Chemical Research Group

Our Challenges for Efficient and Industrializing CO_2 Capture Technologies

Discussions about a new global framework to reduce CO_2 emission is progressing, because China and India addressed the target of CO_2 reduction. The economical issue that advanced countries and developing countries how to invest CO_2 reduction in future is tough choices. We think that economical countermeasures will help the finding the coincidence answer in countries.

CCS (CO_2 capture and storage) will be one of economical promising countermeasure. It is estimated that the cost of CO_2 capture from CO_2 source s is about 60 % of the total cost of CCS, so the reduction of CO_2 capture cost for CCS is important for CCS deployment.

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. Then, there are various CO_2 capture technologies such as chemical absorption, physical absorption, membrane separation, and the oxy-fuel method. Progress in these technologies will result in the best combination between fuel conversion processes and CO_2 capture processes, so we should technically pursue the CO_2 capture technology that have the highest economic benefits in future on the basic view of Fig. 1. Our chemical research group studies on various CO_2 capture technologies, with a special focus on chemical absorption and membrane separation methods. We accomplished COCS Project of which target was reduction of CO_2 capture cost in ironworks by chemical absorption that had developed innovative chemical absorbent to reduce the CO_2 capture cost for flue gas in an ironworks to 3000 JPY/ton-CO_2. We continue to develop a chemical absorbent to reduce this CO_2 capture cost to 2000 JPY/ton-CO_2. Moreover, we started the collaboration with foreign institutes.

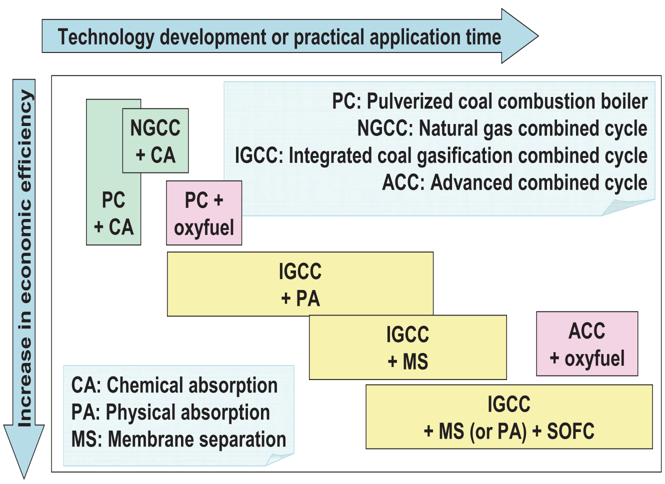


Fig.1 Vision of power plant and CO_2 capture

Next is about our membrane. 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 the membrane module in order to demonstrate with practical coal gasification gas.

Reentry we find two unique materials for CO_2 capture under high pressures. One material is chemical absorbent and the others are adsorbent. We try to evaluate the performance of the process with those materials now.

Above all, we are developing not only innovative technologies for foundation for next generation technologies but also practical and acceptable technologies for the industries on the view of evaluating various new technologies world widely.

Development on CO_2 capture technology by 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 Fig. 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.

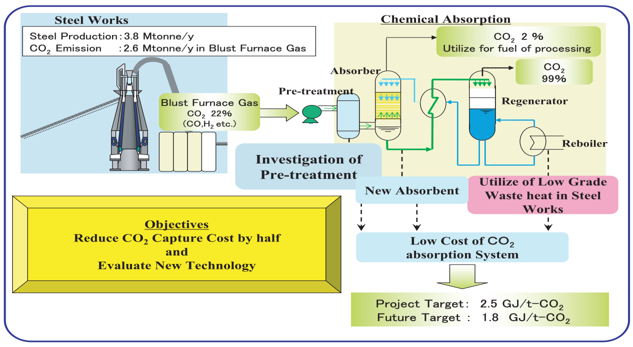


Fig.2 The Outline of cost saving CO_2 capture system (COCS project)

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.

