Journal of the Energy Institute 87 (2014) 28–34

Contents lists available at ScienceDirect

Journal of the Energy Institute

journal homepage: http://www.journals.elsevier.com/journal-of-the-energy-institute

Performance analysis of hybrid solid oxide fuel cell and gas turbine cycle (part II): Effects of fuel composition on specific work and efficiency

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ARTICLE INFO

Article history:
Received 17 July 2012
Accepted 29 April 2013
Available online 18 February 2014

Keywords:
Solid oxide fuel cell
Gas turbine
SOFC–GT
Fuel composition
Specific work
Efficiency

ABSTRACT

The model of the hybrid solid oxide fuel cell (SOFC) and gas turbine (GT) cycle is used to evaluate the impacts of the inlet fuel composition on the specific work and efficiency of the cycle. In order to perform the analysis, the system fueled with methane is considered as the reference case. For alternative cases, methane is partially replaced with hydrogen, carbon dioxide, carbon monoxide, and nitrogen with an increment of 5% at each step. The results indicate that the trend of the variations and the magnitude of the changes depend on the replacing gases. The specific work and efficiency of the SOFC, GT, and cycle as a whole for the cycle with and without anode recirculation can increased, decreased, or remain unaffected when methane is replaced with these species. All these trends are justified by investigating the system's operational parameters. This study confirms the importance of the fuel composition impacts on the SOFC–GT cycle performance.

1. Introduction

Unlike conventional-combustion-based power generation systems, fuel composition may significantly affect the performance of the fuel cell-based power generation systems due to the electrochemical processes involved in the internal operation of the fuel cells [1–3]. These effects are more important for renewable and alternative fuels. In the first part of this presentation, it was shown that the concentration of methane, hydrogen, carbon dioxide, carbon monoxide, and nitrogen can vary between 1.4% and 97.4%, 0%–50%, 1.6%–38.3%, 0%–60.3%, and 0.2%–65%, respectively [3–8].

In this work, the model presented in Suther et al. (2010, 2011) is used to investigate the impacts of fuel composition on the performance of the hybrid solid oxide fuel cell (SOFC) and gas turbine (GT) cycle (SOFC–GT cycle) with two configurations: with and without anode recirculation [9,10]. In Part I of this presentation, Fig. 1 was used to explain the operation of the hybrid SOFC–GT cycle when it was operated in both configurations. In the analysis, first the reference case was presented where the cycle was fueled with pure methane. In this reference case, the overall efficiencies of the hybrid cycle were 74.6% and 73.9%, respectively, for the configurations with and without anode recirculation. The corresponding efficiencies for the SOFC were 58.2% and 50.3%, respectively. Specific works for the SOFC and GT in the system without anode recirculation were 551 and 394 kJ kg_{air}^{-1}, respectively. Also, specific works for the SOFC and GT in the system with anode recirculation were 827 and 369 kJ kg_{air}^{-1}, respectively. Then, methane was replaced with the fuel that was a mixture of CH_4 with each of the following gases: H_2, CO_2, CO, and N_2, with different percentages. In the analysis, 5% of methane was replaced by other species at each step in the corresponding range for each case.

In Part I, the effects of fuel composition on the output power of the SOFC, GT, and the hybrid cycle were investigated. In order to fully understand the behaviors of the system, the effects of fuel composition on the mass flow rate and energy content of various flows throughout the cycle along with some other parameters were investigated.

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http://dx.doi.org/10.1016/j.joei.2014.02.003

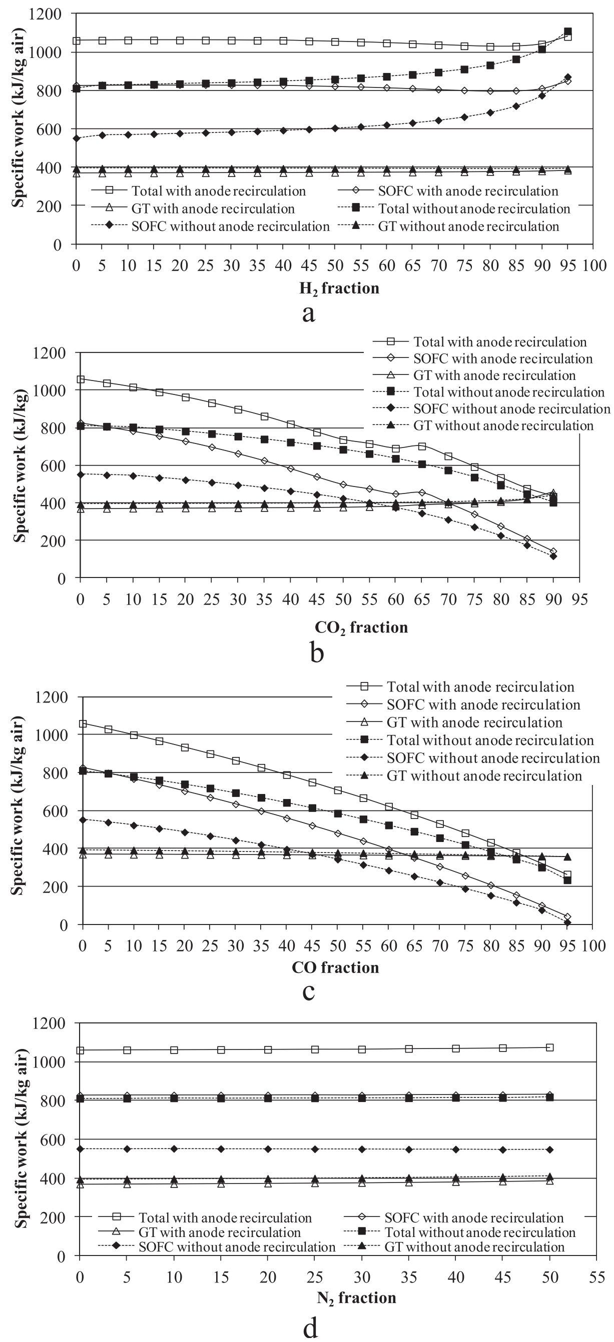

Fig. 1. GT, SOFC, and system specific works versus various components in the inlet fuel a) H_2 b) CO_2 c) CO d) N_2.

In this part of the presentation, the same approach will be used to study the influence of fuel composition on the specific work and efficiency of the SOFC, GT, and the cycle as whole.

2. Effects of fuel composition on specific work

Although output power is an important parameter in a power generation system, it does not indicate any information about the size of equipment and the system as a whole. Therefore, specific work is defined as the output power divided by the inlet air mass flow rate. The specific work can be considered as a representative of the system physical size.

Fig. 1a–d shows how specific works of the GT, SOFC, and system as a whole vary with respect to various components in the inlet fuel for two configurations.

To understand the trend in these graphs, both the output power (Fig. 2a–d in Part I) and air mass flow rate should be investigated. Fig. 2a–d shows the inlet air mass flow rate and air-to-fuel ratio versus various components in the inlet fuel for two configurations, with and without anode recirculation. In this model, the turbine inlet temperature (TIT) is kept constant by manipulating the air-to-fuel ratio. That means to