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Short communication

An ultrasound enhanced direct methanol fuel cell

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Abstract

A novel direct methanol fuel cell (DMFC) incorporating an ultrasonic transducer is introduced based on a recent provisional patent application [J. Ge, J. Han, H. Liu, Ultrasounically enhanced fuel cell system, U.S. Provisional Patent Application No. 60/815,268, June 21, 2006]. The ultrasound transducer is embedded in the methanol supply line and is used to enhance the performance of a DMFC. The technique of introducing ultrasound through methanol supply line significantly reduced the potential losses in ultrasound transmission to the reaction sites of the fuel cell. Series of experiments have been conducted to study the effect of the ultrasound on the performance of the DMFC. The experimental results showed that the high-frequency vibrations of the ultrasound through the methanol supply line enhance the cell performance significantly and consistently. The experimental results unequivocally demonstrated the feasibility of using ultrasound to enhance DMFC performance and the effectiveness of introducing ultrasound into a DMFC via methanol supply line to minimize the wave transmission losses.

Keywords: Fuel cell; DMFC; Ultrasound enhancement; Sonochemistry

1. Introduction

Direct methanol fuel cells (DMFC) are widely considered to be a promising energy conversion device for the future to replace batteries and engines for specialty vehicles. Comparing with the hydrogen PEM fuel cell, the fuel for a DMFC, methanol, has a much higher energy density and can be easily stored with normal storage methods. However, one of the greatest disadvantages of DMFC is its low kinetic activity of methanol reaction at the anode. To compensate the low activity at the anode, large amount of precious metals, such as platinum and ruthenium must be used. Even with a catalyst loading of an order of magnitude higher than that used in hydrogen PEMFCs, the power density of a DMFC is still about an order of magnitude lower than that of a PEMFC. Therefore, any increase in the anode activity will be a significant advancement in DMFC technology.

Ultrasounds have been used in chemistry to enhance chemical and electro-chemical reactions and there is an emergent branch of chemistry, sonochemistry, which deals with the applications of the chemical effects of ultrasound [2]. The chemical effects of ultrasound cannot arise from direct interactions with the reacting molecular species since the acoustic wavelengths in liquid are many orders of magnitude greater than the molecular dimensions. It is believed that the origin of sonochemistry is acoustic cavitations [3]. Ultrasound waves generating cycles of compressions and expansions. During compression cycles the liquid is subjected to a positive pressure and the molecules are pushed together; while during expansion cycles, a negative pressure is exerted on the liquid, pulling the molecules away from each other. During the expansion cycles a wave with sufficient intensity can generate cavities in liquid, especially in liquid with impurities, trapped microscopic gas or solids. It is believed that the enormous local temperatures and pressures [4,5] during the implosion of the bubbles are the source of sonochemistry.

Though sonochemistry has found it applications in various areas, to our knowledge, ultrasounds have not been used in fuel cells for performance enhancements, possibly due to the difficulties of transmitting of ultrasound to the reactions sites, the catalyst layers.

In this paper, a novel approach of introducing the ultrasound via the methanol fuel line [1] is presented. This approach eliminates the various interfaces between the different components of a fuel cell to minimize the ultrasonic wave transmission losses,

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thus ultrasound can be effectively transmited to the reaction sites, the catalyst layer. Series of experiments have been conducted and the results clearly demonstrated the feasibility of using ultrasound to enhance DMFC performance and effectiveness of the technique of introducing ultrasound into a DMFC via methanol supply line.

2. Experiments

The fuel cell test station was manufactured by Fuel Cell Technology, Inc. A major component of the test station is the HP® 6050A system DC electronic load controller, which is capable of controlling the electrical load on the fuel cell as well as measuring the cell voltage versus its current responses. This experimental system also provides control over anode and cathode flow rates, cell operating temperature, operating pressure, and humidification temperature for the cathode. The cathode mass flow rate is controlled and measured by a MKS® mass flow controller, and the anode flow rate is controlled and measured by a peristaltic pump by Gilson, Inc. An ultrasonic transducer is inserted inside the methanol supply line between the pump and the cell to generate high-frequency vibration and the vibration is transmitted through the methanol solution. The schematic of the experimental system is shown in Fig. 1.

