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# Direct air capture by Kawasaki $CO_2$ Capture technology: demonstration at various climatic condition using novel amine solid sorbent

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**Abstract**

Direct Air Capture (DAC) is a key technology for achieving a carbon-neutral society in 2050. Kawasaki Heavy Industries, Ltd. has been developing this technology since 2019, and has demonstrated tests simulating actual weather conditions and long-time tests using real air. In addition, a life cycle assessment was conducted on a carbon circulation society model for agricultural use of $CO_2$ captured by DAC, assuming a near future in 2030. The assessment revealed that the $CO_2$ feed from DAC operated with renewable energy could more decarbonize farming compared with conventional one.

*Keywords:* Direct Air Capture; DAC; Direct Air Cabon Capture and Storage; DACCS; Amine solid sorbent; Low-temperature regeneration;

## 1. Introduction

Efforts to mitigate global warming are fast increasing. In the Paris Agreement, the 1.5°C target was simply an effort goal, but it was defined as a common global target at the 2021 United Nations Climate Change Conference (COP26). Carbon-neutral technologies, such as post-combustion capture implemented in society, have been reported to be necessary but insufficient to achieve this goal. [1] Therefore, to effectively offset $CO_2$ emissions, society must adopt carbon dioxide removal (CDR) technologies, specifically bioenergy with carbon capture and storage and direct air capture and carbon storage (DACCS). Direct air capture (DAC), a technology used in DACCS, is a method for recovering $CO_2$ from the atmosphere. By storing it, negative emissions can be achieved.

Kawasaki Heavy Industries, Ltd. (KHI) is a company that constructs large-scale plants and manufactures transportation equipment such as ships and turbines for power generation. Since the 1980s, this company has been developing $CO_2$ recovery technology called Kawasaki $CO_2$ Capture (KCC) for air conditioning in closed environments such as spacecraft and aircraft. The company has developed post-combustion capture systems by applying this technology to reduce $CO_2$ emissions in the industrial sector since the 2000s. The construction of a 40 t/d scale demonstration plant at a coal-fired power plant is currently underway and is scheduled to begin testing in 2023 [2–3]. Furthermore, in 2019, KHI began developing DAC technology, which is crucial for realizing a decarbonized society [4]. Commissioned from the Ministry of the Environment, Government of Japan, the development of DAC technology

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and modeling of a carbon circulation society that uses $CO_2$ captured by DAC took place from 2019 to 2021. KHI is currently developing the DAC technology to commercialize large-scale DAC systems.

This study presents the evaluation results of the KCC–DAC technology, i.e., the operation outcomes of the DAC lab-scale test equipment under various climatic conditions. The feasibility study of using $CO_2$ captured by DAC, commercialized during the transition period before the commercialization of large-scale DACCS, is then discussed. Finally, prospects for the realization of DACCS are introduced.

## 2. Materials and system development

The KCC is a $CO_2$ capture system that uses a solid sorbent and regenerates it with low-temperature steam. A solid sorbent is a material that selectively captures $CO_2$ with retaining amines in the pores of a porous support (Fig. 1) using the same reaction mechanism as the amine solvent, i.e. carbamate and bicarbonate formation.

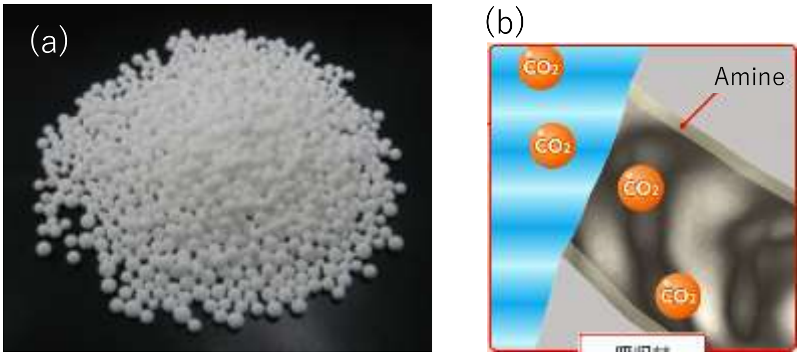


Fig. 1. (a) Solid sorbent; (b) schematic representation of the $CO_2$ capture mechanism into an impregnated amine.

