

mono-olefins. In these processes, a paraffinic hydrocarbon is contacted with oxygen in the presence of a catalyst consisting of a platinum group metal or mixture thereof deposited on a ceramic monolith support, typically in the form of a honeycomb or foam. Optionally, hydrogen may be a component of the feed. The catalyst, prepared using conventional techniques, is uniformly loaded throughout the support. The process can be conducted under autothermal reaction conditions wherein the feed is partially combusted, and the heat produced during combustion drives the endothermic cracking processes. Consequently, under autothermal process conditions there is no external heat source required; however, the catalyst is required to support combustion above the normal fuel-rich limit of flammability. Representative references disclosing this type of process include the following U.S. Pat. Nos. 4,940,826; 5,105,052; 5,382,741; and 5,625,111. Disadvantageously, substantial amounts of deep oxidation products, such as carbon monoxide and carbon dioxide, are produced, and the selectivity to olefins remains too low when compared with thermal cracking. Long term stability of the catalyst and heat management of the system are not addressed.

[0014] M. Huff and L. D. Schmidt disclose in the Journal of Physical Chemistry, 97, 1993, 11,815, the production of ethylene from ethane in the presence of air or oxygen under autothermal conditions over alumina foam monoliths coated with platinum, rhodium, or palladium. A similar article by M. Huff and L. D. Schmidt in the Journal of Catalysis, 149, 1994, 127-141, discloses the autothermal production of olefins from propane and butane by oxidative dehydrogenation and cracking in air or oxygen over platinum and rhodium coated alumina foam monoliths. Again, the olefin selectivity achieved in these processes is not significantly better than thermal cracking, and heat management of the system is not addressed so that catalyst temperatures can greatly exceed gas temperatures.

[0015] U.S. Pat. No. 5,639,929 teaches an autothermal process for the oxidative dehydrogenation of C<sub>2</sub>C<sub>6</sub> alkanes with an oxygen-containing gas in a fluidized catalyst bed of platinum, rhodium, nickel, or platinum-gold supported on alpha alumina or zirconia. Ethane produces ethylene, while higher olefins produce ethylene, propylene, and isobutylene. Again, the olefin selectivity could be improved. Temperature excursions of the catalyst are not controllable on a local level, and the catalyst temperature can be much higher than the gas temperature.

[0016] C. Yokoyama, S. S. Bharadwaj and L. D. Schmidt disclose in Catalysis Letters, 38, 1996, 181-188, the oxidative dehydrogenation of ethane to ethylene under autothermal reaction conditions in the presence of a bimetallic catalyst comprising platinum and a second metal selected from tin, copper, silver, magnesium, cerium, lanthanum, nickel, cobalt, and gold supported on a ceramic foam monolith. The use of a catalyst comprising platinum with tin and/or copper results in an improved olefin selectivity; however, over time at high operating temperatures the second metal vaporizes off the catalyst and catalytic activity decreases. When this occurs the reactor must be shut down to replace or regenerate the catalyst. Again, the temperature of the catalyst can be very much higher than the temperature of the reacting gas leading to poor catalyst life and poor selectivity to olefins.

[0017] L. D. Schmidt, J. Siddall and M. Bearden in AIChE Journal 46 (2000) 1492-1495 report the results of experiments on Pt containing catalysts supported on foam monoliths. While the conversions and yields of ethylene were better than some steam cracking results, "the axial and radial gradients in temperature and concentration are extremely large" suggesting that the catalyst life will be very limited and that process optimization will not be simple.

[0018] L. Late, J.-I. Rundereim, and E. A. Blekkan describe experiments on conventional Pt, Pt—Sn and Sn supported on silica catalysts for the selective oxidation of hydrogen in the presence of propane in Applied CatalysisA: General 262 (2004) 53-61. Their experiments are limited to modest temperatures below 600 C and conversions of alkane are very low.

[0019] U.S. Pat. No. 6,566,573 teaches the autocatalytic oxidative conversion of paraffins to olefins using fixed bed, fluid bed, or monolithic catalysts. Best conversion and olefin selectivity values of 72 and 82% are described. No attempt to control the catalyst temperature is described and the process is operated adiabatically or nearly so, resulting in olefin yields and selectivities in need of further improvement.

[0020] In view of the above, it would be desirable to discover an autothermal catalytic process of oxidizing a paraffinic hydrocarbon to an olefin wherein the selectivity to ethylene is high. Such a process would provide the benefits of a catalytic autothermal process, such as low levels of reactor coking and simplified engineering. It would be even more desirable if a catalytic oxidation process was to achieve a paraffinic hydrocarbon conversion and an olefin selectivity comparable to or exceeding those achieved by commercial thermal cracking processes.

[0021] As described below, the present invention provides novel microchannel apparatus having improved coatings. Microchannel devices provide the opportunity to control the peak temperature of the catalyst, leading to better thermal integration, lower tendency for the catalyst to deactivate, and better product selectivity. The invention also includes methods of conducting reactions through microchannel devices with coated microchannels.

#### SUMMARY OF THE INVENTION

[0022] In a first aspect, the invention provides a method of conducting a chemical reaction, comprising: passing a reactant into a microchannel reactor and converting the reactant to at least one product.

[0023] The microchannel reactor of the first aspect, comprises: a reaction microchannel comprising a metal substrate; a dense and substantially defect-free alumina layer disposed on the metal substrate; and catalyst metal particles directly disposed on the alumina layer. The catalyst on the reactor may have the catalyst characteristics described herein. For example, in some embodiments at least 30% of the mass of the catalyst metal is in the form of particles having a size of 3  $\mu\text{m}$  or more. Preferably, the metal substrate comprises a microchannel wall. Although this reactor is described in connection with a method, the invention also includes the reactor itself.

[0024] In another aspect, the invention provides a process for converting ethane to ethylene, comprising: contacting