

Clean Coal Technologies for Low Carbon Society

We are facing against serious problems -

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Introduction

Japanese industries and academy are facing against serious problems such as decline in economic position of manufacturing, serious global competition in educations, standardization of degrees, professional qualifications and so on. JSME should respond to these problems timely as the society of mechanical engineers.

1.Decline in economic position of manufacturing in Japan

JSME is supported mainly by the engineers in manufacturing industries, service businesses based on manufacturing and academicians in the mechanical sciences. The sales share of Japanese manufacturing industries has been decreasing since the beginning of 90s when Japanese manufacturing industries were overestimated as World No.1. And the percentage of manufacturing in Japanese GDP is now less than 30%. The GDP per-capita of Japan that Continued on page 2

Advanced USC Technology to Reduce CO2 -Emission from Coal Power Plant

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Introduction

1.INTRODUCTION

The Japanese government has launched the "Cool Earth-Innovative Energy Technology Program" in 2008 March to promote international cooperation and actively contribute to substantial global greenhouse gas emissions reductions[1]. 21 technologies that can contribute to



substantial reductions in CO₂ emissions by efficiency improvement and low carbonization were selected. The Advanced Ultra Super Critical pressure power generation (A-USC), Continued on page

Integrated coal Gasification Combined Cycle (IGCC) — Technology

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Introduction

1. Introduction

Japan depends on foreign countries for over 95% of the primary energy supply, and about 25% of electricity is derived from coal. From the view point of energy security, it is important to continue to make



use of coal. However, the carbon emission coefficient of coal is higher than that of oil and the natural gas. So, it must be very important to develop clean coal technologies. Under these circumstances,IGCC (Integrated coal Gasification Combined Cycle) systems are expected as a coal-based power plant of the next generation.

Oxy-fuel Combustion For CO2 Capture From Coal-fired Power Plant

-Introduction Of Callide Oxyfuel Project-

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Introduction

1. INTRODUCTION

From a global viewpoint, thermal power plants are still releasing CO₂ in large quantity at present, which indicates the necessity for a power generation system with Carbon Dioxide Capture and Storage (CCS) in more effective and economical manner. Among all the fossil fuels used



at thermal power plants, coal produces the greatest amount of CO₂ per unit calorific value. Thus, emissions from power plants using pulverized coal seem to be one of the significant sources in capturing CO₂ effectively. Oxyfuel combustion is expected to be one of the promising Continued on page 6

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Continued from page 1 exceeded the world in 2000 is now behind US, UK, France and Germany. Productive manufacturing processes have been transferred to the overseas countries of low labor cost and nonproductive service businesses have become dominant part of Japanese GDP. We are losing technological competitiveness in manufacturing.

The source of National power is GDP and it seems to be necessary to improve the productivity in service businesses in order to increase GDP. However, the important service businesses are based on the products of manufacturing. We have to drive the innovations including the value chain between the manufacturing and services that are directly related to the values of peoples and society.

2.Standardization of academic degrees and globalization of professional engineer qualification

In Europe, the standardization of academic degrees and quality assurance of educations have been discussed especially after Bologna declaration in 1999. In London communiqué 2007, three cycles of degrees, Bachelor, Master and Doctor were determined to be standardized. On the other hand, OECD has started the feasibility study to measure the quality of undergraduate education by a certain kind of tests and Japan has decided to participate in this study in the field of engineering. The movements of the standardization of degrees and quality assurance of education are going rapidly. Academic educations are now in global competition.

There was a certain consensus that the professional qualifications in every country should not act as non tariff barrios for the services provided by people when GATT was reorganized to WTO in 1955. In the same age, the framework of mutual authentication of professional engineer qualification was agreed as NAFTA Engineer in the countries in North American continent and APEC engineer in the Pacific countries, respectively. In Japan, the law for professional engineer qualification was revised in 2000 and new PEJs have been qualified closely related to the accreditation by JABEE that was also newly established to accredit engineering education programs. JSME collaborates with JABEE and is going to reinforce the collaboration wit the Institution of Professional Engineers, Japan. It is necessary for us to increase our efforts to the professional engineer qualification acceptable by international standards.

