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Reduction of carbon dioxide using ceramic carriers with photosynthetic bacteria in anaerobic and in ambient conditions

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This research focuses on studying whether or not it is possible to enhance carrier-bacteria compatibility and carbon dioxide reduction by using ceramic carriers under anaerobic conditions in the presence of light in order to culture the photosynthetic bacteria. It was confirmed that the highest carbon dioxide reduction of approximately 53% was shown by a sample using the highest volume of the ceramic carrier. It was confirmed that such a carbon dioxide reduction is approximately 20% more efficient compared to the sample using the medium only without the ceramic carrier, and approximately 42% more efficient compared to the sample using the ceramic carrier only without the bacteria. Accordingly, it was confirmed that the ceramic carrier and photosynthetic bacteria are compatible, and that the influence of the volume of the ceramic carrier on the carbon dioxide reduction and the continuous supply of the medium during the actual field application serve as limiting factors.

Key words: CO_2 reduction, Photosynthetic bacteria, Ceramic carriers.

Introduction

Global efforts against the intensifying global warming have been accelerating [1, 2]. While the development of industrial technology has enriched human life, increasing carbon dioxide concentration in air because of the use of fossil fuels has become an inevitable by-product, and because of this, abnormal weather phenomena including global warming have been occurring in many parts of the world. Photosynthetic bacteria such as *Thiocapsa roseopersicina* and *Chromatium vinosum* are known to use this carbon dioxide in their metabolism, and are being used in diverse environment improvement fields such as atmospheric carbon dioxide reduction, food factory waste water treatment, and organic waste treatment [3-5]. Research on such photosynthetic bacteria has been actively conducted in Korea as well as in many other nations for applications to various fields. However, research for reducing the atmospheric carbon dioxide in order to use such photosynthetic bacteria in the construction field and in construction materials, in particular, still needs to progress further. Accordingly, in this study, the ceramic carrier produced from the bottom ash and dredged soil produced from the power plants was used to confirm its compatibility with the photosynthetic microorganism as well as to confirm carbon dioxide reduction. In order to use bio/ceramic materials in the field, carbon dioxide reduction was analyzed without using a 27s medium, which provides nutrition to the bacteria. Although there are several barriers to the efficient carbon dioxide reduction using bio/ceramic materials, this research is expected to serve as a basis for global reduction of carbon dioxide using these materials.

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Materials and Method

Ceramic carrier

The ceramic carrier used in this experiment was produced by sieving the artificial lightweight aggregate (LWA) produced by recycling bottom ash and dredged soil produced from the Y power plant located in Korea into 5-10 mm sizes, drying such sieved artificial LWA after cleaning it a few times with distilled water and removing dust from it. The pH after adding 5 g of the ceramic carrier into a beaker filled with 100 ml distilled water was 7.0 ± 0.1, and the water adsorption rate of the ceramic carrier was 4-5%.

Photosynthetic bacteria

In this experiment, *Rhodopseudomonas pentothenatexigens* AE8-5 (hereinafter referred to as the 'photosynthetic bacteria'), which falls under the category of *rhodospirillaceae* (non-sulfur purple bacteria), acquired from the Korea National Environmental Microorganisms Bank (KEM) was used as the photosynthetic bacteria. As an electron donor, such photosynthetic bacteria are known to use diverse organic matters such as hydrogen to fix carbon dioxide under anaerobic conditions in the presence of light [3-5]. In addition, such photosynthetic bacteria are known to grow and develop not only under

Table 1. Composition of 27s medium.

Composition	Amount
Yeast extract	1.0 g
Trisodium citrate dehydrate	1.0 g
Sodium thiosulfate anhydrous	1.0 g
Absolute ethanol	0.5 ml
KH_2PO_4	0.5 g
$MgSO_4 \cdot 7H_2O$	0.4 g
NaCl	0.4 g
NH_4Cl	0.4 g
$CaCl_2 \cdot 2H_2O$	0.05 g
Trace element solution SL-6	1 ml
L-cysteine	0.035 g
Distilled water	1 L
pH	7.0

anaerobic conditions, but also under other conditions (light-existent/light-non-existent conditions and aerobic/anaerobic conditions) [6]. The 27s medium was inoculated with such a synthetic bacteria for culturing under light-existent anaerobic conditions. As the name indicates, the color of the medium turns red when proliferation is successful and brown when the proliferation is unsuccessful [7].

