Experimental Investigation of a JP8 Fuel Processor: Autothermal Reformer and CO-Cleanup Train

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This paper presents an experimental investigation of a fuel processor consisting of a JP-8 autothermal reforming (ATR) reactor and a surrogate-fed CO-cleanup train. The CO-cleanup train, comprising a water−gas shift (WGS) and two preferential oxidation (PROX) reactors, was tested as an integrated reactor train. A finned-wall ATR reactor was examined for light-off behavior and for steady-state product distribution, upon which the CO-cleanup train was designed. The thermal and chemical transient analysis during catalyst ignition indicated that the fuel undergoes deep oxidation to CO_2 and H_2O until 80% of the catalyst bed is ignited, followed by a significant rise in synthesis gas production. The WGS and PROX reactors were tested individually with the objective of identifying operating regimes for maximum CO removal. The PROX reactor train, consisting of two identical reactors connected in series, reduced the CO concentration from 1% to less than 6 ppm. The PROX-1 and PROX-2 reactors were compared in order to elucidate the CO conversion and selectivity loss observed for PROX-1 at $T > 250$ °C and for PROX-2 at temperatures between 120 and 145 °C, suggesting that the CO conversion decrease follows different controlling mechanisms for the two reactors. Finally the CO-cleanup train was tested as three reactors in series, illustrating the critical effect that the CO conversion in the water−gas shift reactor has on the downstream PROX reactors. The CO-cleanup train was operated at the maximum conversion, demonstrating the capability to decrease the CO concentration from 8% to single-digit ppm level.

Introduction

Much of the recent work on fuel processors is focused on the employment of surrogate fuels, biofuels, gasoline, and diesel[1−8] and to a lesser extent on JP8 fuel.[9−14] Since JP8 is the fuel selected by the Department of Defense (DoD) and North Atlantic Treaty Organization (NATO) to be the exclusive battlefield fuel,[15] a better understanding of its properties and behavior is paramount for auxiliary power applications. Alternatively fuel processors can be utilized for bio-oil upgrading[16] as well for combustion enhancement in internal combustion engines.[17]

A fuel processor can be built in a variety of configurations depending on the required product quality. The first processing step is accomplished by the reforming reactor, which can be composed of one of the following: (i) the partial oxidation (POX) reactor, which operates exothermically; (ii) the steam reforming reactor (SR), which operates endothermically; (iii) the autothermal reformer (ATR), which ideally combines POX and SR within the same catalyst bed to ensure thermally neutral operation.[18] The H_2/CO ratio in the product gas depends upon steam-to-carbon (S/C) and oxygen-to-carbon (O/C) ratios. For S/C = 2 and O/C = 1 the ATR reactor typically yields H_2/CO = 4 with a fresh catalyst[19,20] and lower values for an aged catalyst.[21,22] Subsequent processing steps are targeted toward synthesis gas conditioning (adjustment of H_2/CO ratio) or CO removal. If high purity H_2 is required to serve as a feed to a low temperature PEM fuel cell, CO has to be removed thoroughly in a CO-cleanup train. This reactor train consists typically of a water−gas shift (WGS) reactor and one or more preferential oxidation (PROX) reactors.

This work presents an experimental investigation of a novel finned-wall ATR reactor. An analysis of the temperature and product distribution during catalyst ignition with JP8 fuel is included, which to our knowledge has not been reported in literature yet. Additionally a CO cleanup train, consisting of WGS and PROX short contact time (SCT) reactors has been tested in series and as individual reactors.

Autothermal Reforming. ATR reactors convert fuel into a synthesis gas mixture rich in H_2, by utilizing the reaction enthalpy provided by exothermic oxidation reactions to run endothermic ones. The overall process is simplified in the following reaction scheme, showing the POX and SR reactions (equations 1 and 2, respectively).

$$C_{11}H_{21_{(gas)}} + \frac{11}{2}O_2 \rightarrow 11CO + \frac{21}{2}H_2 \qquad \Delta H^o = -966.8\ \text{kJ/mol} \quad (1)$$

$$C_{11}H_{21_{(gas)}} + 11H_2O_{(gas)} \rightarrow 11CO + \frac{43}{2}H_2 \qquad \Delta H^o = +1694\ \text{kJ/mol} \quad (2)$$

While an autothermal operation is ideally achieved by adjusting the relative amounts of fuel, oxygen, and water, this is never attained in practice. The enthalpy provided by the partial oxidation of the fuel must allow for unavoidable heat-losses, which are typical for high temperature units, as well as a selectivity penalty due to competing reactions. Hence the reactor is required to operate with an excess air input compared to the thermally neutral case. In particular, the conversion to H_2 is going to be altered by parallel and series reactions, such as the methanation, steam, and thermal cracking and water−gas shift reactions.[8,23] Flytzani-Stephanopoulos and Voecks[8] found that cracking reactions play an important role in ATR, and their observation was confirmed by recent modeling and experimental work by Gould et al.,[2] and Dorazio and Castaldi.[23] The latter

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