

# AN OVERVIEW OF VARIOUS SEQUESTRATION SYSTEMS OF CO<sub>2</sub> AND ITS STRUCTURAL APPLICATIONS

Bonny Mathew<sup>1</sup>, Manjusha Mathew<sup>2</sup>

<sup>1</sup> PG student, Department of Civil Engineering, Holy Kings College of Engineering, Pampakuda – 686667, India.

<sup>2</sup> Assistant Professor, Department of Civil Engineering, Holy Kings College of Engineering, Pampakuda – 686667, India.

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**Abstract** – Carbon dioxide is a major greenhouse gas in contributing to the global warming. Now-a-days the reduction of CO<sub>2</sub> emission into atmosphere is a serious problem of the world. This paper evaluates various underground disposal methods as well as mineral trapping techniques of carbon dioxide and its structural advantages. It includes the aquifer disposal of CO<sub>2</sub> under different geological conditions and their effects. The various studies reveal that mineral sequestration can be permanent and it demonstrates sufficient strength to the secondary carbonate rocks. Hence mineral trapping in conjunction with structural binder production is possible.

**Key Words:** Carbon dioxide, mineral sequestration, aquifer disposal, geological conditions, binder.

## 1. INTRODUCTION

Now-a-days sustainable construction materials and reduction of environmental pollution as well as waste treatment are the important requirements of the world. This study helps to establish a binder material known as ferrock (Iron Carbonate) which satisfies the above needs to some extent.

Modern world suffers severe health hazards accompanying with pollution. Any type of pollution in our environments and ecosystem causes insecurity, health disorders and discomfort to the normal life. Among the medium at which pollution affects, air is the predominant channel through which most deleterious effects of the pollution happens to human beings and other living organism. World Health Organization defines air pollution as “The presence of materials in the air in such concentration which are harmful to man and his environment”. In fact the air pollution is the existence or accumulation of foreign particles, gases and other pollutants into the air which have an adverse effect on human beings, animals, plants, buildings, etc. The major cause of pollution in the urban areas is due to inefficiently burn petroleum products from the automobiles which release 75% of noise and 80% of the air pollutants. Concentration of the industries in one area is also contributed significantly to the air pollution in that region.

CO<sub>2</sub> is one of the leading air pollutants. Due to excessive combustion activity, the content of CO<sub>2</sub> has been steadily increasing. As carbon dioxide spread over the atmosphere it absorbs more and more of the reflected infrared radiation. This could cause an increase in temperature referred to as

the greenhouse effect. The method to reduce the amount of greenhouse gases (GHG), such as CO<sub>2</sub> in the atmosphere is an active research area. Mineral trapping with mined mineral rocks is one of the promising ways to reduce the concentration of CO<sub>2</sub> in the atmosphere. The mineral carbonation allows chemical sequestration of CO<sub>2</sub> and the secondary carbonate rocks formed during mineral trapping establish mechanical strength which reveals the possibility of using of mineral trapping in conjunction with sustainable binder manufacturing for construction.

## 2. LITERATURE REVIEW

This section includes a brief review on several previous studies about different methods of mineral trapping of CO<sub>2</sub> under various geological conditions in the underground strata. Some of the studies include the properties of iron carbonate and the possibilities of making a binder with the CO<sub>2</sub> trapping.

**Bachu S et al. (1994)** studied about the CO<sub>2</sub> disposal in sedimentary basins based on the evaluation of Alberta Basin in Western Canada. Geochemical and hydrogeological analyses of CO<sub>2</sub> interaction with the aquifer water and rocks and of CO<sub>2</sub> transport in miscible and immiscible phase by the natural flow of aquifer water indicate that, besides stratigraphic trapping, two additional mechanisms are available for the capture and long-term retention of CO<sub>2</sub> in the subsurface. One mechanism is mineral trapping through precipitation of carbonate minerals when CO<sub>2</sub> is injected into basic siliciclastic aquifers. The other mechanism is hydrodynamic trapping when the residence or travel time of CO<sub>2</sub> in low permeability regional aquifers is of the order of thousands to a million years. [1]

