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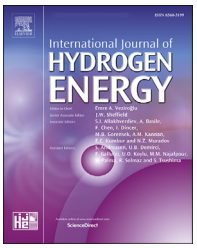

Thermodynamic analysis of a Proton Exchange Membrane fuel cell

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ABSTRACT

In this study, energy and exergy analyses of a 1 kW Horizon H-1000 XP Proton Exchange Membrane (PEM) Fuel Cell has been investigated. A testing apparatus has been established to analyze the system efficiencies based on the first and second laws of thermodynamics. In this mechanism pure hydrogen has been directly used as a fuel in compressed gas formation. Purity of hydrogen was above 99.99%. The system performance was investigated through experimental studies on energy and parametric studies on exergy by changing the operating pressure and operation temperature. The results showed that the energy efficiency of PEM fuel cell is 45.58% for experimental study and 41.27% for parametric study at full load. Also, 2.25% and 4.2% performance improvements were obtained by changing the operating temperature ratio (T/T_0) from 1 to 1.2 and operating pressure ratio (P/P_0) from 1 to 2, respectively.

Introduction

All over the world fossil fuels and fossil fuels-based energy systems have been using extremely high levels with growing world population and energy demands of the population. These fuels and systems have unique importance in every part of life such as transportation of goods and passengers, heating etc. But the most used field of fossil fuels is naturally in vehicles. Fossil fuels cause air pollution and damage the world. Recently, these negative impacts of fossil fuels have been seen more clearly than ever before. Also, fossil fuel resources diminish rapidly and soon or later will vanish. This situation and energy demands of the human will appear as a big problem for the future. That problem and the policies of the countries direct the researchers to study out new alternative energy source and fuels that emit less emissions to the environment. Sun, wind, geothermal, hydroelectric can be count as natural alternative energy sources. But none of these sources can be a direct alternative for the most critic field which is using in vehicles. In the middle of the 1800s fuel cell researches had been conducted. However, after the discovering of the internal combustion engines, the fuel cells fell behind of these engines which use fossil-based fuels. For the last 20 years, applications and the utilizations of the fuel cells have mostly been used instead of internal combustion engine due to decrease of fossil fuels and the negative impacts of these fuels to the environment such as ozone depletion, greenhouse gas effect, global warming etc. for providing power in portable and stationary application. The fuel cells are clean energy conversion devices which convert the chemical energy of hydrogen to the electricity with zero emission. There are several types of fuel cell which are conducted in the studies. Nevertheless, PEM fuel cells step forward with fast start-up, high efficiency, high power density, low operating

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temperature, easy and safe handling. When considered from this point of view many researchers have studied the performance of a PEM fuel cell and the parameters that affects the PEM fuel cell performance [1–5].

Benmouiza and Cheknane [6], Ozen et al. [7] and Eshef and Hamid [8] investigated the effects of operating temperature on performance of single cell fuel cell. Benmouiza and Cheknane [6] were tested the voltage changes that were applied to a single cell fuel cell like Taner [9]. Besides, Santarelli and Torchio [10], Yin et al. [11] and Kim et al. [12] studied the effect of operating pressure of PEM fuel cell. In PEM fuel cell, it was found out that the operating parameters such as operating pressure and temperature and also current density, relative humidity etc. had quite importance. When the effects of operating parameters realised, the studies about energy and exergy terms which are on the basis of thermodynamics first and second law gradually increased [13–17]. Miansari et al. [18] studied the effects of operating temperature and pressure on performance of PEM fuel cell and concluded that operating pressure and temperature could improve performance of the cell. Midilli et al. [19] parametrically investigated the effects of irreversibilities on the thermodynamic performance of PEM fuel cell based on thermodynamics at different operating conditions. It was found that higher current density and membrane thickness caused decrement in efficiency of exergy of PEM fuel cell, and exergy efficiency of PEM fuel cell raised with a increment of cell operation pressure and with a decrement of current density for the same membrane thickness. There are several types hybrid system in the literature which are the combination of PEM fuel cell and other various systems. One of them PEM fuel cell unit in solar-hydrogen system. Yilanci et al. [20] made an investigation about energy and exergy analysis of a 1.2 kW PEM fuel cell. PEM fuel cell fed by hydrogen which was produced from solar based production system. Another investigation is in a marine application. Leo et al. [21] investigated the mechanism which consists of a PEM fuel cell and hydrogen production system. Hydrogen was produced by reforming of methanol and used in PEM fuel cell. The possible integration of this system to the ships and submarines was analyzed. Lastly, the most promising hybrid systems are PEM fuel cell and cogeneration systems. PEM fuel cells are highly efficient systems and thanks to combination of cogeneration system it can become more efficient. Ahmadi and Ehyaei [22] studied exergy and design optimization of a 5 kW PEM fuel cell with cogeneration. The performance investigation showed that for the maximum efficiency and the temperature of fuel cell and voltage should be as high as possible.

