An- Najah National University

Faculty of Engineering and Information Technology

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“Carbon dioxide Capture and Sequestration: Materials and Technology Potentials”

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الإهداء

بسم الله و الحمد و الشكر لله رب العالمين الذي بنعمته تتم الصالحات الحمدلله الذي بتوفيقه و تسهيل منه جل في علاه و بعد خمس سنوات حملت في طياتها الكثير من الصعوبات و المشقة و التعب ها نحن نقف و كلنا فخر بأنفسنا و بكم لنهدي هذه السنوات لكم و لكل من دعمونا و أثرو بنا بكلاماتهم .

نهدي هذا المشروع

الى أمي القلب الحنون من كانت وما زالت بجانبنا بكل المراحل... من تلذذت بالمعاناة و كانت شمعة تحترق لتنير دربنا .

الى أبي من علمنا أن نقف وكيف نبدأ الألف ميل بخطوة ، الى يدنا اليمنى ، الى من علمنا الصعود و عيناه تراقبنا.

الى من هم هدية من الرحمن أخوتي دليلي في الحياة و شمعة تنير دربي .

أصدقاؤنا و أحبتنا الذين أعانونا في مسيرتنا العلمية.

الى من لهم الفضل بارشادنا الى طريق العلم و المعرفة الى دكاترتنا الأفاضل الذين حملو أقدس رسالة من السماء كم نحن فخورون بكم.

الى جامعتنا بيتنا الثاني " جامعة النجاح الوطنية " التي قضينا فيها أجمل اللحظات .. وكليتنا التي نفتخر بها "كلية الهندسة وتكنولوجيا المعلومات" التي جمعتنا بمن يستحقون كل الشكر والتقدير .. لا ننسى الساحات والذكريات الجميلة.

وبهذا نكون أنهينا أجمل سنين العمر بحلوها و مرها ، بالأيام و الساعات و الدقائق التي أمضيناها معا... بجلساتنا الجميلة... بضحكاتنا المتتابعة

Abstract

The rise in the earth's surface temperature caused by global warming due to industrial development and human activities that have caused many gases to be emitted into the atmosphere, including carbon dioxide (CO_2); is a greenhouse gas. Several technologies have emerged that aim to convert CO_2 from its gaseous state into a solid-state. It is an effective way to protect the environment and reduce global warming. Returning it from solid-state to gas can also provide us with a new source of CO_2 at a relatively low cost. The technique of capturing CO_2 based on the interaction of carbon dioxide and water with sodium carbonate (Na_2CO_3) is inexpensive and does not cause environmental effects. The aim of this study was to test the efficiency of absorbing CO_2 using Na_2CO_3 and $Ca(OH)_2$. $Ca(OH)_2$ experiments were carried out at room temperature. The results were that with increasing time, CO_2 absorption increased by flow method. According to Na_2CO_3 experiments were carried out at temperatures 65^{o}C and 85^{o}C at different times (0.25, 0.5, 1, 2, 3) hours. The carbonation process begins at 60°C, that is, the Na_2CO_3 begins to convert into sodium bicarbonate ($NaHCO_3$). The results showed that absorption of the substance at a temperature of 65°C was more efficient than 85°C especially at the beginning (at 0.25 hours). Also, absorption was high initially then decreases with increasing time over the same temperature. Moreover, the weight loss was greater at 85°C; increased absorption of CO_2 was observed when increasing the amount of water. A problem was encountered in leaking CO_2 during the experiments, which led to the idea of developing a reaction system that guarantees higher efficiency and more accurate result in capturing CO_2.

Acknowledgment

While preparing this report and completing this project, we got help and guidance from some respectable people who deserve our deepest gratitude.

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We admit the appreciation of the engineering laboratory engineers, (Eng. Maha Fuqha) and (Mr. Yusuf Ratroot), who have permitted us to use the laboratory equipment needed to complete the work.

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Content

List of Figure

List of Tables

Chapter One: Introduction

Carbon management is the most affecting issue for the health and well-being of society over the coming years. Where human activities and increased consumption of fossil fuels contributed to the emission of gases in the atmosphere, mainly carbon dioxide (CO_2), which led to negative environmental impacts such as global warming and was considered a major environmental issue in the early twenty-first century. Therefore, the development of technologies that can capture carbon dioxide was of the utmost importance. One such technique is carbon dioxide capture and sequestration (CCS), where calcium hydroxide ($Ca(OH)_2$), sodium carbonate (Na_2CO_3), ammonia (NH_3), and Amine (RNH_2) could be used as a scavenger to capture CO_2.

Global warming increasingly thought to be associated with the atmospheric emission of greenhouse gases, principally CO_2. Annual CO_2 emissions in the year 2000 in the United States were about 5.9 billion metric tons, roughly equally divided between the transportation, commercial and residential, and industrial sectors. Initial efforts to limit CO_2 emissions will no doubt focus on large stationary sources, with fossil fuel-fired power plants' obvious prime targets. A number of new power generation concepts that may result in CO_2 control are being developed. These include O_2 combustion with CO_2 recycles, precombustion decarburization, and chemical looping combustion (Spigarelli et al., 2013).

This project aims to choose the most efficient material for absorbing carbon dioxide, and study the best conditions to achieve the best results, so after reading several types of research related to capturing and storing carbon dioxide, a set of materials was approved for experiments that include calcium hydroxide and sodium carbonate that was used in the first graduation project using the static and flow method at room temperature and the results showed increasing time increasing absorption, in the second graduation project, experiments were conducted on sodium carbonate using the static method at temperatures 65ºC and 85ºC at different times, and it was supposed to use ammonia and triethylamine in addition to making a membrane in order to capture carbon dioxide emitted from cars and chimneys but not implemented due to the spread of COVID 19 virus. Parallel to this, a more efficient response system has been improved and developed than the one used by SOLIDWORKS 2016 x64 Edition program (SOLIDWORKS, 2005).