Medium and culture condition

The photosynthetic bacteria were cultured in the 27s medium, and Table 1 shows its composition. One gram of yeast extract was added to the 27s medium per liter of triple distilled water in order to supply the vitamins required for culturing the bacteria, and 1.0 g of trisodium citrate dehydrate was added as the organic matter. In addition, 0.025 g of L-cysteine was added as the agent for reducing the dissolved oxygen.

Subculture

When the bacteria proliferate for a long time within the limited medium, the proliferation process terminates because of the lack of space or nutrients. To prevent this from happening and to carry on the line of the bacteria acquired from KEM, the subculture process was conducted by inoculating a new medium with the centrifuged bacteria every two weeks, and the composition of the medium is as shown in Table 1.

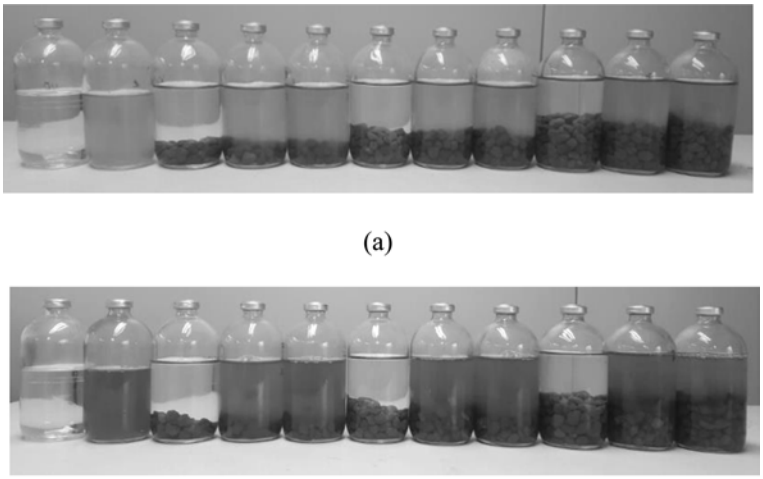
Confirming carbon dioxide reduction

In this experiment, the 27s medium and ceramic carrier were inserted into a 165 ml sealable transparent glass bottle in order to confirm whether or not the bio-ceramic material consisting of the photosynthetic bacteria and ceramic carrier is capable of reducing carbon dioxide. At this point, the purging process was conducted on 100 ml of the medium, 0.5 g/l of the bacteria, and carbon dioxide to fix the carbon dioxide tension (hereinafter referred to as 'Pco_2'). The control group was cultured in a shaking incubator (25-30 ºC, pH 7, 6000 lux, 120 RPM. The reference group was not inoculated with the bacteria, and the remaining conditions were identically applied.

Results and Discussion

Influence of volume of ceramic carrier

It is difficult to assume that the results obtained from



(a)

(b)

Fig. 1. Photographs of specimen 165 ml bottles using 27s medium, bacteria, and ceramic aggregates according to time. The first glass bottle from the left: 100 ml medium only, second bottle: medium and 0.5 g/l bacteria, third bottle: medium with 20 g ceramic aggregate, fourth and fifth bottles: medium with 20 g ceramic aggregate and 0.5 g/l bacteria, sixth bottle: medium with 40 g ceramic aggregate, seventh and eighth bottles: medium with 40 g ceramic aggregate and 0.5 g/l bacteria, ninth bottle: medium with 60 g ceramic aggregate, tenth and eleventh bottles: medium with 60 g ceramic aggregate and 0.5 g/l bacteria. Each bottle equals P_{CO_2} (a) 0 days after inoculation, (b) 3 days after inoculation.

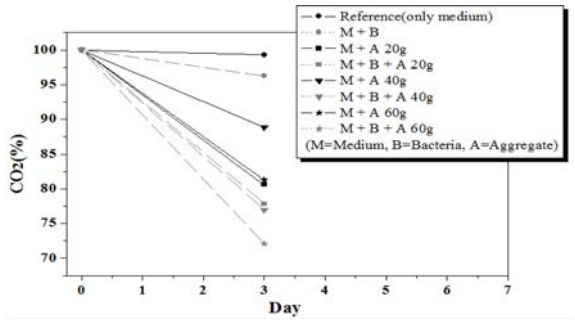


Fig. 2. GC-TCD analyses of the specimens shown in Fig. 1.

the preexisting research [8] were influenced by a single variable, since the influence of the volume of the ceramic carrier on the carbon dioxide reduction was confirmed without fixing the Pco_2. Accordingly, in this study, Pco_2 was fixed through the carbon dioxide gas purging process, and the volume of the ceramic carrier used as the variable was set to 0 g, 20 g, 40 g, and 60 g (Fig. 1).