The experimental fuel cell consists of two 316 stainless steel end plates, two graphite collector plates with machined serpentine flow fields, two diffusion layers, two catalyst layers, and the electrolyte membrane. The cell was kept at a constant temperature through the thermal management system during each experiment. The electrolyte membrane used was Nafion® 117, the gas diffusion layers are carbon cloth on the anode side and ETEK ELAT® on the cathode side; the catalyst on the anode side is Pt–Ru with a loading of 4 mg cm^{-2}, and on the cathode side is Pt with a loading of 4 mg cm^{-2}. The active area of the fuel cell is 5 cm^2.

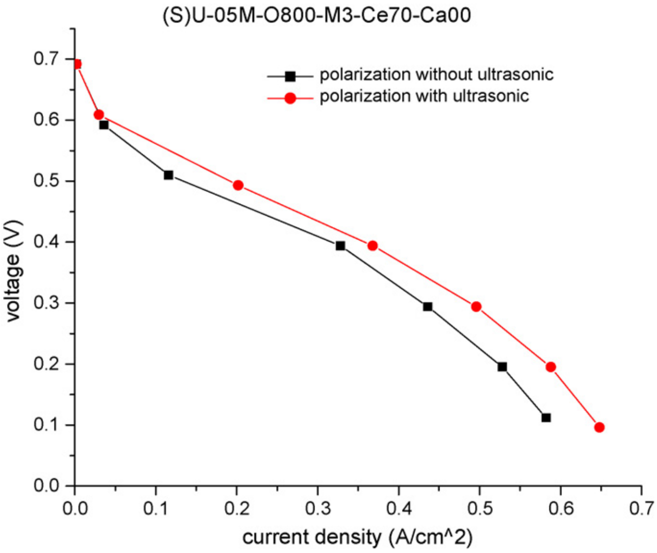

Fig. 2. Comparison of cell polarization curves without and with an ultrasonic effect: methanol concentration, 0.5 M; methanol flow rate, 3 ml min^{-1}; oxygen flow rate, 800 sccm; cell temperature, 70 °C.

3. Results and discussions

A series of experiments with four different methanol concentrations of 0.5–3 M have been carried out to study the enhancement effects of the ultrasound. The cell operating conditions are given below. The methanol feeding flow rate is 3 ml min^{-1}; the cathode reactant is oxygen and feeding flow rate is 800 sccm; the cell temperature is 70 °C; there is no humidification in the cathode inlet. The experimental results are shown in Figs. 2–5. To facilitate comparisons, the experimental data are also tabulated in Tables 1–4. From the experimental results, it is clearly seen that the ultrasound definably enhances the performance of the DMFC. The increases in cell current density at the same cell voltage are significant and consistent, though the percentage of

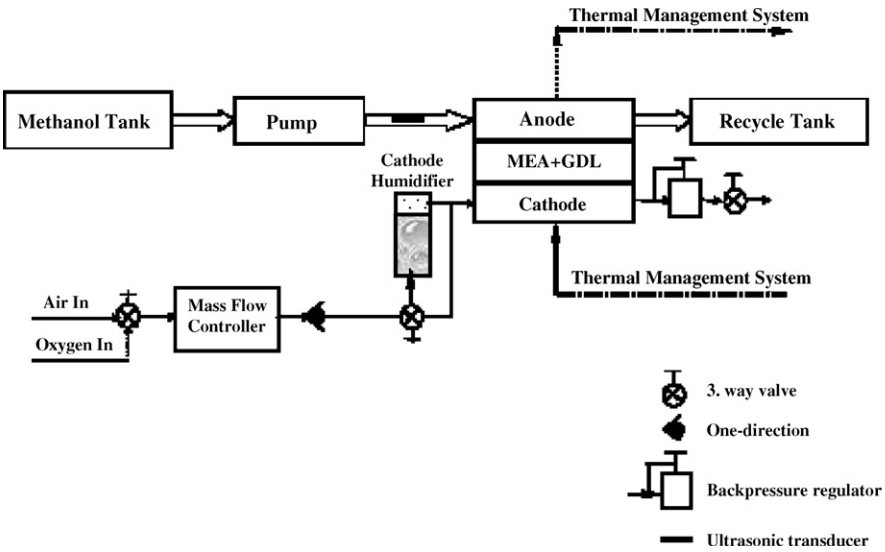

Fig. 1. Schematic of the experimental system incorporating an ultrasound transducer in the methanol supply line.

