ISSN: 2639-7536

Short Communication

Petroleum and Chemical Industry International

Novel Method for CO_2 Fixation and Storage Preventing Climate Crisis: an "Artificial Forest" Model

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Submitted: 29 Dec 2021; **Accepted:** 03 Jan 2022; **Published:** 17 Jan 2022

Citation: *Kenji Sorimachi. (2022). Novel Method for CO_2 Fixation and Storage Preventing Climate Crisis: an "Artificial Forest" Model. Petro Chem Indus Intern, 5(1), 01-04.*

Abstract
In the previously developed method using low NaOH and $CaCl_2$ concentrations, the atmospheric CO_2 is simply fixed to $CaCO_3$ and NaCl, which exist as coal or limestone, and a large chamber comprising spray nozzles to capture CO_2 efficiently by mists or droplets of NaOH solution has been designed. In the present study, a polytunnel made of polymer sheets, an "artificial forest" model, which allows CO_2 penetration instead of the chamber has been proposed. Additionally, using tunnels, mine galleries, and caves instead of polytunnels or hard chambers, an extremely huge space wherein a large amount of CO_2 can be captured efficiently would be prepared without environmental concerns, and this model is definitely practical and economical for direct air capture, and it is consistent with the sustainable development goals (SDGs). Using a miniature polytunnel, the atmospheric CO_2 could be captured efficiently.

According to recent news, we do not doubt that climate change has progressed throughout the globe. Torrential rains caused severe flooding in Europe. A few days ago (2021, early December), one of the largest tornadoes in history attacked the Kentucky region, including several nearby states and causing enormous damages. Additionally, glaciers are melting rapidly worldwide. Recently, in Japan, the meteorological agency has issued several warnings about severe torrential rains that strike once every 50 or 100 years, whereas severe debris flows attacked mountain areas every year. Based on scientific evidence for the relationship between global temperature, atmospheric carbon dioxide (CO_2) increases, and hydroclimate changes, the intergovernmental panel on climate change concluded on August 9th, 2021, that climate change has been caused by human activities that have produced CO_2 since the industrial revolution [1-4].

Although Earth has undergone many periods of significant environmental change over time, the planet's environment has been unusually stable for the past 10,000 years [5]. During this time, various natural systems regulated the Earth's climate and maintained the conditions that enabled human development. However, these regulatory systems have been greatly disturbed, and the planet may be nearing a threshold beyond which unpredictable environmental changes may occur, such as increases in the mean global temperature [6]. To reduce atmospheric CO_2 concentrations as a means of mitigating such effects, the so-called Paris Agreement was reached at the United Nations Climate Change Conference (COP20) in 2015. This agreement was based on the requirement to keep the increase in the mean global temperature below 2 °C relative to the temperature prior to the Industrial Revolution, and preferably less than 1.5 °C. At present, this goal is challenging based solely on the development of carbon-neutral energy systems.

None denying that atmospheric CO_2 concentrations on Earth have increased since the industrial revolution began ~200 years ago, with the invention of steam engines using fossil coal as fuel and internal combustion engines using oil and our present developed civilization has owed to these technical inventions. However, we have paid little attention to the effect of increased atmospheric CO_2 concentration for a long time, while the young generation represented by a Swedish high school student, Greta Thunberg, led to climate change activities "Friday for Future" events as global movements. Unfortunately, this movement would not reach all people on the planet. One of the reasons is our high tolerance of CO_2 concentration in our daily lives. The atmospheric CO_2 concentration in a house room is ~400 ppm, but it easily doubles in the presence of several persons in the same room without ventilation. Even under high CO_2 concentrations of ~1,000 ppm for a certain time in a confined space, our lives do not show any abnormal symptoms. Eventually, many people would be insensitive to a small increase in atmospheric CO_2 concentration, although this small change can be induced climate change crises on Earth. Eventually, certain many people have insisted that climate change is a myth.

The 7th G summit was held in Cornwall, England, on June 12–13, 2021, with climate change being one of the main themes.