This report consists of eleven main chapters, Chapter One introduces carbon dioxide Capture and Sequestration: materials and technology potentials and clarifies the problems that will tend to be solved. Chapter Two shows the main constraints and standards in this study. Chapter Three shows the previous researches and studies published on this subject and included a literature review of the topics related to carbon dioxide Capture, general information about it. Chapter Four includes a brief methodology of our work, summarizes what has been done, and includes experimental work. Chapter Five shows the results and discussion. Chapter Six shows recommendations. Chapter Seven is conclusion. Chapter Eight are references. Finally, Chapter Nine are appendices that contain pictures and samples of calculation.

Chapter Two: Constraints and limitations

There are many challenges encountered during the study and during the experimental work. It includes the following:

- Delay in receiving the necessary materials for experiments, especially chemicals.

-There was some difficulty in obtaining the research published on scientific sites.

-The laboratory manager's did not always match our free time.

-Delayed replacement of the carbon dioxide cylinder.

- The laboratory balance was inaccurate, as the sample reading was changing.

In addition, the outbreak of COVID 19 in the first days of March was one of the challenges that we have faced, which has halted experimental work in the Laboratories. We could not complete the experiments and achieve the desired goals. However, we were able to improve reaction system to be more efficient than the one being used in experiments by means of a SOLIDWORKS 2016 x64 Edition Program (SOLIDWORKS, 2005) that will reduce the leak problems in experiments and improve the measurement of reaction temperature inside the reactor.

Chapter Three: Literature Review

3.1 Carbon capture and storage (CCS) technologies

CCS technologies are the mitigation measures aiming to reduce CO_2 emissions from energy and other energy-intensive sectors (e.g. cement metallurgy, petrochemical, etc.). CCS applied to a modern conventional power plant could reduce CO_2 emissions to the atmosphere by approximately 80–90 % compared to a plant without CCS, as apparently in Figure 1. The first generation of CCS technologies, i.e. scrubbing with amines, is energy-intensive. Second and third-generation CCS technologies such as carbonate looping or chemical looping combustion have been proposed to reduce costs (Haaf et al., 2017).

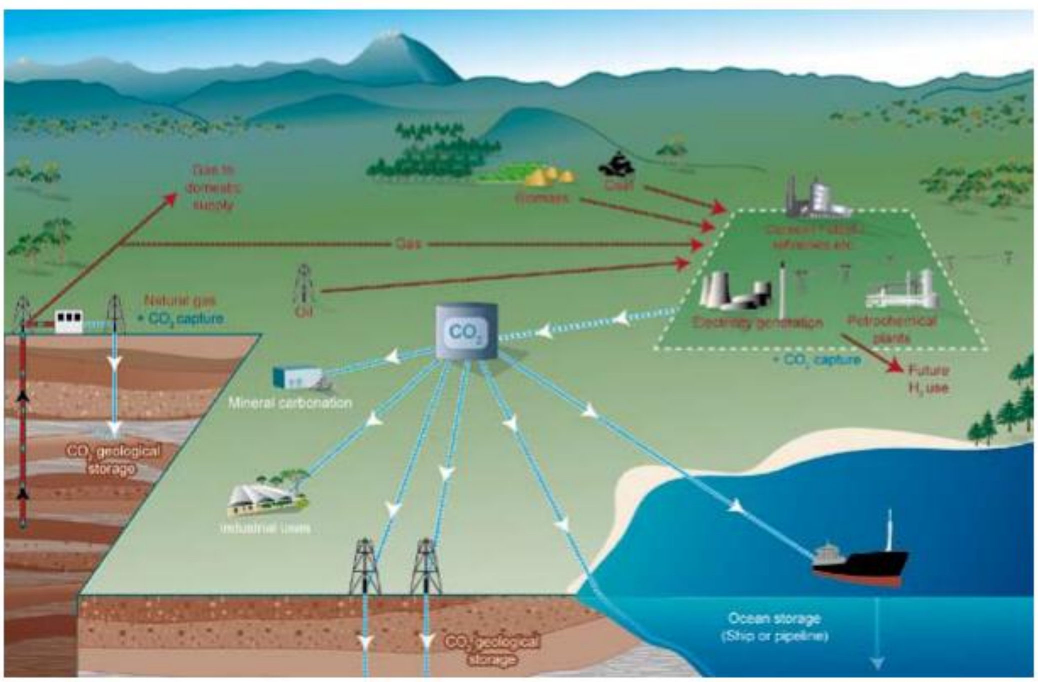

Figure 1: CCS technology aims to capture carbon (Carbon Capture and Storage Schematic diagram of potential CO_2 capture, storage and transport systems (Metz et al., 2005)

3.2 The characteristics of CCS

The capture of CO_2 can be applied to large point sources. The CO_2 would then be compressed and transported for storage in geological formations, in the ocean, in mineral carbonates, or for use in industrial processes. Available technology captures about 85–95% of the CO_2 processed in a capture plant (Metz et al., 2005).

A power plant equipped with a CCS system (with access to geological or ocean storage) would need roughly 10–40% more energy than a plant of equivalent output without CCS, of which most is for capture and compression. For secure storage, the net result is that a power plant with CCS could reduce CO_2 emissions to the atmosphere by approximately 80–90% compared to a plant without CCS, as shown in Figure 2 (Metz et al., 2005).

