Chemical Research Group

Looking ahead to future CO_2 separation technologies and their challenges and innovations

Cessation of thermohaline circulation in the ocean as a result 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 in order 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 last year, in spite of the fact that the above catastrophic phenomenon was not taken into consideration, it was predicted that all countries in the world will suffer from a 5% 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 economical point of view.

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 saving, 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 are going to 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 between fuel conversion processes and CO_2 capture processes, so that CO_2 capture technologies that will consistently increase the economic benefits of technical visions, as shown in Figure 1, are developed.

Our chemical research group studies various CO_2 capture technologies, with a special focus on chemical absorption and membrane separation methods.

We can use chemical absorption to reduce the CO_2 capture cost for flue gas in an ironworks factory to 3700 JPY/t-CO_2. We are developing a chemical absorbent to reduce this CO_2 capture cost to 2000 JPY/t-CO_2. Moreover, we have discovered an excellent, world-class membrane material for the separation of CO_2 from H2-containing gas. We are engaged in the development of the structure of a new membrane composed of this material.

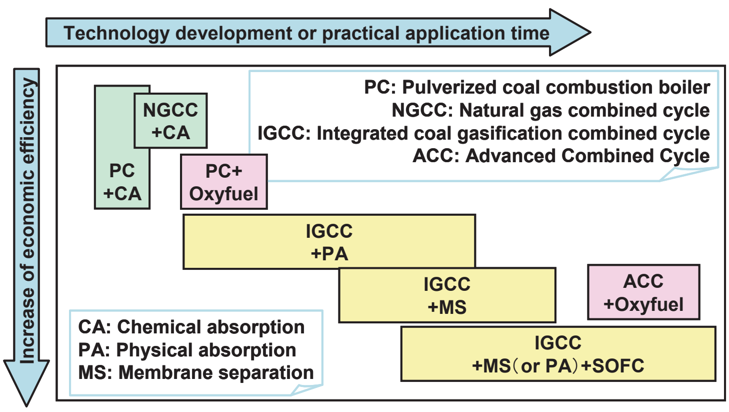

Fig.1 Vision of power plant and CO_2 capture

Development of CO_2 capture technology that uses a chemical absorption system

CO_2 capture by chemical absorption has the potential to be used in practical applications for large stationary point sources of CO_2 in the near future, and a five-year project to this end was started in 2004 in collaboration with four Japanese companies.

The objective of this project is to reduce the CO_2 capture cost to half that of the existing technology for the flue gas (blast furnace gas) stream in an integrated steel works. The main objectives, shown in Figure 2, are the development of new absorbents to enable the capture of CO_2 with less energy use, and the development of a heat utilization technology to use waste heat at steel works to supply low cost steam for regenerating CO_2.

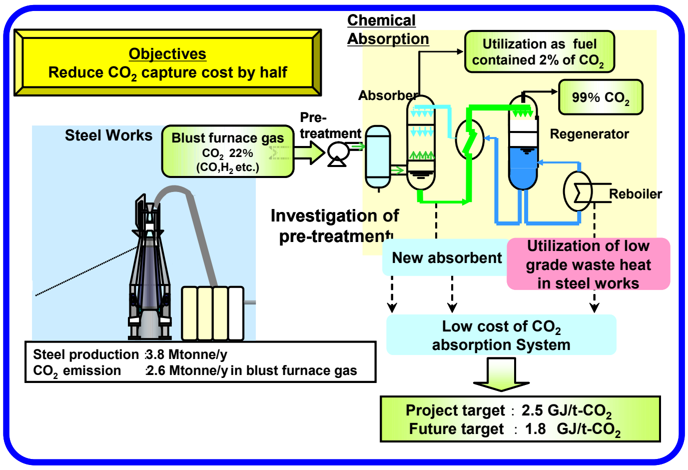

Fig.2 COCS project (Cost Saving CO_2 Capture System)

RITE mainly develops new absorbents. The most desirable characteristics for new absorbents are: a lower heat of reaction with CO_2, fast CO_2 absorbance, and easy separation from CO_2. If this is achieved, CO_2 can be captured from a gas stream with a lower energy input. Among the solvents tested for CO_2 capture, amine solutions have shown the best performance.

