Capturing carbon dioxide from air by using Sodium hydroxide (CO_2 Trapper)

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Abstract - *Carbon dioxide (CO_2) emissions have become one of the most serious issues and this environmental concern is being faced by our civilization today. These emissions are mainly generated from the combustion of coal, oil and natural gas which are the main energy resources in our daily life, economic growth and industrial development. It is widely considered a primary factor in global climate change. In addition, it adversely affects our earth. Switching from fossil fuel would take time and in mean time, emissions will grow to a factor that will take centuries for plants to absorb it. Therefore, we need a solution for this. A possible solution is to capture carbon directly from air same as plants do and store it. This paper presents a way to capture carbon from air by using NaOH. This paper also presents design, materials and cost analysis of prototype created for carbon capturing facility. Reactions and chemicals involved to do so along with experimental data of effectiveness of carbon capturing.*

***Key Words*: Air purifier, Carbon Scrubber, Carbon Capture, Direct Air Capture (DAC), Carbon Dioxide Trapper.**

1. INTRODUCTION

It is well known that CO_2 plays a dominating role in the greenhouse gases. Global climate change leads to the high interest in the technologies relevant to the CO_2 capturing that is one of the potential methods to reduce greenhouse gas emissions. Carbon dioxide (CO_2) emissions have become one of the most serious issues and environmental concerns facing our civilization today. At present even if we stop using fossil fuels or producing excess co_2, we still cannot revert to the present normal state of the earth so we need to remove the excess co_2 more rapidly than flora, as trees would require a long time to absorb the present excess carbon from the atmosphere. Trees also require large amount of cultivating land of the earth which could be used for productive purpose. Keeping in mind all the challenges faced by humanity this project would help overcome the important problem of global warming.

The amount of carbon dioxide (CO_2) in the atmosphere continues to rise and rather rapidly due to unparalleled cumulative CO_2 emissions, provoking the undesirable greenhouse gas effect. Certainly, it is becoming critical to develop economical and practical pathways to reduce the CO_2 emissions; and appropriately, prospective routes to address this enduring challenge are considered. (i) CO_2 emission reduction from post-combustion stationary and mobile sources where CO_2 concentration is in the range of 10–15% and (ii) CO_2 removal from air called direct air cap0ture (DAC), which is another alternative option to reduce greenhouse gases emissions in a uniform way globally. Although DAC is relatively more challenging than post-combustion capture, it is recognized that it might be practical, provided that suitable adsorbent combining optimum uptake, kinetics, and energetics and CO_2 selectivity is available at trace CO_2 concentration.

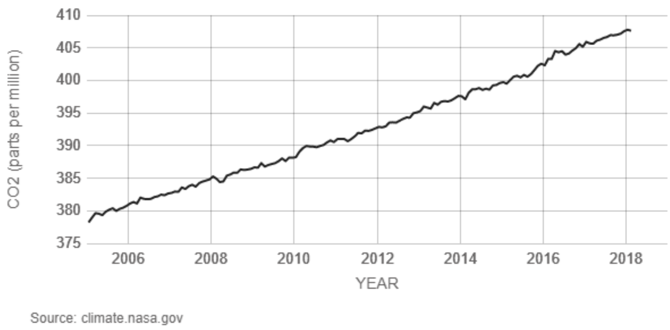

Figure 1: Carbon dioxide ppm level over the time

1.1 Literature Review

Several methods has been developed and used to capture carbon dioxide from high emission sources and store it in different conditions, some of the featured work that has been done is:

Carbon capture and storage (CCS) involves the separation and capture of CO_2 from flue gas, or syngas in the case of IGCC. CCS is a three-step process that includes:

1. LiOH absorption solution developed by NASA use same principle but different compound.

2. Capture of CO2 from electric generating units (or other industrial processes);

3. Compression and transport of the captured CO_2 (usually in pipelines);

4. Underground injection and geologic sequestration (also referred to as storage) of the CO_2 into deep underground rock formations. These formations are often a mile or more beneath the surface and consist of porous rock that holds the CO_2. Overlying these formations are impermeable, non-porous layers of rock that trap the CO_2 and prevent it from migrating upward.

Amine scrubbing:

The dominant application for CO_2 scrubbing is for removal of CO_2 from the exhaust of coal- and gas-fired power plants. Virtually the only technology being seriously evaluated involves the use of various amines, e.g. mono-ethanol-amine. Cold solutions of these organic compounds bind CO2, but the binding is reversed at higher temperatures:

$$CO2 + 2\ HOCH2CH2NH2 \leftrightarrow HOCH2CH2NH3+ + HOCH2CH2NHCO2-$$

As of 2009, this technology has only been lightly implemented because of capital costs of installing the facility and the operating costs of utilizing it.

