Introducing the idea of “CO_2-Bin” in order to Combat Climate Change

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APPROVAL SHEET

This dissertation submitted by Ms. Afsana Shaheen, Mr. Awais Ahmed, and Ms. Rani Habib, is accepted in its present form, by the Institute of Environmental Sciences and Engineering (IESE), School of Civil and Environmental Engineering (SCEE), National University of Sciences and Technology (NUST), Islamabad as satisfying the requirement for the degree of Bachelors in Environmental Engineering.

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Abstract

Currently, ambient CO_2 concentrations are 400 ppm with levels rising more than 2 ppm a year. High concentration of carbon dioxide and Green House Gases (GHGs) accumulate in the atmosphere which result into global temperature rise, extreme heat events, frequent and wide spread fires, draughts, rising sea levels, torrential rains and consequent floods.

The objective of the study was to capture CO_2 from indoor as well as ambient air. This has the advantage that emissions from diffuse sources and past concentrations can be captured. Our setup consisted of an air pump, NaOH solution and a rectangular box of "1.5 x 1 x 0.5" feet^3 which can be installed at any place to capture CO_2 i.e. offices, houses, recreational centers, parking areas and industries. It is designed for indoor air where CO_2 concentration is high comparatively, but it can also capture outdoor CO_2 efficiently as well.

Ambient CO_2 from the air can be captured by passing the air through NaOH solution. Here CO_2 from the air reacts with NaOH solution producing sodium carbonate and water. This method is a cost-effective and efficient for the removal of excess of CO_2 from air.

We have tested different solutions like sodium hydroxide, calcium hydroxide and distilled water to capture CO_2 from air. Sodium hydroxide solution of 0.5M was identified as the best solution for the removal of CO_2 from indoor air and outdoor air.

Maximum removal efficiency of CO_2 was observed as 48.75% by using NaOH solution of 0.5M and 5 L. Solution's efficiency can be enhanced by providing more volume so that the air get larger area to contact with the solution.

INTRODUCTION

To mitigate climate change, reductions in emissions of carbon dioxide (CO_2) are vital in the coming decades. To stabilize the atmospheric CO_2 concentrations, efforts have been made to shift the world's primary energy sources from fossil fuels to other alternatives. This can help us in emission control of carbon dioxide and other harmful gases.

Nearly all current research is based on Carbon Capture and Storage "CCS". CCS emphases on capturing CO_2 from huge, stationary sources such as power plants. This method suggest to separate CO_2 from flue gas, compress it, and then transport it through pipeline to the sequestering underground site. In contrast, the idea we proposed is based on capturing carbon dioxide directly from ambient air "air capture". This approach is inexpensive as compared to capture from point sources, because we need to install a capturing unit at every point source. While by "air capture" we can control CO_2 emissions from any sector, which include emissions from sources such as aircraft and automobiles, where on-board carbon capture is very difficult and the cost of alternatives is high. Additionally, in the future economy with low carbon emissions, capturing air might be deployed to produce negative net emissions.

The climate of Earth has changed during the course of history. In the last 650,000 years there have been seven cycles of glacial advance and retreat, with the sudden end of the last ice age about 7,000 years ago marking the beginning of the modern climate era — and of human civilization. Most of these climate changes are due to very small deviations in Earth's orbit that control the amount of solar energy our planet receives.

Evidences show that Earth has warmed since 1880. A major part of this warming occurred after 1970s. Twenty warmest years have happened since 1981.

Most of the heat is absorbed by oceans, with the top 700 meters of ocean indicating warming of 0.302 degrees Fahrenheit after 1969. Global rise in sea level is about 17 centimeters (6.7 inches) in the last century. The rate of rise in the last decade, is almost double that of the last century (Manzoor K, 2014).

Glaciers are declining universally — including in the Himalayas, Rockies, Alps, Andes, Africa and Alaska.

Acidification of the surface ocean water occurred since the industrial revolution. The total percentage has increased about 35 percent. This increase has resulted from humans activities which emit more carbon dioxide into the atmosphere which leads to higher absorption into the oceans. The quantity of CO_2 absorbed by the upper layer of the oceans is at increasing rate of 2 billion tons per year (Petit *et al*., 1999)

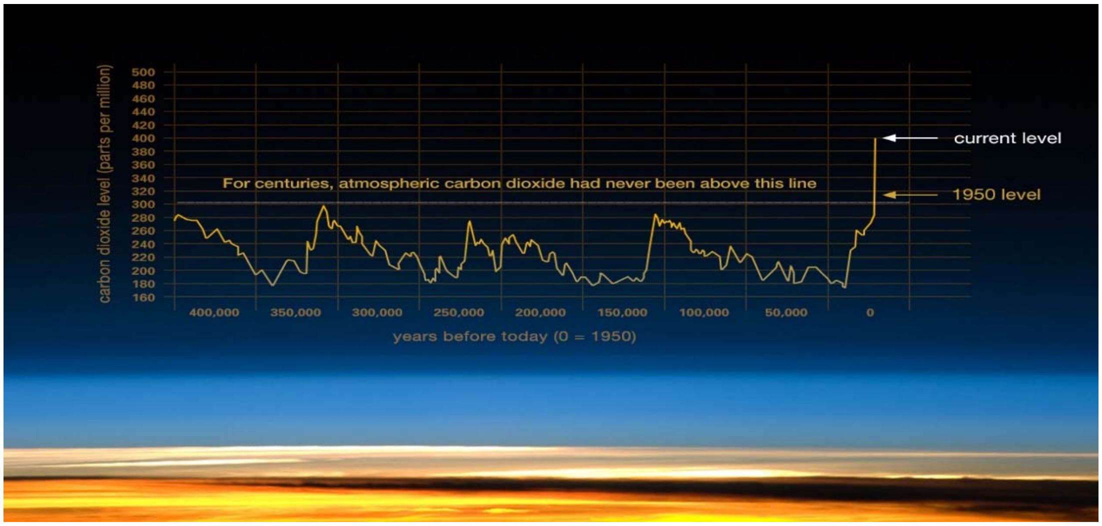


Figure 1.1: This graph, based on the comparison of atmospheric samples contained in ice cores and more recent direct measurements, provides evidence that atmospheric CO_2 has increased since the Industrial Revolution. (Credit: Vostok ice core data/J.R. Petit et al.; NOAA Mauna Loa CO_2 record.)

Key findings from the 1990-2014 U.S. Inventory include:

- In 2014, U.S. greenhouse gas emissions totaled 6,870 million metric tons of carbon dioxide equivalents.
- U.S. emissions increased by 1.0 percent from 2013 to 2014. Recent trends can be attributed to multiple factors driving increased fuel use including year-to-year changes in the prevailing weather and an increase in miles traveled by on-road vehicles.
- Greenhouse gas emissions in 2014 were 9 percent below 2005 levels.

Figure 1.2 below provide an overview of greenhouse gas emission in the United States based on information from the Inventory (Suparco, 2016)

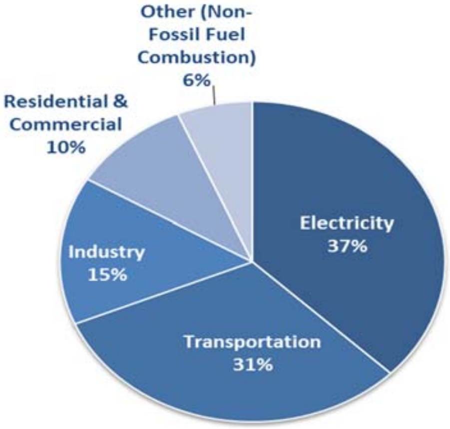


Figure 1.2: Total CO_2 emissions; Note: All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014*

Figure 1.3 shows increase in carbon dioxide from 380 ppm to 392.5 ppm and increase in temperature from 21.29 to 22.83 i.e 1.54 □C.

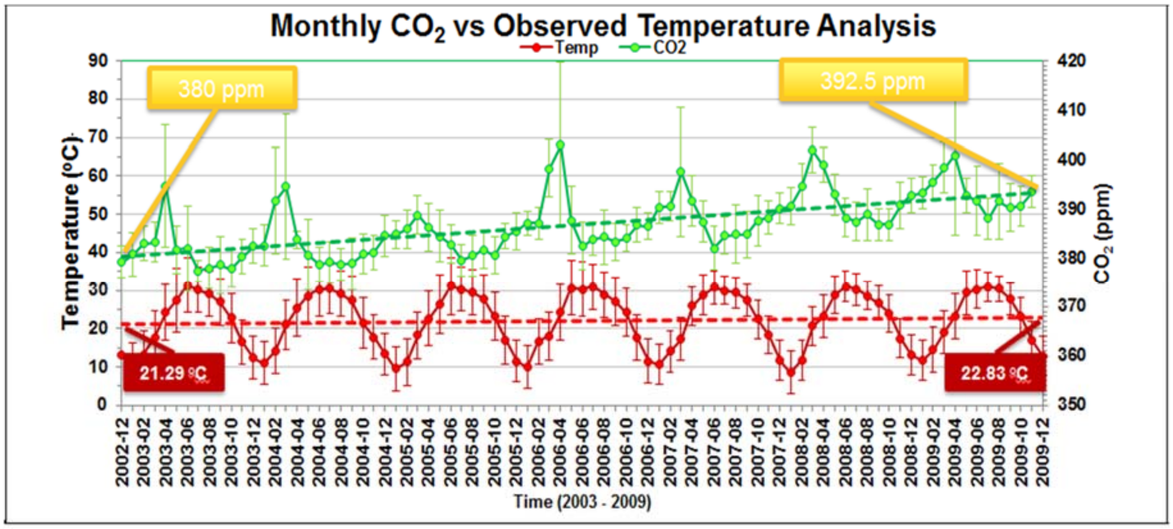


Figure 1.3**:** Rise in temperature of Pakistan over seven years from December 2009 to December 2012 with relation to the emission of carbon dioxide. Source: Khadija Manzoor, 2014 C-CARGO

1.1 Project Background:

Currently we are at 400 ppm of CO_2 outdoors, with levels rising more than 2 ppm a year. Climate change and global warming causes many natural disasters in Pakistan. High concentration of carbon dioxide and GHG accumulate in the atmosphere which result into global temperature rise, extreme heat events, fires and draughts, rising sea levels, torrential rains and consequent floods, food insecurity, depletion of water resources, disorder of natural habitats, energy and power crisis and destroys the economy and natural ecosystem of the country. Pakistan suffers financial cost of $5.2 billion annually due to environmental dreadful conditions (Saul, 2013).