After capturing $CO_2$ from the air in the absorption process, it is possible to recover the absorbed $CO_2$ by supplying low-temperature steam of about 60°C (Fig. 2). The heating temperature is lower than that of the other DAC technologies [5]; therefore, KCC technology has a high use potential for surplus waste heat.

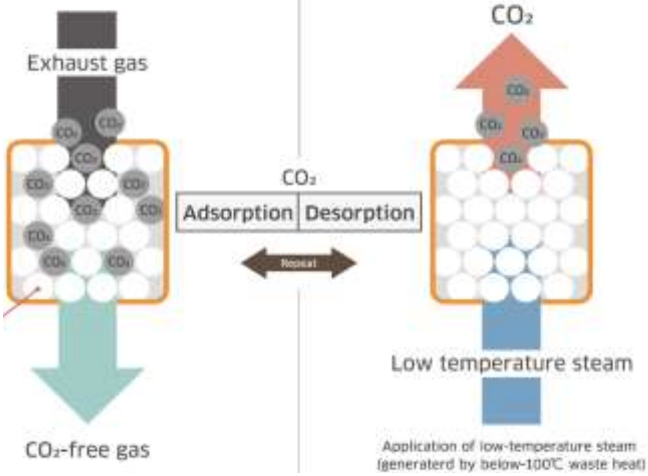


Fig 2 DAC operation by steam-aided regeneration

Because the $CO_2$ concentration is about 1/300 of the coal-fired flue gas, a solid sorbent that more stably captures $CO_2$ is required to apply the KCC system to a DAC. Therefore, an amine for DAC was developed in collaboration with the Kanomata group at Waseda University, and a $CO_2$ capture test with the solid sorbent containing the developed amine was conducted. To test the DAC operation, lab-scale test equipment was also constructed in the KHI's Akashi Works (Fig. 3a). The equipment is designed to capture 5 kg-$CO_2$/day by taking in outside air and directing it to an absorption tower. Outside air can be conditioned for a wide range of climatic conditions by passing through chillers, heaters, and humidifiers. It is also possible to supply fresh outside air without conditioning. The $CO_2$ capture operation consists of absorption and regeneration processes. First, in the absorption process, air is supplied to the absorption column and discharged out of the system after $CO_2$ absorption (Fig. 3b). At the same time, the water absorbed during the regeneration process is removed. After sufficient $CO_2$ is absorbed, the process is switched to a regeneration process, and steam is supplied to recover the desorbed $CO_2$ (Fig. 3b). Only one absorption tower, as shown in Fig. 3, provides intermittent $CO_2$ recovery, but continuous $CO_2$ recovery is possible by constructing a multitower system.

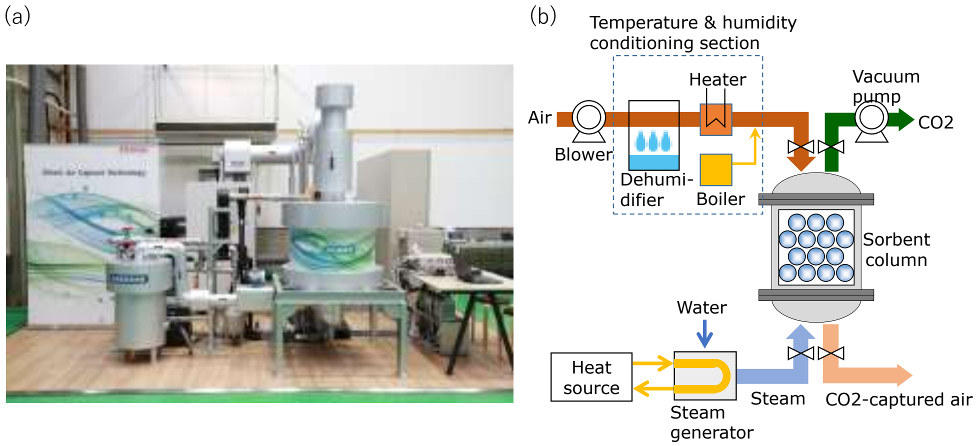


Fig. 3. (a) Lab-scale DAC test equipment; (b) Schematic illustration.

