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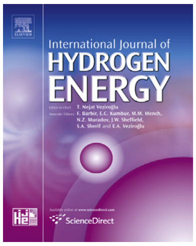

Optimal design and operational tests of a high-temperature PEM fuel cell for a combined heat and power unit

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ABSTRACT

Development of new materials for polymer electrolyte membranes has allowed increasing the operational temperature of PEM fuel cell stacks above 120 °C. The present paper summarizes the main results obtained in a research devoted to the design, fabrication and operational tests performed on a high-temperature PEMFC prototype. A 5-cell stack has been assembled with commercial Celtec P-1000 high-temperature MEAs from BASF Fuel Cells, but the rest of elements and processes have been developed at LIFTEC research facilities. The stack includes different novelties, such as the way in which reactant gases are supplied to the flowfield, the design of the flowfield geometry for both anode and cathode plates, the concept of block that eases the assembling and maintenance processes, and the heating strategy for a very fast start-up. The different procedures comprising the assembly, closing and conditioning stages are also widely described and discussed. Results obtained in the preliminary operational tests performed are very promising, and it is expected that the 30-cells HT-PEMFC stack will deliver an electric power 2.3 times larger than the one initially predicted.

1. Introduction

Nowadays, production of energy worldwide is mainly achieved by combustion of fossil fuels. Depletion of fossil fuel resources and pollution of the environment by the emission of solid particles and greenhouse gases have caused an increasing interest in the development of high efficiency energy generation devices [1–5]. This matter is particularly important in countries like Spain where lack of primary sources (mainly oil and natural gas), social rejection to nuclear power plants, and saturation of hydroelectric plants have led to a strong dependence on foreign Countries.

A well known highly efficient technology to generate electricity and thermal energy from a single fuel source is cogeneration, also known as CHP (combined heat and power). This approach can also be used in a decentralized way, improving energy efficiency, security in energy supply, and reduction of CO_2 emissions. The EU and National

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Governments encourage the use of micro-combined heat and power systems (μ-CHP), in order to meet international and domestic targets on carbon emissions. For example, it is expected that by 2050 μ-CHP systems could provide 30–40% of the UK electricity needs [6]. To achieve this goal, the UK Government has lowered VAT from 17.5% to 5% for households that install μ-CHP systems, and has increased the planned reduction of carbon emissions for households up to 60% by 2050. In the same way, the Dutch Government is promoting similar initiatives and made public funding available to companies developing mass-market CHP systems [7]. μ-CHPs are especially interesting for small family houses (SFH) and medium family houses (MFH), small buildings and small and medium scale enterprises (SME) due to the very low noise and vibration levels. As both electricity and thermal energy demands fluctuate seasonally and hourly in residential buildings, it is necessary to take into account operational strategies for the variations in load demands. Then, it is necessary to develop a rational method of determining the size of the systems, as well as the operational strategies throughout the year [8].

As the minimum required temperature in buildings may vary between 40 °C and 80 °C, an output temperature close to 100 °C is a convenient value for a μ-CHP system. In this context, fuel cells based on proton-exchange membranes (PEMFC) have many attractive features, such as their high power density, rapid start-up, and high efficiency, which make them a promising clean energy technology [9]. Recent progress in this type of PEMFCs has been focused on the development of devices that operate above 120 °C, which are usually called high-temperature PEM fuel cells (HT-PEMFC). The operation of proton-exchange membrane fuel cells at high-temperature provides several advantages over traditional low-temperature ones. On the one hand, the electrochemical kinetics for both anode and cathode reactions are enhanced enabling a potential reduction in the amount of noble metal catalyst used and an increase in the CO tolerance that allows the use of lower quality reformed hydrogen. At the same time, water management is simplified because only water in vapor phase has to be considered, preventing cells from flooding and simplifying the flowfield design. Finally, under these operating conditions, HT-PEMFCs are very simple and reliable devices because complicated humidification subsystems can be avoided, and cooling systems are drastically simplified due to the increase in temperature gradient between fuel cell stack and coolant.

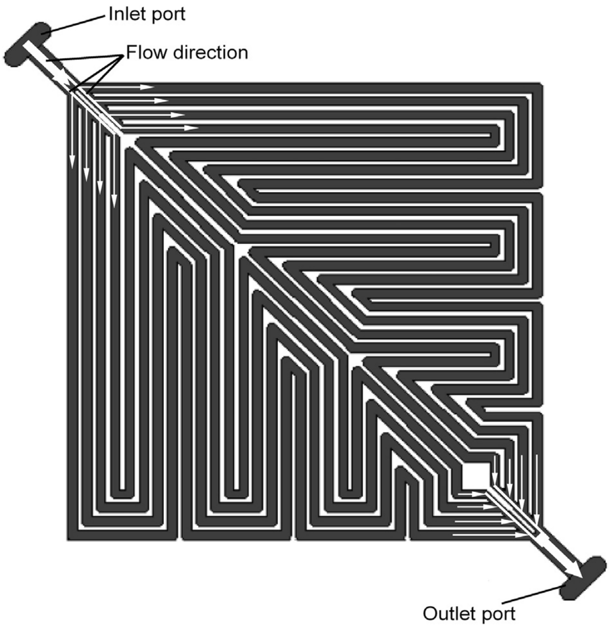

Fig. 1 – Circulation of the reactant gases in the "herringbone-type" flowfield geometry.

This work is focused on the design, fabrication, and operational test of a HT-PEMFC stack that will be used as a CHP-device for residential applications. The electric power is restricted to 1–3 kW that corresponds to the usual load for houses or small residential units. Although commercial MEAs are used, the stack includes several innovations, in particular the way in which reactant gases are supplied to the flowfield, the design of the flowfield geometry for both anode and cathode plates, the concept of blocks that eases the assembling and maintenance processes, and the heating strategy for a fast start-up.

2. HT-PEMFC stack design and systems

2.1. *Monopolar plates. Flowfield geometry for reactant gases*

It is evident that the dimensions of the flowfield geometry, and by extension those of the bipolar plates, are mainly influenced by the size of the membrane electrode assembly (MEA) to be used. For the present research, commercial Celtec®-P 1000 MEAs supplied by BASF Fuel Cells with a standard rectangular active area of 605 cm^2 have been selected. Celtec-P membrane consists of concentrated phosphoric acid associated in a polibenzimidazole (PBI) immobile gel phase. The operating temperature ranges from 120 °C to 180 °C, and no humidification for reactant gases is needed. The phosphoric acid is strongly associated to the PBI membrane matrix and this retains the acid in place, reducing the acid vapor pressure, and its evaporation. Platinum is used as catalyst in anode sides, and a special alloy is suited for the cathode electrodes. These MEAs have a very long-term stability, as well as a high CO tolerance, that makes them suitable for a vast range of practical applications. It should be noted that this type of MEA is highly hygroscopic. So, if the MEA is exposed to humid air at room temperature, water is absorbed and the diluted phosphoric acid may tend to partially wash out and to migrate towards the plate channels. In the same way, contact to liquid water must be avoided, because it would slowly leach out the electrolyte [10].

Even when the operational characteristics of HT-PEMFCs allow the use of very simple bipolar plates (BP) flowfield geometries, a careful design of this element has been performed using Fluid Mechanics equations [11–13]. A "herringbone-type" geometry has been selected to cover the whole flowfield area [14]. A feature of this geometry, as depicted in Fig. 1, is that the total gas flow at the inlet port is divided, one half circulating downward to the lower-left corner, and the other