Glaciers are natural reservoir of fresh water. Their melting water feed the rivers in Pakistan. These glaciers are spread over an area of about 16933 Km^2. Pakistan is a home of 108 peaks above 6000 m, and numerous peaks above 5000 and 4000m. Five of the 14 highest peaks in the world are here (Suparco, 2016).The melting of glaciers not only depletes water resources and causes floods but can badly affect agriculture, drinking water supplies, hydroelectric power, ecological habitats and hence the economy of our country Pakistan.

Pakistan has faced sever kinds of floods during past years. In 2007, Khyber-Pakhtunkhwa was affected by melting glaciers resulted into drastic floods while Sindh and coastal Balochistan were badly affected due to cyclone Yemyin in June and the heavy rains during July and August. At least 130 people died and 2,000 were displaced in Khyber-Pakhtunkhwa in July and 22 people died in August, while 815 people died in Balochistan and Sindh due to flash floods. Large area of the country was flooded in 2010 floods. Almost 20 million people were affected with more than 6 million homeless. More than 8 million Pakistanis were in need of immediate aid. A staggering $43 billion in material losses. 1463 People were reported dead and 2024 injured. 895,259 homes were destroyed (Saul, 2013).

In September 2011, at least 361 people were killed; some 5.3 million people and 1.2 million homes affected as well 1.7 million acres of arable land flooded when massive floods swept across the province of Sindh as a result of monsoon rains. In September 2012, more than 100 people died, and thousands of homes destroyed, with thousands of acres of arable land affected when intense rainfall battered Khyber Pakhtunkhwa, Southern Punjab and Upper Sindh. In August 2013, more than 80 people died during Afghanistan–Pakistan floods. In September 2014 Due to massive rain in Jammu and Kashmir as well as Azad Jammu and Kashmir and in Punjab Created flood condition in River Chenab and River Jhelum (Shebaz R, 2011)

Due to Air pollution chemicals and particulates matter release into the atmosphere. The most common gaseous pollutants include carbon monoxide, sulfur dioxide, chlorofluorocarbons (CFCs) and nitrogen oxides produced by natural sources and anthropogenic activities. In the presence of sunlight nitrogen dioxide reacts with hydrocarbons to produce photochemical ozone and smog. Particulate matter, or fine dust is described by their micrometer size PM_{10} to $PM_{2.5}$. The air in Karachi, Lahore and Rawalpindi is rapidly polluted by automobile smoke, especially Rickshaws and Buses, industrial emissions, open burning of garbage, house fires, and other particles (Manzoor K, 2104).

To tackle these environmental problems it is important to design solution for decreasing the emissions of greenhouse gases especially carbon dioxide. Our project provides a solution that captures carbon dioxide from indoor as well as outdoor causing a substantial decrease in the amount of CO_2 concentration which has already emitted in the past years and are emitting from different sources.

1.2 Problem Statement

Impacts of Climate Change are evident and are mainly caused by the rising GHG (CO_2, CH_4, N_2O,CFCs etc.) levels, and the type of carbon accumulated in the atmosphere is due to fossil fuel combustions (IPCC, 2013).

1.3 Project Statement:

To engineer and design a prototype filter named as " CO_2 – Bin" that will capture carbon dioxide from the ambient/indoor air with further emphasis on cost effective and energy efficient approach.

1.4 Objectives:

The project aims to capture already emitted CO_2 in a cost effective and energy efficient manner in order to combat climate change. The main objectives were:

- To design an equipment in order to sequester CO_2 from indoor/outdoor air.
- To design a filter which is energy efficient, cost effective, easy to operate and environmental friendly

1.5 Project Scope:

As mentioned in the project statement in Section 1.2, the project scope includes developing a prototype filter that can be installed in ambient air (indoor/outdoor) where CO_2 concentration is needed to be controlled. The focus of the project will be to capture carbon dioxide. The development of the prototype filter includes the following phases:

1. designing,
2. engineering,
3. prototype testing and
4. Manufacturing of final design for implementation.

Furthermore, the future scope of project defines the control of global warming, Climate Change, minimizes Health Impacts, and reduces food security.

1.6 Milestone

In the initial stages of the project, certain milestones were set to be achieved over certain period of time. These milestones later became the basis of our project timeline shown in Table 1.1

Table 1.1 Project Timeline

Activities	Sep 2015	Oct 2015	Nov 2015	Dec 2015	Jan 2016	Feb 2016	Mar 2016	April 2016	May 2016	June 2016
Literature Review		✓	✓	✓	✓	✓	✓	✓		
Prototype design				✓	✓	✓				
Preliminary results and efficiency check						✓	✓	✓		
Final design						✓	✓			
Results and analysis						✓	✓	✓		
Thesis Draft preparation						✓	✓	✓	✓	
submission of thesis draft										✓

LITERATURE REVIEW

2.1 Environmental Impacts of CO_2

CO_2 extraction from air is viable and cost-effective alternative to changing the transportation infrastructure to non-carbonaceous fuels. Ambient CO_2 in the air could be removed by passing over absorber surfaces. The CO_2 captured would compensate for CO_2 emission from power generation two orders of magnitude larger than the power.

Air extraction is an appealing concept, because it separates the source from disposal. One could collect CO_2 after the fact and from any source. Air extraction could reduce atmospheric CO_2 levels without making the existing energy or transportation infrastructure obsolete.

The atmosphere would act as a temporary storage and transport system. The report will discuss the potential impact of such a technology on the climate change debate and outline how such an approach could actually be implemented (Stolaroff *et al.*, 2008)

In order to mitigate climate change, deep reductions in CO_2 emissions will be required in the coming decades. Carbon capture and storage will likely play an important role in these reductions. As a compliment to capturing CO_2 from point sources, CO_2 can be captured from ambient air “air capture”, offsetting emissions from distributed sources or reducing atmospheric concentrations when emissions have already been constrained. In the figure 2.1, is the bar plot of percentages of different greenhouse emissions provided by World Resource Institute and Food and Agricultural Organization (sang *et al.*, 2011)

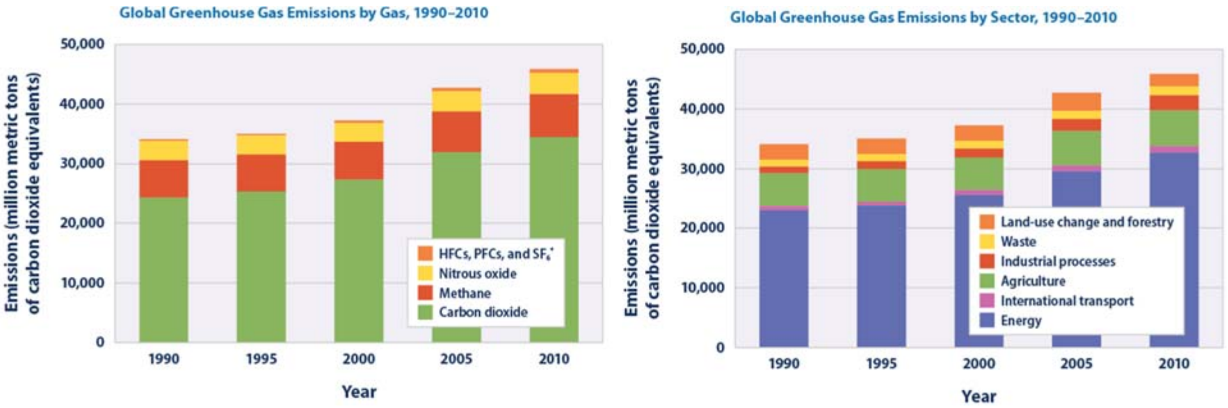


Figure 2.1: Global Greenhouse Gas Emission

In this plot, the level of CO_2 is continuously increasing due to burning of fossil fuels in energy sector and transport vehicles. It is the major greenhouse gas contributing towards climate change and hence the rise in temperature.

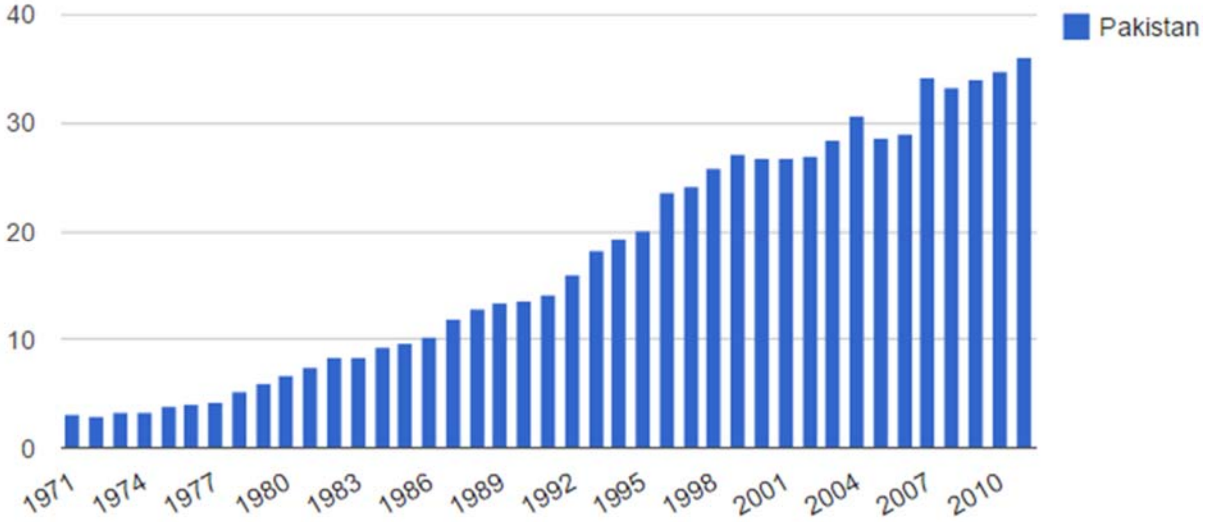


Figure 2.2: Pakistan's Carbon dioxide (CO_2) emissions from transportation (Dawn, 2011)

The World Bank and International Energy Agency both states that CO_2 emissions from transportation are continuously on the rise. In the bar chart data the average value CO_2 emissions from transportation in Pakistan is raised from 2.95 million metric tons in 1972 to a maximum of 36.15 million metric tons in 2011. Hence transportation is further adding the burden of greenhouse gases on our planet earth.