## 3. $CO_2$ capture test under various conditions

Fig. 4 shows typical test results using the lab-scale test equipment (Fig. 3). In this test, the temperature and humidity of the outside air were conditioned to the average at the installation site. In the absorption process, air was supplied to capture $CO_2$ into solid sorbent column. In the regeneration process (Fig. 4), $CO_2$ was desorbed by the steam supply, and it was confirmed that $CO_2$ could be recovered at a high concentration of up to 98.8%. At this test condition, the $CO_2$ yield was more than the designed $CO_2$ capture amount.

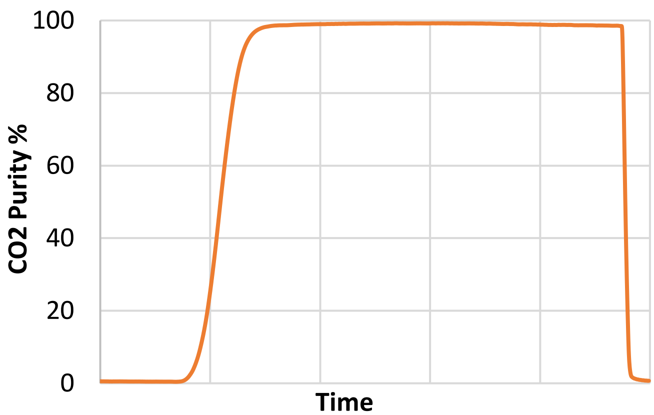


Fig. 4. Typical results of DAC operation at average temperature and humidity of the installation site

Furthermore, a 1000-h continuous $CO_2$ capture test was conducted without conditioning the outside air. Fig. 5 shows the result. The $CO_2$ capture rate exceeded the value of 5 kg-$CO_2$/day because the outside air was lower than the designed condition. The slightly decreasing trend in $CO_2$ absorption is due to the increase in the average atmospheric temperature. It was also confirmed that there was no subsequent performance decrement when the system was operated in rainy weather. The results demonstrated that DAC differs from post-combustion capture in that the $CO_2$ recovery performance is affected by outside air conditions. However, it has been proven that continuous operation is possible even with changes in temperature and humidity.

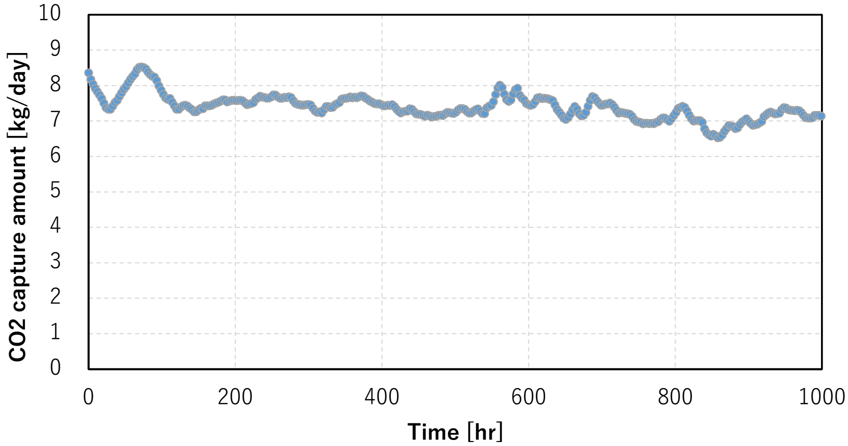


Fig. 5 1000-hour continuous operation test

## 4. summary

KHI has developed a unique DAC system that regenerates the sorbent with steam by applying post-combustion capture technology. It was confirmed that the system could operate stably at wide range of humidity and temperature, verifying the operational feasibility in various weather conditions. A 1000-h operation test using real air also demonstrated that the established system can conduct long-term stable operations.

To achieve negative emission, post processing of DAC-captured CO2 is required. A combination of effective $CO_2$ usage and DAC is considered promising in the near future, up to around 2030. To achieve a carbon-neutral society around 2050, commercialization of large-scale DACCS is crucial. Startups are leading the development of DAC, but KHI will take advantage of its ability to build sizable plants in addition to its original DAC technology to accomplish large-scale DACCS. We will continue to develop these technology for realization of carbon neutral society.

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