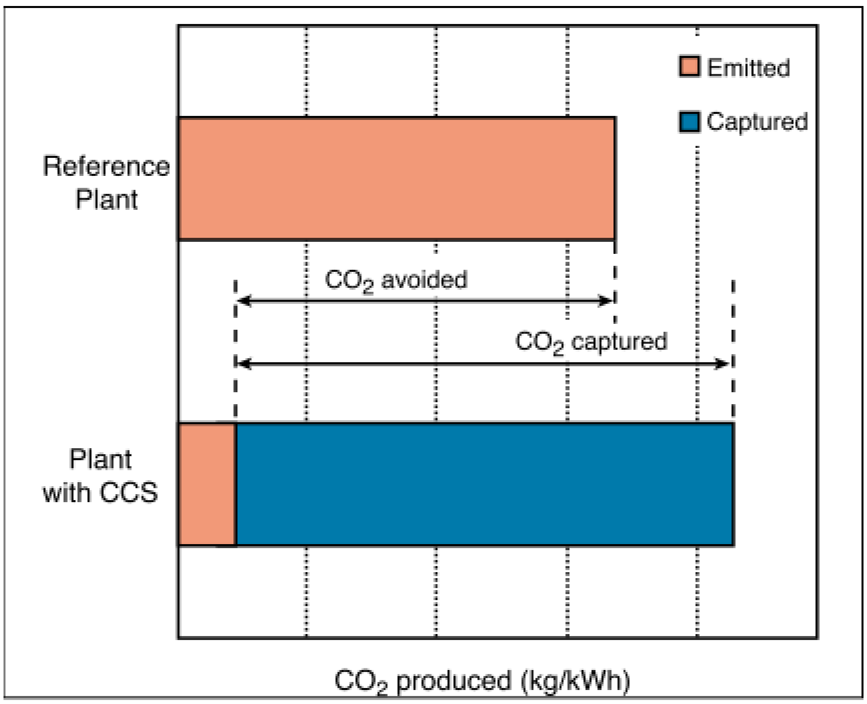

Figure 2 : CO_2 capture and storage from power plants (Metz et al., 2005).

3.3 Methods for carbon dioxide capture and sequestration

The process of transporting and storing carbon dioxide in long-term pools is called "carbon sequestration" which can be emitted or stored; it may be a natural process or process by humans. This strategy requires sequestrating CO_2 from human activities using safe and environmentally acceptable techniques and does not cause leakage risks as much as possible. There are many technological options for CO_2 sequestration, including abiotic and biotic. Biotic components are the living organisms present in an ecosystem, such as bacteria, fungi, plants and animals, and elements produced by them. The abiotic depends on physical and chemical reactions and engineering techniques and has received great attention from researchers, such as scrubbing, and mineral carbonation, geological injection and oceanic injection (Lal, R., 2008).

Free-flowing Hydrated Sodium Carbonate (Na_2CO_3) Powders (HSCPs) with 30 wt % of water can achieve a very high CO_2 sorption capacity within 60 min and fast CO_2 uptake (90% saturation uptake within 16 min). A series of HSCPs with different Na_2CO_3 contents were prepared by thoroughly mixing an appropriate amount of Na_2CO_3 and deionized water at room temperature (Cai et al., 2018).

Magnesium hydroxide carbonation was established at a high concentration of CO_2. Many methods used to analyze carbonation reactions such as x-ray diffraction. $MgCO_3$ precipitate as a thin layer. At 0.76 atm CO_2, the reaction rate of carbonation increased up to 375^{o}C and decrease at high temperature because of the thermal stability which decomposes to $MgO + CO_2$ (Béarat et al, 2004).

Carbonation of olivine minerals are a choice for sequestration because of their low cost (4_5 $ / ton).

$$2Mg_2SiO_4 + CO_2 \longrightarrow MgCO_3 + 2SiO_2$$

During the reaction, the layer of SiO_2 achieved, CO_2 decomposition this layer and react with Mg^{+2} to form $MgCO_3$ studies clarify that aqueous solution carbonate is promising, 30_50% carbonation achieved if > 37 Mm olivine at 135 bar CO_2 and 185 C use in an hour with 1500 rpm stirring. (Mg.95 , Fe.o85) $2SiO_4$ determine using X- ray emissions and impurities were below 1% with aqueous 0.64 M $NaHCO_3$ + 1M NaCl (Béarat et al, 2006).

Technologies for carbon dioxide capture and sequestration are under development. So, there are various routes (Kolle, J. M. 2020, Stolaroff, 2006):

- Organic Carbon Production: Many organisms (flora and forest) naturally capture CO_2 through photosynthesis.
- Metal Carbonate production: Add materials such as $CaCO_3$, K_2CO_3, and Na_2CO_3.
- Capture with a regenerated Sorbent: Most likely, this would be coupled with deep geological sequestration of CO_2.
- Metal hydroxide Sorbents include sodium hydroxide (NaOH) or calcium hydroxide ($Ca(OH)_2$).
- Amine, Ammonium, Zeolite, polyethyleneimine and monoethanolamine.

Carbonate solutions have distinct properties (Spigarelli et al, 2013):

- ✓ Nonhazardous, nonvolatile, and non-fouling.
- ✓ Environmentally benign.
- ✓ No degradation in the presence of oxygen.
- ✓ Low equipment corrosion rate.
- ✓ Possible multi-pollutant control system (SO_x capture).
- ✓ Easy retrofit to current wet flue gas desulfurization units.