2.2 Techniques Used for CO_2 Absorption:

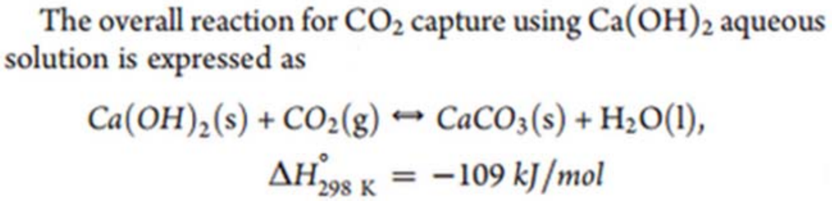
The experiments were performed through a number of techniques and raw solution for absorption of CO_2 before reaching to the best option of Sodium Hydroxide. A brief detail of our research literature proceeds as follows:

2.2.1 Carbon Dioxide Capture Using Calcium Hydroxide:

$Ca(OH)_2$ solution can be used as an effective absorbent to capture CO_2. Through an article we investigated $Ca(OH)_2$ solution reaction with more concentrated CO_2 gas mixtures. The finding helped us to get the data on gram of CO_2 absorbed per gram of $Ca(OH)_2$.

We also found that the filtered solution of Calcium Hydroxide has more capacity to absorb CO_2 rather than the suspended solution of $Ca(OH)_2$ (Sang J, 2011).

The reaction is thermodynamically favorable in the temperature range from ambient to 750 □C,



The overall reaction for CO_2 capture using $Ca(OH)_2$ aqueous solution is expressed as

$$Ca(OH)_2(s) + CO_2(g) \leftrightarrow CaCO_3(s) + H_2O(l),$$
$$\Delta H^{\circ}_{298\ K} = -109\ kJ/mol$$

-------Eq. 1.1

The excess of undissolved $Ca(OH)_2$, which existed in suspension, significantly degraded the CO_2 absorption, which was primarily ascribed to the effect of the simultaneous $Ca(OH)_2$ dissolution and $CaCO_3$ production in hindering the association between Ca^{+2} and $(CO_3)^{-2}$ in suspension (Sang J, 2011).

However when Calcium Hydroxide was compared with Sodium Hydroxide, the later one showed greater efficiency to absorb CO_2. It is elaborated further.

2.2.2 Carbon Dioxide Capture Using Sodium Hydroxide:

It was found that sodium hydroxide was much more efficient in absorbing Carbon Dioxide. The CO_2 absorption capacity increases with the increase in NaOH concentration, liquid volume and air pump speed.

We applied both NaOH and $Ca(OH)_2$ solutions to absorb CO_2 and came with the result that NaOH is the best fit for reducing CO_2 from ambient air. A detailed comparison is illustrated in the result section.

MATERIALS AND METHADOLOGY

3.1 Preliminary Planning

The timeline above gives a chronological view of various steps of our project from beginning till the end. This section focuses on the following areas;

- Preliminary consultations and scoping of the project
- Desk study and literature review to establish context of project
- Conceptual plan for project fabrication and experimentation
- Implementation of the conceptual plan

After the extensive literature review an overall idea was acquired about the air pollution and the problems faced due to it not only by Pakistan but also by the world. After the literature review we discussed it with our supervisor, he appreciated it and we as a team started to understand the shape of project about what should be done to remove the excess amount of CO_2 from atmosphere.

After thorough understanding of the issue we finalized our project "CO_2 Bin", which will reduce the CO_2 concentration in air automatically reducing the chances of greenhouse effect and global warming. We concluded that global warming can prove to be disastrous to our environment, contributing to climate change and several other problems. CO_2, being the prime cause of global warming was selected as the element of concern and solutions were searched and devised to remove CO_2 from ambient air. Improving indoor air quality became our aim in order to make the air safe for breathing.

The aim of the project was to select the optimum conditions on which CO_2 in the indoor could be best treated. As the aim of our project was to choose the best solution based on its carbon dioxide removal efficiency, it was important to know the concentration of CO_2 in indoor air. For this purpose CO_2 meter was set in the lab and readings were noted values for CO_2 concentration with the help of CO_2 meter after an interval of every 30 seconds maintaining an air flow of 10 L/m as it is the optimum flow rate for CO_2

absorption,CO_2 meter takes a couple of minutes to get adjusted. Once this data was recorded, then experiments were performed for different volume and molarity of solvents. Each activity is done with sheer coordination to minimize chances of error like switching off the fans in the lab while performing experiments.

3.2 Experimentation:

Different solutions were preferred at different molarities and volumes, this section will discuss the experiments performed for different solution, finding their efficiencies, comparison of their CO_2 absorption efficiencies respectively and results.

3.2.1 Introduction to Solvents:

In the light of comprehensive literature review and consultation with our supervisor and other experts, three hydroxide solutions were shortlisted as they can react with CO_2 and produce metallic carbonate and water. Hydroxides like NaOH, $Ca(OH)_2$ are most efficient absorbers of CO_2 gas and are derivatives of alkalis and alkaline earth metals. Distilled water was also selected as one of the solvents as it also has the capability of absorbing CO_2. They have been chosen for acidic gases such as carbon dioxide absorption because of their efficiency, stability and easy handling properties.

Calcium hydroxide [$Ca(OH)_2$] Solution:

$Ca(OH)_2$ solution was obtained directly by dissolving already powdered $Ca(OH)_2$ in water stoichiometrically;

The solution produced as a result of above reactions can absorb CO_2 by the following reaction;

$$Ca(OH)_2 + CO_2 \rightarrow CaCO + H2O \text{ ------------------------Eq 3.1}$$

A spatula was used to take 185g of $Ca(OH)_2$ granular powder (its molecular weight, Molecular weight = 40+2(16+1) = 74g) which was weighed on digital balance. Made a 0.5 M solution by dissolving it in 5 L of water. A milky solution is obtained after the above process. Experiments were performed at an average temperature of 25 °C.

Sodium Hydroxide (NaOH):

Sodium hydroxides in commercially known as caustic soda. It is available in several forms such as regular flake, fine flake, crystal flake and powder. Each form is readily soluble in water to form a solution that efficiently absorbs CO_2 from a source at room temperature.

The reaction for CO_2 removal is as follows;

$2NaOH\ (aq) + CO_2\ (g) = Na_2CO_3\ (aq) + H_2O$ + heat----------------Eq 3.2

The reaction above occurs exothermically. Several factors affect the rate at which CO_2 is absorbed into the aqueous solution. These include time available for absorption, temperature of reactants, concentrations of reactants (sodium hydroxide and carbon dioxide), gas flow rate, and absorbing surface area. Greater the concentration of sodium hydroxide available initially, higher will be the rate of absorption. Therefore the reaction rate is highest initially but gradually decreases as the reactants convert into products.

For our experiment, we used a spatula to place pellets of NaOH on a digital balance. Weighed the contents up to 100g and dissolved the pellets in 5L volume of water using a magnetic stirrer to get a 0.5M solution. Next, the solution was cooled down to room temperature. Experiment was performed for 0.2 M and 0.3 M NaOH as well dissolving 16 and 24 g of NaOH pallets in 5 L distilled water respectively.

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3.3 Experimentation Methodology:

The experiments was performed to determine CO_2 removal efficiency of both the solutions; sodium hydroxide and calcium hydroxide. Firstly, CO_2 meter was set in lab for its adjustment. Secondly, we could conveniently carry out our experiments using the indoor air and rest of the equipment required.

As the aim of our project was to choose the best solution based on its carbon dioxide removal efficiency, it was important to know the CO_2 concentrations in the lab. For this purpose we set the CO_2 meter in lab measuring the CO_2 concentrations for two hours maintaining a flow of 10 L/min at room temperature. This helped us getting an average value of CO_2 in room which was 750 ˚C.

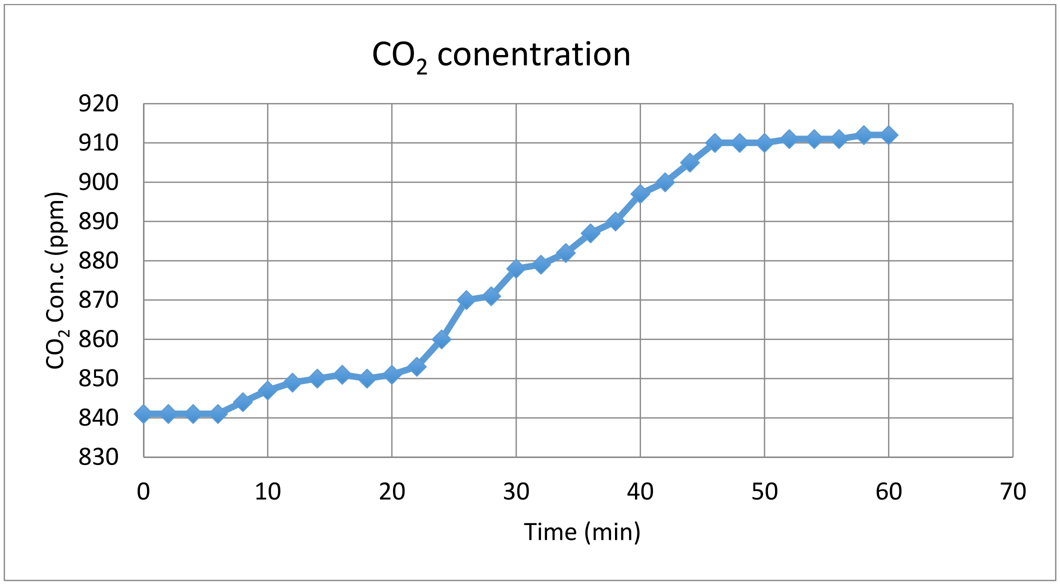


Figure 3.1: Concentration of CO_2 in ambient at 10 L/min on y-axia and time in minutes on x-axis.

Once this data was recorded, we moved to the next step i.e. treatment CO_2 by passing it through sodium hydroxide solution. Experiment was held at three flow rate of 10 L/min.