The following subsections provide an overview of CO_2 capture technology, CO_2 compression, CO_2 pipeline infrastructure for transportation, geologic sequestration, and alternatives to geologic sequestration.

A. CO_2 Capture Technology In general, CO_2 capture technologies applicable to fossil-fuel fired power generation can be categorized into three approaches:

• Post-combustion systems are designed to separate CO_2 from the flue gas produced by fossil-fuel combustion in air.
• Pre-combustion systems are designed to separate CO_2 and H_2 in the high-pressure syngas produced at IGCC power plants
• Oxy-combustion uses high-purity oxygen (O_2), rather than air, to combust coal and therefore produces a highly concentrated CO_2 stream.

Source: Literature Survey of Carbon Capture Technology - Environmental Protection Agency (EPA)

Related work:

1. Gary T. Rochelle (2009). "Amine Scrubbing for CO2 Capture".
2. Li, Jian-Rong (2011). "Carbon dioxide capture-related gas adsorption and separation in metal-organic frameworks"
3. F. S. Zeman; K. S. Lackner (2004). "Capturing carbon dioxide directly from the atmosphere"

2. Experiment

Principle of operation

CO2 trapper works on the principle of alkali bases capacity to absorb carbon dioxide and convert it into carbonate.
Reaction of the alkali bases with carbon dioxide:

When the alkali solution is a fairly concentrated one (pH>10), carbon dioxide directly reacts with it to form the bicarbonate, which further reacts with the alkali to form sodium carbonate (Na2CO3) as the main product by complete neutralization.

$$NaOH + CO2 \rightarrow NaHCO3$$
$$NaOH + NaHCO3 \rightarrow Na2CO3$$

Complete Reaction involved and its intermediate states:

1. Carbon dioxide and water react to make carbonic acid.
$$CO2(aq) + H2O(l) \rightarrow H2CO3(aq)$$
2. Carbonic acid reacts with hydroxide ions to make bicarbonate ions.

$$H2CO3(aq) + NaOH(aq) \rightarrow NaHCO3(aq) + H2O(l)$$

Reaction in aqueous solution:

$$CO2(aq) + Na+(aq) + OH-(aq) \longrightarrow Na+(aq) + HCO3-(aq)$$

Now when carbon dioxide in the air had reacted to form sodium carbonate in the aqueous solution to obtain the absorbent solution (NaOH) back into the system, sodium carbonate is reacted with the calcium hydroxide to get NaOH solution back by the following equation:

$$Na2CO3(aq) + Ca(OH)2(s) \rightarrow 2NaOH(aq) + CaCO3(s)$$

Setup:

We will be using different percentage of NaOH solution for our testing with the prototype made; 1%, 2%, 3% and 5% (w/w) NaOH solution in distilled water. Ambient air with average temperature of 30°C and normal percentage of carbon dioxide is used for the testing. Air flow inside the chamber is regulated with a voltage regulator connected with the fan. Solution is sprayed on custom-made filtration structure made to maximize absorption at lowest possible energy input. Nozzles used are made of brass and named “Mist Nozzle”; solution is supplied by using a pump placed outside the filtration box.

Dimensions:

Hull or Body: 750 x 300 x 750 (L.B.H mm)
Filter Structure: 500 x 300 x 550 (L.B.H mm)
Fan : 200mm Diameter (Voltage Regulated)
Nozzle : 0.5mm (5 holes)
Pump : 5-6 Kg hydraulic pressure (110 psi)

Prototype device of above dimensions is taken to run the test for absorption of CO_2.

1. Air is made to flow through the system by use of an fan which extract air out of the system continuously and speed of the fan can be regulated to increase or decrease the flow of air, this air first pass first layer of dry filters. These dry filters do not let dirt particles to enter the chamber and make only clean air to be processed.

2. Air then enters the chamber where custom-made NaOH filter is place. NaOH (aq) solution is sprayed from the top of the chamber; nozzles form mist of aqueous solution giving uniform spreading of solution over the filter. Filter is so designed so that, speed of air is reduced enough to give enough time for reaction to occur. The design of filter is such that air must pass aqueous solution layers of NaOH, hence improving reaction and surface area for better efficiency.

3. Passing from NaOH solution filter most of the carbon dioxide is absorbed and remaining air is exhausted out of the chamber via voltage-regulated fan.