Monoethanolamine is being used in removing CO_2 from exhaust streams and is a subject inculcated for a period of about the last 80 years. The NH_3 absorption of CO_2 has proven experimentally to be more effective than amine-based absorption that is so far the most acceptable method. This method was shown to more effective than the amine-based process due to its several advantages (Bandyopadhyay, 2010):

i. Having higher loading capacity (mol CO_2 absorbed/mol of absorbent).

ii. Being free from corrosion problem.

iii. Being stable in the environment of the flue gas.

iv. Requiring lower liquid to gas flow ratio.

v. Having multi-pollutant capture capability—especially SO_2 and NO_x removal could be integrated with this process for CO_2 removal, thus eliminating the pretreatment of the flue gas in respect of these pollutants as is required for amine-based processes.

vi. Consuming much less energy for regenerating the solvent, if necessary; else, the process can be routed to yield valuable products like NH_4HCO_3, $(NH_4)_2SO_4$, or NH_4NO_3 that can be put into the soil as fertilizer.

vii. Being more economic than MEA as well a host of other amines.

viii. Being associated with ease of transportation of the NH_4HCO_3 produced as a white crystalline solid; similar to other solid products, it can be easily transported without any extra investment as is often required for ‘‘pipeline transportation of compressed CO_2.

Chapter Four: Methodology

4.1 Materials and supplies

4.1.1 Carbonation

CO_2 was obtained from high purity cylinder. H_2O was fed using syringe pump, the line was heated to ensure vaporization before gases mixing. Fixed-bed reactors have been used to study the capture of CO_2 from simulated flue gas using a regenerable Na_2CO_3 sorbent. CO_2 capture was effective in the temperature range of 60-70°C, while regeneration occurred in the range of 120-200°C, depending on the partial pressure of CO_2 in the regeneration gas (Liang et al., 2004).

4.2 Material and Equipment

There are many different materials that have the ability to absorb carbon dioxide, and these characteristics were adopted in selecting the materials used in this project, and the most important of these characteristics were: their availability, the solubility in water, the extent of danger to the environment and humans, and the possibility of volatilization and price. So the selected materials were: calcium hydroxide, sodium carbonate, ammonia and amine.

Many material and equipment were used to complete this project:

1. Calcium Hydroxide ($Ca(OH)_2$)

   Is used the carbonate anions can interact with the cations present in the water to form insoluble carbonates. For instance, if Ca^{2+} is present limestone, $CaCO_3$ is formed, according to the following reaction:

   $Ca(OH)_2 + CO_2 \Longleftrightarrow CaCO_3 + H_2O$

   As shown in Figure A1 in Appendices.

2. Sodium Carbonate (Na_2CO_3)

   Is used as source for carbonate ions to capture carbon dioxide (CO_2), according to the following reaction:

   $Na_2CO_3 + H_2O + CO_2 \Longleftrightarrow 2NaHCO_3$

   As shown in Figure A2 in Appendices.

3. Ammonia (NH_3)

   is used to absorb carbon dioxide and produces urea from the reaction and is used as a chemical fertilizer for plants, according to the following reaction:

   $2NH_3 + CO_2 \Longleftrightarrow CO(NH_2)_2 + H_2O$

   As shown in Figure A3 in Appendices.

4. Amine (RNH_2)

   is used in capturing carbon dioxide to produce the carbamate used as a cosmetic preservative and also used in medicine, according to the following reaction:

   $RNH_2 + CO_2 \Longleftrightarrow RNHCOO^- + H^+$

   As shown in Figure A4 in Appendices.

5. Reactor

   The used reactor consists of three parts: two cups (like the capsule) and the joint that connects the two cups, Teflon was used to wrap over the teeth of the two cups, and rubber lashes are placed at two sides of the joint to prevent leakage, The reactor was mounted to the vise and being surly tightened after putting the sample to prevent leakage using the pipe wrench. Table 1 shows the characteristics of the used reactor. As shown in Figure 3.

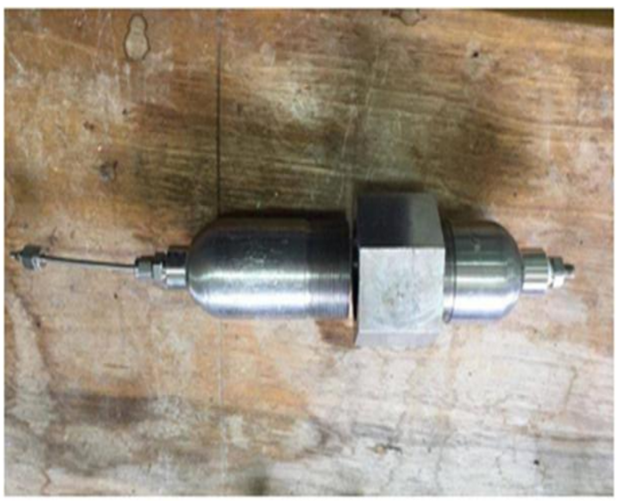

Figure 3 : Reactor.

Table 1: Describe the characteristics of the used reactor.

Reactor	
Alloy	316L SS
Length	8 inch (203 mm)
Diameter	1.9 inch (48.2 mm)
Thickness	0.24 inch (6.1)
Weight	3 lb (1.362 kg)
Internal Volume	150 ml
Pressure Rating	5000(344 bar)

6. Heating Jacket and thermocouple

A cover where the reactor will be placed inside, when switching it on, heat start rises and follows up changing in temperature using a thermocouple.

As shown in Figures A5, A6 in Appendices.

7. Ultrasonic Gas Leakage Detector

A device used to detect any leakage of CO_2 from the system. Its conception stands for using ultrasonic sensors to investigate all connection points.

As shown in Figure A7 in Appendices.

8. Tubes, Fittings and Valves

These supplements are used to complete the loop of the apparatus. The tube used between CO_2 cylinder and the reactor is on SS, 1/16”.

As shown in Figure A8 in Appendices.

This project was implemented in two interconnected stages, first the cleaning stage, second the preparation stage.

In the first stage, the tools were cleaned to avoid errors and the reactor and sample holder were cleaned by H_2O_2 to remove any corrosion layer. Then a plastic mesh was washed and other equipment with deionized water.

