A Big Step toward Zero Emission Power Plants

CO₂ capture system using oxyfuel technology for coal-fired power plants

The emission of CO₂, which is said to be one of the main causes of drastic climate change, has continued to increase. We have continuously been engaged in research and development over the years to accomplish the goal of effectively reducing the emissions of environmental pollutants from coal-fired power plants to zero.

Having completed the demonstration in Callide (Australia), the oxyfuel technology is now moving on to the next step.

CO₂ emission control and securing stable power sources

The emission of CO₂, which is said to be one of the main causes of drastic climate change, has continued to increase. In March 2015, the global monthly average value of atmospheric CO₂ concentration reached to 400 ppm. It is reported that the atmospheric CO₂ concentration must be kept under 450 ppm in order for the global average temperature to remain two degrees Celsius higher than it was before the Industrial Revolution. It is necessary to significantly reduce the amount of CO₂ emission in the coming 10 to 20 years to achieve that goal. In recent years, laws and regulations have been developed toward the promotion of CO₂ emission control. Many countries make efforts to reduce CO₂ emissions based on Paris Agreement.

Coal is a stable and abundant primary energy resource for power generation around the world. The percentage of coal-fired power generation among all forms of electricity generation is relatively high, making coal a major source of electricity.

On the other hand, the issue on coal-fired power plants is CO₂ emissions to atmosphere by burning coal. Therefore, large amount of CO₂ capture and storage from coal-fired power plant is urgent mission. Carbon dioxide Capture and Storage (CCS) technology is being developed as one of the efforts to resolve it. CCS technology already reaches to the commercial stage worldwide and it has begun to be constructed.
CO2 capture system with oxyfuel

Oxyfuel is a technology in which fossil fuels like coal are burned with oxygen (O2) separated from air using an Air Separation Unit (ASU). Bycombusting fuel with oxygen, the flue gas is mainly composed of CO2 and H2O and the CO2 ratio in the flue gas can theoretically be increased up to 90 dry% or higher. CO2 capture system by oxygen combustion is a method of capturing CO2 by removing water, oxygen, and other contaminants from flue gases in the CO2 capture process. Captured CO2 is pressurized and injected into underground storage layers in storage sites.

Oxyfuel boiler system is the technology based on a combination of existing technologies and equipment. It can be a new installation or it can be adapted to existing air combustion power plants. In addition, when the technology is adapted for installation in an existing plant, there is no need to modify boiler pressure parts and steam turbines. As it utilizes the equipment design techniques of existing air combustion boilers to secure heat transfer performance equivalent to air combustion, recycled flue gases are mixed with the oxygen and burned. Furthermore, when new boilers designed especially for oxyfuel are installed in the future, it should be possible to reduce the amount of recirculated gases and to make the boilers smaller.

Oxyfuel systems have several features as described below. There is no need to separate low-concentration CO2 as in the case of the flue gases of air combustion. Furthermore, as the amount of total emission gases is about five times smaller than that of air combustion, the gas treatment system of the CO2 capture process can be much smaller. On the other hand, there are several issues to consider such as the fact that flue gases have high CO2 concentration, that water content and corrosive gas content are concentrated, and that flue gases are recovered. In order to deal with such issues, the following matters must be considered in the design of boilers and their systems.

1. Ascertaining combustion and heat transfer characteristics of the boiler process, attaining adequate CO2 concentration and performance, developing a control method specific to oxyfuel, and reliability in long-term operation
2. Developing an operation method in oxyfuel mode considering stable operation of plants, switching methods between oxyfuel running mode and air combustion running mode, operation in case of emergency stop, safe handling of oxygen, etc.
3. Removal of contaminants from flue gases generated by oxyfuel suitable for transport, storage, and utilization and development of process to capture high-purity CO2
4. Consideration of low-temperature corrosion due to concentration of corrosive gases and H2O

Callide Oxyfuel Project

IHI has conducted fundamental research, combustion tests, and operability studies since 1989, acquiring the techniques needed to apply oxyfuel technology to an actual coal-fired power plant. As a result, we conducted a demonstration project on the integrated processes involved in CO2 capture technology and applied oxyfuel technology to a coal-fired power plant in Queensland, Australia. It was the first attempt in the world to verify that an existing power plant that had been operating commercially could be retrofitted into a CO2 capture type oxyfuel plant.

The Callide Oxyfuel Project started in 2008. Australian and Japanese companies participated in the project with the support of the Australian and Japanese governments. This project was carried out in two stages: ① CO2 capture from oxyfuel combustion in the power plant, and ② the transport of CO2 captured from the power plant and its injection into the ground.

