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WATER CONTENT ESTIMATION OF PEM FUEL CELLS BASED ON EXHAUST BACK PRESSURE

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ABSTRACT

Water content is one of the most significant internal states which affects the performance and durability of proton exchange membrane fuel cells (PEMFCs). However, water content inside fuel cells is difficult to be directly measured. This study aims at developing a new method to fast estimate the water content inside fuel cells. We investigated the relationship between water content and the exhaust back pressure of fuel cells, which indicated that the exhaust back pressure is positively correlated with exhaust water concentration. Then, a two-step algorithm was proposed to estimate water content inside fuel cells. Finally, this algorithm was validated by high frequency resistance experiments. This new estimation method can calculate water content inside fuel cells quickly and is important in developing real-time control strategy.

Keywords: PEM fuel cells, water content, state estimation, exhaust back pressure, online algorithm

NONMENCLATURE

Abbreviations	
PEMFC	Proton Exchange Membrane Fuel Cell
CL	Catalyst Layer
EKF	Extended Kalman Filter
Symbols	
T_{in}	Temperature of cooling water entering the stack
T_{out}	Temperature of cooling water discharged from the stack

1. INTRODUCTION

With energy crisis and environmental pollution becoming increasingly serious, Proton Exchange Membrane Fuel Cell(PEMFC) is a promising alternative with advantages of high efficiency, zero emission, low noise, short start time, etc [1].

The internal state of the fuel cell affects the efficiency and durability of the system. And water content is the most significant but uncertain factor inside a fuel cell. However, the PEMFC is a complex system with coupling of multiphysics, making direct measurement and observation of water content still an unsolved problem. Considerable research has been conducted on this discipline. Seigel [2] established zero-dimensional moving front model to estimate the location of water phase transition inside the GDL. Mckay et al. [3] proposed a lumped parameter model, which can be used to develop a nonlinear open loop estimator of the membrane and electrode humidity. Hu et al. [4] proposed an estimation-oriented model, in which the cathode flow channel was equally divided into two volumes. This model can simultaneously estimate the liquid water saturation in cathode GDL and the current density difference. However, all the model-based estimation methods rely heavily on the accuracy of the model, which is difficult to be directly verified by experiments.

Some research has also been conducted on the relationship between AC impedance spectrum and internal state of fuel cells. Hou et al. [5] carried out experiments on a 2 kW stack and results indicated that the high-frequency ohmic impedance was an effective

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tool for reflecting the water content in the membrane. Toyota Motor Corporation [6] realized the online identification of the water content of the fuel cell with DC/DC converter. However, obstacles still exist when applying EIS to a PEMFC, because the clear relationship between the AC impedance spectrum and specific parameters is still not fully understood, and the device is complex.

This paper explored the relationship between the exhaust back pressure and the water content of the fuel cell, and proposed an algorithm which can online estimate the water content inside the membrane and the catalyst layer(CL) simultaneously.

2. EXPERIMENTS

In order to effectively estimate the water content inside the fuel cell stack, physical quantities that are directly measured should be used. And the exhaust back pressure is a variable which can be easily measured by sensors. We carried out experiments on a typical fuel cell test bench and found that the temperature fluctuated due to the control accuracy. Although temperature fluctuations are unavoidable, the range of changes is small and therefore acceptable. As shown in Fig 1, the stack temperature varied from 59 °C to 61 °C in around 10 minute cycles.

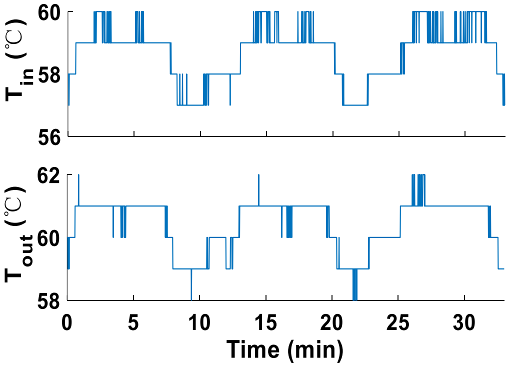

Fig 1 Temperature variety of cooling water entering the stack and discharged from the stack

We also found that the exhaust back pressure changed with time, as shown in Fig 2. Further data analysis found that the cycle of change in exhaust back pressure was consistent with the cycle of temperature fluctuations, indicating that the exhaust back pressure was affected by the internal temperature of the stack.