Fig. 1 shows that as the culture period increased, the medium became a darker red color because of the proliferation of the photosynthetic bacteria. Through this process, it was confirmed that the bacteria proliferated well. In addition, it was also confirmed that the ceramic carrier had no negative influence on the proliferation of the bacteria. The results obtained from the GC-TCD analysis according to the culture period are shown in Fig. 2.

As shown in Fig. 2, it can be confirmed that the carbon dioxide reduction increases as the volume of the ceramic carrier increases. Three days after inoculation, the sample to which 60 g of the ceramic carrier was added indicated an approximate carbon dioxide reduction of 28%, which is 24% more efficient compared to the sample to which no ceramic carrier was added. During the 24 hrs following six days after inoculation, the temperature setting of the incubator unexpectedly changed to -25 °C, partially freezing the sample, and no additional experiments were conducted. Hence, results for seven days after inoculation are not shown. Accordingly, in order to re-conduct the experiment, the frozen bacteria cultured within the incubator was subcultured, then proliferated for 2 weeks, and used in the re-conducted test. Fig. 3 shows the experiments conducted under conditions identical to those used for conducting experiments shown in Fig. 2. In this experiment, it was reviewed whether or not it is possible to reuse the bacteria frozen at -25 °C.

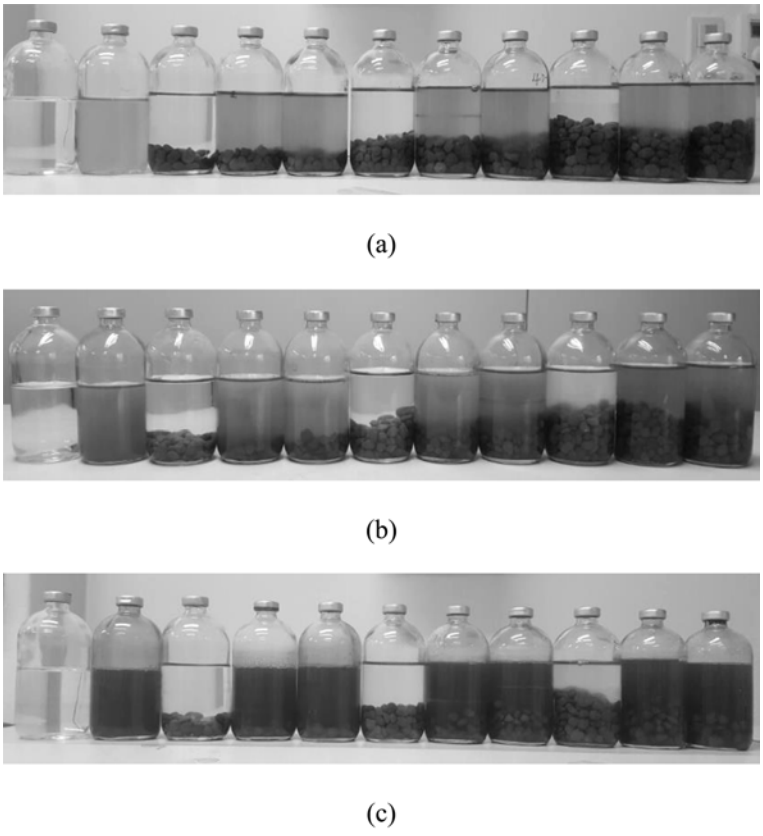


Fig. 3. Photographs of specimen 165 ml bottles using 27s medium, bacteria, and ceramic aggregates according to time. First glass bottle from the left: 100 ml medium only, second bottle: medium and 0.5 g/l bacteria, third bottle: medium with 20 g ceramic aggregate, fourth and fifth bottles: medium with 20 g ceramic aggregate and 0.5 g/l bacteria, sixth bottle: medium with 40 g ceramic aggregate, seventh and eighth bottles: medium with 40 g ceramic aggregate and 0.5 g/l bacteria, ninth bottle: medium with 60 g ceramic aggregate, tenth and eleventh bottles: medium with 60 g ceramic aggregate and 0.5 g/l bacteria. Each bottle equals P_{CO_2}. (a) 0 days after inoculation, (b) 3 days after inoculation, and (c) 7 days after inoculation.

