

Microchannel hydroprocessing

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Unconventional oil, including tar sands and heavy oils, is increasingly important for meeting growing energy needs. However, these lower-quality feedstocks require more hydroprocessing to upgrade them to produce transportation fuels. This, in turn, leads to bottlenecks in refinery throughput. Debottlenecking using conventional technology can be prohibitively expensive, but a new hydroprocessing technology, based on the use of microchannel reactors, could enable refiners to match their hydroprocessing expansion to market demand economically.

Hydroprocessing is a general term encompassing a family of processes that are characterised by the addition of hydrogen to improve material properties. In petroleum and petrochemical industries, one of the most common hydroprocessing applications involves hydrocracking to produce diesel and jet fuel. Hydrocracking is a thermal process that involves depolymerising, or breaking, heavy (long-chain) components into lighter (shorter-chain) ones by adding hydrogen in the presence of a catalyst at relatively high pressures. As in all hydroprocessing reactions, a key feature of hydrocracking is the requirement to create an effective three-phase interface between the liquid product, gaseous hydrogen and solid catalyst.

The small-channel diameters in microchannel reactors mean that heat and mass transfer distances are greatly reduced

The conventional hydrocracking process is generally carried out in a large high-pressure, thick-walled vessel. However, hydrocracking units are not only large and expensive to install; they are also optimised for large capacities in the range 10 000–50 000 b/d, although some smaller and larger units are operating. However, when it comes to refinery debottlenecking, often just a relatively small increase in hydrocracking capacity is all that is required. Microchannel process technology — a developing field of chemical processing that enables rapid reaction rates by minimising heat and mass transport limitations — offers a way forward.

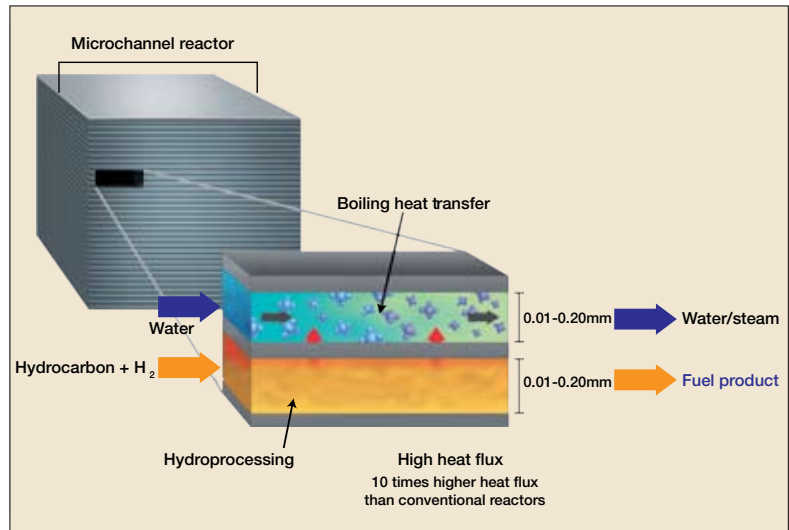


Figure 1 Hydroprocessing microreactor provides short paths for heat and mass transfer
Credit: Velocys, Inc

How microchannel reactors work

Microchannel reactors are made up of thousands of channels with diameters in the millimetre range. These compact reactors were first developed by Velocys, the US-based member of the UK-based Oxford Catalysts Group, for two applications: small-scale gas-to-liquids (GTL) plants for capturing associated and stranded gas both offshore and onshore; and small-scale biomass-to-liquids (BTL) plants for the distributed production of biofuels from feedstocks such as municipal, forestry and agricultural waste. In both processes, heat transfer plays an important role. BTL is based on the highly exothermic Fischer-Tropsch (FT) reaction and GTL relies on both FT and the highly endothermic steam methane reforming (SMR) process. In order to achieve the highest catalytic activity and the longest catalyst life, the heat generated in exothermic reactions, or that required for endothermic reactions, must be transferred efficiently across reactor walls to maintain an optimal and uniform temperature.