As for the second stage, the sample was prepared by weighting Na_2CO_3, water, mesh, and the sample holder, after loading this sample inside the sample holder, it was placed in the reactor, and then the reactor parts were collected and closed tightly. The reactor is placed inside the jacket and the desired temperature is seated by a thermocouple connected inside the jacket contact with the reactor. Then the temperature is calibrated and read. Carbon dioxide was allowed into the reactor through the valve at the bottom; the remaining carbon dioxide inside the reactor did not come out from the other side because it is closed. The sample was completed after a specified time and then placed inside the oven at a temperature ranging between (50-100°C) and left for 18 hours. Then it took out to cool down at room temperature and finally weighed.

4.3 Reaction Procedure for static method experiments

Sodium carbonate (Na_2CO_3) was weighed and put it inside in a sample holder. The cylinder was closed from one side using plastic mesh to prevent the substance exit from the cylinder, then was placed in the reactor, after that the reactor was assembled and sealed tightly. The reactor was installed in Figure A9 in Appendices. The reactor was placed inside the jacket and the desired temperature was sitting by a placed thermocouple inside the jacket contact with the reactor then the temperature was calibrated and was read, as shown in Figure4. CO_2 gas is allowed to enter the reactor through the valve at the bottom; remained CO_2 inside the reactor did not come out from the other side because it is closed. The sample was finished after a specific time and then was placed inside the oven at a temperature ranging between (50-100°C) and left for 18 hrs, then it took out and left to cool at room temperature and finally weighed.

Figure 4: Reaction system installation.

4.4 Measurements

Use the caliber by taking measurements of reactor, as shown in Table 1. The weight of sodium carbonate, calcium hydroxide, mesh and sample holder were taken in gram (g) by an electronic balance in the unit laboratory, as obvious in Figure 5.

Figure 5 : Electronic balance.

The amount of water was determined using a graduated cylinder and dropper in millimeters (ml), as shown in Figure 6.

Figure 6 : Graduated cylinder.

The temperature was measured using a thermocouple in ^{o}C and also a pressure using gauge pressure in psi.

4.5 Improvement reaction system

We have three reactors designed and manufactured by Dr. Hamdallah Bearat at Arizona State University and using two alloys 316L or 304L stainless steel (316L contains 16% chromium, 10% nickel and 2% molybdenum, 304L stainless steel contains 18% chromium and 8% nickel. the molybdenum is added to help resist corrosion).

The used reactor consists of three parts: two cups (like the capsule) and the joint that connects the two cups, Teflon is used to wrap over the teeth of the two cups, and rubber lashes are placed at two sides of the joint to prevent leakage, The reactor is mounted to the vise and being surly tightened after putting the sample to prevent leakage using the pipe wrench, despite all these steps was done to prevent leakage, they were not sufficient for this purpose. After that, the reactor was placed inside the jacket and the desired temperature was sat by a placed thermocouple inside the jacket attached to the reactor. However, it was difficult to install the thermocouple so wires were used in order to fix it but were not sufficient for this purpose. Because of these obstacles, we developed a reactor consist of two parts, one part of the reactor has thermocouple well, well's radius less than reactor thickness, one cup was manufactured connected to the joint (as one piece) but we used the Teflon and rubber lashes for the second cup in order to help us to easily take control over leakage. This reactor was designed using SOLIDWORKS 2016 x64 Edition program (SOLIDWORKS, 2005). As shown in Figures 7, (A10 and A11 in Appendices).

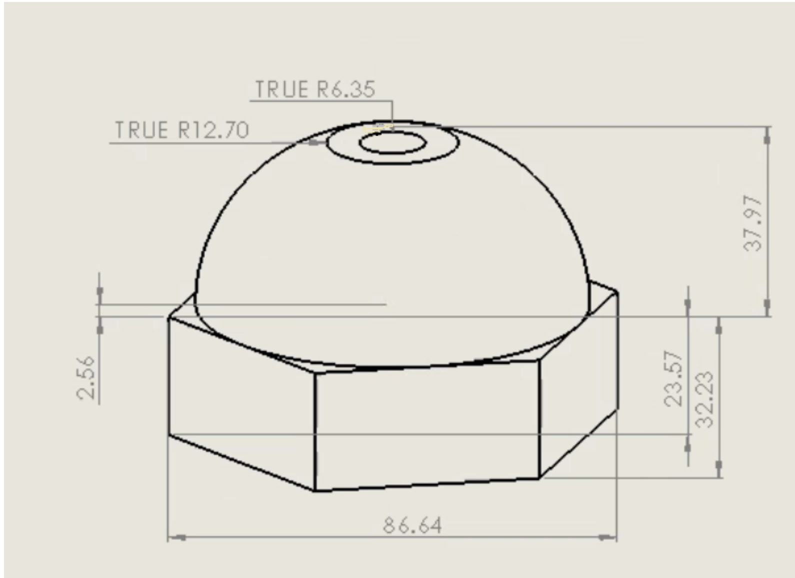

Figure 7: The dimension of reactor.

It was assumed that two reactors were obtained by cutting the closed cylinder shown in Figure 8 into two equal parts. Each part represents the lower cup of the reactor.

