Derek Ng

Ms. Curran

STEM

04 November 2017

Regeneration of Sodium Carbonate using Solar Energy Research Plan Revised

Rationale: Greenhouse gases in the atmosphere have been becoming a major issue today. One of these greenhouses gases include carbon dioxide. There are several methods to remove carbon dioxide, however, many require a lot of energy to do so. One cycle that can be utilized is the sodium carbonate cycle: $Na_2CO_3 + CO_2 + H_2O \leftrightarrow 2NaHCO_3$. A sodium carbonate solution can be used to capture carbon dioxide, and sodium bicarbonate precipitate is formed. The sodium bicarbonate can be decomposed to form sodium carbonate, water, and carbon dioxide by heating it to 100-200°C. In some methods, electricity from a powerplant is used to produce this heat. In other methods, electricity from renewable sources are used. While these methods can produce heat energy, the sun also provides the Earth with heat energy too.

Engineering goal: Use the energy from the sun to directly heat solid sodium bicarbonate to a temperature where the sodium bicarbonate will be able to decompose to form sodium carbonate, carbon dioxide, and water.

Expected outcome: The sodium bicarbonate will decompose to form solid sodium carbonate, carbon dioxide gas, and water vapor.

Procedure: Before the actual experiment is done, smaller-scale testing will be done to help grasp the concepts and to help determine techniques that will help maximize the amount of heat generated. The smaller scale testing will be done indoors. The source of light will be a light bulb not exceeding 300 watts placed inside a metal-shade lamp. A small plastic or glass container will be filled with tap water to be heated by the light. A Fresnel lens, not exceeding 900 centimeters squared, will be placed between the light and the container with the focal point in the water. Different iterations will be done such as replacing the water with sodium bicarbonate or coating the sides of the container in a black layer. The temperature of the substance in the container will be measured on thirty second intervals.

For the actual experiments outside with the sun as the light source, 50 grams of sodium bicarbonate will be put in a glass bowl. A Fresnel lens, not exceeding 0.5 meters squared, will be put in between the sodium bicarbonate and the sun with the focal point on the sodium bicarbonate. The temperature of the sodium bicarbonate will be measured at thirty second intervals with an infrared thermometer. After ten minutes, the lens will be removed, and the product, sodium carbonate, will be left to cool. The experiment will be reset, and the test will be repeated nine more times with the same amount of sodium bicarbonate. After each set of ten tests, the starting amount of sodium bicarbonate will increase by 50 grams.

Data analysis: The temperature of the sodium bicarbonate at thirty second intervals will be recorded. The mass of the sodium bicarbonate will be recorded before a test, and the mass of the product will be recorded after a test. The mass of the product will be compared to the predicted mass of the sodium carbonate to determine how much sodium carbonate was formed. Additionally, a titration will also be performed with a 0.1 M solution of hydrochloric acid to determine the amount of sodium carbonate formed. Paired t-tests will be done to analyze the data.

Risk and safety: The main risk of this project is the use of concentrated heat from the Fresnel lens. For the smaller-scale testing, the heat source will be a light bulb not exceeding 300 watts, and the Fresnel lens will not exceed 900 centimeters squared in area. Because testing is done indoors, extra caution will be taken to decrease the fire hazard. The shade on the lamp will be metal, and the wattage of the bulb will not exceed the wattage posted on the lamp. The Fresnel lens will not be left unattended when it is in front of the light. Extra caution will be taken to make sure that the focal point of the Fresnel lens is never on any surface except for the substance being heated. If the substance exceeds a temperature of 100°C, the experiment will end, and the light will be shut off. No materials will be touched until it has cooled to below 38°C. The testing area will be clear of any clutter. A fire extinguisher and bucket of water will be nearby.

To minimize the risk of fire in the actual experiments outdoors, all tests will be done on pavement in an open area at least five meters away from structures, trees, and bushes. Testing will not be conducted on days with wind excess of 30 kph. The testing area will be cleared of any debris, snow, or ice and inspected for oil or other flammable material before testing begins. There will be a fire extinguisher, bucket of water, and maybe snow located nearby in case of fire. During experimentation, all persons will be at least 0.5 meters away from the area under the lens. The lens will be kept in the shade or parallel to the rays of the sun when not in use to prevent accidental fires. When the lens is outside, it will not be left unattended. During and after testing, the temperature of materials under the lens will not be touched until it has cooled to below 38°C. A infrared thermometer will be used to confirm the temperatures of objects. All loose sheets of paper will be kept on a clipboard to prevent it from being blown into the lens area. If any unauthorized objects enter the lens area while testing, the Fresnel lens will immediately be secured from starting a fire before removing the unauthorized objects.

In addition to fire, chemicals will be involved in this project. The reactant, sodium bicarbonate, will be bought from the supermarket and stored in its original container in an approximately 20°C room. The sodium bicarbonate will remain solid while conducting the experiment. The expected products of the reaction are water vapor, carbon dioxide, and sodium carbonate. The water vapor and carbon dioxide will have mixed into the air after the sodium bicarbonate decomposes, leaving the sodium carbonate. The sodium carbonate will be left to cool below 38°C before being analyzed and disposed of in a wastebasket. If the sodium bicarbonate/carbonate is spilled, the Fresnel lens will be secured from starting a fire before the spilled material is swept with a broom and pan and disposed of in a wastebasket. During experimentation, long sleeves, closed-toed shoes, and sunglasses will be worn to protect the skin from stray particles and the eyes from the bright light.

