International Conference on Power Engineering-2007, October 23-27, 2007, Hangzhou, China

Test Results of Oxy-fuel Combustion and Outline of Demonstration Project in Australia

Toshihiko YAMADA*, Masato TAMURA*, Toshiro FUJIMORI*, Nobuhiro MISAWA**, Takashi KIGA*** and Chris SPERO****
* IHI Corporation, Tokyo, 135-8710, Japan
(E-mail: toshihiko_yamada@ihi.co.jp)
**Electric Power Development Co.,Ltd., Tokyo, 104-8165, Japan
(E-mail: nobuhiro_misawa@jpower.co.jp)
***Japan Coal Energy Center, Tokyo, 108-0073, Japan
(E-mail: tkiga@jcoal.or.jp)
****CS Energy Ltd, Brisbane, Qld 4001, Australia
(E-mail: cspero@csenergy.com.au)

Abstract: Oxy-fuel combustion is expected to be one of the promising systems on CO_2 capture from pulverized-coal fired power plant, and enable the CO_2 to be captured in a more cost-effective manner compared to other CO_2 capture process. Some studies in this area were implemented under Australia-Japan consortium established in 2004. The comparative testing of the important components by using three Australian coals has been recently conducted under both oxy-fuel and air combustion conditions. The purposes of these tests were to obtain design data on flame stability, combustion characteristics and plant operation including turn-down test. The tests have indicated a number of important outcomes including a good comparison of normal air with oxy-fuel combustion, significant reduction in NOx mass emission rates under oxy-fuel combustion and the collection of data to validate other combustion modeling work.

On the basis of the study results, the project under Australia-Japan consortium is now under way for applying oxy-fuel combustion to an existing plant by way of demonstration. This project aims at capturing CO_2 from an actual power plant for storage. The project will be implemented at the power generation system in Callide-A power plant No.4 unit with a capacity of 30MWe in Australia.

Keywords: Coal, O_2, Combustion, CO_2 capture, CO_2 storage

1. INTRODUCTION

Concerning the global warming, Kyoto Protocol entered into force in February 2005, and now many countries are working actively toward the second commitment period starting 2013. The current situation requires us to establish a firm technological basis for reducing CO_2 emissions. From a global viewpoint, however, thermal power plants are releasing CO_2 in large quantity, which indicates the necessity for a power generation system with CO_2 capture and storage. Among all the fossil fuels used at thermal power plants, coal produces the greatest amount of CO_2 per unit calorific value. Thus, emissions from power plants using pulverized coal seem to be one of the significant sources in capturing CO_2 effectively.

Fig.1 shows an example of CO_2 capture at a coal-fired power plant. Research, development and demonstration are in progress for each of the systems shown in this figure.

In the process of capturing CO_2 through oxy-fuel combustion, O_2 is separated from combustion air and used for burning the coal. In this process, it is theoretically possible to improve the CO_2 concentration in the flue gas to 90 dry % or over.[1] When the oxy-fuel combustion technology is applied to power plants, flue gas (which mostly consist of CO_2) are recirculated and mixed with O_2 for the purpose of controlling the flame temperature. With this system, it has been confirmed that the process characteristics help reduce NOx emission. But there are some development issues, including the necessity of saving motive power for oxygen production and the necessary integration among the units for oxygen production, power generation and CO_2 capture process. Great expectations are placed on the oxy-fuel combustion system described in this paper, because it represents a direct CO_2 capture method that is better than other CO_2 capture systems in terms of economical efficiency and technological feasibility.

In the future, it will be increasingly necessary to establish a coal-fired power system with CCS (Carbon Dioxide Capture and Storage). In this respect, it will be important to integrate the CO_2 capture technique into the power generation unit, as well as those of recovery and storage.

