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Enhanced heat transfer with corrugated flow channel in anode side of direct methanol fuel cells

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ABSTRACT

In this paper, heat transfer and flow field analysis in anode side of direct methanol fuel cells (DMFCs) is numerically studied. To enhance the heat exchange between bottom cold wall and core flow, bottom wall of fluid delivery channel is considered as corrugated boundary instead of straight (flat) one. Four different shapes of corrugated boundary are recommended here: rectangular shape, trapezoidal shape, triangular shape and wavy (sinusoidal) shape. The top wall of the channel (catalyst layer boundary) is taken as hot boundary, because reaction occurs in catalyst layer and the bottom wall of the channel is considered as cold boundary due to coolant existence. The governing equations are numerically solved in the domain by the control volume approach based on the SIMPLE technique (1972). A wide spectrum of numerical studies is performed over a range of various shape boundaries, Reynolds number, triangle block number, and the triangle block amplitude. The performed parametric studies show that corrugated channel with trapezoidal, triangular and wavy shape enhances the heat exchange up to 90%. With these boundaries, cooling purpose of reacting flow in anode side of DMFCs would be better than straight one. Also, from the analogy between the heat and mass transfer problems, it is expected that the consumption of reacting species within the catalyst layer of DMFCs enhance. The present work provides helpful guidelines to the bipolar plate manufacturers of DMFCs to considerably enhance heat transfer and performance of the anode side of DMFC.

1. Introduction

With the limitations in fossil fuel resources and crises in environmental pollution, recent attention to alternative power sources for various applications has been very serious. Direct methanol fuel cells (DMFCs) with high efficiency and high environmental compatibility have attracted considerable interest within academic and industrial area as a potential power source for a range of mobile applications.

In this paper, a new method of heat transfer enhancement between cold wall and core hot flow in direct methanol fuel cells are introduced. For this purpose, partial block along the fluid delivery channel are placed and straight flow channel turn into corrugated flow channel. This enhances cooling purpose of main flow and also leads to facilitate over-rib convections and improve the kinetic of reactions within the catalyst layer and better removal of bi-products from the diffusion layer towards the channels [1].

In direct methanol fuel cells, the activation over-potential in the anode half-cell side same as cathode one is very important and cannot be neglected. Fig. 1 shows a schematic of DMFC with the electrochemical half-cell and full-cell reactions. Eq. (1) shows slow reaction electrodes in DMFCs:

$$\begin{aligned}&\text{DMFC anode half-cell reaction}:\quad CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^- \\ &\text{DMFC cathode half-cell reaction}:\quad 1.5O_2 + 6H^+ + 6e^- \rightarrow 3H_2O\end{aligned} \tag{1}$$

Placement of partial blocks (fins) enhances convection heat transfer at the heat exchanging sides and cools core hot flow in anode/cathode side of fuel cells. This work also is recommended in the slow reaction electrodes like the cathode side of PEMFCs or anode and cathode sides of DMFCs.

Corrugated flow channel has widely played important roles to manage the heat exchange between hot and cold heat sources. They can be considered as passive control devices to increase or decrease both natural and forced convection heat transfer. On the natural convection side, in recent years most of the heat transfer enhancements have been done by changing the flow pattern using partitioning rectangular or square enclosures [2–7]. Varol et al. [8] investigated the effects of fin placement on the bottom wall of a triangular enclosures filled with porous media. Aounallah et al. [9] studied the effect of the inclination angle and the amplitude of the undulation on turbulent heat transfer in a confined cavity

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Nomenclature

a	amplitude of shapes of the bottom wall, mm
C_p	specific heat of fluid at constant pressure, kJ/kg K
C	concentration
Da	Darcy number
H	height of the channel ($H = H_1 + H_2$), mm
H_1	height of the open portion of the channel, mm
H_2	height of the porous portion of the channel, mm
k	thermal conductivity, W/m K
K	permeability of the porous medium, m^2
L	1/10 total length of the channel, mm
n	normal vector to face
Nu	local Nusselt number
Nu	average Nusselt number
p	pressure, N/m^2
p^*	estimated pressure
Pr	Prandtl number
Re	Reynolds number
S	total wall length of the bottom wall
S_φ	source term in φ equation
T	temperature, K
T_H, T_C	temperature of the hot and cold wall, K
u, v	velocity component, m/s
u^*, v^*, T^*	velocities and temperature based on p^*
x, y	horizontal and vertical coordinates, m