4. After absorption of CO_2, solution becomes rich in Na_2CO3. This solution is taken to react with $Ca(OH)_2$ to form CaCO3 and NaOH, hence giving back the main working chemical (NaOH). CaCO3 being solid is easy to remove from the aqueous solution.

We used 3, 4, 5% (w/w) solution of NaOH with distilled water to conduct the experiment.

2.1 Components and Working

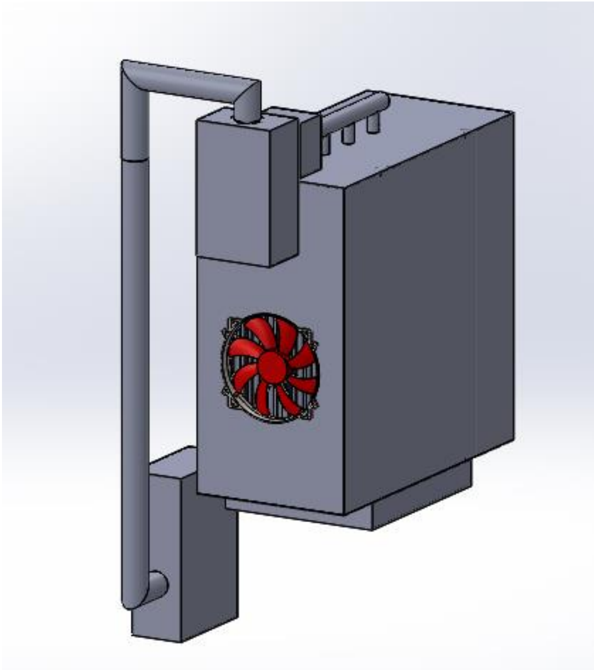

Figure 2: Main body

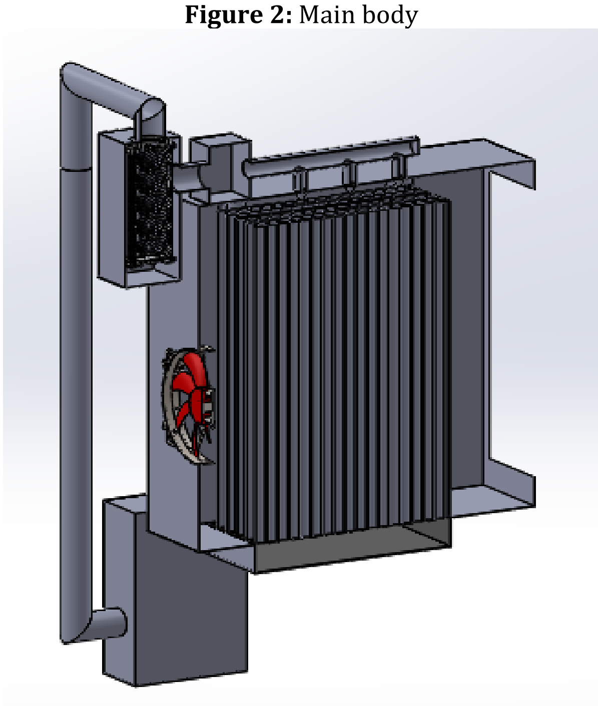

Figure 3: Main body cut section

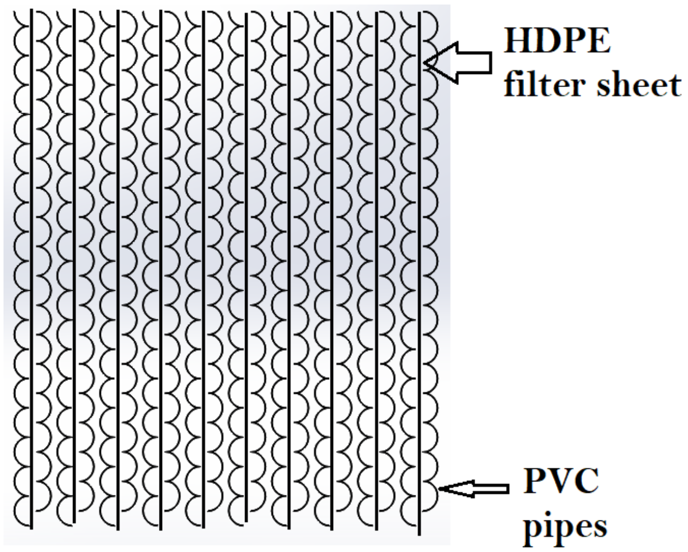

Figure 4: Carbon Dioxide filter (Top View)

