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Performance analysis of irreversible molten carbonate fuel cell – Braysson heat engine with ecological objective approach

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ABSTRACT

An irreversible hybrid molten carbonate fuel cell-Braysson heat engine is taken into account. Basic thermodynamics parameters including power output, efficiency and exergy destruction rate are considered. In addition ecological function and new criteria, which is based on ecological function, for heat engines called as modified ecological function is suggested. Optimum conditions for mentioned parameters above are determined. Numerical results are obtained and plotted. Finally, results are discussed.

1. Introduction

Novel technologies for renewable energy have been studied for last decades, because these technologies are the most promising solution for increasing energy demand and environmental issues. Fuel cells provide electricity and some of them produce high temperature waste heat that can be converted to useful work. They have flexible fuel choice and they are environmental friendly energy sources. They generate electricity by means of electrochemical reactions that hydrogen is main energy source of the system.

Recently, there have been researches to determine performance to irreversible fuel cells including solid oxide fuel cell (SOFC), molten carbonate fuel cell (MCFC), proton exchange membrane fuel cell (PEM), direct carbon fuel cell (DCFC) and phosphoric acid fuel cell (PAFC) [1–5]. Several studies have been performed about fuel cell-heat engine/refrigerator hybrid systems [6–24]. Fuel cell-refrigerator/heat pump applications have been studied in [7–10]. In these papers, PEM fuel cells and PACFs were chosen as top cycles and absorption refrigerators were used for refrigeration applications. MCFCs provide us a potential to utilize it with cogeneration and in hybrid systems, because of their high temperature waste heat. MCFC heat engine applications including Stirling, Braysson, gas turbine and thermionic generator as bottom cycles have been researched in Refs. [11–16]. In [17–19], fuel cell - thermoelectric heat engine usages were investigated and PEM, PAFC and DCFCs were utilized as top cycles. Performances of different type of heat engines hybrid systems application are studied in Ref. [20]. General heat engine - fuel cell hybrid systems were considered in [21,22] and solid oxide fuel cell hybrid system applications can be found in [23–26]. One of the heat engines that can be used as bottom system of MCFC is the Braysson cycle and it was proposed by Frost et al. [27]. Braysson cycle is the combination of Brayton and Ericsson heat engines. These heat engine may be an alternative for power generation from renewable energy sources. Some examples of researches about Braysson heat engine can be found in Refs. [27–32].

In this study, an irreversible MCFC - Braysson hybrid system is taken into account. Basic thermodynamics parameters like, power output, efficiency and exergy destruction rate are considered as well as ecological function proposed by Angulo-Brown [33] and improved by Yan [34]. In addition, a novel thermodynamic criterion, which is based on ecological function, called as modified ecological function for the heat engines is presented and applied to the considered system. Results are obtained numerically and discussed. Finally, ecological and modified ecological functions are compared with each other and recommendations are made.

2. Thermodynamics analysis

Considered system in this paper is shown in Figs. 1a and 1b, it consists of MCFC, which generates electricity and high temperature waste heat, and a Braysson cycle that uses waste heat produced in fuel cell. Anode potential (U_{an}), cathode potential (U_{cat}), ohm overpotential (U_{ohm}) and theoretical maximum potential (U_o) must be calculated to define power and efficiency obtained from MCFC. These potentials are shown as follows respectively [3]:

