Microchannel Apparatus

[0153] Microchannel reactors are characterized by the presence of at least one reaction channel having at least one dimension (wall-to-wall, not counting catalyst) of 1 cm or less, preferably 2 mm or less (in some embodiments about 1.0 mm or less) and greater than 100 nm (preferably greater than 1 μm), and in some embodiments 50 to 500 μm. A catalytic reaction channel is a channel containing a catalyst, where the catalyst may be heterogeneous or homogeneous. A homogeneous catalyst may be co-flowing with the reactants. Microchannel apparatus is similarly characterized, except that a catalyst-containing reaction channel is not required. The gap (or height) of a microchannel is preferably about 2 mm or less, and more preferably 1 mm or less. The length of a reaction channel is typically longer. Preferably, the length is greater than 1 cm, in some embodiments greater than 50 cm, in some embodiments greater than 20 cm, and in some embodiments in the range of 1 to 100 cm. The sides of a microchannel are defined by reaction channel walls. These walls are preferably made of a hard material such as a ceramic, an iron based alloy such as steel, or a Ni-, Co- or Fe-based superalloy such as monel. They also may be made from plastic, glass, or other metal such as copper, aluminum and the like. The choice of material for the walls of the reaction channel may depend on the reaction for which the reactor is intended. In some embodiments, reaction chamber walls are comprised of a stainless steel or Inconel® which is durable and has good thermal conductivity. The alloys should be low in sulfer, and in some embodiments are subjected to a desulfurization treatment prior to formation of an aluminide. Typically, reaction channel walls are formed of the material that provides the primary structural support for the microchannel apparatus. Microchannel apparatus can be made by known methods, and in some preferred embodiments are made by laminating interleaved plates (also known as "shims"), and preferably where shims designed for reaction channels are interleaved with shims designed for heat exchange. Some microchannel apparatus includes at least 10 layers laminated in a device, where each of these layers contain at least 10 channels; the device may contain other layers with less channels.

[0154] Microchannel apparatus (such as microchannel reactors) preferably include microchannels (such as a plurality of microchannel reaction channels) and a plurality of adjacent heat exchange microchannels. The plurality of microchannels may contain, for example, 2, 10, 100, 1000 or more channels capable of operating in parallel. In preferred embodiments, the microchannels are arranged in parallel arrays of planar microchannels, for example, at least 3 arrays of planar microchannels. In some preferred embodiments, multiple microchannel inlets are connected to a common header and/or multiple microchannel outlets are connected to a common footer. During operation, the heat exchange microchannels (if present) contain flowing heating and/or cooling fluids. Non-limiting examples of this type of known reactor usable in the present invention include those of the microcomponent sheet architecture variety (for example, a laminate with microchannels) exemplified in U.S. Pat. Nos. 6,200,536 and 6,219,973 (both of which are incorporated by reference). Performance advantages in the use of this type of reactor architecture for the purposes of the present invention include their relatively large heat and mass transfer rates, and the substantial absence of any explosive limits. Pressure drops can be low, allowing high throughput and the catalyst can be fixed in a very accessible form within the channels eliminating the need for separation. In some embodiments, a reaction microchannel (or microchannels) contains a bulk flow path. The term "bulk flow path" refers to an open path (contiguous bulk flow region) within the reaction chamber. A contiguous bulk flow region allows rapid fluid flow through the reaction chamber without large pressure drops. Bulk flow regions within each reaction channel preferably have a cross-sectional area of 5×10^{-8} to 1×10^{-2} m^2, more preferably 5×10^{-7} to 1×10^{-4} m^2. The bulk flow regions preferably comprise at least 5%, more preferably at least 50% and in some embodiments, 30-99% of either 1) the interior volume of a microchannel, or 2) a cross-section of a microchannel.

[0155] In many preferred embodiments, the microchannel apparatus contains multiple microchannels, preferably groups of at least 5, more preferably at least 10, parallel channels that are connected in a common manifold that is integral to the device (not a subsequently-attached tube) where the common manifold includes a feature or features that tend to equalize flow through the channels connected to the manifold. Examples of such manifolds are described in U.S. patent application Ser. No. 10/695,400, filed Oct. 27, 2003 which is incorporated herein. In this context, "parallel" does not necessarily mean straight, rather that the channels conform to each other. In some preferred embodiments, a microchannel device includes at least three groups of parallel microchannels wherein the channel within each group is connected to a common manifold (for example, 4 groups of microchannels and 4 manifolds) and preferably where each common manifold includes a feature or features that tend to equalize flow through the channels connected to the manifold.

[0156] Heat exchange fluids may flow through heat transfer microchannels adjacent to process channels (such as reaction microchannels), and can be gases or liquids and may include steam, oil, or any other known heat exchange fluids—the system can be optimized to have a phase change in the heat exchanger. In some preferred embodiments, multiple heat exchange layers are interleaved with multiple reaction microchannels. For example, at least 10 heat exchangers interleaved with at least 10 reaction microchannels and preferably there are 10 layers of heat exchange microchannel arrays interfaced with at least 10 layers of reaction microchannels. Each of these layers may contain simple, straight channels or channels within a layer may have more complex geometries. In preferred embodiments, one or more interior walls of a heat exchange channel, or channels, has surface features.

[0157] In some embodiments, the inventive apparatus (or method) includes a catalyst material. The catalyst may define at least a portion of at least one wall of a bulk flow path. In some preferred embodiments, the surface of the catalyst defines at least one wall of a bulk flow path through which passes a fluid stream. During a hetereogeneous catalysis process, a reactant composition can flow through a microchannel, past and in contact with the catalyst.

[0158] In some preferred configurations, a catalyst includes an underlying large pore support. Examples of preferred large pore supports include commercially available metal foams and metal felts. A large pore support has a porosity of at least 5%, more preferably 30 to 99%, and still