Air pump was switched on in order to maintain the flow at 10 L/min. CO_2 meter was adjusted at the exit of the treated air. We recorded the value of treated air at an interval of 30 seconds. The structures called showers were used to mix the solution properly and uniformly. Fans were switched off in order to reduce the turbulence. Ventilation was kept minimum to maintain almost same concentration of CO_2. Each activity is done with sheer coordination to reduce the air to maximum possibility.

Experiments were performed for 0.5 M NaOH solution recording the values after every 30 seconds. Graphs and tables were made. We kept noting results until the solution stopped treating. The procedure was repeated for 0.3 M, 0.2 M NaOH, 0.2 M, 0.3 M, 0.5 M $Ca(OH)_2$ at volumes of 2 and 5 liters. Also were performed for distilled water. Results shown by the graphs will be discussed in detail under Section 4.

Based upon CO_2 removal efficiency of both solutions at each volume, it was concluded that NaOH is far more efficient than $Ca(OH)_2$ in terms of absorbing CO_2. This has been explained in detail under Section 4.

Therefore, subsequent experiments were carried out with 0.5 M sodium hydroxide solution at 5 liters at 10 L/min flow rate. This was selected for final design.

Besides, these two solutions, experiments were also performed using distilled water. It was observed that when CO_2, present in indoor air, passes through distilled water, negligible amount of CO_2 is removed via absorption right from the beginning of the observation time. Thus the idea of using distilled water as our absorbent was completely abandoned. Results of the experiment for distilled water are discussed in Section 4.

3.4: Calculating Removal Efficiency:

The percent CO_2 removal efficiency for each reading of all the solutions was calculated using this simple formula;

$$\text{Removal}\,\mathit{Efficiency} = \frac{CO_{2\,(i)} - CO_{2\,(f)}}{CO_{2\,(i)}} \times 100$$

Where;

$CO_{2\,(i)}$ = CO_2 Concentration before treatment

$CO_{2\,(f)}$ = CO_2 Concentration after treatment

3.5 Calculating Retention Time:

In this case, retention time of a solution is for how long a solution retains its ability to remove CO_2 from the ambient air. It is of key importance in determining the solution to be used in the final prototype. Longer the retention time, less frequently the solution needs to be changed.

We determined the retention time for the following;

Table 3.1: Retention time of the respective solutions.

Absorbents	Molarity (M)	Volume (Litters)	Max .Removal Efficiency %	Duration (minutes)
NaOH	0.5	5	48.75	330
	0.3	2	38.88	285
	0.2	2	32.74	230
$Ca(OH)_2$	0.5	5	36.2	263
Distilled Water	-	5	12.64	105

It is important to note here that all conditions (molarity, temperature and flow rate) had been kept constant while determining the life of each of the three solutions. Optimum values for molarity and volume have been chosen based upon experiments.

Before experiments the room fans were switched off. CO_2 analyzer is powered ON and calibrated in room air during its “zeroing phase”. Now, the instrument is ready to take CO_2 readings. The CO_2 meter was set at the outlet of setup. Readings of percentage CO_2 are recorded after every 30 seconds.

In our case, the experiment was continued for days, until the readings of percentage CO_2 became constant and equal to the percentage of CO_2 in the original concentration of CO_2 in ambient air. Finally, values are tabulated and graph of concentration of CO_2 V/S Time (minutes) is plotted on Microsoft Excel. For details of retention time of each of the solution, see Section 4.

3.6 Design and Fabrication of Prototype (CO_2 Bin):

Components of the Prototype:

- **Sense Air CO_2:**

SenseAir CO_2 is the instrument used to measure CO_2 concentration from ambient air. It has a sensor that detects the CO_2 concentration and displays it on the screen in digits. It had a range of 0ppm to 6000 ppm. It needs to be calibrated once in a while. It was set at the outlet of prototype to measure the CO_2 concentrations after every 30 seconds. Concentration of CO_2 before treatment was also measured by CO_2 meter. It also displays the temperature.

Figure 3.2: SenseAir CO_2.

- **Air Pump:**

An air pump which had a capacity of 70 L/min was used for the CO_2 removal in order to maintain the flow rate of air at 10 L/min. It sucked the air from ambient air in room and delivered it to the set where CO_2 would be treated afterwards. Its end is pipe is connected to a pipe of 1.5 inch which was further divided into 6 pipes having a diameter of 0.25 inch each. These pipes ended in the solution used where they deliver the air to solution. 10 l/min of flow rate is maintained at every pipe.

- **Absorption Chamber:**

A rectangular chamber containing the absorbent used for scrubbing the Carbon Dioxide, collected from ambient air. The reaction occurs here and Na_2CO_3 settles down.

The dimensions of the Absorption chamber are to be set as follows:

- Length: 1 ft
- Width: 0.5 ft
- Height: 1.5 ft

- **Triangular outlet:**

A triangular outlet has been provided on the top of absorption chamber. The outlet has a length of 1 ft at the bottom while a width of 6 inches. The shape and diameter of the outlet have been chosen meticulously, keeping in view the important factors of providing sufficient velocity and pressure drop for exit of clean treated air. Also, the outlet has been designed on the top of the absorption chamber, and not on its sides to eliminate any chances of entrance of solution into the outlet and hence wastage of solution. Addition of a pipe to the outlet further prevents chances of escape of solution from the absorption chamber, thus improving the design.

- **Pipes entering the solution:**

The pipes used are made of rigid and flexible polyvinylchloride (PVC). A bigger pipe having a diameter of 1.5 inch made of rigid PVC was further divided into 6 smaller diameter pipes made of flexible PVC having diameter of 0.25 diameter each at different lengths.

Pipe 1: 0.1 ft

Pipe 2: 0.2 ft

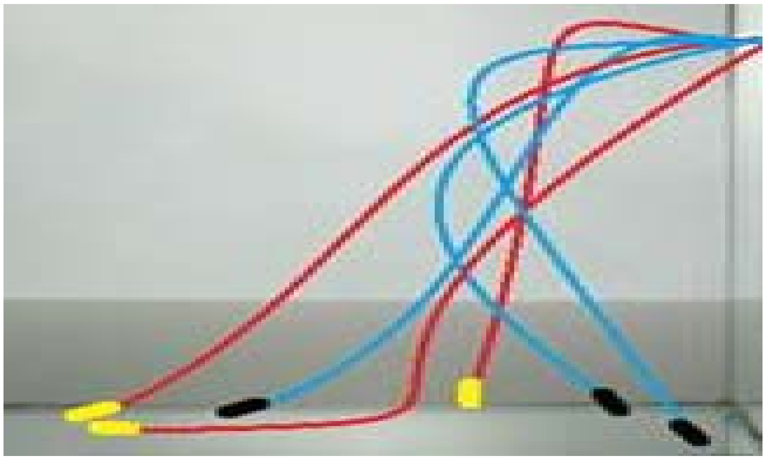
Pipe 3: 0.3 ft

Pipe 4: 0.4 ft

Pipe 5: 0.5 ft

Pipe 6: 0.6 ft

Figure 3.3: pipes at different lengths



Ductility of pipes allows the pipe to be bent at varying depths within the solution so that it gets mixing uniformly within the solution and to promote efficient carbon dioxide absorption. Also, bending the pipes into the solution minimizes chances of liquid entrance into the pipes. In our design, length of the three pipes is as follows;

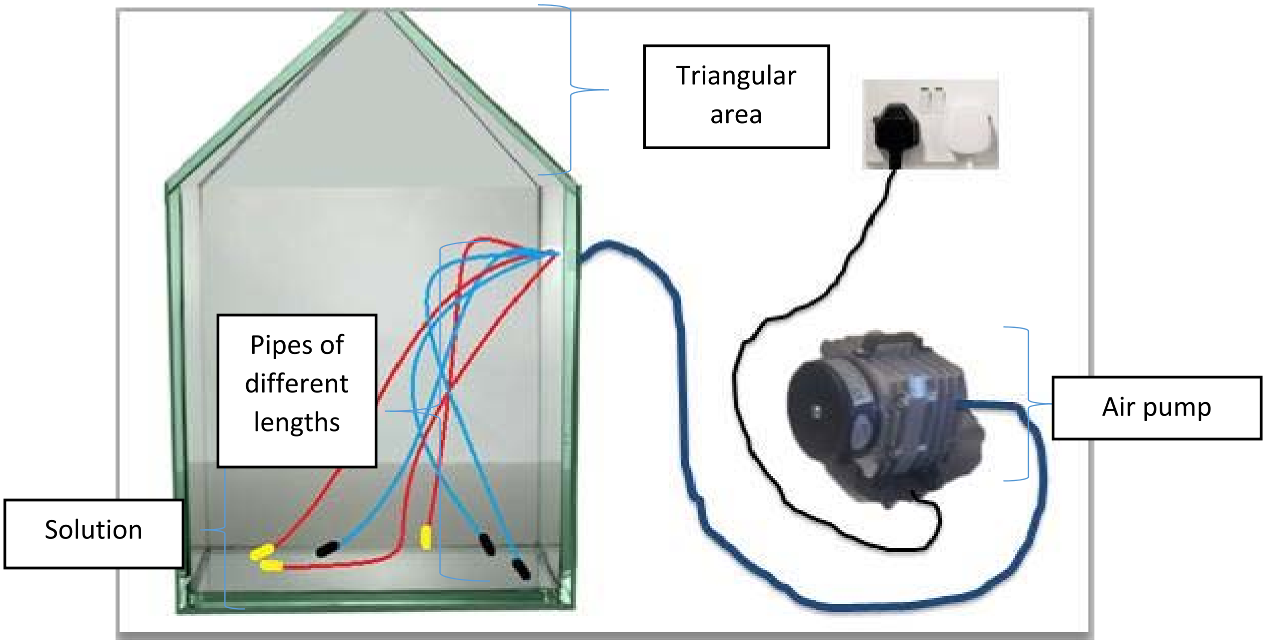


Figure 3.4: Experimental setup and its components.

3.7 Precautions:

The CO_2 meter attached to our lab-scale prototype needed to be checked continuously to make sure that it does not accumulate water vapor within it, as any kind of liquid in the flow meter will stop its working and damage the expensive instrument, in case of liquid accumulation beyond a certain level. A conical outlet has been provided on the top of our final prototype design for the exit of clean exhaust to prevent accumulation of clean air in the setup. We performed experiments in intervals to give the pump a rest, as it can burn out when it get very hot. Moreover, backflow of air was prevented by keeping the level of bigger pipe higher. Ventilation was kept minimum and fans were switched off to get better results.

