a noticeably higher rate (Figure 10 a) than when the catalyst is not present (Figure 10 b). Additionally, the increase of peak intensity at 1060 cm^{-1} indicates that the rate of K_2CO_3 formation is significantly higher with the catalyst as opposed to without. The Raman analysis, therefore, confirms that CO_2 has increased desorption kinetics with the alcohol catalyst present.



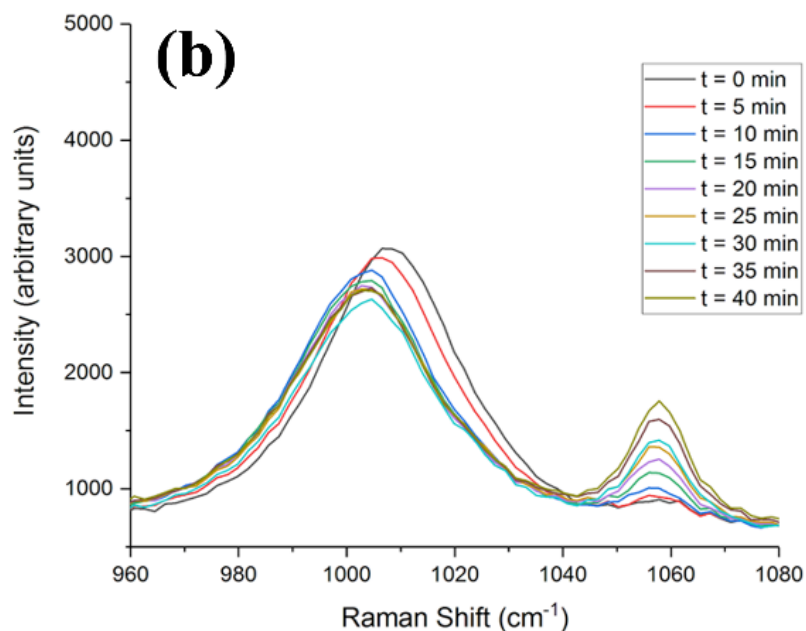


Figure 10. Raman spectra of CO₂ desorption.

3.4.2 *Cyclic stability*

The findings in this study generated two practical questions: (1) can 40 wt% IPA solutions be sustained during multiple regeneration cycles? (2) how stable is the 40 wt% IPA solution? To answer these questions 12 cyclic regeneration experiments were performed (Figure 11). The experiment conditions for the cyclic stability involved absorption for 1 hour followed by 40 minutes of desorption for each cycle. The retention rate from the first experiment and the last experiment was 18.02%. These results suggest that 40 wt% IPA solutions paired with KHCO₃ are reasonably stable and can be used in practical situations.

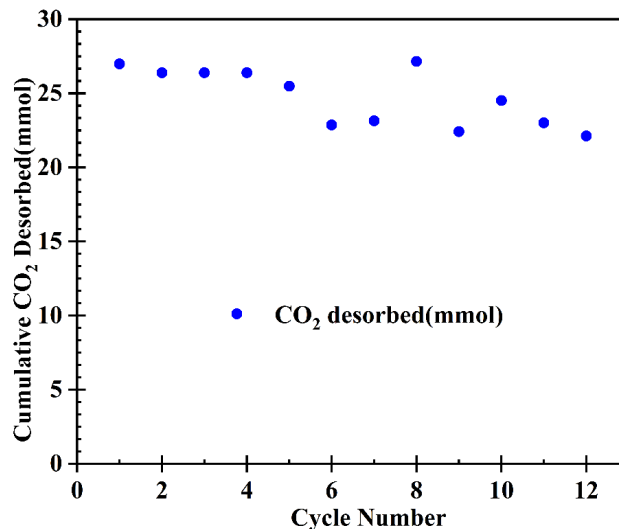


Figure 11. Stability of IPA-H₂O with 20 g KHCO₃, 40 wt% IPA, and 60 wt% H₂O.

3.5 Conclusion

Different alcohol solutions were prepared using KHCO₃, H₂O, and alcohols to study their CO₂ (10% partial pressure) desorption performance. A 40 wt% IPA solution with the KHCO₃ sorbent proved to be the best mixture for CO₂ capture because it increases the amount of CO₂ desorbed at room temperature by the KHCO₃ solution from 9.9×10^{-4} mmol (blank solution) to 15.16 mmol. The 40 wt% IPA solution was also analyzed using a different inorganic sorbent (NaHCO₃) instead of KHCO₃. It was concluded that a higher desorption rate was achieved with KHCO₃, while NaHCO₃ had a higher amount of CO₂ desorbed. During 12 cycles of the CO₂ sorption/desorption reaction, the desorption capacity showed no significant change, proving that the 40 wt% IPA solution remained stable after multiple cycles. These results demonstrate that the addition of IPA can significantly improve the CO₂ desorption of KHCO₃-based sorbents and that a catalytic CO₂ capture route can be economical and energy-efficient.

Chapter 4: Future directions for CO₂ capture

The next step towards the implementation of this technology is to better understand the potential environmental impacts of the new CO₂ capture process by performing LCA studies. The use of ionic liquids to capture CO₂ is an area that requires more research & development in the future. Ionic liquids (ILs) are liquids that are made up of ions and have a melting point of less than 100 °C. Ionic liquids have gone from being poorly understood materials to be the focus of a lot of study in the recent decade. Academic research and industrial applications have been becoming popular in the recent years. In the chemical industry, at least eight chemical processing applications are now in use [2]. Furthermore, as seen by several recent articles, ionic liquids are being scrutinized more closely for CO₂ capture applications [3,4]. Ionic liquids, for example, have the potential to reduce the energy requirement for CO₂ collection by up to 16 percent when compared to a 30 percent MEA-based solvent [3]. The potential use of ionic liquids as "green" alternatives to volatile organic solvents has piqued people's curiosity. This claim is because ionic liquids are non-volatile at room temperature. As a result, the danger of exposure to ionic liquids is far lower than that of a volatile solvent. This eliminates one of the most essential (and costly) routes for absorption by the body. This is especially crucial for chemical sector workers. Most ionic liquids are non-flammable at ambient and higher temperatures due to their non-volatility. The capacity to individually control the cation and anion provides an easy way to customize many solvent properties, which is why ionic liquids have been advocated as "designer solvents." Solvent polarity, acid/base character, density, viscosity, and thermal stability can all be adjusted to meet the needs of a particular process. Ionic liquids have been recommended for CO₂ capture due to their large liquid range, high thermal stability, extremely low volatility, good solubility of CO₂, and the ability to manipulate solvent properties through ion selection.

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