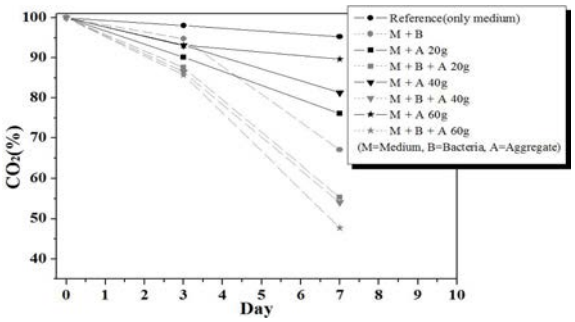


Fig. 4. Results of GC-TCD analyses of the specimens shown in Fig. 3.

As shown in Fig. 3, although the bacteria was exposed to conditions where it was extremely difficult for the bacteria to survive, upon reusing the bacteria after the subculture process, the color of the sample turned red according to the culture period, and this proves that the proliferation process was successful. Through this it was determined that as long as the photosynthetic bacteria survives extreme weather conditions during actual application, and as long as the conditions are again satisfied, the bacteria may continue to proliferate again, and thereby, continuously decrease the atmospheric carbon dioxide concentration.

By comparing the carbon dioxide reduction three days after inoculation, shown in Fig. 2 and Fig. 4, it was confirmed that the absolute value varied, but the sample using the ceramic carrier and bacteria indicated a similar pattern of high reduction. The sample using 60 g of ceramic carrier showed an efficiency of 29% in Fig. 2 only showed an efficiency of 14%, as shown in Fig. 4. It was determined that the absolute value reduced because the experiment was conducted again by subculturing the bacteria that showed low activity because of its exposure to extreme conditions. However, it was also determined that maintaining approximately half the carbon dioxide reduction even after exposure to extreme conditions may be useful in case of actual application.

The sample using 60 g of ceramic carrier and 0.5 g/l bacteria indicated the highest carbon dioxide reduction of 52.75% seven days after inoculation. This was 42.4% more efficient than the sample using the ceramic carrier only. In addition, when compared to the sample using the bacteria only, its reduction was 19.78% more efficient. Through such results, it was confirmed that the highest efficiency occurs when both the bacteria and ceramic carrier are used.

Carbon dioxide reduction without medium

Based on the theory that carbon dioxide reduction is more efficient when both the bacteria and ceramic carrier are used, carbon dioxide reduction was conducted under medium-free conditions to confirm whether it can be used in the field. For the control group, 280 ml glass bottles using 200 ml of medium and 120 g of ceramic carrier was inoculated with 0.05 g of bacteria. For the reference group, 165 ml bottles using 100 ml of medium and 20 g, 40 g, and 60 g of ceramic carrier were sealed. Carbon dioxide purging was conducted on all samples, and the samples were then cultured for seven days in the incubator. The cultured samples are shown in Fig. 5.

Fig. 5. Photographs of specimen using 27s medium (a) Reference group: 165 ml glass bottles using 100 ml medium and 20, 40, 60 g aggregates (b) Control group: 280 ml glass bottles using 200 ml medium and 120 g aggregates with 0.5 g/l bacteria.

Fig. 6. Photographs of specimens three days after removing medium. The first three bottles from the left: culture on 100 ml medium and 20 g aggregates with 0.5 g/l bacteria, the next three bottles: culture on 100 ml medium and 40 g aggregates with 0.5 g/l bacteria, the last three bottles: culture on 100 ml medium and 60 g aggregates with 0.5 g/l bacteria. Each bottle has the same P_{CO_2} and culture period.