Oxy-fuel combustion technology has been attracting increasing attention worldwide from the above-mentioned reasons because it has a potentiality for providing a breakthrough solution that helps reduce CO_2 emissions. In relation to this technology, many countries are conducting

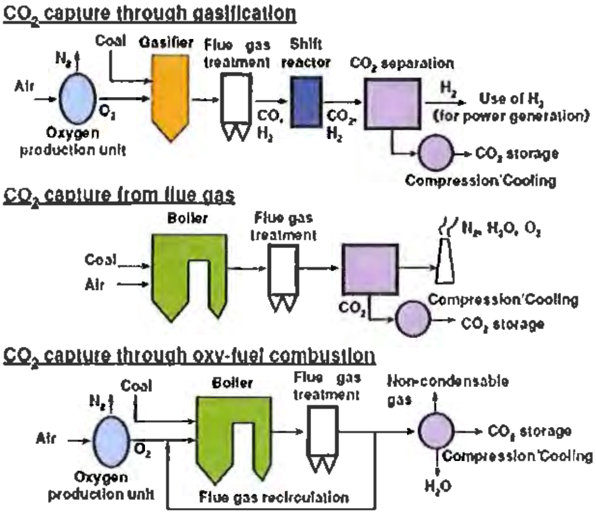


Fig.1 CO_2 capture from coal-fired power plant research and development. Major trends of R & D activities related to oxy-fuel combustion are summarized as follows:

*An electrical power company, Vattenfall, has started a demonstration project of oxy-fuel combustion at a 30 MWt plant[2], being supported by the German government. The demonstration plant will be built in Schwarze Pumpe power plant. It will start operation in 2008 to recover CO_2 from flue gas.

*U.S. companies, such as Praxair, are working on the R & D activities of oxygen production, aiming at utilizing a membrane separation technique[3] that is more efficient and requires less cost than the existing technique of cryogenic distillation.

*Jupiter Oxygen announced the oxy-fuel clean coal retrofit to Ohio 25MWe plant. In the immediate release[4], retrofit will be completed in 2008, and the plant will meet FutureGen's 2020 goals for ultra-low emissions of mercury, NOx, SOx, and particulates, as well as capturing CO_2.

*In the media fact sheet[5] by SaskPower, Babcock & Wilcox Canada and Air Liquide, approximately 8,000tonnes of CO_2 per a day would be captured at 300MW clean coal plant using oxy-fuel and sequestered in underground deep saline aquifers or sold to oil companies for use in enhanced oil recovery. A decision on whether to proceed with the project will be made in mid-2007, with an in service date of 2011.

2. TEST RESULTS OF BOTH AIR AND OXY-FUEL COMBUSION

For the purpose of verifying the flame stability and the characteristics of combustion and heat transmission, combustion tests were conducted at pilot-test facilities of IHI in Aioi Works where the oxy-fuel combustion system was simulated.

2.1 Test Facilities and Methods

The test furnace is a vertical and cylindrical furnace with a capacity of 1.2 MWt, an inside diameter of 1.3 m, and a length of 7.5 m. Fig.2 shows the system configuration of combustion test facilities in IHI's Aioi works. In the oxy-fuel combustion, the flue gas taken out after the bag filter is supplied to the burner by the GRF (Gas Recirculation Fan) and is also used as gases for transporting pulverized coal as well as for combustion. The combustion gas is mixed with oxygen for adjusting the oxygen concentration at the inlet of the furnace.

Combustion test under both air and oxy-fuel conditions combustion was performed at the heat input range between 0.8MWt and 0.48MWt. Three kinds of Australian coal were used as shown in Table 1.

