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Development of oxy-fuel IGCC system

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Abstract

CO2 emission control is significant issue as a countermeasure for a global warming problem. Utility companies are required to reduce CO2 emission from thermal power stations and make various efforts to improve thermal efficiency and to utilize carbon neutral fuels such as biomass fuels. CCS (CO2 capture and storage) technology is regarded as one method to reduce CO2 emission, but CCS required great decrease of thermal efficiency. As amount of fossil fuel on the globe is so restricted, it is important to keep high thermal efficiency as high as possible, in order to utilize valuable fossil fuel effectively. This project plans to develop innovative gasification technology with CO2 capture, which can keep thermal efficiency as high as state of the art IGCC plant, namely more than 40% (HHV). This is to gasify coal with mixed gas of O2 and recycled CO2 flue gas, just like oxy-fuel combustion system. We expect following two merits. First merit is to simplify the system. As the CO2 concentration in exhaust gas is almost 100%, this system doesn't require CO2 separation unit. So no steam is required to bleed from steam cycle in order to maintain absorber for CO2, therefore thermal efficiency is kept high even after capturing CO2. We expect another merit in this system. Generally speaking, CO2 gas works as gasifying agent for coal, so high CO2 concentration improves gasification performance of gasifier. This paper is to report the status of the project executed by CRIEPI.

1. Introduction

To cope with global warming problem, many countries began to develop technologies to reduce emission of carbon dioxide. In western countries, thermal power generation industry is required to consider introduction of CCS system. But CCS requires huge amount of energy to capture and store CO_2, so it is important to reconcile reduction of CO_2 emission and improvement of thermal efficiency. In Japan, "Cool Earth-Innovative Energy Technology Program" was formulated in 2008 to reduce emission of CO_2 toward the year 2050. In the same year, the Japan CCS Co.ltd was established to execute feasibility study on thermal power generation with CO_2 capture focusing of specific place. In 2010, the cabinet decided "Basic Energy Plan" to define fundamental policy on energy. In the plan, various concrete countermeasure to reduce CO_2 emission were examined, for example, improvement of thermal efficiency of existing coal-fired power station, mixing of biomass into coal as fuel, replace of old-fashioned coal-fired power station. This plan describes that newly constructed power stations are required to restrict CO_2 emission less than the same level of state of the art IGCC. This plan also mentioned introduction of CCR to newly planned coal-fired power station. The plan mentioned that detailed items are to be discussed considering the situation of

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present CCS projects running in western nations. Now it is required to develop the innovative IGCC technology with CO_2 capture, which can keep high thermal efficiency about 42% (HHV).

2. Description of proposed system

The newly proposed “Oxy-fuel IGCC system” is to apply the concept of oxy-fuel system, namely, flue gas is recycled to gasifier and gas turbine with adding necessary oxygen. Therefore, comparing to conventional pre-combustion system, shift reactor and CO_2 capture unit are not required. But as CO_2 concentration in recycled flue gas is almost 100%, gasification reaction in high CO_2 concentration gas, in other words “CO_2-O_2 coal gasification reaction”, is to be evaluated precisely. This system uses a recycled flue CO_2 gas to feed pulverized coal into gasifier and gasifying agent with adding some oxygen. As gas turbine combustor is so called “closed gas turbine”, recycled flue CO_2 gas with some oxygen is fed instead of air for combustion. Exhaust gas from gas turbine is mainly consist of CO_2 and H_2O, therefore after recovering heat in HRSG, necessary amount of flue gas is compressed and recycled to gas turbine. Rest of flue gas is fed to water scrubber, Hg removal system and mist separator. After these treatments, flue gas becomes high concentration CO_2 gas. Necessary amount of flue gas is bled for gasification and combustion, and rest of them is compressed and sent to storage site.

Comparing to conventional pre-combustion system, this system doesn’t require shift converter and CO_2 separation unit, so high thermal efficiency of IGCC doesn’t decrease so much. In addition to above mentioned two reasons, following reasons keep the thermal efficiency of this system more than 40% (HHV) even after capturing CO_2. CO_2 can act as gasification agent, increase of CO_2 concentration in gasifier is expected to enhance gasification efficiency of gasifier, comparing to the gasification efficiency of oxygen blown gasification, in other words, N_2- O_2 gasification. CO_2 concentration in working gas of gas turbine is so high that specific heat ratio is quite small. Therefore, temperature differences between inlet and outlet of gas turbine and compressor are smaller than conventional IGCC, and application of regenerative heat exchanger is quite effective to keep high thermal efficiency. As hot gas cleanup system, consist of metallic filter and hot gas desulfurization unit, is used for Syngas in the system, cleanup system is expected to be simplified and necessary energy to cleanup Syngas is expected to be reduced. Water scrubber to remove halogen is equipped after HRSG, energy loss is lower than conventional system.

