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Short communication

Controllable fuel cell humidification by ultrasonic atomization

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HIGHLIGHTS

- An ultrasonic atomizer was designed to improve the efficiency for PEMFC.
- The atomizer can adjust the relative humidity to improve the fuel cell performance.
- The RH values can reach or exceed 90% for both air and hydrogen given optimal parameter settings.
- Compared to a bubble type humidifier, the atomizer can actively increase the humidity.

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ABSTRACT

Compared with the conventional bubble-type humidifier used for PEMFC (proton exchange membrane fuel cell) humidification, ultrasonic atomization has the advantages of a small size, ease in refilling and changing temperature, and more importantly, controllable humidity. This study develops a unique ultrasonic atomization system that includes a gas heating pipe, an ultrasonic driving circuit, an ultrasonic atomizer, and humidity sensors. The reactive gases used are hydrogen and air. The gas humidity increases due to the ultrasonic micro water droplets that blend with the gases. The humidity is controlled by adjusting either the heating temperature or the driving voltage. In addition, the size of the micro water droplets can be manipulated by adjusting the driving frequency. An increased driving frequency leads to a smaller mean droplet diameter, which increases the humidification efficiency. A relative humidity of at least 90% can be maintained for gas flow rates between 1 and 25 LPM. The conventional bubble-type humidification can achieve only ~80% relative humidity under the same conditions. The *I*–*V* curve also indicates that an optimal humidity is required for improved performance. Thus, a dynamic controllability of the humidification is important, especially for high-capacity FC (fuel cell) performance.

1. Introduction

Proton exchange membrane fuel cells (PEMFCs) are considered potential energy sources for automobile power and residential applications given their advantages over other fuel cells in terms of rapid start-up, high power density, low operating temperature, and immediate response to changes in the demand for power. However, PEMFCs require that high water content be maintained in the electrolyte to ensure high ionic conductivity. Therefore, the membrane must be fully humidified to offer a low resistance to the current flow and to increase the overall efficiency of the PEMFC [1,2].

Three methods for humidification have traditionally been employed: Bubble-type humidification is the most commonly used method in which the dry reactive gases are pumped directly into hot water and humidified after absorbing its thermal energy. Because the humidity is controlled by the temperature of the water, this method cannot easily control the humidity. Therefore, although this method is inexpensive and easy to operate, it is a relatively passive method. Because Teflon is breathable and waterproof, a membrane made of a thin Teflon film is also commonly used for humidification. Hot water passes over one side of a thin Teflon film, and the dry reactive gas passes over the other side. However, after long periods of operation, the pores of the Teflon film become blocked by impurities in the water, reducing the moisture exchange. In addition to these two methods, steam injection also provides an efficient humidification technique, utilizing a nebulizer to produce an intensive spray into an enthalpy mixer. The dry reactive gas is humidified when combined with the sprayed vapor. However, the humidification is discontinuous because the nebulizer is unable to produce a continuous spray.

Ultrasonic waves were first proposed for generating vapor sprays by Wood and Loomis in early 1927 [3]. They observed that a thin liquid layer could be atomized on a Langevin-type vibrator operating at 300 kHz. When a high-intensity ultrasonic wave

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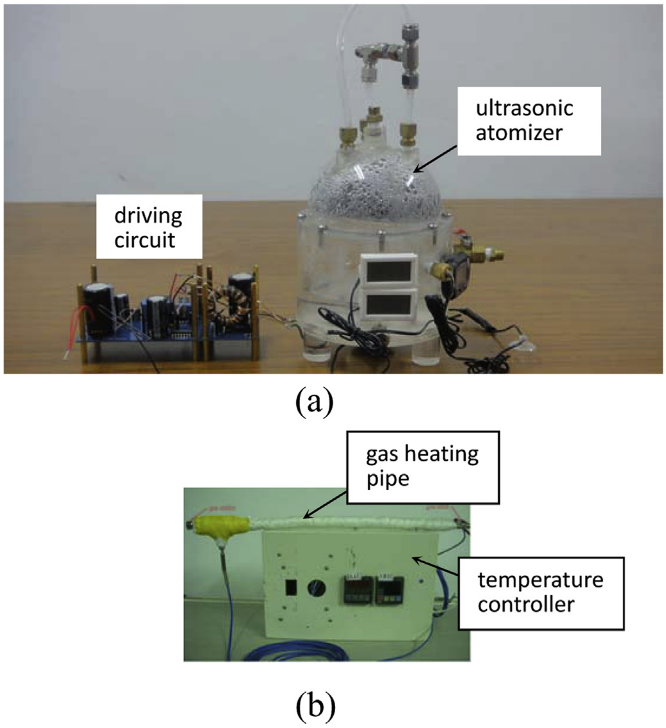

Fig. 1. Homemade ultrasonic atomization system (a) driving circuit and ultrasonic atomizer (b) gas heating pipe.

vibrates a liquid, small droplets can be excited from the surface of the liquid, a phenomenon called ultrasonic atomization. Ultrasonic atomization induced by a shock vibration from a piezoelectric crystal film can focus the energy into an ultrasonic geyser on the surface of the liquid. Cavitation can occur in the ultrasonic geyser, and the liquid can be transformed into a vapor bubble after vibration. The pressure in the bubble is quite unstable, and the diameter of the bubble increases with its internal pressure. When the pressure of the bubble reaches a critical value, it will eventually collapse. Then, the bubble is transferred to an intensive spray, achieving ultrasonic atomization [4–6]. In 1871, the size of a water droplet was compared with the wavelength of capillary waves calculated using Kelvin's equation [7]. In 1962, Lang studied the relationship between drop size and excitation frequency by measuring the size of drops generated from ultrasonic vibrators excited in the range from 10 to 800 kHz [8].

