High pressure catalytic conversion of n-pentane on H-ZSM-5

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The flight of aircraft and missiles at hypersonic speeds (> Mach 5) is hindered by overheating of the engine and electronic components caused by fuel combustion and air friction [1]. Currently, aircraft are cooled by transferring thermal energy from the engine and sensitive electronic systems to the fuel; in such cases, the maximum amount of heat that can be removed is determined by the heat capacity, thermal stability, and initial temperature of the fuel. The cooling capacity can be improved by utilizing *endothermic fuels*, fuels that undergo endothermic chemical reactions driven by the thermal energy removed from the aircraft [2,3]. A potential endothermic reaction is the cracking of hydrocarbons on solid catalysts to produce lighter molecules, with olefins being preferred to maximize endothermicity.

In this study, the effects of temperature (633-723K), pressure (10-60 bar) and weight hourly space velocity (WHSV) (400-1500 h^{-1}) on the conversion of pentane on H-ZSM-5 were investigated to determine the potential of this reaction/catalyst system for endothermic cooling. H-ZSM-5 was chosen because of its use in industrial fluidized catalytic cracking units to increase light olefin yield [4]. Pentane was chosen as it is the simplest liquid hydrocarbon at STP and its high cooling potential (pentane cracking to ethane and propylene has a heat of reaction of 1.15 MJ/kg). 5-25% pentane conversion was observed at a pressure of 40 bar and temperatures in the range of 633-723K. At a temperature of 673K, saturation kinetics (i.e. the rate of pentane consumption does not increase with increasing pressure) were observed at pressures above 30 bar, resulting in approximately 14% conversion. At 40 bar and 673K, increasing WHSV (400-1500) resulted in decreased pentane conversion (26-10%). Propane and butane were the major products, followed by heavier C6+ compounds and other light products (C1-C4 paraffins and olefins). An inverse relationship between the production of C6+ and other light compounds was observed with changes in reaction conditions: C6+ carbon selectivity increased from 20% at 10 bar to 27% at 60 bar, while it declined from 28% at 633K to 18% at 723K.

The high selectivity (>70%) to propane and butane, along with the observed changes in the selectivity to light olefins and heavy C6+ compounds, indicate that bimolecular reactions, such as hydride transfer and alkylation, control product distribution. While the product distribution from the high pressure conversion of n-pentane resulted in an endothermic process, hydride transfer reactions led to the transformation of high energy olefins into low energy paraffins and aromatics, resulting in a decrease of the process endothermicity. Hydride transfer occurs readily on H-ZSM-5 and other zeolites, and an alternative catalyst that suppresses these reactions should improve selectivity to light olefins, which will increase cooling capacity of the endothermic fuel.

References

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