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Developments in fuel cell technologies in the transport sector

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ABSTRACT

The demand for clean power source which can be used to run the various types of vehicles on the road is increasing on a daily basis due to the fact that high emissions released from internal combustion engine play a significant role in air pollution and climate change. Fuel cell devices, particularly Proton Exchange Membrane (PEM) type, are strong candidates to replace the internal combustion engines in the transport industry.

The PEMFC technology still has many challenges including high cost, low durability and hydrogen storage problems which limit the wide-world commercialization of this technology. In this paper, the fuel cell cost, durability and performances challenges which are associated with using of fuel cell technology for transport applications are detailed and reviewed. Recent developments that deal with the proposed challenges are reported. Furthermore, problems of hydrogen infrastructure and hydrogen storage in the fuel cell vehicle are discussed.

Introduction

Due to the growing global concerns on the depletion of petroleum based energy resources, and the environmental pollution and climate change caused by the burning of fossil fuels, renewable energy systems are suggested to play an increasing role in the transport sector year by year. Fuel cells have received an increased attention in recent years owing to their high efficiencies and low emissions. A fuel cell is an electro-chemical power source which converts chemical energy in the form of fuel directly into electrical energy. However, unlike other electro-chemical power sources such as batteries which store their reactants within a cell, the reactants are fed continuously to it from external stores. Also, the electrodes in a fuel cell are not consumed as in a battery, irreversibly in a primary cell and reversibly in a secondary cell, and do not take part in the reaction. Fuel cells are already used to generate electricity for other applications, including in spacecraft and in stationary uses, such as emergency power generators [1,2].

The transport sector is one of the major contributors of hazardous emissions to the environment in recent years. Many researches have been working on energy consumption

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analysis and fuel types were compared with each other including alternative fuel systems which are leading to more development in fuel technology [3]. This development can in turn reduce the oil consumption for transport [4]. There are two approaches in dealing with vehicle emissions problem. The first approach is the fuel type which can be addressed by either enhancing the quality of conventional fuel or by using alternative fuel systems. The second approach is upgrading the engine technology which includes in-use vehicles emission and the new vehicles emission standards. In parallel with these developments; the transport sector has a good effect on a viable eco-driving strategy and reduction of excess fuel consumption [5,6]. Achour et al. [7] developed a representative tool for the local authority in identifying the air quality caused by traffic emissions, in fact, many of these researches have to be applied in the developing countries as the transport sector is facing problems in oil supply [8].

Although the concept of a fuel cell was developed in England in the 1800s by Sir William Grove, the first workable fuels cells were not produced until much later, in the 1950s. During this time, interest in fuel cells increased, as NASA began searching for ways to generate power for space flights [9]. Several types of fuel cells are classified according to the electrolyte employed. The most popular type of fuel cells is the Proton exchange membrane fuel cells, also known as polymer electrolyte membrane (PEM) fuel cells (PEMFC). PEMFC use a solid polymer as an electrolyte and porous carbon electrodes usually containing a platinum or platinum alloy catalyst. They are typically fuelled with pure hydrogen supplied from storage tanks or reformers. Hydrogen fuel is processed at the anode where electrons are separated from protons on the surface of a platinum-based catalyst. The protons pass through the membrane to the cathode side of the cell while the electrons travel in an external circuit, generating the electrical output of the cell. On the cathode side, another precious metal electrode combines the protons and electrons with oxygen to produce water, which is expelled as the only waste product; oxygen can be provided in a purified form, or extracted at the electrode directly from the air.

PEM fuel cells are used primarily for transportation applications and some other stationary applications. Due to their fast start up time and favourable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles, such as cars and buses. Transport consumes about one quarter of the world total energy. In the case of internal combustion engines, a large part of the fuel energy is emitted as heat due to friction loss and exhaust gas [2]. In 2012, shipment of fuel cell systems increased appreciably almost double that of the previous year to reach a total of 45,700 units, of which a considerable progress in the transport market has been achieved. The transport industry also saw massive progress as more fuel cell electric vehicles (FCEV) were manufactured. Hyundai for instance introduced the I X 35 FCEV, while Toyota during that period also generated the Mirai 2015 [10–12]. In this paper, an overview of the proton exchange membrane fuel cell (PEMFC) was given. The application of the PEMFC in the transport market was displayed. The recent challenges and developments that are related to the cost, durability and performance, the hydrogen refuelling infrastructure and the hydrogen storage in the vehicles are discussed.

The proton exchange fuel cell components

The main components of a single PEMFC power source are, according to [13–20]:

- ➢ Membrane Electrode Assembly (MEA) which consists of proton conducting electrolyte, cathode/anode porous electrodes, anodic/cathodic catalyst layers and gas diffusion layer. MEA is considered as the "heart" of the PEM fuel cell, because it is typically inserted by two flow field plates that are often mirrored to make a bipolar plate when cells are stacked in series for greater voltages.
- ➢ Anode/cathode current collectors with the reactant flow fields (also called bipolar plates). They act as electron conductors and they are in contact with the anode/cathode gas diffusers. The Bipolar Plates have the following functions to perform: to distribute the fuel and oxidant within the cell, to facilitate water management within the cell, to separate individual cells in the stack, to carry current away from the cell, and to facilitate heat management. For general transport applications, the graphite-based composite materials are best suited for Bipolar Plates as they offer excellent chemical resistance and good thermal and electrical conductivity combined with a lower density than metal plates. If strength is an additional criterion than only metal plates are a viable possibility.
- ➢ Auxiliaries that are needed for thermal and water management and for compression and transportation of gases (e.g. Anode/Cathode gas channel that supply the fuel cell with reactants).

The main components of the PEM fuel cell stack are displayed in (Fig. 1). It has been noticed that the subcomponents of the MEA are very important to study from an economical point of view, especially the electrodes, because they represent the main contributors to the overall PEMFC stack cost. the current state-of-the-art of materials for fuel cells presents

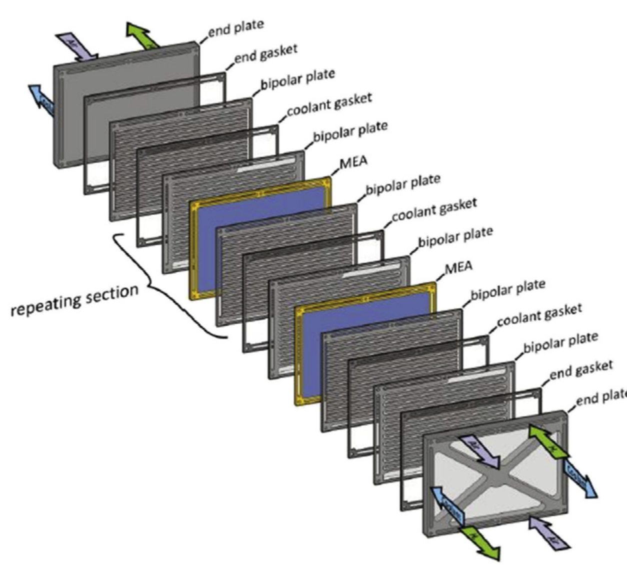

Fig. 1 – Main components of PEMFC stack [16].

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