Capture, React & Build (14211)

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Assiut STEM school – Grade 11 – semester 2

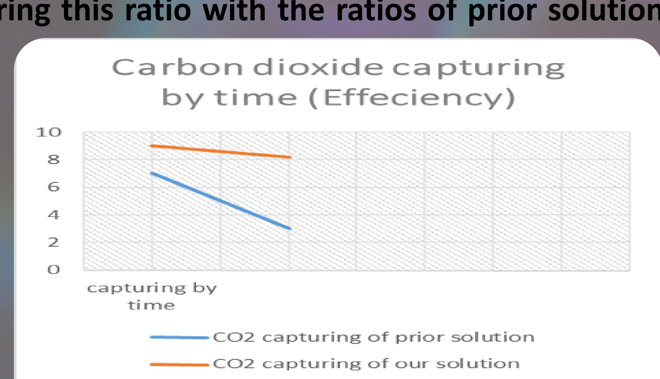
Keywords: calcium carbide residue, limestone, coral reefs and green house gases

Abstract

It is well known that the developing countries like Egypt face many challenges in order to keep up with the developed ones around the world. To reach this level of progressiveness, Egypt had to increase its industrial base and due to that there was a dramatic rise of the CO_2 emissions especially from the cement factories among the country. Therefore, our research has focused on finding a solution that has a high efficiency and at the same time doesn't cost much to lower the CO_2 emissions. From this research, a solution that mimics a process – to be specific a reaction - done by the coral reefs to build their skeleton was selected. This solution depends on the $CaCO_3$ which is a product of the reaction that involves captured CO_2 reacting with $Ca(OH)_2$ in water that works as a medium. To apply this process, a prototype was constructed. It consists of a tank with two pipes connected to it. The first pipe for the CO2 stream and the second one is for calcium carbide residue (waste) as the calcium hydroxide was replaced by this waste in order to decrease the cost. After testing it according to the chosen test plan, the recorded results showed a high efficiency in capturing the CO2 with a very low cost and they also showed huge amounts of CaCO3 produced. (CaCO3 is the major component in the cement industry).

Introduction

The industrial sector plays a significant role in our lives but with the massive numbers of factories, the environment started to get deteriorated because of the creation of waste and the greenhouse gases emissions. The cement which is the basic component of the constructing material and one of the most abundant substances is the leader of this deterioration as approximately 15% of the overall CO2 emissions are produced by manufacturing it and it accounts for about 4% of the global warming besides its hazards on the humans' health. Due to the realization of the its consequences, many projects have been established by the government and specialized organizations. One of these projects is "Low-Carbon Roadmap for the Egyptian Cement Industry". This project has various disadvantages but very few advantages. The disadvantages are the high cost, the low efficiency and the depletion of the energy resources. The main advantage is reducing the CO2 emissions by 4% but because of the huge amounts of CO2 this percentage is considered low. After reviewing the problem and its previous solutions, three design requirements have been selected to make sure the solution is appropriate for both Egypt's economic situation and the market demands. They are the low cost, the eco friendliness and the high efficiency. The solution that was chosen mimics the process which is used by the coral reefs to build their skeleton. This process is about capturing the CO2 from the air and letting it react with Ca(OH)2 that exists in the water to produce CaCO3 and water that could be reused in the next reaction. The solution is low in cost as all of its components are wastes obtained from other industries such as calcium carbide residue. The cost is 1 pound for every 1 kg of CO2 that needs to be treated. On the other hand, the prior solution costs 10 pounds for every kg thus, our solution decreases the cost by about 90%. Its efficiency is high as all the amount of the captured CO2 is being treated. Also, it doesn't harm the environment, instead it helps getting rid of CO2. The prototype is represented by a tank connected with two pipes, one for the CO2 stream and the other for the CCR as a source of calcium hydroxide. It was tested by practical experiment and theoretical calculations to know the number of moles before and after the CO2 passing through calcium carbide residue. The efficiency was calculated by dividing the output over the input and then comparing this ratio with the ratios of prior solutions. *As shown in graph (1)*



graph(1) represents a comparison between the efficiency over time of our solution and the prior solution

Materials & Methods

A system was made to make carbon dioxide react with calcium ions in a salt water that works as a medium and the methods of making it are shown below:

1. A tank was used as a place for the reaction then a hole was made in its side.
2. A small pipe was connected to the tank to help the calcium carbide residue get into it. Another pipe was connected to the tank from the top of it to work as a passage for carbon dioxide.
3. The calcium carbide residue (waste) was filtered by the filtration paper to separate the calcium carbonate and impurities from it *as shown in figure (2)* <u>(Filtration process)</u>