Heat transfer is one area where microchannel reactors excel. Conventional reactor systems rely on massive hardware to manage the heat flows. In contrast, the small-channel diameters in microchannel reactors mean that heat and mass transfer distances are greatly reduced, leading to greatly improved heat and mass transfer. This means that more active catalysts can be used. As a result, in microchannel reactors, chemical reactions are greatly intensified. Reactions occur 10 to 1000 times faster than in conventional systems, resulting in very high volumetric productivity, while efficient and precise temperature control is still maintained. Recognising that microchannel reactors have the potential to transform the refining industry by greatly reducing the size of the chemical reaction hardware,

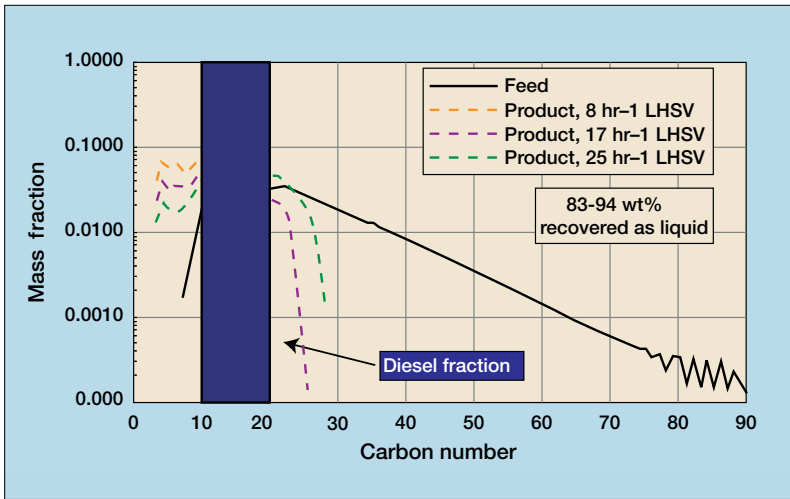


Figure 2 Microchannel hydrocracker performance

Credit: Velocys, Inc

while at the same time improving performance and increasing efficiency in hydroprocessing, Velocys has built on its experience in developing FT microchannel reactors technology (see *PTQ*, Q2 2010, 95–97) to develop microchannel hydrocrackers (see Figure 1).

Advantages on three fronts

The use of microchannels for hydroprocessing enables advantages for hydroprocessing on three fronts: hydrodynamics; heat transfer; and mass transfer. In contrast to conventional reactors, which are constrained by heat removal, microchannel reactors are able to take full advantage of higher catalyst activity because the

additional heat of reaction released by the more active catalyst is removed effectively using interleaved heat exchange channels. Thus, reactions can occur at rates closer to their intrinsic reaction rate values without the development of hot spots and the attendant loss of selectivity.

The greatly improved heat transfer properties of microchannel reactors offer other advantages. Conventional reactors require proprietary designs with interstage cooling, liquid redistribution and gas quench sections to maintain thermal control. For example, in a conventional commercial reactor, hydrocracking vacuum gas oil may require several interstage cooling sections to accommodate the high heat release. In contrast, in microchannel reactors, the coolant channels are adjacent to the reaction channels. This makes it possible to carry out heat removal in a single stage.

Mass transfer is also improved in microchannel reactors. The smaller catalyst particle size employed in microchannel reactors (0.1–0.4mm) compared to that in conventional reactors (2–5mm) results in higher mass transfer rates due to reduced diffusion distance. This makes more of the interior catalyst active sites available to participate in the reaction. The small catalyst particle size also has hydrodynamic benefits because it promotes the spreading of liquid across all catalyst particles via capillary forces. This maintains the catalyst in a