The changes in the temperature of the stack caused the membrane to circulate between water absorption and drainage and resulted in fluctuations in the water content inside the membrane, which further led to the changes of the water concentration in the exhaust.

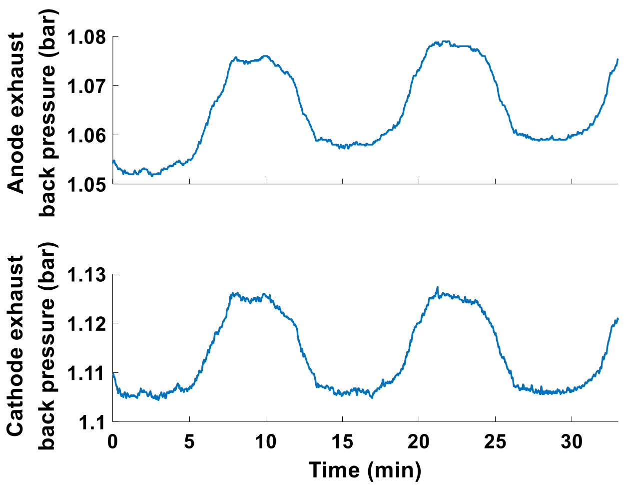

Fig 2 Changes in anode and cathode exhaust back pressure

Fluctuations in the water concentration cause changes in exhaust back pressure because the content of substance components affects the relative molecular mass, density and viscosity of the mixture. Thus, we explored the relationship between the exhaust back pressure and the water content inside the fuel cells.

The exhaust back pressure in the cathode and anode side both changes with the fluctuations in the cooling water which influence the water content inside the fuel cells. The experiment results indicate that the water content inside the fuel cell might affect the exhaust back pressure. Therefore, an algorithm could be proposed to estimate the water content cell using the exhaust back pressure.

3. ESTIMATION ALGORITHM AND VALIDATION

3.1 Estimation algorithm

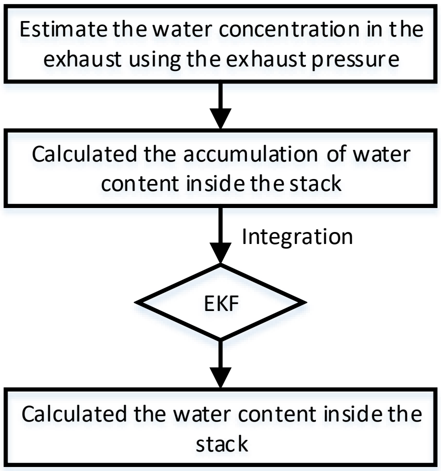

Fig 3 Process of the estimation algorithm

The process of the algorithm is shown in Figure 3. The first step of the algorithm is to estimate the water

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concentration in the exhaust using the exhaust pressure. If the exhaust contains liquid water, it is assumed to be a misty flow. Next, the Reynolds number of cathode and anode need to be assumed because they affect the friction factor in the two-phase flow [7]. It can be assumed that the cathode Reynolds number is between 2×10^3 and 2×10^4 due to the large flow rate. While the anode Reynolds number is assumed to be less than 2×10^3 because of small flow rate in anode. Then we can use the two-phase flow model to derive the equation for exhaust back pressure and the water concentration. Newton iteration method can be used to solve the nonlinear equation to obtain the water concentration in the exhaust.

The next step is to calculated the accumulation of water content inside the fuel cell stack. The Increment of water in the stack is equal to the water content in the intake gas plus the amount of water produced by the reaction, then minus the water content in the exhaust. The water content can be calculated by the integration of the Increment of water.

