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Development of cylindrical laminated methanol steam reforming microreactor with cascading metal foams as catalyst support

Wei Zhou [a,b,*], Yuzhi Ke [a], Qinghui Wang [c], Shaolong Wan [d], Jingdong Lin [d], Junpeng Zhang [a], K.S. Hui [e]

[a] Department of Mechanical & Electrical Engineering, Xiamen University, Xiamen 361005, China
[b] State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 10084, China
[c] School of Mechanical and Automotive Engineering, South China University of Technology, Guangzhou 510640, China
[d] College of Chemistry and Chemical Engineering, Xiamen University, Xiamen 361005, China
[e] School of Mathematics, Faculty of Science, University of East Anglia, Norwich NR4 7TJ, United Kingdom

HIGHLIGHTS

- Cascading metal foams were used as catalyst supports in microreactor for hydrogen production.
- Ultrasonic vibration method was employed to investigate the loading performance.
- Metal foams without clearance cascading showed the highest hydrogen production performance.
- Methanol conversion and H_2 flow rate gradually increased with increasing PPI.
- Cu foam exhibits increased hydrogen production and higher stability than Ni foam.

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ABSTRACT

In this study, the cascading metal foams were used as catalyst supports for constructing a new type of cylindrical laminated methanol steam reforming microreactor for hydrogen production. The two-layer impregnation method was used to load the Cu/Zn/Al/Zr catalysts, and the ultrasonic vibration method was then employed to investigate the loading performance of metal foams with different types and thicknesses. Furthermore, the effect of the type of catalyst placement, pores per inch (PPI) and foam type on the performance of methanol steam reforming microreactor was studied by varying the gas hourly space velocity (GHSV) and reaction temperature. Compared with two other types of catalyst placement studied, the microreactor containing catalyst-loaded metal foams without clearance cascading (3×2) showed the highest hydrogen production performance. When the PPI of the metal foam was increased from 50 to 100, both the methanol conversion and the H_2 flow rate gradually increased. Our results also showed that a microreactor with Cu foam as a catalyst support exhibits increased hydrogen production and higher stability than those of a microreactor with Ni foam.

1. Introduction

Hydrogen has received extensive attention as an energy source because it has a higher combustion heat value and pollution-free characteristics [1]. In recent years, with the development of proton exchange membrane fuel cell (PEMFC) technology, the expectations have risen that hydrogen will become a significant clean fuel in the near future [2,3]. However, hydrogen also has several obvious disadvantages such as a low boiling point, high flammability, and difficulty of transport and perfusion, which hinder the popularization and application of PEMFC. Currently, the online hydrogen fuel processing systems involved the microchannel technology, which is characterized by compactness, high efficiency, and low cost, and can convert liquid hydrocarbon fuel to hydrogen for PEMFC in transient operation [4,5]. Microchannel reactors can be integrated with PEMFC, which does not increases the volume and weight significantly, while the fuel cells can use the existing hydrogen fuel system to provide a continuous supply of hydrogen, which is an important foundation for the construction of effective fuel cells. Therefore, the development of efficient microreactors for hydrogen production is crucial to meet the requirements of various applications [6].

* Corresponding author at: Department of Mechanical & Electrical Engineering, Xiamen University, Xiamen 361005, China.
E-mail address: weizhou@xmu.edu.cn (W. Zhou).

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In general, the traditional microreactors for hydrogen production are classified into three types—parallel, curved, and micro-pin-fin arrays—and fabricated by means of MEMS, laser machining, electrical discharge machining, and traditional machining technology [7–12]. The catalyst is usually coated by means of impregnation as well as chemical and physical vapor deposition. However, the catalysts coated on these structures exhibit a series of disadvantages such as low adhesion, ease of shedding, and high machining cost [13–15]. The microreactors for the methanol steam reforming reaction with porous metal materials as catalyst support are characterized by short reaction flow path and low pressure drop, and the catalyst support has a three-dimensional porous structure and a large specific surface area, such that the catalyst can be coated more evenly to form a microstructure catalyst [16]. Thus, porous materials show potential as a new generation catalyst supports of microreactors for hydrogen production. Metal foams [17–20], metal fiber porous materials [21–24], and porous ceramics [25] have all been successfully used in various chemical reaction systems.

Metal foams are commonly made by means of a direct foaming of metals, in which mass production may be implemented easily with low cost [26]. Metal foams are made up of mesh pore and have a polyhedral shape exhibiting high specific surface area, low density, and large pore size, and have been widely used as catalyst support materials [27]. Roy et al. developed a methane reforming reactor for hydrogen production with a Pd-Rh metal foam catalyst structure; they found that it demonstrated excellent catalyst stability and activity, and could be widely applied in the processing of solid oxide fuel cell [18]. Aartun et al. coated a Rh catalyst on the surface of aluminum foam by means of impregnation, and then was successfully employed for the partial oxidation and steam reforming reaction of propane [19]. Yang et al. prepared a Co-W-B-P/Ni catalyst on the surface of a nickel surface using ultrasonic assisted electrodeposition, and showed that the catalyst can be used in the hydrolysis process of ammonia borane with a remarkable hydrogen production efficiency due to its high catalytic activity and recyclable properties [20].

