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Short communication

Customized design for the ejector to recirculate a humidified hydrogen fuel in a submarine PEMFC

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Abstract

The customized design of an anode recirculation system that uses an ejector based on the humidified hydrogen is proposed for a submarine PEMFC. Generally, the ejector is useful to enhance its system performance and to easily be operated and maintained since it does not require any parasitic power and has very simple structure. However, the existing commercial ejectors do not meet the practical operating requirements of the PEMFC system with the humidified hydrogen recirculation since the included water raises the ejector performance reduction and accompanying operating limits. The subsonic flow ejector designed by the proposed approach has met the desired entrainment ratio through the whole operating range of the target system as well as it allows the additional advantages to improve the system efficiency and simplicity and to overcome the conventional operating limits.

Keywords: PEMFC; Ejector; Subsonic flow; Design; Submarine

1. Introduction

In a polymer electrolyte membrane fuel cell (PEMFC), one of the important issues to improve the efficiency of a fuel cell system is the hydrogen recirculation management. Hydrogen fuel to the anode side of the fuel cells is excessively supplied to reduce the risk of fuel cell starvation and to purge the water droplets that are accumulated on the surface of its flow path. However, releasing the unused hydrogen reduces the efficiency of the system and may have negative environmental impact. To solve this problem, Rodatz et al. suggest the use of an ejector and the used of a pump (or blower) as an anode side recirculates system [1]. In particular, the application of the ejector for the recirculation system of the automotive fuel cell is very useful in terms of its system efficiency, operation, and maintenance since the ejector needs no parasitic power and has very simple mechanical structure.

In case of the ejector for the automotive PEMFC, the performance of the entrainment ratio depends on the operating conditions of the PEMFC system. However, the commercial ejectors cannot meet the requirements of the ejector performance during those operations of the automotive PEMFC. Thus it is necessary to design the ejector customized for the fuel cell system. Many existing research works have been conducted about the ejector design for the refrigeration system, absorption system, and so on [2–5]. Recently, some studies to apply ejector into the fuel cell have been performed [6–8]. However, these approaches have some practical limits to assume the perfect water removal of the recirculated hydrogen. It is difficult to reach the perfect dry of the hydrogen as well as it arises the additional defects such as consumption of power, increase in a system complexity and frequent equipment errors by using an water removal equipment though they theoretically have showed a good performance.

This paper addresses the methodology of design for the ejector with a humidified recirculation hydrogen fuel in a submarine PEMFC. The proposed design approach make the customized ejector with constant throat and mixing tube areas be acceptable in not the whole operating range but the practical operating range. The main goal of the ejector design is to keep its entrainment ratio more than a predefined threshold during the practically acceptable operating range. To achieve the optimally customized ejector, the physical properties of the humidified hydrogen is newly introduced and subsonic ejector flow is applied to prevent a water freezing, a physical wear and a roaring sound which supersonic ejector flow generally raise due

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Nomenclature

A	area (m^2)
C_p	specific heat of gas at constant pressure ($kJ\,kg^{-1}\,K^{-1}$)
C_v	specific heat of gas at constant volume ($kJ\,kg^{-1}\,K^{-1}$)
D	diameter (mm)
f	flow rate (SLPM)
k	tolerance of the ejector exit pressure
M	Mach number
Mw	molecular weight
P	pressure (kPa)
R	gas constant ($kJ\,kg^{-1}\,K^{-1}$)
t	temperature (°C)

Greek symbol

γ	C_p/C_v

Subscripts

e	exit of ejector, condenser
m	flow mixed with the primary and secondary flows
mix	flow mixed with water and gas
P	primary flow
s	suction or secondary flow
sat	satuation
set	set point
sy	suction flow at the location of choking for the secondary flow

to the water in the recirculated hydrogen. And then the ejector manufactured according to the design values is verified by experimental test within the practical operating range. He design values are the diameters of the nozzle throat and mixing tube area.

2. Customized design approach

Fig. 1 shows the architecture of the proposed design procedure for the ejector with a humidified recirculation flow. The proposed approach is based on the two-dimensional and iteratively numerical solving method. Firstly, the ejector design conditions are defined based on the operating conditions of a target fuel cell system. From the given ejector design conditions, the initial pressure, temperature, flow rate of the primary and secondary flows are determined. And then two design values and the ejector exit pressure are iteratively calculated from the determined conditions by gradually updating the primary flow pressure until the calculated exit pressure is approximately equal to its required design. The detail relationships among the design values and the ejector's operating conditions are referred to [9]. The primary flow pressure has to be always more than the ejector exit pressure like Eq. (1). However, primary flow pressure can be less than the ejector exit pressure with the infeasible design values before the optimal solutions are found. Therefore, the optimal design values are also iteratively decided by updating the secondary flow Mach number until the relationship between the primary flow pressure and the ejector exit pressure (Eq. (1)) is acceptable. The detail equations needed to calculate can be also shown at [9]:

$$p_e \leq \left(\frac{2}{\gamma_m + 1}\right)^{\gamma_m/(\gamma_m - 1)} p_p \tag{1}$$

Fig. 2 shows the physical properties of the humidified hydrogen. In case of the PEMFC, the recirculated flow includes the water since the water is generated by the electric chemical reactions. The entrainment ratio is generally reduced since the molecular weight of the water is larger than that of the hydrogen. To overcome the problem, it is necessary to increase both the driving force from the primary flow and the suction area of the secondary flow based on the properties of the humidified hydrogen fuel. The water vapor saturation pressure is a strong function of temperature like Eq. (2). The water mass fraction according to the gas is calculated using Eqs. (3) and (4):

$$\log_{10} p_{sat,H_2O} = -2.1794 + 0.02953 t_{H_2O} - 0.000091837 t_{H_2O}^2 + 0.00000014454 t_{H_2O}^3 \tag{2}$$

$$x = \frac{p_{sat,H_2O}\mathrm{Mw}_{H_2O}/p_{mix}\mathrm{Mw}_{mix}}{1 - p_{sat,H_2O}\mathrm{Mw}_{H_2O}/p_{mix}\mathrm{Mw}_{mix}} \tag{3}$$

$$\mathrm{Mw}_{mix} = \frac{p_{sat,H_2O}}{p_{mix}}\mathrm{Mw}_{H_2O} + \left(1 - \frac{p_{sat,H_2O}}{p_{mix}}\right)\mathrm{Mw}_{gas} \tag{4}$$

3. Case study

3.1. Definition of design conditions

In case of the ejector for the automotive PEMFC, the performance of the entrainment ratio depends on the operating conditions of the PEMFC system. The operating conditions of the ejector are directly affected by the ones of the fuel cell system as followings (Fig. 3): (1) the primary flow rate of the ejector follows the various load required by the automotive application; (2) the exit pressure of ejector has to reach 300 kPa as the inlet pressure of the PEMFC stack; (3) the suction pressure in the recirculation flow has to drop into 277 kPa as the inlet pressure decreases throughout the anodic flow field; (4) the temperatures of the primary and secondary flows are varied by the operating temperature of the condenser. The design conditions of ejector from the target submarine PEMFC system are determined as shown in Table 1.

3.2. Results of the customized design

The Mach number represents the speed of a flow as followings: the Mach number 1 is a sonic flow, the Mach number more than 1 is a supersonic flow, and the Mach number less than 1 is a subsonic flow. The secondary flow Mach number is initialized with "1" and the changed amount of the Mach number is