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0196-8904/

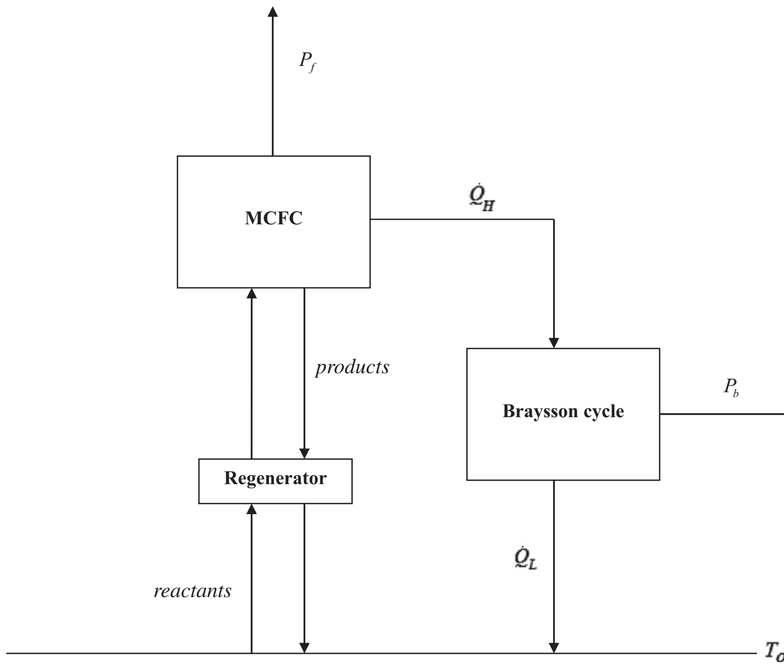

Fig. 1a. MCFC - Braysson hybrid heat engine.

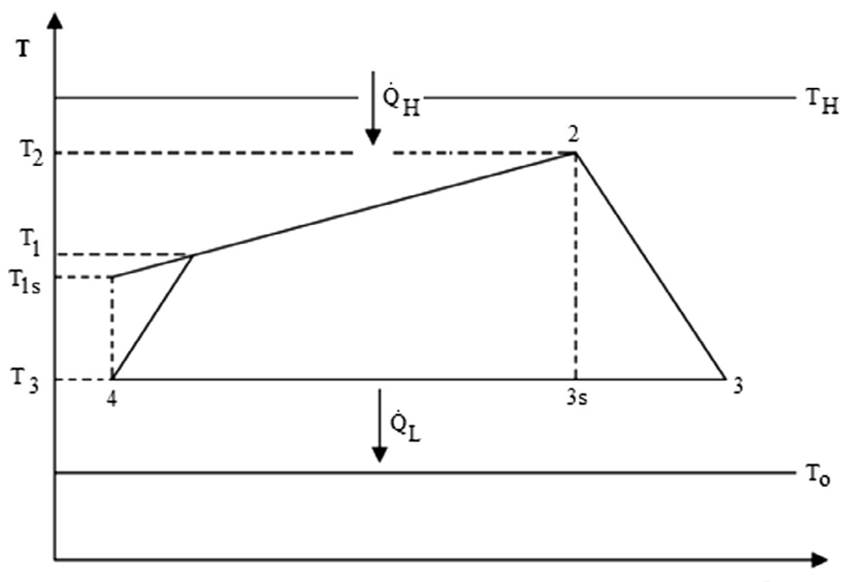

Fig. 1b. T-s diagram Braysson heat engine.

$$U_{an} = 2.27 \times 10^{-9} j e^{\left(\frac{E_{act,an}}{RT}\right)} P_{H_2,an}^{-0.42} P_{CO_2,an}^{-0.17} P_{H_2O,an}^{-1} \tag{1}$$

$$U_{cat} = 7.505 \times 10^{-10} j e^{\left(\frac{E_{act,cat}}{RT}\right)} P_{O_2,cat}^{-0.43} P_{CO_2,cat}^{-0.09} \tag{2}$$

$$U_{ohm} = 0.5x10^{-4} j e^{\left(3016\left(\frac{1}{T}-\frac{1}{923}\right)\right)} \tag{3}$$

$$U_o = E_o + \frac{RT}{n_e F} \ln\left(\frac{P_{H_2,an}(P_{O_2,cat})^{0.5} P_{CO_2,cat}}{P_{H_2,an} P_{CO_2,an}}\right) \tag{4}$$

where j is the current density, $P_{H_2,an}$ is partial pressure of hydrogen at the anode, $P_{CO_2,an}$ is the partial pressure of carbon dioxide at the anode, $P_{H_2O,an}$ is the partial pressure of water at the anode, $P_{O_2,cat}$ is the partial pressure of oxygen at the cathode, $P_{CO_2,cat}$ is the partial pressure of carbon dioxide at the cathode, R is the universal gas constant, T is the operating temperature of the MCFC, E_{act} is the activation energy, F is the Faraday constant, n_e is the number of electrons and E_o is the ideal standard potential.

$$E_o = \frac{-\Delta g^o}{n_e F} \tag{5}$$

Cell voltage is written by using Eqs. (1)–(5) [3]:

$$U_{cell} = (U_o - U_{an} - U_{cat} - U_{ohm}) \tag{6}$$

Power and efficiency of the fuel cell is written in Eqs. (7) and (8) [3]: