Open Questions for Cyan and Opportunities to Help

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1 Summary

The Aqueous Cyan is a variation on the original Cyan that I have been experimenting with. As with all Cyan designs, the goal is to come up with a distributed direct-air carbon dioxide capture (DACC) device that is *efficient*, *cheap*, and *easy* for non-technical people to build and operate.

I am an electronics engineer and have a lot of gaps in my knowledge; I am hoping that people in other fields of expertise and with an interest in direct-air carbon capture will be able to help answer some of the questions below.

2 Description

The Aqueous Cyan uses the same chemical reaction and some of the same parts as the Classic Cyan, but in a different physical form. The input material is still calcium hydroxide ($Ca(OH)_2$), which is readily available to consumers as "hydrated lime." This material, when wet or in solution, reacts with CO_2 to form calcium carbonate ($CaCO_3$). The *overall* chemical equation is

$$Ca(OH)_2\,(s) + CO2\,(g) \leftrightarrow\ CaCO_3\,(s) + H_2O\,(l)$$

In the Classic Cyan, as described by its inventor, Dahl Winters, humid air is passed over a quantity of moist $Ca(OH)_2$; the moisture is maintained by pumping air through a container of water with an aquarium aerator. After the reaction proceeds to completion, the remaining material is dried and weighed. The increase in weight tells us how much $CaCO_3$ has been generated, and we can then calculate how much CO_2 has been captured.

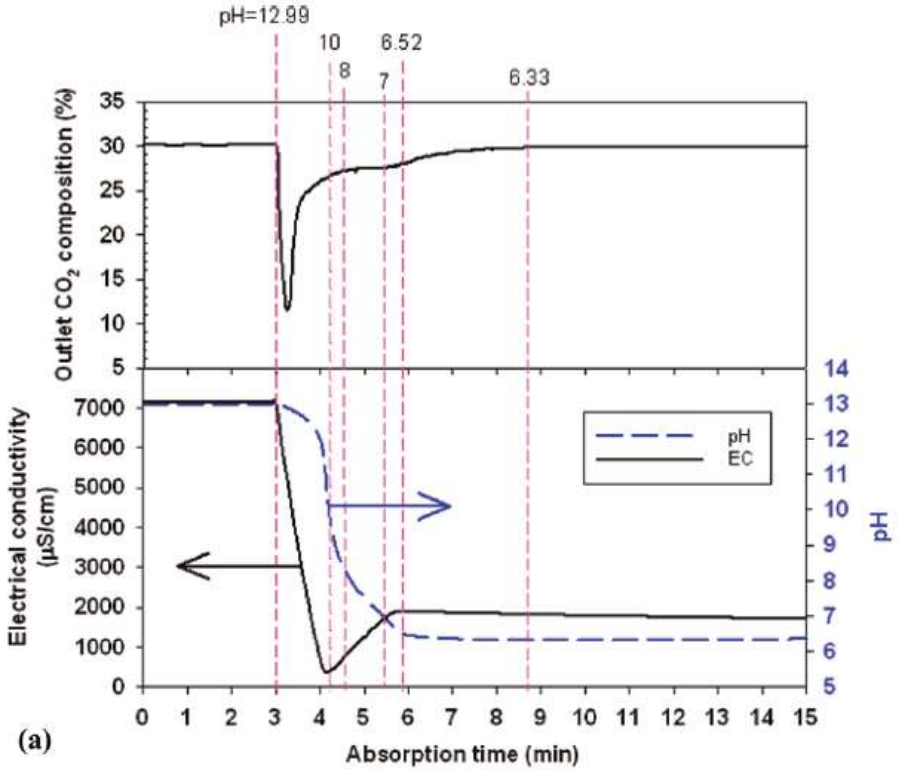
The Aqueous Cyan uses a container such as an empty soda bottle filled with a solution of $Ca(OH)_2$. The same aquarium aerator now bubbles air through the solution; the CO_2 in the air now dissolves in the solution and reacts with the $Ca(OH)_2$, which precipitates to the bottom. This is the reaction studied by Han *et. al*. in https://pubs.acs.org/doi/10.1021/ef200415p .

The intention of the aqueous scheme is to increase the surface area of the $Ca(OH)_2$ exposed to atmospheric CO_2 and to enable a cleaner separation of the solid $CaCO_3$ output from the dissolved $Ca(OH)_2$ input. In actual operation, the setup will normally be loaded with more $Ca(OH)_2$ than will dissolve, so initially this excess input material will be in solid form at the bottom of the vessel, and should gradually dissolve and engage in the reaction until it is all consumed.

The Aqueous Cyan is still in an early prototype phase, and there are a number of questions that need to be explored on the way to optimizing it. Input is sought

from chemists, chemical engineers, mechanical engineers, economists, and energy experts. I go into some of these questions below, and suggest opportunities to contribute.

3 The Aqueous Cyan Operating Cycle



In Han's paper, as the CO_2 capture process goes forward the pH of the solution, initially about 13, drops until the solution reaches neutrality. During this process, production of the $CaCO_3$ precipitate stops about when the pH reaches 10 and the electrical conductivity (EC) reaches a minimum. After this point, some CO_2 absorption continues at a lower rate, and some of the $CaCO_3$ precipitate is converted into HCO_3^- ions and redissolved.

We can choose to stop this iteration of the cycle at any point, dump the liquid solution, and optionally save the $CaCO_3$ precipitate from the bottom.

Q: How to separate out and dry the precipitate?

Q: When do we stop the process, empty the container, and start anew?

That depends on what we would like to optimize:

- If we want to maximize the rate of CO_2 capture, we should stop well before pH=10; note from the graph above that the rate of absorption is highest at high pH (evidenced by the lower outlet CO_2 composition seen in the top

graph); after that, we will continue to expend energy but with a lower rate of absorption.
- To maximize the total CO2 absorption per run, we should keep running until no more CO_2 is absorbed (pH~7).
- To maximize output of precipitate, we would stop around pH=10, before the $CaCO_3$ starts to convert into the HCO_3^- ions.

4 More Chemistry Questions

Q: What is the concentration of various ions during CO2 capture?

Han's paper discusses qualitatively the relative amounts of each ion during each pH segment; is there a way to quantitatively compute this as a function of absorbed CO2, and initial material molarity?

Q: What is the effect of impurities of the input material (nominally $Ca(OH)_2$, but commercial bags of "hydrated lime" are never 100% pure)?

Q: What chemistry determines the EC, and does its minimum correspond theoretically to a useful stopping point?

5 Chemical experiments

It would be very helpful if someone with access to a chemistry lab can do some experiments to answer the following:

Q: What is the actual chemical composition of each variety of commercially-supplied hydrated lime? [Also useful for Classic Cyan!]

Q: At the end of the Cyan's run cycle, what is the chemical composition of the output material / precipitate? [Also useful for Classic Cyan!]

- *Especially useful for verifying the amount of CO_2 that was captured.*

6 Technology / Mechanical Issues

Q: Can we find a more energy-efficient air pump? Can we find one that runs from a low dc-voltage (e.g. 5V)? [Also useful for Classic Cyan!]

Q: Is there a better air diffuser for injecting the air into the liquid solution? [Also useful for Classic Cyan!]

7 Big Picture Issues

Q: What is the total carbon footprint for building and operating this device, including manufacture and transport of parts and material, and energy consumed in operation? [Also useful for Classic Cyan!]

Q: What can we do with the output material after it has captured the CO_2 ? [Also useful for Classic Cyan!]