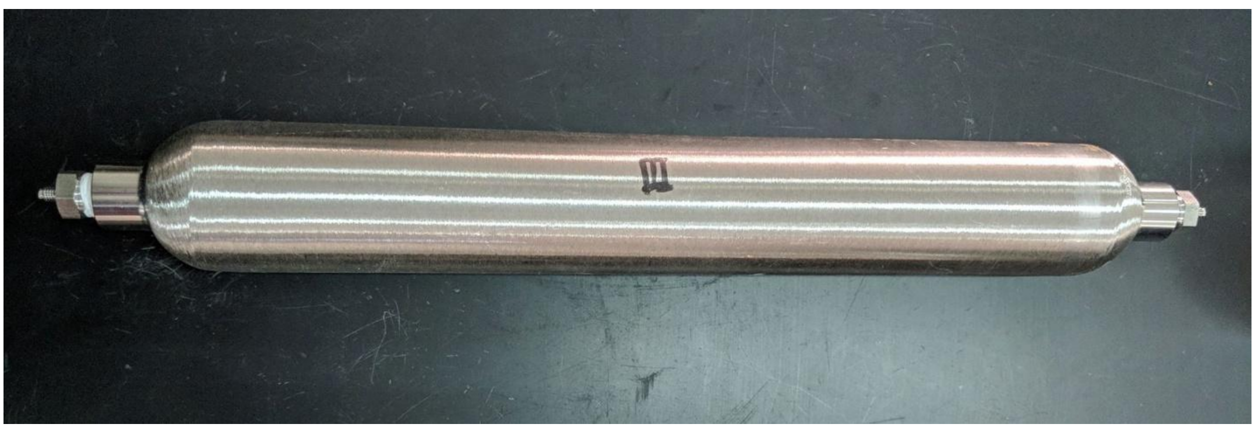

Figure 8 : Closed cylinder.

The two parts shown in Figure 9 represent the upper cup for which improvement has occurred.

Figure 9 : The piece used to make the top part.

Chapter Five: Results & Discussion

Note: the readings of temperature and pressure were taken using equipment from the unit lab, Material Science Department, College of Engineering and Information Technology, An-Najah National University.

5.1 Carbon dioxide capture using $Ca(OH)_2$

This experiment is about the reaction between calcium hydroxide with water and CO_2 to produce calcium carbonate, in order to know the efficiency of capturing CO_2, according to the following chain of reactions:

$$Ca(OH)_2 \Longleftrightarrow Ca^{+} + 2OH^{-}$$

$$CO_{2\,(g)} \Longleftrightarrow CO_{2\,(l)}$$

$$CO_{2\,(l)} + H_2O_{\,(l)} \Longleftrightarrow H_2CO_3$$

$$H_2CO_3 \Longleftrightarrow H^{+} + HCO_3^{-}$$

$$HCO_3^{-} \Longleftrightarrow H^{+} + CO_3^{--}$$

$$Ca^{+} + CO_3^{-} \Longleftrightarrow CaCO_3$$

$$Ca(OH)_2 + CO_2 \Longleftrightarrow CaCO_3 + H_2O$$

Table1 2: Theoretically obtained results.

	Molar mass (g/mol)	Number of moles	Mass (g)
$Ca(OH)_2$	74	0.1	7.4
CO_2	44	0.1	4.4
$CaCO_3$	100	0.1	10
H_2O	18	0.1	1.8

Table1 3: Describe the result of $Ca(OH)_2$ reaction.

Time	Mass before reaction (g)	Mass after reaction (dry) (g)	Mass gain (g)	Theoretical gain (g)	Extent of reaction %
1	18.4	20.7	2.3	4.4	52.2
2	18.4	21.1	2.7	4.4	61.3
3	18.4	21.4	3	4.4	68.1

The results of the first project showed that the absorption of carbon dioxide by calcium hydroxide increases with the increase in time using the flow method at room temperature.

Although $Ca(OH)_2$ aqueous solution can be effectively used as an absorbent to capture CO_2. The $Ca(OH)_2$ concentration in the solution strongly influenced the capture performance of the absorbent. The simultaneous $Ca(OH)_2$ dissolution and $CaCO_3$ production in the absorbent may have substantially hindered the combination of Ca^{2+} with CO_3^{2-} in suspension. Therefore, a higher $Ca(OH)_2$ concentration in suspension further reduced the CO_2 absorption capacity and produced substantially agglomerated $CaCO_3$ with low crystallinity (Han et al, 2011) .

5.2 Carbon dioxide capture using Na_2CO_3

This experiment is about the reaction between sodium carbonate with water and $CO_2$to produce Bicarbonate, in order to know the efficiency of capturing CO_2, according to the following chain of reactions:

$$Na_2CO_3 \Longleftrightarrow 2Na^+ + CO_3^-$$

$$CO_{2\,(g)} \Longleftrightarrow CO_{2\,(l)}$$

$$CO_{2\,(l)} + H_2O_{\,(l)} \Longleftrightarrow H_2CO_3$$

$$H_2CO_3 \Longleftrightarrow H^+ + HCO_3^-$$

$$Na^+ + HCO_3^- \Longleftrightarrow NaHCO_3$$

$$Na_2CO_{3(S)} + H_2O_{\,(L)} + CO_{2\,(g)} \Longleftrightarrow 2NaHCO_{3\,(S)} \qquad \Delta H_R° = -135 \text{ kJ/mol } Na_2CO_3$$

Table 4: Theoretically obtained results of Na_2CO_3.

	Molar mass (g/mol)	Number of moles	Mass (g)
Na_2CO_3	106	0.1	10.6
H_2O	18	0.1	1.8
CO_2	44	0.1	4.4
$NaHCO_3$	84	0.2	16.8

Experimentally, several experiments were carried out on temperatures 65ºC and 85ºC at different times**, under pressure = 710 psi.** And the results were as shown in Tables 5 and 6 bellow.

The results shown in Table 5 are obtained below and weight gain was initially observed, after which weight loss started gradually with increasing time. This indicates that most Na_2CO_3 was consumed within approximately 15 minutes (Cai et al., 2018).

Table 5: Describe the result of reaction at 65^oC.

