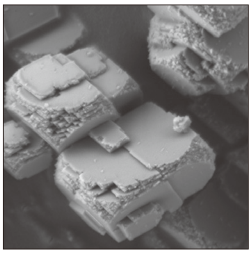

Feasibility Study of Iron Carbonate Synthesis

Masato BABA*, Tetsuya NAKAJIMA, and Toru MAEDA

To achieve carbon neutrality, it is necessary to reduce CO_2 emissions and increase the amount of CO_2 absorption simultaneously. One method to increase CO_2 absorption is through carbon recycling, which involves the production of functional materials and iron carbonate (trademark: metacol), using iron and CO_2, which have an affinity with our manufacturing sites. This paper reports on this method. We aim to utilize iron carbonate in our own products, incorporating the emitted CO_2 into material circulation and continuously isolating it from the atmosphere. Through principle verification, functional evaluation, equipment design, factory verification, and intellectual property protection, we will proceed to validate customer value. We will confirm achieving a negative CO_2 balance and profitability, and aim to contribute to carbon neutrality through carbon recycling.

Keywords: CO_2, carbon neutrality, carbon recycling, iron, functional materials

1. Introduction

Carbon neutrality refers to a state where the emissions and absorption of greenhouse gases, primarily CO_2,*1 are balanced. Achieving this requires not only reducing emissions but also increasing absorption. Methods to increase CO_2 absorption include enhanced oil recovery (EOR),*2 direct utilization of CO_2,*3 and carbon recycling.*4 [1]

Carbon recycling involves using CO_2 as a raw material for manufacturing various products such as chemicals, fuels, minerals, and others (BECCS,*5 blue carbon/marine biomass,*6 enhanced weathering,*7 reforestation,*8 etc.).[1] By using raw materials sourced through carbon recycling for production activities and recycling the CO_2 emitted back into the carbon recycling process, it is possible to continuously isolate CO_2 from the atmosphere and incorporate it into material cycles. In pursuit of the practical application of our unique carbon neutrality technology, we have explored the potential of carbon recycling to produce functional minerals from CO_2 and metals that have an affinity with our manufacturing sites. The goal is to achieve a negative CO_2 balance, where the absorption exceeds emissions, and verify the profitability.

2. What is Iron Carbonate?

Iron carbonate is a mineral composed of iron and CO_2. Iron carbonate is mined worldwide as a component of siderite,*9 a type of iron ore,[2] and also generated from green rust*10 during the corrosion process of iron.[3] Iron carbonate is also one of the end products of CCS,*11 EOR, and enhanced weathering, which are in the practical stage of methods to increase CO_2 absorption.[4],[5] Thus, absorption of CO_2 by iron occurs in nature, and the product, iron carbonate, is an unexpectedly familiar material. However, iron carbonate is not industrially produced[6] and examples of its use in carbon recycling have never been reported.

Traditionally, iron carbonate has required special conditions for synthesis.[6] On the other hand, iron carbonate is able to be synthesized under universal conditions using CO_2, iron, and water as raw materials, and is expected to be a promising technology to solve three social problems (iron recycling, CO_2 absorption, and hydrogen supply) at once.[7]

Based on these prior findings, we assumed that iron carbonate is able to be synthesized under universal conditions and is a functional material that is able to be used for our products, and verified carbon recycling to produce iron carbonate from CO_2 and iron that have an affinity with our manufacturing sites.

3. Background of the Study

3-1 Verification of the principle of iron carbonate synthesis

Iron carbonate synthesis is an exothermic reaction in which iron carbonate and hydrogen are synthesized from iron, CO_2 and water. The reaction equation is shown below.

$$Fe + CO_2 + H_2O \rightarrow FeCO_3 + H_2 + 61\ \text{kJ/mol} \quad \cdots\cdots\cdots (1)$$

First, we confirmed this reaction by experiment. A diffuser connected to an air pump was placed in a beaker, and iron powder wrapped in a nonwoven fabric was suspended above the diffuser. Water was added until the iron powder was submerged, and its position was adjusted so that it would come in contact with air bubbles generated by the diffuser when the air pump was operated. This served as the reactor.

A sealed container equipped with a power supply contained the reactor and CO_2 concentration meter, with an air pump connected to the power supply (Fig. 1).