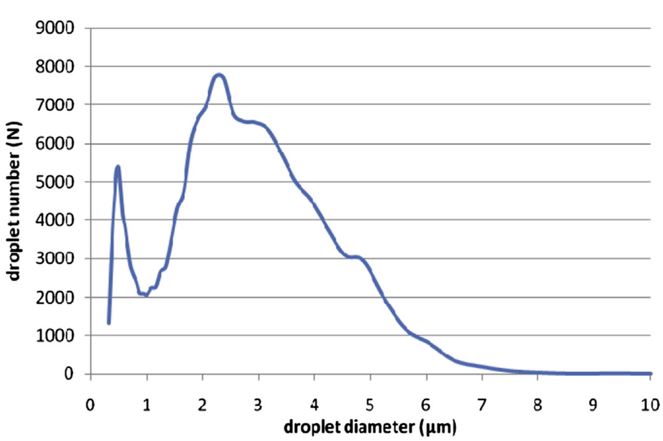

Fig. 2. The distribution of water droplet size for 2.58 MHz driving.

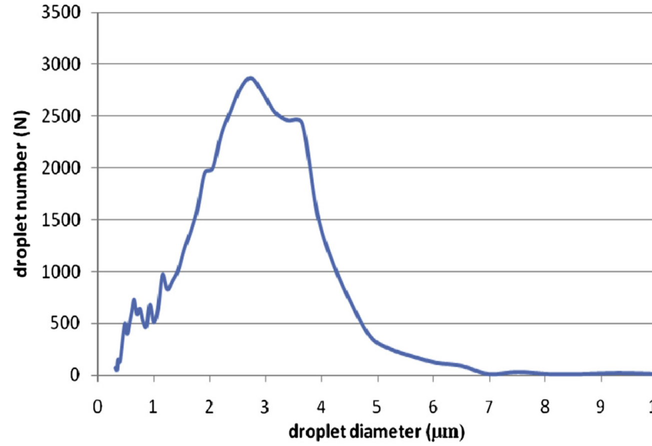

Fig. 3. The distribution of water droplet size for 1.75 MHz driving.

Because ultrasonic atomization is an efficient and controllable method for producing intensive sprays, a custom ultrasonic atomizer was used to study fuel cell humidification.

2. Experimental setup

The custom ultrasonic atomization system shown in Fig. 1 consists of a driving circuit, a gas heating pipe, an ultrasonic atomizer, thermal couples, and relative humidity (RH) sensors. The driving voltage is tunable from 30 to 150 V. The driving frequency ranges from 1.5 MHz to 2.6 MHz. The water particle size is dependent upon the driving frequency. To avoid the resonant frequencies of the piezo transducer, frequencies of 1.75 MHz and

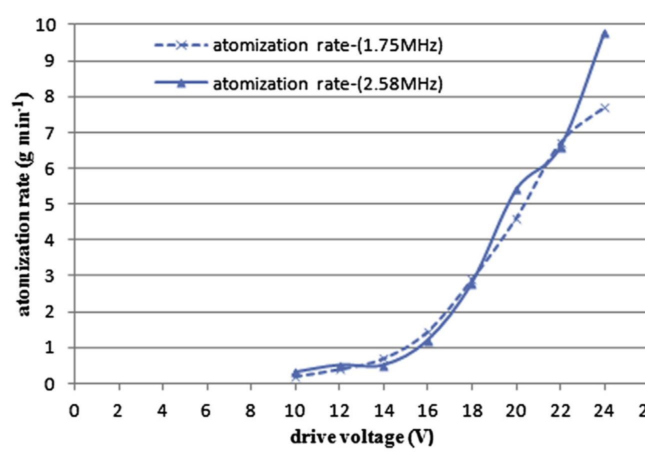

Fig. 4. The atomization rate for various driving voltage.

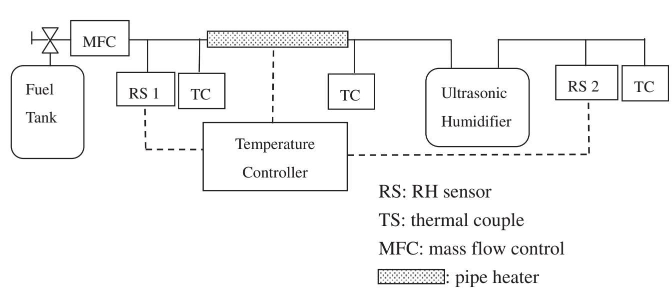

Fig. 5. The setup for the humidity measurement.