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Potential contribution of zeolite membranes towards carbon neutrality

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Abstract

The sixth synthesis report (A6) of the Intergovernmental Panel on Climate Change (IPCC) was submitted in March 2023. It states that it is important to limit temperature rise to below 1.5°C, and that a rapid reduction in greenhouse gases is essential to achieve this. Global warming countermeasures require more energy-saving technologies, highly efficient and low-cost CO_2 capture technologies and effective utilization of the captured CO2, so-called CCU technologies. Zeolites have much to contribute in the fields of CO_2 separation, recovery by adsorption and catalytic reactions for CCU, which are becoming increasingly important towards carbon neutrality. In this presentation, the results of our investigations into the potential contribution of zeolite membranes to CO_2 reduction will be presented.

The relationship between CO_2 recycling society and zeolites

In reducing CO_2 emissions, energy efficiency must first be improved by introducing energy-saving processes and increasing the efficiency of equipment, as shown in Fig. 1. Furthermore, it is important to electrify energy and to use renewable energy sources such as solar and wind power for the electricity. The still emitted CO_2 needs to be captured, used and stored as efficiently and cost-effectively as possible using various CO_2 capture technologies. The relationship between CO_2 recycling society and zeolites is summarized in Fig. 2.

The main components of biogas are CO_2 and CH_4. Biomethane, from which CO_2 is separated, has recently attracted attention. Biomethane would be CO_2-neutral and if the CO_2 from biomethane could be sequestered, it would be a carbon-negative technology. Zeolite membranes are expected to be a technology with the potential to separate and capture CO_2 at a lower energy cost.