**Nesic.S et.al. (1996)** A predictive model was developed for uniform CO<sub>2</sub> corrosion, based on modeling of individual electrochemical reactions in a water-CO<sub>2</sub> system. Model takes into account the electrochemical reactions of H<sup>+</sup> ion reduction, carbonic acid (H<sub>2</sub>CO<sub>3</sub>) reduction, direct water reduction, oxygen reduction, and anodic dissolution of iron. The required electrochemical parameters (e.g., exchange current densities and Tafel slopes) for different reactions were determined from experiments conducted in glass cells. The corrosion process was monitored using polarization resistance, potentiodynamic sweep, electrochemical impedance, and the weight-loss measurements. The model was applicable for uniform corrosion with no protective films

present. Performance of the model was validated by comparing predictions to results from independent loop experiments. Predictions also were compared to those of other CO<sub>2</sub> corrosion prediction models. Compared to the previous largely empirical models, the model gave a clearer picture of the corrosion mechanisms by considering the effects of pH, temperature, and solution flow rate on the participating anodic and cathodic reactions.[2]

**Kaszuba J.P et al. (2003)** studied the reactive behavior of supercritical CO<sub>2</sub> under conditions relevant to geologic storage and sequestration of carbon is largely unknown. Experiments were conducted in a flexible cell hydrothermal apparatus to determine the extent of fluid-rock reactions, in addition to carbonate mineral precipitation, that may occur in a brine aquifer-aquitard system that simulates a saline aquifer storage scenario. The system was held at 200°C and 200 bars for 59 days (1413 h) to approach steady state, then injected with CO<sub>2</sub> and allowed to react for another 80 days (1924 h). In addition to magnesite precipitation, silicate minerals (quartz, plagioclase, microcline and biotite) in the aquifer and the aquitard display textures (etch pits, mineralization) indicating significant reaction. Changes in elemental abundances in the brine following addition of CO<sub>2</sub> include pH decrease and enrichment in Cl<sup>-</sup>, partly due to supercritical CO<sub>2</sub> desiccation of brine. Geologic sequestration systems have potential for geochemical reactions that extend beyond simple aqueous dissolution of CO<sub>2</sub> and precipitation of carbonate. These reactions may produce geochemical and geotechnical consequences for sequestration and provide important characteristics for monitoring and evaluation of stored CO<sub>2</sub>. [3]

**Park .A.A et al.(2003)** studied that, it is essential to reduce the emission of greenhouse gas CO<sub>2</sub> in order to stabilize its levels in the atmosphere while allowing the continued use of fossil fuels. Abatement of CO<sub>2</sub> by mineral carbonation has been proposed as one of the most promising methods for CO<sub>2</sub> emission control in the flue gas from coal-fired power plants. However, little is known about the fundamental characteristics of CO<sub>2</sub>-mineral reactions. The overall goal of this study was to investigate the mechanisms of the aqueous reactions of CO<sub>2</sub> with Mg-bearing minerals. Specifically, the focus was on the enhancement of the mineral dissolution.[4]

**Nordsveen .M et.al (2003)** presented a mechanistic model of uniform CO<sub>2</sub> corrosion which covers the following: electrochemical reactions at the steel surface, diffusion of species between metal surface and the bulk including diffusion through porous surface films, migration due to establishment of potential gradients, and homogenous chemical reactions including precipitation of surface films. The model can predict corrosion rate as well as the concentration and flux profiles for all species involved. Comparisons with laboratory experiments have revealed the strengths of the model such as its ability to assist in understanding complex processes taking place during corrosion in the presence of surface films.[5]

