



Operational characteristics of a passive methanol catalytic combustor assisting vapor generation for direct methanol fuel cells



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ABSTRACT

Searching for a passive method to provide heat for a vapor-feed direct methanol fuel cell (DMFC) is still a challenging technical issue before it is put into practical use. This work develops a passive methanol catalytic combustor based on a pervaporation membrane, which is intended to be used as an assistant heat source for a vapor-feed DMFC. To validate the effectiveness of this method, a traditional bubbling-based system is prepared for comparison. Results show that the pervaporation operation outperforms the bubbling mode and facilitates self-ignition at a lower air feed rate (AFR). The increase of AFR promotes a higher permeation flux of methanol vapor, but may inversely cause heat loss because the enhanced air flow is apt to bring more heat away from the combustor. The AFR has dual effects on the processes of vapor generation and heat dissipation, which must be optimized to realize a balance between these two factors. The dynamic responses of catalyst temperature to the variation of AFR are also investigated in this work.

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1. Introduction

Using liquid fuel instead of hydrogen gas is regarded as a promising solution in favor of fuel storage safety, convenient operation and compact system structure for proton exchange membrane fuel cells [1–3]. In this field, an alternative way is to use an online hydrogen production system based on fuel reformation [4], but this method must call for extra power consumption and thus pulls down the system efficiency. With this background, increasing attentions are devoted to the direct methanol fuel cell (DMFC), which is more likely to be used for portable applications. Nevertheless, compared to the hydrogen-based fuel cell, a DMFC mostly has a lower power density due to catalytic inactivity and in particular methanol crossover (MCO) [5,6]. In order to mitigate the effects of MCO, a few groups attempted to use vaporous rather than liquid methanol to feed the fuel cell [7]. On the one hand, this idea helps reduce both methanol and water uptake in the polymer electrolyte membrane. On the other hand, the vapor flow brings in more heat to the reaction area to enhance the catalytic activity and accelerate the methanol consumption. These aspects combine to depress MCO to a great extent.

To this end, some studies used an electrical heater to vaporize the methanol fuel in a DMFC [8–10], but this inevitably causes more parasitic power losses and thereby reduces the system efficiency. An alluring choice is to reuse the waste heat from an external electronic device or

directly from a fuel cell through a dedicated heat-transfer element such as heat pipe and heat sink. However, this method must require more complex thermal management and system integration [7]. To address such issues, many researchers fall back on pervaporation membranes (PMs) to passively transform aqueous methanol into gaseous phase [11–13]. Although this technique gets rid of additional heating devices, how to actively control the generation rate of methanol vapor is still an intractable problem. Hence, it is quite necessary to develop controllable strategies for passive methanol vaporization.

A viable solution for passive heating is to incorporate a catalytic combustor as a heat provider for a vapor-feed DMFC. Guo and Faghri [14] proposed a novel approach based on catalytic combustion to assist in vaporizing the methanol fuel. For this embodiment, methanol was delivered by using a fuel wick connected to a fuel tank. Yuan et al. [15] compared different heating modes of a catalytic combustor used as the heat producer for a DMFC and evaluated the bubbling and injection methods for methanol supply. How to realize spontaneous start-up of the combustor was presented. Recently they designed a vapor-feed DMFC system coupled with a catalytic burner that used a sintered porous wick to transport methanol to the combustion chamber in a passive way [7]. Based on this method, the heat generation process could be adaptively regulated by altering the oxygen/air feed rate, thus promoting a more convenient control of the methanol vaporization process.

Despite the above efforts, there is still plenty of scope to explore the feasibility of using catalytic combustion to provide heat for vapor-feed DMFCs. In the present study, we attempt to combine the advantageous

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functions of pervaporation and catalytic combustion for heat production. A passive methanol catalytic combustor based on a pervaporation membrane is invented. Different from the traditional catalytic combustion system based on fuel pumping and electric heating, this prototype works in a passive-feeding mode, and can be started and operated in an ambient environment. This study gives out an effective way to realize fast start-up of the combustion reaction at a lower air flow rate, and validates a more compact system setup than that which depends on bubbling-based fuel feeding mode.

