

genolysis, hydrometallation, hydrosilation, hydrolysis, hydrotreating (HDS/HDN), isomerization, methylation, demethylation, metathesis, nitration, polymerization, reduction, reformation, reverse water gas shift, Sabatier, sulfonation, telomerization, transesterification, trimerization, and water gas shift. Combustion is another preferred reaction. Hydrocarbon steam reforming is especially preferred (such as methane, ethane or propane steam reforming).

[0109] In some preferred embodiments, Gas hourly space velocity (GHSV) of the inventive methods may range from $1,000 \text{ h}^{-1}$ to $10,000,000 \text{ h}^{-1}$ based on reactor volume, or $1,000 \text{ ml feed}/(\text{g catalyst})(\text{hr})$ to $10,000,000 \text{ ml feed}/(\text{g catalyst})(\text{hr})$. In other preferred embodiments, GHSV is at least $10,000 \text{ h}^{-1}$ or at least $10,000 \text{ ml feed}/(\text{g catalyst})(\text{hr})$; more preferably at least $100,000 \text{ h}^{-1}$ or at least $100,000 \text{ ml feed}/(\text{g catalyst})(\text{hr})$; more preferably at least $500,000 \text{ h}^{-1}$ or at least $500,000 \text{ ml feed}/\text{g catalyst}$; more preferably at least $1,000,000 \text{ h}^{-1}$ or at least $1,000,000 \text{ ml feed}/(\text{g catalyst})(\text{hr})$.

[0110] Oxidative Dehydrogenation (ODH)

[0111] This invention discloses methods for the oxidative dehydrogenation of alkane(s) and/or aralkane(s) to alkene(s), alkenadiene(s) and/or aralkene(s). The hydrocarbon may be any alkane or aralkane of C_2 up to C_{20} . Examples of alkane include ethane, propane, isobutane or butane or higher alkanes including up to C_{20} linear and branched alkanes; examples of aralkane include ethylbenzene; examples of alkene for the purpose of this invention include ethylene, propylene and also alkenadienes such as butadiene; examples of aralkene include styrene. Preferred examples of hydrocarbons are C_2 - C_{18} alkanes, preferably C_2 - C_{10} alkanes, isobutane, propane, ethane, ethylbenzene, or C_{10} - C_{15} alkanes such as could be used for making detergent alcohols. The alkanes can be linear, branched and cyclic. Hydrocarbons can be obtained commercially either in pure form or in mixtures. Hydrocarbons can also be derived from other reactions, and the output of these reactions used with or without an intervening purification step. Systems of the invention can be described as including apparatus and/or catalyst in combination with reactants and/or products. By "including" is meant "comprising", however, it will be understood that any of the terms "consists of" or "consists essentially of", may alternatively be used to describe more limited aspects of the invention. Additionally, any of the individual components (such as ethane, for example) may preferably be present in at least 20% purity (based on carbon atoms), or at least 50%, or at least 90%, or 100% purity.

[0112] The source of oxygen is preferably a gas capable of providing molecular oxygen, which may conveniently be molecular oxygen or air. Oxygen (O_2) is preferred over air, and in preferred embodiments, the O_2 : N_2 ratio (or the O_2 :diluent ratio) entering a reaction chamber is one or greater, more preferably at least 3, and still more preferably at least 10. In some embodiments, the hydrocarbon/oxygen (O_2) ratio in the feed preferably is 2.0 or more, in some embodiments between 1 and 3, in some embodiments 1.8 or more, in some embodiments 2.5 or more.

[0113] For ODH of ethane to ethylene the ethane: H_2 feed ratio is preferably in the range 1:0 to 1:1, preferably 1:0.2 to 1:0.6, most preferably 1:0.25 to 1:0.5, and the ethane: O_2 feed ratio is preferably in the range 1.8-4.0 and in some embodiments 1:0.25 to 1:0.5 depending on the overall reaction selectivities and conversion. The H_2 : O_2 ratio is preferably in the range of 0.5 to 3.0.

[0114] An alternate microchannel design for ODH reactions is the close coupling of an endothermic reaction in an adjacent microchannel. The placement of an endothermic reaction such as a steam reforming reaction next to the exothermic ODH reaction allows for the highest rate of heat transfer. An endothermic reaction that can be placed in the adjacent microchannel is alkane cracking. A typical heat flux for convective cooling in a microchannel reactor is on the order of $1\text{-}5 \text{ W}/\text{cm}^2$. The incorporation of a simultaneous endothermic reaction to provide an improved heat sink will enable a typical heat flux of roughly an order of magnitude above the convective cooling heat flux.

[0115] Reactor designs for ODH may include distributed injection of oxidant. Reactor designs for ODH are described in US Published Patent Application 20040034266, published Feb. 19, 2004, U.S. patent application Ser. No. 10/441,921, filed May 19, 2003, incorporated herein by reference as if reproduced in full below.

[0116] In some preferred embodiments, an adjacent channel (or channels) carries an oxygen source that is distributed over a length of the reaction microchannel(s). In some preferred embodiments, oxidant enters a reaction chamber at more than 3 points along the chamber length. In some embodiments where a reaction chamber is defined by plural walls (typically four), there are oxidant inlets on one, or more than one, wall of the reaction chamber.

[0117] Preferred temperature ranges of the ethane ODH process in the present invention include: a temperature ranging from 335 to 1100°C ., more preferably $500\text{-}1050^\circ \text{C}$., and in some embodiments about 700 to about 1000 .

[0118] The amount of heat that can be transferred through a plane separating the process reaction chamber from a heat exchanger is a function of the method of heat transfer. For convective heat transfer from a hot fluid in a heat exchange channel to a dehydrogenation reaction chamber, the amount of heat (as defined as Watts per square cm of reaction chamber wall area that is adjacent to the heat exchanger) transferred for a gaseous heat transfer fluid is preferably at least $1 \text{ W}/\text{cm}^2$ and may be up to about $15 \text{ W}/\text{cm}^2$. For a liquid heat transfer fluid used in convective heat transfer, higher heat transfer fluxes are achievable and may range from at least $1 \text{ W}/\text{cm}^2$ to about $30 \text{ W}/\text{cm}^2$. For conductive heat transfer from an exothermic reaction, much higher rates of heat transfer are attainable and heat flux may range from about $10 \text{ W}/\text{cm}^2$ to about $100 \text{ W}/\text{cm}^2$. These defined ranges of heat fluxes are for steady-state operation and average over the area of a process reaction chamber wall that is adjacent to a heat exchanger; or, in a reactor with multiple channels (more than two channels), an average over the areas of all dehydrogenation reaction chambers adjacent to heat exchanger(s) in all the channels in operation.

[0119] In some preferred embodiments, a portion of a reactor with catalyst (a first reaction chamber) is in heat exchange communication with a portion of the reactor without catalyst (an adjacent heat exchanger), and ethane is cracked in the portion of the reactor without catalyst. In preferred embodiments, the residence time of the reactant gas in the portion of the reactor containing the catalyst is less than the residence time of the reactant gas in the adjacent heat exchanger. In some preferred embodiments, the residence time in the first reaction chamber is less than half (in