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Efficient catalyst by a sequential melt infiltration method to achieve a high loading of supported nickel nanoparticles for compact reformer

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ABSTRACT

The development of high-performance Ni catalysts including the formation and stabilization of active Ni nanoparticles with high surface areas by increasing their metal dispersion at the high metal loading have been major issues in the design of a compact reformer for hydrogen production. Herein, we first report a facile method based on the sequential melt infiltration process for creating highly dispersed Ni nanoparticles (~7.5 nm) incorporated into alumina support (Ni/Al_2O_3) with high Ni load (45 wt%). They showed much higher hydrogen productivity and reaction rate than that of the incipient wet-impregnated Ni catalyst and commercial Ni catalyst as well as good thermal stability in steam-methane reforming under harsh conditions.

Introduction

Green hydrogen as the clean energy source has been intensively studied in recent years [1]. Typically, green hydrogen is produced by electrolyzing H_2O using CO_2-free clean electricity from renewable energy sources. However, the price of green hydrogen is much more expensive than producing hydrogen from conventional steam methane reforming technology because electrolysis requires high electricity demand and clean electricity from renewable energy sources are very expensive [2]. According to a recent report by FCH-JU [3], green hydrogen can be more cost-effectively produced if biogas is used as the hydrogen source via the steam reforming process. Biogas is a gas mixture that mainly consists of both CH_4 and CO_2. Biogas is produced by the anaerobic digestion process of various bio-wastes including municipal solid waste, discards from food processing, animal manure, sewage, stillage, and energy crops/agricultural residues [4,5]. Biogas can be considered as renewable energy where a complete CO_2-neutral carbon cycle is possible by capturing the released CO_2 from the reforming process into biomass (e.g., photosynthesis reaction) and generating additional biogas from this biomass (e.g., anaerobic decomposition of biomass). The utilization of biogas for green hydrogen production can also reduce greenhouse gas emissions by preventing CH_4 released in the atmosphere (CH_4 is 21 times stronger than CO_2 as a greenhouse gas) [6].

Based on the European Biogas Association (EBA) Report 2015, there was a record growth for the number of biogas plants and total installed capacity in Europe [7]. The biogas industry is considered to be an indispensable part of European development, and it has been recently reported that there were more than 660 biogas utilization plants in UK [8], and 13,000 plants in Germany [9]. In 2018, the American Biogas Council (ABS) has presented the environmental and economic benefits of considering biogas as a waste management solution. Also, there are reported that the current US Biogas Market possessed more than 2,200 operational biogas systems and there were more than 13,500 identified potential new biogas system opportunities [10]. G.D. Marcoberardino et al. performed the economic analysis to estimate a hydrogen production cost of around 5 $€\cdot kg^{-1}$ of hydrogen from biogas [4]. Braga et al. also reported the economic analysis, which showed that 0.27 US $\$\cdot kWh^{-1}$ with a payback period of 8 years is possible [6]. Therefore, biogas can be an economically viable raw energy resource to produce green hydrogen.

Because biogas is typically found in remote areas with small volumes, biogas reforming is suitable for decentralized (or distributed) hydrogen production, such as in a robust containerized solution to supply hydrogen to existing fueling stations where biogas and electricity are readily available. That is, many biogas resources are suitable for small-scale reformers supplying on-site hydrogen [3]. On-site hyrogen production by small-scale reformers

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