Figure (2) illustrates the filtration process

4. A reaction was made to produce one mole of carbon dioxide. The reaction involves adding one mole of sodium carbonate to two moles of the diluted HCl to produce 1 mole of carbon dioxide <u>as shown in following equation:</u>

$Na_2CO_3 + 2\ HCl = 2\ NaCl + CO_2 + H_2O$

5. The carbon dioxide passed through the pipe to enter the tank at the same time when 89 grams of filtered calcium carbide residue entered as a stream through the other pipe *as shown in figure (3)*

Figure (3) represents the system of the prototype

6. The resulted solution was filtered to separate the precipitated CaCO3 from the water

<u>Test plan</u>:

After one mole of carbon dioxide had reacted with calcium carbide residue, the amount of calcium carbonate produced was noticed to know how many moles were produced.

<u>The standard equation is</u>: $Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$

But the calcium carbide residue is not pure as 80% of its content is $Ca(OH)_2$. Therefore, calculating the amount of calcium carbide residue that should be increased would define the efficiency of carbon dioxide capturing.

-The cost was calculated and then it was compared to the prior solution.

Materials	Tank	Pipe	Calcium Carbide residue	Filter Paper	Reaction between sodium carbonate and HCL for getting carbon dioxide	
Images						
cost	15L.E	From chemistry lab	From INSUMAT company	From chemistry lab	From chemistry lab	Total 15L.E

Results

After testing the prototype three times, the results were as following:

<u>First trial</u>

- Succeeded or failed: Failed
- Explanation: The trial failed because of the high cost as the calcium hydroxide which has been used in it was expensive.

<u>Second trial</u>

- Succeeded or failed: Failed
- Explanation: After using 1 mole of calcium carbide residue to react with 1 mole of CO_2, there was a remain of CO2 that hasn't been treated.

<u>Third trial</u>

- Succeeded or failed: Succeeded
- Explanation: when the concentration of calcium carbide residue has been increased, the excess of CO_2 produced from the reaction was negligible which means the efficiency is high.

The calculations of the cost and the efficiency of each trial are illustrated in the table below:

Trial number	The cost for every 46 grams of treated CO_2	The excess of carbon dioxide	Efficiency
First trial	15 pounds	—	—
Second trial	0.1 pound	10 grams	80%
Third trial	0.125 pound	2.76 grams	94%

Analysis

As cement industry is one of the most common industries in Egypt and ranks as the top source of CO_2 emissions, a solution had to be found to get rid of the its consequences. The reason why cement industry emits large amounts of CO_2 *as shown in the chart (4)* is because it needs high thermal energy which could reach 1400 C to separate The limestone ($CaCO_3$) into calcium oxide and carbon dioxide. A solution is a mimic of a process of building skeletons that is made by coral reefs. It was mimicked in order to capture CO_2 emissions - that are considered as waste- from cement factories. This process includes capturing CO_2 from the air to be reacted with calcium ions (Ca^{+2}) in $Ca(OH)_2$ - that exist in seawater- to produce $CaCO_3$(limestone). The same process *as shown in figure (5)* could be applied in factories and the $CaCO_3$ that is produced could be used as an input in manufacturing cement. A prototype was constructed to see whether the solution meets the selected design requirements -which are low cost, high efficiency and eco-friendliness- or not. *The prototype was tested three times and they were done as following:*

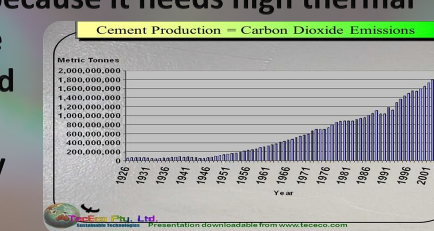


chart (4) shows the amounts of carbon dioxide emissions over the years

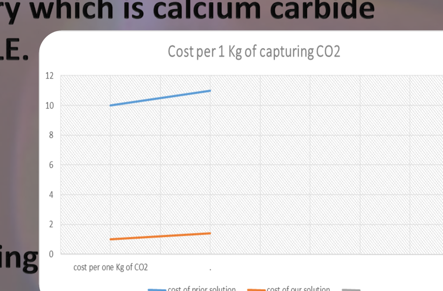
Figure (5) shows the process done by the coral reefs for building their skeleton

<u>First trial:</u>

The equation used: $Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$.

According to the previous equation, for treating 1 mole of CO_2, 1 mole of Ca(OH)2 must be added. Thus, for every 46 grams of CO_2, there must be 74 grams of $Ca(OH)_2$ available. Therefore, in large scales, as there are tons of CO_2 that are emitted from factories, tons of $Ca(OH)_2$ will be needed to get rid of these emissions and as the cost of 100 grams of $Ca(OH)_2$ is 20 LE, the cost of capturing these emissions would be millions of pounds.

