Thermodynamic Analysis of Power Generation System Based on Solid Oxide Fuel Cell With External Reforming

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ABSTRACT: Due to the capability of using Exhaust gases of power plants directly in the reforming process and producing high-quality syngas, the tri-reforming process is a considerable kind of reforming process. In the present study, a power generation system based on solid oxide fuel cells with specific capacity and equipped to the external reforming is proposed and investigated form the viewpoint of thermodynamics. In order to conduct the external reforming process, exhaust gases from the system including the steam, carbon dioxide and oxygen are recycled and utilized as the reforming agents in the reactor. In order to model the proposed system thermodynamically, the principals of mass and energy balance are applied in engineering equation software. Effects of such important parameters as the current density and solid oxide fuel cell operating temperature on the system performance indicators including the various voltages, fuel mass flow rate, power generation and the energy as well as the exergy efficiencies of the system are investigated. The parametric study results show that for the lower values of the current density e.g. 1000 A/m² and 900 ºC and higher values of the solid oxide fuel cells operating temperature e.g. 900 oC, the system energy and exergy efficiencies enhance up the maximum values of 55.04% and 53.11%, respectively.

1- INTRODUCTION

Serious worries about decreasing fossil fuel resources as well as their environmental impact, e.g. global warming, motivates researchers to move forward to the more efficient power generation systems [1]. In this regard, Solid Oxide Fuel Cells (SOFC) with the capability of converting the fuel chemical energy directly into electrical energy could be regarded as promising methods to produce electricity in a green and efficient way. Considering the point that the SOFCs operate at high temperatures; they have high potential to integrate with the bottoming power generation cycles and processes e.g. gasification and reforming [2].

Dietrich et al. [3] investigated the effects of Anode Off-Gas Recycling (AOGR) on the performance of small-scale propane driven SOFC system. They reported that the efficiency of the system with anode off-gas recycling is improved. Saebea et al. [4] presented the analyzed performance of a SOFC system coupled to an ethanol reforming process with anode off-gas recycling. The results demonstrated that under the same thermodynamic conditions, anode Exhaust Gas Recirculation (EGR) leads to an increase in the electrical efficiency of the system. Faro et al. [5] analyzed the performance of a biogas fed SOFC integrated with the tri-reforming process. They concluded that the proposed system is suitable for small-sized power plant applications. Walluk et al [6] investigated the effects of auto-thermal reforming for SOFC systems with anode off-gas recirculation. It was found that for the

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optimal value of 45 % for AOGR, the maximum efficiency of the reforming process is achieved. Mehr et al. [7] analyzed a biogas fed solid oxide fuel cell power generation system with anode and cathode recycling thermodynamically and economically. The results revealed that comparing the simple system, the energy efficiency of the SOFC with anode and cathode recycling is improved by up to 6.81%. Furthermore, they reported that the unit product cost of the system with anode and cathode recycling gets about 35% cheaper. Biogas fed solid oxide fuel cell-based plant coupled to the external tri-reforming was proposed and simulated by Manenti et al. [8]. They investigated the influence of current density and reforming parameters on the cell potential behavior. A comprehensive investigation of the anode EGR in solid oxide fuel cell systems with various fuels was conducted by Rokni [9]. The results outlined, that the amount of EGR depends strongly on the type of fuel used in the system. A comparative study on the effects of using external reforming against internal reforming was performed by Chitsaz et al. [10]. The optimization results showed that the exergy efficiency of the system with internal reforming is about 9.6% higher than that of with external reforming.

Surveying the literature demonstrates that all the studies on the coupling of the SOFCs to the external reforming limits to the anode and/or cathode off-gas recycling and there is no study on the chemical recuperation of the afterburner exhaust gases. In this regard, the present work is an attempt to fulfill this lack of information and investigate the effects of chemical
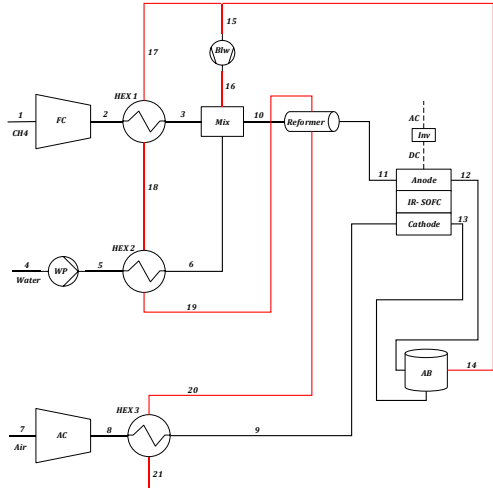
Fig. 1. Schematic of the proposed SOFC system

