

A Review on Carbon Dioxide Bio-sequestration

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Abstract

With the increase of global warming impacts on the environment new options for reducing carbon dioxide are developing. This paper gathered various direct (active) and indirect (passive) methods of CO₂ bio-sequestration. Direct (active) which are structural or intracellular carbonate depositions by microbes. Indirect (passive) ways of bio-sequestration of CO₂ are by physical or chemical modification of the medium. This modification could be either by providing alkalinity or cation source or even increasing the active concentration of cation in the environment. One the main challenges of cation-carbonate precipitation is to find the adequate concentrations of cation. Some the available industrial cation sources could be desalination industry, steel industry, gypsum, and solvary process. Finally, suggested applications of combining CO₂ mineralization during wastewater treatment have been addressed. Nitrification/denitrification, sulphur removal (desulphurisation) and fermentation/methane as sequential process could be potential options for CO₂ mineralization.

1. Introduction

With the increase of global warming impacts on the environment, new regulations are applied for CO₂ polluters. Many countries agreed with the Kyoto protocol have now more encouragement and force to reduce the amount of CO₂ of the air (Kodama, Nishimoto et al. 2008). However, many of the proposed solutions are not long-lasting ones as they will only postpone the problem for a later time. A sustainable solution to reduce the amount of CO₂ is to mineralize it in rocks and subsequently remove the CO₂ from the carbon cycle (Harkes, Booster et al. 2008). CO₂ mineralization is a thermodynamically reliable and stable method (Millero 1995).

Carbonatogenesis is a common natural phenomenon (Reid, Visscher et al. 2000; Sigel, Sigel et al. 2008). If this process occurring in nature is induced by a few percentage it will easily compensate for the amount CO₂ produced by humans. Carbonatogenesis has already been a well recognized process; however not all carbonatogenesis leads to CO₂ reduction, some even increase the amount of CO₂ of the air (Whiffin, van Paassen et al. 2007). To have the carbon source of carbonate from CO₂; CO₂ should have first been altered to CO₃²⁻ which can occur under high pH in water.

Biological processes can directly or indirectly sequester carbon dioxide. Structural or intracellular carbonate depositions by microbes are direct (active) ways of CO₂ sequestration (Ehrlich and Newman 2008). Studies have shown that bacteria and some algae can precipitate CaCO₃ mostly at their cell surface (Lopez-Garcia, Kazmierczak et al. 2005).

Indirect (passive) ways of bio-sequestration of CO₂ are by physical or chemical modification of the medium. This modification could be either by providing alkalinity or cation source or even increasing the active concentration of cation in the environment. The latter could happen by removing or inhibiting other coating ions. Many Biological processes such as denitrification, desulphurisation and methane production increase the pH during their metabolic pathways and consequently with higher alkalinity available in the environment, carbonatogenesis rate is induced (Castanier, Le Métayer-Levrel et al. 1999). On the other hand, there are available biological processes by some bacteria, algae, and plants which enhance the rate of weathering of alkaline rocks which could be the main source of cations for precipitation of cation-carbonate (Willscher and Bosecker 2003; Webster and May 2006; Balogh-Brunstad, Keller et al. 2008).

2. Cation Source

One the main challenges of cation-carbonate precipitation is to find the adequate concentrations of cation such as calcium or magnesium. If the product of the concentrations of cation such as calcium and carbonate exceeds the solubility product of CaCO₃, it will precipitate(Ehrlich and Newman 2008).

$$[Ca^{2+}][CO_3^{2-}] = K_{sol} = 10^{-8.32} \quad (2.1)$$

Therefore, if as a result of microbial activity the medium becomes alkaline in the presence of adequate concentration of cation, precipitation can occur. Cation mostly calcium can be available from various sources.

Industrial Source of Calcium

2.1 Desalination Industry

Of the 7,500 desalination plants in operation worldwide 60% are located in the Middle East whereas 12% of the world's capacity is produced in the America, mostly in the Caribbean (Qutob 2004)

Recently the industry is also getting important in Greece, Cyprus, Spain for Europe and the market for desalination will continue to grow as the planet gets more crowded. For instance, Spain has more than 700 plants producing approximately 1,600,000 cubic meters of water each day, or enough for about 8 million inhabitants (MIT 2005). If all the available calcium (assuming a sea concentration of 400ppm) were all converted to lime, this would amount to 1.6 kt/day, or 0.6 Mt/yr.

