修 士 論 文 概 要 書

Summary of Master's Thesis

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研究指導名 Research guidance	エクセルギー工学	学籍番号 Student ID number	CD 5216BG03-1		
研究題目 Title	Sensitivity analysis of operating condition on energy penalty of supercritical coal-fired power plant with CO_2 capture process				

1. Research background

Globally, coal-fired power plants are the main electric power source, which provides over 42% of global electricity supply. However, at the same time, they account for over 28% of global CO_2 emissions. Anthropogenic CO_2 emissions is the greatest contributor for global warming caused by greenhouse effect. Post-combustion CO_2 capture and storage (CCS) technology from coal-fired power plants appears to provide a near-term strategy to solve the global warming problem. Amine-based chemical absorbents are technically mature and attractive for the CCS technology, but, integrating CO_2 separation and compression process will bring significant energy penalty to the power plant, and decreases the net electricity efficiency dramatically. Exploring the optimized configurations and operating conditions based on the integrated simulation model combined with coal-fired power plant and CCS is essential to improve the system efficiency by reducing the energy penalty associated with CO_2 capture process and thereby reducing cost.

2. Research method

2.1. Supercritical coal-fired power plant simulation

Fig. 1 (a) shows the block diagram of the supercritical coal-fired power plant (SCPP) with CO_2 capture. In this study, the SCPP of 550 MWe net power was simulated in Aspen Plus with suitable thermodynamic property models, as shown in Fig. 1 (b). Four property methods were selected for the simulation of the power plant: Peng Robinson and Boston Mathias (PR-BM) for the estimation of properties of solid; Electrolyte NRTL for the electrolytes components in the CO_2 capture process; Ideal gas equation for air and flue gases; and the STEAMNBS steam table for water and steam. The reference SCPP is reported by National Energy Technology Laboratory (NETL) and our developed base model without CCS was totally consistent with the reference within 0.7% data error, in terms of all calculation results of material and heat streams

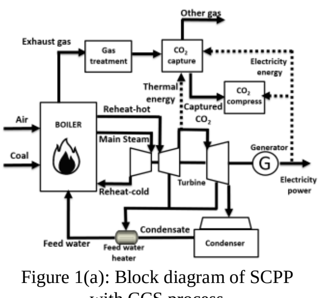

Figure 1(a): Block diagram of SCPP with CCS process

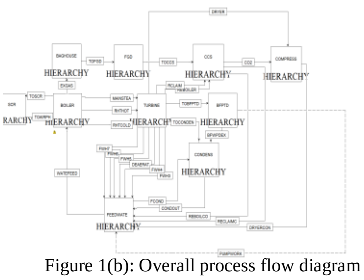

Figure 1(b): Overall process flow diagram of SCPP with CCS process

2.2. Simulation with CCS process

In the full-scale CCS simulation process, monoethanolamine (MEA) 30wt% amine solution was introduced to separate CO_2 from exhaust gas. The heat source of the reboiler in the stripper came from the steam extraction of turbine system. The pressure of extracted steam was an important parameter that strongly affects both the net efficiency drop of power plant and regeneration heat of CO_2-rich solution in the CCS process. The regeneration heat consists of latent heat, sensitive heat and CO_2 dissociation heat, and the pressure inside the stripper associated with the temperature of the extracted turbine steam gives impact on the sensitive heat, latent heat, and effective CO_2 loading, thus, directly affecting the regeneration heat. The reference SCPP with CCS is also reported by the same paper, but it employed a black box commercial CCS system. Our developed model with CCS was validated by using the same energy penalty index with the reference.

2.3. Amine solution selection

Methyldiethanolamine (MDEA)/piperazine (PZ) binary amine solution is a promising candidate because a slow CO_2 absorption rate of MDEA can be enhanced by the addition of small amounts of absorption activators such as PZ. These features are regarded as possible approaches to reduce the energy penalty, and the MDEA/PZ simulation model that was validated by the experimental result of the 10kg/day-scale CO_2 recovery apparatus was used as another option for the CCS process.

3. Research Results

3.1. Net efficiency drop caused by integration of CCS process

The full-scale CO_2 capture and compression simulation process, which used MEA 30wt% amine solution as CO_2 absorbent was integrated into the SCPP model. The pressure inside the stripper was kept at 0.2 MPa, and 90% CO_2 inside the exhaust gas was captured. According to the simulation results, the regeneration heat in the stripper was 4.37 MJ/kg-CO_2. The electricity penalty for the CO_2 capture and CO_2 compression processes was 72.2 MW. This electricity penalty resulted in the decrease of high heat value (HHV) net efficiency from 40.7% to 29.8%.

3.2. Regeneration heat reduction

A series of MEA 30wt% amine solution-based CO_2 capture process simulations were completed in the experimental scale, which varied the pressure of extracted steam from 160 to 800 kPa, and the pressure inside the stripper was also changed by it from 140 to 780 kPa (i.e., the pressure loss was kept at 20 kPa, which was consistent with NETL's reference data). The temperature difference between top and bottom of the stripper was kept constant at 40 ºC, while the temperature inside stripper changed with manipulating the pressure. As shown in Fig. 2, the results showed that the regeneration heat would decrease from 4.43 to 3.84 MJ/kg-CO_2 corresponding to the pressure increase. However, the electric power loss in the turbine system increased due to exergy loss.

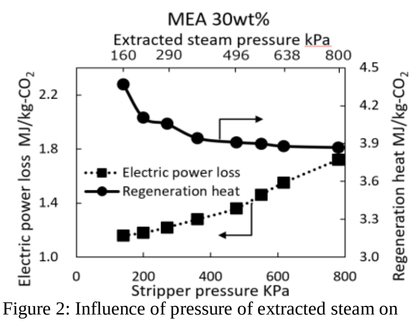

Figure 2: Influence of pressure of extracted steam on electric power loss and regeneration heat

According to the experimental results, different concentration will have influence on the performance for the MDEA/PZ binary amine solution system. Keeping the total amine concentration at 30wt%, the combination of MDEA 15wt% and PZ 15wt% amine Solution indicated the lowest CO_2 regeneration heat. Using the tested experimental conditions (i.e., 0.2MPa pressure inside stripper and 40 ºC temperature difference between top and bottom of stripper) in the simulation, the CO_2 regeneration heat was 3.76 MJ/kg-CO_2, which was lower than that of 30wt% MEA at the same operation condition, as shown in Fig. 3.

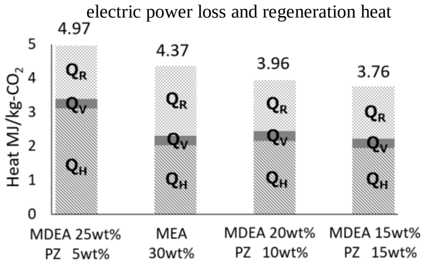

Figure 3: Regeneration heat of MEA and MDEA/PZ at same operation condition