

From the cell to the stack. A chronological walk through the techniques to manufacture the PEFCs core

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ABSTRACT

In the recent decades, researchers have been focussing more and more on renewable energy because of the known climate crisis that will occur in the near future. One possible solution is the use of fuel cells that generate clean energy. Regarding fuel cell technologies, polymer electrolyte fuel cells (PEFCs) are widely used for portable, stationary or automotive applications as well as backup systems for emergency situations. To build a full PEFC stack, a single cell is used, which is then stacked with more similar cells (the number of cells depends on the electrical power required) and are then integrated into the final product. In a cell, there are two parts that deserve special attention: membrane electrode assembly (MEA) and bipolar plates (BPs). This paper is dedicated to carry out detailed review of processes involved in these two parts, describing the catalyst deposition techniques and BPs manufacturing methods. Finally, a discussion of how to assemble the cells to build a stack of suitable power is included. The review shows the different techniques in chronological order to be able to understand where the fuel cells technology started, and all of the new developments that have been made over time. Each of the techniques has been studied separately in order to provide a comprehensive analysis of the various possible methods found in the scientific literature. After a description and analysis of each technique, a comparative evaluation has been carried out to highlight the most important characteristics of each technique. The review also shows that for fuel cells manufacturing technology to achieve good rates of accuracy, mass production and homogeneity, research should be aimed at achieving less restrictive manufacturing and environmental conditions, and equipment is required with lower costs.

1. Introduction

In the last decade, research is focused on renewable energy, especially owing to the concerns of society about the environmental problems [1]. An attempt is being made to replace conventional energy sources with renewable energy sources (RES) to avoid damaging the environment [2]. Lately, RES (which include biomass, hydropower, geothermal, solar, wind and marine energy) are receiving more attention and currently provide up to 14% of the total world energy demand [3]. The main drawbacks of these energy sources are the energy cost and the low production of energy due to the specific environmental milieus for each geographic location [4] and not all types of RES are available in all locations [5]. Therefore, fuel cells technology might solve some of the drawbacks because their electrical production does not depend on the environmental conditions or location and the only requirement is to have available hydrogen.

Nowadays, with respect to fuel cells, many technologies are being

developed for different applications. For example, Alkaline Fuel Cell (AFC) technology is only used for space applications as a result of the electrolyte poisoning with CO₂ [6]. The phosphoric acid fuel cell (PAFC) technology is suitable to the stationary cogeneration market [6,7]. Its disadvantages are the high operating temperature and the need for long warm-up periods [8]. The solid oxide fuel cell (SOFC) and molten carbonate fuel cell (MCFC) technologies [9] are suitable to large-scale MW grid applications in spite of their technical inconveniences such as: the electrolyte control, a limited lifespan of the cell due to corrosion, high sensibility to sulphur, electrolyte losses and high costs [10]. The direct methanol fuel cell (DMFC) technology is being considered for portable power generators [11], although one of the major concern is to improve the catalyst performance [12]. Lastly, the polymer electrolyte fuel cell (PEFC) technology is probably receiving the most attention. This is due to its good properties such as high power density, low operating temperature, zero emissions, easy operation, simplified design and relatively quick start-up and shut-down

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Nomenclature

AC-PEFC	air-cooled polymer electrolyte fuel cell
AFC	alkaline fuel cell
BoP	balance of plant
BP	bipolar plate
CCM	catalyst coated membrane
CCS	catalyst coated substrate
CL	catalyst layer
CNC	computer numerical control
DMFC	direct methanol fuel cell
EDM	electrical discharge machining
GDE	gas diffusion electrode
GDL	gas diffusion layer
IBAD	ion beam assisted deposition

MEA	membrane electrode assembly
MCFC	molten carbonate fuel cell
MW	megawatts
PAFC	phosphoric acid fuel cell
PE	polymer electrolyte
PEFC	polymer electrolyte fuel cell
PEM	polymer electrolyte membrane
Pd	palladium
Pt	platinum
PVD	physical vapour deposition
R&D	research and development
RES	renewable energy sources
SOFC	solid oxide fuel cell
TPB	three-phase boundary

functionality [13,14]. PEFCs are suitable to a wide range of applications including portable, stationary and automotive power delivery [15] as well as in backup systems for emergency situations (e.g. earthquakes, terrorist attacks).

