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Humidification strategy for polymer electrolyte membrane fuel cells – A review

Yafei Chang[a], Yanzhou Qin[a], Yan Yin[a,*], Junfeng Zhang[a], Xianguo Li[a,b,*]

[a] *State Key Laboratory of Engines, Tianjin University, 135 Yaguan Road, Tianjin 300350, China*
[b] *Department of Mechanical and Mechatronics Engineering, University of Waterloo, Waterloo, ON, Canada*

HIGHLIGHTS

- Reviewed methods for the humidification of polymer electrolyte membrane fuel cells.
- Categorized into internal and external humidification methods.
- Presented advantage and drawback of each humidification method.
- Summarized suitable applications for each humidification method.

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ABSTRACT

Polymer electrolyte membrane fuel cells are promising power sources because of their advantage such as high efficiency, zero emission and low operating temperature. Water management is one of the critical issues for polymer electrolyte membrane fuel cells and has received significant attention. The membrane within the fuel cell needs to stay in hydrated state to have high ion conductivity and durability, which requires proper humidification. Both internal and external methods have been utilized to humidify the polymer electrolyte membrane. Numerous studies on fuel cell humidification have been conducted in the past decades, especially in recent years. This review aims to summarize the main humidification methods and the related studies. The internal humidification methods are classified as physical methods and chemical methods. The external humidification methods include gas bubbling humidification, direct water injection, enthalpy wheel humidification, membrane humidifiers, and exhaust gas recirculation. The working principle and performance of each method are introduced and the advantage and drawback are summarized. Further, the humidification methods for alkaline anion exchange membrane fuel cells are also briefly reviewed, because of more recent studies showing their potential of using non-precious metal catalysts. This review can help to choose proper humidification strategy for specific polymer electrolyte membrane fuel cell application and may inspire further investigations.

1. Introduction

Fuel cell is one of the most promising energy conversion devices which can convert chemical energy of the fuel (such as hydrogen) to electrical energy directly with high efficiency and zero pollution. It has consequently received increasing attention in recent years due to increasing concerns and awareness in the supply and use of primary energy, environmental protection and energy sustainability.

There are many different types of fuel cells according to the different electrolytes and fuels used, such as polymer electrolyte membrane fuel cell (PEMFC), direct methanol fuel cell (DMFC), solid oxide fuel cell (SOFC), molten carbonate fuel cell (MCFC), phosphoric acid fuel cell (PAFC), alkaline fuel cell (AFC), and alkaline anion exchange membrane fuel cell (AEMFC) [1]. Among all these types, PEMFC is regarded as the most promising alternative power source for automotive application owing to the advantage of low noise, low operating temperature and high power density [2]. It is also suitable for residential power generation since both heat and power can be utilized simultaneously with high efficiency [3]. In addition, PEMFC may be used for portable applications such as electronic devices, owing to its high energy capability [4]. The schematic of a PEMFC is shown in Fig. 1. It mainly consists of bipolar plate, gas diffusion layer (GDL), catalyst layer (CL) and polymer electrolyte membrane (PEM). Hydrogen is supplied to the anode while air (or oxygen) is supplied to the cathode.

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* Corresponding authors at: Department of Mechanical and Mechatronics Engineering, University of Waterloo, Waterloo, ON, Canada (X. Li).
E-mail addresses: yanyin@tju.edu.cn (Y. Yin), x6li@uwaterloo.ca (X. Li).

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Nomenclature

A	membrane area, m^2
$\dot{m}$	mass flow rate, kg s^{-1}
P	pressure, Pa
x	molar fraction

Greek letters

λ	stoichiometry ratio

Superscripts and subscripts

air	cathode inlet air
DI	dry side inlet
DO	dry side outlet
H_2O	water (liquid/vapor)
outlet	cathode outlet
sat	saturation

Abbreviations

1D	one dimensional
AEMFC	alkaline anion exchange membrane fuel cell
CFD	computational fluid dynamics
CL	catalyst layer
DMFC	direct methanol fuel cell
GDL	gas diffusion layer
MCFC	molten carbonate fuel cell
MEA	membrane electrode assembly
PAFC	phosphoric acid fuel cell
PEMFC	polymer electrolyte membrane fuel cell
PFSA	perfluorosulfonic acid
PSU	polysulfone
PTFE	polytetrafluoroethylene
RH	relative humidity
SOFC	solid oxide fuel cell
WRR	water recovery ratio
WTR	water transfer rate

Reactant gases flow through the GDLs, then electrochemical reactions occur in the CLs. The only by-product is water, thus the fuel cell is quite environmentally friendly.

