Applied Energy xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Theory and practice of flow field designs for fuel cell scaling-up: A critical review ☆

Junye Wang *

Faculty of Science and Technology, Athabasca University, 1 University Drive, Athabasca, AB T9S 3A3, Canada

HIGHLIGHTS

- Revisit in flow distribution theories in fuel cells.
- Analysis of main issues and challenges in concepts and criteria of flow field designs.
- Uneven flow distribution as a root cause of low durability and reliability after scaling-up.
- Characteristic parameters for assessment of uneven flow distribution.
- Measures to tackle issues of durability and reliability using flow field designs.

ARTICLE INFO

Article history:
Received 21 September 2014
Received in revised form 7 January 2015
Accepted 9 January 2015
Available online xxxx

Keywords:
Flow distribution
Flow field design
Flow field theory
Water management
Durability
Reliability

ABSTRACT

It is a major challenge to transform a laboratory scale production of fuel cells to an industrial scale in terms of throughput, operating lifetime, cost, reliability and efficiency. In spite of a number of efforts, the durability, reliability and cost of fuel cells still remain major barriers to scaling-up and commercialization. Unless these challenges are fully understood there is little chance of overcoming them. In fact, though much fundamental research has been performed, there is still no clear understanding of both the theoretical solution and technical measures needed to solve the durability and performance degradation of fuel cells in the scaling-up process. In this critical review, we will revisit advances in theory of flow field designs. Then, we will analyze main issues and challenges in concepts and criteria of flow field designs and development of theoretical models. We will focus on uneven flow distribution as a root cause of low durability and reliability and performance degradation and why flow field designs are a strategic solution to integrated performance, flow conditions, structure and electrochemical processes. Finally, we will discuss criteria and measures to tackle uneven flow distribution as well as critical durability and performance degradation in the scaling-up of fuel cells.

Contents

☆ This paper is included in the Special Issue of Clean Transport edited by Prof. Anthony Roskilly, Dr. Roberto Palacin and Prof. Yan.

* Tel.: +1 7803944883.
E-mail address: junyew@athabascau.ca

http://dx.doi.org/10.1016/j.apenergy.2015.01.032
0306-2619/

Please cite this article in press as: Wang J. Theory and practice of flow field designs for fuel cell scaling-up: A critical review. Appl Energy (2015), http://dx.doi.org/10.1016/j.apenergy.2015.01.032

1. Introduction

Fuel cells are a low carbon technology because of their highly efficient and clean operation. As an engine, fuel cells have the potential to replace internal-combustion (IC) engines in vehicles and power generators in stationary and portable power applications. Therefore, as energy-efficient, environment-friendly, and fuel-flexible engines, fuel cells have many potential large market niches, such as combined heat and power (CHP), backup power and batteries, off-grid power, unmanned aerial vehicles (UAV), submarines, vehicle fuel cells (VFC) and material handling. Fuel cells can be classified, according to the nature of the electrolyte they use: as alkaline fuel cell (AFC), direct methanol fuel cell (DMFC), proton exchange membrane fuel cell (PEMFC), direct ethanol fuel cell (DEFC), molten carbonate fuel cell (MCFC), phosphoric acid fuel cell (PAFC), and solid oxide fuel cell (SOFC). Each type of fuel cell requires particular materials and fuels and has both advantages and disadvantages for specific applications. Despite many different types, fuel cells all consist of an anode, a cathode and an electrolyte that allows charges to move between the two sides of the fuel cell (Fig. 1). For the automotive industry the PEMFC have been extensively adopted because of their high-energy density, low operating temperatures, quick start-up and zero emissions.

