Renewable Energy 39 (2012) 313–322

Contents lists available at SciVerse ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Qualitative investigation on effects of manifold shape on methanol steam reforming for hydrogen production

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ARTICLE INFO

Article history:
Received 4 May 2011
Accepted 16 August 2011
Available online 3 September 2011

Keywords:
Methanol steam reforming
Velocity distribution
Fluid mechanics
Numerical analysis

ABSTRACT

Fluid velocity distribution among microchannels plays important role on the reaction performances. In this work, the velocity distribution among microchannels with two different manifold structures is compared by a three-dimensional CFD model under two situations respectively, no reaction and methanol steam reforming occurs. Then the performances of methanol steam reforming in both plates are experimentally investigated, and the effect of manifold shape on the hydrogen production performances is qualitatively analyzed by the combination of simulation results of velocity distribution. It is found that the microchannel plate with right-angle manifold enables narrow velocity distributions under different entrance velocities and reaction temperatures, whether no reaction occurs or methanol steam reforming is progressing, which can be the critical element results in better conversion rate and selectivity of process than that of the microchannel plate with oblique-angle manifold. Optimizing the structural parameters to facilitate a relatively uniform velocity distribution to increase the hydrogen production performances may be a key factor to be considered.

1. Introduction

Technical progress over the last decade has enabled Polymer Electrolyte Membrane Fuel Cells (PEMFCs) to be gradually applied as portable power supply within 5–10 years [1]. Although PEMFC technology has been well developed, the choice of fuel supplying the fuel cell with hydrogen is still unresolved. Hydrogen can be directly stored on board or produced on site by reforming liquid hydrocarbon fuels using microchannel reactors. The latter method has been the primary focus of interest [2]. Among various types of fuel, methanol is one of attractive fuels due to its low reforming temperature, high hydrogen-to-carbon ratio and safety storage. Moreover, of all considered reactions, methanol steam reforming offers the highest attainable hydrogen concentration, of up to 75%, and a relative small amount of carbon monoxide [3,4].

As on-board hydrogen supply for PEMFCs, microchannel fuel reformers need to be addressed several challenges, such as compactness, lightweight, rapid start-up and high reliability. Great efforts had been made to focus on the integration of reformer system [5–7] or their components, such as catalysts [8,9], reaction mechanisms [10,11]and fuel option [1,12]. Reactor construction is also one of important factors for the reaction performances. Nowadays, laminated-sheet structure as shown in Fig. 1 is regarded as one of the preferred constructions for microchannel fuel reformers, in which multiple sheets patterned with parallel microchannels and manifolds are stacked and then brazed or bonded together [13–17]. How to optimize the structural parameters of microchannel sheet to improve the reaction performances of hydrogen production has always been a research focus.

Fluid velocity distribution among microchannels plays an important role on the reaction performances. Relatively uniform velocity distribution offers clear advantages such as high conversion rate and selectivity of process. A lot of researches [18–20] had been focused on the fluid velocity distribution among microchannels by numerical modeling or simulation. It was found that the structural parameters of microchannels and manifolds greatly influenced the velocity distribution among microchannels. However, sparse attempts have been reported in the literature concerning on how to increase the hydrogen production performances by optimizing the structural parameters to facilitate a relatively uniform velocity distribution.

It is obvious that the structural parameters of microchannels govern the velocity distribution among microchannels. However, the manifold shape also shows significant effects on the velocity distribution [21–23] In addition, the design of manifold shape is generally limited by the sheet dimension. In this work, two kinds

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0960-1481/$ – see front matter
doi:10.1016/j.renene.2011.08.027

of microchannel plates with different manifold structures were selected to analyze the velocity distribution among microchannels by a three-dimensional CFD model. Velocity distributions in both plates were compared under two situations respectively, no reaction and methanol steam reforming occurred. Then the performances of methanol steam reforming in both plates were experimentally investigated, and the effect of manifold shape on the hydrogen production performances was qualitatively analyzed by the combination of simulation results of velocity distribution.

2. Simulation and experimental

2.1. Microchannel plate structure

The lamination of multiple microchannel plates could be favor for the coupling of endothermic and exothermic reactions to improve energy recycle. As a result, the manifold shape was generally designed to be oblique-angle [13–15]or right-angle [16] for leaving another side as a separate flow passage of another fluid. In this work, two kinds of typical manifold structures were applied as prototypes to investigate their effects on the performances of methanol steam reforming for hydrogen production, as shown in Fig. 2, one was the microchannel plate with right-angle manifold (MPRM) and the other was the plate with oblique-angle manifold (MPOM). 2 mm-thick red copper was used as the plate material. The structural parameters of two kinds of manifolds were shown in Fig. 2(a) and (b), respectively. Each plate contained 50 parallel microchannels fabricated by micro-milling process, with dimensions of 35 mm in length, 270 μm in width and 1000 μm in depth, as shown in Fig. 2(c).

