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Experiments on PEMFC performance enhancement by pulsating cathode flow

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Key words : PEMFC (Proton Exchange Membrane Fuel Cell), BOP (Balance Of Plant), pulsating cathode flow, mass transport

Abstract : Experiments have been performed to investigate effects of pulsating cathode flow on a 10-cell proton exchange membrane fuel cell (PEMFC) stack. For all the experiments, the flow rate, temperature and relative humidity of hydrogen at the anode inlet are fixed. The effects of the pulsating frequency, amplitude and flow rate at the cathode inlet on performance of 10-cell PEMFC are examined. The polarization and power curves show that the power output and limiting current is substantially increased when the pulsating component is added to cathode flow channel. The maximum power output increases by up to 38% and enhancement of the overall performance is more pronounced at lower flow rate region.

Nomenclature

A : pulsating amplitude, Vpp
f : pulsating frequency, Hz
I : current, A
P : power, W
Q : flow rate, lpm
V : voltage, V

subscript

c : cathode of fuel cell

1. Introduction

As a renewable and environmental-friendly energy source, fuel cells have been a subject of intense research interest due to their high energy efficiency, low emission, few moving parts, low noise and cleanness of energy production, to name a few. The fundamental aspects of fuel cells have been documented[(1-2)]. Among the various types of fuel cell, a proton exchange membrane fuel cell (PEMFC) is expected as one of the most promising candidates for future power source on account of their high power density, simple structure, quick start-up and easy operation[(3)]. The component design and integration of a PEMFC have been examined in detail[(4-8)]. Most of these studies are concerned with the component material of a fuel cell stack and the proton transport media to improve the performance of PEMFC. However, relatively little work has been done in a balance of plant (BOP), even though a design of BOP system is also crucial for the efficient operation of a PEMFC[(9)]. Nowadays, the system level research and development have been the topics of importance[(10-12)].

A practical PEMFC system includes a fuel supply, an air supply, a water management sub-system, a thermal management sub-system, a power electronics subsystem and fuel cell stack[(1,3,13)]. In the BOP system, the blower is generally used for uniform air supply to the stack. The supplied air is diffused through the gas diffusion layer (GDL). The performance of a fuel cell is strongly affected by the diffusive mass transport in GDL which is

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proportional to the reactant concentration gradient between a catalyst layer in MEA and a flow channel in bipolar plate. Also, the limiting current density increases with higher reactant concentration gradient. To ensure the sufficient reactant concentration in the flow channel, the higher flow rate of a reactant is required for the enhanced convective mass transport. Thus, the blower with higher capacity is generally used to increase the performance of a fuel cell since it enhances the reactant mass transport. However, the increase of blower capacity brings forth its higher parasitic power consumption, larger BOP volume and higher noise as well.

In the research field on conventional fluid dynamics, the enhancement of heat and mass transport by pulsating flow has been reported[14-16]. The fluid mixing and heat transfer are enhanced by the periodical convective fluid motion induced by pulsating flow. Thus, the pulsating air supply to the cathode inlet may be considered for higher concentration of oxygen in the cathode flow channel. In the present study, the effect of pulsating cathode flow on the overall performance of a 10-cell PEMFC is investigated. The polarization curve and corresponding power curve are experimentally obtained to identify the effect of pulsating frequency, amplitude and flow rate on the overall performance.

2. Experimental setup and procedure

The present experimental set-up was composed of an air supply, a hydrogen supply, a nitrogen supply, a temperature control unit and a fuel cell stack, as shown in Fig. 1. A NP50 PEM fuel cell stack (heliocentris Energyiesysteme GmbH) which consisted of 10 cells was selected. The active area of a cell was 5cm×5cm and each cell had 14 straight air flow channels which were open-air cathode type. The cross sectional area and length of a channel were 2mm×3mm and 7cm, respectively. Hydrogen with a purity of 99.999% was supplied to the anode of stack through a MFC from a compressed hydrogen tank. A steady main airflow was fed to the cathode of stack from a compressed air tank through a rectangular Plexiglas duct with pulsating flow by woofer. The flow rate, temperature and humidity were controlled by a MFC, a heater and a humidifier. A pressure regulator kept the internal pressure of the stack at 1.5bar. In order to control the operating stack temperature, a temperature control unit was installed.

