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A Comparison of Fischer-Tropsch Synthesis in a Slurry Bubble Column Reactor and a Continuous Stirred Tank Reactor

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A Slurry Bubble Column Reactor (SBCR) is a gas-liquid-solid reactor in which the finely divided solid catalyst is suspended in the liquid by the rising gas bubbles. SBCR offers many advantages over fixed-bed type reactors such as: 1) improved heat transfer and mass transfer; 2) isothermal temperature profile is maintained; and 3) relatively low capital and operating cost. Fischer-Tropsch Synthesis (FTS) takes place in a SBCR where the synthesis gas is converted on catalysts suspended as fine particles in a liquid. The synthesis gas flows in a bubble phase through the catalyst/wax suspension. The volatile products are removed with unconverted gases, and the liquid products are separated from the suspension. A gas distributor located in the bottom of the reactor produces the bubbles in the reactor.

A considerable interest has been expressed in using the SBCR to carry out FTS particularly for the conversion of stranded natural gas into liquids. Currently, the Center for Applied Energy Research (CAER) is utilizing a Prototype Integrated Process Unit (PIPU) system for scale-up research of the FTS. The purpose of this study was to compare the performance and activity decline of a precipitated Fe/K Fischer Tropsch Synthesis (FTS) catalyst in a revamped slurry bubble column reactor (SBCR) to that of previous CSTR and SBCR runs using the same catalyst and operating conditions. The activity decline measured in the revamped SBCR system was shown to be similar to that of the CSTR experiments. The apparent activity decline in a previous SBCR run was due a transient startup effect from the slurry filtration system.

1. INTRODUCTION

The PIPU is a pilot plant system built in the early 1980s for studying a multitude of synthetic fuel/chemical processes. In the mid 1990s, a direct coal liquefaction reactor within the PIPU plant was reconfigured as a SBCR for FTS studies (see Figure 1.). The reactor was originally designed to operate with coarse catalyst pellets (>500 μm). Consequently, the reactor system did not contain a wax separation system sufficient for smaller catalyst particles that are typically used in FTS. Therefore, a slurry accumulator and a batch wax filtration system were installed.

During the period from 1995-96, attempts to operate the direct liquefaction reactor in a F-T mode were successful in that a clear wax product could be obtained. However, the initial activity observed in the bubble column was about 10-15% less than that of comparable CSTR

runs. Also, the rate of conversion decline (and apparent catalyst deactivation) in the SBCR was much greater than that observed in the CSTR. It was hypothesized that the apparent increased deactivation rate in the SBCR was caused by the depletion of catalyst inventory due to the nature of the wax/catalyst separation system.

The CAER SBCR plant was overhauled and redesigned to incorporate automatic slurry level control and wax filtration systems. These design changes will allow a more constant inventory of the catalyst to be maintained in the reactor while reducing slurry hold-up in the catalyst/wax separation system. In addition, the wax filtration system was rearranged to accept a variety of filter elements. These additions were meant to enhance the stability of the reactor operation so that long-term tests can be conducted to study catalyst deactivation and attrition under real-world conditions.

In the following discussion, we will detail the results and operational experiences the enhanced SBCR system. Objectives of the run were to: 1) test the new slurry level control system; 2) compare the performance of a precipitated Fe/K Fischer Tropsch Synthesis (FTS) catalyst in the enhanced SBCR and a continuous stirred tank reactor (CSTR); and 3) determine the effectiveness of the catalyst/wax filtration system.

2. EXPERIMENTAL

All FTS runs were conducted in either CSTR or SBCR systems. Two types of SBCR configurations were used in this study: 1) SBCR (old)- a bubble column with a large volume filtration/settling tank arrangement; and 2) SBCR (new)- a bubble column with a flow through filter arrangement with a small slurry hold-up volume. Activation and synthesis conditions for each reactor configurations are listed in Table 1. A precipitated iron catalyst having atomic composition of 100 Fe/4.4 Si/1K was used for each reactor experiment.

2.1. CSTR Apparatus

The one-liter CSTR used in this study has been described in detail in the literature [1-2]. The following is a brief description of the reactor system.

Catalysts were suspended in Ethyflo 164 hydrocarbon (Ethyl Corp.), which is reported to be a C_{30} 1-decene homopolymer. The initial loading of the catalyst in the slurry was 20 wt%. Hydrogen and carbon monoxide were metered by mass flow controllers to attain a H_2/CO ratio of 0.7. The synthesis gas was delivered to the catalyst slurry via a sparger tube located below an impeller blade turning at 750 rpm. The reactor effluent exited the reactor and passed sequentially through two traps maintained at 333 and 273 K. Accumulated reactor wax was removed daily through a tube fitted with a porous metal filter. A dry flow meter was used to measure the exit gas flow rate.

The catalysts were activated with syngas with a H_2/CO ratio of 0.7. In general, the activation gas flow was started at ambient conditions and the reactor temperature was ramped to the desired set point at a 2 K min^{-1} rate. After the activation temperature was reached, the conditions were maintained for 24 h. Following the activation treatment, the reactor was brought to FT synthesis conditions: 1.21 MPa, 543 K, 5.0 normal L h^{-1} (g of Fe) $^{-1}$.