2.2. Numerical simulation

When methanol steam reforming is progressing, the velocity values of reactants in multiple microchannels are difficult even impossible to be exactly measured by experiments since a gas mixture of reactants and products contains in the microchannels. Only some works had been done to measure the velocity value of single fluid in a single microchannel [24,25] or observe the flow pattern in parallel microchannels [26,27]. So the fluid velocity distributions under different temperatures and entrance velocities corresponding to the gas hourly space velocities (GHSV) were qualitative analyzed by numerical simulation performed with Fluent software here.

The flow zone of fluid was extracted from the microchannel plate as a simulation object for the analysis of velocity distribution, as shown in Fig. 3. The model consisted of an inlet and corresponding manifold, an outlet and corresponding manifold as well as parallel microchannels with rectangular cross-sections. The primary distinguishes of two manifold shapes resulted from the different location of inlet/outlet. In the design process of manifolds, the bottom length L_m and side height H_{in}/H_{out} of manifolds were firstly determined, and then the position and magnitude of the inlet/outlet were chosen, two tangent lines from the manifold bottom and side to the inlet/outlet were respectively made, which yielded the final manifold shape. Two coordinate systems $X_1O_1Y_1$ and $X_2O_2Y_2$ were established to determine the relative position of manifold and inlet/outlet, respectively. The coordinate of inlet P_{in} and outlet P_{out} in respective system were defined as (X_{in},Y_{in}) and (X_{out},Y_{out}). And their radiuses were respectively defined as R_{in} and R_{out}. The microchannel length, width, depth and number were defined as L_c, W_c, E and N, respectively. Microchannels were

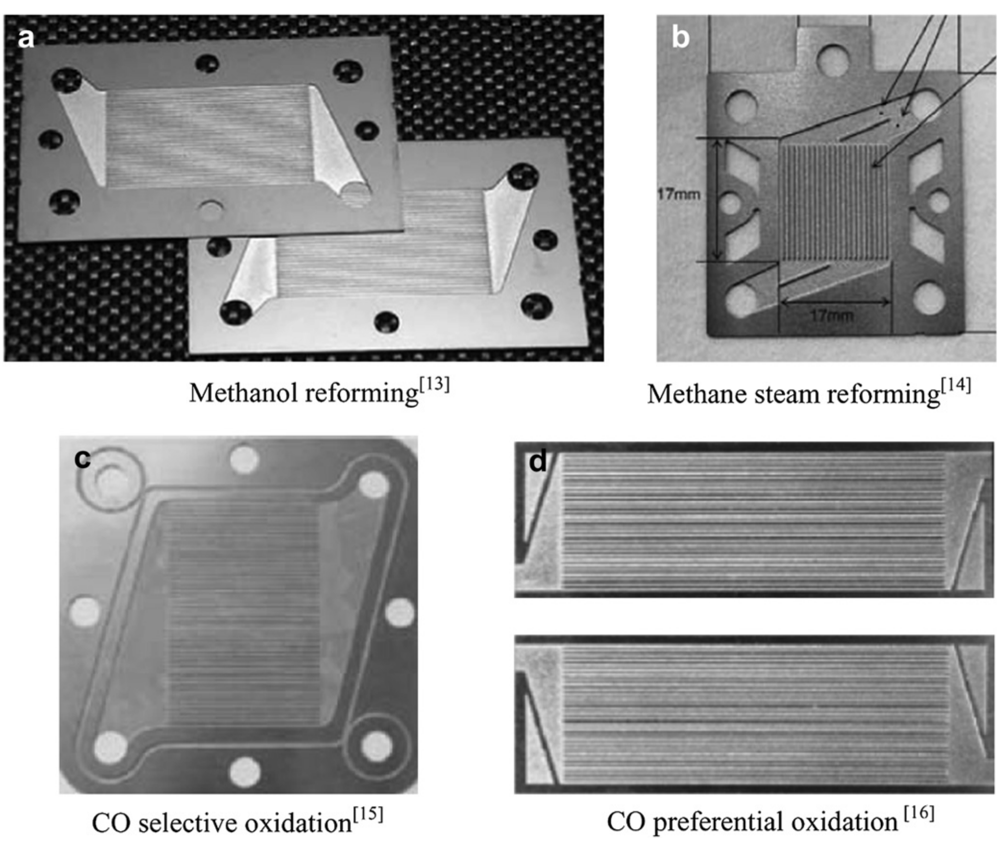

Fig. 1. Typical structures of microchannel sheets used for microchannel fuel reformers.