As a first step for the screening and development of new absorbents, 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's samples of commercial amine solvents selected were analyzed using laboratory apparatus. Furthermore, compound amine solutions, that can compensate for deficiencies in the amines, were prepared and their performance was investigated.

From these investigations, several type of high performance absorbents (RITE-3,4 series), that showed different characteristics, were developed. In succession, new absorbents (RITE-5,6 series) has been developed through the basis of our experimental database and theoretical design of molecular structure of new amine compounds using the quantum analysis approach. As the result of bench-scale test, the energy for CO_2 capture of the best of these absorbents is estimated to be 2.5 [GJ/tonne-CO_2]. This value is very low compared to the 4.0 [GJ/tonne-CO_2] for a standard MEA (mono-ethanol amine) solution, so we have confirmed the accomplishment of the project target (Fig. 3).

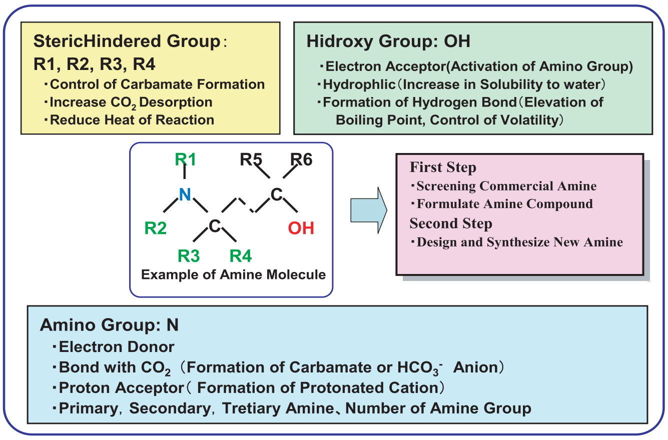


Fig.3 Development of new absorbents

The fruits of this project has succeeded to a new project of "COURSE 50" aiming at a drastic reduction of CO_2 emission in an integrated steel works. A development of new absorbents with a higher performance and application study by pilot-scale plant is scheduled hereafter.

Furthermore, based on the current knowledge on CO_2 absorbents, a development on new absorbents suitable for high pressure gas stream has also been carried out since 2007. In general, amine solvents can easily react with CO_2 under atmospheric pressure condition independent of reaction temperature. But we have confirmed that some amine solvents , nevertheless they do not react under atmospheric pressure, react with CO_2 depending on reaction temperature under high pressure condition (Fig. 4). We have proposed a new CO_2 capture system in pressurized point sources of CO_2 with these absorbents.

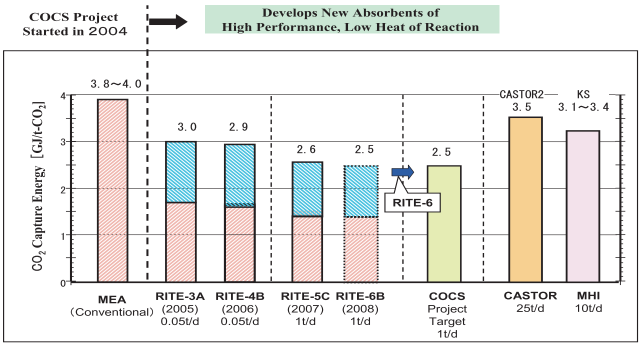


Fig.4 Reduction of CO_2 capture energy by new absorbents

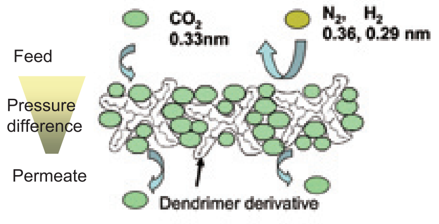
The second step of the project has also been carried out, in which new types of amine compounds, designed and prepared based on the current knowledge, are evaluated by a similar method. Furthermore, research on the optimum conditions for the chemical absorption system has been carried out, so that the 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.