Nevertheless desalination remains a very energy intensive business. Two to four kWh/m³ is not unusual (Busch and Mickols 2004). Besides this high energy consumption, wild life depletion and brine disposal directly into coastal areas are key problems. The marine environment has indeed been negatively impacted in many direct and indirect ways by desalination units: the use of the coast line for recreation and tourism is affected, near the outlets, the temperature of coastal waters increases and noises outcomes of the high-pressure pumps and energy recovery turbines are introduced in the environment (Qutob 2004).

The chemical composition of reject brine depends on the desalination units. A comparison of the brine from inland desalination plants in the eastern region of Abu Dhabi Emirate reported a Ca^{2+} concentration rang of 173 and 923 mg/l and a pH variation between 4, 1 and 7.95 (Mohamed, Maraqa et al. 2005).

Depending on the brine's composition a detailed screening of microbial organisms possibly thriving on it should be done. In Dupraz et al., 2004 a natural example of an early carbonate precipitation in a hypersaline lake in the Bahamas is reported and microbe–mineral interactions are discussed (Dupraz, Visscher et al. 2004). In this case, sulphate reduction showed high activity in close association with the carbonate precipitate at the top of microbial mats.

2.2 Steel Industry

Melt products from the steel industry (slag), becoming a waste at the end of the process with examples of composition: CaO: 39%; MgO: 12%; SiO₂: 36%; Al₂O₃: 10% can be one the sources of calcium. This product is used in roads and soil amendments. The drawback of using of such source for microbiological point of view is its high amount of heavy metals present (Willscher and Bosecker 2003).

2.3 Gypsum (or anhydrate)

Gypsum $\text{SO}_4\text{Ca} (2\text{H}_2\text{O})$ generated by flue gas de-sulfurization (FGD) units which use limestone to exchange sulfate for carbonate. Lab experiments on SRB *Desulfobacterium* species showed that sulfate reduction with gypsum as the electron acceptor resulted in calcite formation (Karnachuk, Kurochkina et al. 2002).

2.4 Solvay Process

In solvay process lime and sodium chloride are as input in the process, while sodium carbonate and calcium chloride constitute the output. Its prime usage is in paper or as dryer. However, most finishes as waste in “waste white water” and

return in ionic form to the sea. It has high potential as Ca^{2+} source with high amount of sodium carbonate production.

3. Potential Application

The cost of industrial rate carbonatogenesis can be significantly reduced for olivine and serpentinites if we can efficiently dissolve the minerals in a weakly acidic environment.

There have been researches on rock weathering by chemical solution under low pH (Kojima, Nagamine et al. 1997; Ah-Hyung Alissa Park 2005). As mentioned by Park, A.-H. A et al (2005), limiting factor in CO_2 mineralization is dissolution rate of CO_2 and dissociation of carbonic acid, rather than the dissolution rate of minerals. The reason of the low precipitation rate in their experiment might be due to the low pH in the system which they required for rock weathering. As for the carbonate production, thermodynamically CO_2 can be bound as a carbonate under high pH.

Therefore, if there are already sequential processes available which combine an acidifying process followed by an alkaline process can be beneficial to use. Some of the wastewater treatment systems could have high potential in this sense. Therefore, we can apply the carbon dioxide sequestration in current wastewater treatment facilities. At the same time get use of this application with extra advantages such as obtaining higher gas purity produced during anaerobic digestion processes by removing the CO_2 . There are several process involving of low and high pH sequentially such as, sulphur removal (desulphurisation) and nitrification/denitrification. While acidity could be provided by nitrification, fermentation process, alkalinity could be provided during denitrification, methane production and desulphurisation.

Various wastewater treatments have been extensively studied and optimal conditions for different reaction have been obtained. Primarily experiments have been conducted to show the potential and feasibility of implementing of alkaline

rock weathering and CO₂ sequestration during various process of wastewater treatment.

4. Conclusions

As mentioned in this paper, bio-sequestration of CO₂ has great potential in reduction of the amount CO₂ either by direct (active) or indirect (passive) ways. The input for CO₂ mineralization could be available from waste of various industries such as desalination industry, steel industry, gypsum, and solvary process. In addition, this process could be applied in combination with current plants such as wastewater treatment plants. Fermentation/methane production, sulphur removal (desulphurisation) and nitrification/denitrification have the potential of such practice are.

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