3. Gasification reaction in CO_2-O_2 atmosphere

CRIEPI has established a numerical simulation tool for coal fired power station from conventional boiler to IGCC gasifier. To apply this tool for CO_2- O_2 gasifier, it is necessary to clarify gasification reaction by CO_2 gas. CRIEPI has equipment to analyze reaction under high pressure, named pressurized drop tube furnace, PDTF. PDTF is drop tube reactor with four electric heaters. We can arrange appropriate temperature distribution inside installed ceramic tube .Various kinds of fuel, bituminous coal, sub-bituminous coal, lignite, biomass, was fed by screw feeder installed at the top of reactor. Averaged feed rate is 30 to 500g/h in case of bituminous coal. Composition of flow gas can be arranged using mass flow controller. As a result of heat treatment, flying particles inside ceramic tube are captured by sampling probe, whose vertical position is adjustable to realize appropriate residential time of particle in high temperature region. Maximum pressure inside the reaction tube is 2.5MPa, and highest temperature inside the tube is 1800 degree C, this is the highest performance in the world. After various experiments by this furnace, we found out that L-H model is better to describe gasification reaction. Now established L-H model was transferred to simulation code of our own. The performance of our simulation code is already confirmed, in our air-blown gasifier, whose capacity is 3tpd, in N_2-O_2 mode. We are to confirm its applicability to CO_2- O_2 mode, and apply this simulation code to evaluate the design of gasifier for CO_2- O_2 gasification, appropriate fuel injection pattern or adequate shape of gasifier.

4. Confirmation of gasification reaction in 3TPD gasifier

In previous work CRIEPI estimated coal gasification characteristics using our original coal gasification performance analysis program code which was simplified to a one dimensional model. The results of coal gasification performance showed improvement of cold gas efficiency for 2% and drastic reduction of char particle. This is the effect of improvement of gasification reaction by increase of CO_2 gas. It is important to prove this improvement effect of CO_2 on coal gasification performance using actual pressurized entrained flow coal gasifier. CRIEPI have own 3TPD coal gasifier. In this gasifier, we can capture flying char particles and Syngas inside gasifier by sampling probe. This gasifier is basically two staged air-blown one, but it can vary O_2 concentration up to about 30%. As installed CO_2 gas supply system, we can evaluate the effect of CO_2 gas on coal gasification performance. We have already executed various gasification experiments, and obtained data are to be examined by numerical simulations mentioned above. As a goal of this project, appropriate design of CO_2-O_2 gasifier, position or angle of fuel injection port and shape of gasifier, are to be clarified.

5. Determination on carbon deposition boundary in hot-gas cleanup system

From the view point of maintenance of hot-gas cleanup system, high CO_2 concentration Syngas is not appropriate. Because carbon deposition sometimes caused in desulfurization catalyst may deteriorate catalyst. To clarify carbon deposition phenomena and develop a method to prevent deterioration of catalyst, fundamental examinations are programmed in the project. New apparatus are installed to evaluate carbon deposition behavior in hot-gas cleanup system. This apparatus have a honey cam desulfurization catalyst unit installed inside it. This catalyst is exposed to Syngas arranged as mixture of various gases supplied from bombs. And this catalyst can be exposed to actual Syngas bled from 3TPD gasifier, as a bleeding line for Syngas was constructed from gasifier to this cleanup experimental apparatus. We already evaluated carbon deposition boundary, and found out predominant factor for the tendency of carbon deposition. In general, carbon deposition in high CO concentration gas was mainly affected by two reactions, but in this system, the Bourdard reaction is so important. So we processed obtained data by an index calculated from partial pressure of CO and CO_2, and found out that this index is quite dominant. We have already obtained data to confirm this index plays quite an important role. If this index is enough high, carbon doesn’t deposit. So as a method to prevent carbon deposition, we are to adjust this index in hot-gas cleanup system. We have already examined one method and successes in preventing carbon deposition.