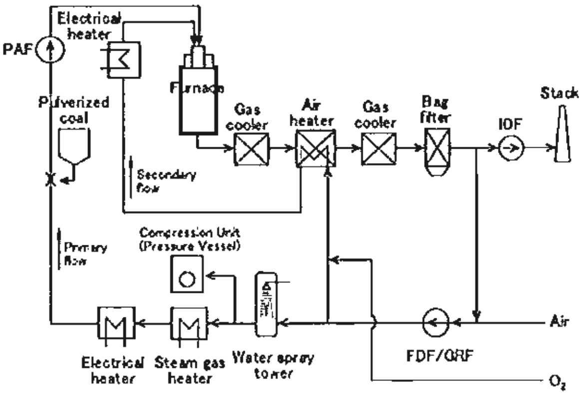


Fig.2 System configuration of combustion test facilities

Table 1 Coal Analysis

Coal type		Coal A	Coal B	Coal C
HHV	[MJ/kg]	23.7	27.9	30.0
Proximate analysis				
IM	[ad %]	8.8	4.1	14.0
Ash	[dry %]	19.3	18.2	6.9
VM	[dry %]	25.7	40.9	34.1
FC	[dry %]	55.0	40.9	59.0
Ultimate analysis				
Carbon	[dry %]	63.5	65.6	74.4
Hydrogen	[dry %]	2.8	5.3	4.2
Nitrogen	[dry %]	0.73	0.72	1.91
Oxygen	[dry %]	13.5	9.7	11.8
Sulfur	[dry %]	0.24	0.57	0.88

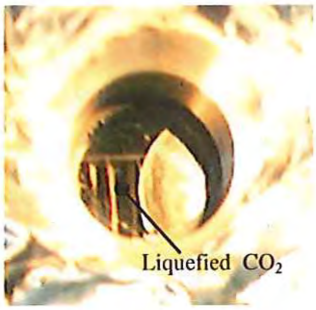


Fig.3 Photo of captured CO_2 in the liquefaction
*A view from the inspection port on the pressure vessel
*The horizontal line is the liquefied CO_2 surface
*The bright part to the right of the inspection port reflects the light

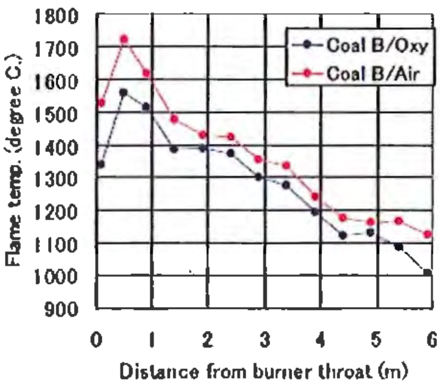
2.2 CO_2 Capture

CO_2 capture test was conducted in order to confirm the process and CO_2 liquefaction from the actual flue gas during oxy-fuel combustion. Because the furnace pressure was controlled to be positive during an operation and CO_2 sealing was applied to necessary points to prevent the air ingress into the process, the concentration of CO_2 in the flue gas from the oxy-fuel combustion was as high as 90 dry % in the combustion tests. In order to confirm the CO_2 capture, compression and cooling units were added to the flue gas line of the combustion test facilities for confirming CO_2 liquefaction. Under the condition of 0 degree C / 7 MPa in the vessel, liquefaction and capture of CO_2 were observed, which means that the oxy-fuel combustion system with CO_2 capture is applicable. Fig.3 shows the photo of captured CO_2 in the pressure vessel.

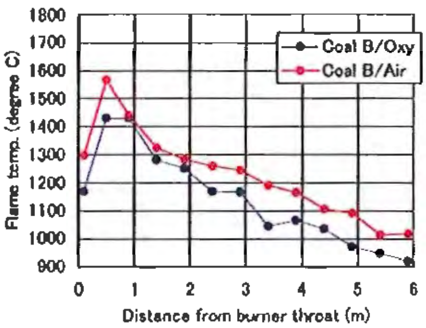
2.3 Flame Stability and flame temperature

Fig.4 shows the photos of flame at heat input of 0.8MWt, 0. 64MWt and 0.48MWt. Flame shape of oxy-fuel at 0.8MWt is similar to that of air combustion, however flame shape of oxy-fuel at 0.48MWt is different from that of air combustion. In oxy-fuel combustion, the concentration of oxygen taken into the boiler must be kept to be higher than that of air combustion. The secondary air (recirculating flue gas) is significantly reduced in quantity at low burner load in oxy-fuel combustion, because a constant flow is necessary for the primary air (recirculating flue gas) for transporting pulverized coal. In the test, swirling flows in the secondary flow made it difficult to maintain the flames shown in Fig.4. It was confirmed that the flame stability must be enhanced by

Fig.4 Photos of flame at air and oxy combustion on Coal B



1) 0.8MWt



2) 0.48MWt

Fig. 5 Flame temperature

supplying oxygen directly to the burner in order to ignite easily under high concentration of O_2, considering the temporary fluctuation etc..

