Thermal Science and Engineering Progress 8 (2018) 118–129

Contents lists available at ScienceDirect

Thermal Science and Engineering Progress

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

Effect of flow field design and channel/header ratio on velocity distribution: An experimental approach

Hayder A. Dhahad*, Ekhlas M. Alfayydh, Karrar Haleem Fahim

Mechanical Engineering Department, University of Technology, Baghdad, Iraq

ARTICLE INFO

Keywords:
Plates design
Area ratio
Fuel cells
Flow distribution uniformity
Geometry effect
Pressure loss

ABSTRACT

In this paper, an investigation was carried out to observe the effect of flow field design on flow distribution uniformity and its effect on a fuel cell performance. The research followed two methodologies; the first examined the effect of several flow field plate designs (Single Serpentine, parallel Z, 2Z, U, and 2U) on distribution uniformity of flow velocity. The second methodology involved studying the effect of header/channel area ratio on flow velocity distribution in "Parallel Z and U- type" flow fields in an attempt to obtain a more uniform distribution of flow velocity. Results acquired from first research methodology showed that using the serpentine flow field design resulted in a very small non-uniformity coefficient of flow velocity distribution of nearly 0.0271 which indicates uniform flow velocity distribution with highest pressure drop, while the U-type yielded the highest non-uniformity coefficient (0.246–0.249) which represents non-uniform distribution of flow velocity with lowest pressure drop. The results obtained from the second research methodology while using a fixed header area and variable channel area for both parallel Z and U-type channels; showed a decrease in non-uniformity coefficient with decreasing header/channel area ratio with increasing overall pressure drop in both types of flow channel design.

1. Introduction

Fuel cells are one of the most important applications of alternative and renewable sources of energy that can replace internal combustion engines. In addition to using hydrogen as a fuel, they are environmentally friendly and produce only electricity, water and heat [1–3].

However, the use of these cells faces many challenges that effect the performance of the fuel cells, one of the most prominent of these challenges is the designs of flow field plate which are responsible on distributing reactant gases evenly throughout the cell, removing excess water efficiently, and supplying a conduction route for the electrons from the external circuit. It was found that the most common types of designs of flow field is single serpentine which has high pressure drop and uniform flow distribution, while another design of flow field such as parallel type (Z & U-type) has low pressure drop but non-uniform distribution. So, many researchers have gone to study the possibility of improving the uniformity of flow distribution through flow field plate [4–10]. Thus, the most of these researches were theoretical studies and it can be concluded from the results that the uniformity of flow distribution depends on three main factors: a-the ratio of total loss coefficient of channels, b-the ratio of header length to header diameter and c-the ratio of sum of the areas of all channels to the cross-sectional area of header.

Also, it must be noted that number of researches experimentally studied the effect of changing designs of flow field plate on the performance of fuel cell [11–15], Chao Wang et al. [11] investigated numerically the effect of height/width-tapered flow fields on the cell performance of proton exchange membrane fuel cells. They reported that two types of flow fields with tapered channels designs. The experimental results revealed that flow fields with tapered design at high current densities better performance compared with traditional flow fields, hence superiority of tapered design with flow fields contributed in promote high efficiency of PEMFCs and effective removal excess water in channels. Masaya et al. [12] developed a various types of flow fields such as serpentine, parallel, pin and porous flow fields to enhance mass transport property. Because of the limits of thin and channel width, the authors have developed a porous type flow field unique pore diameter distribution. They were investigating the fuel cell performance and impedance characteristics compared with those of the conventional flow fields. The results revealed that the porous flow-field exhibits the smallest gas diffusion resistance at a high current density operation regardless of humidity conditions. These results indicate that the porous flow-field conducts water management well at high current

* Corresponding author.
E-mail address: 10592@uotechnology.edu.iq (H.A. Dhahad).

https://doi.org/10.1016/j.tsep.2018.08.013
Received 24 April 2018; Received in revised form 17 August 2018; Accepted 18 August 2018
2451-9049/