**Wu .S.L et.al (2004)** employed X-ray photoelectron spectroscopy (XPS), scanning electron microscopy (SEM) and X-ray diffraction (XRD) to systematically characterize the chemical composition and the microstructure of the surface film on N80 oil tube steel exposed to CO<sub>2</sub> corrosion. A crack-free laminar surface film was observed on the N80 oil tube steel under turbulent flow condition for 72 h at 80°C with a carbon dioxide partial pressure of 0.5 MPa. The surface film was composed mainly of a complex carbonate (Fe, Ca)CO<sub>3</sub> and of a limited amount of α-FeOOH. The complex carbonate produced under the condition of this study was unstable and partially decomposed into α-FeOOH in desiccated air. The extending of the corrosion testing time and the formation of complex carbonate both contributed to the enhanced stability of the surface film. [6]

**Xu .T et al. (2004)** studied that CO<sub>2</sub> disposal into deep aquifers is a potential means whereby atmospheric emissions of greenhouse gases may be reduced. As a prelude to a fully coupled treatment of physical and chemical effects of CO<sub>2</sub> injection, the authors have analyzed the impact of CO<sub>2</sub> immobilization through carbonate mineral precipitation. Batch reaction modeling of the geochemical evolution of three different aquifer mineral compositions in the presence of CO<sub>2</sub> at high pressure were performed. The numerical experiments provide useful insight into sequestration mechanisms, and their controlling geochemical conditions and parameters. [7]

**Xu .T et al. (2005)** developed a conceptual model of CO<sub>2</sub> injection in bedded sandstone-shale sequences using hydro-geologic properties and mineral compositions commonly encountered in Gulf Coast sediments. Numerical simulations were performed with the reactive fluid flow and geochemical transport code TOUGHREACT to analyze mass transfer between sandstone and shale layers and CO<sub>2</sub> immobilization through carbonate precipitation. Results indicate that most CO<sub>2</sub> sequestration occurs in the sandstone. The major CO<sub>2</sub> trapping minerals are dawsonite and ankerite. The CO<sub>2</sub> trapping capacity depends on primary mineral composition. The initial abundance of chlorite and oligoclase therefore affects the CO<sub>2</sub> mineral-trapping capacity. The sequestration time required depends on the kinetic rate of mineral dissolution and precipitation. The addition of CO<sub>2</sub> as secondary carbonates results in decreased porosity. The leaching of chemical constituents from the interior of the shale causes slightly increased porosity. [8]

**Lee .S.O et.al (2007)** studied that Iron oxide is the main contaminant of clay and silicate minerals used during the production of high quality ceramics. Its content has to be removed to generally less than 0.1% for achieving the required whiteness of 90% ISO or higher for clay and silicate materials. Oxalate has been used to dissolve iron oxide from various sources. The dissolution is affected by oxalate concentration, solution pH and temperature. The mineral phase is also critical in determining the reaction rate. Hematite is slow to dissolve whereas iron hydroxide and

hydroxyoxides such as goethite and lepidocrosite can be easily dissolved. [9]

**Matter .J.M, Kelemen .P.B (2009)** investigated that anthropogenic greenhouse-gas emissions continue to increase rapidly despite efforts aimed at curbing the release of such gases. One potentially long-term solution for offsetting these emissions is the capture and storage of carbon dioxide. In principle, fluid or gaseous carbon dioxide can be injected into the Earth's crust and locked up as carbonate minerals through chemical reactions with calcium and magnesium ions supplied by silicate minerals. This process can lead to near-permanent and secure sequestration, but its feasibility depends on the ease and vigour of the reactions. Laboratory studies as well as natural analogues indicate that the rate of carbonate mineral formation is much higher in host rocks that are rich in magnesium- and calcium-bearing minerals. Such rocks include, for example, basalts and magnesium-rich mantle rocks that have been emplaced on the continents. Carbonate mineral precipitation could quickly clog up existing voids, presenting a challenge to this approach. However, field and laboratory observations suggest that the stress induced by rapid precipitation may lead to fracturing and subsequent increase in pore space. Future work should rigorously test the feasibility of this approach by addressing reaction kinetics, the evolution of permeability and field-scale injection methods. [10]

