Analysis of Heat and Power Outputs in Bio-oil Fueled Solid Oxide Fuel Cell Systems for Industrial Applications

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Highlights

- A heat-to-power ratio of the solid oxide fuel cell system fueled by bio-oil is analyzed.
- The fuel cell system is designed to meet the energy demand of a pulp and paper process.
- Primary energy consumption in two operational modes is considered.
- The system in the heat load determined by electricity mode is suitable for all paper types.

1. Introduction

Solid oxide fuel cell (SOFC) is an attractive technology for combined heat and power generation. It can be operated under a partial load condition with high efficiency [1]. However, the challenge is matching the electricity and heat outputs of the SOFC system with a variation in energy demands. A heat-to-power ratio is the key factor of the SOFC system, which can be varied according to changes in heat and power loads [2]. In general, an operational range of the heat-to-power ratio depends on fuel types, fuel processing technologies and system configurations [3]. In this study, the capability of the SOFC system integrated with the reforming process of bio-oil, a liquid fuel derived from the fast pyrolysis process of biomass, in response to a change in power and heat demands is investigated. A sorption enhanced steam reforming (SESR) process which combines hydrogen production, CO_2 removal and hydrogen purification in a single unit is employed to produce high purity hydrogen for SOFC operation. Design of the proposed SOFC system to provide heat and power in two operational modes: heat load determined by electricity (HLDE) and electricity determined by heat load (EDHL), is carried out.

2. SOFC integrated with bio-oil reforming process

Figure 1 shows the schematic diagram of the bio-oil SESR and SOFC integrated process. The process is simulated using Aspen Plus process simulator and the minimization of the Gibbs free energy method is used to determine product compositions based on Peng-Robinson equation of state. In the SESR section, bio-oil is converted into hydrogen via sorption enhanced steam reforming using CaO as absorbent. The hydrogen-rich gas obtained is sent to the SOFC section to produce electricity and heat via electrochemical reactions.

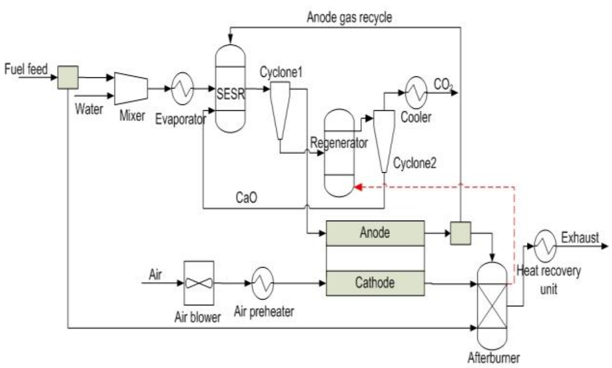

Figure 1. Schematic diagram of the bio-oil sorption enhanced steam reforming and SOFC integrated process.

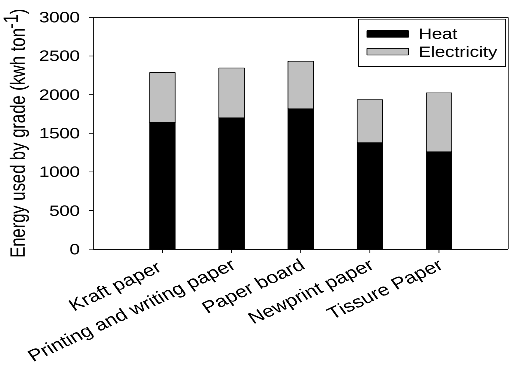

Figure 2. Heat and power demand of different paper grades in the paper industry [6].

Because of a complex compound of the bio-oil aqueous fraction, the model compound of bio-oil consisting of 55.6% acetic acid, 18% hydroxy acetaldehyde, 8% furfural, 4% acetaldehyde, 8% hydroxy acetone, 4% guaiacol and 2.4% dextrose [4] is assumed. At the design condition, the SESR and SOFC are run at 600 and 800^{o}C, respectively. The cell operating voltage and current density are approximately 0.7 V and 920 mA cm^{-2}. The validation of the SESR and SOFC models was presented in the previous work [5].

3. Results and discussion

The proposed bio-oil SESR and SOFC system is used to supply heat and power to a pulp and paper industry, as a case study [6]. Figure 2 shows the fluctuation of heat and power loads needed for producing different paper grades. It is shown that the heat-to-power ratio of the process is varied between 1.5 and 3 and the process requires the electrical energy from the SOFC integrated system in the range between 1200 and 1800 kW (based on the production rate is 100,000 tons per year). The results show that the thermal output of the proposed SOFC system operated in HLDE mode is less than the thermal demand for most grades of the paper except the paper board grade. In EDHL mode, additional electricity from the external power grid to supply the process for the paper board grade is needed because the heat and power demand is less than the rated heat-to-power ratio. Comparing the fuel consumption between HLDE and EDHL modes, it is found that the SOFC integrated process needs the additional energy supply in EDHL mode lower than that in HLDE mode, but the primary energy consumption of the SOFC integrated process in EDHL mode is higher because it generates excess by-product of the electricity.

4. Conclusions

In this study, a variation of heat and power outputs in the bio-oil SESR and SOFC integrated system was analyzed. The SOFC system was designed to match the power and heat demand for a pulp and paper industry in two operational modes. The paper process needs the additional heat supply from a back-up boiler in HLDE mode. However, the SOFC integrated system in HLDE mode achieves more benefit than the system in EDHL mode, which needs higher fuel consumption, for all grades of the paper product. As the amount of required fuel and carbon dioxide emissions are varied in the SOFC systems with different modes of operation, economic and environmental impact assessments should be further considered to obtain an optimal system design.

Acknowledgements

Support from The Royal Golden Jubilee Ph.D. Program (The Thailand Research Fund) and Chulalongkorn Academic Advancement into Its 2nd Century Project is gratefully acknowledged.

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Keywords
Solid oxide fuel cell system; Heat-to-power ratio; Bio-oil; Hydrogen.