Fig.5 shows the flame temperature that was measured by optical-thermometer at 0.8MWt and 0.48MWt. From the results, flame temperature of oxy-fuel at both conditions is 100 degree C lower than that of air combustion. This is because flue gas from oxy-fuel includes the high level of CO_2 and H_2O that have high emissivity.

2.4 Combustion Characteristics

Three types of Australian coal were used for confirming the combustion characteristics that are NOx, SO_2 and carbon-in-ash without staging. The results are shown in Fig.6.

It was confirmed that the NOx and SO_2 emissions from the stack during oxy-fuel combustion were less than those from air combustion by 60~70 % and 20~30 % respectively. The main reason for NOx emission reduction is that NOx contained in the recirculating flue gas is reduced in the flame at the burner zone. Another reason is that combustion take place under very little nitrogen in oxy-fuel combustion. And the reason for SO_2 emission reduction is because sulfur is captured into the ash in the furnace, due to the concentration of SO_2 by the recirculating flue gas. Carbon-in-ash in the oxy-fuel combustion was less than that of air combustion. One of the reasons for it seems to be the total amount of flue gas,

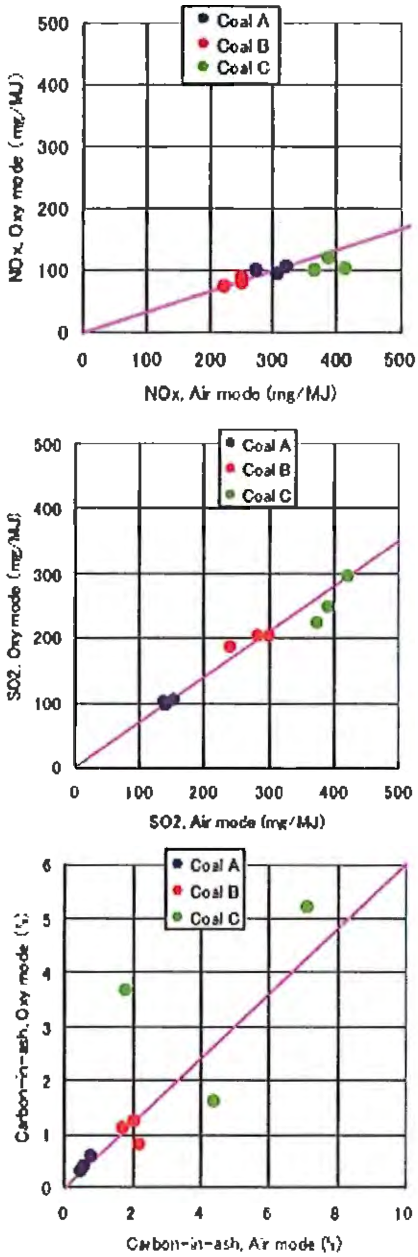


Fig.6 NOx emission, SO_2 emission and carbon-in-ash

which was less than the one in air combustion and stayed longer in the furnace. Another reason is in the local combustion which took place under the condition of the high level oxygen with the secondary flow containing high level oxygen.

2.5 Heat Transmission Characteristics

In oxy-fuel combustion actually, the concentration of oxygen introduced into the boiler is adjusted for ensuring the same characteristics of radiant heat transmission as in air combustion. In a combustion test, a simulated heat transfer tube was installed in the radiant heat transmission section in the furnace, and the heat absorption into it was observed both in air combustion and oxy-fuel combustion. The test confirmed that more or less the similar heat transmission characteristics when the data of air combustion were obtained when the concentration of oxygen taken into the boiler was approximately 27 wet % in oxy-fuel combustion as shown in Fig.7. The result of trend data of heat flux during both conditions is shown in this figure.