3.Significant decrease in the number of students would be engineers

The number of students choosing engineering course has been decreasing significantly in spite that the ratio of the numbers between the students choosing natural science category and human/social science categories. This is serious problem if we recognize that most of the innovations have been driven by technological innovations. Academic societies, industries and Japanese government are making various efforts for young people to be interested in engineering, respectively. It is necessary to promote the collaborations of the societies based on the comprehensive and panoramic view of those efforts. We asked Japan Federation on Engineering Societies to play a coordinating role and marked the first concrete step. Based on the collaborations between society and government local branches, we are expecting to be able to take actions all over Japan.

4. Roles of the Japan Society of Mechanical Engineers

JSME is the society for engineers and researchers involved in machines and mechanical sciences. Many of the members are engineers working in industries. It is necessary for JSME to be familiar and to be easily accessible to them. The presence of JSME has been advancing gradually. By responding to the problem of member's concern timely, JSME will become more familiar to the members. Newly established Innovation Center plays an important role to respond to the problems in academic educations and manufacturing. We are facing against serious problems but I believe we can get over them.

Integrated coal Gasification Combined Cycle (IGCC) Technology

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2. Outline of IGCC system

IGCC system is a new power generation technology aiming at higher thermal efficiency than the conventional coal-fired power plant by integrating coal gasification with combined cycle power generation system (Fig.1). In IGCC system, coal is gasified in a gasifier to produce synthetic fuel gas. The fuel gas is burned to operate a gas turbine. Then, high temperature exhaust gas from the gas turbine is sent into the boiler to produce steam that is used to operate a steam turbine.

The Cool Water Program (CWP) executed in the 1980's was an originator of present IGCC. CWP was a collaborative project in the United States and Japan, and it was operated for five years from 1984. It was proven to approve IGCC technically first in the world. After CWP project, Four IGCC plants began operation in Europe and USA in the 1990's (Table 1).

3. Major project in Japan

3.1 EAGLE (coal Energy Application for Gas, Liquid and Electricity) Project1)

The purpose of the EAGLE project is to develop the high efficient gasification system which is applicable for multipurpose use. The main research items of the EAGLE project ware the development of the oxygenblown entrained flow gasifier and the establishment of the gas clean-up technology for fuel cells. Table 2 show the specifications of EAGLE pilot plant. The operation of the 150 t/d pilot plant has started in March 2002. Through the operation, all development targets for the gasification performance and the gas clean-up performance, etc. have been already achieved. Current main item is the establishment of the CO2 capture technology.

3.2 IGCC Demonstration Plant Project2)

CRIEPI and Mitsubishi Heavy Industries Co., Ltd. set up the bench scale gasifier (2t/d coal gasifier) in 1983 and



Fig.1 Basic flow diagram of IGCC system

Table.1	Summary	of operating	g IGCC	plant in	foreign	countries
				1		

		Tampa	Wabash River	Buggenum	Puertollano
	Location	Florida, USA	Indiana, USA	Netherlands	Spain
Gasifier		Texaco (GE)	E−Gas (ConocoPhillips)	Shell	Prenflo (Shell)
Coal Feed		CWM	CWM	Dry	Dry
Gasifying Agent		Oxygen	Oxygen	Oxygen	Oxygen
	GT type	GE 7FA	GE 7FA	Siemens V94.2	Siemens V94.3
	GT	192 MW	192 MW	156 MW	200 MW
ler	ST	123 MW	104 MW	128 MW	135 MW
Pov	Gross	315 MW	296 MW	284 MW	335 MW
	Net	250 MW	262 MW	253 MW	300 MW
Net Efficiency (Design, HHV)		39.7 %	37.8 %	41.4 %	41.5 %
Start-up		Sept 1996	Oct 1995	Jan 1994	Dec 1997

Coal Gasifier	Oxygen blown entrained flow
Capacity	150 ton/day
Pressure	2.5 MPa
Clean-up System	Cold gas clean-up using MDEA
Air Separation Unit	Pressurized cryogenic separation
Oxygen Purity	95 vol%
GT Power	8,000 kW