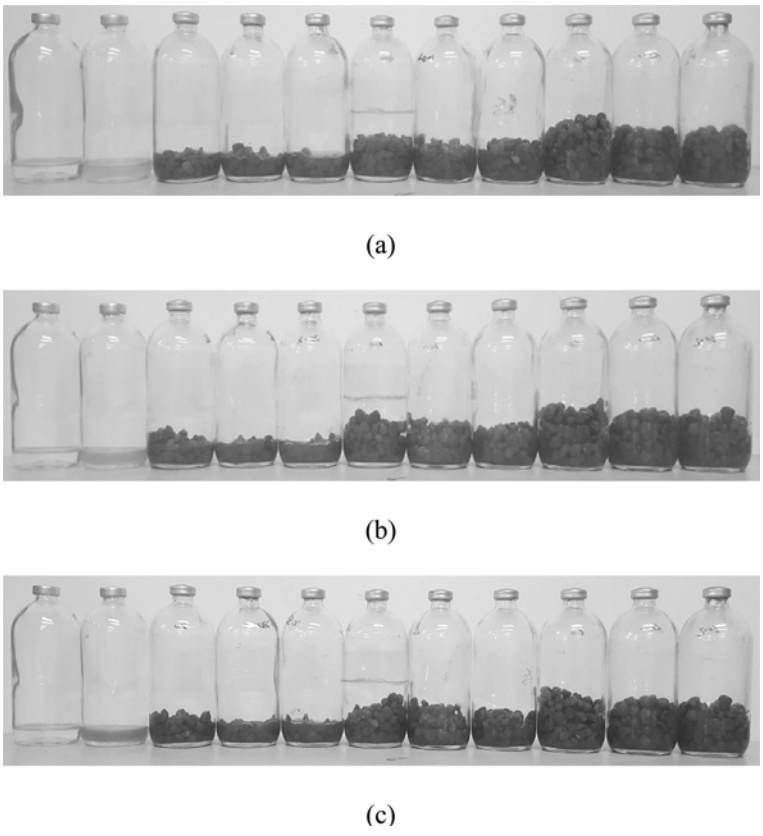


Fig. 7. Photographs of specimen 165 ml bottles using 27s medium, bacteria, and ceramic aggregates with time. First glass bottle from the left: 10 ml medium only, second bottle: medium and 0.5 g/l bacteria, third bottle: medium with 20 g ceramic aggregate, fourth and fifth bottles: medium with 20 g ceramic aggregate and 0.5 g/l bacteria, sixth bottle: medium with 40 g ceramic aggregate, seventh and eighth bottles: medium with 40 g ceramic aggregate and 0.5 g/l bacteria, ninth bottle: medium with 60 g ceramic aggregate, tenth and eleventh bottles: medium with 60 g ceramic aggregate and 0.5 g/l bacteria. Each bottle equals P_{CO_2}. (a) 0 days after inoculation, (b) 3 days after inoculation, (c) 7 days after inoculation.

Fig. 5 shows (a) the reference group and (b) the control group. As a result of visually comparing the bacteria proliferation level of the samples shown in Fig. 1(b) and Fig. 3(c) seven days after the culture process, for this experiment, it was indirectly confirmed through the less darker red color that the proliferation process was not as active. It was determined that although the culture process was conducted under conditions where the volume of the medium and the volume of the ceramic carrier were doubled, such a result is influenced by the bottle size or other variables (brightness and bacteria activity level), which is different from the previous experiment. The samples cultured for seven days were taken out from the ceramic carrier and sieved for a minute to remove the medium. Then, 20 g, 40 g, and 60 g of the sieved samples were inserted and sealed into 165 ml glass bottles. In addition, carbon dioxide purging was conducted, and the appearance of the samples is as shown in Fig. 6.

As shown in Fig. 6, samples containing only the ceramic carrier without removing the medium from them were prepared, and the GC-TCD analysis was conducted immediately after and three days after inoculation. No carbon dioxide reduction was observed. Different from the assumption that the bacteria will be

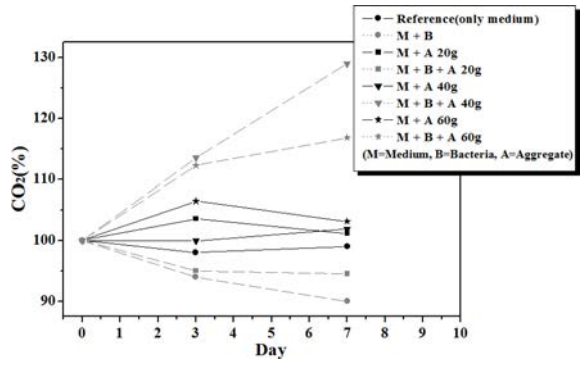


Fig. 8. Results of GC-TCD analyses of the specimens shown in Fig. 7.