Table -1: Key Points of the components

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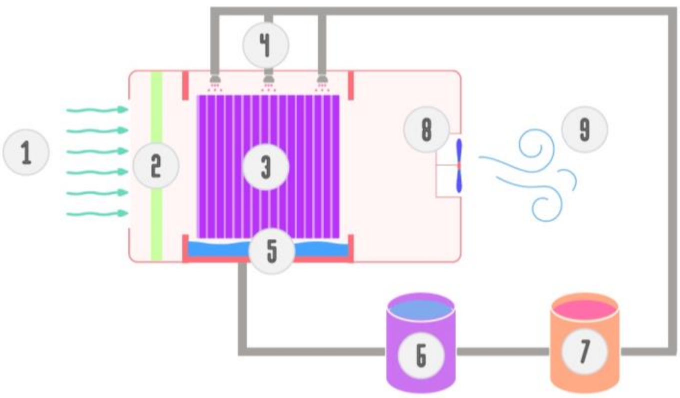
S. No	**Component**	**Feature**	**Material used**
1.	Main Body (Outer shell)	Water proof and High strength	G.I. (22 Gauge) (Painted inside with plastic paint)
2.	Dust Filter	Prevents dust from entering main reaction area	HDPE or PVC fine mesh filter
3.	Chemical Carbon Filter	Shape of structure slows down air speed and promotes reaction with NaOH for better absorption, Chemical safe material	PVC pipes and HDPE filter Sheets
4.	Nozzle (3 Units)	Misting nozzles spray solution all over the filter uniformly	Brass or PVC
5.	Connecting pipes	Transports the solution from one compartment to other	PVC or PU
6.	Sodium Carbonate drip storage	It collects the dripping solution from the filter and stores it until transported to other chamber	HDPE , PVC , PU
7.	Fan	Voltage regulated speed control	Plastic
8.	Chemical storage compartment	It stores both NaOH and Ca(OH)2, leak proof, high strength	HDPE, PVC, Polypropylene or Poly Urethane
9.	Pump	Circulates solution with high pressure for nozzles to work	–



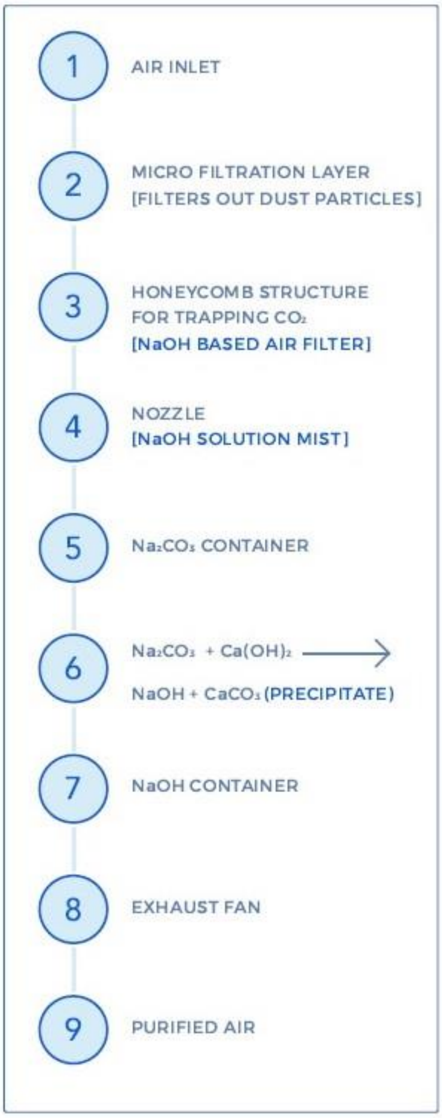


Figure 5: Working of prototype systematically

1. Ambient air enters through the dust filter (air temp – 30°C at 1atm); all the dust and macro impurity are filtered here
2. Now air moves to the chemical carbon filter where NaOH is spraying and structure is such made that air moves slowly while making contact with walls of NaOH solution and crosses HDPE filters many times which increase the chance of Carbon to be reacted with NaOH. In this process Carbon Dioxide from air get filtered out as it reacts with NaOH to form Na_2CO3 (Sodium carbonate) and makes air free from Carbon Dioxide.
3. This air free from Carbon exits out of the body via exhaust fan.
4. Sodium carbonate that is made is collected at the bottom of the carbon filter and taken to chemical storage area where Na_2CO3 is made to react with Calcium Hydroxide ($Ca(OH)_2$) to form NaOH which is again used in the reaction and Calcium Carbonate which is easy to separate out.
5. NaOH obtained is recirculate repeatedly to filter out Carbon Dioxide.