CO_2 and H_2 separation with a polymeric membrane

Japan's government has declared the reduction of CO_2 emission to half by 2005 as "Cool Earth 50". One promising means of dimidiating CO_2 emission is the development of an integrated coal gasification combined cycle with CO_2 capture & storage (IGCC-CCS). In the process of IGCC-CCS, CO_2 separation membranes will play an important role of reducing CO_2 capture cost. The cost estimates indicate that CO_2 capture cost 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. Fig. 5 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 separation membrane. Fig. 6

shows conceptual diagram of the PAMAM dendrimer incorporated material and its CO_2/H_2 separation properties along with the data reported in Science and others. Our PAMAM dendrimer incorporated material shows the world largest CO_2/H_2 selectivity of 30 or more.



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.

Fig.5 Conceptual diagram for the CO_2 molecular gate

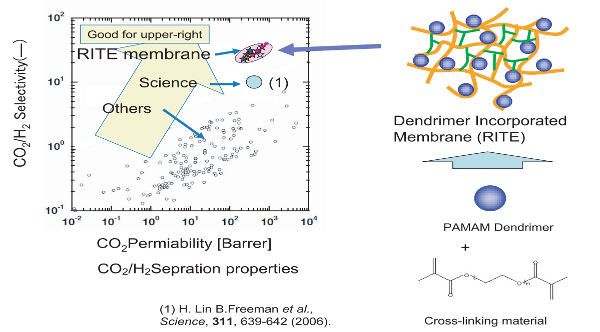


Fig.6 Dendrimer incorporated membrane and its performance

In developing the commercial membrane module with the PAMAM dendrimer incorporated material, RITE involves recently four major membrane companies, Daicel Chemical Industries, Ltd, Kuraray Co., Ltd., Nitto Denko Corporation, and Toray Industries. Fig. 7 shows conceptual module designs of the membrane, hollow fiber type and spiral wound type. RITE and Nippon Steel Engineering Co., Ltd. will test the trial membrane modules with newly developed simulator and demonstrate the availability of the membrane module for capturing CO_2 from a pressurized gas stream such as coal gasification.

In developing this CO_2 molecular gate membrane, the RITE conducted joint research with many foreign partners such as the US Department of Energy's National Energy Technology Laboratory (NETL) as a recognized project of the Carbon Sequestration Leadership Forum (CSLF), University of Texas at Austin and Norwegian University of Science and Technology.

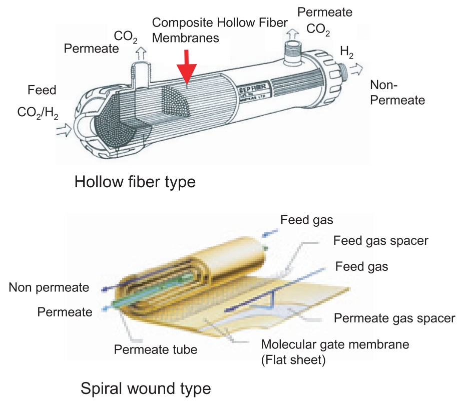


Fig.7 Conceptual module design

Advanced CO_2/H_2 separation materials incorporating active functional agents (GCEP)

The RITE had conducted the developmental work "Sub-nano structure controlled materials: development of innovative gas separation membranes" from the Global Climate and Energy Project (GCEP) of Stanford University, USA. In a succeeding project, advanced CO_2/H_2 separation materials incorporating active functional agents is on going.

In the theme of advanced CO_2/H_2 separation materials incorporating active functional agents, supercritical and subcritical CO_2 works as a structure directing agent of CO_2 affinity materials. Fig. 8 shows the schematic image of the concept. Excellent CO_2 separation membrane will be obtained by strict morphology regulation in molecule scale. In the figure, supercritical CO_2 regulates the CO_2 affinity materials of membrane material in the preferable morphology for CO_2 permeation (State A). After removing supercritical CO_2, the preferable morphology would be held to form an excellent CO_2 separation membrane.

