Strategic Development of Catalyst-Membrane System for CO_2 and Biomass Conversions

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Abstract:

Biomass has become an attractive source of renewable energy and materials. Conversion of biomass into useful products can be performed by using pyrolysis to produce liquid fuels and chemicals or gasification to produce syngas. Utilization of biomass by gasification is an environmentally beneficial method for the production of syngas, which can be upgraded to produce a broad range of hydrocarbons such as methanol and ammonia by the Fischer–Tropsch process. At the same time, limiting the rise of CO_2 (carbon dioxide) concentration in the atmosphere by capturing CO_2 from various emissions is a critical challenge facing the world today. Hence, the past decade has seen a huge increase in research related to utilization of biomass and CO_2 as raw materials for fuels and chemicals.

For catalytic conversion of biomass to syngas, several challenges have to be solved, mainly in the impurities produced such as tar, a mixture of heavy condensable hydrocarbon compounds including single-ring to five-ring aromatic compounds such as toluene and naphthalene, which can decrease the efficiency of process operations on condensation in the particulate filters and pipe outlets, resulting in blockages and reduction of the effective gas flow. As a result, it can cause significant increases in maintenance and operating costs. The conventional method to reduce the tar in commercial gasifiers includes the use of high temperatures above 800°C to burn off the tar, resulting in high cost. The use of catalyst for tar cracking provides a promising way to make the process more economical and efficient as a catalyst can reduce the reaction temperature and increase the product yield. Additionally, CO_2 reforming of methane and CO_2 methanation to produce syngas and methane respectively, are the two important reactions to convert CO_2 into useful chemicals, and have been studied a lot in last decades. To address the main issue to develop economic, active and stable catalysts for these topics, our group has developed several strategies to design and prepare stable Ni-based catalysts for CO_2 and biomass reforming applications, such as:

- Doping with base metals; alkali metals promotes water dissociation there by enhances steam reforming reaction at low steam conditions and suppress carbon formation.[1]
- Bimetallic catalysts; By forming alloy, the synergetic effect helps to suppress carbon formation.[2,3]
- Catalysts derived from specific structures; we have found that catalysts derived from perovskite, hydrotalcites and phyllosilicate have a strong metal-support interaction, which helps to eliminate carbon formation.[1,4]
- Organic-assistant synthesis; Organic molecules can complex with Ni during impregnation synthesis which increases dispersion of Ni and decreases Ni particles size, eliminating carbon formation.[5]
- Core-shell catalysts; Covering Ni nanoparticles with an inert shell can immobilize them, thus avoiding sintering of Ni particles, which enhances the carbon resistance.[6,7]

Conversion and stability in steam or CO_2 reforming can be simultaneously increased by introduction of minute quantities of oxygen into the reaction mixture, that helps to burn off coke

and at the same time, reduce the heat required in the reaction due to exothermic coke oxidation. However, it is crucial to precisely control and limit the oxygen partial pressure along the reactor to prevent over-oxidation and loss of selectivity. Our group has expertise in developing highly energy efficient integrated catalytic membrane reactors where oxygen is introduced slowly into the reforming reaction through an oxygen permeable perovskite membrane to ensure high activity, stability and selectivity. Our work focuses on developing and tuning membrane composition and morphology to increase compatibility with catalyst material, stability under reaction conditions and optimizing permeation to maximize syn-gas yield.[8,9]

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