Development of Anodic Flux and Temperature Controlling System for Micro Direct Methanol Fuel Cell

M M Li, C Liu, J S Liang, C B Wu and Z Xu

1 Key Laboratory for Micro/Nano Technology and System of Liaoning Province, Dalian University of Technology, 116023, China
2 Key Laboratory for Precision and Non-traditional Machining Technology of Ministry of Education, Dalian University of Technology, 116023, China
E-mail: chongl@dlut.edu.cn, limiaomiao_mems@163.com

Abstract. Micro Direct Methanol Fuel Cell (μDMFC) is a kind of newly developed power sources, which effective apparatus for its performance evaluation is still in urgent need at present. In this study, a testing system was established for the purpose of testing the continuous working performance such as micro flux and temperature of μDMFC. In view of the temperature controlling for micro-flux liquid fuel, a heating block with labyrinth-like single pass channel inside for heating up the methanol solution was fabricated. A semiconductor-refrigerating chip was utilized to heat and cool the liquid flow during testing procedures. On the other hand, the two channels of a high accuracy double-channel syringe pump that can suck and pump in turn so as to transport methanol solution continuously was adopted. Based on the requirements of wide-ranged temperature and micro flux controlling, the solenoid valves and the correlative component were used. A hydraulic circuit, which can circulate the fed methanol cold to hot in turn, has also been constructed to test the fatigue life of the μDMFC. The automatic control was actualized by software module written with Visual C++. Experimental results show that the system is perfect in stability and it may provide an important and advanced evaluation apparatus to satisfy the needs for real time performance testing of μDMFC.

1. Introduction
Micro Direct Methanol Fuel Cell has a promising application prospect especially for portable power sources, because of its advantages such as high power density, high energy conversion efficiency, low start temperature and environmentally benign emission [1-4].

As a kind of special power system, μDMFC has different characteristics comparing with other power source, because of the requirements of volumetric shrinkage and newly developed manufacturing techniques [5]. For example, the thermodynamics characteristic of μDMFC may have new features comparing with the traditional fuel cell. With the volumetric reduction of the μDMFC, the influence of reactant temperature under micro flux conditions is to be determined by theoretical analysis and experimental study. However, present researches are still in a primary level and only suitable for fuel cells that range from several dozens watts to several thousand kilowatts, while the testing system for micro or miniature fuel cells are usually constructed in laboratories and could only meet some special evaluating requirements [6-7]. Under the demand of accurately controlling of micro
flux and wide-range temperature for liquid feed μDMFC, a testing platform includes soft and hardware module has been established in this work for the purpose of evaluating influence of anodic working condition on μDMFC performance.

Consider to the above mentioned requirements for the μDMFC testing, a newly developed controlling system to satisfy the needs for micro flux and accuracy temperature control, as well as long-term methanol solution circulation, was proposed in this paper. The schematic drawing of the whole controlling system is shown in Figure 1.

![Figure 1. Schematic drawing of the whole controlling system.](image)

A high accuracy, double channels syringe pump was used in the system for delivery of the methanol solution to the μDMFC. A programmable electronic load was adopted to simulate the variation of the external load and record the changing profile of output voltage and current of the μDMFC during the test. The temperature controlling of flowing methanol solution was fulfilled by a home made heat-and-refrigerate module. Finally, the control of flowing status of the methanol solution can be done by an elaborate designed hydraulic circuit as show in figure 1.

The functions of different modules of the above mentioned controlling platform are as follows: continuous methanol solution was transported by the two channels that can suck and pump in turn (when one channel pumps the methanol solution to the temperature control module, another channel will suck the methanol solution from first container; When needs to clean the fuel cell after experiment, deionized water will be pumped from the second container ); A PID based, closed-loop controller was utilized in the heat-and-refrigerate module to maintain the liquid temperature in the inlet of the μDMFC within the precision of ±1°C; The communication between computer and controllers is realized through the RS232 COM. Meanwhile, status information form different modules of the controlling system can be gathered by and displayed on the control computer.

2. Hardware and Software platform

2.1. Temperature control

The specifications of the temperature controlling module are as follows: temperature range from room temperature to 90 °C and controlling precision is ±1°C. Figure 2 shows the schematic drawing of this module.

In the temperature controlling module, the heating/cooling unit, which directly related to the temperature precision of the liquid flow, is one of the most important components. In order to control the temperature of the methanol solution through flowing pass of the liquid unit, a special temperature controlling package include a brass heating block, two piece of semiconductor-refrigerating chips and cooling fans was designed, manufactured and assembled in this work (as show in Figure 3 (a)). Inside
the block, a labyrinth-like flowing pass of the methanol solution was made to ensure adequate time for temperature heating and controlling of the liquid flow (Figure 3 (b)).

The total length of the flowing pass of the liquid and the power needed for changing the temperature of the methanol solution during the flow can be determined by the equation of the energy balance [8-9]. Assuming laminar flow in the channel, we can get:

\[ q_m C_p (t_1 - t_2) = \alpha \pi d l \left[ \frac{1}{2} (t_1 + t_2) - t_w \right] \]  

Herein, \( q_m \) is the heat density, \( C_p \) is specific heat of fluid, \( t_1 \) and \( t_2 \) are inlet and outlet liquid temperature, respectively, \( \alpha \) is the coefficient of heat convection, \( d \) is hydraulic diameter of the channel, \( l \) is total length of the channel, \( t_w \) is the local wall temperature.

