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Design and Preparation of a Ni Steam Reforming Catalyst

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Background

Steam reforming catalysts play an essential role in the production of hydrogen, which is an essential fuel, feedstock, and reactant in the worldwide chemical industry. These steam reforming catalysts use a finely dispersed metal, supported on a porous ceramic material, to produce hydrogen from hydrocarbon sources. This is shown in reaction 1, where HC denotes hydrocarbon, H_2O denotes water, H_2 denotes dihydrogen, CO denotes carbon monoxide, CO_2 denotes carbon dioxide, and CH_4 denotes methane.

$$HC + H_2O \rightarrow H_2 + CO + CO_2 + CH_4 \tag{1}$$

However, the actual mechanisms by which the reaction occurs are much more complicated[1]. The catalyst must enable three separate chemical processes to occur. First, the hydrocarbon must adsorb onto the metal sites and dissociate into carbon and hydrogen species. Second, water must absorb onto an oxide sites and dissociate into oxygen and hydrogen species. Third, the metal sites must facilitate the combination of carbon and oxygen species to produce carbon monoxide and carbon dioxide and the combination of hydrogen surface species to produce dihydrogen, the desired product. Other requirements for a steam reforming catalyst include a high thermal stability and a promoter that protects the catalyst from deactivation by coking.

Typical metals used in steam reforming catalysts include noble metals such as rhuthenium, rhodium, palladium, platinum, as well as other metals such as nickel and cobalt. All of these metals are able to dissociatively adsorb the hydrocarbons as well as produce carbon dioxide and dihydrogen to some degree. The noble metals are typically more active than nickel and cobalt. However, they also are much more expensive. Due to its low cost and high activity compared to cobalt, nickel is the metal of choice for the steam reforming of hydrocarbons.

Due to the proprietary nature of the state of the art technology in steam reforming catalysis, many companies and research institutes are unable to compare their catalysts with other commercial catalysts. To facilitate this comparison a catalyst designed according to the above principles is needed. Therefore, Calvin H. Bartholomew and I designed and prepared a steam reforming catalyst to fill this need.

Design

The steam reforming catalyst design was based on the principles described above. Nickel was chosen for the metal because of its low cost and high catalytic activity. The nickel metal loading was chosen to be 15% by weight to provide suitable activity. A magnesia-alumina spinel was chosen for the support because it combines a high thermal stability with numerous oxide sites that provide activity for the dissociative adsorption of water. Additionally, magnesia acts as a promoter to prevent carbon deposition and lengthen the life of the catalyst.

Preparation

The catalyst was prepared from existing Kaiser Alumina 1/8 inch spherical pellets. The dried pellets were impregnated with a stoichiometric amount of magnesium nitrate (aqueous solution) and ramped to 850°C to decompose the nitrate and deposit the magnesium metal in the pores of the pellets. The pellets were heated at 850°C for 8 hours to facilitate the formation of the spinel crystal structure. After cooling, the magnesia-alumina spinel pellets were impregnated with an aqueous nickel nitrate solution and dried overnight, turning the color of the pellets from a pure white to a deep green. Calcination of the nickel nitrate impregnated pellets was done at 400°C. This calcination decomposed the nitrates and deposited the nickel metal ions on the surface of the catalyst pores, changing the color of the pellets to gray. Reduction of nickel to the metal was done by Brian Critchfield of the BYU Catalysis Laboratory.

Future Work

The resulting catalyst will be characterized in the future by the BYU Catalysis Laboratory to determine its physical properties (surface area, chemisorptive uptake, pore size distribution, etc.) and activity for steam reforming. Based on the literature[1] and principles discussed above, it is expected that the catalyst will exhibit high steam reforming activity.

Conclusion

A steam reforming catalyst has been prepared based on general principles of catalysis and steam reforming. Once characterization of the catalyst has been completed and the steam reforming activity determined, comparison with other catalysts will be possible[2].

References:

1. Farrauto RJ and Bartholomew CH, 1997. *Fundamentals of Industrial Catalytic Processes*. Blackie Academic & Professional.

2. Acknowledgements: Dr. Calvin Bartholomew for guidance and help with this research, and Brian Critchfield for help with the reduction of the catalyst.