Table.2 Specifications of EAGLE pilot plant

Table.3 Specifications of demonstration plan	Table.3	Specification	s of demo	onstration	plant
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Power output		250 MW		
Coal Gasifier		Air blown entrained flow		
Capacity		1,700 ton/day		
Clean-up System		Cold gas clean-up using MDEA		
Gas Turbine		1,200°C class		
Target Efficiency		40.5 % (Net, HHV)		
Emission	SOx	8 ppm		
(16 % 0)	NOx	5 ppm		
(10 % 02)	PM	4 mg∕m³N		

have developed a prototype of the air blown pressurized two-stage entrained flow gasifier with dry coal feed system (Fig.2). This gasification technology was employed in the 200t/d pilot plant project. The test operation of the pilot plant was started in March 1991 and successfully completed in February 1996. Based on the results from the pilot plant, Japanese government and all Japanese electric power companies decided to construct the IGCC demonstration plant using the air-blown gasifier, and Clean Coal Power R&D Co., Ltd. was established in June, 2001 to conduct the demonstration project. The specifications of demonstration plant are shown in Table 3. The output is 250MW, and the capacity of the gasifier is 1,700t/d. The target net thermal efficiency of the demonstration plant is 40.5% (HHV basis). The operation has started in September, 2007 and the long-term operation test of 2,000 hours was carried out as planned from June to September,





2008.

4. Conclusion

From the viewpoint of the energy security and the global environment, the importance of IGCC has risen more and more. Development for commercial plant is advanced, and it is convinced to be established as a Japanese original, excellent IGCC technology.

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Advanced USC Technology to Reduce CO₂ Emission from Coal Power Plant

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Continued from page 1 that aims to commercialize 700°C class pulverized coal (PC) power system with 46% power generation efficiency by around 2015 and 48% efficiency by around 2020, is included in the technologies. We have started a large-scale development of the A-USC technology in 2008 August. 700°C class boiler, turbine and valve technologies, which include high temperature material technology, will be developed. Some candidate materials for boilers are being tested. Turbine rotor and casing materials are being developed and tested, as well.

2. TREND IN STEAM CONDITION OF POWER PLANTS

The trend in the steam condition for steam power plants in Japan is shown in Figure 1. The steam temperature was raised from 538° C to 566° C at the end of the 50's, and remained at this temperature until 1993, when a 593°C reheat steam temperature was achieved at Chubu Hekinan power station.

Steam power plants that have been built recently usually have a steam temperature of around 600° C and a steam pressure of 25 MPa. We usually call this steam condition,



Fig. 1 Power Plant Steam Condition in Japan[2]



Fig. 3 Selected Materials[2]

USC (Ultra Super Critical steam condition). The improvement of the steam condition is achieved mainly through the development of high temperature materials. It is no exaggeration to say that the USC has been made possible by the newly developed ferritic steels containing 9-12% chromium.

The 700°C class A-USC technology is being developed from the 600°C class USC by raising the steam temperature 100°C . The target net thermal efficiency using a higher heating value of fuel is 46-48% (Figure 2). This is relatively more than 10% higher than the 600°C class USC. That means the CO_2 emissions are reduced by more than 10%.

The Institute of Applied Energy did a case study on a coal power plant retrofit with the 700° C class A-USC technology[2]. The objectives of the study were to:

- Clarify the economical and environmental superiority of A-USC technology when it is used to retrofit aged coal power plants.

- Define the technical challenges for the development of A-USC.

In the study, we selected materials for the 700°C class A-USC (Figure 3). Ni or Ni-Fe-based alloys were chosen for parts of the super heaters and reheaters, the large steam pipes and the valves going from the boiler to the turbines, and parts of the turbine rotors and casings. The turbine rotors consist of Ni-based alloy and 12Cr steel, which are welded together. The turbine nozzles and blades for the high temperature stages use Ni-based materials that are



Conventional Use



Fig. 4 Use of Ni-Base Alloys

being used for gas turbines.