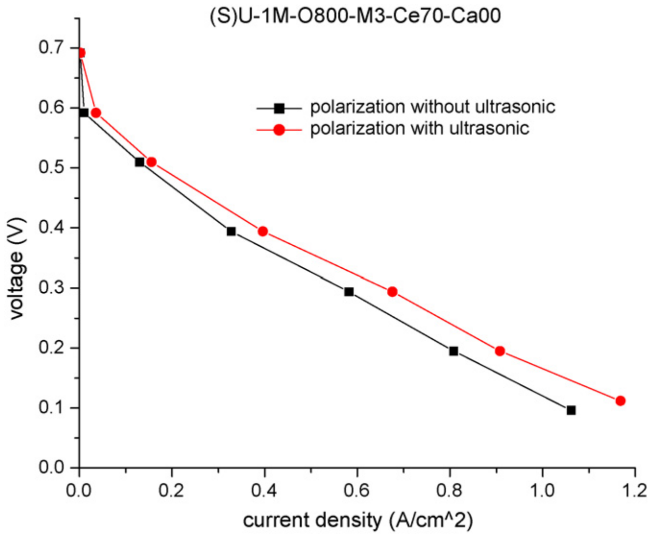

Fig. 3. Comparison of cell polarization curves without and with an ultrasonic effect: methanol concentration, 1 M; methanol flow rate, 3 ml min^{-1}; oxygen flow rate, 800 sccm; cell temperature, 70 °C.

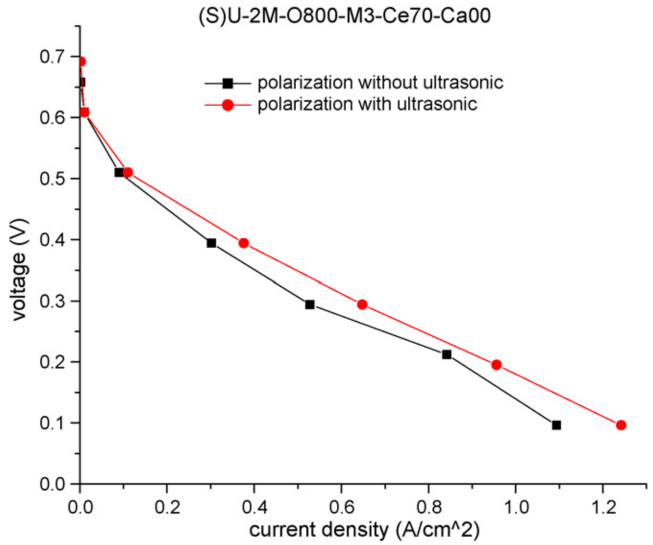

Fig. 4. Comparison of cell polarization curves without and with an ultrasonic effect: methanol concentration, 2 M; methanol flow rate, 3 ml min^{-1}; oxygen flow rate, 800 sccm; cell temperature, 70 °C.

Table 1
Data for cell polarization curves without and with an ultrasonic effect as shown in Fig. 2

U (V)	Current density (A cm^{-2})		Power increase (%)
	Without ultrasonic	With ultrasonic	
0.692	0.002	0.002	0
0.609	0.03	0.03	0
0.510	0.116	0.1734	49.4828
0.394	0.328	0.368	12.1951
0.294	0.436	0.496	13.7615
0.195	0.528	0.588	11.3636
0.096	0.592	0.648	9.4595

Methanol concentration, 0.5 M; methanol flow rate, 3 ml min^{-1}; oxygen flow rate, 800 sccm; cell temperature, 70 °C.

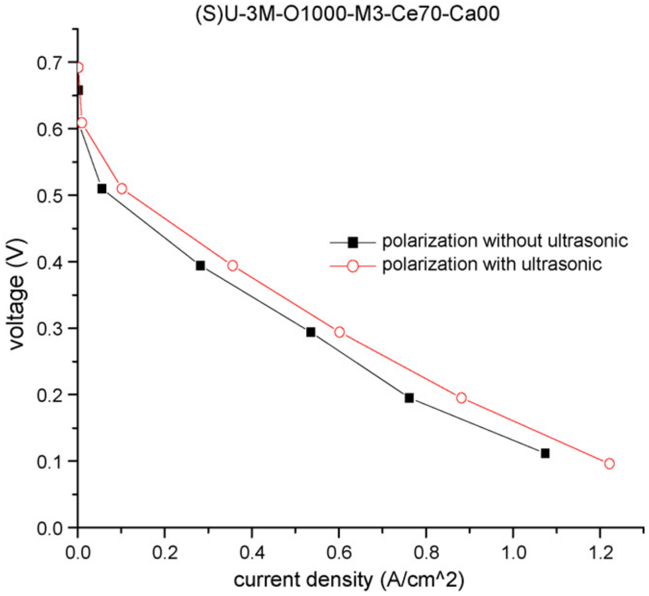

Fig. 5. Comparison of cell polarization curves without and with an ultrasonic effect: methanol concentration, 3 M; methanol flow rate, 3 ml min^{-1}; oxygen flow rate, 800 sccm; cell temperature, 70 °C.

