Toward the Realization of Zero Emission Power Plants

CO_2 capture system for coal-fired power plants with oxyfuel combustion technology

Coal-fired power plants emit large amounts of CO_2, which constitutes one of the largest causes of global warming. Successful reduction of environmental pollutants to zero would not only enable effective use of coal with abundant recoverable reserves, but also help solve environmental issues.

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Callide-A power plant with oxyfuel combustion technology

Amid calls to curb global warming, it seems that only slow progress is being made to reduce CO_2 emission, which is said to be the main cause. Global CO_2 emissions are still increasing and coal-fired power plants emit a large amount of CO_2 into the atmosphere. Power plants burning petroleum, natural gas, coal, etc. create heat which is used to generate steam that rotates turbines to generate electricity. Currently, efforts are being made to minimize fuel consumption through enhancement of efficiency with improved steam conditions for pulverized coal-fired power plant and increased inlet temperature for gas turbine. Additional efforts include shifting from coal to natural gas, which almost halves CO_2 emission per unit calorific value as well as the efforts to reinforce application of renewable energy such as biomass, wind, and solar power generation. Nevertheless, these efforts have not fundamentally addressed the attempt to significantly reduce CO_2 in the atmosphere. Meanwhile, according to the latest data, coal-fired power generation is one of the main sources of electric power, accounting for roughly 45% of the power in the United States and 40% in Germany, while the share in Japan is around 25%. The share is as high as approximately 80% in China and approximately 70% in India. For this reason, measures are being devised to reduce CO_2 emissions from coal-fired power generation that emits such a large amount of CO_2 per unit of calorific value. Development of CO_2 Capture and Storage (CCS) technology is underway with great expectations. This CCS technology has the advantage of significantly reducing CO_2 emissions from power plants per unit kW·h (t-CO_2/kW·h) to almost 1/10 compared to conventional plants, which do not have this technology. However, the cost of power plants with CCS technology is 40 to 60% higher, therefore the development and commercialization of this technology needs to be supported by governments at present. Commercialization of the CCS technology is being researched for future implementation by developing a legal framework and reducing overall costs.

In this context, IHI has been advancing research and development on oxyfuel combustion technology since 1989 as a form of CO_2 capture technology of the kind being sought for wide application at coal-fired power plants. This article describes the overall efforts for applying oxyfuel combustion technology to coal-fired power plants.

Oxyfuel CO_2 capture system

Oxyfuel combustion technology provides coal combustion with oxygen (O_2) separated from the air by an Air Separation Unit (ASU). Application of this technology to power generation systems is in its initial stages as a conventional equipment design based on air combustion is being considered. In the fuel combustion process, O_2 gas is mixed with recirculated flue gas instead of burning the fuel solely with O_2 in order to secure heat-transfer performance comparable to conventional air combustion. In this manner, CO_2 concentration can be theoretically increased to over 90% (dry basis) in the flue gas from combustion mainly consisting of CO_2 and H_2O. The oxyfuel CO_2 capture system comprises an additional method of removing water and non-condensable gas in flue gas to provide high concentration CO_2.

CO_2 captured by the system is pressurized at a storage site before being injected underground into a storage layer.

The main features of an oxyfuel CO_2 capture system are summarized as follows:

(1) No need to separate low concentration CO_2 as is the case with flue gas from air combustion.

(2) The total amount of flue gas is reduced to approximately 1/5 the amount from air combustion, which is conducive to downsizing the flue gas treatment system.

(3) Nitrogen oxide contained in the flue gas is recirculated, recombusted, and thereby significantly reduced by the system.

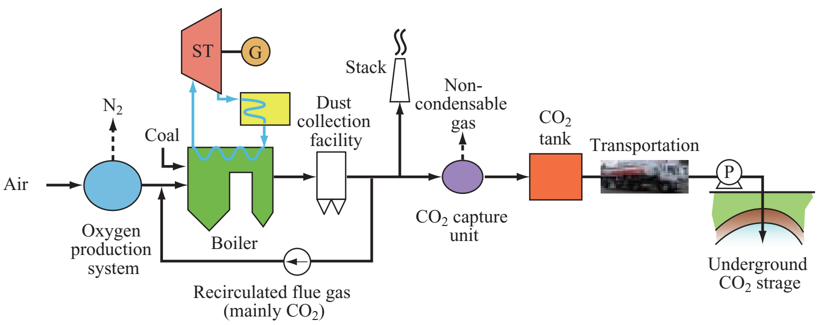
(4) Oxygen concentration can be raised locally, which promises to improve combustion.