A 0.1 M solution of hydrochloric acid will be used to perform a titration on the sodium carbonate. Due to the corrosive nature of hydrochloric acid, splash goggles, an apron, long-sleeved clothing, and closed-toed shoes will be worn. If spilled, the hydrochloric acid will be diluted with water, and the surfaced will be dried with paper towels before being put in the wastebasket. The hydrochloric acid will be stored in a dry, tight container in a cool room.

Discussion of results and conclusion: If 240 grams of sodium carbonate can be produced in ten minutes, then the experiment will be considered successful. Theoretically, if there is 380 grams of sodium bicarbonate, about 240 grams of sodium carbonate is produced and 100 grams of carbon dioxide can be stored. If successful, the process used to regenerate sodium carbonate can be incorporated into the cycle that uses sodium carbonate to capture carbon dioxide. The amount of energy needed to be produced by power plants to run the carbon capture cycle would be reduced, which could also reduce the cost to run it. If the cost is low enough, a large amount of carbon capture devices could be manufactured and placed around the world, especially in places that receive a lot of sunlight each year if the method in this project is used.

With carbon capture devices being commonplace, it may be possible to achieve negative carbon emissions.

Bibliography

Advantages of Fresnel Lenses. (n.d.). Retrieved October 21, 2017, from https://www.edmundoptics.com/resources/application-notes/optics/advantages-of-fresnel-lenses/

Geng, Y., Li, C., Cao, Y., Chen, H., Kuang, Y., Ren, X., & Bai, X. (2016). Cost analysis of air capture driven by wind energy under different scenarios. *Journal of Modern Power Systems and Clean Energy*, 4(2), 275-281. Retrieved September 17, 2017, from https://link.springer.com/article/10.1007%2Fs40565-015-0150-y

Goeppert, A., Czaun, M., Prakash, G., & Olah, G. A. (2012). Air as the renewable carbon source of the future: an overview of CO2 capture from the atmosphere. *Energy and Environmental Science*, (7), 7833-7853. doi:https://doi.org/10.1039/c2ee21586a

Hayashi, H., Taniuchi, J., Furuyashiki, N., Sugiyama, S., Hirano, S., Shigemoto, N., & Nonaka, T. (1998). Efficient Recovery of Carbon Dioxide from Flue Gases of Coal-Fired Power Plants by Cyclic Fixed-Bed Operations over K2CO3-on-Carbon. *Industrial & Engineering Chemistry Research, 37*(1), 185-191. doi:http://doi.org/10.1021/ie9704455

Kaplan, G. M. (1985). *Understanding solar concentrators*. Retrieved October 21, 2017, from http://pdf.usaid.gov/pdf_docs/PNABC955.pdf

Khalilpour, R., Milani, D., Qadir, A., Chiesa, M., & Abbas, A. (2017). A novel process for direct solvent regeneration via solar thermal energy for carbon capture. *Renewable Energy*, 104, 60-75. doi:https://doi.org/10.1016/j.renene.2016.12.001

Liu, Y., Deng, S., Zhao, R., He, J., & Zhao, L. (2017). Energy-saving pathway exploration of CCS integrated with solar energy: A review of innovative concepts. *Renewable and Sustainable Energy Reviews*, 77, 652-669. doi:https://doi.org/10.1016/j.rser.2017.04.031

Lund, H., & Mathiesen, B. V. (2012). The role of Carbon Capture and Storage in a future sustainable energy system. *Energy*, 44(1), 469-476. doi:https://doi.org/10.1016/j.energy.2012.06.002

Material Safety Data Sheet: Gaseous CO2. (2015, April 25). Retrieved October 21, 2017, from http://www.uigi.com/MSDS_gaseous_CO2.html

Material Safety Data Sheet Sodium bicarbonate MSDS. (2013, May 21). Retrieved October 21, 2017, from http://www.sciencelab.com/msds.php?msdsId=9927258

Material Safety Data Sheet Sodium carbonate MSDS. (2013, May 21). Retrieved October 21, 2017, from http://www.sciencelab.com/msds.php?msdsId=9927263

Material Safety Data Sheet Water MSDS. (2013, May 21). Retrieved October 21, 2017, from http://www.sciencelab.com/msds.php?msdsId=9927321

Polak, R. B., & Steinberg, M. (2012). *U.S. Patent No. US20120003722A1*. Washington, DC: U.S. Patent and Trademark Office.

Senese, F. (n.d.). *What happens when sodium bicarbonate is heated?* Retrieved October 21, 2017, from http://antoine.frostburg.edu/chem/senese/101/inorganic/faq/carbonate-decomposition.shtml

Zeman, F. (2007). Energy and Material Balance of CO2 Capture from Ambient Air. *Environmental Science & Technology*, *41*(21), 7558-7563. doi:http://doi.org/10.1021/es070874m