

Efficiencies of Enzymo-Chemical Reactions in Capture of Carbon Dioxide

Abstract: CO₂ in the atmosphere is a major driver of global warming, trapping heat in the atmosphere. Much CO₂ release and the resultant increases in global warming have been attributed to widespread human use of fossil fuels. Keeping CO₂ from the atmosphere is called sequestration, and specifically focusing on power plants, which generate 33% of emissions current methods involve using liquid amine scrubbers to purify CO₂ from coal flue gas, and then injecting it into mile deep underground sites. This method is inefficient, logistically and financially, to deploy en masse to global powerplants. This project aims to find a better method to sequester CO₂, through biochemical reactions. The enzyme carbonic anhydrase, catalyzes interconversion of CO₂ and water to carbonic acid, around a million times per second in ideal conditions. Carbonic acid is then reacted with calcium hydroxide(a base) to form calcium carbonate, a precipitate with many industrial uses. Proof of concept was provided through testing four 15 min. trials of 4 different millimolar concentrations of carbonic anhydrase in a prototype bucket with a 200 micron polypropylene mesh, simulating a reaction chamber with high CO₂ concentration(10 g of CO₂ and water, 20 g of calcium hydroxide); measured for efficiency and cost to effect ratio, through a 100% CO₂ sensor. The 5 micromolar concentration was best in cost to efficiency, 50 micromolar was best in total sequestration. At industrial scale, this could sequester 1 ton of CO₂ in 12 hours at a cost of \$3,800 dollars.

Introduction

Global warming is a prevalent concern in our world today. As the Earth's temperature rises, human actions wipe out more and more species, cause more devastating natural disasters, melt the ice caps, and turn our oceans acidic; among other things (Bradford 2017). Global warming can be majorly correlated with a rise in human fossil fuel consumption and rise in the carbon dioxide resulting from combustion (Jouzel 2007). Carbon Dioxide traps heat in the atmosphere through reflecting it back, not letting it escape. This is known as the greenhouse effect. The need for artificial carbon sinks becomes apparent. In order to combat this, scientists have come up with various ways to sequester, or trap CO₂, before it enters the atmosphere. Current chemical methods are difficult due to the stability of the CO₂ (Creutz 2001) molecule (Electrons are evenly matched, and then molecule has a 180 degree geometry), but the amide sequestration method has emerged as a reliable, if quite expensive method of CO₂ capture (Barnard 2016); specifically from powerplants, which generate around 33% of US emissions (EPA 2018). However, the underground sequestration of CO₂, trucked, then injected into mile deep sites is immediately inefficient and costly, as well as shown to be ineffective. First, a site must be found, then the gas must be transported, and finally injected. Only 1-3% of CO₂ turns to cap rock as intended (Allinson 2014). Leakage can range from anywhere to 1-10% per 10 years, meaning that carbon dioxide is still eventually going to escape into the atmosphere. This project's purpose is to find an alternative, biochemical method to sequestration. Using an enzyme, Carbonic Anhydrase (CA, henceforth), to catalyze the interconversion of CO₂ and water (Brown 2010) to Carbonic acid at a rate of a million times per second in ideal conditions (CO₂: water ratio is 22:9).

CA is an enzyme that thrives in slightly basic conditions, but doesn't denature until pH 2.5(Faridi 2016). Carbonic acid may then be reacted with calcium hydroxide(a base) in a 1:2 ratio to obtain calcium carbonate, a precipitate with many uses in construction, as an antacid, agriculture, and in bio cement(self healing). The enzyme is by far the most expensive part of the chemical process, so the efficiencies at different enzyme levels will be tested. My hypothesis is that if 5 micromole, 10 micromole, 20 micromole, and 50 micromole concentrations of carbonic anhydrase solution are tested in a carbonic acid-calcium carbonate reactor, then the 50 micromole solution will have the highest sequestration in a given amount of time, while the 20 micromole concentration will have the highest efficiency to cost ratio.

Material and Methods

- $(\text{Ca}(\text{OH})_2)$ calcium hydroxide near pure powder
- water
- Carbonic Anhydrase enzyme - 500 microliters
- KC 30 100% CO_2 sensor
- 5 gallon Home Depot bucket and airtight cap
- flexible meshing- plastic polypropylene
- 10-100 microliter pipettes
- Laptop
- Apparatus- This test bed for the chemical process rate/prototype was built by attaching polypropylene meshes 8 inches off the bottom of the bucket, and then coiling the CO_2 sensor and sealing the bucket with an airtight cap

Procedure

1. Insert 10 g calcium hydroxide bed on bottom of bucket
2. Insert 5 g Calcium Hydroxide on second mesh layer
3. Make one of 4 micromolar CA solutions(500 ml)
4. Pour CA solution on mesh so as to prevent leaking
5. Stabilize CO₂ concentrations around 1400 ppm as needed(with dry ice)
6. Plug in sensor(to a laptop with necessary software)
7. Seal apparatus with cap
8. Start 15 minute trial
9. Record concentration at end of trial, observe patterns through trial
10. Clean out bucket, repeat 4 times for each concentration and controls