density. Rahimi-Esbo et al. [13] proposed a novel gas flow field to improve water removal in PEM fuel cell. Seven flow fields are studied and their performances are examined at the optimum channel to rib ratio. Novel serpentine flow field design intended at effective water removal is presented and tested. The results showed that 2–1-serpentine flow field has the highest performance especially at high current distributions. Tabbi Wilberforce et al. [14]. Proposes modifications to some of flow field plate designs of PEM fuel cell using CFD techniques, to decrease the pressure drop in the flow channels. This reduction in pressure drop will contribute to the improvement of performance. A mixture of both the serpentine and the parallel flow channels was aimed to achieve a better performance causing from the existence of the serpentine channel portion and at the same time guarantee overall lower pressure drop owing to the existence of the parallel bypass. Chowdhury et al. [15] investigate numerically and experimentally the effect of novel convergent-divergent serpentine flow fields on PEM fuel cell performance. From experimental results was found that convergent serpentine flow fields better performance from divergent serpentine flow fields and conventional constant channel depth flow fields. Furthermore, good management water and thus prevent flooding water has occurred, because of high velocity flow in convergent serpentine flow fields. On the other hand, a very limited number of them studied the effect of flow field plate design on the uniformity of flow distribution through flow field plate, experimentally [16–18]. Barreras et al., 2005 [16] investigated the flow distribution in parallel flow field Z-type arrangement, to visualize the flow pattern, laser induced fluorescence has been applied. Sugii and Okamoto, 2006 [17] experimentally investigated the flow distribution in a transparent model of polymer electrolyte fuel cell (PEMFC) using Micro-PIV technique, which consisted of straight channels of 1.0 mm width and 0.5 mm depth. Results showed that the velocity distribution of the gas flow with Reynolds numbers of 26 and 130 were successfully measured. Hecht et al., 2010 [18] experimentally studied the flow and transport phenomena in multi serpentine flow field using two techniques which was molecular flow tagging velocimetry and micro particle image velocimetry (Micro-PIV). It was found that the velocity of the seeding flow parallel to the channel structure decline along the channel length due to the perpendicular flow cross the channel structure. Mehdi and Saeed [19–22] have many studies in this field. In Ref. [19] they evaluated the flow distribution and heat transfer characteristics of a hybrid nanofluid inside two microchannel heat sinks. Then a rather uniform temperature distribution is obtained on the heating surface. It was found that employing the heat sink with more path changes and also using the nanofluid as heat transfer fluid can be promising options to be utilized in electronics cooling. Also, in Ref. [20] a novel distributor liquid block for CPU is evaluated compared with two conventional liquid blocks including serpentine and parallel geometries. Comparisons of the flow distribution uniformity was made. The results showed that the novel distributor liquid block had a superior efficacy based on both thermal performance and irreversibility rates. In other hand, in Ref. [21] they investigated the uniform flow distribution in a specific liquid block working with the water–Al_2O_3 nanofluid for utilization in electronics cooling. The results showed that the effect of the concentration and particle size on the surface temperature was greater than that on pumping power, while the Reynolds number had a rather similar effect on the two objective functions. In Ref. [22] they were used a nanofluid containing silver nanoparticles in a liquid block heat sink for cooling of an electronic processor. The liquid block under study has 20 channels. By increasing Reynolds number and particle concentration, temperature distribution becomes more uniform in processor surface and heat transfer coefficient also increases. Furthermore, the surface temperature decreases with increasing concentration and Reynolds number. Soroush et al. [23] studied theoretically the flow distribution in a parallel channel fuel cell by embedding small cylindrical obstacles to improve uniformity of the flow distribution among the channels. The cylindrical obstacles were inserted in the distributor of a PEMFC. Different arrays for the obstacles were investigated to distinguish the design with a specific level of uniformity. The results showed that by applying cylindrical obstacles in the distributor, the flow becomes more uniform, such that the maldistribution factor decreases between 35% and 51% for different Reynolds numbers. Moreover, the pressure drop intensifies by increasing the mass flow rate. Cyril et al. [24] investigated the flow distribution in a multi-scale fluidic network consisting of a number of elementary ladders. (CFD) simulations were performed. For the multiscale fluid network, non-uniform flow distribution was observed even under very low flow-rate conditions. For higher flow-rate conditions, significant flow nonuniformity seems inevitable. The insertion of optimized perforated baffles could provide a remarkable improvement on flow distribution uniformity. Min et al. [25–26] developed a CFD-based evolutionary algorithm to obtain the flow distribution among parallel channels in Ref. [25]. Results showed that the optimized distribution curves obtained by performing the evolutionary algorithm were in good agreement with the target curves, with acceptable increase in pressure drop. In Ref. [26] they were presented a numerical and experimental investigation on the realization of target flow distribution among parallel mini-channels, using the optimized baffle insertion method. A 15-channel fluidic network integrated with the distributor and the collector was fabricated and tested. PIV technique was used for the flow distribution measurement while CFD simulations were also performed for comparison. CFD results and PIV data showed that different target distributions could be successfully achieved by the optimized baffle insertion method. The robustness of the optimized baffle for uniform distribution was also evaluated and discussed to provide some guidelines for future applications.

In this work, a study on the effect of flow field design implemented in PEM fuel cells on air distribution uniformity was conducted. The research followed two study methodologies, the first methodology involved studying the effect of flow field plate design on velocity distribution uniformity (ϕ) which included experimenting with five different designs of flow field (single serpentine, parallel Z, 2Z, U and 2U-type). These configurations are the most used in fuel cell applications. The second methodology comprised studying the effect area ratio (header/channel) on velocity distribution for both of parallel Z and U-type to try to reach a more uniform velocity distribution. This subject has been widely studied in theory but practical studies are very limited and almost rare.

2. Experimental description

The experiments were carried out for laminar flow. The compressor delivers the air to the pressure tank, for damping the pressure fluctuations of delivery flow and to supply compressed air to the test section at constant pressure. The tank is provided with a pressure gauge of (8) bar.

2.1. Design and manufacturing process

For this experimental study, an active channel area of 52,500 mm^2 was considered of aluminum bipolar plate material. The dimensions of the bipolar plates were 750 mm × 70 mm × 3 mm. Housing was manufacturing from Perspex with dimension of (195 × 140) mm^2. The aluminum flow field plate was inserted into the Perspex housing, it was manufactured by milling machine, with dimensions' equals to the dimensions of aluminum plate. Two holes with diameter of (6) mm were perforated at the back of housing, one of them for supplying air while other for discharging air, also external edge of housing was perforated with number of holes (12). The cover plate was manufacturing from Perspex with dimension equal to the housing. It was perforated with number of holes as follows:

– (12) holes at external edge of the cover plate, its distribution was similar to the housing. However, the holes were used to assembly