The materials used for 700° class components are basically Ni or Ni-Fe based materials. They have been used for the high temperature parts of jet engines and gas turbines with metal temperatures of up to and over 900°C because of their superior strength at elevated temperatures. They also have been used for chemical equipment and oil and gas drilling equipment in corrosive environments, but at relatively low temperatures. Compared to these uses, the required characteristics of the materials for the A-USC system are different as shown in Figure 4. The temperature range for the materials of the A-USC system goes from 700 to 800° C and the weight of the parts usually exceeds 5 tons, though the weight of very high temperature parts of jet engines and gas turbines are usually less than 10kg. Corrosion and oxidation resistance are required at 700 to 800° C in combustion gas and steam environments. It is necessary to weld large parts to build the boiler and steam turbines. The boiler and steam turbine materials should be able to be used for decades without repair. The thermal expansion coefficient should be close between materials that are welded or connected to avoid thermal stress.

4. A-USC TECNOLOGY DEVELOPMENT PROJECT

We have started large scale development of the A-USC technology. All major boiler and steam turbine manufacturers in Japan are included in the project as shown in Figure 5.

The objective of the project is to develop 700°C -class A-USC component technologies for large capacity pulverized coal power plant systems. The master schedule



Fig. 5 A-USC Project Participants

	Creep Rupture	Fatigue	Oxidation	Corrosion-	Bending		
					Pipe	Tube	Welding
HR6W	0	0	0	0	0	0	0
HR35	0	0	0	0	~	·	0
Alloy 617	0	0	0	0	0		0
Alloy 263	0	0	0	0	-	0	0
Alloy 740	0	0	0	0	-	1	0
Alloy 141	0	0	0	0	-		0
B-9Cr Steel	0	0	0	0			0
LC-9Cr Steel	0	0	0	0	0	0	0
SAVE12AD	0	0	0	0			0

Fig. 7 Boiler Candidate Materials

is shown in Figure 6. The 9-year project consists of system design, boiler steam turbine and valve technology development, and boiler component and small turbine tests. Material development and evaluation of large steam pipes and boiler tubes followed by long term testing will be conducted. Welding and pipe bending technology will be developed as well. Materials for the rotor, casings and bolts of steam turbines will be developed and evaluated. These materials will also be tested over long periods.

Figure 7 shows the candidate materials for boilers. HR6W is a Ni-Fe based alloy and HR35, Alloy 617, Alloy263, Alloy740, Alloy141 are Ni based alloys for use at temperatures higher than 650°C . B-9Cr steel, LC-9Cr steel and SAVE 12AD are ferritic steels for use at temperatures lower than 650°C . These materials will be tested to verify the characteristics of creep rupture, fatigue, oxidation and corrosion. Welding and bending tests will be conducted to check the manufacturability of



Fig. 6 Master Schedule

the materials.

There are some candidate materials for steam turbine rotors. Ni based alloys, FENIX-700, LTES and TOS1X, are being developed and tested for use at temperatures higher than 700° C.

5. CONCLUSION

A-USC is one of the remarkable technologies being developed to reduce CO_2 emission from fossil fuel power plants and one which was chosen in Japan's national program, the 'Cool Earth-Innovative Energy Technology Program' which was launched in March 2008 to promote international cooperation and actively contribute to substantial global greenhouse gas emissions reductions.

A large scale 9-year project began in August, 2008 to develop A-USC technology. Major Japanese manufacturers of boilers and steam turbines are cooperating in the project to develop the technology efficiently and quickly. Some boiler and steam turbine materials are being developed and tested in those companies to verify the necessary characteristics for use in a 700°C steam condition.

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OXY-FUEL COMBUSTION FOR CO $_{\rm 2}$ CAPTURE FROM COAL-FIRED POWER PLANT -INTRODUCTION OF CALLIDE OXYFUEL PROJECT-

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Continued from page 1 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 from the power plant. The demonstration project (Callide Oxyfuel Project) on this field is now under way for applying oxyfuel combustion to an existing power plant that is the power generation system in Callide-A power plant No.4 unit with a



Fig.1. Oxyfuel combustion for CO₂capture and storage



Fig. 2 Flame at both air and oxyfuel combustion at pilot-scale combustion facilities

capacity of 30MWe in Australia. One of main objectives of this project is to capture CO_2 from an actual power plant for CO_2 storage. At present, the studies toward the commercialization plant through this demonstration project on this area are implemented.