Worldwide research and experimental development are underway for a system with the above features, as it is deemed a key future technology for CO_2 capture from coal-fired power plants. The commissioning about oxyfuel combustion of a demonstration plant in the Callide Oxyfuel Project with the participation of IHI Corporation began in March 2011. This is the first operational demonstration in which an already operating coal-fired power plant will be modified into an oxyfuel power plant. Further efforts to achieve the commercialization of oxyfuel power plant is to be attempted in the near future.

However, technical challenges remain to be examined with the boiler and the overall system because the combustion takes place in a CO_2 atmosphere having different specific heat and radiation properties from nitrogen as well as more water and greater concentrations of corrosive substances.

(1) Boiler process

Oxyfuel involves combustion in an O_2/CO_2 atmosphere as flue gas is recirculated. Therefore, the challenges are to assess the combustion properties (ignition, combustion temperature, ash property, behavior of trace elements) and heat-transfer properties (radiation, convection), as well as ensure performance including the reliability of plant control and instrumentation, durability of components after years of operation (corrosion, erosion), CO_2 concentration in flue gas, and boiler efficiency.



Overall system flow of a power plant with CO_2 capture and storage using oxyfuel combustion technology

(2) Technical challenges for plant operation

Stable operation flexibility must be ensured regarding: the operating method during the oxyfuel process, the switching method between air combustion mode, and startup and shutdown methods. Additionally, measures must be taken to check operation in the event of emergency shutdowns and to ensure safety in oxygen handling.

(3) CO_2 capture process

The key challenge of CO_2 capture from flue gas in oxyfuel combustion is the development of an optimal process for obtaining highly pure CO_2 including the pretreatment method, removal of trace elements that affect unit durability, and setting the right temperature and pressure conditions for CO_2 capture. The capture conditions and purity of CO_2 depends on the methods for transporting and storing captured CO_2. For this reason, storage and transportation must be considered in the research and development for efficient capture.

Callide Oxyfuel Project

The ongoing Callide Oxyfuel Project is aimed at a demonstrating a comprehensive CO_2 capture and storage process using oxyfuel combustion technology applied at a coal-fired power plant. This is the first operational demonstration to prove that an existing coal-fired power plant can be modified into an oxyfuel power plant capable of capturing CO_2 by actually modifying a commercially operated plant to use oxyfuel combustion technology.

Australia and Japan jointly examined candidate sites for this project in fiscal years 2004 and 2005 in response to a proposal by Australia. Project planning was carried out during fiscal years 2006 and 2007 based on the findings. Based on the support from both the Australian and Japanese governments, participating companies from both countries organized a Joint Venture (JV) which serves as the executive body of the project. Three companies from Japan are participating in the JV, namely Electric Power Development Co., Ltd. (J-POWER), Mitsui & Co., Ltd., and IHI. Japan Coal Energy Center provides technical support.

The Stage I of this project involves CO_2 capture using the oxyfuel process. In the Stage II, the captured CO_2 is stored underground and monitored.

Retrofit work for CO_2 capture process from oxyfuel flue gas is underway and commissioning of the oxyfuel power plant is being carried out for the Stage I. Commissioning for oxyfuel combustion and CO_2 capture will be completed in September 2012 before the planned operational demonstration. Specific site selections, test drilling, and licensing procedures will be carried out for the Stage II before transporting the captured CO_2 by tanker truck to a storage site where it is to be injected underground.

The following considerations were made regarding technical challenges in applying oxyfuel to the existing power plant:

(1) Heat transfer at the boiler furnace (furnace heat absorption)

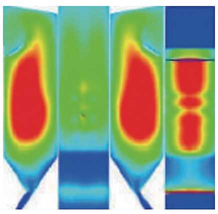
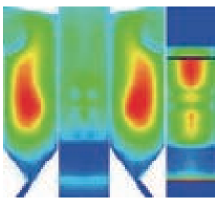
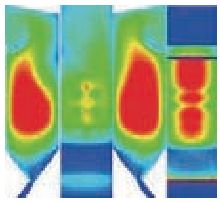
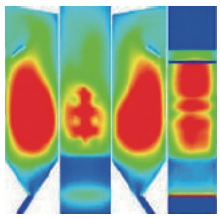
The amount of recirculated flue gas in the oxyfuel process influences furnace heat absorption, boiler performance, and the equipment involved in the process. For this reason, furnace heat absorption was evaluated by numerical analysis in order to determine the appropriate amount of recirculated gas in the target boiler. It was assessed that heat absorption and heat-transfer performance comparable to air combustion can be provided by maintaining the oxygen concentration around 27% for all of the combustion gas.

