Chemical Research Group

Looking ahead to Future CO_2 Separation Technologies and their Challenges

The cessation of thermohaline circulation in the ocean because of global warming, which will have a destructive influence on the Earth's environment, is an issue that needs to be addressed. We need to determine to what extent the CO_2 concentration in the atmosphere should be controlled scientifically to prevent this phenomenon. The probability of cessation of thermohaline circulation in the ocean is several percent at a CO_2 concentration of 550 ppm, and this probability increases by several tens of percent at a CO_2 concentration of 650 ppm.

In the Stern Review released in 2006, although the above catastrophic phenomenon was not taken into consideration, it was predicted that all countries in the world will suffer a 5% gross domestic profit (GDP) loss due to global warming if the global warming problem is not addressed. The review stated that a contribution of 1% of GDP to combat global warming is reasonable from an economic point of view. The Japanese government recently moved to build a new framework to reduce global CO_2 emission after the signing of the Kyoto Protocol.

A CO_2 concentration of 550 ppm is twice the concentration that was present during the Industrial Revolution. If we set a target CO_2 concentration of 550 ppm for 2100, it has been predicted that not only energy savings, fuel switching, renewable energy sources (solar cells, wind power and biomass) and nuclear energy, but also CO_2 capture and underground storage will be necessary to achieve this goal. As the cost of CO_2 capture from CO_2 sources is estimated to be 70% of the total cost of CO_2 capture and underground storage, it is important for the commercialization of this technology that the CO_2 capture cost for CO_2 capture and storage (CCS) is reduced.

Conversion technologies of fossil energy will progress, and we consider the power generation system of a boiler steam turbine evolving into a combined cycle with a gas turbine for power generation and a combined cycle with a fuel cell. Various CO_2 capture technologies such as chemical absorption, physical absorption, membrane separation, and the oxy-fuel method have been developed.

Progress in these technologies will result from development of the best combination of fuel conversion processes and CO_2 capture processes, so that CO_2 capture technologies that have economic benefits, as shown in Figure 1, are developed.

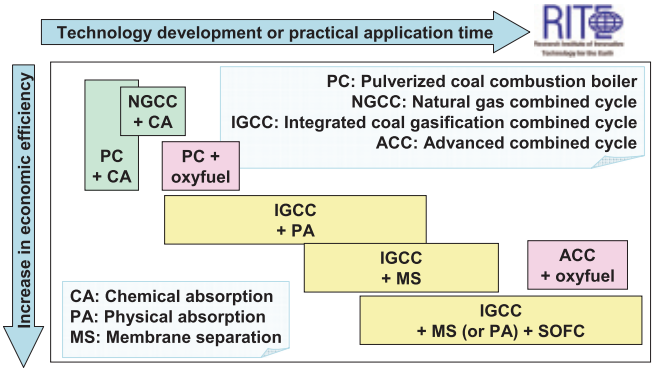

Fig. 1 Vision of power plant and CO_2 capture

Our chemical research group studies various CO_2 capture technologies, with an emphasis on chemical absorption and membrane separation methods. We use chemical absorption to reduce the CO_2 capture cost for flue gas in an ironworks factory to 3400 JPY/ton-CO_2. We are developing a chemical absorbent to reduce this CO_2 capture cost to 2000 JPY/ton-CO_2. Moreover, we have discovered an excellent membrane material for the separation of CO_2 from H_2-containing gas. We are engaged in the development of the structure of a new membrane composed of this material and are developing a membrane module for demonstration with real coal gasification gas.

CO_2 capture technology with chemical absorbents

The chemical absorption process, where amine solvent selectively absorbs CO_2 in flue gas and desorbs CO_2 with heating, has the potential to capture CO_2 at large and atmospheric stationary emission sources in practical applications. The most important issue in the chemical absorption process is the development of new solvents to reduce the CO_2 capture cost.

The Research Institute of Innovative Technology for the Earth (RITE) has promoted a project named "A Cost-effective CO_2 Capture System Using Low-grade Waste Heat" since 2004 as a five-year project, with the RITE being responsible for the development of new solvents. The objective is to reduce the CO_2 capture cost in removing CO_2 from the blast furnace gas stream in integrated steel works by almost half compared to the cost of current technology (Figure 2).

