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CO_2 capture test for a moving-bed system utilizing low-temperature steam

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Abstract

In the process of capturing CO_2 from flue gas (combustion exhaust gas), the lowering of CO2 capture energy is considered a significant issue. If some or all of the CO_2 capture energy can be compensated with the waste heat, a significant energy saving is possible. In our proposed CO_2 adsorption process, because the CO_2 is captured using low-temperature steam, an energy-saving process that makes it is easy to utilize the waste heat can be created. In this paper, we conduct bench tests aimed at developing a moving-bed system suitable for large-scale plants in order to verify the performance of the adsorbent. The results demonstrated that an moving-bed system could be established to capture 1.6t/day of CO_2 from coal combustion exhaust gas.

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1. Introduction

Carbon capture and storage (CCS) is a core technology used as a countermeasure against global warming, and early realization is expected for that. Various methods have been developed to capture CO_2, such as liquid-absorption method, adsorbent method, and membrane-separation method, and of these, the liquid-absorption method is in operation as a CCS demonstration plants. The required energy involved in regeneration is one of the major problems in CO_2 capture technology. In the liquid-absorption method, for example, because steam of over 120 °C is required during regeneration, when applied to a thermal power plant, a 10% to 20% drop can be assumed at the power-generation end. If the thermal energy can be produced using the waste heat, a significant reduction in energy loss is possible, and the drop in power production can be avoided.

We have been involved in the development of an adsorbent to capture low-concentration CO_2 (1000 to 5000 ppm) for living spaces [1]. Using this technology as a basis, we improved the adsorbent to use with combustion exhaust gas that contains a high concentration of CO_2 (e.g., coal combustion exhaust gas: 13%) and conducted experiments on a fixed-bed bench scale [2]. Consequently, we verified that an adsorbent can remove the CO_2 from combustion exhaust gas and high-concentration CO_2 is captured by using steam at 60 °C. The results show that an energy-saving CO_2 capture system (KCC System: Kawasaki CO_2 Capture system) utilized the waste heat was established.

However, when considering its application to large-scale plants, a fixed-bed system has the disadvantages of increased numbers of towers and components. For that reason, we determined that the adoption of a moving-bed system, for which the facilities can be made more compact by adjusting such parameters as the circulating volume of the adsorbent, would make possible its application to a large-scale CO_2 source.

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2. The KCC system

2.1. CO_2 capture utilizing low-temperature steam

The adsorbent we developed is obtained by impregnating a porous material with an amine compound. The amine compound is selected because of its high affinity for CO_2, and an optimum pore size adopted for the porous material. The KCC CO_2 capture system is shown in Fig.1. During the adsorption process, when the adsorbent layer is aerated with a gas containing CO_2, CO_2 content is selectively adsorbed. The adsorbent can no longer capture CO_2 when the amount of adsorbed CO_2 reaches saturation point. In the desorption process, when steam is blown through the adsorbent layer, the CO_2 is desorbed from the adsorbent. We can capture CO_2 at a high concentration over 95%.

The greatest feature of the KCC system is that CO_2 can be captured using low temperature steam (e.g., 60 °C). Waste heat at 100 °C or lower is not used in power plant, cement plant, or other large industrial sources of CO_2 generation. Therefore, through the use of this low-temperature waste heat, we can significantly reduce the energy to capture CO_2.

2.2. KCC moving-bed system

The main equipment in the KCC moving-bed system, as shown in Fig.2, consists of the adsorption reactor, desorption reactor, and adsorbent dryer. The adsorbent circulates around these three equipment using conveying equipment, such as a conveyer that help in moving it forward, and then the adsorbent falls down due to gravity. The adsorbent first flows into the adsorption reactor, in which coal combustion exhaust gas is passed through the adsorption reactor, the CO_2 in the exhaust gas is adsorbed by the adsorbent, and the gas not containing CO_2 (CO_2-free gas) is discharged from the outlet of the adsorption reactor. The adsorbent that has adsorbed the CO_2 is then transferred to the desorption reactor. Steam is introduced to the desorption reactor, and the CO_2 in the adsorbent is then desorbed, and high-concentration CO_2 is captured from the outlet of the desorption reactor. The adsorbent with moisture content is transferred to the adsorbent dryer, where it is ventilated with dry gas, and the moisture inside the adsorbent is adjusted. The adsorbent discharged from the adsorbent dryer then flows into the adsorption reactor once to remove the CO_2 in the exhaust gas.