Time (hr)	Mass before reaction (g)	Mass after reaction wet (g)	Mass after reaction dry (g)	Mass Gain (g)	Theoretical gain (g)	Extent of reaction %
0.25	10.62	17.30	14.93	4.31	6.2	69.00
0.5	10.61	17.40	13.86	3.36	6.2	54.00
1	10.6	15.04	13.72	3.12	6.2	50.30
2	10.61	17.18	13.86	3.12	6.2	50.30
3	10.6	16.72	13.43	2.83	6.2	45.64

Based on the results obtained in Table 6, the percentage of carbon dioxide absorption at 85°C was generally lower than the ratio at 65°C, but water was added to a sample of 0.5 hours and 2 hours, increasing from 6.3 to 4.70 g. An increase in the resulting mass was observed, which helped absorb carbon dioxide and reduce the effect of heat on the sample. The extra water on the surface helps create a basic alkaline water environment. When CO_2 spreads to the surface, it interacts with water and exothermic reaction (Cai et al., 2018).

Table 6: Describe the result of reaction at 85°C.

Time (hr)	Mass before reaction (g)	Mass after reaction wet (g)	Mass after reaction dry (g)	Mass Gain (g)	Theoretical gain (g)	Extent of reaction %
0.25	10.62	17.88	13.70	3.08	6.2	49.67
0.5	10.62	16.17	16.87	6.25	6.2	100
1	10.61	17.66	13.75	3.14	6.2	50.6
2	10.60	17.40	16.00	5.40	6.2	87.09
3	10.61	18.03	13.44	2.83	6.2	45.64

Several factors were observed to influence the reaction including the dissolving of Na_2CO_3 is partially dissolved in water, where the Na_2CO_3 particles are suspended and provide an excellent interface between the gas and the liquid to capture CO_2, which leads to an enhanced ability to absorb it (Liang et al., 2004). Generally, in these experiments, the amount of water added to Na_2CO_3 was 3.6g, except for 0.5 hours and 2 hours at a temperature of 85°C, the amount of water was increased to 4.70g. Also, the concentration of Na_2CO_3 has a significant influence of capture, means that at low Na_2CO_3 concentration (aqueous solution or slurry), it's not ideal for capturing because of low gas _ liquid contact surface area. That why some samples did not get good results (Cai et al., 2018).

Bicarbonate formation from carbon dioxide and Na_2CO_3 reaction with water has effective for capturing CO_2; however, the thermodynamics of this reaction is not well understood (Toan et al., 2019). The carbonation process begins at 60°C, that is, the Na_2CO_3 begins to convert into $NaHCO_3$. Whereas the researchers concluded that, at a temperature of 70°C and 80°C resulting mass decreases due to the formation of the Wegscheider's salt (Na_2CO_3,$3NaHCO_3$) that leads to a decrease in the resulting mass (Liang et al., 2004).

5.3 Carbon dioxide capture using ammonia and amines

Due to an outbreak of Covid-19 virus, we were unable to use these substances to know how well they would perform in capturing carbon dioxide.

Chapter Six: Conclusion

Capture and sequestration technology with a static reaction system holds a promising future, whether in the world of industry, the environment, or academic research. As the world suffers from the problem of global warming because of industrial progress, human activity and increased CO_2, which engineers and scientists are seeking to find a quick solution to. Several experiments and new materials have been discovered to contribute to the high absorption of $CO_2$from the atmosphere. According to our experiments the calcium hydroxide that was used in the first graduation project using a constant method and a flow at room temperature showed an increase in absorption over time, whereas for Na_2CO_3 the CO_2 absorption at 65°C was the best and most efficient. However, the increase in the amount of water added to some experiments at 85 degrees increased efficiency. During experiments, we encountered a problem with CO_2 leakage, which led to the idea of improving and developing a two-part reaction system. What makes this technique (CCS) useful is that it can be carried out using a simple process design like the design of the reaction static system we used, and by owning the proper tools, providing the appropriate conditions, and to specify more closely the parameters to study.

Chapter Seven: Recommendation

In the project, many challenges faced, therefore some recommendations for the next generations:

1. Providing the facilities, materials and equipment like flow meter to measure the amount of CO_2 inter to the reaction, which is necessary to complete the project.

2. Checking the accuracy of reading laboratory devices and providing more accurate devices.

3. As a futuristic step, designing and manufacturing a membrane that can absorb carbon dioxide beside manufacture the reaction system that was developed within this project and improved more if necessary.

4. Providing laboratories at all times so that students can complete their projects without obstacles.

5. Providing advanced devices for performing sample analyzes to know more accurate information such as X-ray diffraction.

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Chapter Nine: Appendices

9.1 Appendices A

Figure A 1: Calcium hydroxide.

Figure A 2: Sodium Carbonate.

Figure A 3: Ammonia.

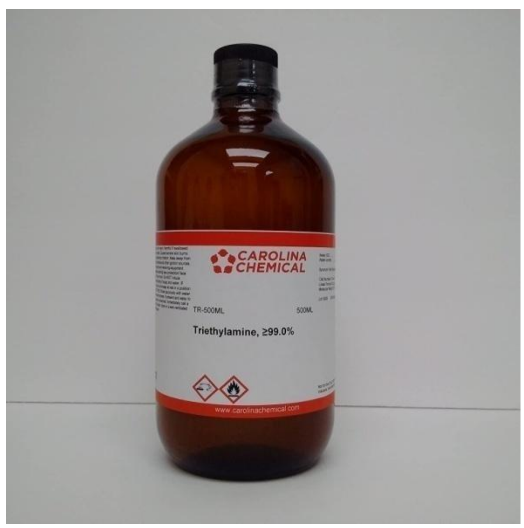

Figure A 4: Amine.

Figure A 5: Thermal Jacket.

Figure A6: Thermocouple.

Figure A 6: Gas detector.