Then, the extended Kalman filter(EKF) with voltage feedback which is derived from on the reduced dimension model [8] is used to eliminate integral error and calculate the water content inside the proton exchange membrane and the CL, respectively. The detailed equations in the algorithm is not presented in this paper due to the length limit.

3.2 Algorithm validation

In order to verify the validity of the estimation algorithm, we used the data from the experiment mentioned above to calculated the water concentration in the exhaust. Fig 4 shows the water concentration in the anode exhaust obtained by the estimation algorithm.

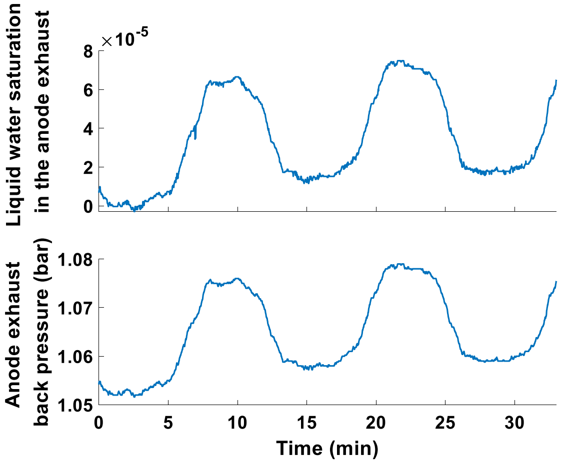
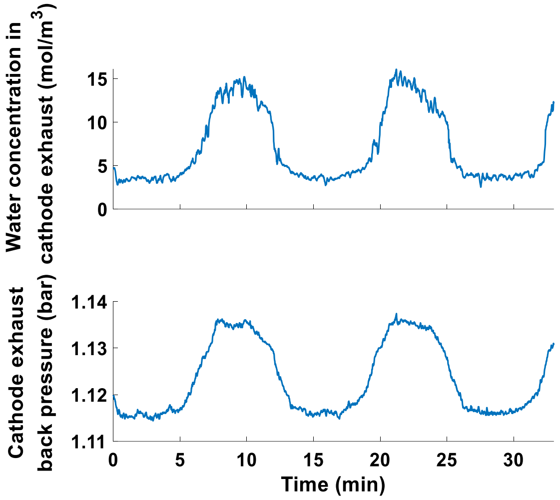


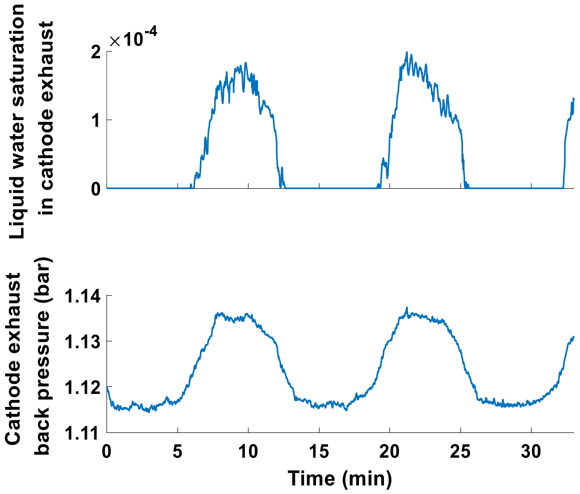
Fig 4 Liquid water saturation in the anode exhaust and anode back pressure

The water concentration in the exhaust is positively correlated with the exhaust back pressure because the mobile viscosity of the water vapor and liquid water is less than the other components in the exhaust. This strong correlation indicates that the method of estimating the water concentration in the exhaust based on the exhaust back pressure is reasonable. According to the assumption of the algorithm, the anode exhaust always contains liquid water and is therefore in a misty flow.

Fig 5 shows the water concentration in the cathode exhaust obtained by the estimation algorithm. The water concentration in the cathode exhaust fluctuates around saturated water vapor concentration. The state of the cathode exhaust is between the single gas phase flow and the misty flow containing liquid water. Therefore, the liquid water saturation in the cathode exhaust gas varies widely, and the maximum value reaches 2×10^4.