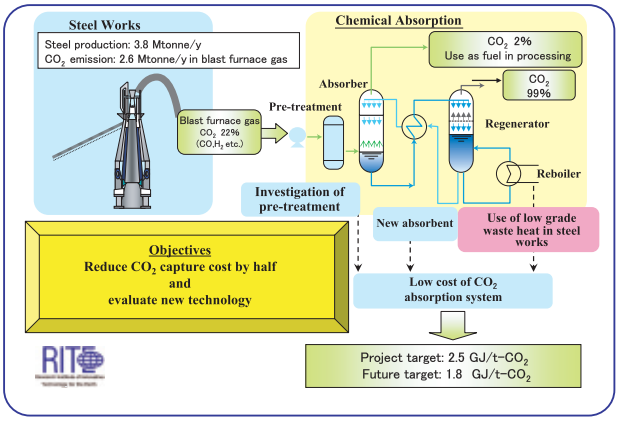

Fig. 2 Outline of cost savings in the CO_2 capture system (COCS project)

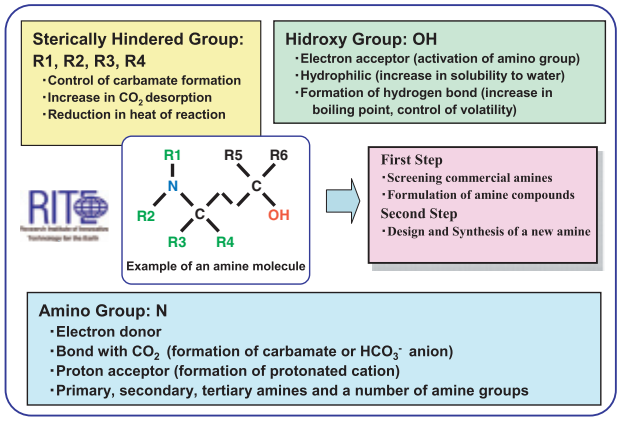

Fig. 3 Development of new absorbents

Desirable performances of the new solvent are low reaction heat, fast CO_2 absorption rate, and large separation capacity for CO_2. Through these performances, CO_2 has been separated from a gas stream using less energy. Figure 3 shows a scheme for the development of new solvents. Initially, we investigated reaction characteristics of several hundred commercial amine solvents that have good CO_2 capture performances. We then measured the reaction rate with CO_2, CO_2 absorbance capacity and the reaction heat using laboratory apparatus. Furthermore, we attempted to create a novel mixture of several amines in which each amine compensates for their deficiencies of others. We made a new solvent and repeatedly improved its performance. In this way, three types of high performance solvents (RITE-3,-4 and -5 Series), which have different characteristics, have been developed to date. Furthermore, high-performance solvents (RITE-5 and -6 series) have been developed from our experimentally formulated database and a theoretical approach to determining the molecular structure of new amine compounds using quantum theory analysis. The best energy performance for CO_2 capture among these solvents was 2.7 GJ/ton-CO_2, which is very low compared to the 4.0 GJ/ton-CO_2 of the standard MEA (monoethanolamine) solution. It is estimated these absorbents can achieve a 40% reduction in CO_2 capture costs.

Future work will be an experimental study of the high performance absorbents and to find optimum conditions for the absorbents in building the most cost-effective CO_2 capture system.

Chemical absorbent under high pressure

Based on current knowledge of solvents in CO_2 capture from a gas stream under atmospheric pressure, a research and design program for new solvents suitable for a high pressure gas stream has been running since 2007. In general, amine solvents for an atmospheric pressure condition can easily react with CO_2 independent of reaction temperature. However, we have confirmed that some amine solvents have large CO_2 capacity depending on reaction temperature under a high-pressure condition; nevertheless, they cannot react under atmospheric pressure (Figure 4). We intend to propose a new system for CO_2 capture from pressurized point sources through the development of these solvents.

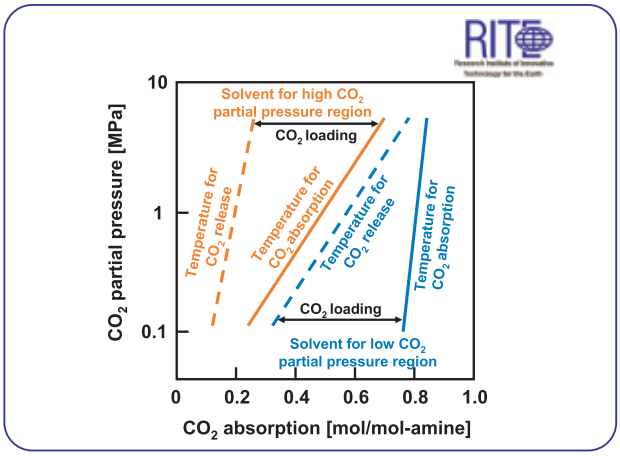

Fig. 4 Comparison of characteristics of chemical solvents applicable in high and low ranges of CO_2 partial pressures

Novel techniques for regenerating the chemical absorbent

We are developing a regeneration technique for accelerating CO_2 desorption with a pressure difference to reduce the energy consumption in a chemical absorption system. To date, the following observations have been made. Desorption can be accelerated by flashing the solution into a reduced pressure space, which can reduce electric energy consumption by more than half in comparison with the conventional method that uses high temperatures. Moreover, by using low-temperature waste heat, as shown in Figure 5, it is possible to achieve an electric energy consumption about 1/4 (0.1 kWh/kg-CO_2) of that of the conventional chemical absorption method. We will attempt to apply this method to the separation of CO_2 from flue gases, chemical processes, bioprocesses, etc., while efforts are made to further reduce energy consumption.

