Techno-economic analysis of an integrated gasification combined cycle (IGCC) plant with carbon capture storage

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Abstract

Although the efficiency and energy contribution of renewable energy are rapidly growing, coal is still an important fuel to meet the global energy demand. The integrated gasification combined cycle (IGCC), which is one of the coal power plants, has high efficiency and minimum cost penalties and has a high potential for further technological improvements [1]. The IGCC with CCS consists of a coal gasification process, integrated syngas purification process and power generation process. Since the operational change of one unit in the integrated process can influence the other units, techno-economic analysis for performance and cost assessment of the integrated overall process is essential.

Several studies have conducted an IGCC performance analysis for bituminous coal only. On the other hand, about 53% of global coal reserves are of low rank, sub-bituminous coal and lignite [2]. Thus, the techno-economic analysis of IGCC with CCS for sub-bituminous coal must be investigated. Furthermore, the utilization of a carbon capture process (CCP) for the IGCC is urgently required to curb CO$_2$ emissions. However, CCP evaluation alone does not provide accurate information on energy efficiency and carbon reduction for the overall IGCC plant because each unit process is integrated to other processes.

In this study, a techno-economic analysis of the entire syngas process including carbon capture unit was conducted for a 500 MW-class IGCC with Shell gasifier using a sub-bituminous coal. The configuration of power generation process is presented in Fig. 1. The Integrated syngas purification process consists of a scrubber, WGSR, dual-stage Selexol, refrigerator, triethylene glycol (TEG) dehydration process, SWS, Claus process, hydrogenation process, and a 5-stage CO$_2$ compressor. The acid gas and CO$_2$ were separated in the dual-stage Selexol process, and the removal of >99% H$_2$S was fixed as an essential prerequisite for the integrated syngas process due to ever-tightening environmental regulations. Therefore, the efficiency of CO$_2$ capture was evaluated at this constrain.
The process simulation of the integrated syngas purification process was performed using Aspen Plus (Aspen Technology Inc., USA). The performance of Shell gasifier using sub-bituminous coals was simulated using a gPROMS software package (Process Systems Enterprise, UK). To obtain reliable simulation data, the simulation was based on an appropriate equation of state (EOS) and reliable organizations such as DOE (Department of Energy) and NETL. The EOS used for each unit is as follows:

- Air separation unit, syngas cooling unit, water gas shift reactor and flue gas in a combined cycle: Peng-Robinson EOS with the Boston Mathias alpha function (PR-BM)
- Sour water stripper: Electrolyte nonrandom two-liquid activity coefficient model (ELECNRTL)
- Dual-stage Selexol process: Perturbed-chain statistical associating fluid theory (PC-SAFT)
- Steam turbine and water in HRSG: NBS/NRC steam tables 1984

The amount of oxygen and intermediate pressure steam fed to the gasifier were optimized to maximize the cold gas efficiency (CGE) of Shell gasifier. And the amount of Selexol solvent was determined to satisfy the 90% of carbon capture efficiency. In addition, the net power of steam turbine was optimized by adjusting the amount of HP, IP and LP water.

Economic analysis is essential to perform plant feasibility studies. In this study, the capital cost, including equipment cost, material cost and direct labor cost and operating cost including water usage cost, waste water treatment cost, slag disposal cost, CO$_2$ transport & storage cost and fuel cost, were calculated. Finally, the cost of electricity (COE) and net carbon capture cost, excluding the cost of H$_2$S removal, were derived from results of economic analysis. All the cost was calculated by using the power law of capacity and the results of process simulation.
Fig. 2 shows the variation in CGE with oxygen to coal feed rate (OF) ratio and steam to coal feed rate (SF) ratio. As shown in Fig. 2, the variation in the CGE with OF ratio and SF ratio showed a convex curve. The optimal OF ratio and SF ratio to achieve maximum CGE were 0.75 and 0.1 respectively. And the maximum value of CGE of coal in this study was approximately 81%.

![Graph of CGE variation with OF and SF ratios](image)

The net plant efficiency (HHV basis) of the integrated whole process was about 32%. The COE was determined as approximately 90 USD/net-MWh. And the net carbon capture cost per ton of CO₂ was determined as approximately 32 USD. The results can contribute toward estimating the carbon tax.

References