(a) Water concentration in the cathode exhaust



(b) Liquid water saturation in the cathode exhaust

Fig 5 Liquid water saturation in the cathode exhaust and cathode back pressure

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Fig 6 shows the results of Reynolds number calibration for anode and cathode exhaust flows. Since the anode flow rate is small and the cathode flow rate is large, and the dynamic viscosity of hydrogen is larger than that of air, the Reynolds number of the cathode exhaust gas flow is much larger than that of the anode side. The Reynolds number of the cathode exhaust gas flow and the anode exhaust gas flow are around 1.05×10^4 and 5×10^2, respectively, which are both in accordance with the assumptions of the algorithm.

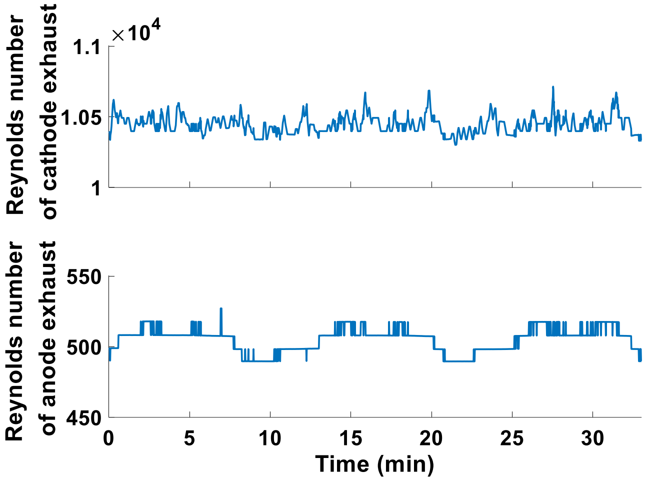

Fig 6 Reynolds number calibration

In order to verify the accuracy of the estimation algorithm. High frequency resistance scanning on a 50 cell stack was carried out, and the average cell high frequency resistance could be obtained. At the same time, the average cell high frequency resistance was calculated by the estimated water content in the membrane and the CL. Fig 7 shows the comparison between the calculated average cell high frequency resistance by the algorithm and measured average cell high frequency resistance. The estimated results of the algorithm were strongly consistent with the measured values, indicating that the algorithm had high accuracy.

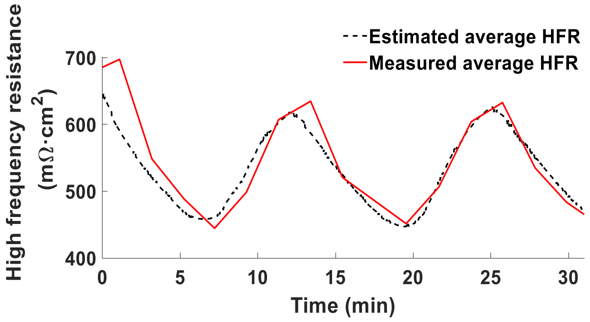

Fig 7 Estimated and measured average high frequency resistance

The results also indicate that the algorithm based on the exhaust pressure is an effective approach to estimating the water content inside the membrane and the CL of fuel cells.

4. CONCLUSION

The circulation between water absorption and drainage of the proton exchange membrane causes the change of water content in the exhaust of fuel cells, which further leads to fluctuations in the exhaust back pressure. In order to explore the relationship between the exhaust back pressure and the water content inside fuel cells, we carried out an experiment in which the temperature fluctuation of the cooling water was actively controlled. The results showed that the exhaust back pressure of both cathode and anode side were also changed, indicating that the exhaust back pressure was a reflection of water content inside fuel cells.

Then we designed an online algorithm for water content estimation using the exhaust back pressure. The algorithm utilized Newton iteration method to solve the nonlinear equation for the water concentration in the exhaust. The solution was then used in the EKF algorithm to estimate the water content inside the membrane and the catalyst layer simultaneously. An experiment of high frequency resistance scanning was conducted to validate the whole algorithm. The estimated results of the algorithm agreed well with the experimental measurements. This estimation algorithm will be applied to real-time state monitoring and water management of the PEMFC in future work.

ACKNOWLEDGEMENT

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