An acoustic woofer (Sammi Sound Technology Corporation, SR-08B100) was installed in a rectangular chamber to produce an oscillatory flow. The rectangular chamber for the woofer was connected to the Plexiglas duct with a flexible tube to eliminate transmission of structural vibration. A function generator (HP-3120A) brought forth a sinusoidal signal with specific frequency and the signal was amplified by a signal amplifier. The amplified signal was delivered to the woofer via a digital oscilloscope (LeCroy, LT342) to check the input frequency and voltage.

The following procedure was adopted for the start-up, performance measurement and closing-down operation[9,17]. First, nitrogen was used to purge impurities inside the anode and cathode channels of the stack during 20 minutes. In an effort to activate the MEA inside the stack, the air and hydrogen were supplied for 30 minutes under a current loading of 3A. After reaching a stead state, the open-circuit-voltage (OCV) was measured. The current loading was increased to a specific value. The voltage output was determined from the stack in the steady state at constant operating temperature. The polarization curves were measured by using an electric load (Daegil Electronics Co., EL-500P) with various current loading conditions. After the measurement was finished, nitrogen was supplied to the anode and cathode for purging again in order to prevent degradation of MEA performance due to crossover of hydrogen and oxygen that remained at the anode and cathode. Simultaneously, the stack was cooled down by the temperature control unit until the stack temperature reached the ambient value.

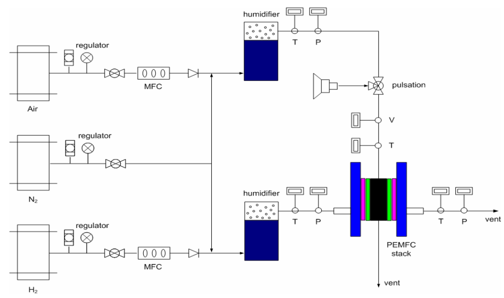
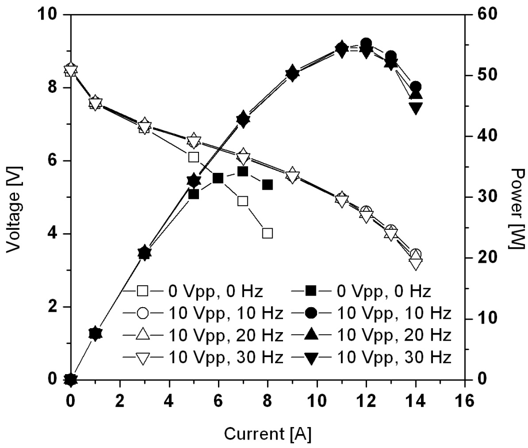


Fig. 1 Schematic diagram of experimental set-up

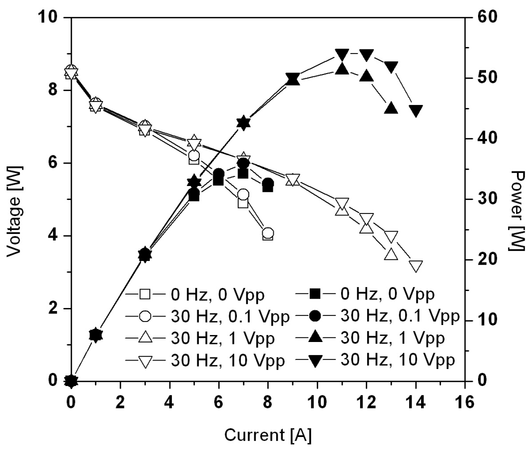
3. Results and discussion

In an effort to investigate the effect of the pulsating cathode flow, all experiments were carried out under the constant anode inlet condition. The flow rate, temperature and relative humidity of hydrogen were fixed at 1lpm, 40°C and 50%, respectively. The operating stack temperature was controlled at 50°C. For the cathode, the temperature and relative humidity of air at the cathode inlet were fixed at 33°C and 70%, respectively. The polarization and power curves of the NP50 stack according to the pulsating frequency and amplitude when the air flow rate is 10lpm, are demonstrated in Fig. 2. As is evident, the performance of a PEMFC stack is increased by the pulsating cathode flow which enhances the mass transport of reactant in cathode flow channels. The maximum power output in case of the uniform flow is approximately 35W.

However, when the pulsating component is added to cathode flow channels by woofer, it is dramatically augmented up to 55W. As shown in Fig. 2(a), there is no significant deviation between the uniform and pulsating flow in the activation loss region. However, the pulsating cathode flow has strong influence on the concentration loss region due to the enhanced diffusive mass transport of air between the catalyst layer in MEA and the flow channel in bipolar plate. Therefore, the corresponding power output is hardly ever affected by the pulsating flow at low current loadings, while the deviation of power output between the uniform and pulsating flow is considerably increased at high current loadings. Furthermore, the limiting current density is also enhanced from 7A to 11A. The polarization curve and corresponding power curve are hardly ever changed with the pulsating frequency (10Hz $\leq f \leq$ 30Hz). However, as illustrated in Fig. 2(b), the performance of the NP50 stack increases as the pulsating amplitude increases from A=0.1Vpp to A=10Vpp at a fixed pulsating frequency.