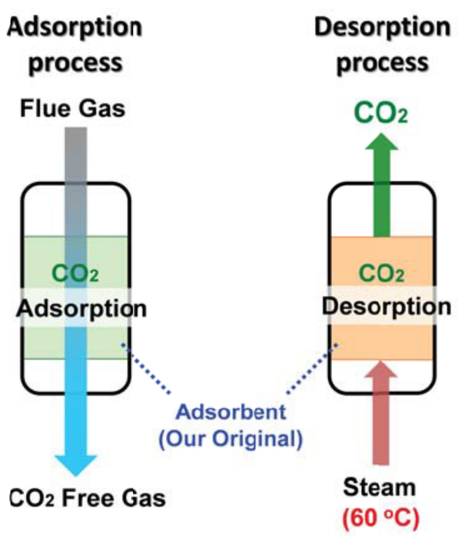

Fig. 1. The KCC CO_2 capture system.

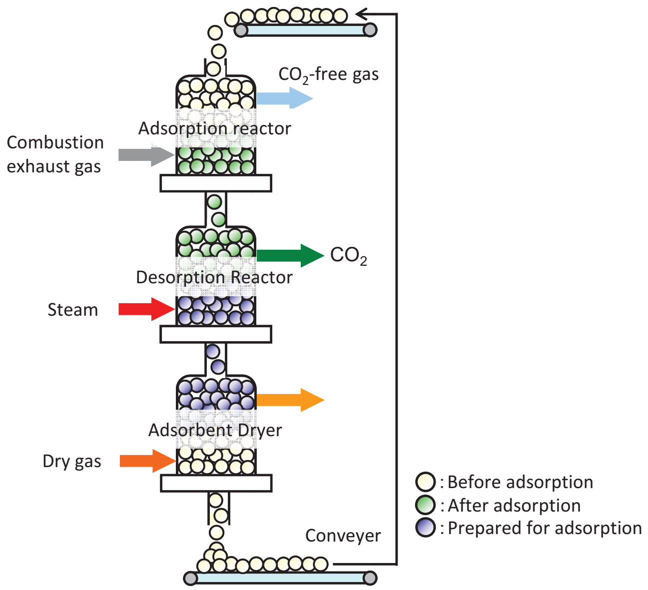

Fig. 2. Overview of the KCC moving-bed system.

2.3. CO_2 capture from a gas engine utilizing hot wastewater

To find the CO_2 capture energy needed for the KCC moving-bed system that utilizes low-temperature waste heat, a feasibility study was conducted for applying KCC system to a gas engine.

The system used in the investigation is shown in Fig. 3. Water is used for cooling engine and the water becomes hot water the temperature of which is approximately 100 °C. However, this quantity of heat is usually discarded as waste heat without being used. We studied applications the KCC system to 60°C steam generated by the waste heat of cooling water as a heat source.

In the KCC moving-bed system, electric energy is required, for example, for the conveyer to circulate the adsorbent inside the equipment. In this study, we estimated the electric power required to capture 3.2 t/h of the CO_2 discharged from a gas engine made by our company, which generates 7800 kW of electricity. Table 1 shows the conditions used in this study and calculated results for the required primary energy. The required electric power for this system was approximately 1200 kW. Electric power is shown as the value converted to primary energy with a conversion efficiency of 0.4. Converting this energy to the amount per ton of CO_2 captured, it becomes 1.3 GJ/t-CO_2.

When CO_2 is captured using the liquid-absorption method, heat energy is required for use in the regeneration and electric energy is required for operating the equipment. In the KCC moving-bed system, because waste heat is utilized as the heat energy, the value in practice is negligible.

Table 1. Conditions for the study and calculated results for the electric power.

Production of electricity	7800	kW
CO_2 recovered amount	3.2	t/h
Steam temperature	60	°C
Required primary energy	1200	kW

3. CO_2 capture test

3.1. Test equipment

To capture the CO_2 contained in exhaust gas by KCC moving-bed system, tests were performed using a bench-test plant (20 m height). The KCC moving-bed bench-test plant is shown in Fig.4.

The exhaust gas from a pulverized coal-combustion test facility was supplied to the moving-bed bench-test plant. The flow of the equipment is shown in Fig.5. The bench-test plant was consisted of an adsorption reactor, a desorption reactor, and an adsorbent dryer, with an adsorbent circulating system and a gas system comprising three systems, as described below.

