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Modeling and simulations of fuel cell systems for combined heat and power generation

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ABSTRACT

Combined heat and power (CHP) fuel cell systems have been under development for the past several decades to enable distributed power generation. These fuel cell systems consist of several subsystems, such as a fuel cell stack, a fuel processing system, heat exchangers, and a heat recovery system. Optimal integration of these subsystems is critical to develop highly efficient, cost effective fuel cell systems for CHP generation. In this paper, we describe the system modeling of a 20 kW fuel cell system, in which a PEM fuel cell stack is connected with fuel processors, i.e., a steam reformer with water gas shift and preferential oxidation reactors. The model is implemented within a commercial flow-sheet simulator, ASPEN HYSYS. We also analyze the effects of key operating parameters on the electrical and thermal efficiency of the 20 kW power systems. The simulation results indicate that the fuel delivery rate and air-fuel ratio supplied into the burner are major control factors to achieve a net electrical power of 20 kW and an acceptable CO concentration level (<10 ppm).

Introduction

A polymer electrolyte membrane fuel cell (PEMFC) is considered to be a promising alternative power source for distributed energy or combined heat and power (CHP) applications owing to its high efficiency and low pollution in comparison with traditional combustion-based electricity-generating technologies. PEMFC systems utilize hydrogen that is generated from hydrocarbon fuels, such as natural gas, liquefied petroleum gas, methane, and bio-gas. In particular, biogas reforming contributes to a considerable reduction in greenhouse gas emissions, and therefore, the use of biogas for fuel cell applications is quite attractive from the standpoint of environmental safety and high energy efficiency. Biogas created by organic wastes, e.g., sewage, manure, food wastes, and landfill mainly consists of methane and carbon dioxide (CO_2) with minor species of oxygen, nitrogen, H_2S, NH_3, etc. It is well known that some of these minor species (e.g., H_2S) can damage several key components in the system and thereby can reduce both system performance and long-term durability. Fig. 1 shows a typical CHP fuel cell system using biogas that consists of four major subsystems, i.e., a fuel pretreatment module, fuel processor, fuel cell power system, and heat recovery system. Owing to its complex configuration, the system requires a high degree

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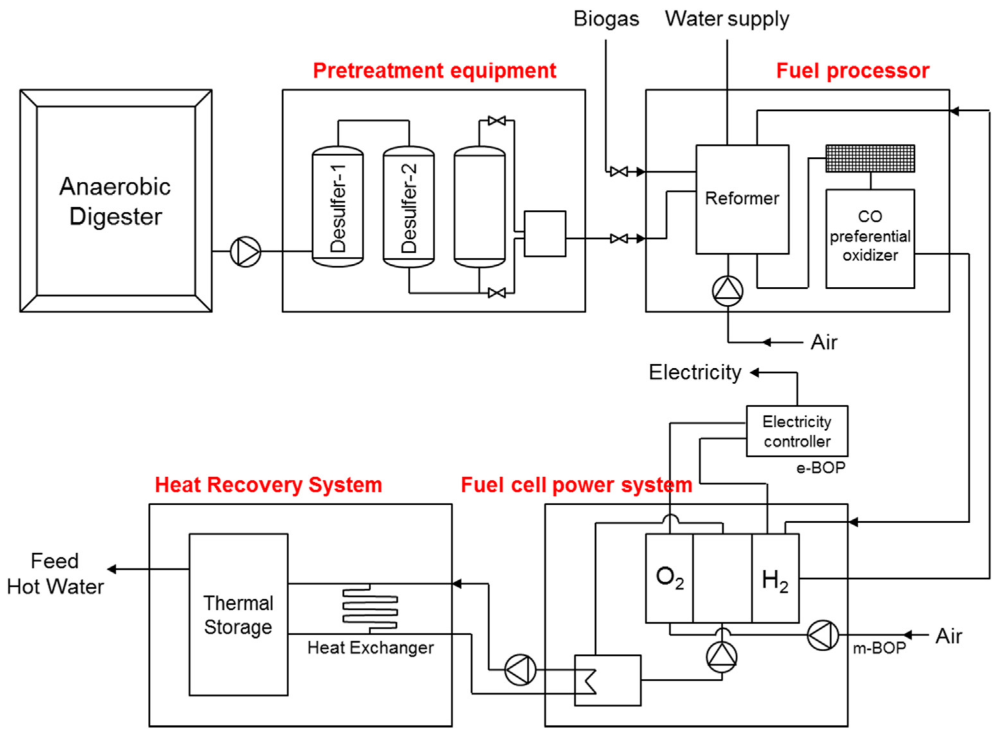