Results

Data Table- CO₂ sequestered as a measure of CO₂ left at trial end, from 1400 ppm baseline

5 micromolar CA solution	10 micromolar CA solution	20 micromolar CA solution	50 micromolar CA solution
1. 950 ppm CO ₂ concentration at trial end	760 ppm at trial end	640 ppm at trial end	520 ppm at trial end

2. 965 ppm	740 ppm	670 ppm	540 ppm
3. 920 ppm	725 ppm	645 ppm	535 ppm
4. 985 ppm	750 ppm	685 ppm	550 ppm
Cost as ratio of 500 microliter solution: \$3.50	\$7	\$14	\$36

Figure 1. A lower number indicates a better result(more ppm sequestered)

Average CO₂ levels after trial by CA concentration

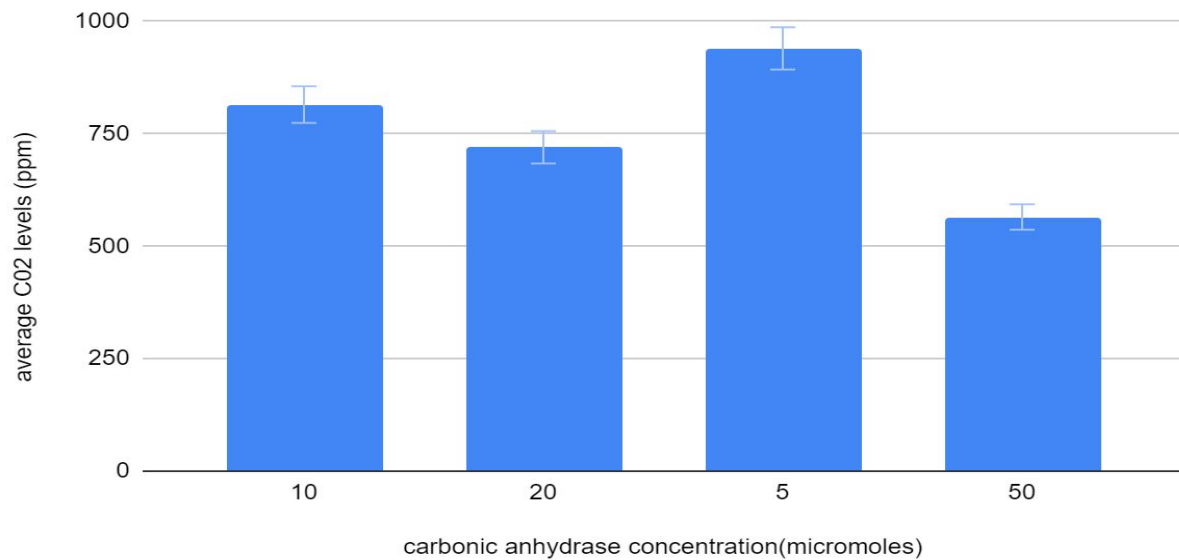


Figure 2. Graph of results- a smaller bar means the most carbon dioxide sequestered in the trial

Average CO₂ levels after trial by CA concentration

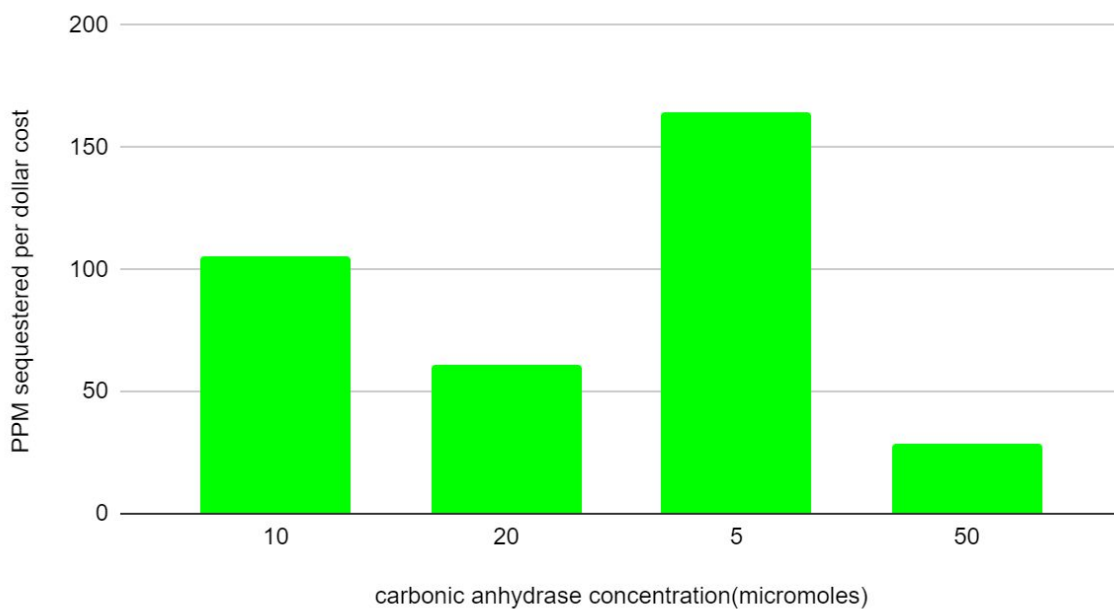


Figure 3. Graph of results- plots cost of enzyme required against amount sequestered- a higher

ppm means the concentration has a higher value in this specific testing environment



