Cost Evaluation of Direct Air Capture (DAC) Process (Vol. 2) : Adsorption Method

Summary

The costs and issues of DAC processes using amine / nanofiber systems and MOFs-74 (Metal-Organic Frameworks) systems were investigated. The amine/nanofiber system has low adsorptivity and high airflow resistance of the adsorbent [1]. The energy cost was higher, and the DAC cost for the assumed case was 117 JPY/kg-CO_2. The energy cost of MOFs system which assumes a honeycomb structure is low due to a lower air-flow resistance than the amine/nanofiber system. However, because the price of MOF as an adsorbent is high, it is necessary to double the life of the adsorbent (four years) at least. The DAC cost is estimated at 71 JPY/kg-CO_2 and verification is needed for such estimation in the future. In the case of the KOH-$CaCO_3$ alkali absorption method studied so far, the DAC cost is estimated at 35 JPY/kg-CO_2 [2]. This is a promising process at the moment though there is a challenge to prove whether the cost can be lower.

Proposals for Policy Development

- It is necessary to develop technology to reduce the cost of DAC to less than 35 JPY/kg, or preferably less than 20 JPY/kg-CO_2.
- The alkali absorption method, the NFC-amine adsorption method, and the MOFs adsorption method have many issues to be demonstrated and developed. Thus, all these methods need to be developed with clear goals.
- In order to develop optimal adsorbents, the results obtained by making full use of computational chemistry and other methods need to be applied to specific developments for efficient studies.

1. Evaluation and cost of amine/nanofiber system

A fiber filter formed by impregnating nanofibers (NFC) with amine ($H_2N(CH_2)_2NH(CH_2)_3SiCH_3(OCH_3)_2$: AEAPDMS) was used as an adsorbent.

(1) Evaluation of CO_2 adsorptivity of AEAPDMS

In order to evaluate the heat of adsorption by understanding the mechanism by which AEAPDMS adsorbs CO_2, quantum chemical calculations were performed, and the change in adsorptivity due to the change in electronic state in the presence or absence of water, the ease of adsorption, and the heat of adsorption were estimated.

Quantum chemistry provides a powerful tool for improving the efficiency of technology development in this field (Fig. 1. Example of molecular structure).

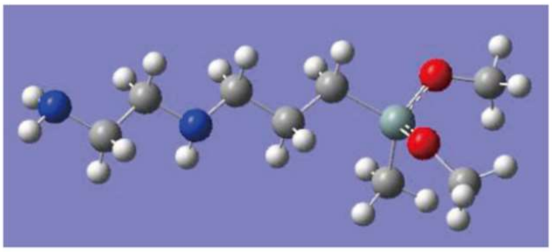

Fig. 1. Example of the molecular structure of AEAPDMS

(2) Study using assumed process

In the assumed process for examining performance and cost, the CO_2 concentration in the air was set to 400 ppm, the CO_2 capture rate to 112 t/h, and the CO_2 concentration at the outlet of the adsorption bed to 0 ppm. Assuming an adsorption rate of 0.5 mol/kg/h, the adsorption and desorption cycles were 60 minutes each, resulting in a DAC cost of 117 JPY/kg-CO_2 (Table 1).

2. Evaluation of MOFs-74 (Metal-Organic Frameworks) system and DAC cost

MOFs (Metal Organic Frameworks) are hybrid materials synthesized by the self-assembly of metals and organic ligands. It has also been investigated for the adsorption of CO_2, and it has been confirmed that Mg-MOF-74 has a large adsorption capacity, but the development is currently in the laboratory stage. Assuming a honeycomb structure as the adsorption layer, the cost was calculated as in 1. (2), and it was 71JPY/ kg-CO_2 (Table 1).

3. Discussion and issues

In addition to the NFC-amine and MOFs methods, the costs of the KOH-$CaCO_3$ alkaline method and the amine absorption method for coal boiler flue gas were compared (Table 1). The first three methods are DAC and have an inlet CO_2 concentration of 400 ppm. The last method, amine absorption, has an inlet CO_2 concentration of 14.3%.

Table 1. Comparison of CO_2 capture costs (CO_2 capture rate 112t/h)

	DAC		DAC		DAC		Coal boiler flue gas		Remarks
Process	NFC-amine method		MOFs Method		Alkali method		Amine absorption		
					CO_2 400ppm→110ppm		CO_2 14.3%→1.56%		
Fixed cost (JPY/kg-CO_2)		51.9		26.7		20.7		3.6*	*Capacity is corrected to 112 t/h
Variable cost (JPY/kg-CO_2)		65.0		44.4		14.7		5.9	
Electric Power	4.14 k Wh/kg	49.7	1.6kWh/kg	19.2			0.14kWh/kg	1.7	12JPY/kWh
Heat					8.84MJ/kg	1	2.5MJ/kg	3.8	1.5JPY/MJ
Absorbent		15.3		25.2		1.4		0.2	
Other								0.2	
Total (JPY/kg-CO_2)		116.9		71.1		35.4		9.5	

The theoretical energy required to separate CO_2 for DAC was four times higher than for boiler flue gas, resulting in a higher DAC cost by adsorption methods (NFC-amine and MOFs methods). The features of each process are as follows: (1) In the case of CO_2 capture from boiler flue gas, the capture efficiency is 90% and the cost is less than 10 JPY/kg, but the outlet cannot be zero carbon because of the absorption method. (2) In the case of DAC, the inlet concentration of CO_2 is as low as 400 ppm, and the capture cost is about 35 JPY/kg for the alkaline method (outlet CO_2 concentration: 110 ppm) [2]. In places like the U.S., where LNG is inexpensive (0.35 JPY/MJ), the price is about 25 JPY/kg-CO_2. This method has its challenges, but it is a promising process. (3) The NFC-amine method has high costs of equipment and power due to a high air-flow resistance of the adsorbent, and the current cost is over 100 JPY/kg. (4) The MOFs method has a lower air-flow resistance and power cost, so it could be less than 100 JPY/kg, but experimental proof is required. In order to reduce the cost of DAC to less than 35 JPY/kg, or preferably less than half, there are many issues that need to be resolved, and it is necessary to proceed with demonstration experiments such as improving the performance of the adsorbent, extending its life, and reducing its ventilation resistance.

[1] Jan Wurzbacher, "Capturing CO_2 from Air," Herbstworkshop Energiespeichersysteme, TU Dresden, 9 November 2017.

[2] LCS, Proposal Papers for Innovation Policy Development, "Cost Evaluation of the Process of Direct Air Capture (DAC) Process of Carbon Dioxide," February 2020.

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