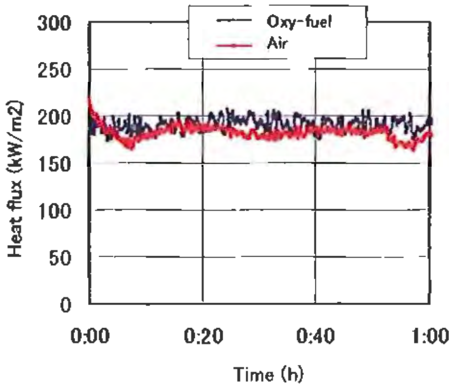


Fig.7 Radiant heat transmission characteristics in the furnace

Table 2 Outline of the existing boiler

Items	Details
Plant name	Callide-A power plant No.4 unit
Output	30MWe
Fuel	Raw Coal ※Total moisture content: 12-15%, Ash content: 20-24%, Calorific value: 18-20.5 MJ/kg
Steam condition	Steam flow: 123,410kg/h Main steam pressure: 4.1MPa Main steam temperature: 460 degree C
Major facilities	Mills: 3 (Beater mill) Burners: 6 (Front firing) AH: Tubular type

3. DEMONSTRATION PROJECT IN AUSTRALIA

On the basis of the study results described above, studies are now under way for applying oxy-fuel combustion to an existing plant by way of demonstration.[6] These studies comprise an Australia-Japan joint project, in which a demonstration plant of oxy-fuel combustion will be completed by the end of 2008. This project aims at recovering CO_2 from an actual existing power plant for storage. The outline of the project is as follows:

3.1 The Power Plant and the Storage Site

Fig.8 shows the candidate site of the existing power plant and the storage for the project. Specifically, the project is implemented at the power generation system in Callide-A power plant No.4 unit owned by CS Energy on the east coast of Australia. The features of the unit are shown in Table 2. This unit was selected because it has an adequate capacity as a demonstration plant. Additionally, it is currently out of service and thus is available for modifications.

The storage site is planned to be located in a depleted gas field, which is about 250 km to the west of the power plant site. This site was selected because it is not far away from the power plant site, the estimated CO_2 storage capacity is

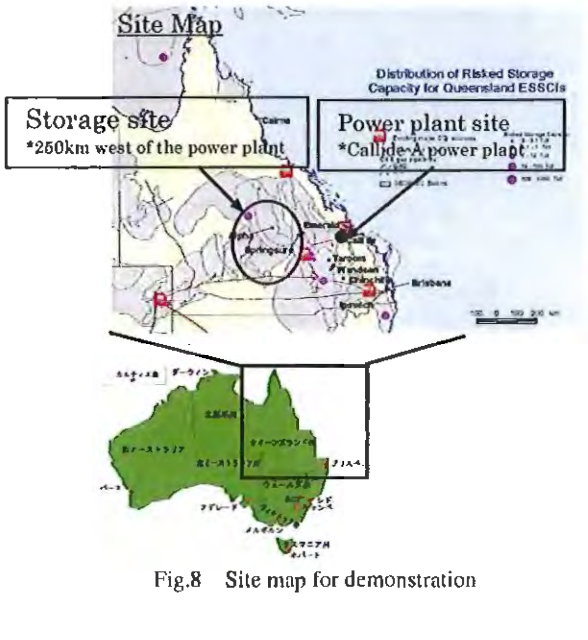


Fig.8 Site map for demonstration

Table 3 Project schedule

Item	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Feasibility Study	■	■	FS									
Boiler modification & Demonstration of CO_2 recovery			Design, Construction, Test run	Design, Construction, Test run	Design, Construction, Test run	Demonstration operation	Demonstration operation	Demonstration operation	Demonstration operation	Demonstration operation		
Demonstration of CO_2 storage			Test drill, Design, Construction, Test run	Test drill, Design, Construction, Test run	Test drill, Design, Construction, Test run	Test drill, Design, Construction, Test run	Test drill, Design, Construction, Test run	CO_2 Storage & Monitoring	CO_2 Storage & Monitoring	CO_2 Storage & Monitoring	CO_2 Storage & Monitoring	
Summary												■

sufficient, and the reservoir characteristics such as permeability and porosity are adequate for CO_2 storage.