RESULTS AND DISCUSSIONS

The results obtained were from the testing, carried out on the lab-scale prototype, as well as from the final design (CO_2-Bin) using $Ca(OH)_2$ solution, NaOH solution, and distilled water. The sensor used was SenseAir CO_2 ranges between 0 to 6000 ppm.

After wide-ranging literature review and existing work from IESE, we selected two chemicals (NaOH and $Ca(OH)_2$) for the absorption of CO_2 from both ambient and indoor air .

Optimum flow rate was selected as 10 L/min (Gillani *et al.,* 2015) on the basis of previous experiments done at IESE by final year students.

Firstly, experiments were performed for 2 l solution of 0.2 M, 0.3 M and 0.5 M solutions of sodium hydroxide and distilled water. It was observed that 0.5 M solution removed higher amount of CO_2 and exhibited CO_2 absorptions for longer time period.

Experiments were also performed for 0.5 M calcium hydroxide, 0.5 M sodium hydroxide and distilled water with 5 litters. 0.5 M sodium hydroxide was observed to be most efficient and exhibited CO_2 absorptions for longer time period.

4.1 Phase 1: Checking for best absorbent:

4.1.1 Scenario 1: CO_2 Absorption with distilled water

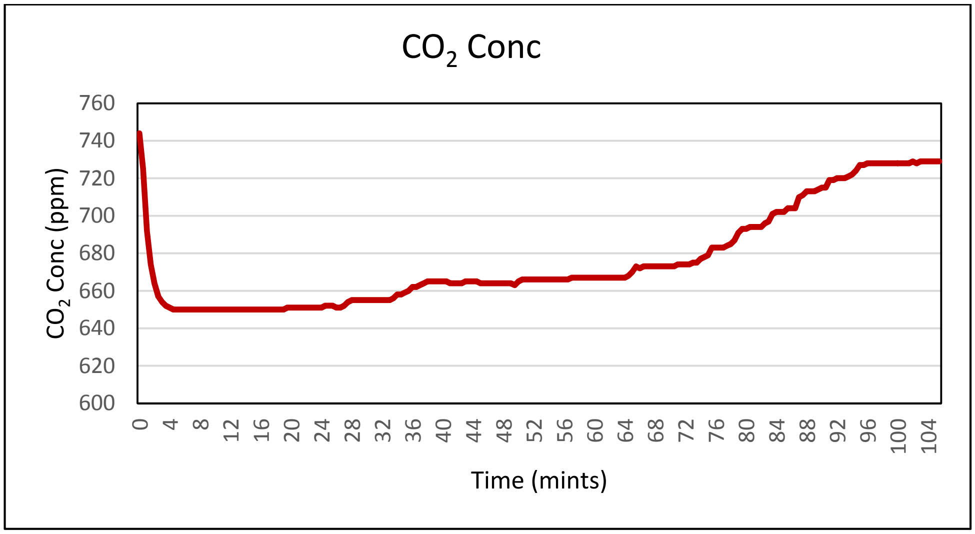


Figure 4.1: Graph of Percentage of CO_2 with Time using distilled Water

Efficiency graph of distilled water:

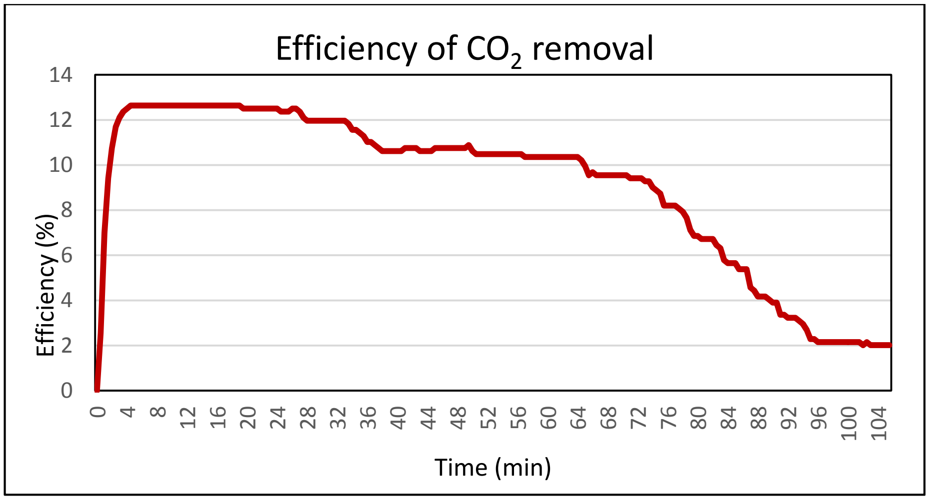


Figure 4.2: Graph of Efficiency of CO_2 removed with distilled water

It can be seen that distilled water has tendency of absorbing CO_2 and its maximum efficiency is 12.65%.

4.1.2 Scenario 2: CO_2 Absorption with 0.2 M NaOH with 2 L.

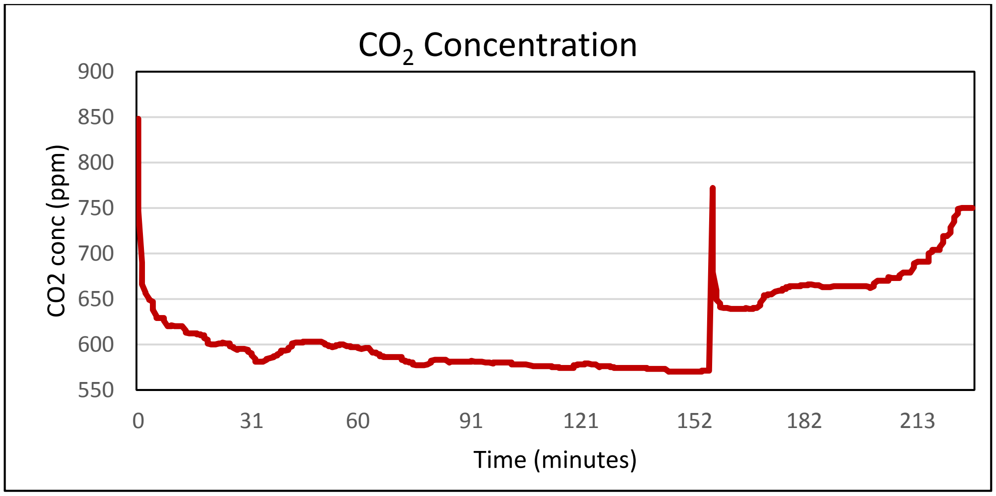


Figure 4.3: Graph of Percentage of CO_2 with Time using 0.2 M NaOH

Efficiency graph of 0.2 M NaOH:

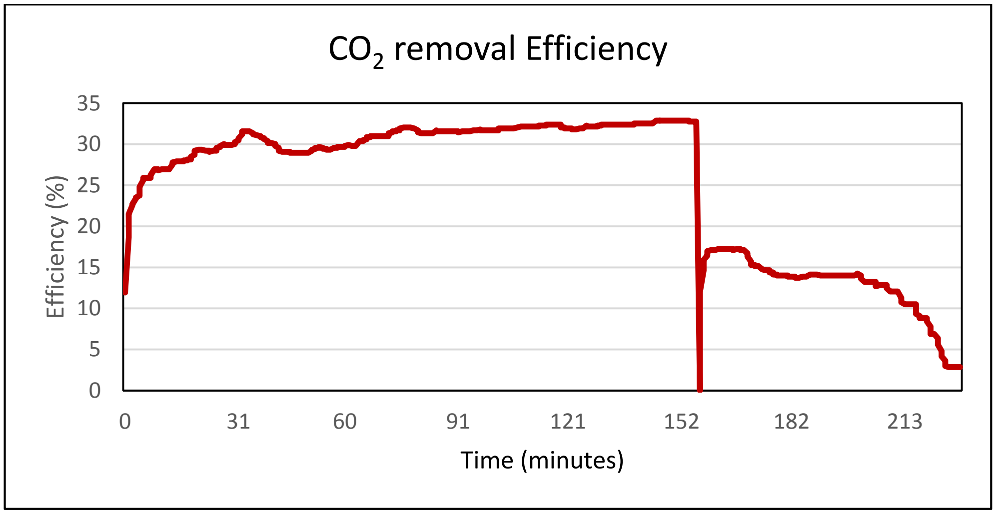


Figure 4.4: Graph of Efficiency of CO_2 removed with Time 0.2 M NaOH

Hence it can be observed from the above results that using 0.2 M NaOH solution, the percentage of CO_2 drops to a maximum of 570 ppm hence giving the maximum efficiency of 32.75%.

4.1.3 Scenario 3: CO_2 Absorption with 0.3 NaOH solution with 2 L.

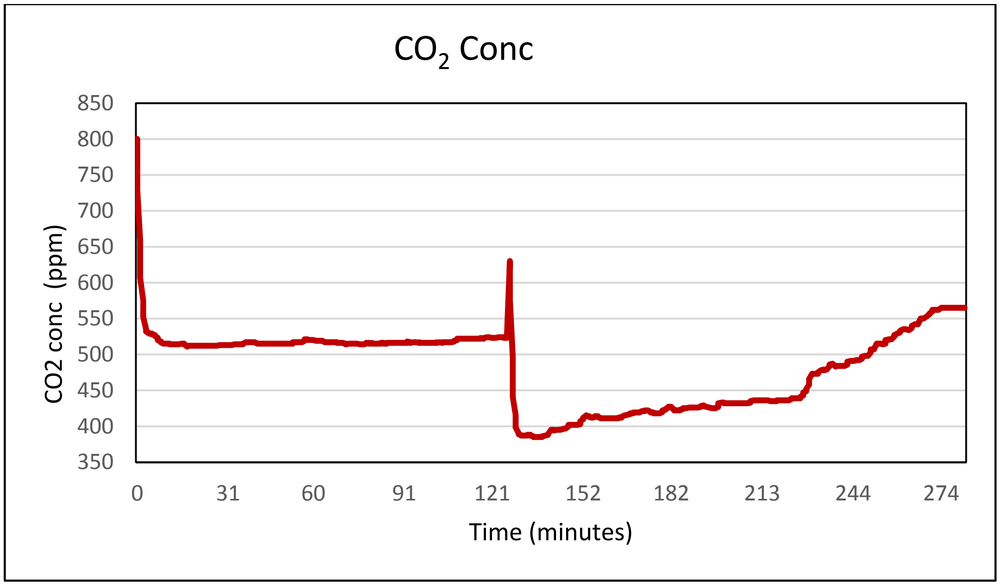


Figure 4.5: Graph of Percentage of CO_2 with Time using 0.3 M NaOH

Efficiency graph of 0.3 M NaOH:

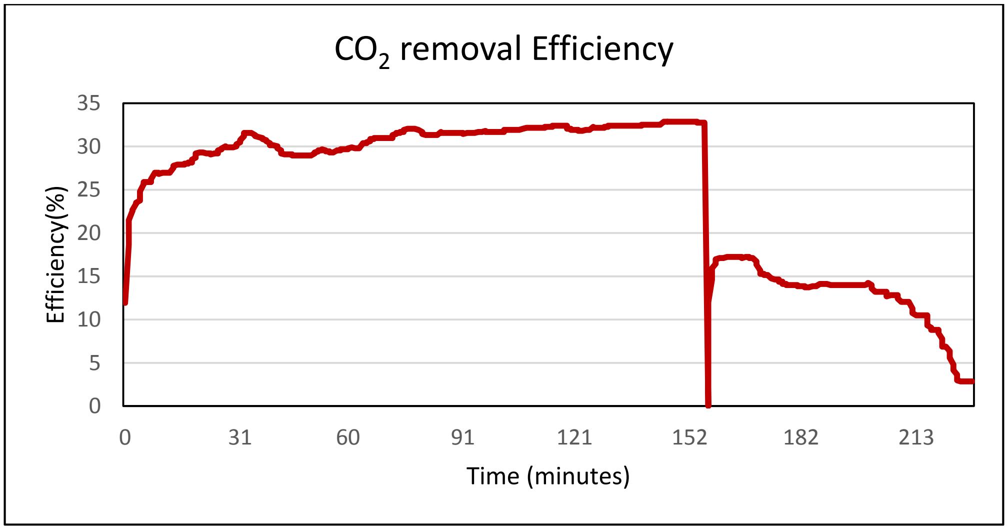


Figure 4.6: Graph of Efficiency of CO_2 removed with Time 0.3 M NaOH

It can be observed from the above results that using 0.3 M NaOH solution, the percentage of CO_2 drops to a maximum of 380 ppm hence giving the maximum efficiency of 38.88%.

4.1.4 Scenario 4: CO_2 Absorption with 0.5 M NaOH with 2 L.

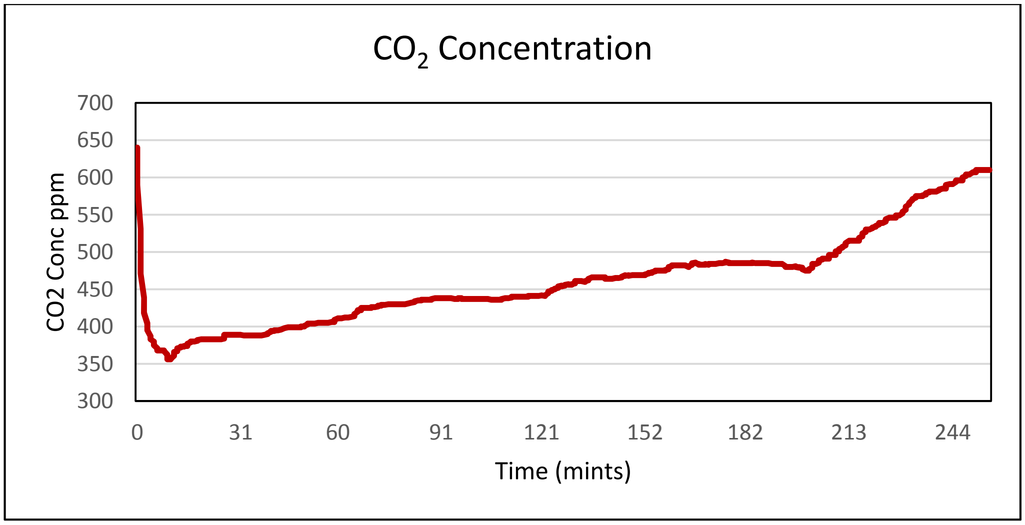


Figure 4.7: Graph of Percentage of CO_2 with Time using 0.5 M NaOH

Efficiency of 0.5 M NaOH

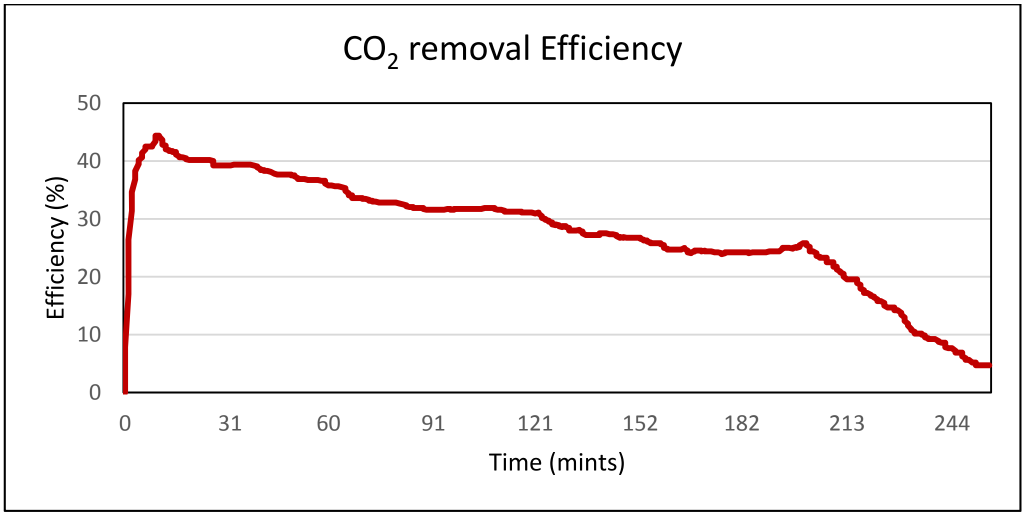


Figure 4.8: Graph of Efficiency of CO_2 removed with Time 0.5 M NaOH

Hence it can be observed from the above results that using 0.5 M NaOH solution with 2 L, maximum efficiency of 44.37%

4.1.5 Scenario 5: CO_2 Absorption with 0.5 M NaOH with 5 L.

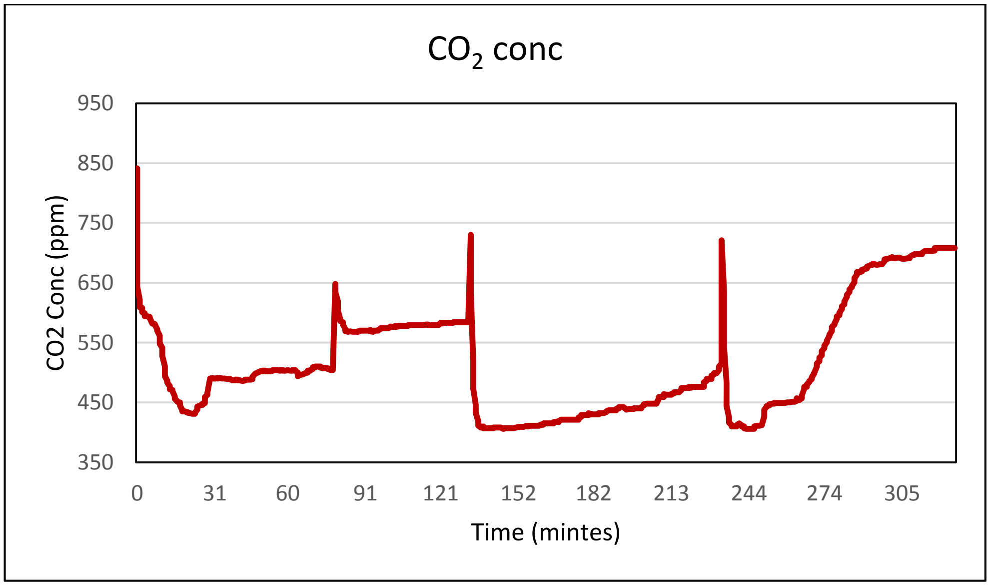


Figure 4.9: Graph of Percentage of CO_2 with Time using 0.5 M NaOH

Efficiency of 0.5 M with 5 l

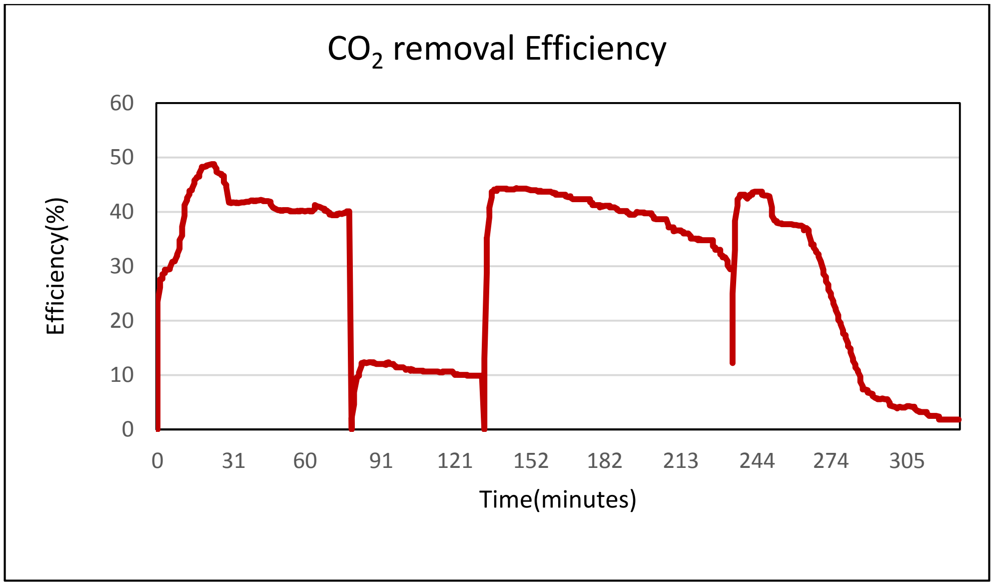


Figure 4.10: Graph of Efficiency of CO_2 removed with Time 0.5 M NaOH

Hence it can be observed from the above results that using 0.5 M NaOH solution, maximum efficiency of 48.75%

