Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

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

Optimization of dry reforming of methane over Yttrium Oxide-Cobalt/Mesoporous alumina using response surface methodology

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ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Y_2O_3-Co/Al_2O_3
Dry reforming of methane
Optimization
Response Surface Methodology

ABSTRACT

Dry reforming of methane (DRM) has attracted significant attention due to its advantages in converting undesirable ozone-depleting gases, carbon dioxide (CO_2) and methane (CH_4), into syngas for Fischer-Tropsch synthesis. However, developing the best catalysts for DRM with superior catalytic activity and stability is still challenging. Additionally, process optimization is an important task for improving the efficiency, safety, and profitability of the process. Previously, our research group has reported an excellent catalytic performance of Yttrium Oxide-Cobalt/Mesoporous Alumina (Y_2O_3-Co/MA) due to the excellent distribution of Co and strong metal-support interaction. As a continuity, this study optimized the catalytic performance of Y_2O_3-Co/MA toward DRM. The optimization process was evaluated using the Response Surface Methodology (RSM) under three independent variables, which were reaction temperature (700 – 900 °C), weight hourly space velocity (15000–35000 mL g_{cat}^{-1} hr^{-1}), and CH_4/CO_2 ratio (1:1–3:1). The optimum operating conditions were successfully anticipated, with the good agreement of data between the model predictions and experiments. Y_2O_3-Co/MA presented the catalytic performance of X_{CH_4} of 88.97%, X_{CO_2} of 95.57%, H_2 yield of 30.98%, and CO yield of 69.36%, at the reaction temperature of 900 °C, WHSV of 30,690 mL $g_{cat}^{-1}h^{-1}$, and CH_4/CO_2 ratio of 1.027.

Selection and peer-review under responsibility of the scientific committee of the 6th International Conference of Chemical Engineering & Industrial Biotechnology (ICCEIB 2022).

1. Introduction

A significant increase in global energy demand and fossil fuel consumption has resulted in an increase in greenhouse gases (GHGs) emissions. Moreover, rapid global economic growth and human activities accelerated the GHGs emissions [1,2]. In this regard, global awareness and policies regarding GHGs have been increasing and consequently boosting the number of researchers on reducing pollution and converting GHGs into value-added products. For instance, methane is converted into syngas (hydrogen and carbon monoxide) via reforming technology, which is essential in producing fuel gas, ammonia, and methanol. Several reforming technologies have been reported, including steam reforming of methane, dry reforming of methane (DRM), and partial oxidation of methane [3]. Among these methods, DRM is the preferred method due to the consumption of the two most abundant GHGs, which are carbon dioxide (CO_2) and methane (CH_4), and the more environmentally friendly fuel formed [2,4].

DRM could be one of the solutions to reduce CO_2 emissions to the atmosphere. However, it is still unfeasible at the industrial scale due to the main drawback of this technology which is severe catalyst deactivation through coke deposition and metal sintering. As studied by Anil et al. [5], noble metals such as ruthenium, platinum, and palladium have high resistance to coke formation, but it is not economical for industrial scale due to the high cost. Hence, cheaper transition metal catalysts such as cobalt and nickel are widely used as an alternative. Cobalt (Co) showed good activity in DRM because of its capability to enhance the catalyst's stability and restrain coke formation [6]. In fact, Co was widely used as the catalyst for soot oxidation because of its high efficacy in decreasing soot emissions [6,7].

In order to further improve the effect of support, mesoporous Al_2O_3 (MA) has been chosen as the support. The confinement effect

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https://doi.org/10.1016/j.matpr.2023.04.690
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the 6th International Conference of Chemical Engineering & Industrial Biotechnology (ICCEIB 2022).