Scientific research on fuel cell technologies in the laboratory has advanced at an amazing pace [1–3]. However, most of efforts have been on single cells or their components at the laboratory scale, such as catalyst layer (CL) [4–9], membrane electrolyte assembly (MEA) [6,10], gas flow channel structure [10–14], gas diffusion layer (GDL) and micro-porous layer (MPL), as well as electrode materials [6,15,16] and bipolar plates (BP) [17–24]. A number of alternatives to materials and catalyst, together with improvements in cell design and manufacturing, have further increased power density, reliability and durability, which are essential if the fuel cell is to compete with the conventional engines, such as IC engine, while reducing manufacturing costs. As a result, the power density of a SOFC has reached over 3.0 kW/m^2 at 6.0 V [25], a DEFC over 240 mW/m^2 at 1.6 V [26] and a PEM Fuel Cell (PEMFC) over 1.78 mW/cm^2 at 60 °C [27].

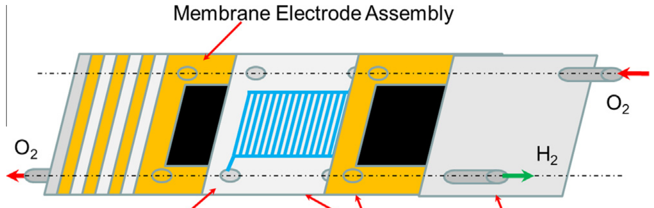

Fig. 1. Schematic of fuel cell stack [50].

Fuel cells are in a variety of sizes according to different requirements. An individual fuel cell produces relatively small electrical potentials, about 0.7 volts, which is not sufficient to power most industrial devices. So it is necessary to scale-up fuel cells for use in such devices. Hence, individual fuel cells are combined in series or parallel into a fuel cell stack to increase the voltage and power output. The scaling-up of fuel cells is usually performed after the single cell has successfully met its targets of durability and reliability, including all the components in the cell, such as membrane, GDL, CL, BP and electrodes. A typical fuel cell stack may consist of tens or hundreds of fuel cells. This type of scaling-up technology, using repeated units, is designed on a basic assumption that a successful unit performance can be repeated by all other units in the assembly or a successful cell performance can be repeated by all other cells in the stack if these cells are made of the same materials, catalyst and structures, and operate under the same operational conditions.

The power output of a stack is ideally a linear sum of the power output of all the individual cells placed in series or parallel in the stack, and its durability and lifetime should be that of the worst cell of its all corresponding cells in the stack. However, these ideal targets have not yet been achieved. The question of how to bring these technologies out of the laboratory and engineer practical systems for power production at industrial scales are particularly challenging and exciting [28–32]. Critical areas being addressed by DOE's Fuel Cell Technologies Office (FCTO) [31] include low durability and high cost, advanced manufacturing, improvements in hydrogen storage and production technologies, and mechanisms to achieve cost-effective hydrogen distribution and dispensing infrastructure. Despite several successful pilot projects around the world, to date none have proven to be cost-effective, durable, reliable and efficient enough to widely replace the traditional methods of generating power, such coal-fired, IC engine, gas turbine, hydroelectric, or even nuclear power plants except for some specific applications [32]. Major technical barriers of fuel cells are not only durability but also reliability. The reliability may be more important than durability for acceptance by end-users but receives a little attention. Reliability is the likelihood that a fuel cell stack will not fail without maintenance, repair and overhaul within a specific time period [30]. Therefore, the durability, reliability and cost of fuel cell systems after scaling-up remain the most critical issues before fuel cells can achieve a reasonable penetration into the portable, stationary, and transportation energy production markets [28–30,33,34].

The objective of this paper is to review advances in flow field theories and designs of fuel cells, and analyze main issues and challenges in concepts and criteria of flow field designs and in the development of theoretical models. We focus on why uneven flow distribution is a root cause of low durability and reliability at the industrial scale and why flow field designs are a strategic solution to integrated performance, flow conditions, structure and

Please cite this article in press as: Wang J. Theory and practice of flow field designs for fuel cell scaling-up: A critical review. Appl Energy (2015), http://dx.doi.org/10.1016/j.apenergy.2015.01.032