An exhaust port and an intake port were provided in the sealed container and connected to a vacuum pump and a CO_2 cylinder, respectively. After the vacuum pump was operated to create a negative pressure in the sealed container, the CO_2 cylinder was opened and CO_2 was

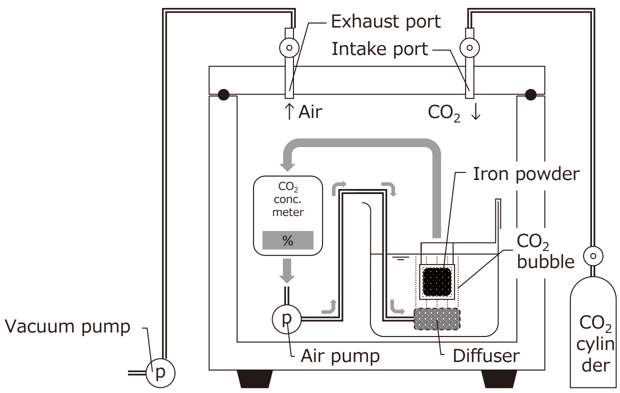

Fig. 1. Equipment to verify the principle of iron carbonate synthesis

injected repeatedly until the CO_2 concentration in the container reached 100%. When the reactor was operated, the atmosphere inside the container was bubbled by the diffuser and came in contact with the iron powder. The increase in CO_2 absorption over time was facilitated by the installation of the iron powder (Fig. 2).

To obtain iron carbonate for evaluation, the reactor was scaled up to a 300 L size and the operating time was extended to 7 days. X-ray diffraction measurements of the precipitate after the reaction indicate that only iron carbonate is present in the precipitate, with no metallic iron. In electron microscopic observations, crystals in the trigonal system were found in the precipitates, which are classified as iron carbonate (Fig. 3).

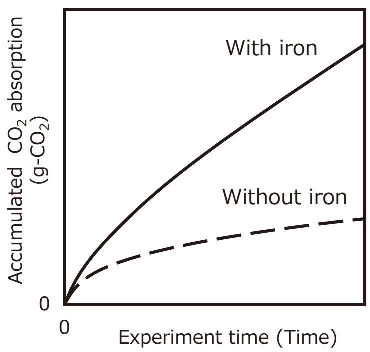

Fig. 2. CO_2 absorption reaction by iron

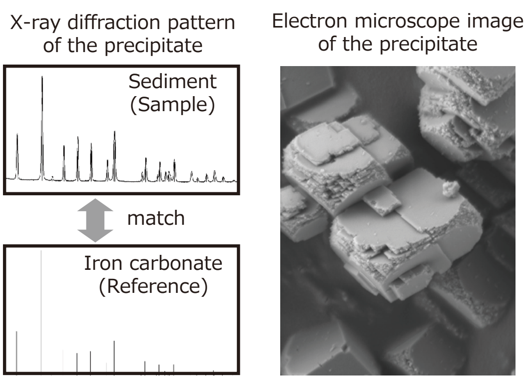

Fig. 3. Analysis results of the precipitate

The above confirms the absorption of CO_2 by iron and the synthesis of iron carbonate at ambient temperature and pressure.

3-2 Verification of iron carbonate functionality

Iron carbonate was confirmed to be safe in 9 different evaluations and was found to be an incombustible material that does not cause dust explosions. Iron carbonate also exhibited UV reflectivity and deodorizing properties. Iron carbonate was successfully filled in the resin up to 60% by weight, and the composite material improved in rigidity, heat dissipation, and nonflammability. Iron carbonate was expected to have different applications from those of iron due to its paramagnetic and other unique properties such as low electrical conductivity (Table 1).

In summary, we confirmed that iron carbonate has different functionalities from iron and can be considered as a material for use in our own products.

Table 1. Functional properties of iron carbonate

Item	Item	Representative value
Powder	safety	Confirmed through the evaluation over oral toxicity, mutagenicity, skin sensitization, skin irritation, repeated skin irritation, photoirritation, phototoxicity, eye irritation, and human patch testing
	Ammonia deodorization	Yes
	Ultraviolet and infrared Absorption	Yes
	Magnetism	Weaker than iron (paramagnetic)
	Conductivity	Smaller than iron (insulating)
	Dust explosion	No
60% resin composite material	Rigidity	Improved by Approx. 150%
	Heat dissipation	Improved by Approx. 170%
	Nonflammability	Improved by Approx. 140%

3-3 Verification of iron carbonate synthesizer

As indicated by the reaction equation for iron carbonate synthesis, flammable hydrogen gas was generated during the iron carbonate synthesis experiment. Prior to the plant demonstration, a risk was predicted that the leaked hydrogen gas could be ignited by a fire of the CO_2 emission source.

As a countermeasure, two equipment units were separately developed. One of them is the CO_2 capture and fixation unit, which converts CO_2 captured from CO_2 emission sources into carbonate and does not produce hydrogen. The other one is the CO_2 utilization unit, which synthesizes iron carbonate from carbonate and iron and produces hydrogen. This change in the process eliminated the risk of hydrogen gas ignition during the plant demonstration and allowed the captured CO_2 to be transported as solid carbonate without the use of pipelines or cylinders. At the same time, a method was demonstrated to synthesize iron carbonate from carbonate and iron without additional energy input.