2. OXY-FUEL COMBUSTION

Fig. 1 shows an overall process of CCS using the oxyfuel combustion process. There are 3 kinds of CO_2 capture from coal fired power plant and oxyfuel process is one candidate of the CO_2 capture from coal fired power plant. Research, development and demonstration on these systems are in progress for each of the systems all over the world.

In the process of capturing CO₂ through oxyfuel combustion, O₂ is separated from combustion air and used for burning the coal. In this process, it is theoretically possible to improve the CO₂ concentration in the flue gas up to 90 % or over, and the flue gas is cooled and compressed in order to capture the CO₂ of more than 98 % purity at the CO₂ purification unit for CO₂ underground storage. When the oxyfuel combustion technology is applied to power plants, flue gas, which mostly consist of CO_2 , are recirculated and mixed with O_2 before combustion for the purpose of controlling the flame temperature. With this system, it has been confirmed that the process characteristics help to 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 CO₂ capture process. Great expectations are placed on the system described in this paper, because it represents a direct CO₂ capture method that is better than other CO_2 capture systems in terms of economical efficiency and technological



Fig. 3 Results of furnace simulation

feasibility.

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

3. CALLIDE OXYFUEL PROJECT

Some researches and studies on this area were performed for the basic combustion characteristics using the drop tube furnace, the flame stability and combustion characteristics in the pilot-scale combustion test facilities shown in Fig. 2, the burner & furnace numerical simulation to confirm the furnace heat absorption shown in Fig. 3 and feasibility through the conceptual design of 1,000MWe power plant.

On the basis of the study results described above, Joint Venture for the demonstration project of oxyfuel combustion was established in 2008, that is called "Callide Oxyfuel Project", and the works are now under way for applying oxyfuel combustion to an existing power plant by way of demonstration. This project aims at capturing and storage CO_2 from an actual existing power plant and also obtaining the economical and technical data or knowledge for the commercialization.

The project is implemented at the power generation

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Fig. 4 Image of 1,000MWe class oxyfuel power plant with CO_2 capture and storage

system in Callide-A power plant No.4 unit owned by CS Energy on the east coast of Australia. The capacity of this unit is 30MWe without reheat cycle, main steam flow at 30MWe is approximately 130t/h and coal feed rate is approximately 30t/h. Regarding the application of oxyfuel combustion to the existing power plant, 2 of air separation units with the capacity of 330t/day and O₂ purity of 98% will be installed near the power plant, air/gas flow system of the boiler will mainly be modified and CO₂ purification unit with the compression and cooling will also installed. It will be expected to have the CO₂ capture rate of 50 - 100 ton per a day at the condition of the liquefied CO₂.

The candidate CO_2 storage site is in the process of the site selection. At this stage, the area of CO_2 storage

is planning to be about 250 km to the west of the power plant site. This area was selected because it is not far away from the power plant site, the estimated CO_2 storage capacity is sufficient, and the reservoir characteristics such as permeability and porosity are adequate for CO_2 storage. After the decision of the site and the layer, trial drilling at storage site will be implemented.

Project mainly consists of stage 1 and 2. In stage 1, demonstration operation of oxyfuel combustion with CO_2 capture will be performed for four years after the plant completion at the middle of 2011. In stage 2, the injection of captured CO_2 from the power plant will start in 2011 simultaneously, and the demonstration of CO_2 injection into the underground and the monitoring of CO_2 storage will be performed for three years. This demonstration project will be summarized at 2016.

4. CONCLUSIONS

Oxyfuel combustion technology has been attracting and increasing attention worldwide 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 research and development towards the realization of this technology which is one candidate of the CO_2 capture from the power plant.

We would like to have much knowledge and information through the studies including above and the demonstration operation at Callide-A, and contribute to reduce CO_2 from the pulverized-coal fired power plant using oxyfuel technology (Fig. 4).

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