Despite the advantages mentioned above, technical challenges such as water management remain to be resolved, hindering the performance improvement and commercialization of fuel cells. Water management has been regarded as one of the critical issues for practical PEMFCs [2]. The membrane needs to maintain sufficient hydration level to conduct protons efficiently. In addition, low humidification or non-humidification operation may accelerate the membrane degradation process due to the radical formation [5] and membrane dehydration [6]. However, too much water may result into the phenomenon known as water flooding in the porous electrode structures which may impede the reactants transport. Thus the amount and distribution of water within the fuel cell structure need to be optimized in order to achieve high conductivity and durability of the proton-conducting membrane while facilitating the transport of reactants.

In order to investigate techniques for the water management and humidification of PEMFCs, different methods have been proposed such as adding microporous layers [7], improving the GDL pore structure [8], and designing novel flow field structure [9]. The membrane is originally in dry state and needs to be supplied with water during operation. Internal or external humidification methods are adopted to humidify the membrane in most cases. The internal humidification methods are classified as physical methods and chemical methods in this paper according to the principles of operation involved. The external humidification methods include gas bubbling humidification, direct water (liquid/vapor) injection, enthalpy wheel humidifiers, membrane humidification, and exhaust gas recirculation. Humidification system is an important auxiliary system for PEMFC which may influence the performance and durability of the fuel cell. It is of great importance to choose proper humidification strategy for different applications. For example, for portable or vehicle applications, internal humidification may be preferable to reduce weight and space; while for stationary applications, sufficient humidification performance becomes more important, thus gas bubbling humidification or direct water injection method is more preferable. In order to choose proper humidification strategy, it is necessary to understand the characteristics and research techniques for each humidification strategy. Actually, plenty of work has been done comprehensively in recent years. However, very few relevant literature review about this topic has been published.

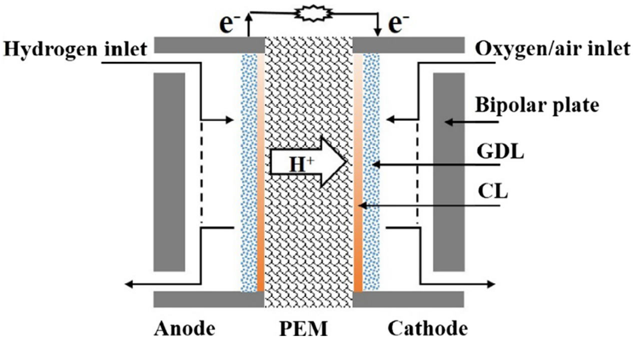

Fig. 1. Schematic of a proton exchange membrane fuel cell (PEMFC).

Thus the objective of this paper is to review the published studies on the internal and external humidification methods for PEMFCs. The advantage and disadvantage of each method are summarized and recommendations are given for practical applications. Furthermore, AEMFCs have been drawing much attention in recent years because of the possibility of using non-precious catalyst in alkaline environment [10]. Water management for AEMFCs shares much similarity to PEMFCs, although they also have their uniqueness which results from the different electro-chemical reactions involved. Thus challenges to the water management and humidification for AEMFCs are also briefly described.

This review is organized as follow. Internal humidification methods are presented in Section 2. Internal humidification is classified as physical methods and chemical methods, which will be given in Section 2.1 and 2.2 separately. External humidification methods are reviewed in Section 3 including gas bubbling humidification, direct water (liquid/vapor) injection, enthalpy wheel humidifiers, membrane humidification and exhaust gas recirculation. Humidification for AEMFCs is provided in Section 4, emphasizing the difference from and similarity to PEMFCs. Finally, the conclusions and directions for future research are given in Section 5.

2. Internal humidification

The internal humidification methods aim to maintain the membrane in a hydrated state by changing the internal PEMFC structure or composition without adopting external devices. According to the different water management strategies, internal humidification methods are classified as physical methods and chemical methods in this review.