**Flaathen .T.K et al.(2009)** A detailed study of the chemical composition of the groundwater surrounding the Mt. Hekla volcano in south Iceland was performed to assess fluid evolution and toxic metal mobility during CO<sub>2</sub>-rich fluid basalt interaction. These fluids provide a natural analogue for evaluating the consequences of CO<sub>2</sub> sequestration in basalt. The concentration of dissolved inorganic C in these ground waters decreases from 3.88 to 0.746 mmol/kg with increasing basalt dissolution while the pH increases from 6.9 to 9.2. This observation provides direct evidence of the potential for basalt dissolution to sequester CO<sub>2</sub>. Reaction path calculations suggest that dolomite and calcite precipitation is largely responsible for this drop in groundwater dissolved carbon concentration. The concentrations of toxic metal(loid)s in the waters are low, for example the maximum measured concentrations of Cd, As and Pb were 0.09, 22.8 and 0.06 nmol/kg, respectively. Reaction path modelling indicates that although many toxic metals may be initially liberated by the dissolution of basalt by acidic CO<sub>2</sub>-rich solutions, these metals are reincorporated into solid phases as the groundwaters are neutralized by continued basalt dissolution. The identity of the secondary toxic metal bearing phases depends on the metal. For example, calculations suggest that Sr and Ba are incorporated into carbonates, while Pb, Zn and Cd are incorporated into Fe (oxy)hydroxide phases.[11]

**Gislason .S.R et al. (2010)** analyze the thermodynamic and kinetic basis for mineral storage of CO<sub>2</sub> in basaltic rock, and how this storage can be optimized. Mineral storage is

facilitated by the dissolution of CO<sub>2</sub> into the aqueous phase. The amount of water required for this dissolution decreases with decreased temperature, decreased salinity, and increased pressure. Experimental and field evidence suggest that the factor limiting the rate of mineral fixation of carbon in silicate rocks is the release rate of divalent cations from silicate minerals and glasses. Ultramafic rocks and basalts, in glassy state, are the most promising rock types for the mineral sequestration of CO<sub>2</sub> because of their relatively fast dissolution rate, high concentration of divalent cations, and abundance at the Earth's surface. Admixture of flue gases, such as SO<sub>2</sub> and HF, will enhance the dissolution rates of silicate minerals and glasses. Elevated temperature increases dissolution rates but porosity of reactive rock formations decreases rapidly with increasing temperature. Reduced conditions enhance mineral carbonation as reduced iron can precipitate in carbonate minerals. Elevated CO<sub>2</sub> partial pressure increases the relative amount of carbonate minerals over other secondary minerals formed. The feasibility to fix CO<sub>2</sub> by carbonation in basaltic rocks will be tested in the CarbFix project by: (1) injection of CO<sub>2</sub> charged waters into basaltic rocks in SW Iceland, (2) laboratory experiments,(3) studies of natural analogues, and (4) geochemical modelling. [12]

**Naganuma .T et al.(2011)** studied that the effectiveness of CO<sub>2</sub> geological storage depends on a combination of physical and geochemical trapping mechanisms. Over time, the physical process of residual CO<sub>2</sub> trapping and geochemical processes of solubility trapping and mineral trapping increase. This paper proposes a concept of enhanced mineral trapping system of CO<sub>2</sub> geological storage by means of microbially mediated processes and describes some results of related preliminary microbial experiments. [13]