A typical cell of a PEFC system is formed by a sandwiched structure that consists of six main parts (Fig. 1), from the outermost to the innermost: (1) end plate (x2) for providing support to the cells assembly; (2) current collector (x2) for current collection and delivery to load [16]; (3) bipolar plate (BP) (x2) for separating the individual cells, delivering the reactant gases, providing an electrical connection, removing the water by-product, dissipating the reaction heat and carrying the clamping force [17,18]; (4) gasket for avoiding leaks of reaction gases; (5) gas diffusion layer (GDL) (x2) for providing a barrier to liquid water, keeping the catalyst layer (CL) partially hydrated and distributing the gases properly [19]; and finally (6) membrane electrode assembly (MEA) for conducting positive hydrogen ions (protons), but no electrons [10,20,21].

From a single cell with similar structure to that shown in Fig. 1, a stack is built by assembling a determined number of BPs and MEAs, depending on the electrical power required. Regarding the manufacturing of the stack, BPs are the responsible for the 40% of the total stack cost [22] and for around the 80% of the stack weight [23–26]. In the same way, in each cell the MEA requires another 40% of the total stack cost, which is divided into two parts: 96% for the material and 4% for the fabrication process [22]. Therefore, in a PEFC system, the stack is undoubtedly the most expensive, heaviest and largest component. Inside the stack, the process used for the MEAs manufacturing and the technique used for the BP implementation determines the stack's weight, volume and cost (Fig. 2).

The aim of this paper is to carry out a detailed chronological review of manufacturing processes involved in above-cited these two key parts (MEA and BP). Current literature hardly includes summaries of the manufacturing techniques related to PEFCs; and there are hardly any papers that do so in chronological order to showcase the path development these systems have undertaken. Likewise, the study presented in [14] analyses the existing PEFCs manufacturing techniques but it only provides a review of alternatives for MEAs and BPs within the scope of vehicle propulsion. This work leaves out manufacturing techniques for other common applications such as micro-power, stationary or back-up power. In contrast, the review carried out in [27] focuses on a variety of strategies to develop advanced GDLs justifying their role in an effective management of water in PEFCs. Nevertheless, according to Fig. 2a and b, regarding cost and weight, GDL is the least significant part in the PEFC structure. However, a key part in a PEFC structure is the BPs as a whole. In this sense, [24] gives a comprehensive overview of the most common designs for the flow fields, but does not include a review on how to manufacture the full BPs.

With the aim of complementing and completing the reviews done in

these cited works, this paper describes the catalyst deposition techniques and BPs manufacturing methods; and it analyses the current and future direction of the R&D activities for reducing the weight and volume of the whole stack. The review is based on the order in which the different techniques have appeared. Each of the techniques has been independently studied to provide a more comprehensive analysis of the alternatives found in the literature. After performing a description and analysis of each technique, a comparative evaluation has been developed to highlight the most important features of each one. The review also shows that several features associated with the MEA or BPs such as precision, mass production and homogeneity require a deeper research focused on guaranteeing less restrictive environmental and operating conditions and cheaper equipment. The review of the state of the art shows the advantages and disadvantages of the different methods involved in the manufacturing process, and it also shows how disadvantages of older manufacturing techniques became challenges for new methods resulting in better commercial products for the market.

Contrary to what happens in most of the review papers that can be found in the scientific literature, the aim of this work is not to describe in depth each of the actual methods that can be used for catalyst deposition, BPs manufacturing or stack assembly. The goal of this work is to give an overview about the different techniques classified according to their nature and what the user has at his disposal to design and manufacture a fuel cell right now.

The rest of this paper is written as follows: Section 2 focuses on the different catalyst deposition methods in a MEA. First deposition techniques (manual techniques like Spraying) lead to others based on pattern transfer like Screen Printing or Decal Transfer. Thanks to the

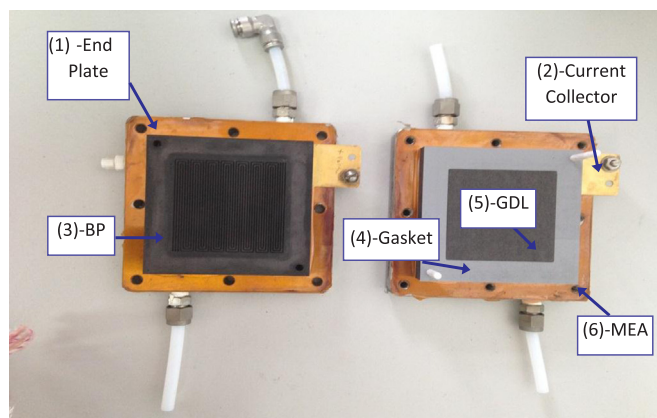


Fig. 1. Single fuel cell with a 50 cm² active area from Teledyne™ with three-channel parallel serpentine flow fields (channels of 0.76 mm wide and deep). Graphite bipolar plate's layout is cross-flow with horizontal channels in both anode and cathode.

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