The adsorbing system consisted of a condenser and a heater to adjust the temperature and humidity of the combustion exhaust gas. The exhaust gas could be supplied at a maximum flow rate of 1000 Nm^3/h, and the gas temperature could be adjusted from 10 °C up to 60 °C.

The regeneration system consisted of a boiler to generate steam, a pressure-reducing valve to adjust the temperature and pressure of the steam, water-injection equipment, and a capture pump to capture the CO_2 exiting the desorption reactor outlet. Steam could be supplied with a steam temperature from 50 °C to 100 °C, and the drying system consisted of a fan to take in outside air and a condenser and heater to adjust the temperature and humidity of the dry gas. The adsorbent was transferred in a downward direction, and inversely each gas flows.

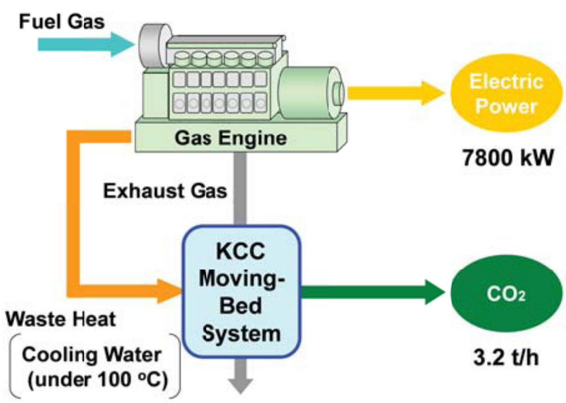

Fig. 3. KCC system utilizing hot wastewater from a gas engine.

Fig. 4. Appearance of the KCC moving-bed bench-test plants.

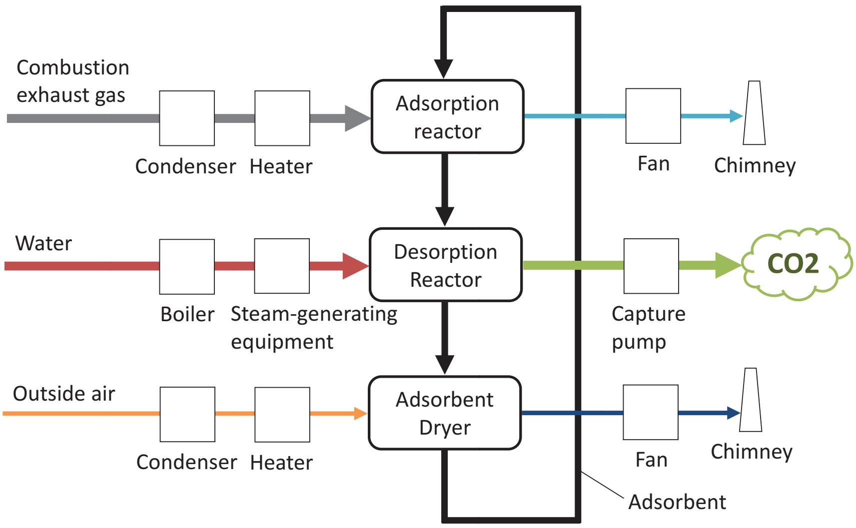

Fig. 5. Flow of the KCC moving-bed bench-test equipment.

3.2. Test conditions

Test conditions are shown in Table 2. The flow rate of the adsorption gas was 250 Nm^3/h for a CO_2 concentration of 13%, and 1.7 t/day of CO_2 were contained within this gas. The steam temperature was selected to be 60 °C. The adsorbent completed a cycle within the equipment in a period of 52 min. The tests were performed about three cycles, and the flow rate and temperature in the system had stabilized during this tests.

Table 2. Test conditions.

Adsorption gas flow rate	250	Nm^3/h
CO_2 concentration of adsorption gas	13	%
Adsorbed gas temperature	35	°C
Steam temperature	60	°C
One cycle time	52	Minute

4. Test results

Fig.6 shows the CO_2 concentration in the inlet and outlet gas in the adsorption reactor and the amount of adsorbed CO_2. The horizontal axis is the test time, and the vertical axes show the CO_2 concentration on the right-hand axis and the amount of adsorbed CO_2 on the left-hand axis. The CO_2 concentration in the gas is 13% at the inlet of the adsorption reactor and 1% or less at its outlet, from which we can see that over 90% of the CO_2 gets adsorbed continuously. The amount of adsorbed CO_2 in this case was 1.6 t/day. In a moving-bed system using an adsorbent, it is possible to adsorb at least 99% of the CO_2 by setting appropriate values for the adsorbent layer and the circulating adsorbent volume relative to the CO_2 concentration in the exhaust gas and the flow rate.