Fig. 1 – A typical fuel cell CHP system using biogas.

of optimization to achieve good overall performance and cost reduction.

Fig. 2 schematically displays a typical fuel processor of a fuel cell CHP system that consists of a series of several sub-reactors. The primary fuel-reforming reactor illustrated in Fig. 3 is based on stream reforming (SR) but it can also comprise partial oxidation (POX) or autothermal reforming (ATR), i.e. various combinations of both SR and POX. The SR reactor is usually connected to water gas shift (WGS) and preferential oxidation (PrOx) reactors in series to further reduce CO contamination to acceptable levels. In addition, several auxiliary burners are required to preheat the incoming fuel and steam as well as to supply heat to the endothermic SR process. In general, an SR reforming temperature of around 650 °C and excess steam (e.g., steam to carbon ratio, SCR = 2.7) are required to increase the hydrogen yield for PEMFC operations [1].

Many numerical models for hydrogen-reforming processes have been developed and presented in the literature [2–9]. Using a simple thermodynamic equilibrium model, Galvagno et al. [2] analyzed the hydrogen conversion rate of biogas as a function of operating temperature and pressure. They compared the thermal efficiencies for SR, ATR, and PrOx processes, but additional reactors such as WGS and PrOx and their interaction with the main reactors were neglected in their calculations. Javier et al. [3] developed a simple thermodynamic-equilibrium-based ethanol processor model wherein a steam reformer, high- and low-temperature WGS, and PrOx reactors were connected. They mainly analyzed the effects of SCR, reformer temperature, and intermediate compounds during stream reforming. Later, Javier et al. [4] included various empirical PEMFC stack models in their ethanol processing system and studied the influences of key system operating conditions such as temperature, pressure, and hydrogen utilization. Salemme et al. [5], Ersoz et al. [6],

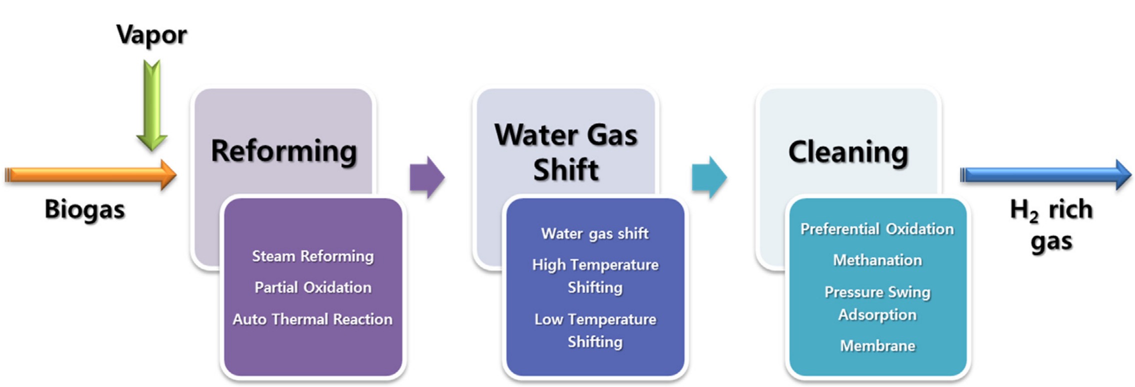

Fig. 2 – Schematic of the fuel processor for the fuel cell CHP system.