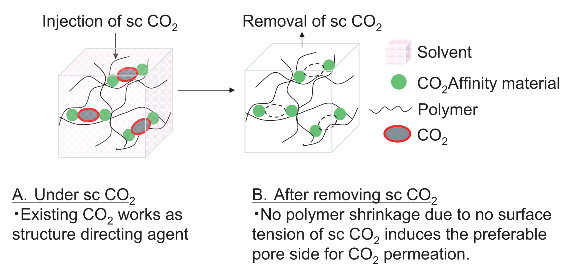


Fig.8 Concept of supercritical(sc) CO_2 structure directing method

Development of an energy-saving CO_2-PSA process using hydrophobic adsorbents

In this project, newly prepared hydrophobic adsorbents have been proposed as CO_2 adsorbents for the separation of CO_2 from high pressure gas. They can overcome such obstacles to adsorption processes. Hydrophobic adsorbents have an advantage over traditional adsorbents such as activated carbon and zeolites because they can adsorb CO_2 in the presence of water vapour, which is usually present in flue gases from fossil fuel combustion. Furthermore, vacuum pump can be eliminated for the adsorption process from high pressure gas.

CO_2 adsorption capacities of 13X zeolite and newly synthesized adsorbents were shown in Fig. 9. It was confirmed that the adsorbent synthesized in our study had a hydrophobic property and adsorbed considerable amounts of CO_2 under high CO_2 pressure. It was also confirmed they adsorbed CO_2 even in the presence of water vapor.

From the CO_2 separation experiment using CO_2-N_2 and CO_2-H_2 mixed gas flow, it was confirmed that the new adsorbent was effective for the CO_2 separation from the gas flow in the presence of water vapor. Evaluation of the process cost is now in progress using two tower type continuous adsorption-separation experimental apparatus.

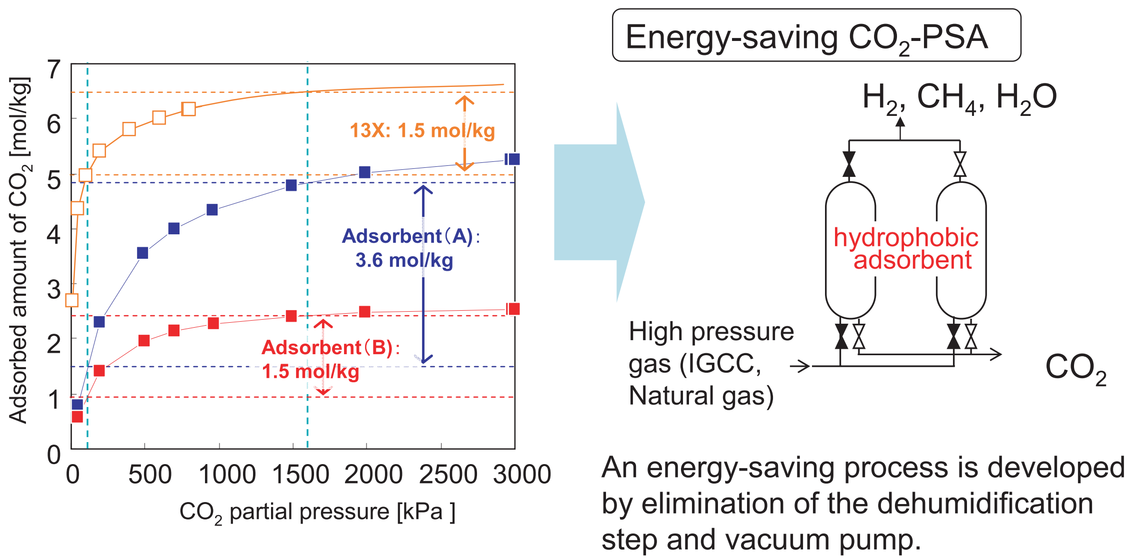


Fig.9 Development of an energy-saving CO_2-PSA process using hydrophobic adsorbents