3. Results

These experiment results are obtained from 100% carbon dioxide gas fed to the reaction chamber just for testing the correct working of the project. The removal efficiency of CO_2 as a function of operating temperature is shown in Chart 1 with the inlet CO_2 concentration of 4%. As observed in the chart 1, with increasing the operating temperature, the reaction rate increases resulting in enhancement of the CO_2 removal efficiency. Chart 1 shows that the maximum removal efficiency of 63% is related to 100 °C with 3 wt. % of aqueous NaOH for the rate of 0.063 lit/s. Moreover, the sharp change in the green line shown in Chart 1 returns to the accuracy of the CO_2 analyser as well as higher reaction rate. In order to evaluate the influence of the absorbent concentration, two different aqueous solution of NaOH with the values of 3 and 1 wt. % is used and the results are depicted in Chart 2. As can be seen, increasing the absorbent concentration from 1 to 3 wt. % leads to an enhancement in removal efficiency due to providing higher driving force to the reaction. As the concentration of absorbent is increased, the rate of reaction will also be favoured due to providing higher concentration of the reactant.

These results are obtained from infrared CO_2 sensor, air was heated from a rapid air heater just for testing purposes. Source of this result is Reference [1]: "A novel rate of the reaction between NaOH with CO2 at low temperature in spray dryer" by Yadollah Tavan and Seyyed Hossein Hosseini.

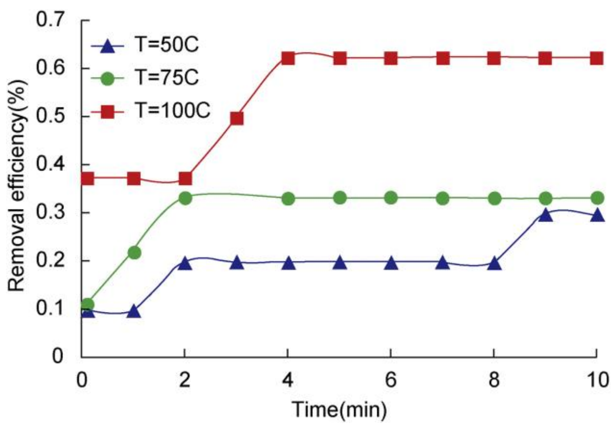


Chart 1: Plot for different temperature of air

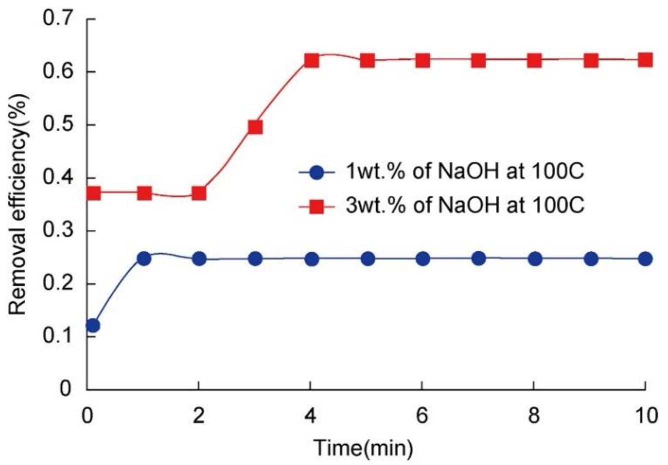


Chart 2: Plot for different concentration of NaOH

Cost Analysis

Cost analysis of components that are used in this system are as follows:

1. Initial cost of body : 12,000 to 16,000 rupees
2. Cost of chemicals : NaOH : 8200 rupees / Ton (One time) $Ca(OH)_2$: 4000 rupees / Ton *(Reoccurring Cost)
3. Cost of Energy: It consumes about 40W – 70W energy depending upon pump (This energy can be free if solar energy panel is used and results in no carbon emissions)

3. CONCLUSIONS

In practical application of the project ambient temperature of air would be around 30 – 40 °C considering weather conditions in India, ambient air also holds about 0.04% of carbon dioxide hence actual efficiency would certainly be lowered than ideal 100% carbon rich air. Conducting experiments along with the structure made by us actual efficiency of carbon removal varied between 30-60%. Carbon removal efficiency grows with increase in temperature and concentration of carbon dioxide in air passing through this filter hence it can be ideal to use in capturing carbon from carbon rich emission sources.

It is ideal for use in:

Power plant emission control Oil refinery and oil extraction emissions control Fossil fuel powered objects like automobiles, etc.

This can also be used for DAC Direct Air Capture, i.e. capturing carbon from ambient air itself.

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