Greek symbols

ρ	density, kg/m^3
δ	the slope of the bottom wall
θ	dimensionless temperature
μ	dynamic viscosity, N s/m^2
ν	kinematic viscosity, m^2/s
ε	porosity

Subscripts

f	fluid
M	mean temperature
m	porous medium
in	input plane of channel
out	exit plane of channel
n	north face of control volume
e	east face of control volume
s	south face of control volume
w	west face of control volume
p	cell center

with two differentially heated side walls. Rathish Kumar and Shalini [10] performed numerical study of non-Darcian natural convection in a wavy vertical enclosure filled with a porous medium. Khanafer et al. [11] analyzed natural convection heat transfer inside a cavity with a sinusoidal vertical wavy wall and filled with a porous medium.

Heidary and Kermani [12] computed the heat transfer enhancement and hydrodynamics of the flow field in a wavy channel with

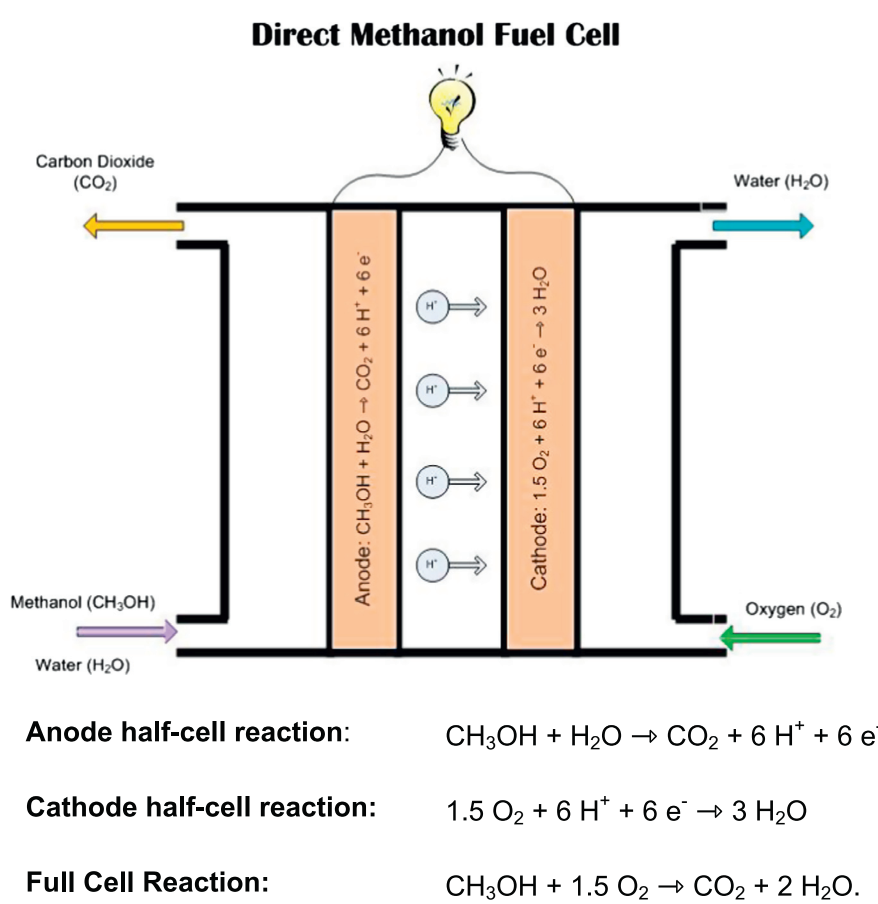

Fig. 1. Schematic picture of direct methanol fuel cell (DMFC).