adsorbed onto the pore and the surface of the ceramic carrier, and will become active under medium-free conditions because of the low pore adsorption percentage (4-5%), only an insufficient volume of the medium and bacteria were adsorbed, and because the adsorbed medium was used as the nutrient throughout the seven days of the bacteria proliferation process, there was an insufficient volume of nutrient in the remaining medium required for the proliferation process. In addition, it approximately takes from 3-4

weeks to a few months to form a bio-film on the surface of the ceramic carrier. However, since the culture period was shorter than this, it was not long enough to form a bio-film on the surface of the ceramic surface, and only an insufficient volume of the bacteria was adsorbed onto the surface of the ceramic carrier [9]. Hence, in the next experiment, 10 ml of the medium was additionally added to allow the bacteria to be continuously cultured, and the process is as shown in Fig. 7.

As shown in Fig. 8, different from the previous experiment where carbon dioxide was not fixed under the medium-free conditions because of the inactivation of the bacteria, the sample using the medium and 20 g of ceramic carrier showed an approximate carbon dioxide reduction of 10% seven days after inoculation. This result could be seen as evidence that the bacteria have been adsorbed onto the ceramic carrier through the seven days of the culture period. This is because of the supply of new medium allowed the bacteria adsorbed onto the ceramic carrier to use the nutrient matter within the medium to remain active continuously. Accordingly, it was confirmed that it is difficult to remove carbon dioxide while completely isolating the medium that supplies the nutrient matter required by the bacteria, and that supplying a small volume of the medium re-activated the bacteria, and thereby, allowed them to remove the atmospheric carbon dioxide. The continuous supply of the medium serves as the limiting factor in applying the bio/ceramic carrier used in this research in real applications. Additional research must be conducted in order to overcome this barrier.

Conclusions

The purpose of this research was to examine the influence of the volume of the ceramic carrier on the carbon dioxide reduction when used along with a photosynthetic bacteria of bacteria for removing carbon dioxide under anaerobic conditions in the presence of light, and to examine the carbon dioxide reduction under medium-free conditions through actual field application.

When bottles with 100 ml of medium and 20 g, 40 g, and 60 g of ceramic carrier were inoculated with the bacteria, the carbon dioxide reduction increased as the volume of the ceramic carrier added increased, and the sample to which 60 g of ceramic carrier was added showed the highest carbon dioxide reduction of 53% seven days after inoculation. Although the photosynthetic bacteria were accidently exposed to the extreme condition of -25 ^{o}C for 24 hrs, a similar result, but with a smaller value of carbon dioxide reduction, was obtained through subculturing the bacteria. Accordingly, it was determined that, in an actual case, the photosynthetic bacteria exposed to extreme conditions, such as winter seasons, would continue to proliferate once the conditions required for the proliferation process become optimum. The carbon dioxide reduction indicated by the bacteria subcultured after exposure to extreme conditions were identical to those indicated by the bacteria never exposed to extreme conditions.

The bacteria cultured with the ceramic carrier under medium-free conditions for a week showed no carbon dioxide reduction. However, it showed an approximate carbon dioxide reduction of 10% when 10 ml additional medium was supplied. It seems this is because the bacteria adsorbed onto the ceramic carrier continue to proliferate again as the medium is re-supplied. Accordingly, this signifies that it is essential to continuously supply the medium for continuous carbon dioxide reduction, and it was determined that this will serve as a barrier to the actual application of the bio/ceramic carrier used in this experiment. However, this is considered as one of the barriers to overcome in order to reduce carbon dioxide, and it is necessary to continue this research further.

This research is significant in that it serves as a foundation for future studies. It was confirmed that using the photosynthetic bacteria along with the ceramic carrier is more effective in reducing carbon dioxide than using the bacteria alone, and that the bacteria exposed to extreme conditions can continue to proliferate again in future as long as the required conditions are once again satisfied. In the future, provided that a study for developing a ceramic carrier that shows high bacteria compatibility, highly proliferation rate, and high medium capacity is conducted, it would be possible to develop an outstanding bio/ceramic material that can be used in the actual field for efficient carbon dioxide reduction in the not too distant future.

Acknowledgments

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