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Short communication

A plate-type reactor coated with zirconia-sol and catalyst mixture for methanol steam-reforming

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Abstract

A plate-type reactor with 10 channels is designed for methanol steam-reforming and its performance is investigated in the temperature range 210–290 °C. A catalyst coated with zirconia-sol solution in the channels of the reactor exhibits a good adherence with the substrate that is maintained even after reaction including fast feed flow rates at high temperature. Five plate-type reactors are stacked in order to test their performance for methanol steam-reforming. At 270 °C, hydrogen at 3.1 l h^{-1} is obtained at a feed flow rate of 2.0 g h^{-1}, which corresponds to results for a conventional packed-bed reactor under various reaction conditions.

Keywords: Plate-type reactor; Methanol steam-reforming; Zirconia-sol solution; Fuel cell; Hydrogen production

1. Introduction

Large amounts of hydrogen are used for many industrial applications [1,2]. More recently, hydrogen has attracted interest as an energy carrier for fuel cells, especially in vehicle applications, due to its high efficiency and negligible pollution [3,4]. It is difficult, however, to store and handle hydrogen directly as an on-board fuel. On the other hand, fuels such as gasoline, ethanol, methane and methanol can be converted into hydrogen-rich gas. This can be achieved through various technologies such as steam-reforming, autothermal reforming, and partial oxidation that involve various unit components such as a reformer, a shift reactor and a selective oxidation reactor. Methanol is an attractive fuel because of its low reforming temperature and low content of sulfur compounds. The former attribute results in reduced heat losses, requires less insulation and simplifies thermal management of the integrated system. In addition, methanol offers much higher specific energy than either lithium batteries or stored hydrogen, which makes the fuel an attractive candidate for portable power systems.

It is important for the fuel reformer to be both small and lightweight for portable devices. Conventional reformer technology based on the packed-bed reactor has disadvantages in terms of size and weight. Therefore, there has been considerable interest in the development of microreactors with microchannels [5–11]. The microreactor exhibits reduced heat and mass transfer resistances and allows chemical reactions to proceed at much higher rates, which provides for increased efficiency.

Battelle [6–8] has developed micro-process technology for various devices including fuel vapourization, fuel processing, catalytic combustion, and partial oxidation. A microchannel methanol reformer of size ranging from 25 to 100 W_e has been designed and tested. The system consists of a methanol reformer, a combustor, two vapourizers, and a heat exchanger. Other researchers [12] developed a methanol steam-reformer that consisted of stainless-steel plates with microchannels. The plate-type micro reformer had dimensions of 75 mm × 45 mm × 100 mm and comprised of six plates with 40 channels each. The reformer used a Cu/ZnO

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catalyst and was operated at 150–270 °C. A sufficient amount of hydrogen for running a 50 W_e unit was obtained.

A plate-type methane reformer has also been patented [13]. The main unit included a combustor filled with a catalyst and a reforming reactor filled with another catalyst. A heat-conductive partition wall was sandwiched between the combustor and the reformer, and therefore effective heat transfer was achieved and the reformer was more compact than a conventional tubular reactor. On the other hand, Loffler et al. [14] developed a more compact plate reformer in which the catalyst was coated on the plate such that, the heat was transferred only through a solid.

In this study, a plate-type reactor with channels is developed and is evaluated for methanol steam-reforming. The reactor is designed such that the heat from the combustion reaction is used for the endothermic reforming reaction. The performance of the plate-type reactor is investigated at various operating conditions and compared with that of a packed-bed reactor. In addition, a technology for catalyst coating is presented in order to improve the adherence between the catalyst and the substrate.

2. Experimental

2.1. Plate-type reactor design

The plate-type reactor was manufactured from 304 stainless steel by an etching process. The size of the plate was 80 mm length, 35.5 mm width, and 1 mm thickness. The plate contains 10 channels of 45 mm length, 1 mm width, and 0.5 mm depth. As shown in Fig. 1, the reactant mixtures pass through an inlet A and are distributed over the plates, then pass over the parallel channels, and are finally collected in an outlet B. The inlet C and outlet D are included for the combustion reaction. After the catalyst was applied, five plates were stacked and tested for methanol steam-reforming. A stainless-steel gasket of 0.2 mm thickness was placed between each plate and the whole reactor was contained in a stainless-steel housing.

2.2. Catalyst coating

A commercial copper-containing reforming catalyst (ICI 33-5: CuO 50%, ZnO 33%, Al_2O_3 8%, BET surface area: 66 $m^2\,g^{-1}$) was used for the methanol reforming reaction. In order to coat the catalyst, a zirconia sol solution was used. Zirconia is a ceramic material that has superior adhesive properties than other ceramics in high-temperature combustion reactions [15]. The zirconia-sol acts as a binder and was prepared by adding HNO_3 (HNO_3:Zr = 1:2) to a zirconium isopropoxide isopropanol complex (Aldrich, 99%). 1.33 g of zirconia powder (<10 μm) was mixed with 0.07 g of zirconia-sol to give ratio of 95:5 and then 10 ml of isopropyl alcohol was added to obtain adequate viscosity (material A). Also, diluted zirconia-sol solution (material B) was prepared by adding 1 ml isopropyl alcohol to 200 μl of zirconia-sol solution (material A). The zirconia-sol solution was ball-milled

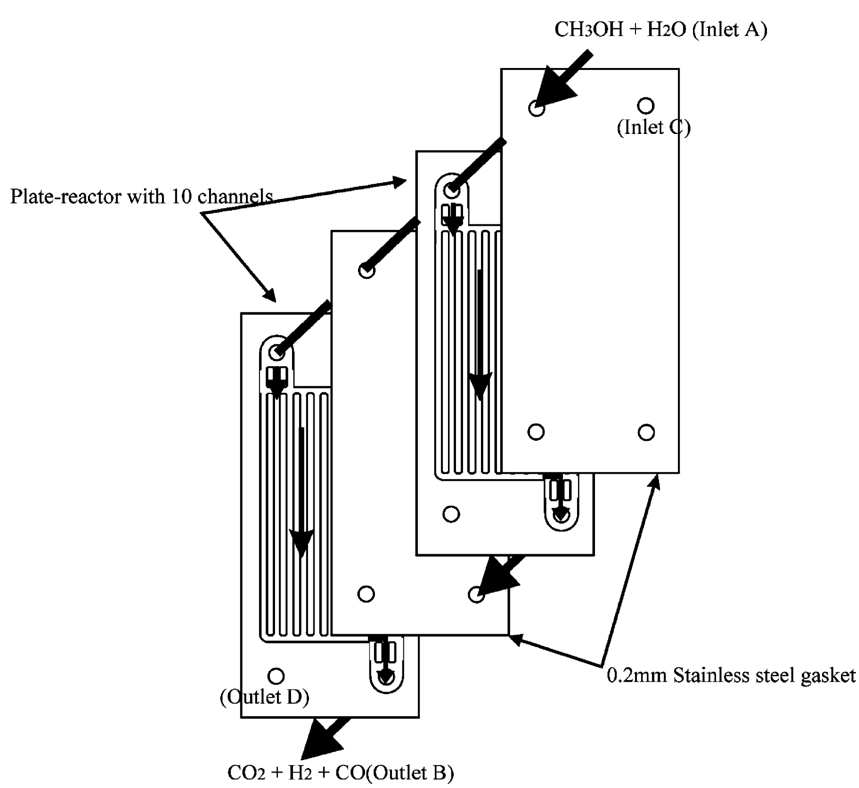

Fig. 1. Schematic diagram of plate-reformer with fluid flow.