According to the heat transfer criterion equation in the channel, we can also get:

\[ Nu_f = \frac{\alpha \times d}{\lambda} = 1.86 \times (Re_f \times Pr_f \times \frac{d}{l})^{1/3} \times \left( \frac{\eta_f}{\eta_w} \right)^{0.14} \]

\[ \alpha = 753.314 W / \left( m^2 \cdot K \right) \]

\[ l = 0.02408 m \]

\[ \frac{1}{\bar{\lambda}} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2} \]
Herein, $Nu_f$ is Nusselt number, $\lambda$ is thermal conductivity of fluid, $Re_f$ is Reynolds number, $Pr_f$ is Prandtl number, $\eta_f$ is dynamic viscosity of fluid, $\eta_w$ represents dynamic viscosity of fluid in the wall.

Thus the interior channel in the heating block should longer than $0.02408m$.

The semiconductor-refrigerating chip in this system is a device that can act as small heat pump. The heating or cooling status of the chip can be changed by changing the polarity of the supply current. Electronic device has a merit such as very fast response, small volume, without noise, and pollution free, etc. Figure 4 shows power supply and the transition circuit according to the controlling requirements of the semiconductor-refrigerating chip and the testing system.

Figure 4. The power actuation and the transition circuit.

2.2. Flowing control
In this work, the flow rate requirement of the methanol solution was set to 0-100ml per hour. Moreover, a long-term liquid circulation with temperature shifts between cold to hot are also needed for fatigue testing of the $\mu$DMFC. To satisfy these requirements, a flowing control system was designed as shown in Figure 5. There are four working positions of the flowing control system, which are listed as follows: (1) prepares the first liquid (such as methanol solution); (2) prepares the second liquid (such as the DI water); (3) pump the first liquid; (4) Pump the second liquid. Each working position of the flowing control system can be implemented by a certain status combination of the six solenoid valves that are shown in Figure 5.

Figure 5. Flowing control system.

2.3. Software design
The software module in this research was designed to provide functions to control, monitor and record the status parameters of the $\mu$DMFC and the whole control system. The software module was
programmed by using Object Oriented Visual C++ program language, and close-loop controlling scheme based on PID controller was also implemented. The main interface of the software module includes five functional parts: flow control, temperature control, hydraulic circuits’ control, fatigue test and status control. The real-time status parameters of the flowing control module can be gathered and displayed on the software interface that have an imitating LED style. The software also provides very convenient ways to the end user for setting different working modes as well as the limitation values of the whole system. For example, the working modes of the syringe pump, namely, high speed pumps, normal speed pumps and fast sucking, can be set by simply click on the relevant icon in the interface. The value of the liquid temperature can be display in the software by digital-tube-like windows and real-time curves of temperature versus time. On the other hand, the flow rate and temperature of the liquid fuel can be also acquired and stored in a certain files that are specified beforehand by the software module. Finally, the flow controlling module in the software provides an integrated environment for status control of the methanol solution and DI water subject to the requirement during performance evaluation of the μDMFC. The end user of this system can directly set experimental data in the interface instead of doing these jobs one by one in relative apparatus. As shown in Figure 6, the interface of software controlling module has a terse, explicit style and is very convenient for use.

3. Results and discussion
The photograph of the hardware of the integrated anodic flux and temperature controlling system for micro direct methanol fuel cell is shown in Figure 7.

The temperature sensors that installed in the outlet of the heating block are calibrated by using a two-step methodology. First, using a high accuracy mercury thermometer with 0.1°C resolution to calibrate the temperature sensor. The mercury thermometer and the temperature sensor are immerged into the water bath simultaneously, and different temperature values are enacted. The different temperature of the sensor and the thermometer under the steady state was recorded, and curves for precision comparison between the sensor and the thermometer were obtained. Second, the temperature sensors were installed into the outlet of the heating block and the inlet of the fuel cell respectively. The calibration results are shown in Figure 8. From the results, it can be seen that the error of the
The temperature sensor we used in our system is less than 0.4% (or ±0.4 °C within the whole testing range), which can well satisfy the requirement of the testing system.

The experiment was carried out in different points of testing temperature under constant liquid flow rate according to the requirement of the μDMFC. During the experiment, the liquid was heated to the expecting temperature when passed the labyrinth-like channel system, reached the outlet of the heating block, and heated the temperature sensor. For a static experiment consideration, each temperature testing was last for more than 800 seconds. Three curves with different expecting output temperature during this procedure were obtained by the sensors and compared. During the test, average temperatures data come from sensors that symmetrically installed in the outlet of the heating block were adopted. The controlling results of three different expecting temperatures (40, 60 and 80 °C) of the liquid fuel under a flow rate of 99 ml/h are shown in Figure 9. It can be seen from Fig.9 that with the increase of the expecting liquid temperature in outlet of the heating block, the heating time required will also increase, mainly because of the higher power loss as heat radiation at higher temperature. It also can be seen that the overshoots of each controlled expecting temperature are less than ±0.5 °C, fall into the range of the design requirement (±1 °C) of the system.

4. Summary

Under the demand of accurately controlling of micro flux and wide-ranged temperature for liquid fuel feeding to μDMFC, a testing platform including soft and hardware module has been successfully established in this work for the purpose of evaluating influences of anodic working condition on μDMFC performance. Experimental results show that the precision of temperature controlling of the system is better than ±1 °C, and the highest flux controlling precision is 0.1 ml/h. The system is perfect
in stability and very convenient for operation. It may provide an important and advanced evaluation apparatus, which will satisfy the needs for real time performance testing of μDMFC, to relative researches and potential fields of industry.

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