The first stage began with retrofit work and commissioning. Demonstration of oxyfuel combustion and CO2 capturing started in December 2012 and finished in March 2015. It achieved over 10 000 hours of accumulated oxyfuel operation and over 5 500 hours of CO2 processing unit operation. Much data concerning plant performance in oxyfuel operation and facility reliability were obtained. The main test items are described below.

1. When oxyfuel technology is applied to an existing boiler plant, it should be operated at the performance level equivalent to the required air combustion. It was confirmed
that operation is automatically switched between air combustion and oxyfuel combustion. The flames of air combustion and oxyfuel combustion with different boiler inlet O2 concentrations are shown in the photos. Although the brightness of flame is different, performance equivalent to air combustion is achieved at a certain load.

(2) Durability of mechanics in long-term operation was confirmed for both component parts of the retrofitted and existing parts.

(3) The following factors which are important for large-scale commercial plants were verified: low load operation, changes in load, controllability, plant operation in case of emergency (safe stop, rapid load reduction), and mode transition to oxyfuel under low load.

(4) The CO2 concentration from the CO2 Processing Unit (CPU) was nearly 100% pure. In addition, the operation performance of equipment, the removal characteristics of atmospheric pollutants in exhaust gases, and the behavior of trace elements were examined.

In the second stage, part of the CO2 captured in the first stage was transported overland to the state of Victoria from October to December 2014 and was injected underground in the Otway Project Site of the CO2CRC (Cooperative Research Centre for Greenhouse Gas Technologies). The injection facility had already been constructed by CO2CRC. The injected CO2 was used to assess its geochemical and geophysical behavior in the storage layer. This was the first time in the world that CO2 captured from an oxyfuel boiler in a coal-fired power plant was injected into underground. This was also the first time in Australia that CO2 captured from a thermal power plant was injected into underground. The objective of the project, a complete demonstration of total process from CO2 capture to injection, was accomplished.

Because an existing boiler plant was retrofitted for application of oxyfuel, performance design for determination of ASU and CPU specifications and additional equipment installation with a limited layout were required. Therefore, the status inspection of existing facilities and commissioning for performance demonstration were conducted before the retrofit. The retrofit work was carried out after data necessary for designing was collected. In addition, since behavior unexpected at the time of design frequently occurred while the retrofitted plant was operated, adjustments for stable operation were conducted one after another during the commissioning and the demonstration. Furthermore, since the staff members working in the plant had to operate and maintain not only the boilers but also the facilities such as the ASU and CPU, which do not exist in conventional power plants, considerable efforts were required to learn and master the techniques. In such circumstances, as a result of support from equipment suppliers and efforts made by the staff members of the plant, long-term operation of the oxyfuel plant and CO2 capture were achieved.

**Toward the next project**

At present, we are actively developing a project that aims to realize large scale commercial facilities with a CO2 capture system from an oxyfuel plant.

While this technology is to be applied to power generation plants, the possibility of not only capturing CO2 but also industrially utilizing CO2 (CCUS: Carbon Capture, Utilization,
and Storage) has been considered in recent years. CCUS raises the value of captured CO₂ and realizes economically effective CO₂ capture. For example, captured CO₂ can be utilized for EOR (Enhanced Oil Recovery) which increases oil production from oil fields where oil production has decreased. Furthermore, since oxyfuel technology generates nitrogen separated by an ASU, the utilization of nitrogen can also contribute to improved economic efficiency. Shale gas production (fracturing) and fertilizer production are examples of nitrogen utilization. Improvement in economic efficiency by measures such as the marketing of such by-products opens up possibilities for the capture technology of CO₂ from oxyfuel.

If the oxyfuel technology is applied to the coal-fired power plant, economic efficiency can be improved by utilizing captured CO₂. In addition, selling nitrogen generated by the ASU for industrial use can provide an economically advantageous CCS system.

**Conclusion**

Oxyfuel boiler systems can not only be constructed as new plants but existing plants can also be retrofitted into CO₂ zero emission plants. We strongly believe that this is an important technology. We will make use of our abundant experience in plant operations obtained from the demonstration in the Callide Oxyfuel Project and create a develop power generation system with CO₂ capture on a commercial scale. Optimization of processes that vary between projects and the development of more effective systems are important issues as well.

We will continue to put forth efforts for early commercial implementation and to achieve more advancements in order to realize the idea of an economically effective and highly efficient CO₂ capture system.

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