Figure 3 shows a plan for the screening and development of new absorbents. As a first step, the reaction characteristics, such as the reaction rate of CO_2, the amounts of CO_2 absorbed and the heat of reaction with CO_2, of almost 100 samples of commercial amine solvents selected by the plan shown in Figure 3, were analyzed using laboratory apparatus. Furthermore, compound amine solutions, that can compensate for deficiencies in the amines, were prepared and their performance was investigated.

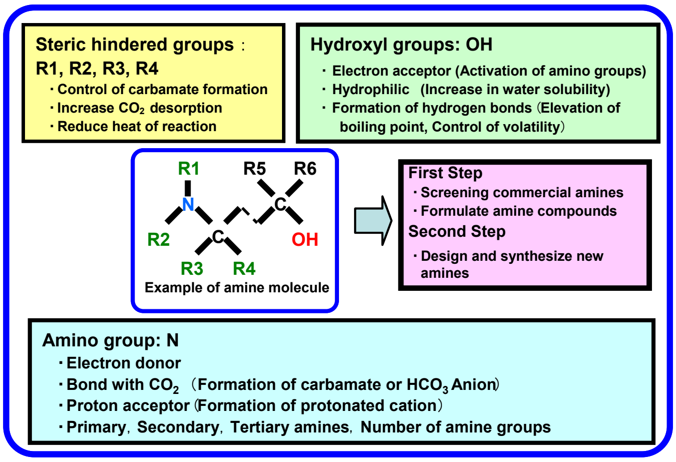

Fig.3 Development of new absorbents

From these investigations, three type of high performance absorbents (RITE-3A,-4A,-4B), that showed different characteristics, were developed. The energy for CO_2 capture of the best of these absorbents is estimated to be 2.9 [GJ/t-CO_2]. This value is very low compared to the 4.0 [GJ/t-CO_2] for a standard MEA (monoethanol amine) solution, and is close to the project goal of 2.5 [GJ/t-CO_2], as shown Figure 4.

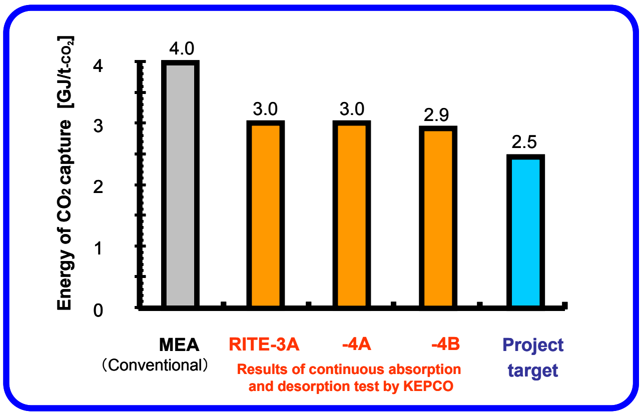

Fig.4 Energy of CO_2 capture target and results

The second step of the project has also been carried out, in which new types of amine compounds, designed and prepared based on the current knowledge, are evaluated by a similar method. Furthermore, research on the optimum conditions for the chemical absorption system has been carried out, so that the best performance can be obtained from the new absorbents. Currently, the aim of the project is to reduce the CO_2 capture energy down to the target value.

Development of new techniques for regenerating the chemical absorbent solution

A regeneration technique using a material that accelerates CO_2 desorption under conditions where there is a pressure difference is being developed, in order to reduce the energy consumption of the regeneration process of the chemical absorption method, as shown in Fig. 5.

Up to now, the following observations have been made: Desorption can be accelerated by the material and the processing conditions, which can reduce energy consumption by over 1/2 in comparison with high-temperature heating regeneration of the absorbent solution in the conventional chemical absorption method.

