Demonstration of Hitachi’s CO2 Capture System
for Flue Gas from Power plants

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Abstract

A coal-fired thermal power plant plays an important role as a stable energy resource in many countries in the world, and reduction of carbon dioxide emission from the plant is one of the essential topics in preventing global warming. Hitachi started developing technologies related to the emission reduction early 1990s and is currently demonstrating its proprietary technologies of carbon capture, collaborating with research institutes and utilities overseas as well as domestic ones. This paper introduces Hitachi’s two technologies in the post-combustion process which captures carbon dioxide in flue gas of conventional coal-fired plants; a chemical absorption method and an oxy-fuel combustion one. Hitachi has developed its original solvent and process with minimum energy consumption for the chemical absorption, and has also advanced its combustion technology for oxy-fuel process.

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1. Introduction

COMBATTING climate change has become an important issue as energy demand expands along with worldwide economic growth. Coal-fired thermal power plants play an important role as a key source of energy in many countries because the coal is cheap and coal reserves are extensive and geographically widespread rather than being concentrated in particular areas. A problem with coal, however, is that it emits a large quantity of CO2 (carbon dioxide) per unit of output and this has created a strong demand for the development of CCS technologies that can separate out and capture the CO2 as a new approach that can help move toward a low-carbon society. Hitachi is working to achieve the practical realization of CCS based on the various environmental technologies that it has built up over time. This article describes Hitachi’s development vision for CCS technology, and two CO2 separation and capture techniques, namely CO2 scrubbing and oxy-fuel combustion.

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2. Hitachi’s Development Roadmap

Hitachi has established a global network with sites in Japan, USA, and Europe and collaborates with local research institutions in these countries on the development of technologies for CCS and for improving the efficiency of coal-fired power (see Fig. 1). Four specific technologies under development are: (1) 700°C-class A-USC (advanced ultra super critical), (2) CO₂ scrubbing (a CO₂ capture technology), (3) Oxy-combustion, and (4) IGCC (see Fig. 2). A-USC is a technique for dramatically improving the efficiency of power generation, CO₂ scrubbing is a technology suitable for retrofitting existing power plants for partial CO₂ capture, and oxy-combustion is an efficient technology to achieve full CO₂ capture. IGCC, in turn, is an extremely clean technology that gasifies the coal and uses the resulting hydrogen as the primary fuel for power generation. The combination of these four technologies is capable of reducing emissions of NOx (nitrogen oxides), SOx (sulfur oxides), CO₂, and other pollutants to a very low level and mitigating the efficiency loss associated with CO₂ capture, and together they constitute a new generation of coal-fired thermal power that can also achieve economic viability. The following sections describe the CO₂ scrubbing and oxy-combustion methods of CO₂ capture.

3. DEVELOPMENT OF CO₂ SCRUBBING

3.1 Overview

The use of CO₂ scrubbing to remove CO₂ is a technology that has already been proven in natural gas purification, chemical plants, and elsewhere. However, there are problems that need to be resolved before it can be applied in coal-fired power plants, including the significant reduction in generation efficiency caused by heat losses and the degradation of the solvent caused by oxide gases such as SO₂ (sulfur dioxide) in the flue gas.

Hitachi commenced research and development in the early 1990s and conducted trials including basic experiments and pilot testing using actual gas to develop solvents and equipment suitable for use with the flue gas from coal-fired boilers. Now Hitachi is working to put the technology into practice and Hitachi Power Systems America, Ltd. has joined some projects sponsored by the U. S. Department of Energy to collaborate with power companies and institutes on the performance evaluation of its proprietary solvent for coal-fired power plants.

3.2 Solvent Development

Solvent development was performed using bench equipment together with basic experimental apparatus (see Fig. 3). This equipment consisted of an absorber, desorber, and fluid circulation unit and allowed tests using a synthesized gas that simulated boiler flue gas to be carried out under a range of conditions. Hitachi conducted screening tests for a large number of different solvents over a period of time to develop the H3 amine solvent which is suitable for use with the flue gas from coal-fired boilers.

Previous solvents were primarily for CO₂ removal during natural gas production and were negatively affected by the oxide gases and oxygen in the flue gas of coal-fired boilers. Also, because the volume of gas to be processed is far larger, the design of the equipment needs to take appropriate account of the thermal properties, flow characteristics, and other basic properties of the solvent. Through this work, Hitachi selected the most suitable amine from a range of options and further optimized its performance using additives and other additions.
3.3 Demonstrations Using Actual Flue Gas

In joint research with The Tokyo Electric Power Company, a pilot plant capable of treating 1,000 m$^3$/h of flue gas was installed at the company’s Yokosuka Power Plant and demonstration experiments were conducted on actual flue gas using the H3 amine solvent developed by Hitachi (2), (3) (see Fig. 4). After conducting various characteristics tests to confirm the performance, a 2,000-hour continuous operation test was performed. Fig. 5 shows some of the results of this test. A reliable and high level of CO$_2$ removal performance was achieved in a test using flue gas containing 30 ppm of SO$_2$. The removal ratio exceeded 90% and the captured CO$_2$ had a purity of 99% or better, both of which were excellent results. Also, the energy consumed to capture the CO$_2$ was 20 to 30% less than that for the standard MEA (monoethanolamine) solvent. Hitachi is now working to improve further the properties of amine solvents.

Another factor to consider is that a wide range of different coals are used around the world and this results in differences in characteristics such as the amount of ash or concentrations of oxide gases in the flue gas. Accordingly, Hitachi also plans to conduct tests using actual flue gas in Europe. The pilot plant for this purpose has the capacity to treat 5,000 m$^3$/h of flue gas (see Fig. 6) and evaluation tests at existing power plants are planned to start as part of joint research with a German utility companies in which Hitachi Power Europe GmbH is taking a central role. The tests will also conduct experiments on a newly improved solvent.
3.3 Constructing Optimum System

To ensure that CO₂ capture plant can be incorporated into coal-fired power plants, it is necessary to construct an optimum system with consideration for providing compatible interfaces. The main items of investigation are as follows.

1) SO₂ scrubbing upstream of the CO₂ absorber

Because the SOₓ contained in the flue gas from a coal-fired boiler will degrade the solvent, it is considered necessary to reduce the concentration to 10 ppm or less at the inlet to the CO₂ capture plant. For this purpose, configurations that locate an additional scrubber upstream of the CO₂ absorber are considered. Hitachi, however, has an existing FGD (flue gas desulfurization) system with excellent performance that has demonstrated 99% or better SO₂ removal efficiency at many different sites and this permits designs with no additional scrubber.

2) Steam supply to desorber (bleed-off from steam turbine)

Hitachi also has considerable experience with steam turbines and is developing steam systems that minimize the reduction in efficiency associated with bleeding off steam. Hitachi is also developing a system to recover waste heat from the flue gas to minimize the quantity of steam that needs to be supplied from the turbine.

3) Reuse of waste heat from CO₂ compressor

The captured CO₂ gas is either compressed and transported or compressed and liquefied so that it can be sequestered. The captured CO₂ gas has a high moisture content and recovery of the water, compression heat, and other by-products of this process is an important factor for improving the system efficiency. Because of the large volume of gas being processed, it is also essential to minimize the compression power requirements. Hitachi also has extensive experience in the manufacture of centrifugal CO₂ compressors for various types of plant including urea synthesis (4) (see Fig. 7). Development work on enhancements such as improving the overall efficiency of systems that use these technologies is under way.
4. DEVELOPMENT OF OXY-COMBUSTION

4.1 Overview

Oxy-combustion works by diluting oxygen with recirculated flue gas and using this instead of air as the combustion-supporting gas (see Fig. 8). Because the resulting flue gas consists mainly of CO$_2$ and water, the CO$_2$ can be compressed and liquefied simply by removing the water and therefore large-scale capture equipment such as a CO$_2$ scrubber is not required. Also, because the volume of combustion gas for oxy-combustion is less than for air combustion, the boiler and flue can be made more compact. However, the issues that need to be considered in practical realization of this method include the changes in flame stability, heat transfer, and other characteristics that result from using a different combustion-supporting gas, and the corrosion caused by the build-up of SOx that results from flue gas recirculation.

Hitachi has been involved in the development of coal-fired boilers for many years and has world-class testing facilities (basic test equipment and pilot plants) and numerical analysis techniques that are being used to advance this work. Hitachi is also working with overseas electricity generation companies on developments that include scaling up this technology with the aim of bringing it into commercial use.

4.2 Development of Oxy-combustion Burner

With oxy-combustion, the main component of flue gas changes from N$_2$ (nitrogen) to CO$_2$. Because CO$_2$ has a greater retardant effect on combustion than N$_2$, it causes worse flame stability. In response, Hitachi has developed a new burner with a high level of flame stability even under oxy-combustion conditions. The combustion test rig shown in Fig. 9 was used in the development of this burner.

The test rig provides a model of the basic structure of an actual burner and can be used to evaluate combustion and heat transfer characteristics when the concentrations of CO$_2$, water, and other components are varied by recirculating the flue gas. Hitachi also participated in European projects through Hitachi Power Europe and is worked on developments for use in demonstration plants. It was conducting 30-MWth-class burner combustion trials at the Schwarze Pumpe coal-fired power plant in Germany and evaluating reliability issues associated with scaling up this technology (see Fig. 10).
4.3 Development of Flue Gas Recirculation System

As the volumetric flow rate of flue gas produced by the reaction between fuel and oxygen is roughly one-fifth of that for air combustion, the concentration of SO$_3$ (sulfur trioxide) in the flue gas is approximately five times higher which increases the potential for corrosion in the flue gas line. In response, Hitachi has developed its own new recirculation system which reduces the concentration of SO$_3$ in the flue to a level at which corrosion is no longer a problem (1 ppm or less). Experiments to verify the operation of the complete system were conducted using a large-scale facility capable of testing the entire process from combustion to flue gas treatment, including this new recirculation system (see Fig. 11).

5. FUTURE DEVELOPMENTS

Hitachi is working with local utility companies in Europe and America on plans for CCS demonstration trials. For CO$_2$ scrubbing, Hitachi is involved in projects in Saskatchewan in Canada and Norway. For oxy-combustion, Hitachi is involved in projects in Germany and Finland. Hitachi intends to advance international collaboration through these projects, integrate CCS technology with existing power generation technology, and investigate and overcome the obstacles to its commercialization which include economics and reliability. Enhanced oil recovery, one of the potential methods for sequestering CO$_2$, is already in practical use and can be used to recover additional oil from old oil fields by injecting CO$_2$ under pressure. The economic benefits of this are large. Hitachi is making progress toward the practical realization of CCS technology by combining the CO$_2$ capture technology it has developed with technology for transportation and sequestration.

6. CONCLUSIONS

This article has described Hitachi’s development roadmap for CCS technology, and two CO$_2$ separation and capture techniques, namely CO$_2$ scrubbing and oxy-combustion.
The International Energy Agency published a technology roadmap for CCS in October 2009\(^{(6)}\). The roadmap stated that, to achieve the objective of halving the level of CO\(_2\) emissions by 2050, 100 CCS plants would be required worldwide by 2020 and 3,400 by 2050. This shows how CCS technology is essential to protecting the global environment. Hitachi will continue to work on technology development to contribute to preventing global warming.

**References**


