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Experimental determination of the water vapor effect on subsonic ejector for proton exchange membrane fuel cell (PEMFC)

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ABSTRACT

A test facility for experimental determination of the ejector, used in the anode recirculation loop of the polymer electrolyte membrane fuel cell (PEMFC), was set up in this paper. Based on a 1-dimensional constant-pressure mixing model, an ejector with a convergent nozzle and a cylindrical mixing tube was designed. By the test facility, entrainment ratio and hydrogen mole recirculation ratio of the designed ejector were tested on different conditions, corresponding to the PEMFC stack operation protocols. The difference of the entrainment ratio and the mole recirculation ratio effectively shows the influence of water vapor on the actual recirculation quantity of hydrogen fuel. Results show when the hydrogen was saturated humidified at 60 °C, the entrainment ratio of the designed ejector ranged from 2.3 to 2.8, changing the primary flow rate from 26 to 38 standard liters per minute (SLPM) and the mole recirculation of hydrogen ranged from 0.75 to 0.8.

Introduction

During practical PEMFC operation, water is created on the cathode as a result of fuel oxidant. Some of the water produced at the cathode may pass to the anode side where it can condense, and thereby creating water droplets that are accumulated on the surface of the flow path and may counteract the hydrogen fuel flow. This may result in insufficient hydrogen being provided to the active area of the fuel cell. In some PEMFC systems, excess fuel is passed through the channel to drive the water droplets, at the same time reduce the risk of fuel cell starvation [1–3]. The starvation usually leads to reverse current decay conditions, which are detrimental for the cathode catalyst carbon support [4,5]. However, to vent excess fuel into the atmosphere is undesirable in many instances. In order to minimize the waste that would result from venting the unconsumed reactants should be recirculated via a recirculation loop. And when anode gas recirculation is applied, impurities and inert gases accumulate in the anode gas recirculation loop, especially with high fuel utilization [6–8]. Ejectors, with a very simple mechanical structure and needlessness of parasitic power can realize it and were gradually used in the PEMFC system, some research works have been conducted about the ejector design and optimization for the PEMFC system [9–11].

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Kim et al. [11] addressed a methodology of design based on a 1-D constant-pressure mixing model or the ejector with a humidified recirculation hydrogen fuel in a submarine PEMFC. The subsonic flow ejector designed by the proposed approach has met the desired entrainment ratio through the whole operating range of the target system. Zhu et al. [10] introduced a new theoretical model that employed a two-dimensional concave exponential curve to analyze the flow characteristics of the convergent nozzle ejector, the treatment of velocity was an improvement compared to the 1-D ejector theories. Douglas et al. [12] has studied the variable geometry ejector, in which a needle can change the size of the primary supersonic nozzle opening to minimize performance loss.

In practical fuel cell system, the recirculated hydrogen fuel entering the ejector is expected to be or near saturation with water vapor, and possibly even contain liquid water droplets. Douglas et al. [12] carried out an experiment to proof-test the ejector's water tolerance by observing the losses of pressure rise from secondary inlet to outlet. However, the influence of water vapor, even liquid droplets, on the hydrogen recirculation capacity of subsonic ejector has not been studied. Due to the existence of water vapor in the secondary flow, the actual mass flow rate of recirculated hydrogen needs to be measured and calculated in an ejector test facility. And thereby, the stoichiometric ratio of hydrogen fuel will be calculated, which can reflect whether the excess of hydrogen can keep the PEMFC system a steady water management. Therefore, to set up an ejector performance test facility and investigating the factual hydrogen stoichiometric ratio is a significative and basal research.

In this paper, we aim to build an ejector test bench to investigate the performance of the ejector used in a PEMFC system for the given operating condition, which meets the designed value of the PEMFC stack, for example, the fluid of secondary flow is saturated humidification at 60 °C. Moreover, the ejector was manufactured according to the researches [9,13], and was improved on properly.

Experimental set up and procedure

Test facility

A schematic diagram of the ejector performance test system that was used in the present study is shown in Fig. 1. The system is mainly composed of a gas flow recirculation loop, including several gas circuit components and electrocircuit elements. The gas circuit includes pressure reducing meter, rotor flow meter, humidifier tank, globe valve, needle valve. The major elements of the electrocircuit are temperature transducers, heater, electric heating belt, temperature controlled meter and thermo switch.

The operation of the ejector performance test can be described as follows: the high pressure and normal temperature hydrogen from gas tank is adjusted to a required pressure by the pressure reducing valve enters the subsonic nozzle of the ejector. Through the convergent nozzle, the primary flow has a very high velocity at the exit of the nozzle and produces a high vacuum in the suction chamber, and it entrains the secondary flow into the chamber from the mixing flow, part of which is expelled to extensive space, surely security. The two flows first mix in the entrance of mixing chamber, and then, the pressure of the mixed flow rises to a pressure in the diffuser. The mixing flow discharges from the ejector to two paths, exhaust and recirculation respectively. For the recirculation loop, the secondary flow can be

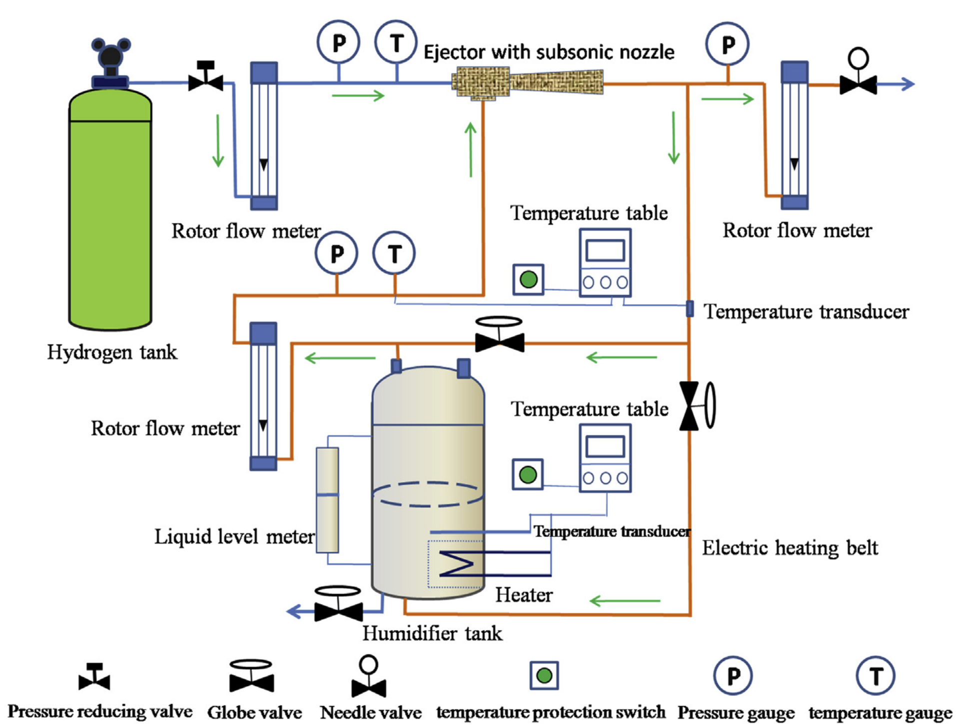

Fig. 1 – Schematic diagram of test facility.

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