4.1.6 Scenario 6: CO_2 Absorption with 0.5 M $Ca(OH)_2$ with 5 L.

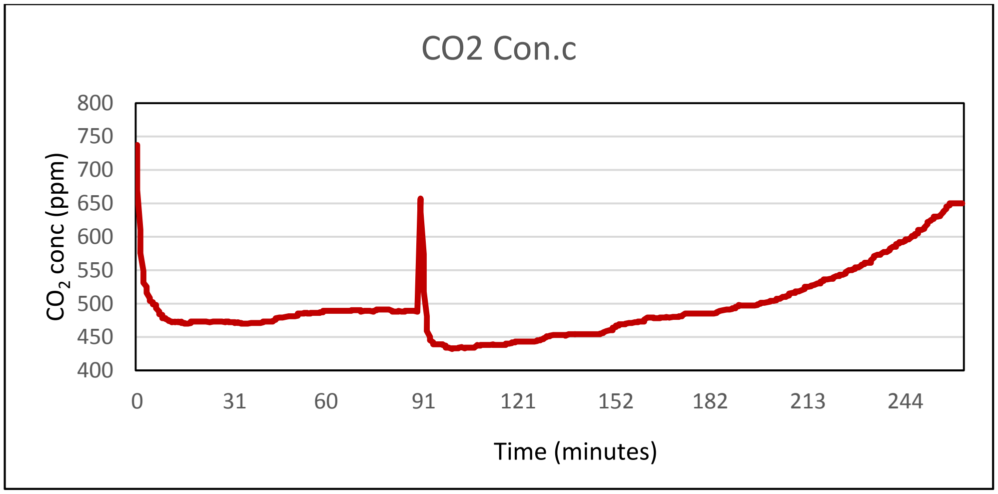


Figure 4.11: Graph of Percentage of CO_2 with Time using 0.5 M $Ca(OH)_2$

Efficiency of 0.5 M $Ca(OH)_2$:

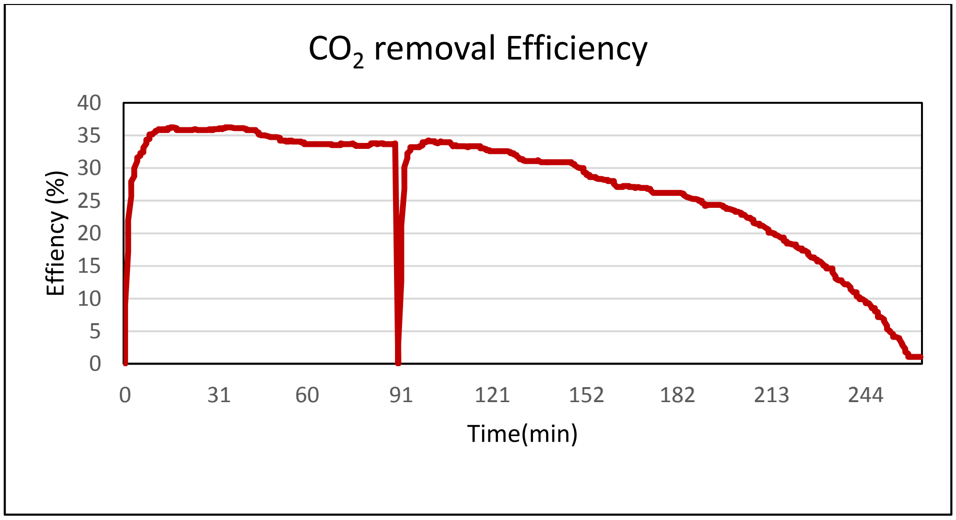


Figure 4.12: Graph of Efficiency of CO_2 removed with Time 0.5 M $Ca(OH)_2$

It can be observed from the above results that using 0.5 M $Ca(OH)_2$ solution, maximum efficiency of 36.2%.

4.2 Phase 2: Comparison between efficiencies of NaOH, $Ca(OH)_2$ and distilled water.

4.2.1: Comparison between different solutions

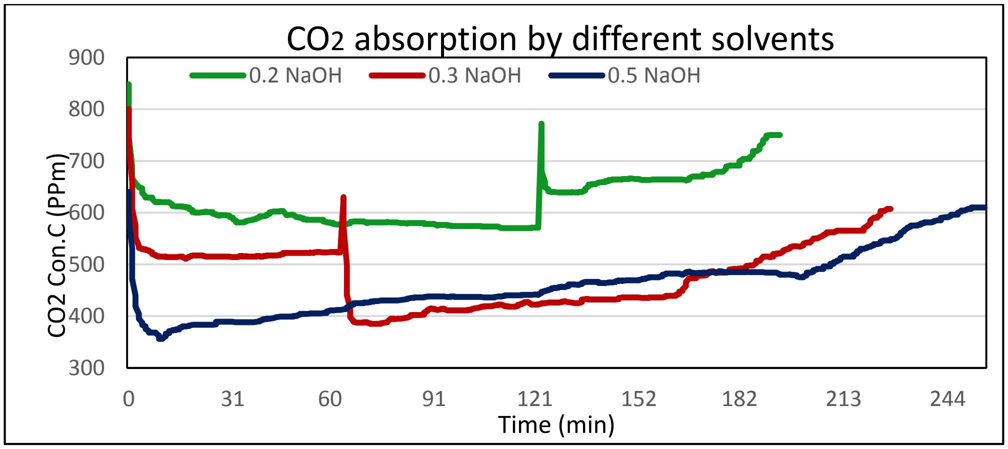


Figure 4.13: Graph of Percentage of CO_2 with Time using different molar solutions

4.2.2: Comparison between efficiencies of different molar solutions

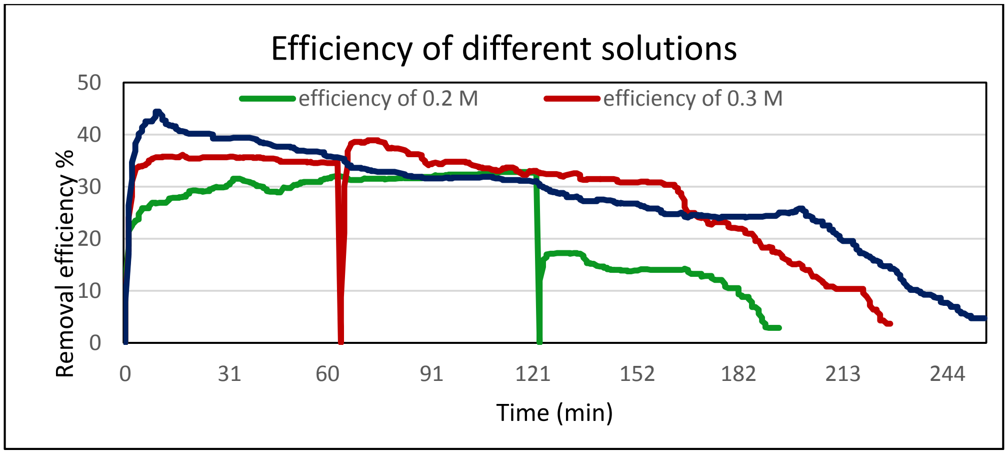


Figure 4.14: Graph of Efficiency of CO_2 removed with Time by different molar solution.

Hence it can be observed from the above results that using 0.5 M NaOH solution is more efficient as compare to 0.2 M and 0.3 M.i.e 48.75% maximum efficiency.

4.2.3 Comparison of different solutions (NaOH, Ca(OH)2 and distilled water)

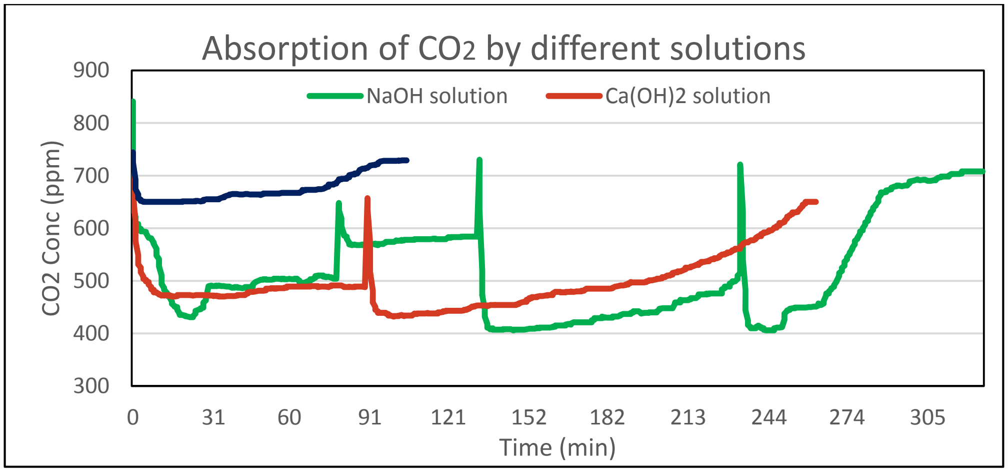


Figure 4.15: Graph of Percentage of CO_2 with Time using different solutions

4.2.4 Comparison of efficiencies of different solutions

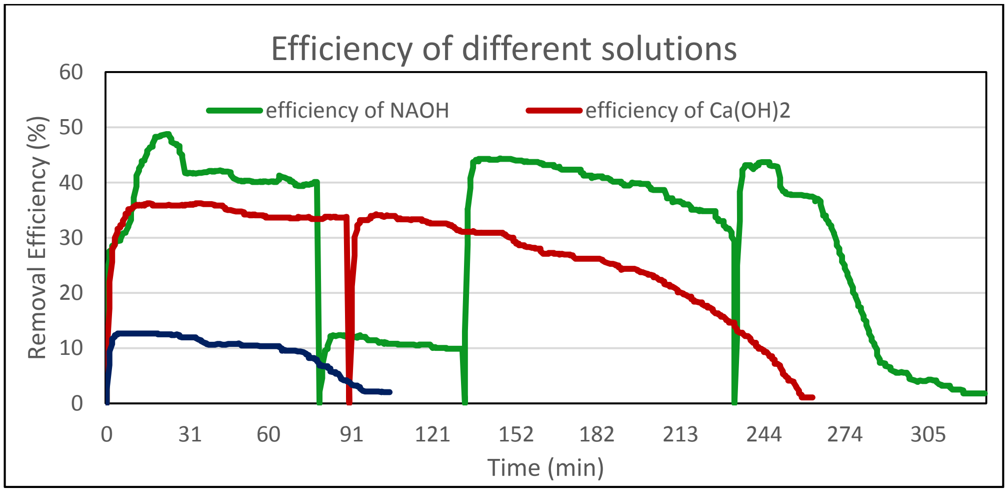


Figure 4.16: Graph of Efficiency of CO_2 removed with Time by different solutions

4.2.4: Best Absorbent Selection based on efficiency:

As depicted in the above results, the maximum efficiency of CO_2 removal is achieved when NaOH is used as an absorbent. NaOH absorbent gives us a maximum efficiency of 48.75% ..