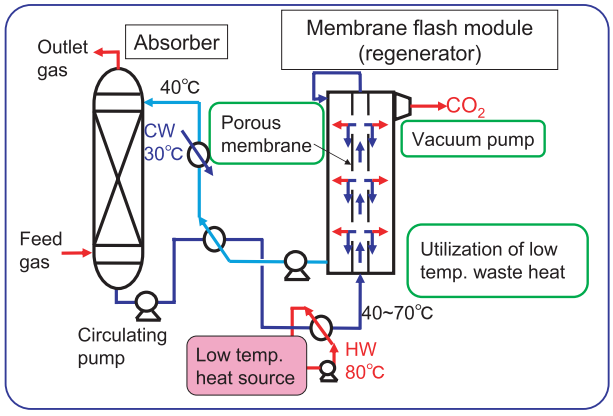

Fig. 5 Example of membrane flash flow with heating

CO_2 and H_2 separation with a polymeric membrane

One promising means of decreasing the cost of CO_2 separation is the development of new, high-performance CO_2 separation membranes that allow CO_2 recovery via membrane separation from pressurized gas streams. An integrated gasification combined cycle (IGCC) with CCS such as the FutureGen project in the USA provides a pressurized gas stream containing about 40% CO_2 with H_2. CO_2 would be separated with a membrane injected under the ground for the CCS, and H_2 would be used as a clean fuel. The cost of CO_2 capture from the pressurized gas stream with a membrane might be 1500 JPY/t-CO_2 or less.

We are currently developing a CO_2 molecular gate membrane with the goal of producing a new, high-performance separation membrane. Figure 6 shows the basic outline of the CO_2 molecular gate function. The pathway for gas molecules is occupied solely by CO_2, which acts as a gate to block the passage of other gases. Consequently, the amount of N_2 or H_2 permeating to the other side of the membrane is greatly limited and high concentrations of CO_2 can be obtained. The RITE dendrimer having excellent CO_2/H_2 selectivity is fixed stably in a cross-linked polymer matrix to form the active layer of a resulting composite membrane. The composite membrane showed a record CO_2/H_2 selectivity of at least 20 at an elevated pressure. The RITE is now improving the selectivity and developing practical membrane modules of the dendrimer composite membrane.

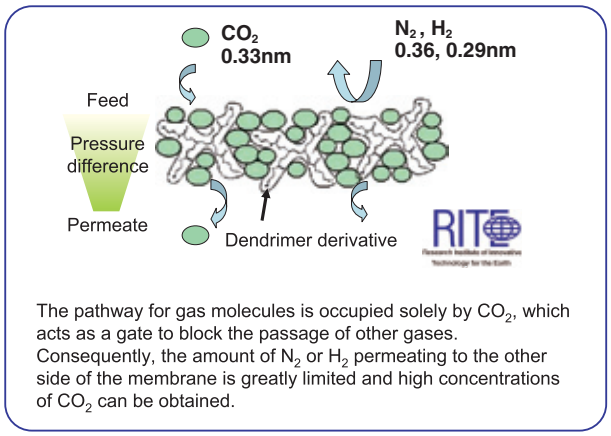

Fig. 6 Conceptual diagram for the CO_2 molecular gate

In developing this CO_2 molecular gate membrane, the RITE conducted joint research with the US Department of Energy's National Energy Technology Laboratory (NETL) as a recognized project of the Carbon Sequestration Leadership Forum (CSLF). Testing of the dendrimer composite membrane module developed by the RITE (Figure 7) was carried out at the NETL (Figure 8).

