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Declaration

I declare that no part of the work referred to in this thesis has been submitted in support of an application for another degree or qualification from this or any other University or Institution.

Abstract

The proton exchange membrane fuel cell (PEMFC) technology is one of most clean power and producing devices that have high efficiency. The PEMFC is very complex system, the operating principles is based on thermodynamics, electrochemistry, hydrodynamics and mass transfer theory. Consequently, complete mathematical model is difficult. PEMFC performance is directly proportional to the flow channel design on bipolar plates. So, bipolar plates have been studied theoretically and experimentally.

In modeling and simulation the COMSOL software has been used to solve Navier–Stokes equation in flow channels and Brinkman's equation in the porous gas diffusion layer. The main effective parameters in this study were pressure drop, effective area and residence time. The data has been verified with published data. A parametric study has been carried out to study the different parameters affecting bipolar plates performance. The experimental study has been done by using fuel cell test station (850 e). Furthermore the performance of PEMFC was investigated by using different bipolar plate designs as parallel or straight bipolar plate, two, three and six passes header serpentine flow channels, two, three and six passes serpentine flow channels with square bend, two, three and six passes serpentine flow channels with curvilinear bend and spiral design.

Summary

Atmospheric pollution and greenhouse warming has been a big problem that challenge the world in the recent years due to noticeable increase in global warming rate. It is speculated that CO_2 is considered to be responsible for about half of the global warming rate. Fuel cells are one of the best ways that can be used to overcome the pervious mentioned problems.

Recently, all countries need more efficient energy- conversion systems. Our fuel resources, such as oil, coal, etc. are limited. Higher efficiency energy conversion means less pollution, since less fuel is consumed and less emission created for the same energy output. One of the possible means to achieve these goals are fuel cells.

Now, the world is facing an energy crisis and one of the methods to resolves this issue is the study of fuel cells and improve their performance. As is known there are many types of fuel cells such as alkaline fuel cell (AFC), phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC), solid oxide fuel cell (SOFC), and the proton exchange member fuel cells (PEMFC).

Proton exchange membrane fuel cell (PEMF) is one of successful types of fuel cells because it is working in low temperature and high efficiency. PEMFC performance is direct proportional to the flow channel design on bipolar plates. Channel design parameters, channel size, channel geometry and arrangement can raise the PEMFC voltage, current density consequently.

In this investigation, bipolar plates (BPPS) designs have been studied numerically such as Parallel or straight bipolar plate, Dual, triple and six passes header serpentine, Dual , triple and six passes serpentine flow channels with square bend , Dual , triple and six passes serpentine flow channels with curvilinear bend and spiral design. On the other hand some designs studied experimentally six serpentine flow channels with square bend and six serpentine flow channels with curvilinear bend.

BPPs have been studied numerically by using commercial computational fluid dynamics (CFD) tool (COMSOL). The incompressible Navier-Stokes equations in the flow channels and the Brinkman equations for the porous gas diffusion layers (GDLs), using the Free and Porous Media Flow interface has been solved by COMSOL to define the best design and by using server FUJITUS Intel (R) xeon (R) cpu E5630 @2.53 GHZ, 2.53 GHZ (2 processors) ,RAM 64 GB. The obtained results give a designer the good idea on which design parameters would be optimal to get the best PEMFC performance. The main effective parameters in this study were pressure drop, effective area and residence time. The data has been verified with published data.

The results of mathematical model for the serpentine square bend exhibit consistently higher pressure drops compared to curvilinear bend which is due to the sharpness the turns of square bend. The use of multiple serpentine channels decrease the gas path length, and consequently decreases the pressure drop. Decrease in cross sectional area would lead to more uniform distribution gas concentration at electrode surfaces, but with increase or decrease in pressure drop which affect the compressor power. The pressure drop is important of for both air and hydrogen but the bipolar effective area and residence time play other important parameters to enhance the PEMFC performance. The parallel or straight bipolar plate design may be the optimum design for air and hydrogen if it will be implemented a back pressure unit but it will be complicated configurations. The spiral design is the optimum design for air and hydrogen.

The parameters which have been studied are hydrodynamic and geometric. The fluid dynamic parameters includes: different velocities of air and hydrogen .The geometric parameters include: bipolar plate channel width, bipolar plate channel depth and bipolar plate channel cross sections as triangle, semicircle, trapezoidal and square.

The numerical results indicate that: The effect of gas velocity on the pressure drop with velocity increase in both side's air (cathode side) and H_2 (anode side) the pressure drop increases. As expected for bipolar plates the increase in channel width or depth is associated with decrease in pressure drop in both side's air (cathode side) and hydrogen anode side. For bipolar plate channel cross sections, for air (cathode side), the lowest pressure drop occurred with semicircle design followed by square design then trapezoidal design finally triangle design. So the optimum cross section design occurs semicircle design at low velocities. And For H_2 (anode side), the lowest pressure drop occurs semicircle design followed by square design then trapezoidal design finally triangle design. So the optimum cross section design is the semicircle design at low velocities.

Experimentally the two designs are six passes serpentine flow channels with square bend and six passes serpentine flow channels with curvilinear bend have been implemented and tested by Scribner (850 e) fuel cell test station .Cell voltage verses cell current density and cell power density verses cell current density have been measured for the two designs taking into considerations all parameters effecting PEMFC performance such as cell, anode and cathode temperatures, stoichiometric ratio and flow rates for hydrogen and oxidant.

List of publications

[1] M. E. Youssef, Walaa. M. Galal , A. A. Elzatahry, M. M. Sorour, , "DESIGN AND MODELING OF BIPOLAR PLATES FOR PEMFC BY USING COMSOL SOFTWARE," proceeding of the global conference on global warming (GCGW-2012) 8-12 july 2012, Istanbul, turkey, pp. 41-53, 2012.

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Nomenclature

English letters

E	Equilibrium potential (V).
E^o	Standard potential (V).
F	Faraday's constant (J/V-mol)
ΔG	The change in Gibbs free energy (KJ/mole).
ΔH	The change in enthalpy (KJ/mole).
I	Identity matrix.
i	The current flowing through the cell (A).
i_o	The exchange current density (A/ cm^2).
i_L	The limiting current (A).
k	The permeability of the porous medium (m^2).
n	moles electrons
p	Pressure (Pa).
R	Universal gas constant (J/Kg.K)
r	Total cell resistance
T	Temperature (K).
u	The velocity vector in the open channel ($m\ s^{-1}$).

Greek letters

α	The electron transfer coefficient of the reaction
ε	The porosity of the gas diffusion layer.
η_{act}	Reaction rate loss
η_{ohm}	Resistance loss
η_{conc}	Gas transport loss.
η	Fuel cell efficiency
μ	The fluid dynamic viscosity (Pa.s).
ρ	The density of the fluid ($kg\ m^{-3}$).

Abbreviation

(a)	Anode
(c)	Cathode
AFC	Alkaline fuel cell.
PAFC	Phosphoric acid fuel cell.
PEMFC	The proton exchange member fuel cells.
MCFC	Molten carbonate fuel cell.
SOFC	Solid oxide fuel cell.
BPPs	Bipolar plates.
GDLs	Gas diffusion layers.
MEA	The membrane electrode assembly
FCTS	Fuel Cell Test Station
L.H.V	Lower heating value
Pt	platinum

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