Fig.7 shows the amount of CO_2 captured and the CO_2 concentration in the gas at the outlet of the desorption reactor. The amount of captured CO_2 is 1.6 t/day. This result indicates that the total amount of CO_2 adsorbed in the adsorption reactor is successfully captured in the desorption reactor. In addition, the concentration of the captured CO_2 can be maintained at 95% or more. The remaining 5% included in the captured gas can be considered from the composition, mainly as air due to leaks in the adsorption reactor and adsorbent dryer. By devising a good connection between each of the towers, it should be possible to capture much higher concentration of CO_2.

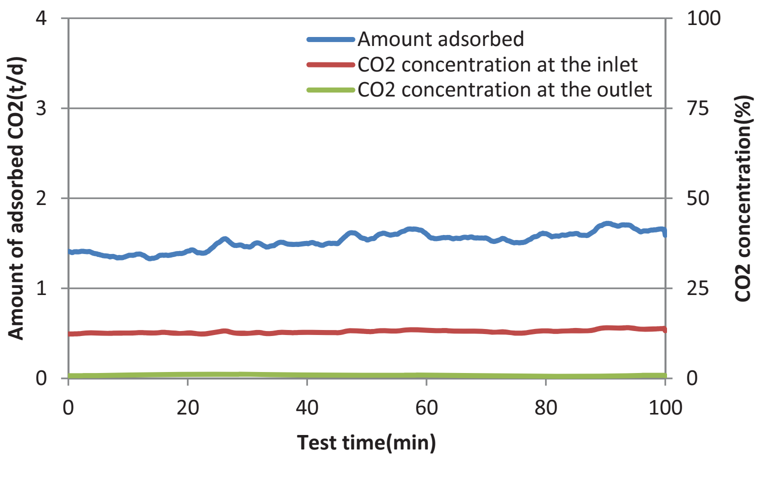

Fig. 6. CO_2 concentration in the gas at the inlet and outlet of the adsorption reactor and the amount of adsorbed CO_2.

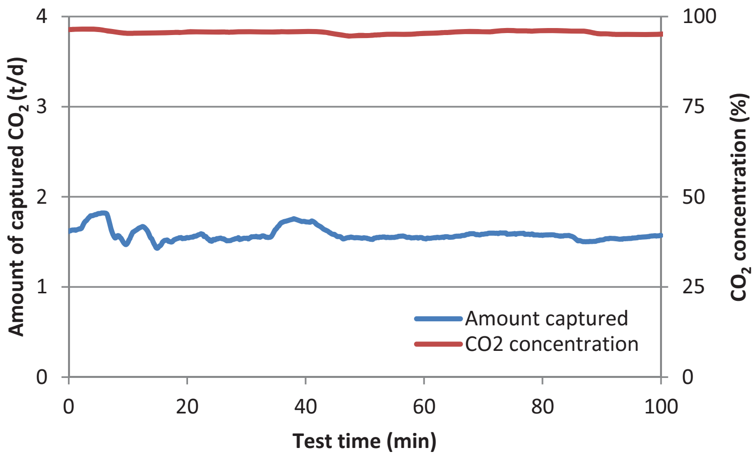

Fig. 7. Amount of captured CO_2 and CO_2 concentration.

5. Conclusion

Our findings can be summarized as follows:

• By blowing coal combustion exhaust gas through the moving adsorbent layer, it is possible to continuously adsorb CO_2. Moreover, the adsorbed amount in this test was 1.6 t/day. It indicates that over 90% of CO_2 contained in the exhaust gas has been adsorbed.

• By moving the adsorbent adsorbed the CO_2 and by introducing steam into it at a temperature of 60 °C, the CO_2 can be captured in high concentration.

• In this test, the 1.6 t/day of all CO_2 adsorbed in the adsorption reactor was captured at desorption reactor, and the CO_2 concentration of the gas was 95% or more.

• The required energy for a KCC system to capture CO_2, using steam generated by the hot wastewater from a gas engine as the heat source, was the electric energy of 1.3GJ/t-CO_2 in feasibility study.

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