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Exergoeconomic Analysis of a Solid Oxide Fuel Cell Based Trigeneration System with External Reformer and Dimethyl Ether

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ABSTRACT: In the present study, Exergoeconomic analysis of a combined solid oxide fuel cell with a gas turbine, a generator-absorber heat exchanger and heating process heat exchanger for heating, cooling and power production as a tri-generation system is conducted. An external steam reformer is applied to convert di-methyl ether as oxygenated fuel to hydrogen for the electrochemical process of the solid oxide fuel cell. The influence of the primary design parameters (fuel utilization factor and anode inlet temperature) on several variables (energy and exergy efficiencies, exergy destruction and unit costs of the power) are examined. Results show that energy efficiency of proposed system is 38% higher than standalone solid oxide fuel cell. It was found that the maximum exergy destructions occurred in afterburner, solid oxide fuel cell and recuperator. An increase in anode inlet temperature leads to reduction of exergy destruction in afterburner and fuelcell. Unit cost of power is equal to 23.51 $/GJ and decreases with an increase in fuel utilization factor or increasing of anode inlet temperature. Increasing of utilization factor will increase all exergy efficiencies by 12%. The effect of increase in anode inlet temperature on exergy efficiencies is positive but compared with the other parameter is lower and will increase them by 8%.

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1. Introduction

This novel tri-generation system is consisted of a Solid Oxide Fuel Cell (SOFC), an air Brayton cycle for producing power, a Generator Absorber heat eXchanger (GAX) for cooling and Heat eXchanger (HX) for heating. The oxygenated fuel (di methyl ether), water and air are slightly pressurized to the operating pressure of the SOFC stack. Producing hydrogen from di methyl ether need reforming process and the steam reforming is the best choice. In mixer, the water is mixed with di methyl ether, then the mixture is entered into the external steam reformer. The preheated air entered into cathode while the products of the external reformer are supplied to the anode side. The electrochemical reactions occurred in the fuel cell stack. An inverter is utilized to convert the Direct Current (DC) power achieved by the fuel cell into the Alternating Current (AC) power which is grid quality electricity. The excess air and unreacted fuel which leaves the SOFC and enters into the After-Burner (AB), combust completely and generate high-temperature gases. The exhaust gases from the AB warm up the working fluid of bottoming brayton cycle in a heat exchanger. In bottoming cycle, the hot and high pressure air expands through a turbine and produces power. In a mixer, the expanded gases are mixed with a part of exhaust gases from the air heat to the generator of the GAX system for cooling purposes. The remaining thermal energy is recovered through a HX for heating purposes [1].

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2. Methodology

In line with the goals of this study, the modeling of the SOFC system, and the energy, exergy as well as Exergoeconomic analyses of considered tri-generation system is performed [2-4]. The Engineering Equation Solver (EES) software is used to solve the resulting equations. Thus, it is possible to study unit cost of product, exergy destruction rate of different components, first and second law efficiencies as well as the way those vary with the variation of anode inlet temperature and fuel utilization factor.

3. Results and Discussion

Based on the results, as fuel utilization factor increases, second law efficiencies increase while first law efficiencies have a 1percent decrease. Increase of fuel utilization factor leads to an increase in fuel concentration and consequently higher concentration voltage loss. While other voltage losses are almost constant. Higher fuel utilization factor means lower consumption of fuel and air. Thus the required power for pumps and compressors will decrease. Although the decrease of fuel and air flow rates causes lower temperature in different points of cycle and consequently lower net electrical power as well as lower cooling and heating capacity, but he effect of fuel consumption decrease is dominant and leads to