At present, cooperation with companies is being promoted, to apply this method to the separation of CO_2 from flue gas, chemical processes, bioprocesses, etc., while development is progressing with the aim of further reducing the energy consumption.

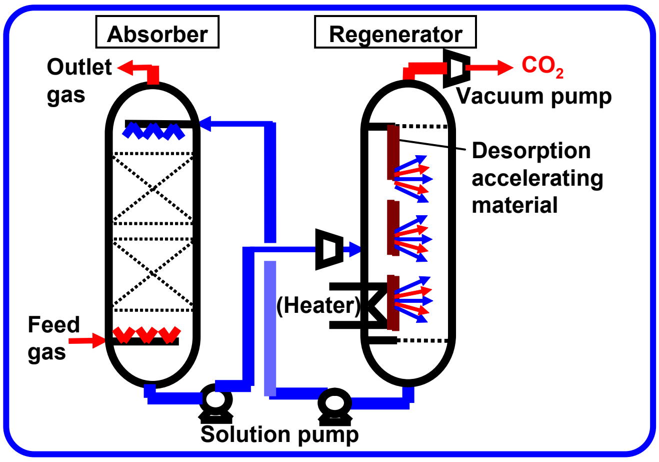

Fig.5 Concept of accelerated regeneration method

CO_2 and H_2 separation with a polymeric membrane

One promising means of lowering 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.

RITE is 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 membrane of the RITE dendrimer shows excellent CO_2/N_2 selectivity of more than 1000, which would have the potential to replace an amine solution. Furthermore, the dendrimer has the world record for CO_2/H_2 selectivity, 730. The dendrimer membrane can attain a CO_2 separation cost of 1,500 JPY/t-CO_2 or less when the membrane system is used for CO_2 separation from a pressurized gas stream such as the product from a water-gas shift reaction.

In developing this CO_2 molecular gate membrane, 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 developed by RITE was carried out at the NETL (Figure 7).

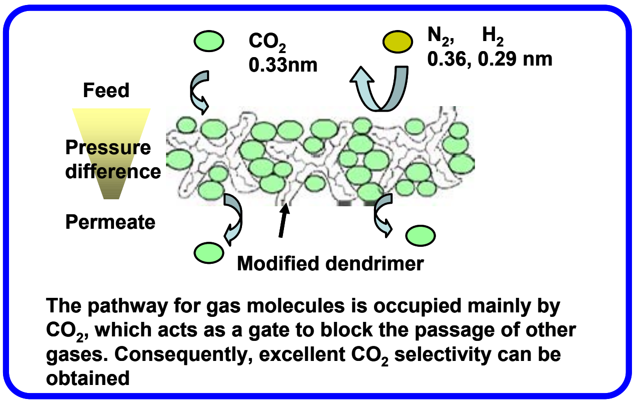

Fig.6 Molecular gate membrane

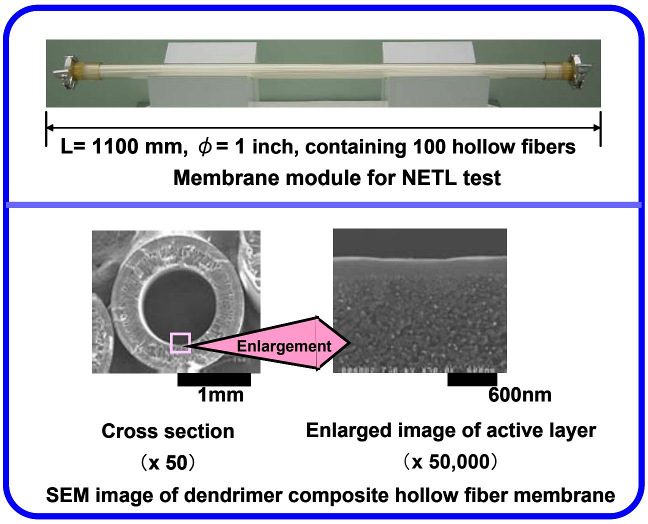

Fig.7 Dendrimer composite membrane module

Development of an inorganic membrane for the catalytic membrane at high temperature

