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Editorial

Developments in Hydrogen Fuel Cells

Abdul Ghani Olabi [1,2,*] and Enas Taha Sayed [3]

1 Sustainable Energy & Power Systems Research Centre, RISE, University of Sharjah, Sharjah P.O. Box 27272, United Arab Emirates
2 Mechanical Engineering and Design, School of Engineering and Applied Science, Aston University, Aston Triangle, Birmingham B4 7ET, UK
3 Chemical Engineering Department, Minia University, Elminya 61519, Egypt
* Correspondence: aolabi@sharjah.ac.ae

Abstract: The rapid growth in fossil fuels has resulted in climate change that needs to be controlled in the near future. Several methods have been proposed to control climate change, including the development of efficient energy conversion devices. Fuel cells are environmentally friendly energy conversion devices that can be fuelled by green hydrogen, with only water as a by-product, or by using different biofuels such as biomass in wastewater, urea in wastewater, biogas from municipal and agricultural wastes, syngas from agriculture wastes, and waste carbon. This editorial discusses the fundamentals of the operation of the fuel cell, and their application in various sectors such as residential, transportation, and power generation.

Keywords: fuel cells; proton exchange membrane fuel cells (PEMFC); residential applications; transportation; power generation

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1. Introduction

The demand for alternative green energy technologies is becoming urgent in order to face the severe environmental impacts of conventional fuel fossil resources [1,2]. The fuel cell is an environmental energy conversion device which is suitable in a wide range of applications. Fuel cells have many advantages such as simplicity, wide operating temperature window, quick refuelling and start-up, and high energy density [3–5]. Generally, a fuel cell converts the chemical energy of fuel and oxidant into electricity, water, and heat. Commonly, a fuel cell incorporates two electrodes, an anode and a cathode, separated by an electrolyte membrane. The fuel is oxidized at the anode catalyst layer producing electrons and protons. The protons and electrons are conveyed to the cathode side via the electrolyte membrane and external circuit, respectively [6]. There are various types of fuel cells depending on operating temperature, the type of electrolyte membrane, the fuel used, or the application. The type of the electrolyte membrane and operating temperature decide the electrochemical reactions that occurred in the fuel cell. Based on the electrolyte membrane, there are five types of fuel cells, including alkaline fuel cells [7], solid oxide fuel cells [8,9], proton exchange membrane fuel cells [10], molten carbonate fuel cells [11], and phosphoric acid fuel cells [12].

2. Discussion

Background: Proton exchange membrane fuel cells (PEMFCs) operate at a low-temperature range (<80 °C) and are evolved mostly for portable, stationary, and transportation-based applications. Hydrogen is a renewable energy source that is ideal for our future zero-carbon demands for combined heat and power sources [13,14]. Normally, hydrogen is fuel or anode reactant, and oxygen is oxidant or cathode reactant, whereby hydrogen is oxidized at the anode producing electrons and protons. The protons and electrons transfer to the cathode side through the electrolyte membrane and external circuit, respectively, where they react with oxygen from the air to form water. It is a green and clean approach as the only by-product is water, as seen in Figure 1.

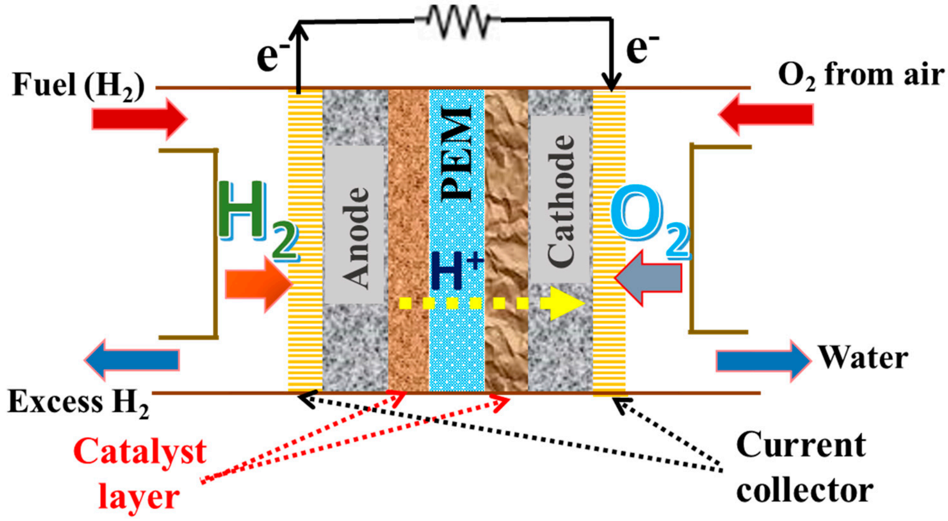

Figure 1. Schematic of Hydrogen Fuel Cell.