The CO_2 capture and fixation equipment was installed in the plants to verify whether a negative CO_2 balance could be achieved. We verified CO_2 capture and fixation

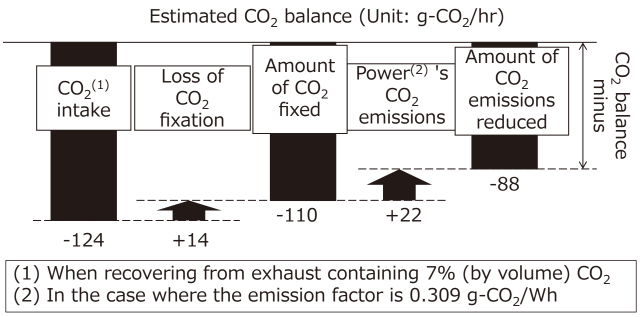

Fig. 4. CO_2 balance of CO_2 capture and fixation equipment

through factory demonstrations at the headquarters plant of Sumitomo Electric Sintered Alloy, Ltd. and the Osaka and Itami Works of Sumitomo Electric Industries, Ltd.

Based on the above, we confirmed that a negative CO_2 balance can be achieved through iron carbonate synthesis.

3-4 Protection of intellectual property

In preparation for practical application, we have applied for patents for iron carbonate materials, synthesis methods, synthesis equipment, resin composite materials and their applications, and business models. We have also applied for the trademark "metacol" for the technology brand.

3-5 Verification of customer value of iron carbonate and equipment

The CO_2 capture and fixation equipment we developed (Photo 1) is owned by Tokyu Land Corporation and installed in the "Forest Biomass Boiler" at the Tateshina Tokyu Golf Course in the Tokyu Resort Town Tateshina, run by Tokyu Resorts & Stay Co, Ltd. This equipment uses CO_2 captured from flue gas to produce golf tees and bottles & sleeves, contributing to achieving carbon negativity beyond carbon-neutrality.[8] We will continue to verify customer value of iron carbonate and equipment to confirm profitability.

Photo 1. Appearance of CO_2 capture and fixation equipment

4. Conclusion

Aiming for practical application of our unique carbon neutrality technology, we verified the possibility of carbon recycling to produce functional minerals from CO_2 and iron, which have an affinity with our manufacturing sites.

In principle verification, we confirmed the absorption of CO_2 by iron under ambient conditions and the synthesis of iron carbonate. We also confirmed that iron carbonate can be a material with different functionality from iron, leading to the design of an iron carbonate synthesis equipment and verification of a negative CO_2 balance through factory demonstrations. We protected our intellectual property in preparation for practical application.

Moving forward, we will validate the customer value of iron carbonate and the equipment to ensure profitability. Through carbon recycling that produces iron carbonate from CO_2 and iron, we aim to contribute to the achievement of carbon neutrality by balancing CO_2 emissions and absorption.

5. Acknowledgements

We would like to thank Professor Hiromi Eba of Tokyo City University for her guidance on the theory of iron carbonate synthesis.

This development was subsidized by the Osaka Prefectural Government's Carbon Neutrality Technology Development and Demonstration Project.

Technical Terms

*1 CO_2: A colorless, odorless gas at room temperature. It is released into the air through human and animal respiration and the combustion of organic matter. The solid form is dry ice. It is considered the most impactful greenhouse gas raising the average global temperature. Carbon dioxide.

*2 EOR: Enhanced oil recovery (EOR) is a technology to increase the recovery rate of crude oil. It is applied to reservoirs with low recovery rates using conventional production methods, or to production wells where production efficiency has decreased due to the passage of time since production began.

*3 Direct use of CO_2: CO_2 is used as an industrial gas in welding shield gases, as well as in the beverage and food fields, such as carbonated water, and in the medical field. It is also used for fresh preservation and transportation in the form of dry ice.

*4 Carbon recycling: The concept to reuse CO_2 as a resource for products and fuels, aiming to reduce CO_2 emissions. Benefits are expected, such as contributing to reducing global warming by recovering and reusing emitted CO_2.

*5 BECCS: A technology that combines biomass power generation with carbon capture and storage (CCS).*10

*6 Blue carbon / Marine biomass: Natural phenomenon that atmospheric CO_2 is taken up by marine ecosystems and stored in the ocean for long term. Marine biomass, specifically derived from marine algae, is one result of this process.

*7 Enhanced weathering: This technology artificially accelerates the natural action of calcium and magnesium contained in rocks to mineralize and semi-permanently fix atmospheric CO_2 as carbonates by crushing natural rocks and expanding their specific surface area.

*8 Reforestation: Technology that utilizes the action of plants to fix CO_2 into sugars using solar energy through photosynthesis.

*9 Siderite: A type of mineral composed mainly of iron carbonate (a carbonate mineral). A mineral of the calcite group, typically forming rhombohedral crystals in the trigonal system. It exhibits a glassy luster in colors like pale yellow and brown, chalybite.

*10 Green rust: A mixed-valence iron oxide mineral consisting of divalent and trivalent iron atoms formed during the corrosion process of iron.

*11 CCS: Abbreviation for carbon dioxide capture and storage, a technology for separating and capturing CO_2 and storing it underground or other geological formations.

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