Electric vehicles have been developed and used instead of ordinary automobiles using gasoline, to reduce atmospheric CO_2 concentrations. While electric vehicles do not exhaust CO_2 directly into the atmosphere, the current electricity generated by renewable energy is insufficient to power electric vehicles. However, hydrogen vehicles have been developed, although the cost is expensive. Indeed, hydrogen usage does not exhaust CO_2; however, its production process using brown coal and high-temperature water produces a significant amount of CO_2, except for the electrolysis of water. Additionally, because nuclear power plants are one of energy sources that do not emit CO_2 into the atmosphere, they can contribute to reducing the atmospheric CO_2 concentration. However, nuclear plants cannot directly capture the accumulated CO_2 in the present atmosphere. In other words, nuclear power plants cannot immediately contribute to improving climate change at present.

CO_2 can be captured from the atmosphere or from flue gas via several techniques, including absorption, adsorption, and membrane gas separation [7-14]. Absorption with amines is currently the dominant technology, while membrane and adsorption processes are still in the developmental stages with the construction of primary pilot plants anticipated in the future. Synthetic membranes are useful for desalination, dialysis, sterile filtration, food processing, dehydration of air, and other industrial, medical, and environmental applications because of their energy requirements, compact design, and mechanical simplicity. In addition, biopolymer cellulose membrane can be used instead of synthetic membranes because they have similar characteristics [15-17]. Recently, we developed a novel method for CO_2 fixation and storage [18]. This method is based on simple chemical reactions involving sodium hydroxide (NaOH) and calcium chloride ($CaCl_2$). Using low concentrations of these chemicals prevented the formation of Ca $(OH)_2$ in the absence of CO_2 but resulted in calcium carbonate ($CaCO_3$) formation in the presence of CO_2 bubbling.

To show the rapid CO_2 fixation based on the low concentration of NaOH and $CaCl_2$, the precipitation reaction was conducted on the slide glass. The clear droplet (100 µl) consisting of 0.05 N NaOH and 0.05 M $CaCl_2$ was spread on the slide glass, and left in the room. $CaCO_3$ precipitates were clearly formed on the droplet surface even after 1 min, and then increased time dependently (Figure 1). Precipitate formation apparently reached to plateau level at 3 min. This result indicates that the atmospheric CO_2 was rapidly captured to form $CaCO_3$ precipitates. Note that the products of our developed method are $CaCO_3$ and NaCl, which naturally exist as coral or limestone. Moreover, CO_2 fixation could be achieved without any external addition of chemicals using seawater instead of NaCl electrolysis and $CaCl_2$. We proposed a large chamber comprising spray nozzles to fix CO_2 efficiently by mists or droplets of the NaOH solution [18]. Using a polytunnel made of polymer sheets (an artificial forest), which allows CO_2 penetration, instead of the chamber could be cost effective (Figure 2). This simple polytunnel model, which is constructed with polymer sheets instead of hard materials, such as steel, ceramic and plastic, could significantly cut the construction cost [19]. In this case, solar panels can be replaced as polytunnel roofs. Using a miniature of polytunnel (420 L) equipped a nozzle, which forms mist could simply reduce atmospheric concentration (~500 ppm) to 80 ppm for 15 min (Figure 3). Additionally, using tunnels, mine galleries, and natural caves instead of polytunnels or hard reaction chambers, an extremely huge space wherein a large amount CO_2 can be captured efficiently would be prepared without environmental concerns, and this system does not need external air supply because of the self-diffusion of CO_2 through their gates. This model is definitely practical and economical for direct air capture, and it is consistent with the sustainable development goals (SDGs).