Anode reaction: $H_2 \rightarrow 2H^+ + 2e^-$
Cathode reaction: $2H^+ + \frac{1}{2}O_2 + 2e^- \rightarrow H_2O$
Overall reaction: $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$

2.1. Applications of PEMFC

It is imperative to take steps to implement the energy transition and reach the Paris Agreement's targets for reducing greenhouse gas emissions. PEMFCs can be utilized in various applications, such as residential, portable, and transportation-based applications, and in power generation.

2.2. Residential Application

It is expected that by the year 2050, more than two-thirds of the world's population will reside in urban areas, which will account for almost two-thirds of the world's primary energy demand and more than 70% of greenhouse gas emissions [15]. As a result, achieving several goals is necessary for the energy transition, aiming to produce 100% renewable energy by 2050 to create carbon-neutral communities [16]. Cities must put in place mechanisms to adapt to climate change and lessen its effects. In order to increase the energy efficiency of the residential sector of European Mediterranean cities, several energy supply systems were compared employing fuel cells that are fed from the natural gas network [17]. Eight distinct possibilities were created in total, each differing in terms of the fuel cell distribution, cogeneration system power, and mode of operation. The benefits and drawbacks of each arrangement were determined through the comparison of the alternatives. PEMFC is also successfully used for combined heat and power purposes in residential applications [18]. In general, fuel cells are used for various purposes in residential applications [19].

2.3. Transportation Applications

A significant amount of greenhouse gases is emitted from the transportation sector; therefore, the application of electric vehicles can save the environment [20–24]. Compared to battery-powered electric vehicles, fuel cell-based electric vehicles are more attractive due to the ease of charging and the long lifetime. The safety of hydrogen fuel cells in electric vehicles included the diffusion and oxidation behaviour of hydrogen fuel [25]. The risk of a hydrogen leak or combustion of fuel cells in electric vehicles is manageable as long as proper precautions are followed. The aspects of hydrogen fuel cells in the transportation sector have been discussed previously [26]. It was revealed that the energy source utilized to produce hydrogen has a significant impact on how well the fuel cell electric vehicles work. Renewable energy sources have a positive effect on the future of fuel cell-based vehicles [26]. In general, there is a big demand for the commercialization of fuel cell-based vehicles as the best choice for the electric vehicles sector [27,28].

2.4. Power Generation

Unlike heat engines based on combustion, which need a four-step energy conversion process (chemical–thermal–mechanical–electrical energy), fuel cells offer a unique one-step energy conversion process (chemical—electrical energy). PEMFC fuelled with hydrogen gas was used as a grid-connected electrical generator to generate power [29]. The rate of fuel delivery and air supply pressure had a significant impact on the PEMFC's performance. The PEMFC could successfully supply electrical power to the grid, according to simulation data, and it operated effectively under specific air and fuel pressures [29]. Due to the high efficiency of solid oxide fuel cells and high power capabilities, several studies investigated the role of SOFC in power plants. All of the results demonstrated the potential of the high-temperature fuel cells in improving the overall performance of the power plants [30–32].

2.5. Portable Applications

The rapid growth in the technology has resulted in increasing the energy demand of portable devices. Fuel cells especially direct alcoholic fuel cells [33–37] and hydrogen fuel cells have a great potential to replace secondary batteries in portable devices. Several studies have been carried out concluding the potential of fuel cells in portable applications [38–40].

3. Conclusions

Fuel cells are environmentally friendly energy conversion devices that have high efficiency compared to conventional energy conversion devices. Fuel cells are promising devices for various applications such as residential, transportation-based, and power plant-based applications. A lot of work is being carried out to overcome the challenges of employing fuel cells, such as the high cost of the catalyst and high degradation rate, before they are ready for commercial applications.

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