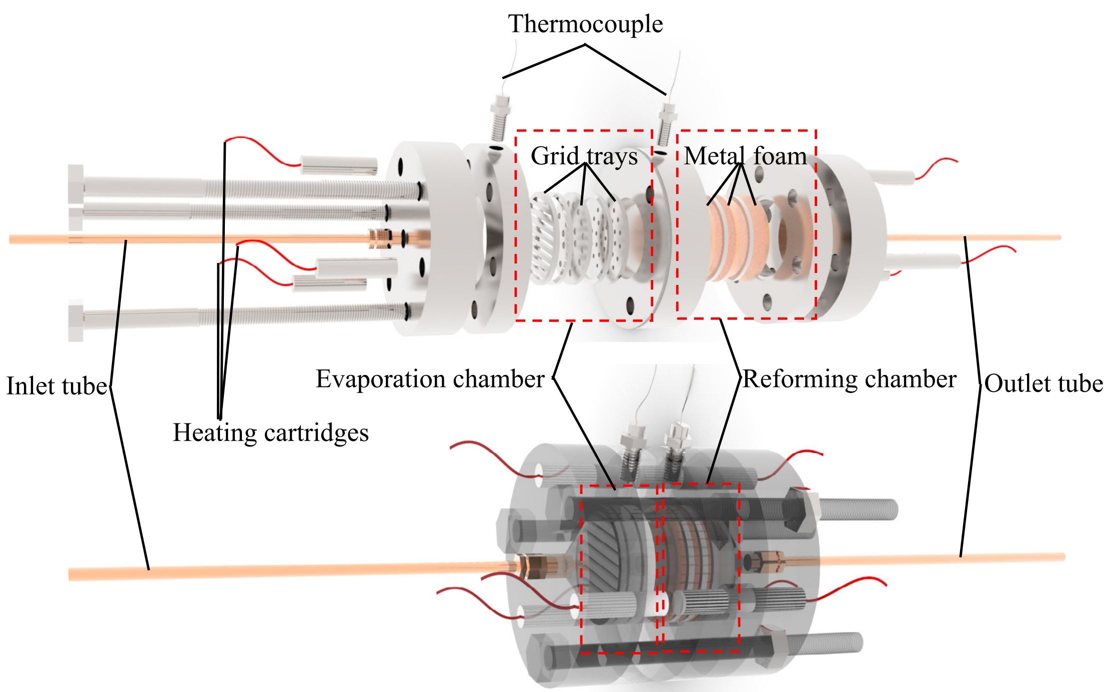

Fig. 1. Diagram of cylindrical laminated methanol steam reforming microreactor for hydrogen production.

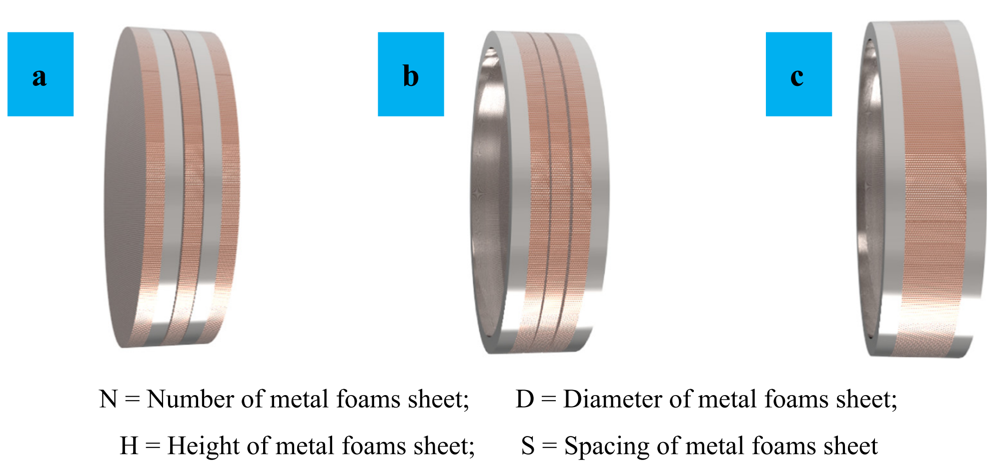

Fig. 2. Diagram of the three types of metal foam placement in the reforming chamber: (a) T1: N = 3, D = 40 mm, H = 2, S = 2; (b) T2: N = 3, D = 40 mm, H = 2, S = 0; (c) T3: N = 1, D = 40 mm, H = 6.