

Mixed metal (Mn, Al, Ti) cobalt oxide model systems for optimizing sustainable aviation fuel production via Fischer-Tropsch synthesis

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Introduction

In the era of energy transition with the goal to lower greenhouse gas emissions and to overcome the impact on climate changes, the Power-to-Liquids (PtL) technology poses as a key potential solution, especially in the hard to abate aviation sector. Sustainable aviation fuel (SAF) may be produced through Fischer-Tropsch (FT) synthesis, the conversion of synthesis gas into long-chain hydrocarbons using iron or cobalt-based FT catalysts. Recently, manganese promotion of cobalt was demonstrated to efficiently increase the yield of SAF,¹ while modification of metal oxide supports allows for operation at high conversion levels in the FT synthesis.²

The efficiency of FT catalysts largely depends on the physico-chemical properties of the surface of the catalysts. Manganese promotion of cobalt-based FT catalysts may result in Mn^{2+} on the edge of manganese oxide structure, which interacts with adsorbed carbon monoxide species.² At a molar Mn:Co ratio of 0.15, the promotional effect of manganese on cobalt-based FT catalysts was amplified.¹ In general, deactivation of cobalt-based FT catalysts via formation of metal-support compounds (MSCs), such as cobalt titanate or aluminate, represents another challenge when operating at high conversion rates.^{4,5} In the present study, we investigate the role of promotion on the formation of cobalt manganese, titanate or aluminate in cobalt FT model catalysts. Cobalt oxide and mixed cobalt oxide nanoparticles are prepared separately via the surfactant-free benzyl alcohol route.⁴ Subsequent deposition of these nanoparticles on various support materials yield model catalysts, which are thoroughly characterized to advance the development of efficient FT catalysts for SAF production.

Materials and Methods

Mixed metal cobalt oxide nanoparticles were synthesized via surfactant-free heat treatment of dissolving cobalt acetate tetrahydrate and other metal (Mn, Ti, Al) precursors in benzyl alcohol.⁵ After the precursors were completely dissolved, ammonia solution was added to adjust the pH of the solution to provide optimal reaction condition. The solution was flash heated in an oil bath to complete the synthesis. After cool-down and repetitive washing, the nanoparticles were collected. The mixed metal cobalt oxide nanoparticles were deposited on various support materials to obtain the model catalyst.³ Synthesized nanoparticles and model catalysts are characterized with X-ray diffraction (XRD), inductively coupled plasma optical emission spectroscopy (ICP-OES), transmission electron microscopy (TEM), and X-ray absorption spectroscopy (XAS). Additional catalytic activity testing would be conducted jointly with collaborating partners.

Results and Discussion

The synthesized cobalt oxide nanoparticle sizes range from 9 nm to 14 nm in spinel structure according to analysis by means of XRD. Additionally, the synthesized cobalt aluminate, cobalt titanate, and cobalt manganese oxide were also identified as spinel structures. Further investigation towards the formation of cobalt manganese oxide targeted composition of manganese-to-cobalt (Mn/Co) molar ratio from 0 to 0.5 to observe the incorporation of manganese in the spinel structure. Figure 1 shows a maximum Mn incorporation at Mn/Co ratio of 0.2, which results in the largest crystal lattice expansion. Unable to incorporate more manganese in the spinel structure, hausmannite structure was observed for higher ratio.

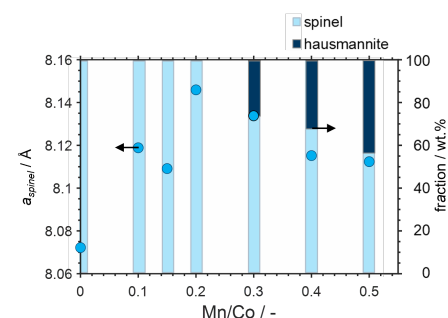


Figure 1. Mn incorporation in Co_3O_4 spinel structure.

Thorough characterization methods were also applied to the synthesized cobalt aluminate and cobalt titanate. In the synthesis of cobalt titanate, titanate oxide rutile and anatase was observed at Ti/Co molar ratio of 2. The detailed observations later applied to the formation of model catalyst to advance the development of FT catalyst for SAF production.

Significance

The research is part of the CARE-O-SENE⁶ project that connects German and South African partners for the development of optimized catalyst for producing green kerosene. The goal of the research project is to provide a competitive green alternative for the aviation sector. Synthesis and preparation of nanoparticles and model catalyst would support the characterization team of the research project to optimize the cobalt FT catalyst.

References

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