Today most of vehicles or most of energy conversion units use fossil fuels in order to obtain energy or power. However, these vehicles and conversion units emit emissions which are harmful for population and nature. Especially, PEM fuel cells have zero emission using pure H_2 and the efficiency of these devices are higher. Although fuel cells are eco-friendly energy conversion devices, there is an important drawback which is cost. The aim of this study is to identify the best operating conditions for the PEM fuel cell in order to operate the fuel cell highly efficient to ignore this drawback. In this study energy and exergy analysis were carried out to by use of a 1 kW self-humidified PEM fuel cell. 1st and 2nd laws of thermodynamic efficiencies related with quantity and quality were determined and compared with each other for different operating temperature and operating pressure conditions.

Material and methods

First and second law of thermodynamics

Thermodynamics could be defined as the scientific study of the energy. Even though everyone has an idea in the aspect of energy, it is difficult task to make a completely precise definition for that term. The ability of causing changes can be thought as energy. These changes could be occurred by means of work and heat.

The first law of thermodynamics (FLT) also known as the conservation of energy principle indicates that there are two ways to change the energy of a closed system; which are energy transfer by heat change or by work [23].

The conservation principles are not always sufficient, but the second law of thermodynamics (SLT) combines the conservation of energy and mass principles together with property relations. The second law is also considered, including performance limits for thermodynamic cycles. This can also be defined as energy has quality as well as quantity [24].

Energy and exergy analysis

Energy is the basic term of thermodynamics and it is very important subject for engineering analysis. Thermodynamics studies let to be known of efficiency, behavior and performance characteristics of any system that is in interaction with heat and work. Thermodynamics analyses are generally based on energy conservation (FLT) and the calculations are made on the inlet and outlet quantities of energy and masses [25].

Exergy is the useful work potential that can be achieved by bringing a system into equilibrium with its surroundings. It is also called available energy or availability. Every system has a quantity of exergy, in the case of no equilibrium with its environment, and oppositely, in the case of the equilibrium with its environment it has zero exergy means it has no ability to do work with respect to its environment [26].

Energy efficiency can be deficient on the evaluating the performance of the system and how it is close to its ideal efficiency. Moreover, the energy analyses may not give the accurate results which are spoiled by the thermodynamic losses within the system and cause to deviate from ideality. The exergy analysis gives precise results considering those thermodynamic losses. The basic inefficiencies can be shown by the energy analysis results within the wrong parts of the system. This means a realistic efficiency definition is required. This can only be conducted by exergy efficiency since exergy analysis allows many of the limitations of energy analysis to get over. It is useful in identifying the magnitudes, locations, and causes of process inefficiencies thanks to the second law [27].

For the performing of the energy and exergy analysis a 1 kW Horizon H-1000 XP PEM fuel cell is used (Fig. 1.). The technical specifications of the PEM fuel cell are listed in Table 3.

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