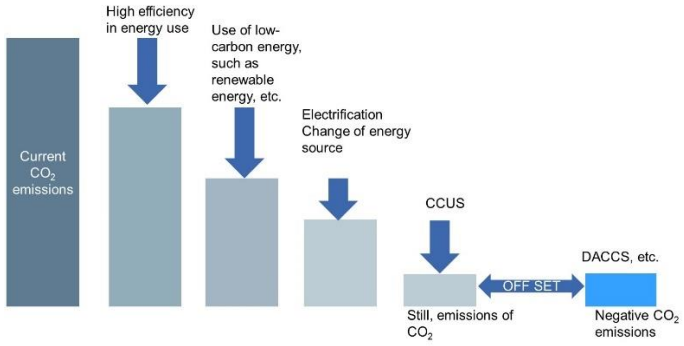

Fig.1 Image of efforts to achieve carbon neutrality

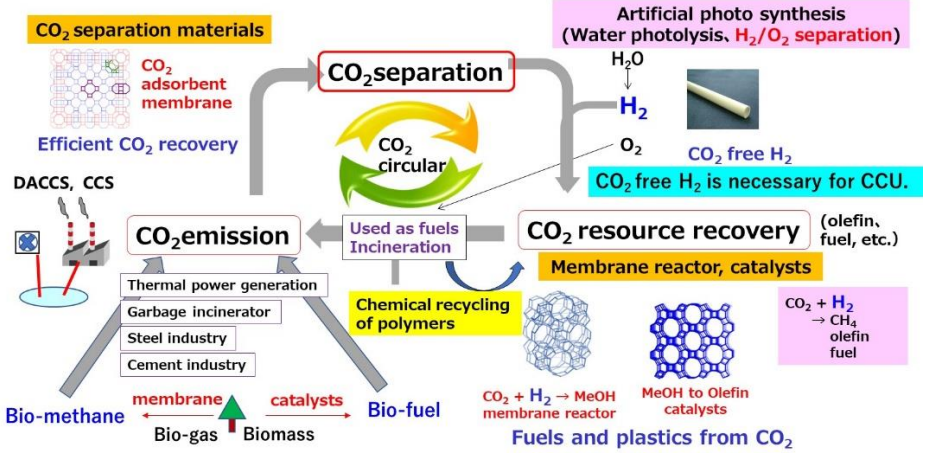

Fig.2 Relationship between Net Zero CO_2 emissions society and zeolites

Introduction to examples of zeolite membrane RD for CO_2 emissions reduction

We have performed various RDs related to zeolite membranes. We have developed a high-silica CHA-type zeolite membrane with a strong XRD pattern of specific crystal planes, which we have named ZEBREX™ [1]. This CHA-type zeolite membrane is effective for Pervaporation (PV) and Vapor Permeation (VP), such as solvent dehydration under high water content and acidic conditions, which is expected to save energy and is difficult to achieve with conventional A-type zeolite membranes and it has been put to practical use. In addition, gas separation is also being investigated. In particular, it has shown high CO_2 permeability and separation selectivity in CO_2/CH_4 separation, and demonstration tests for biogas separation are ongoing in Hokkaido, Japan, with favorable results. Studies are also being conducted on hydrogen separation. One such project is the NEDO Artificial Photosynthetic Chemical Process Project in Japan. This project consists of (1) photolysis of water by a photocatalyst under sunlight to produce hydrogen/oxygen, (2) safe separation of hydrogen from the produced hydrogen/oxygen mixture gas using separation membranes, etc., and (3) production of olefins such as ethylene and propylene as chemical raw materials from this solar hydrogen and CO_2 using zeolite catalysts. In the hydrogen separation process of (2), the development of separation membranes and separation membrane modules that separate hydrogen from the hydrogen/oxygen mixture gas that forms the detonation gas produced by the photocatalyst, with high efficiency and safety. However, in CHA-type zeolite membranes, hydrogen and oxygen, or nitrogen as a model gas for safety purposes, all permeate through the pores because the size of both hydrogen and oxygen, or nitrogen as a model gas for safety purposes, is small compared to the pore size of a normal zeolite. Therefore, an attempt was made to control the pore size by surface modification of the zeolite membrane, which resulted in high separation performance. The permeance ratios of CHA-type membranes before and after surface modification for hydrogen/nitrogen, CHA-type/nitrogen and hydrogen/CH_4 are shown in Fig. 3, based on measurements of the permeance of CO2, hydrogen, nitrogen and CH_4 gases at 0.1 M Pa G and 50 °C for the CHA-type zeolite membrane before surface modification and the membrane after surface modification. The permeance ratio for hydrogen/nitrogen increased significantly from 6 to nearly 100. Similarly, the permeance ratios of CO_2/nitrogen and hydrogen/CH_4 also increased significantly, suggesting that the surface modification controlled the pore size. Using this surface-modified CHA membrane, hydrogen/oxygen mixed gas separation experiments were carried out. As a result, the hydrogen concentration permeated from the hydrogen/oxygen = 2/1 mixture exceeded 96% using the modified zeolite membrane, which was outside the explosion range, and the hydrogen recovery rate was well above the target of 90%.

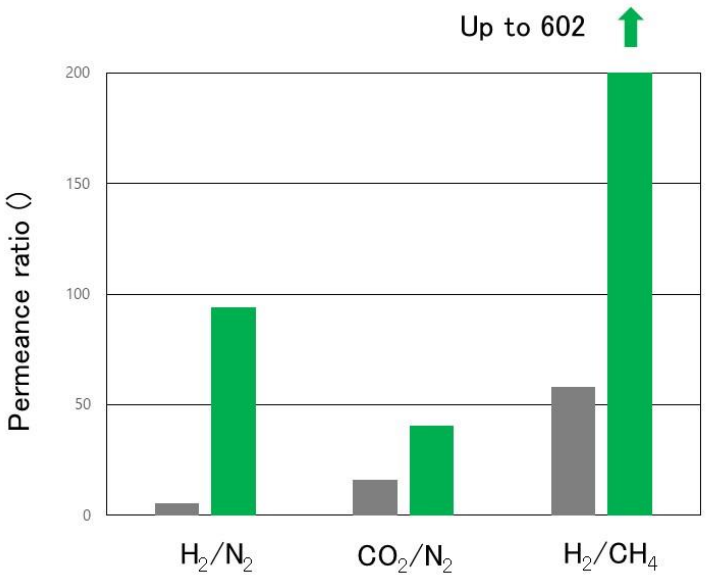

Fig.3 The permeance ratios of CHA-type membranes before and after surface modification

References

[1] Sugita, M., Takewaki, T., Oshima, K., Fujita., “Inorganic porous support-zeolite membrane composite, production method thereof, and separation method using the composite,” 2013 U.S. Patent 8376148.