ABSTRACT

The Integrated Gasification Combined Cycle (IGCC) is one of the most promising coal-based electrical power-producing technologies. The gas-side of the IGCC plays an important role in the efficiency of the process. This is because the gas turbine generates 60% of the gross power produced, while the air separation unit is the highest consumer of power in the IGCC plant. The gasifier is also responsible for the generation of the fuel-gas, which is the main source of energy for the combined cycle. Hence, optimizing the gas-side of the IGCC will lead to an improvement in the efficiency of the entire plant. Consequently, this work focused on the optimal flowsheet synthesis of the gas-side of the IGCC process.

The first step in achieving this included developing a novel optimization technique for the synthesis and design of an optimal entrained flow gasifier. The developed technique was then applied to three examples taken from literature. The first example studied was the optimal synthesis and design of a dry, nitrogen-fed entrained flow gasifier. The objective function for this example was the maximization of the cold gas efficiency of the gasifier. In this example, an improvement of 6% in the objective function relative to the base case was achieved. The optimal gasifier design for this example was a continuous stirred tank reactor followed by a plug flow reactor. Other findings included higher steam to coal ratio but a lower oxygen to coal ratio relative to the base case. The results also showed that although all the oxygen enters the reactor network through the first reactor, part of the total steam fed enters through the second reactor.

The second example under this section was the synthesis and design of a dry, carbon dioxide-fed entrained flow gasifier. The objective function for this example was the maximization of the higher heating value of the produced fuel-gas. The optimal solution for this example led to an improvement of 6.2% in the objective function relative to the base case. The optimal gasifier design was a plug flow reactor with a side stream. For this example, the optimal feeding

condition had higher steam to coal ratio but a lower oxygen to steam ratio relative to the base case.

The final example under this section was the synthesis and design of a slurry-fed entrained flow gasifier. The objective function for this example was the lower heating value of the fuel-gas product. The results showed an increase of 13.3% of the objective function relative to the base case. The optimal gasifier design was a plug flow reactor with a side stream followed by a continuous stirred tank reactor. The oxygen to coal ratio for the optimal design was lower than that of the base case. It was observed that the optimal feed distribution was 70% of the coal fed at the entrance of the plug flow reactor and the remaining 30% fed as a side stream.

The second step in this study involved the synthesis of an optimal flowsheet of the gas-side of the IGCC process. This was achieved by integrating the developed gasifier model into an IGCC framework. The developed model was applied to two examples. Example 1 was an IGCC plant with a dry-fed entrained flow gasifier. Example 2 was an IGCC plant with a slurry-fed entrained flow gasifier. Three scenarios were explored in each example. The base case or scenario 1 for each example is the simulation of a standard IGCC plant. The second scenario is the synthesis and design of an optimal gasifier with a background IGCC process. The decision variables in scenario 2 were the gasifier volume, reactor configuration, steam to coal ratio and the oxygen to coal ratio. The third scenario is the determination of the optimal flowsheet path for the IGCC process. In addition to the decision variables in scenario 2, scenario 3 also determined the optimal integration between the air separation unit and the gas turbine. In each of these examples, scenarios 2 and 3 were compared to the base case. The objective function of both examples was the thermal efficiency of the IGCC plant.

In example 1, an improvement of 6.79% and 10.96% in the objective function relative to the base case was achieved for scenario 2 and scenario 3 respectively. For both scenarios, the optimal gasifier design was a CSTR followed by a PFR. This agreed with the results from the optimization of the standalone gasifier in the first step. Both scenarios also had higher steam to coal ratio relative to the base case, which agreed with results in the first step. However, the optimal oxygen to coal ratio for both scenarios were high relative to the base case. This deviated from the results in the first step.

In example 2, an improvement of 11% and 15.8% in the objective function relative to the base case was achieved for scenarios 2 and 3 respectively. For both scenarios, the optimal gasifier is a plug flow reactor with a side stream. The optimal oxygen to coal ratios for both scenarios were higher relative to the base case, which was different from the optimization of the standalone gasifier.

This study shows that a superstructure optimization technique is an effective tool for the design of standalone gasifiers and the synthesis of the optimal flowsheet of an IGCC plant. The differences in the optimal oxygen flowrates for the gasifier either as standalone or as part of an IGCC plant show the need for the simultaneous optimization of multiple units in a process instead of sequential optimization.