**Rivera-Grau .L.M et al. (2012)** synthesized a coconut-oil modified hydroxyethyl- imidazoline and used as an inhibitor of CO<sub>2</sub> corrosion for carbon steel in 3% NaCl solution at 50°C. The testing techniques includes potentiodynamic polarization curves, linear polarization resistance, electrochemical impedance spectroscopy, and the electrochemical noise measurements by using 20 ppm of inhibitor. Results indicated that, even when the commercial imidazoline decreased the corrosion rate with efficiency higher than 400%, the coconut-oil modified imidazoline reduced the corrosion rate by more than 85%, giving promising results for using it as a green corrosion inhibitor. [14]

**Qafoku .O et al. (2012)** studied that Olivines, significant constituents of basaltic rocks, have the potential to immobilize permanently CO<sub>2</sub> after it is injected in the deep subsurface, due to carbonation reactions occurring between CO<sub>2</sub> and the host rock. To investigate the reactions of fayalitic olivine with supercritical CO<sub>2</sub> (scCO<sub>2</sub>) and formation of mineral carbonates, experiments were conducted at temperatures of 35°C to 80°C, 90 atm pressure and anoxic conditions. For every temperature, the dissolution of fayalite was examined both in the presence of liquid water and H<sub>2</sub>O

saturated scCO<sub>2</sub>. The experiments were conducted in a high pressure batch reactor at reaction time extending up to 85 days. The newly formed products were characterized using a comprehensive suite of bulk and surface characterization techniques: X-ray diffraction, Transmission/Emission Mossbauer Spectroscopy, Scanning Electron Microscopy coupled with Focused Ion Beam, and High Resolution Transmission Electron Microscopy. Siderite with rhombohedral morphology was formed at 35 °C, 50 °C, and 80 °C in the presence of liquid water and scCO<sub>2</sub>. In H<sub>2</sub>O-saturated scCO<sub>2</sub>, the formation of siderite was confirmed only at high temperature (80°C). Characterization of reacted samples in H<sub>2</sub>O-saturated scCO<sub>2</sub> with high resolution TEM indicated that siderite formation initiated inside voids created during the initial steps of fayalite dissolution. Later stages of fayalite dissolution result in formation of siderite in layered vertical structures, columns or pyramids with a rhombus base morphology. [15]

**Klein .E et.al. (2013)** quantified long-term mineral trapping at a reservoir scale for the Ketzin pilot site for CO<sub>2</sub> storage. An integrative approach coupling geochemical to reservoir simulations was therefore used which helps in reduction of computational time compared to fully coupled reactive transport simulations. Data needed for the numerical simulations is supplied by geophysical and geological investigations at the site as well as by core and fluid sample analysis. Geochemical simulations show that mineral trapping is consecutively taken over by siderite, dolomite and magnesite, whereby the effective rate of mineral reactions strongly depends on the porosity. Results at reservoir scale after 10,000 years yield continuous growth of mineral trapping with an amount of 17,000 tonnes, which is about 25% of the totally injected CO<sub>2</sub>. [16]

**Neithalath .N et.al (2014)** reported experimental results and analysis on the effect of source materials and curing conditions on mechanical properties of a unique binder system that utilizes the carbonation of metallic iron powder for cementation properties. The experiments carried out showed that waste iron powder in combination with commonly used concrete ingredients, such as fly ash, limestone powder, and metakaolin as minor components can be carbonated to produce a binding material with acceptable properties for a wide range of construction applications. [17]

### 3. CONCLUSIONS

From all the above literatures, it can be concluded that the mineral carbonation enables chemical sequestration of CO<sub>2</sub> and hence the sequestration is virtually permanent. It has also been noticed that the secondary carbonate rocks formed during mineral trapping demonstrate mechanical strength which opens up the possibility of using mineral trapping in conjunction with sustainable binder production for construction. Sequestration of CO<sub>2</sub> is possible using the iron powder only if the CO<sub>2</sub> is in aqueous state. Industrial waste iron can be utilized to trap aqueous CO<sub>2</sub> and to form a

sustainable binder for structural applications thus reducing waste as well as CO<sub>2</sub> emission.

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