Since zeolite and mesoporous silica possess well-defined micro/meso-pores 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 some candidate zeolite structures for CO_2-N_2 or CO_2-H_2 separation and have started synthesis of new zeolite membranes. Synthetic conditions for zeolite seed crystals have been studied and, recently, we successfully synthesized a new zeolite seed crystal which had never previously been used for zeolite membrane.

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 by reaction with surface OH groups. As shown in Figure 8, a new type of hydrogen separation membrane was prepared by template synthesis of Pd nanoparticles in the pores of mesoporous silica membrane. It was found that dense Pd nanoparticles, of almost equivalent size to the mesopores, were successfully prepared into the pores by impregnation of Pd salt, and that 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) a larger module production and (4) application of the membrane reactor under changing reaction conditions.

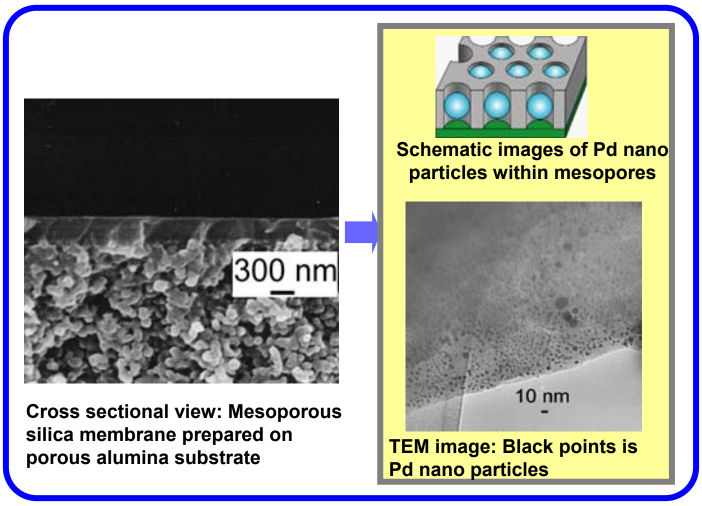

Fig.8 Hydrogen separation membrane with Pd nano particles within mesopores

Plasma PM removal system for diesel vehicles

Recently, emission controls for diesel vehicles have become extremely severe, even though no satisfactory PM removal technologies have been developed yet. Plasma PM removal technology has potential as an innovative technology for the after-treatment of exhaust gases from diesel vehicles. This project is a joint study with Daihatsu Motor Co., Ltd., which is supported by NEDO (Comprehensive Technological Development of Innovative, Next-Generation, Low-Pollution Vehicles, R&D of innovative after-treatment systems). RITE is investigating the mechanisms of plasma discharges and plasma PM oxidation. It is also developing a PM removal system as shown in Fig. 9. A PM removal system with a power supply and a small plasma reactor can be loaded onto a diesel car. This reactor will have a high PM removal ability and low pressure loss.

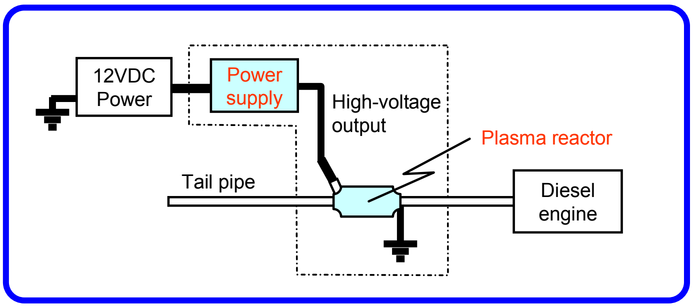

Fig.9 Plasma PM removal system