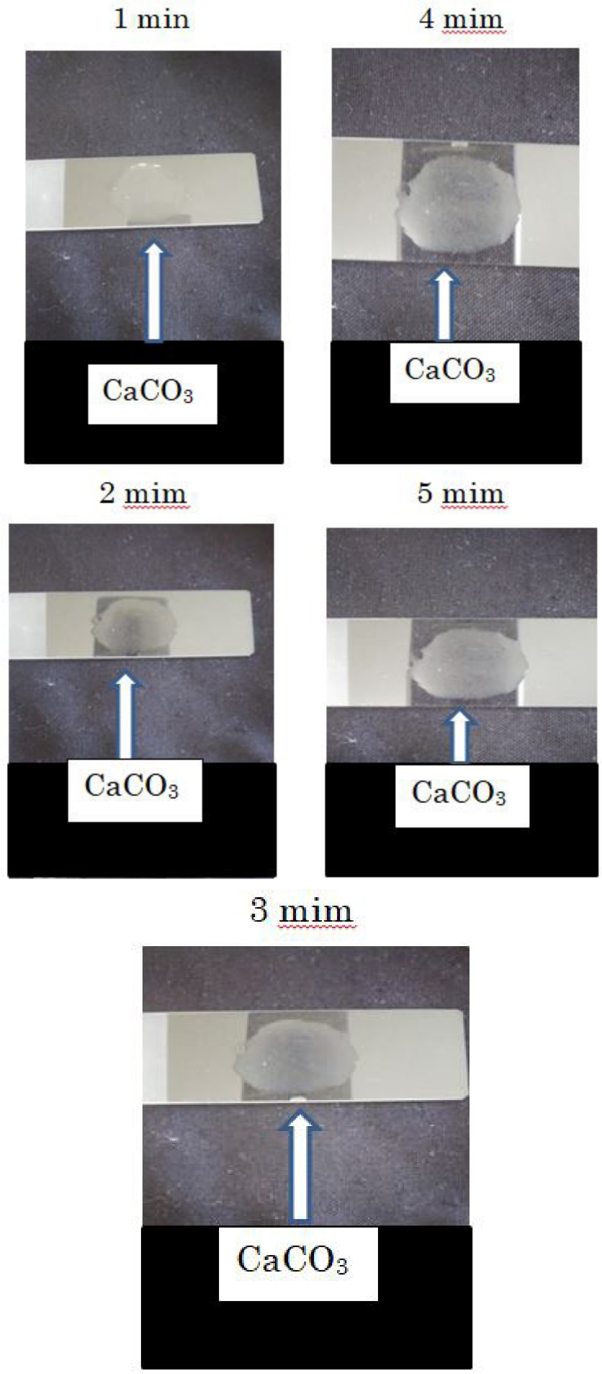

Figure 1. Calcium carbonate ($CaCO_3$) precipitate formation on slide glass. A droplet (100 µl) consisting of 0.05 N NaOH and 0.05 M $CaCl_2$ was spread on the slide glass, and then left in the room. The photos were taken by a cellular phone after 1, 2, 3, 4 and 5 min.