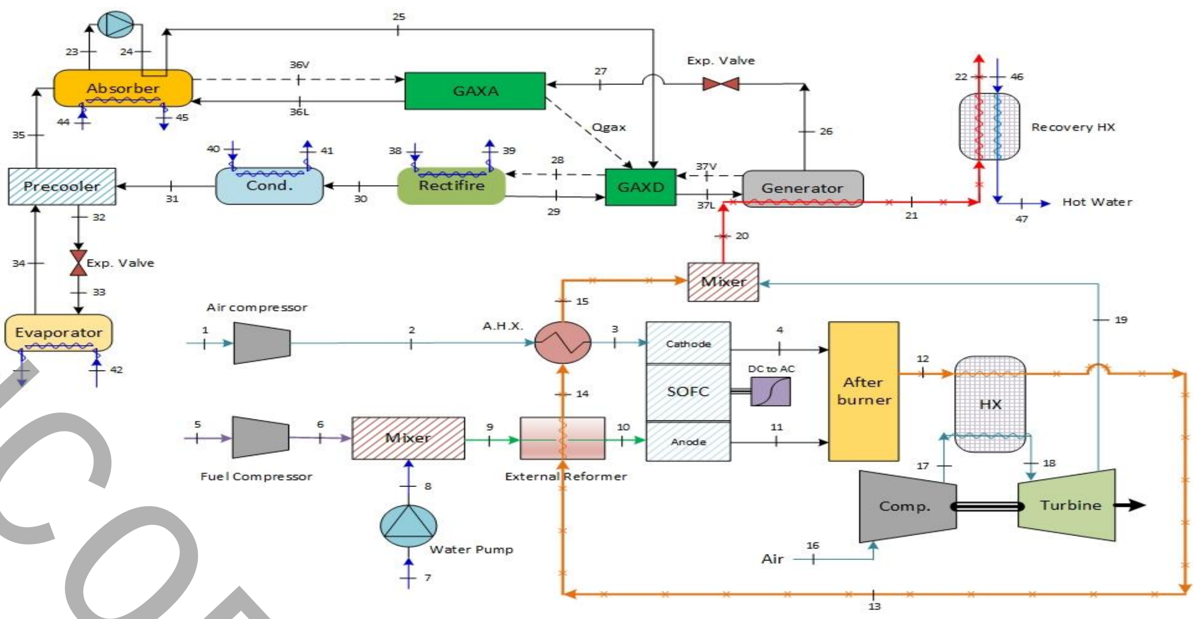

Fig. 1. A Schematic diagram of the proposed trigeneration system

increase of second law efficiencies about 12%. About first rule efficiencies this reductions are almost equivalent and just a reduction of 1% is observable.

Referring to results, after burner, SOFC and recuperator have the highest exergy destruction. Except in SOFC, an increase in fuel utilization factor lowers the exergy destruction in components. As mentioned before, higher utilization factor means higher voltage loss in SOFC and consequently higher exergy destruction. The reduction of exergy destruction in other components is due to the lowered temperature difference between cold and hot stream.

As shown in Fig. 2, by the increase of fuel utilization factor, unit cost of power will decrease. The reason is the reduced amount of fuel and air and lower cost of equipment (pumps, compressors and heat exchangers with reduced size).

Referring to the results, as anode inlet temperature increases, all first and second law efficiencies increase. Although cooling capacity of evaporator decreases due to the decreased flow rate of air and fuel, the increased power and heating capacity makes first law efficiency of tri generation system increase.

The highest exergy destruction rate belongs to afterburner, while SOFC and recuperator are in second and third place. By increasing the anode inlet temperature exergy destruction rate in after burner and SOFC are decreased while it is increased in recuperator. The exergy destruction in these two components is because of the chemical reaction occurring in them and decreases as the anode inlet temperature increases. At higher anode inlet temperatures, chemical reactions occur in higher temperature and are faster, with reduction of the voltage loss, the exergy destruction reduces. The hot flow temperature at the inlet of air heat exchanger reduces with the increase of the anode inlet temperature and this means lower temperature difference in the heat exchanger, which is the reason of lowering the exergy destruction.

As it can be observed in Fig. 3, an increase in the anode

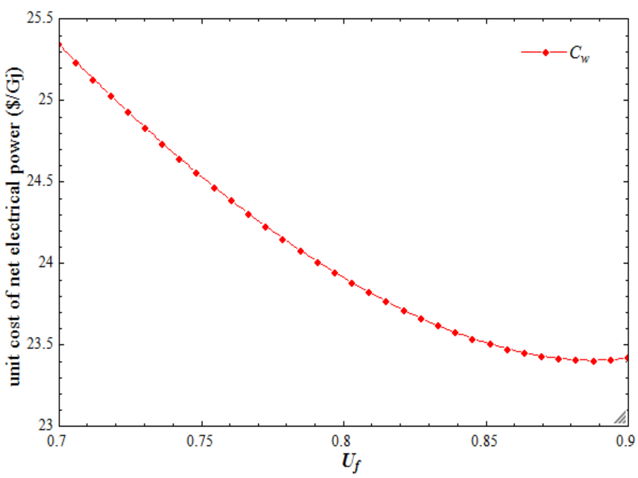

Fig. 2. The influence of fuel utilization factor variation on unit cost of power

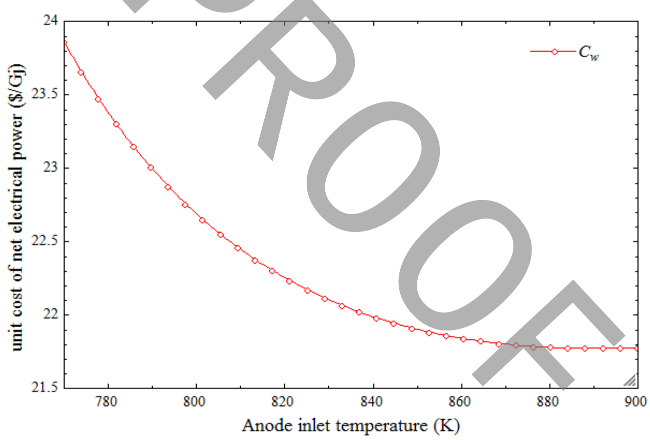

Fig. 3. The influence of anode inlet temperature variation on unit cost of power

inlet temperature is observed to lower the unit cost of net electrical power which is due to higher net electrical power at lower fuel flow rate and less air molar flow rate which leads to the reduction of fuel and components cost.

4. Conclusions

Results show that energy efficiency of proposed system is 38% higher than standalone SOFC. It was found that the maximum exergy destructions occurred in afterburner, SOFC and recuperator. An increase in anode inlet temperature leads to reduction of exergy destruction in afterburner and fuelcell, while it has reverse effect on exergy destruction rate in recuperator. Unit cost of power is equal to 23.51 $/GJ at a specific condition and decreases with an increase in fuel utilization factor or increasing of anode inlet temperature. Increasing of utilization factor will increase all exergy efficiencies by 12%. The effect of an increase in anode inlet temperature on exergy efficiencies is positive but compared with the other parameter is lower and will increase them by 8%.

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