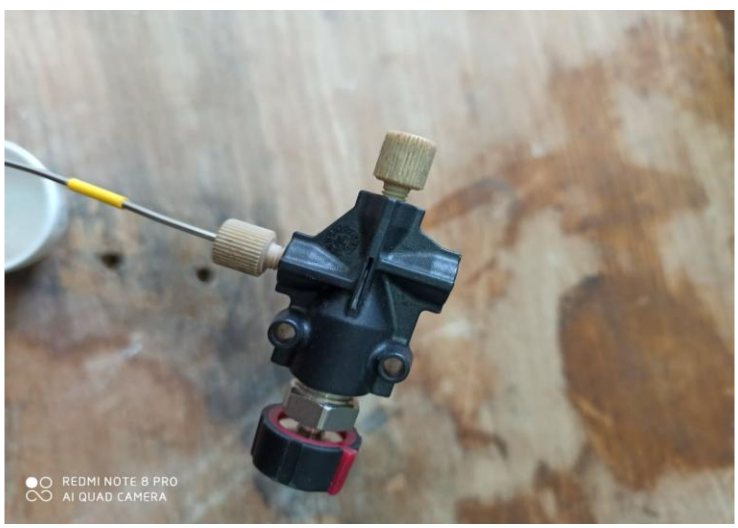

Figure A 7: Tubes and valve.

Figure A 8: Reaction installing.

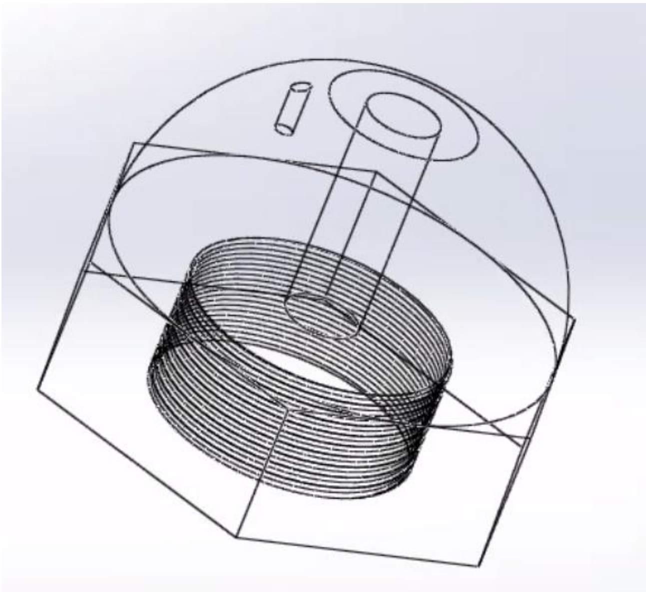

Figure A 9: Describe design of Reactor.

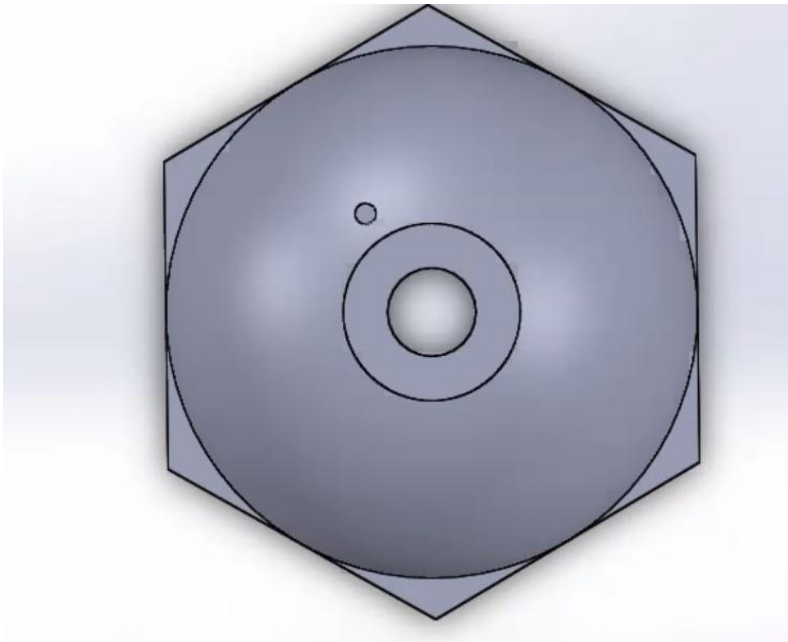

Figure A 10: Reactor design.

Figure A 11: Pipe wrench.

9.2 Appendices B

Sample of calculation for Table 2:

Number of moles = $\frac{mass}{\text{molar mass}}$

$$0.1 = \frac{mass}{74} \Longrightarrow \text{mass} = 7.4 \text{ g}$$

Sample of calculation for Table 3:

For 1 hr:

Mass gain = mass after reaction – mass before reaction

= 11.8 – 7.4 = 4.4 g

$$\text{Extent of reaction \%} = \frac{\Delta\text{m experemantal}}{\Delta\text{m theoretical}} \times 100\% = \frac{2.3}{4.4} \times 100\% = 52.2\%$$

Sample of calculation for Table 4:

Number of moles = $\frac{mass}{\text{molar mass}}$

$$0.1 = \frac{mass}{106} \Longrightarrow \text{mass} = 10.6 \text{ g}$$

Sample of calculation for Table 5 and 6:

For 0.25 hr in Table 5:

Mass gain = mass after reaction – mass before reaction

= 14.93 – 10.6 = 4.31 g

$$\text{Extent of reaction \%} = \frac{\Delta\text{m experemantal}}{\Delta\text{m theoretical}} \times 100\% = \frac{4.31}{6.2} \times 100\% = 69\%$$