Table 2
Data for cell polarization curves without and with an ultrasonic effect as shown in Fig. 3

U (V)	Current density (A cm^{-2})		Power increase (%)
	Without ultrasonic	With ultrasonic	
0.692	0.002	0.002	0.0000
0.592	0.010	0.036	260.0000
0.510	0.130	0.156	20.0000
0.394	0.328	0.396	20.7317
0.294	0.582	0.676	16.1512
0.195	0.808	0.908	12.3762
0.096	1.062	1.218	14.6893

Methanol concentration, 1 M; methanol flow rate, 3 ml min^{-1}; oxygen flow rate, 800 sccm; cell temperature, 70 °C.

Table 3
Data for cell polarization curves without and with an ultrasonic effect as shown in Fig. 4

U (V)	Current density (A cm^{-2})		Power increase (%)
	Without ultrasonic	With ultrasonic	
0.658	0.002	0.005	150.000
0.609	0.010	0.010	0.000
0.510	0.090	0.110	22.222
0.394	0.302	0.376	24.503
0.294	0.528	0.648	22.727
0.195	0.907	0.956	5.402
0.096	1.094	1.242	13.528

Methanol concentration, 2 M; methanol flow rate, 3 ml min^{-1}; oxygen flow rate, 800 sccm; cell temperature, 70 °C.

Table 4
Data for cell polarization curves without and with an ultrasonic effect as shown in Fig. 5

U (V)	Current density (A cm^{-2})		Power increase (%)
	Without ultrasonic	With ultrasonic	
0.658	0.002	0.005	150.00
0.609	0.002	0.010	400.000
0.510	0.056	0.102	82.1429
0.394	0.282	0.356	26.2411
0.294	0.536	0.602	12.3134
0.195	0.762	0.882	15.7480
0.112	1.134	1.222	7.7601

Methanol concentration, 3 M; methanol flow rate, 3 ml min^{-1}; oxygen flow rate, 800 sccm; cell temperature, 70 °C.

increase depends on the operating conditions. It can be seen from the experimental results, at typical operational cell voltage range, the increase of cell power output due to ultrasound is around 20%. These experimental results also demonstrated the effectiveness of the technique of embedding the ultrasound transducer in the methanol supply line.

Though it is not the objective of this paper to study or hypothesize the exact mechanisms of ultrasound enhancement of DMFC fuel cell performance, the following are some of the possible mechanisms. (1) Cavities caused by the ultrasound at the catalyst surface increase the catalyst activity and reduce the activation overpotential loss. (2) Ultrasound vibrations enhance methanol transfer to the reaction sites and reduce the concentration overpotential loss. (3) Ultrasound vibrations increase the conduction of proton inside the Nafion® polymer electrolyte and reduce ionic ohmic loss. (4) Ultrasound vibrations facilitate the removal of the carbon dioxide bubbles from the catalyst layer and the diffusion layers, thus reduces the catalyst surface area blocked by carbon dioxide gas.

Systematic and detailed investigations are warranted to study the fundament mechanisms of how and to what extent the ultrasonically high-frequency vibration enhances fuel cell performances. It is reasonable to believe that the effectiveness of the ultrasound depends on its frequency and intensity, method of incorporation into fuel cell system, and fuel cell operating conditions. Thus the great potentials of ultrasound enhancement of fuel cell performances are yet to be explored.

4. Concluding remarks

Experiments have been conducted on a novel ultrasound enhanced direct methanol fuel cell, where an ultrasonic transducer is embedded in the methanol supply line. The experimental results showed that the high-frequency vibrations of the ultrasound through the methanol supply line enhance the cell performance significantly and consistently. The power increase due to ultrasound in the typical cell operating voltage is around 20%. The experimental results unequivocally demonstrated the feasibility of using ultrasound to enhance DMFC performance and the effectiveness of introducing ultrasound into a MDFC via methanol supply line to minimize the wave transmission losses. The exact mechanisms of the ultrasound enhancement and the potential effects of ultrasound on the durability of fuel cells require further research.

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