2. Experimental

2.1. Combustor design

Fig. 1 illustrates the configuration of the catalytic combustion system comprised of the main combustor, catalyst bed, gas mixing chamber, pervaporation membrane and liquid methanol chamber. For practical use, the open side of the main combustor can be connected to the host device, e.g. fuel cell. A built-in reservoir was created at the bottom for methanol storage. Methanol could be filled in through a fueling hole located in the side-wall of the methanol chamber. The Nafion® 117 membrane (Dupont, Inc.) was used as the pervaporation medium through which the methanol permeated and was released in the form of vapor phase. In the gas mixing chamber, the methanol vapor was mixed with the supplied air and then flowed toward the catalyst bed together. Here, the air flush offered an active force bringing the methanol vapor away from the phase-change interface so that the fuel could be continuously vaporized. A catalyst layer embedded inside the reaction chamber was sandwiched between the catalyst bed and gas cartridge. A single spiral channel was grooved at the bottom of the combustor for exhaust gas ventilation. To visualize the internal phenomena, we used polycarbonate to make the fuel chamber and gas mixing chamber. The catalyst bed and gas cartridge were made of aluminum. Several silicon rubber gaskets were used to seal the gaps between the involved components.

2.2. Catalyst fabrication

In this work, we used Pt/Al₂O₃/Ni as the catalyst for methanol combustion reaction. This catalyst system has been proven effective to trigger combustion reaction at an ambient temperature [16]. The catalyst layer was based on porous Ni foam with a nominal porosity of 95% and a thickness of 2 mm. For the sake of enhancing the effective surface area of catalyst support, the Ni-foam substrate was painted with a dispersing agent of 40 wt.% alumina sol and then sintered in a muffle furnace at 500 °C for 2 h. Subsequently, this composite was dipped into the chloroplatinic acid solution (0.02 g mL⁻¹) and treated under the same sintering condition. The catalyst Pt was finally achieved via reduction reaction between the chloroplatinic acid (H₂PtCl₆ · 6H₂O) and methanol vapor. This provides a more controllable method for Pt fabrication. In this study, a catalyst loading of 1.25% Pt was prescribed. The appearance and microscopic view of the catalyst layer were shown in Fig. 2.

2.3. Testing strategy and setup

In order to reveal how much methanol vapor left as well as the methanol/oxygen ratio of the reactants, we quantified the weight loss of the methanol in the whole system. Generally, the selective permeability of the pervaporation membrane was characterized by the value of total permeation flux, J (kg m⁻² h⁻¹), which could be calculated by the following equation [17,18]:

$$J = \frac{m}{A \cdot \Delta t} \quad (1)$$

where m , A , Δt respectively represent the permeation mass of the fuel (g), the effective permeation area (cm²) and the time (s).

Since the referred liquid phase in this experiment was only methanol, and the effective area of the pervaporation membrane was fixed, the variable J was used to characterize the methanol evaporation and methanol-supply ability of this system. After liquid methanol was

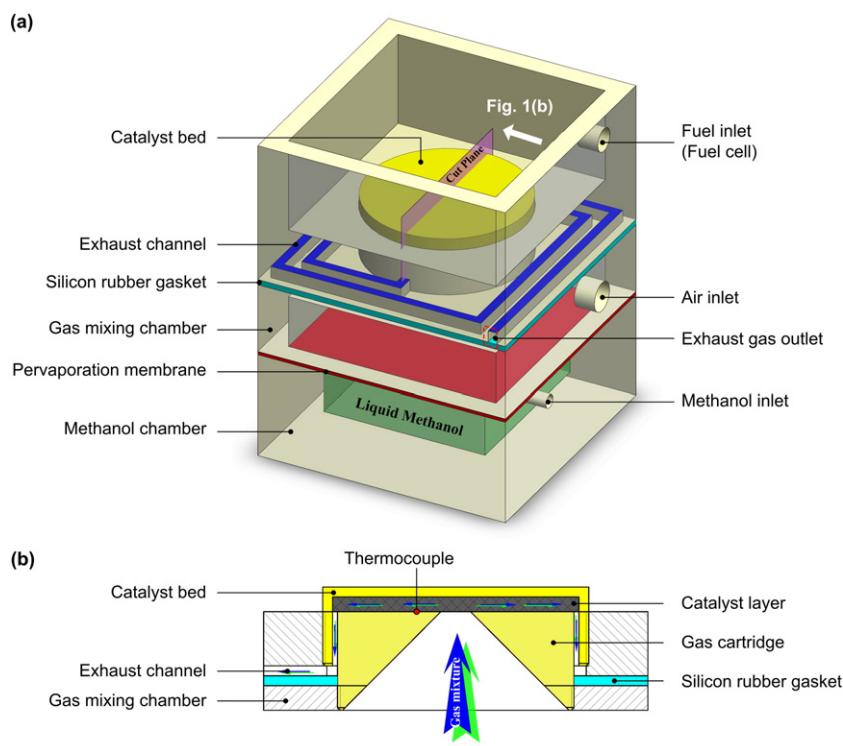


Fig. 1. Schematic of the configuration of the pervaporation-based passive methanol catalytic combustor.

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