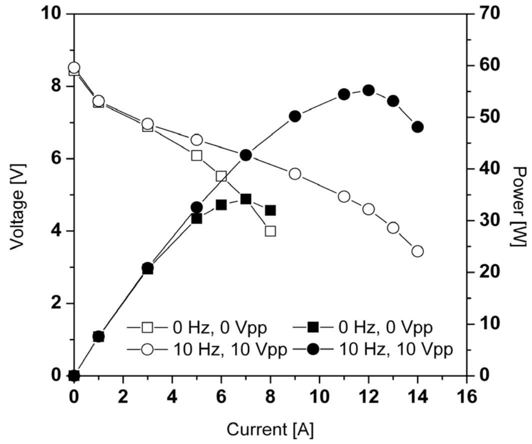


(a) Frequency

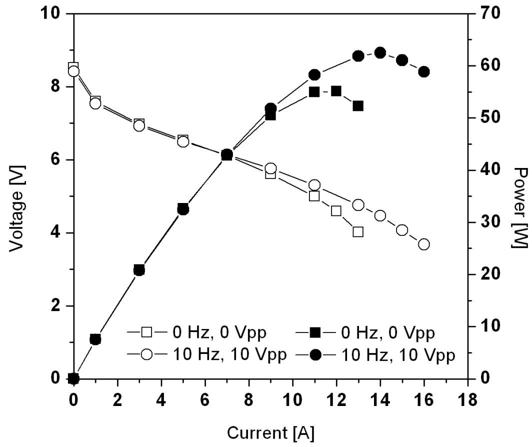


(b) Amplitude

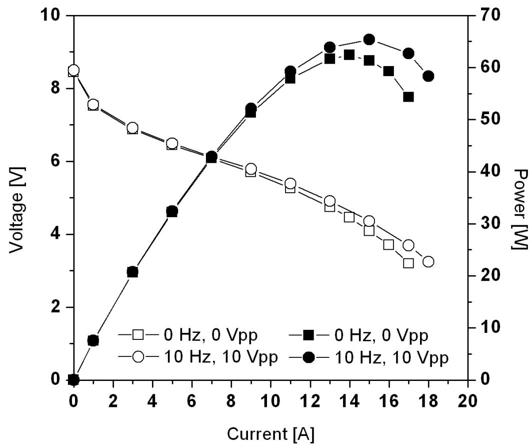
Fig. 2 Effect of pulsating cathode flow on polarization and power curves



(a) Q_c=10lpm



(b) Q_c=20lpm



(c) Q_c=30lpm

Fig. 3 Effect of pulsating cathode flow rate on polarization and power curves

Fig. 3 demonstrates the polarization curves and corresponding power curves of the NP50 stack according to the cathode flow rate when the pulsating frequency and amplitude are fixed at f=10Hz and A=10Vpp, respectively. The pulsating cathode flow provides 38%, 13% and 5% higher maximum power output compared to the uniform cathode flow when the cathode flow rate, i.e., Q_c is 10lpm, 20lpm and 30lpm, respectively. Enhancement of the NP50 stack performance is more pronounced as the flow rate decreases since the pulsating amplitude is fixed at A=10Vpp regardless of the cathode flow rate. Thus, the pulsating flow with the constant peak-to-peak amplitude gives rise to more enhanced mass transport at lower flow rate region.

4. Conclusions

The effect of the pulsating cathode flow on the overall performance of a 10-cell PEMFC has been investigated. The polarization curve and corresponding power curve are experimentally obtained to identify the effect of pulsating frequency, amplitude and flow rate on the overall performance. The performance of a 10-cell PEMFC is substantially increased by pulsating cathode flow which enhances the mass transport of reactant in the cathode channels. The increased power output and limiting current are measured at higher pulsating amplitude. On the other hand, the polarization curve and corresponding power curve is hardly ever changed with the pulsating frequency. The maximum power output increases by 38%, 13% and 5% when the cathode flow rate is 10lpm, 20lpm and 30lpm, respectively. Enhancement of the overall performance is more distinct at lower flow rate region.

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