Thermal Power Generation Systems with CO_2 Capture

Background and Objective

The reduction of CO_2 emission in coal thermal power generation for global warming control is an important problem for the electric utilities. Therefore, the high-efficiency technology and biomass utilization are promoted in power generation systems. In recent years, CO_2 Capture and Storage (CCS) as an effective global warming control measure has been attracting attention. In Europe and the United States, many plans for CCS projects have been announced. However, current CCS technology has many problems such as significant reduction of power generation efficiency and high cost.

To offer a futuristic option that solves these problems, CRIEPI have proposed highly efficient IGCC system with CO_2 capture (Fig. 1). In this project, we evaluate the feasibility of this system, the development issues for practical use, and advance the development of the elemental technology.

Main results

1. Modeling of char gasification for the O2-CO2 blown gasifier

The O_2-CO_2 blown gasifier is used in this system. The gasification reaction is promoted by high partial pressure CO_2 and H_2O in this gasifier. It is necessary for the analytical evaluation to construct a char[*1] gasification model that can be applied under the condition where CO_2 gasification competes with H_2O gasification. We constructed a new char gasification reaction model according to the amount of active sites[*2] that CO_2 and H_2O are absorbed. This model can express the char gasification rate with a high degree of accuracy (Fig. 2). In addition, simple numerical analyses of reductor parts of the gasifiers were performed using this model. It was found that the carbon conversion efficiency of O_2-CO_2 blown gasifier is 10 point larger than that of Air blown gasifier (Fig. 3) [M09014].

2. Optimization of the dry gas desulfurization process

Consideration of the optimized process to prevent carbon deposition, which may cause deterioration effect on the desulfurization performance, is an extremely important issue, because the coal derived gas in this power plant contains a very high concentration of carbon monoxide (around 60% vol.). Retardation of the carbon deposition by steam addition to the process gas was evaluated from its effect on the reaction rate of desulfurization sorbent at various temperature and steam concentration. (Fig. 4) Prevention of carbon deposition required steam concentration of 10% vol. at 500˚C to retain the reaction rate over than base condition (450˚C, steam concentration of 5% vol.) This result enabled us to design optimization by considering the operating condition of the desulfurization process [M09015].

3. Fundamental issues and guideline for design of Gas Turbine(GT) combustor

This system is different from the conventional GT, and is a fuel-oxygen combustion closed GT cycle using the recycled gas mainly composed of CO_2 and steam. To establish this system, reducing O_2 and unburned fuel in the exhaust is required, thus the fundamental issues for design of the GT combustor were reviewed (Table 1). In addition, fundamental combustion analyses were conducted focusing O_2 concentration at the reaction zone. As a result, it has been clarified that the fundamental outlines of design the GT Combustor for IGCC with CCS, for example the conventional design methods of GT combustors can be applied utilizing O_2 concentration around the burner as a loadstar [M09009].

*1 : Char is the solid material including combustible content and ash that remains after coal pyrolysis.
*2 : Active site is the point or carbon at which CO_2 or H_2O molecules are adsorbed.

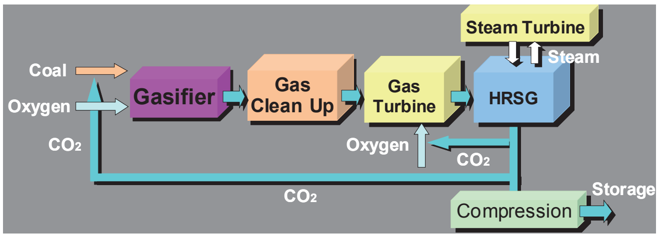

Fig. 1 Concept of high efficient IGCC with CO_2 Capture

This system consists of O_2-CO_2 blown gasifier and O_2 combustion closed GT with exhaust CO_2 circulation. It is expected to have higher thermal efficiency (more over 40% : HHV Net) and the system simplification, compared with the existing IGCC with CO_2 capture.

