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Effective hydrogen production from propane steam reforming using M/NiO/YSZ catalysts (M = Ru, Rh, Pd, and Ag)

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ABSTRACT

This study has investigated the propane steam reforming (PSR) performance of M/Ni/YSZ catalysts (M = Ru, Rh, Pd, and Ag) for effective hydrogen production. To improve the catalytic performance, particularly with respect to the duration of the catalyst, YSZ (yttria-stabilized zirconia) is used as a support and noble metals such as Ru, Rh, Pd, and Ag are introduced as promoters. YSZ is used to suppress carbon deposition as it provides lattice oxygen to carbon coke on the catalyst. Noble metals provide synergy, assisting Ni metal in improving dehydrogenation. Preferentially, the PSR performance of 1.0 wt.% M/Ni/YSZ catalysts are measured to find which noble metal is suitable as a promoter. The result confirms that the Rh component is the best promoter for M/Ni/YSZ. This study also demonstrates the appropriate amount of Rh to use, based on the PSR performance over Ni/YSZ and 0.1, 0.5, and 1.0 wt.% Rh/Ni/YSZ for 100 h. The results confirm that Ni/YSZ becomes deactivated at 76 h, but the catalysts with the Rh promoter have much higher durability. Thus, this study concludes that 0.5 wt.% Rh/Ni/YSZ is the best catalyst because it does not have excessive Rh content and also does not show any discernable decrease in the PSR performance. Moreover, the Rh/Ni/YSZ catalysts had a higher resistance to carbon deposition because of the presence of the Rh promoter, which could improve lattice oxygen mobility of the Rh/Ni/YSZ catalyst.

1. Introduction

Hydrogen is an important energy carrier because it is eco-friendly and has a high energy density. Moreover, as the world will soon confront a reality in which hydrogen plays a much larger role in society, supported by the widespread commercialization of hydrogen energy conversion and storage, the methods of hydrogen production will become more important. Currently, water electrolysis, gasification of coal and biomass, partial oxidation of hydrocarbons, and steam reforming of hydrocarbons are some of the commercially methods to obtain hydrogen; steam reforming is well known as a method that affords the most economical way to produce hydrogen [1,2].

Feed gases for steam reforming are usually light hydrocarbons such as methane [3], ethane [4], propane [5], butane [6], and oxidized compounds such as methanol [7], ethanol [8], and dimethyl ether [9]. Particularly, propane has many advantages; for example, it can be used worldwide as fuel; it has a well-developed infrastructure and relatively high energy density; and though it is a gas, it is compressible to a transportable liquid at normal temperature. In addition, compactible steam reformers for providing hydrogen to fuel cells in households, rather than industries, should also be developed, as fuel cells can be generalized for use in households. However, the supply of feed gas can be limited in places that do not have well-developed infrastructures to transfer or supply feed gas to a fuel cell, for example, rural, wild, and camping areas. Therefore, propane is one of the most promising candidates that can be accepted in these situations because it can be commonly stored as liquefied petroleum gas (LPG). Hence, studies on hydrogen production through PSR need to be conducted. Theoretically, the overall reaction for PSR can be written as follows [10,11]:

$$C_3H_8 + 6H_2O \rightarrow 3CO + 10H_2 \qquad \Delta H = 499\ \text{kJ mol}^{-1}$$

The reaction can be typically distinguished as follows:

Steam reforming:

$$C_mH_n + mH_2O \rightarrow mCO + (m + 1/2n)H_2 \qquad (C_3H_8 + 3H_2O \rightarrow 3CO + 7H_2)$$

Water gas shift:

$$CO + H_2O \rightarrow CO_2 + H_2 \qquad \Delta H = -41.1\ \text{kJ mol}^{-1}$$

In practice, steam reforming is usually performed at high temperatures, and common catalysts based on Ni/Al_2O_3 are widely used for steam reforming. However, these catalysts, such as $NiAl_2O_4$, can easily

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