3.2 Schedule

The entire schedule of the project is shown in Table 3. For this demonstration project, Australia and Japan jointly conducted a feasibility study in FY 2004[7] and FY 2005[8]. Based on its results, detailed studies have started in 2006, aiming at the completion of the plant by the end of 2008. Demonstration operation of oxy-fuel combustion with CO_2 capture will be performed for five years after the plant completion. Storage of captured CO_2 will start in the third year of the demonstration operation, and thus demonstration of CO_2 injection and monitoring of CO_2 storage will be performed for three years.

4. FUTURE CHALLENGES

As described above, demonstration of a power generating system using oxy-fuel combustion is now about to start. Hopefully by the year 2010, it will be demonstrated that the system is reliable and economically efficient for CO_2 capture. Great expectations are placed on the further research and development. It is foremost to ensure a steady implementation of the Australia-Japan demonstration project, so that it will be the first step toward commercialization. With regard to the demonstration and the future commercialization, possihle challenges are summarized as follows:

5.1 Stability and safety in the operation of a power generating system by using oxy-fuel combustion

It is necessary to ensure the stability of oxy-fuel combustion and heat transmission characteristics in the process of demonstration, so that it will be verified that this power generating system has no problem. Because oxygen is used the system operation procedures must be established to reflect sufficient attention to safety.

5.2 Stable operation of a CO_2 recovery system

In applying the oxy-fuel combustion technology, CO_2 must be recovered stably. It is required that stable operation and performance of the facilities are ensured with relatively higher availability.

5.3 Efforts for reducing cost and enhancing efficiency

The oxy-fuel combustion technology is applied to a CO_2 recovery system which is highly feasible with relatively few technical difficulties. The primary importance is in the reduction of the oxygen production cost and the required motive power. Thus, research and development for this purpose is necessary to be performed simultaneously with the efforts toward commercialization.

5.4 Total system optimization for power generation and CO_2 recovery/transportation/ storage

There are various types of power generating systems utilizing pulverized coal, depending on locations, applicable regulations and fuel properties. Storage sites are also varied, and each depleted gas field used for storage has its own characteristics. CO_2 transportation distance determines the transportation system. In respect to these, the challenge is in the establishment of a total system in an efficient and economically viable manner. Optimization of the total system must be done by utilizing not only the oxy-fuel combustion system but also the possibilities of other CO_2 recovery systems.

5. CONCLUSION

We could obtain a lot of knowledge of oxy-fuel combustion through the combustion test. Based on these result, studies are now on progress to have demonstration of the oxy-fuel combustion system that is one candidate of the CO2 recovery from the coal-fired power plant.

ACKNOWLEDGMENTS

This paper and the studies for the demonstration project were greatly supported by NEDO (New Energy and Industrial Technology Development Organization), as well as by Australian organizations such as CCSD (Cooperative Research Center for Coal in Sustainable Development), University of Newcastle and many others in Australia and Japan. The authors express gratitude to them for their help and support.

REFERENCES

[1] K. Kimura et al. ; JSME-ASME Int. Conf. On Power Eng.-93, Sept. 1993, Tokyo
[2] Lars Stronberg et al., ; 8th Int. Conf. on Greenhouse Gas Control Technologies, June, 2006, Trondheim, Norway
[3] Juan Li et al., ; Proc. 31st Int Tech. Conf. On Coal Utilization & Fuel Systems, May, 2006, Clearwater, Florida, USA
[4] Jupiter Oxygen News for Immediate Release ; "World's First Oxy-fuel Clean Coal Retrofit Announced", Sep., 2006
[5] SaskPower/Air Liquide/Babcock & Wilcox Canada Media Fact Sheet ; "Clean Coal Project Technology Announcement", Oct, 2006
[6] C. Spero; Proc. Clean Coal Day in Japan 2004, Advanced Clean Coal Tech. Int. Symp. 2004, Sept. 2004, Tokyo
[7] NEDO; "Report on the Clean Coal Technology Promotion Project 2004: Study on the Application of Oxygen Combustion Technology to an Existent Pulverized Coal-Fired Power Plant"
[8] NEDO; "Report on the Clean Coal Technology Promotion Project 2005: Study on the Application of Oxygen Combustion Technology to an Existent Pulverized Coal-Fired Power Plant"