Figure 4. An open test bed photo- sensor, mesh, and biochemicals

Two controls were used. One was the calcium hydroxide and water in the apparatus with no enzyme, as a negative control. The furthest this control went in any trial was to 1310 ppm, but had simply slowed to an inprogressable rate after 6 minutes. The other was just meshing in the apparatus, in order to check for leakage in the test bed, returning a lowest value of 1380 ppm left at trial end over 4 trials(insignificant). With a significance value of 0.05, the expected value being the calcium hydroxide control avg., using chi square and a online calculator, p values for each concentration came out to be 0.023, 0.028, 0.037, and 0.031- hypotheses are statistically acceptable.

Discussion

The sequestration hypothesis was proven correct, as the 50 micromole solution did

sequester the most carbon dioxide in the time allotted (Figure 2). The cost efficiency hypothesis was proven incorrect as it was 5 (Figure 3), not the 20 micromole solution which sequestered the most CO₂ per dollar. A general trend noticed was that it seems that at lower levels of CO₂ concentration, adding enzyme does not seem to help after a certain threshold due to lower concentration of reactants. In order to create the most efficient process, it would be wise to finely match the Using these numbers we've gotten, we can now check for the viability of this process to be applied in a power plant. The average US power plant emits 1000 tons of CO₂ per day. In this experiment, specifically using the 50 micromole concentration, the device was able to sequester 0.5 grams of CO₂ in 15 minutes. We assume it could sequester 2 grams from plain, 1400 ppm, air in an hour, around 800 g if concentrations were closer to 100%, also accounting for the upper bounds of enzyme activity. To sequester a ton (million grams) of CO₂ with an enzyme content a hundred times more, it would take about 12 hours with near 100% CO₂ content at a cost of around 3,800 dollars, which is less expensive in total than current methods, and provides a permanent chemical storage solution. One of the main sources of error/ regret is that the device was not entirely tested at 100% CO₂ concentration. Future research includes attempts at making a more efficient prototype, perhaps with an enzyme gel based adsorption and filter chambers. Using mass production techniques, the high cost of the CA enzyme could be lowered. Other research includes biocement using calcium carbonate, or cement with carbonic anhydrase which can be both a structural support and absorb carbon dioxide. Sequestration rates could also be compared to plants. Ultimately, this seems to be a promising, new method of carbon dioxide sequestration, which, with

refinement, can be widely applied to help combat CO2 release and global warming as a whole.

Works Cited



Science Lab.com
Chemicals & Laboratory Equipment



Health	2
Fire	0
Reactivity	0
Personal Protection	J

Material Safety Data Sheet Calcium hydroxide MSDS

Section 1: Chemical Product and Company Identification		
Product Name: Calcium hydroxide		
Catalog Codes: SLC4525, SLC1732, SLC3523, SLC5311		
CAS#: 1305-62-0		
RTECS: EW2800000		
TSCA: TSCA 8(b) inventory: Calcium hydroxide		
CI#: Not applicable.		
Synonym: Hydrated lime; Slaked Lime; Calcium Oxide, hydrated		
Chemical Name: Calcium Hydroxide		
Chemical Formula: Ca(OH) ₂		
Contact Information:		
Sciencelab.com, Inc. 14025 Smith Rd. Houston, Texas 77396		
US Sales: 1-800-901-7247 International Sales: 1-281-441-4400		
Order Online: ScienceLab.com		
CHEMTREC (24HR Emergency Telephone), call: 1-800-424-9300		
International CHEMTREC, call: 1-703-527-3887		
For non-emergency assistance, call: 1-281-441-4400		

Section 2: Composition and Information on Ingredients		
Composition:		
Name	CAS #	% by Weight
Calcium hydroxide	1305-62-0	100
Toxicological Data on Ingredients: Calcium hydroxide: ORAL (LD50): Acute: 7340 mg/kg [Rat.]; 7300 mg/kg [Mouse].		

Section 3: Hazards Identification
Potential Acute Health Effects: Very hazardous in case of eye contact (irritant). Hazardous in case of skin contact (irritant), of eye contact (corrosive), of ingestion, of inhalation. Corrosive to eyes and skin. The amount of tissue damage depends on length of contact. Eye contact can result in corneal damage or blindness. Skin contact can produce inflammation and blistering. Inhalation of dust will produce irritation to gastro-intestinal or respiratory tract, characterized by burning, sneezing and coughing. Severe over-exposure can produce lung damage, choking, unconsciousness or death. Inflammation of the eye is characterized by redness, watering, and itching.
Potential Chronic Health Effects: Hazardous in case of skin contact (irritant). CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available.

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