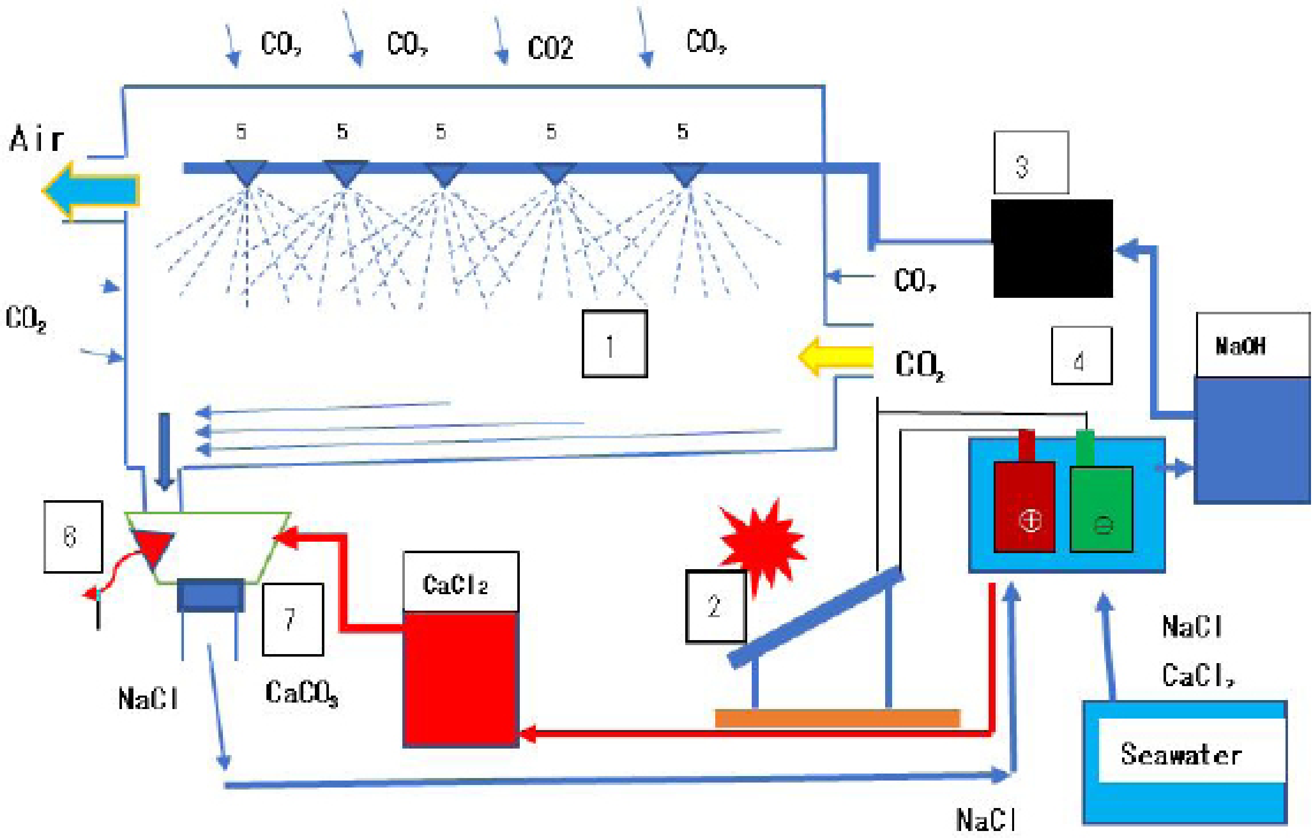

Figure 2: Schematic model using polytunnel for CO_2 fixation. 1); Polytunnel, 2); Solar panel, 3); Pump, 4); Electrolysis Chamber, 5); Nozzle, 6); Sensor and 7); Filter

Figure 3: Photo of polytunnel equipped with mist former. The miniature polytunnel (69 x 49 x 124 cm), FGH 124, was purchased from CAINZ, and a set of mist former which was constructed with a nozzle and 0.8 LPM direct drive pump, #7527, was purchased from Green Com. Japan.

CO_2 storage, geo-sequestration by injecting CO_2 into underground geological formations, such as oil fields, gas fields, and saline formations, has been suggested, although these systems are still projects for the future. However, the proposed method can achieve both CO_2 fixation and storage [18] simultaneously. The combination of large scale polytunnels that spontaneously absorb CO_2 from atmosphere could be imitated like an "artificial forest" using simple and economical technology [20, 21].

Our present civilization has been obviously been created through the use of fossil fuels including coal, oil, and natural gas, and this means that our daily lives are supported by a large cohort of fossil fuel workers. To make real change, we must essentially ignore this fact. We must carry out smooth change to renewable energy from fossil energy while maintaining lifestyle and redeploying these workers. The smooth energy source transfer from fossil fuel to renewable energy sources requires renewable energy development. It contributes not only to reduction of atmospheric CO_2 concentration in the future, but also serves to reserve valuable natural energy sources for future generation. The drastic social changes imposed, however, may induce not only significant social concerns but also a slowdown of the accumulated atmospheric CO_2 reduction.

Readers in the United States of America, the People's Republic of China, India, and Japan declared that their countries would achieve a carbon-neutral society by 2050, 2060, 2070, and 2050, respectively. These achievements apparently would be effective to prevent a global climate crisis. However, we should recognize the fact that the present climate change, which has been caused by the present accumulated atmospheric CO_2 exhausted not only from our daily activities including industrial activities but also from natural phenomena even before the Industrial Revolution. Thus, accumulated atmospheric CO_2 should be reduced immediately to prevent the present ongoing rate of climate change. The concept of the carbon-neutral society by 2050 seems to be far too late.

Renewable energy production systems, such as solar radiation and wind power, can really reduce CO_2 emission into the atmosphere but cannot reduce the present accumulated atmospheric CO_2, which has induced the current climate change. Thus, using the method, which can capture most efficiently the atmospheric CO_2 not only from the present atmosphere and exhaust gases but also from the future CO_2, which will be emitted by human activities, is extremely important and should be developed as soon as possible.
The ultimate human evolution has been achieved based on the industrial revolution which has resulted in climate change. Thus, as we are responsible for this crisis, we have amoral duty to address the situation through global cooperation beyond just making changes to our economy. Everyone must recognize that both wealth and civilization would be valueless on a ruined Earth without human prosperity [22].

Competing Financial Interests

The author declares that the present data have been used to support applications to the Japan Patent Office (PTC/JP2019/03400, PTC/JP2019/045839, PTC/JP2019/045390, PTC/JP2019/048178, PTC/JP2020/02064, PTC/JP2020/02990, PTC/JP2020/029505, PTC/JP2020/002064, PTC/JP2020/031010, JP2021-321, 2021-090928 and 2021-126892).

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