Fig. 2. Effects of current density on the power production and system energy as well as the exergy efficiencies

Fig. 3. Effects of current density on the power production and system energy as well as the exergy efficiencies
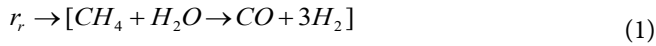
reoperation and tri-reforming on the performance of a SOFC based plant from the viewpoint of thermodynamics.

2- METHODOLOGY

The schematic of the proposed SOFC power generation system integrated with the tri-reforming process through exhaust gas recycling is depicted in Fig. 1.

The dominant chemical reactions occurring in the SOFC are as following:

Reforming

$$r_r \rightarrow [CH_4 + H_2O \rightarrow CO + 3H_2] \tag{1}$$

Shifting

$$s_r \rightarrow [CO + H_2O \rightarrow CO_2 + H_2] \tag{2}$$

Overall reaction

$$o_r \rightarrow [H_2 + \frac{1}{2}O_2 \rightarrow H_2O] \tag{3}$$

The fuel utilization factor and relation between the cell parameters and overall reaction are defined as the following:

$$U_f = \frac{(Fuel)_{consumed}}{(Fuel)_{supplied}} = \frac{o_r}{\dot{n}_{H_2,11} + 3r_r + s_r} \tag{4}$$

$$j = 2Fo_r / N_c A_c \tag{5}$$

Finally, the power generation is calculated as follows:

$$\dot{W}_{AC,inv} = \eta_{inv} \times N_c \times V_c \times I \tag{6}$$

$$V_c = V_n - V_{loss} = V_n - (V_{ohm} + V_{act} + V_{con}) \tag{7}$$

3- DISCUSSION AND RESULTS

Regarding the Figs. 2 and 3 for the lower values of current density and higher values of SOFC temperature; the efficiency of the system is improved. These are because even though at low currents and higher fuel mass flow rates; the power production of the system is decreased; the fuel mass flow rate is also reduced more intensively.
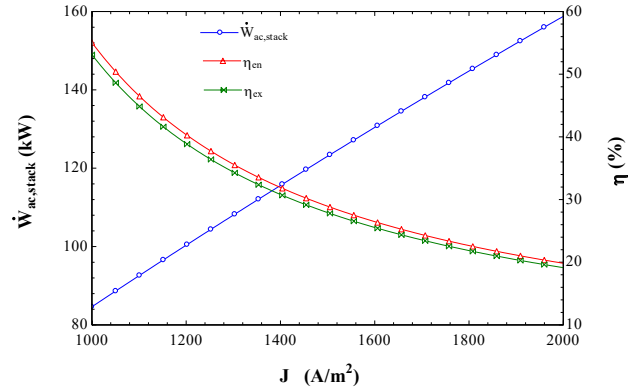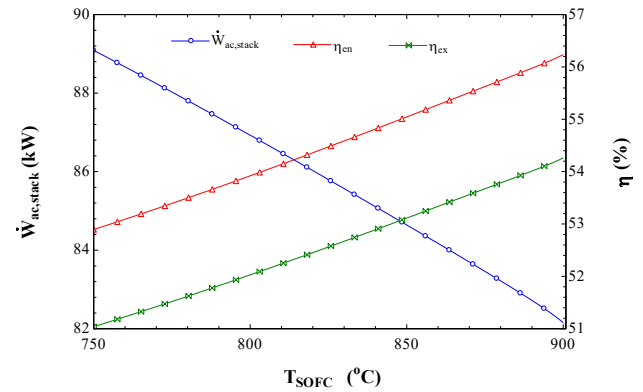
4- CONCLUSIONS

Lower current densities and higher operating temperatures are suggested for SOFC systems with EGR form viewpoints of energy and exergy.

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