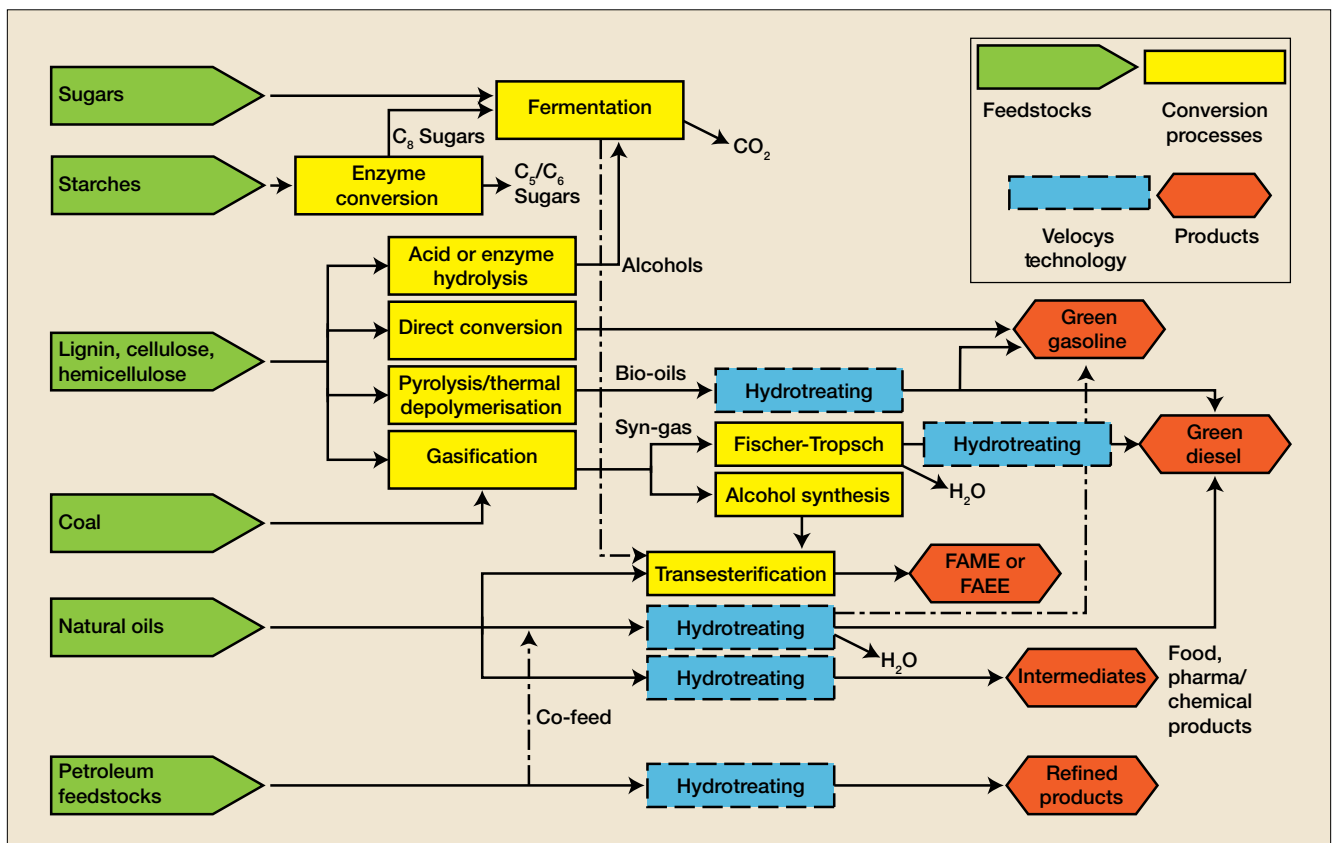


Figure 3 Overview for hydroprocessing opportunities

Credit: Velocys, Inc

well-wetted state and prevents the development of dry spots. In addition, the reduction in liquid film thickness over the catalyst surface due to shear thinning of the liquid reactants leads to a reduction in mass transport resistance external to the catalyst. All of these factors encourage improved contact of the gas and liquid phases with the catalyst and greater apparent catalyst activity.

This combination of improved hydrodynamics, heat transfer and mass transfer results in greatly improved productivity. Laboratory experiments using a small-scale microchannel hydroprocessor to crack FT waxes into a liquid product demonstrated that reactor productivity was 10 to 30 times greater than that expected for a conventional FT hydrocracker (see Figure 2). Microchannel hydroprocessors are now being trialled by two refinery operators.

Microchannel reactors reduce the need for surplus hydrogen, leading to reduced recycle and recompression costs

Improved economics

As well as improved productivity, microchannel technology offers refiners large-scale economics on smaller scales. This translates into less costly facilities with a smaller footprint and lower catalyst costs. Since microchannel devices offer high catalyst productivity, the quantity of precious metals used in catalysts can be minimised, thus reducing catalysts costs. In addition, the improved heat removal in microchannel reactors helps to preserve catalyst activity and prolong catalyst life by reducing hot spot formation.

The use of microchannel reactors for hydroprocessing can also result in lower operating costs. Hydroprocessors typically use five to ten times as much hydrogen as is needed for the stoichiometric reaction. Due to the improved liquid/gas/catalyst interface they offer, microchannel reactors reduce the need for surplus hydrogen, leading to reduced recycle and recompression costs.

All in all, adding a microchannel hydrocracker either downstream of a conventional hydrocracker or on the recycle loop looks to be a useful way to add supplemental hydrocracking capacity cost-effectively and bit by bit as needed (see Figure 3). Microchannel hydrocrackers could also prove to be an inexpensive way to add permanent capacity to refineries. This could be of particular interest to the European refining industry, where overall refining capacity has substantially increased over the past 35 years. Since European refiners tend to increase capacity by adding new units to existing refineries rather than building new ones, finding more cost-effective ways to add capacity is an essential requirement.