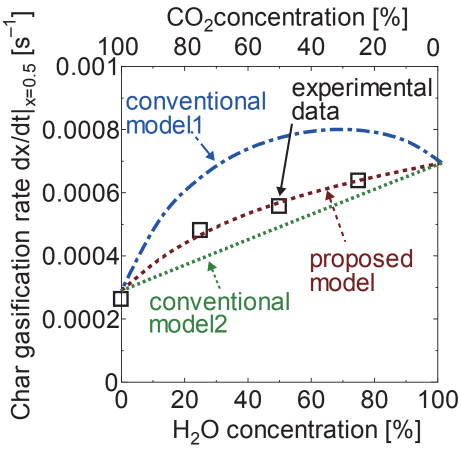

Fig. 2 Char gasification rate in CO_2/H_2O coexistence (measured by TG, American coal, 900° C)

Proposed model express the char gasification rate better than conventional models.

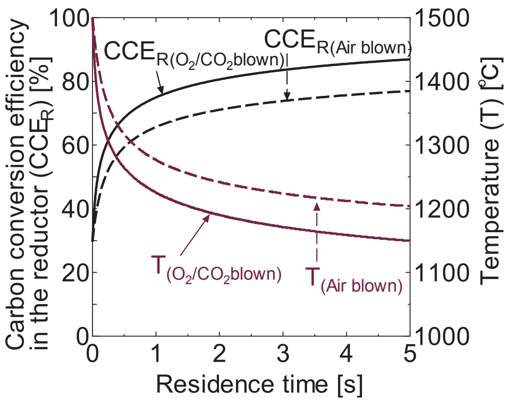

Fig. 3 Simple numerical analysis results of the reductor (the part where char gasification mainly progress) of the 2 stage entrained bed gasifier

Carbon conversion of O_2/CO_2 blown gasifier is expected to be much higher than that of air blown gasifier because of high CO_2 part pressure.

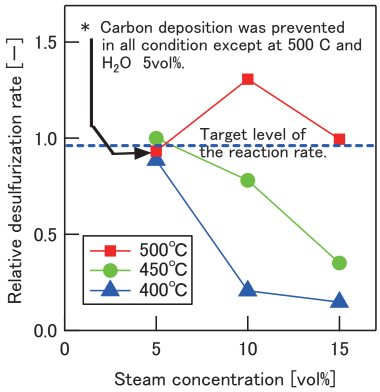

Fig. 4 Relative desulfurization rate of the sorbent at varied steam concentration (Base condition is 0.98 MPa, 450°C, steam concentration of 5% vol.)

Operating temperature has to be raised to retain reaction rate of desulfurization to compensate negative effect from the steam addition for prevention of carbon deposition.

Table 1 Comparison of the Combustor characteristic between GT for IGCC with CCS and Natural Gas Burning GT.

Fundamental issues written in red for design have been clarified by comparing with conventional GT combustors.

		GT Combustor for IGCC with CCS (Closed Cycle GT)		Natural Gas Burning GT Combustor (Air Breathing Open Cycle GT/Conventional GT)	
Working Medium		diluent *	Burned Gas (CO_2+H_2O)	Oxygen	Air
		Oxygen	O_2		
		Fuel	Coal Gasification Gas	Fuel	Natural Gas (Major Conp.:CH_4)
O_2 Concentration at Combustion Zone		0～100 %vol.(Controllable)		21 %vol.(Not Controllable)	
Local Maximum Temp.		Lower than 3080℃ (Controllable by O_2 Concentration)		2219℃ (Not Controllable)	
Equivalence Ratio (at Combustor Exit)		$\phi \fallingdotseq 1$ (Stoichiometric Combustion) Reducing O_2 in exhaust is needed for CO_2 separation.		$\phi \fallingdotseq 0.5$ (Oxygen Rich Combustion)	
NOx	Thermal NOx	Even if the flame temperature is high, NOx formation is little for the low N_2 partial pressure.→Counter measures not necessary. (Non Premixed combustion)		If the flame temperature is high, NOx formation increases.→Some measures necessary (Premixed Combustion/Stratified Combustion)	
	Fuel NOx	Ingenuity for reducing NOx conversion ratio is required when the fuel includes nitrogen.		The little nitrogen content in the fuel eliminate the need for reducing NOx.	

*Diluent is needed to control the flame temperature in fuel-oxygen combustion system.