(2) Oxygen mixture

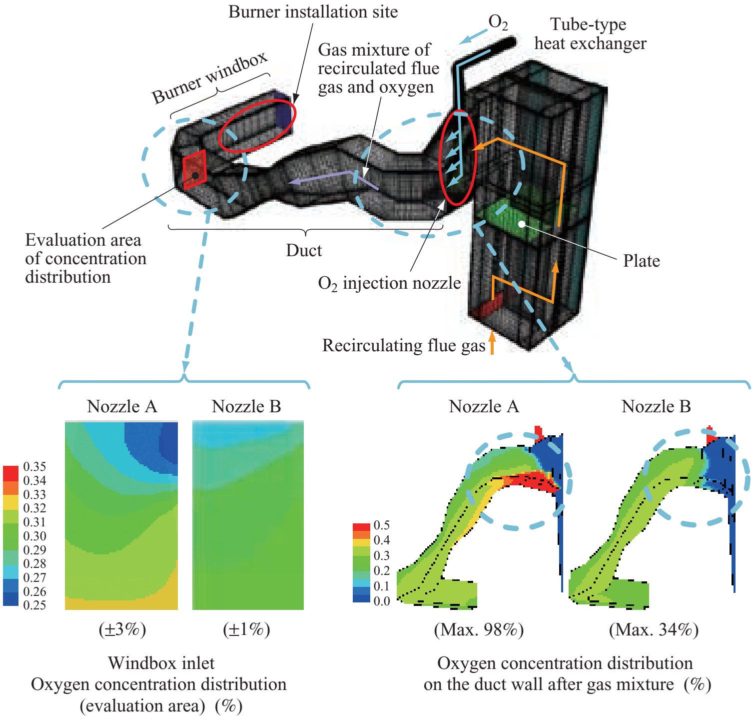
Insufficient mixture of recirculated flue gas and oxygen can result in uneven oxygen concentration among different burners to which the gas mixture is distributed. Thus, the nozzle structure was focused on, in order to achieve an even oxygen mixture by employing numerical analysis. The number of nozzles, their position, flow velocity, and direction were optimized based on the results of numerical analysis and a nozzle with excellent mixture performance was selected.

(3) Flue gas property

An experiment was conducted at the pilot scale combustion test facilities with three kinds of Australian coals in order to check the combustion characteristics. The results showed a significant reduction of NO_x. Although SO_2 concentration had increased, it was demonstrated that the overall emission of SO_2 can be reduced thanks to the capture of its sulfur content by the ash.

Item	Unit	Air combustion	Oxyfuel case 1	Oxyfuel case 2	Oxyfuel case 3
Total amount of gas	t/h	140	170	140	120
Boiler inlet oxygen concentration	%	21	22	27	30
Analyzed heat flux distribution  200 0	kW/m^2				
Furnace heat absorption	—	Baseline	Reduced	Almost the same	Increased

Furnace heat absorption analysis results



Simulation results for mixing oxygen

Vertical combustion test facilities at D&D (Demonstration & Development) Park in IHI's Aioi Works

Toward commercialization

The oxyfuel CO_2 capture system needs a large amount of power for the ASU and the CO_2 capture process. At present, plant efficiency is estimated to drop by 5 to 10% (absolute value) depending on the conditions associated with CO_2 capture. With further improvement in the efficiency of these units, the power plant as a whole can also reduce coal consumption, the need for oxygen production, and flue gas. Thus, efficiency can be enhanced synergistically. At present, an ultra-supercritical pressure power plant (i.e., a system with steam temperature of 593°C or more) is widely used in coal-fired power plants. IHI is pursing even higher efficiency by developing a 700°C-class advanced ultra-supercritical pressure boiler technology, which provides steam temperature in the range of 700°C. The application opens the door to oxyfuel CO_2 zero emission power generation.

This technology is intended for application in power plants which call for reliability in operation. In order to turn this technology into a commercial reality, what is needed is steady research and development for achieving higher efficiency and cost reduction for individual units and the whole plant, as well as a study for expanding the capacity of commercially viable ASU.

This article has outlined the Callide Oxyfuel Project and challenges related to the commercialization of the oxyfuel combustion technology. IHI intends to thoroughly examine and evaluate this technology through the demonstrational operation at Callide Oxyfuel Project for completing a reliable CO_2 capture power generation system after further operational demonstration at a commercially viable scale. Further research, development, and demonstrations will be conducted to provide a highly efficient CO_2 capture system combined with economically viable storage system in the future.

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