To overcome this problem: another cheap source of $Ca(OH)_2$ was used. This source is the waste of acetylene gas industry which is calcium carbide residue(CCR). The cost of 1kg of CCR is 1.4 LE. By this, the cost is decreased by about 95% *as shown in graph (6)*



Graph(6) represents a comparison between the cost of treating 1 kg of Co2 by our solution and the prior one

<u>Second trial:</u>

In this trial: 74 grams of CCR (1mole) was added to 46 grams of CO2 (1 mole). According to the equation used in the first trial, 1mole of $CaCO_3$(100 grams) have to be produced from the reaction. However, the amount produced was 80 grams only. This means that not all the amount of CO_2 was captured due to the shortage in $Ca(OH)_2$. That is because CCR residue has 80% of its content $Ca(OH)_2$ *as shown in the chart (7)*

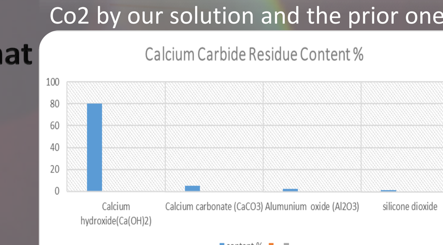


Chart (7) illustrates the content of CCR

The efficiency was affected significantly by this as there was an excess of CO2 that wasn't captured (about 20% of the overall amount).

To overcome this problem: 1.25 mole of CCR was used to get 1 mole of $Ca(OH)_2$

<u>Third trial:</u>

By overcoming the previous problems and Adding 92 grams of CCR residue, instead of 74 grams for every mole of CO_2 , 94 grams of calcium carbonate was produced as vaterite polymorph ($CaCO_3$ type) the texture *shown in figure (8)*

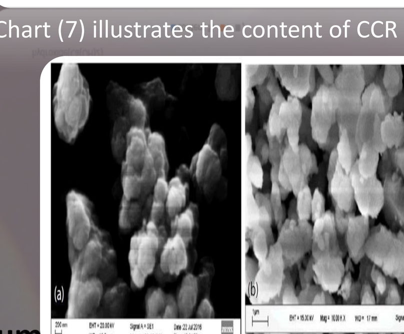


Figure (8) shows the texture of the **vaterite polymorph**

All the design requirements were met as the table below indicates:

Design requirement	First trail	Second trail	Third trail
Cost for 1 mole of CO2 treated(46grams)	Wasn't met (costed 15 LE)	Met (costed 0.1 LE)	Met (costed 0.125LE) As 1.25 mole of CCR was used
Efficiency (the amount of CO2 captured to the input amount) (calculated mathematically)	Met (about 100% of the amount was captured)	Wasn't met (about 80% of the amount was captured)	Met (about 100% of the amount was captured)
Green house	Met	Wasn't met	Met

To calculate the efficiency of our prototype practically, the concept of percentage yield which is:

$$\frac{\text{Actual mass produced(practically)}}{\textit{Mathematical mass calculated}} \times 100\% = \frac{94}{100} \times 100\% = 94\%$$

Conclusion

Lots of deductions can be inferred from the failures and success of the prototype's test plans:

- The project could be applied in the factories as the materials used in it are wastes which would help making the cost affordable. Also, by replacing the calcium hydroxide with the calcium carbide residue, the cost would decrease significantly and the quality would remain the same. The results showed that our solution is more efficient than the prior solutions as well.
- The second failed trial illustrated the importance of using 1.25 mole of Calcium carbide residue instead of just 1 mole in order to get 1 mole of CaCO3.
- The $CaCO_3$ produced is vaterite polymorph which is a type of limestone that is qualified to be used in the cement industry.

Recommendation

For further modifications, the future pioneers are recommended to search for another efficient way to remove the impurities of calcium carbide residue -in order to turn it into a pure calcium hydroxide-instead of the prevalent filtration process that expends money and time. Another recommendation is to benefit from the small amount of heat that calcium carbide residue produce when it's dissolved in water. This heat could be used either in burning the input components to produce cement or drying the calcium carbonate (limestone) after precipitation to be available as an input in the cement industry.

Literature Citation

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Acknowledgement

We are grateful to all of those with whom we have had the pleasure to work during this and other related projects. Each one has provided us extensive personal and professional guidance. we would especially like to thank Dr. Mohamed Emran and Dr. Al Doshy. As our teachers and mentors Mr. Mahgoub Hashem, Mr. Mohamed Adly and Mr. Montaser Ali. And finally we would like to thank our capstone leader Mr. Ahmed Abd El hafeez , our capstone teacher Mr. Mohamed Goda and our School principle Mr. Abd El Rahman eliwa, who have taught us more than we could ever give them credit for here.

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