Topics in Catalysis
https://doi.org/10.1007/s11244-023-01881-w

ORIGINAL PAPER

Efficient Methane Dry Reforming Process with Low Nickel Loading for Greenhouse Gas Mitigation

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Accepted: 20 September 2023

Abstract

In this study, a series of nickels supported on gamma alumina with a metal dosage ranging from 0.5 to 3 wt.% were prepared and employed as the catalysts. The effect of nickel dosage on material properties, reaction performance, and catalyst deactivation was investigated. At a low dosage, the nickel-free having low metal-support interaction contributed significantly to the total active site. The basicity of the material was enhanced along with the increase in nickel loading. The presence of active metal showed a great impact at the beginning leading to big improvements in feedstock conversion. However, beyond a nickel dosage of 2 wt.%, further additions did not noticeably influence the reaction performance. Regarding catalyst deactivation, different carbon species were observed on catalyst surface, depending on the nickel dosage. Catalysts with less than 2 wt.% nickel exhibited amorphous carbon as the dominant morphology on the spent catalyst. In contrast, catalysts with $2Ni/Al_2O_3$ and $3Ni/Al_2O_3$ compositions showed graphitic carbon as the main side product. These findings provide insights into the relationship between nickel dosage, catalyst properties, and catalytic performance in methane dry reforming. By understanding the effects of nickel loading on material properties and reaction behavior, researchers can optimize catalyst design and develop more efficient and stable catalysts for sustainable syngas production.

Keywords Methane Dry Reforming · Nickel-based Catalyst · Carbon Deposition · Catalyst Basicity · Nickel Dosage

1 Introduction

Nowadays, the energy sector is one of the largest sources of greenhouse gases (GHGs) emissions, with the burning of fossil fuels being the primary contributor. As the global population continues to grow, the energy demand is expected to increase, leading to further greenhouse gases emissions, and exacerbating the effects of climate change [1, 2]. Hence, it is crucial to limit the amounts of carbon dioxide (CO_2) and methane (CH_4)- the two main components of GHGs released into the atmosphere. Recently, there has been an increase in interest in the dry reforming of methane technology with the advantages of using both CO_2 and CH_4 as feedstocks and the high applicability of synthetic gas (syngas) products. Some of the syngas applications are shown in Fig. 1.

In general, the main reaction (Eq. 1) is highly endothermic due to the great thermal stability of CH_4 and CO_2. At a severity condition, the side reactions mainly include methane decomposition (Eq. 2), carbon monoxide disproportionation (Eq. 3), and reverse water gas shift (RWGS, Eq. 4). The first two reactions result in the formation of coke which encapsulates the metal active centers leading to rapid catalyst deactivation [3, 4]. Meanwhile, the RWGS consumes hydrogen to form a less valuable CO [5] and limits the applicable product [6].

$$CH_4 + CO_2 \rightarrow 2CO + 2H_2\,(\Delta G^\circ = 247.31 - 0.25T\,kJ\,mol^{-1}) \quad (1)$$

$$CH_4 \leftrightarrow 2H_2 + C\,\,(\Delta G^\circ = 74.87 - 0.08T\,kJ\,mol^{-1}) \quad (2)$$

$$2CO \leftrightarrow CO_2 + C\,(\Delta G^\circ = -172.44 + 0.18T\,kJ\,mol^{-1}) \quad (3)$$

$$CO_2 + H_2 \leftrightarrow CO + H_2O\,(\Delta G^o = 41.17 - 0.04T\,kJ\,mol^{-1}) \quad (4)$$

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