Hence, in terms of efficiency of the solution, NaOH is selected as the best absorbent.

4.3 Phase 3: Calculating the Retention Time

After checking the efficiency of both the solutions, another extremely important parameter to be calculated is the Retention Time of the solutions used for absorption of CO_2 i.e. how long the solution will last. In order to calculate this time SenseAir CO_2 is used for the testing purpose. Subsequently, a graph of this CO_2 at a regular time interval is plotted to calculate the total time the solution takes to expire.

4.3.1: Retention Time of NaOH absorbent solution

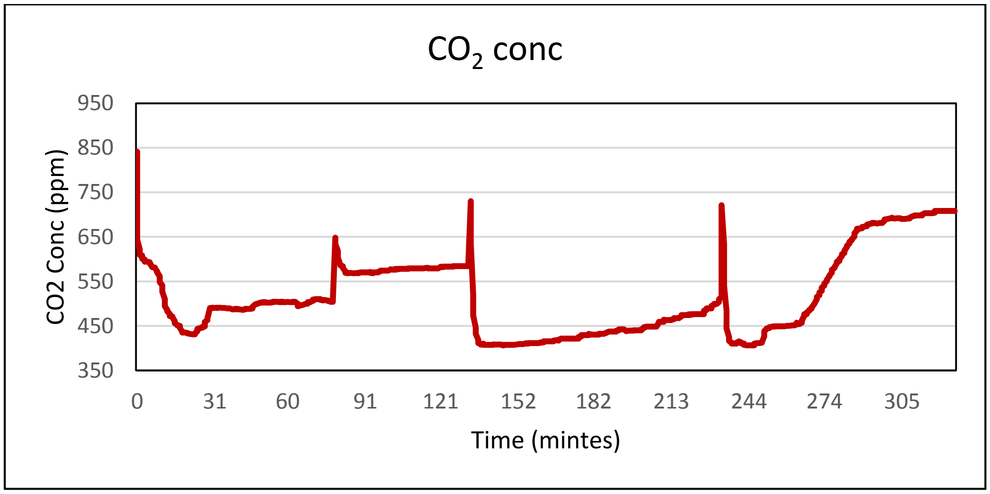


Figure 4.17: Graph of retention time of NaOH

The retention time of the NaOH absorbent solution was calculated to be 330 mins i.e. ~ 5 Hrs.and 30 minutes. This Retention time is subject to some set factors that are Flow rate equals 10 scfh (0.236 l/s) for a 0.5 molar solution of 5 L volume.

If the Molarity along with the volume of the solution is increased according to the design Parameters for a specific vehicle, the life of the solution will also increase respectively.

4.3.2. Retention Time of Ca $(OH)_2$ absorbent Solution

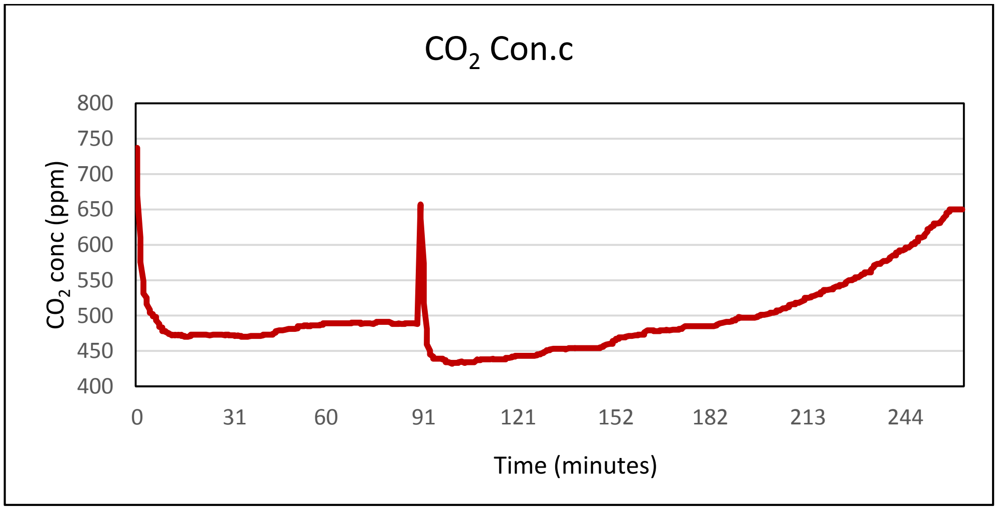


Figure 4.18: Graph of retention time of $Ca(OH)_2$

It is observed from the above graph, the retention time of $Ca(OH)_2$ absorbent solution is 263 minutes~ 4 hr and 23 mins

4.3.3: Selection of the best absorbent based on the Retention Time

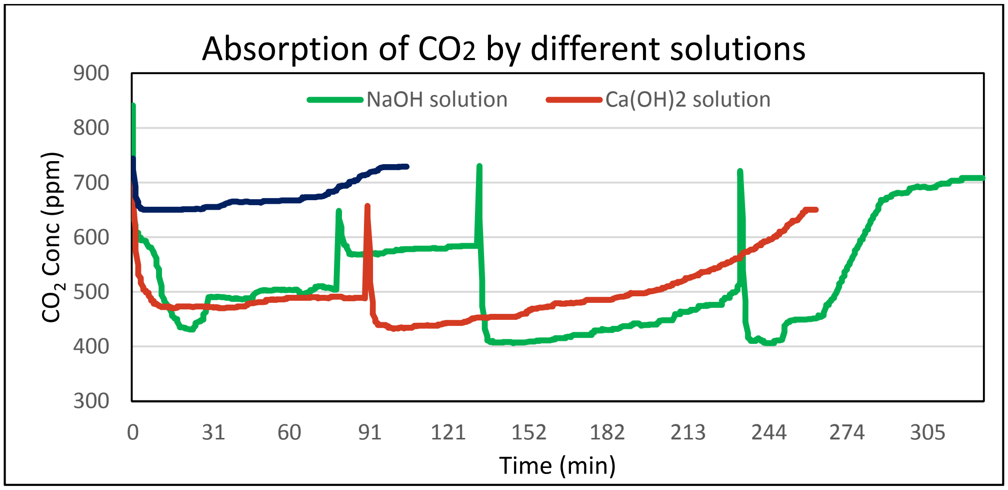


Figure 4.19 Selection of the best absorbent based on the Retention Time

It is concluded that NaOH is selected as the best absorbent as it has the longest Effective Retention time i.e. greater than 5 hrs. Table 4.1 shows the overall results:

Table 4.1: summary of results for different solutions.

Absorbents	Molarity (M)	Volume (Litters)	Max .Removal Efficiency %	Duration (minutes)
NaOH	0.5	5	48.75	330
	0.3	2	38.88	285
	0.2	2	32.74	230
$Ca(OH)_2$	0.5	5	36.2	263
Distilled Water	-	5	12.64	105

COST AND BENEFIT ANALYSIS

Cost of every component was analyzed before the final prototype. Following table 5.1 contains the cost and benefit analysis of absorbents used in this prototype filter with respect to maximum and average removal efficiencies and per kg price of absorbent material. Capital cost of this prototype design was about Pk. Rs.16000 and on commercial scale it can be further reduced by approximately 30 %.

Table 5.1: Cost-Benefit Analysis between different Absorbents.

Sr. No	Absorbent Used (5 L)	Removal Efficiency (%)	Cost	Life Calculated For 0.5 M solution)	cost/hr.
1.	Lab grade NaOH	48.75	1400 Rs per Kg	5.5 hours	Rs.25.45
3.	$Ca(OH)_2$	36.32	1400 Rs per Kg	4.38 hours	Rs.42.30
4.	Distilled Water	12.64	60 Rs per Liter	1.75 hours	Rs.171.40

Hence NaOH is the best absorbent selected on the basis of cost and benefit analysis as it’s cost is low and removal efficiency is highest amongst others.

CONCLUSION

After extensive literature review and experiments were performed for different solutions (e.g distilled water, NaOH and $Ca(OH)_2$) in order to explain CO2 absorption. The absorption efficiency was measured at different volumes and molarities for both solutions. The absorption efficiency appeared to decrease with the increase in the flow rate. Moreover, NaOH solution proved to be a better absorption solution than $Ca(OH)_2$ and distilled water based on its efficiency and cost and benefit analysis it proved to be a cheaper absorbent.

Therefore, optimal conditions were identified as 0.5 M solution of NaOH at a flow rate of 10 L/min is a better absorption solution as compared to a 0.5 M solution of $Ca(OH)_2$ at a flow rate of 10 L/min for the removal of CO_2 from indoor air

In addition to CO_2 removal from indoor air, it can also be used in outdoor locations like parking areas, industrial areas and traffic signals.

The prototype designed is easy to use and handle. Once the setup is run it does not need any extensive maintenance until the solution efficiency is diminished. Hence it is cost effective and efficient having an efficiency of 48%.

RECOMMENDATIONS AND FUTURE DIRECTIONS

- The instrument or the prototype can be made more efficient by lower pressure drop. Also by increasing the surface area of the reaction chamber.
- Increasing the concentration of solution by increasing its volume also increases its efficiency and retention time.
- A sensor must be designed to sense the expiry of the solution used.
- An indicator can be used to indicate that the device has been attached properly so that any local mechanic or layman can install the device in a room.
- The air pump used can be used using a solar panel as well in order to decrease the amount of electricity uses and make it environmental friendly.
- Copper pipes can be used instead of PVC pipes as they can be bent to any angle.
- It can be used in parking areas and traffic signal areas after further increasing its volume so that its residence time will increase.

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