Comparative Study of SBA-15 and CNT Supports for Iron Catalysts in Fischer-Tropsch Synthesis

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Significance and Relevance

This study highlights the impact of support materials on the performance of iron-based catalysts in Fischer-Tropsch synthesis (FTS). Fe/CNT outperformed Fe/SBA-15, achieving higher CO conversion (49% vs. 21%) and lower methane selectivity (27% vs. 52%). Notably, Fe/CNT favored long-chain hydrocarbons (C_5+ selectivity of 18%) over Fe/SBA-15 (7%). These results demonstrate the significant role of support in modulating catalytic activity and selectivity. The combination of advanced characterizations provides deeper insight into structure-activity/selectivity relationships, paving the way for rational design of more efficient FTS catalysts.

Preferred and 2nd choice for the topic:
Sustainable and clean energy production and transport
Fundamental advances in understanding catalysis
Preferred presentation: Poster

Introduction and Motivations

The goal to lower greenhouse gas emissions now and to overcome the impact on climate changes in future can be achieved exploiting the Power-to-Liquids (PtL) technology, especially in the hard to abate aviation sector. Sustainable aviation fuel (SAF) may be produced through Fischer-Tropsch synthesis (FTS), the conversion of synthesis gas into long-chain hydrocarbons using iron or cobalt-based FT catalysts[1-3]. The iron-based catalysts are an economically attractive alternative to the cobalt-based materials, their performance is strongly related to the structure of active site during the reaction. The chemical state and phase of iron and its interaction with support are the key parameters to understand the structure-activity relationship and the deactivation mechanism[4].

Results and Discussion

The performance of two iron-based catalysts, Fe/SBA-15 and Fe/CNT, during the FTS were studied focusing on how support material influences hydrocarbon selectivity and CO conversion. Both catalysts were synthesized using the deposition-precipitation method [5-6]. The SBA-15 mesoporous silica support was synthesized by USP laboratory and its structure was confirmed by X-ray diffraction (XRD), while commercially obtained multi-walled carbon nanotubes (MWCNTs) were functionalized by nitric acid treatment at 120°C for 6 hours to remove amorphous carbon and introduce surface functional groups. Hydrogen temperature-programmed reduction (H_2-TPR) analysis revealed three distinct Fe reduction peaks, indicating multiple stages of iron oxide reduction. Reduction temperatures were optimized for each support's stability and feasibility, with Fe/SBA-15 reduced at 650°C and Fe/CNT at 380°C, balancing thermal requirements with support tolerance.

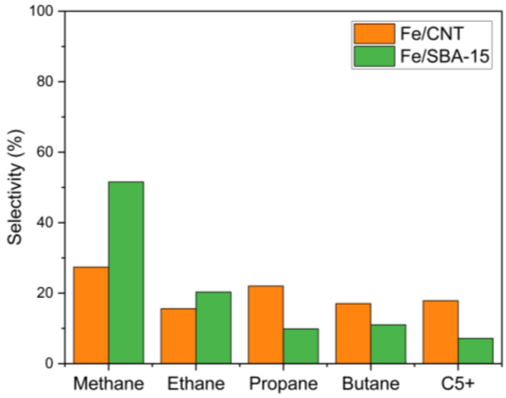
FTS reactions were performed at 285°C, with a weight hourly space velocity (WHSV) of 3200 mL/h*gcat, under 20 bar pressure and a $CO:H_2$ ratio of 1:2. Pre-reaction characterization using Brunauer–Emmett–Teller (BET) surface area analysis, inductively coupled plasma (ICP) spectrometry, and X-ray absorption spectroscopy (XAS) provided detailed insights into catalyst composition and structural properties. Post-reaction X-ray photoelectron spectroscopy (XPS) offered crucial information on surface chemistry and iron oxidation states, with an emphasis on the formation of iron carbide structures, the active phase for FTS. This analysis helped elucidate the extent of iron carbide formation.

The results (Figure 1) showed a strong influence of support material on the catalytic performance of iron-based catalysts. Fe/CNT exhibited a higher CO conversion of 49%, compared to 21% for Fe/SBA-15, suggesting that the CNT support leads to a higher catalytic activity. Additionally, Fe/CNT demonstrated a lower methane selectivity of 27%, in contrast to a significantly higher methane selectivity of 52% for Fe/SBA-15. Selectivity towards C_5+ hydrocarbons was higher for Fe/CNT (18%) compared to Fe/SBA-15 (7%), suggesting that the CNT support favors the formation of long-chain hydrocarbons, while the SBA-15 support triggers more towards methane production.

These findings underscore the importance of support selection in tuning catalyst reducibility, stability, and hydrocarbon selectivity in Fischer-Tropsch synthesis, highlighting the advantages of mesoporous silica and carbon nanotube supports in influencing reaction pathways. This work enhances understanding of the role of support materials in iron-based catalyst performance, providing insights for developing tailored catalysts for efficient FTS and emphasized the importance of applying the combined characterization approach to enable the rational catalyst design.

Figure 1: Influence of support material on the catalytic performance of iron-based Fischer-Tropsch catalysts. Selectivity is categorized by hydrocarbon groups based on carbon number. Comparatively, SBA-15 support is shown to enhance methane production and restrict hydrocarbon chain growth.

Figure 1 – Comparison of hydrocarbon selectivity for CNT- and SBA-15 supported FTS catalyst (conditions: 285°C, WHSV at 3200 mL/h*gcat, 20 bar and 1CO:2H_2)



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