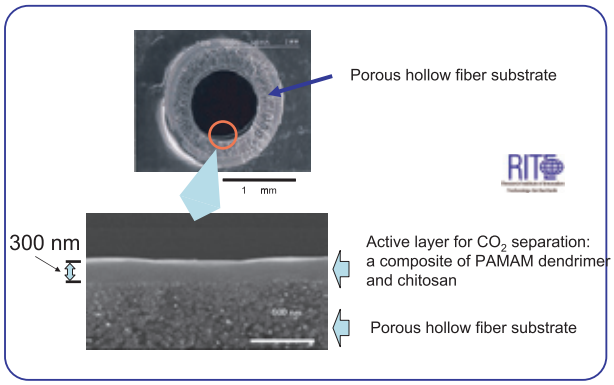

Fig. 7 Dendrimer composite membrane at ambient pressure

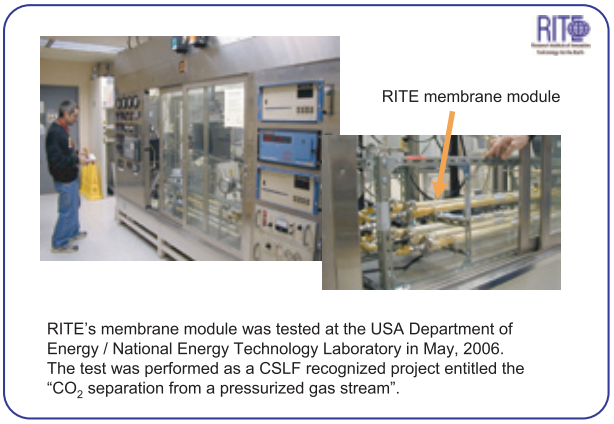

Fig. 8 RITE's membrane module test at USA DOE/NETL

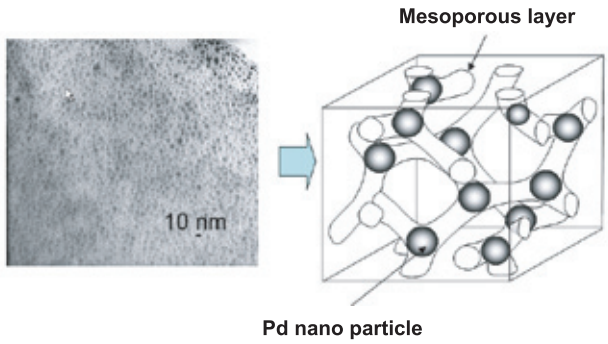

Fig. 9 Hydrogen separation membrane with Pd nano particles within mesopores

Inorganic membrane for the catalytic membrane at high temperature

Because zeolite and mesoporous silica possess well-defined micro/mesopores with low thermal expansion/mobility of the framework, considerable attention has been focused on the production of membranes that are capable of separating gases with high selectivity. Based on the simulation results, we selected candidate zeolite structures for CO_2 separation and have begun synthesis of new zeolite membranes.

On the other hand, since mesoporous silica has uniform, large pores as well as a high surface area, a variety of guest molecules can be introduced into the pores. A new hydrogen separation membrane was prepared by the impregnation of Pd salt in the mesoporous silica membrane and the additional growth of Pd nanoparticles by electroless plating. As shown in Figure 9, it was found that Pd nanoparticles seeds for electroless plating, which were of almost equivalent size to the mesopores, were successfully prepared into the pores by impregnation of Pd salt and the membrane showed H_2 selectivity from a mixture of H_2 and CO_2. We are now planning: (1) improvement of the performance of the membrane, (2) evaluation of its durability, (3) production of a larger module and (4) application of the membrane reactor under changing reaction conditions.

Plasma PM removal system for diesel vehicles

Recently, the emission control for particulate matter (PM) from diesel vehicles is becoming extremely severe, although no satisfactory PM removal technologies have yet been developed. The plasma PM removal technology has potential as an innovative technology for the after treatment of exhaust gases from diesel vehicles. This project (Comprehensive technological development of innovative, next-generation, low-pollution vehicles, and R&D of innovative after-treatment systems) is a joint study with Daihatsu Motor Co., Ltd., which is supported by the New Energy and Industrial Technology Development Organization. RITE is 1) to investigate the mechanisms of plasma discharges and plasma PM oxidation and 2) to develop a PM removal system that can be loaded onto a small diesel vehicle. The PM removal system includes a power supply and a small plasma reactor of high PM removal ability and low pressure loss (Figure 10).

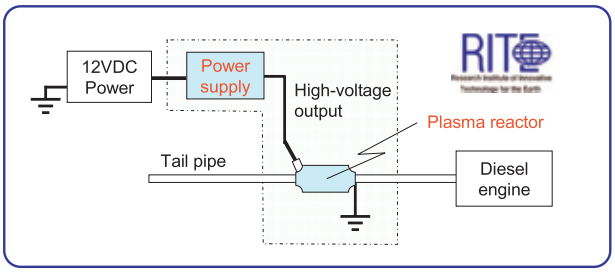

Fig. 10 Plasma PM removal system