Microchannel reactors in fuel production

A demonstration plant aims to confirm the potential for microchannel and other technologies in the distributed production of biofuels

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Biofuels produced entirely from waste such as agricultural by-products and municipal solid waste have attracted attention as a substitute for petroleum-based transport fuels. Since they do not contain aromatics or sulphur-containing contaminants, the liquid fuels produced via biomass to liquids (BTL) are typically of a higher quality, and they burn more cleanly than petroleum-based diesel and jet fuels. They could also prove to be valuable in the effort to reduce carbon emissions. A study carried out by the Southern Research Institute Carbon to Liquids Development Center in the US used the GREET (Greenhouse gases, Regulated Emissions & Energy use in Transportation) model to show that biomass-based FT diesel (biodiesel) production and use results in net greenhouse gas (GHG) emissions savings of 135% compared to petroleum-based diesel, and GHG savings of 129% compared to petroleum-based gasoline. This is largely because bio-derived synthetic diesel production relies on biomass, rather than fossil fuels, as a feedstock.

Despite their potential advantages, economic, environmental and technical obstacles remain to be overcome before biofuels produced from waste can achieve wider application. A major problem is that it takes roughly one tonne of biomass to produce one barrel of liquid fuel. As a result, to avoid the economic and environmental costs of transporting feedstock to central processing plants, BTL production facilities need to be relatively small and located near the source of the feedstock. Establishing small-scale distributed production of biofuels as a practical and economically feasible option requires, in turn, the development of relatively small facilities that can produce typically 500–2000 bpd of liquid fuels, efficiently and cost-effectively.

Microchannel reactors intensify chemical reactions, enabling them to occur 10 to 1000 times faster than in conventional systems

The Fischer-Tropsch (FT) process, in which synthesis gas (syngas), a mixture of carbon monoxide (CO) and hydrogen (H_2), is converted into various liquid hydrocarbons using a catalyst at elevated temperatures, is a key process in BTL. However, fixed-bed or slurry-bed reactors, the two conventional reactor types currently used for FT processes, are designed to work at minimum capacities of 5000 bpd. They only function well and economically at capacities of 30 000 bpd or higher, and the technology does not scale down efficiently.

However, new reactor designs, such as microchannel reactors, combined with more efficient FT catalysts optimised for use in them, offer a practical way forward. Microchannel reactors are compact reactors that have channels with diameters in the millimetre range. They are well suited to the job because they greatly intensify chemical reactions, enabling them to occur at rates 10 to 1000 times faster than in conventional systems. For example, microchannel FT reactors developed by Velocys and using a new highly active FT catalyst developed by Oxford Catalysts accelerate FT reactions by 10–15-fold compared to conventional reactors, and exhibit conversion efficiencies in the range of 70% per pass. This is a significant improvement over the 50% conversion (or less) per pass achieved in conventional FT plants. Their efficient conversion rates, combined with their modular construction, makes microchannel FT reactors, in theory, an excellent tool for small-scale distributed production of biofuels from a wide variety of sources.

Demonstration plant

Developing the technology is one thing. Establishing it as a practical and commercially viable solution is another. A demonstration plant now being commissioned in the town of Güssing, Austria, by a coalition that includes project developer and lead engineering integrator SGC Energia (SGCE), the Oxford Catalysts Group, developers of the microchannel FT technology, along with the engineering firm, Repotec, the Technical University of Vienna (TUW), and gasification facility owners Biomass CHP Güssing aims to operate an FT microchannel reactor and effectively integrate it with other key steps in

Figure 1 The Güssing gasification plant *Courtesy: SGCE*

the BTL process, including biomass gasification and syngas cleaning.

In the late 1980s, the town of Güssing, located in southern Austria near the borders of Hungary and Slovenia, was the administrative centre of the poorest region in Austria. Then, in the 1990s, the city developed a model to replace energy dependence on fossil fuels with renewable sources. By 2001, Güssing had achieved energy self-sufficiency through the installation of a biomass plant that takes advantage of steam gasification technology. The developments in Güssing led to the establishment of the Renewable Energy Network Austria (RENET). As a result, Güssing has become a magnet for companies and researchers keen to develop renewable energy technologies.

Other factors determined the choice of Güssing as the site for a demonstration of FT microchannel biofuels production technology. These included the enthusiasm expressed by the local technology community as well as the availability of a new test facility and R&D building with the utilities in place for SGCE to install the FT and gas conditioning skids necessary for its trial. Güssing is also home to a gasification plant that has been operating in a stable manner for seven years (Figure 1). The syngas resulting from this gasification process has the necessary characteristics and high H_2/CO ratio required for FT.

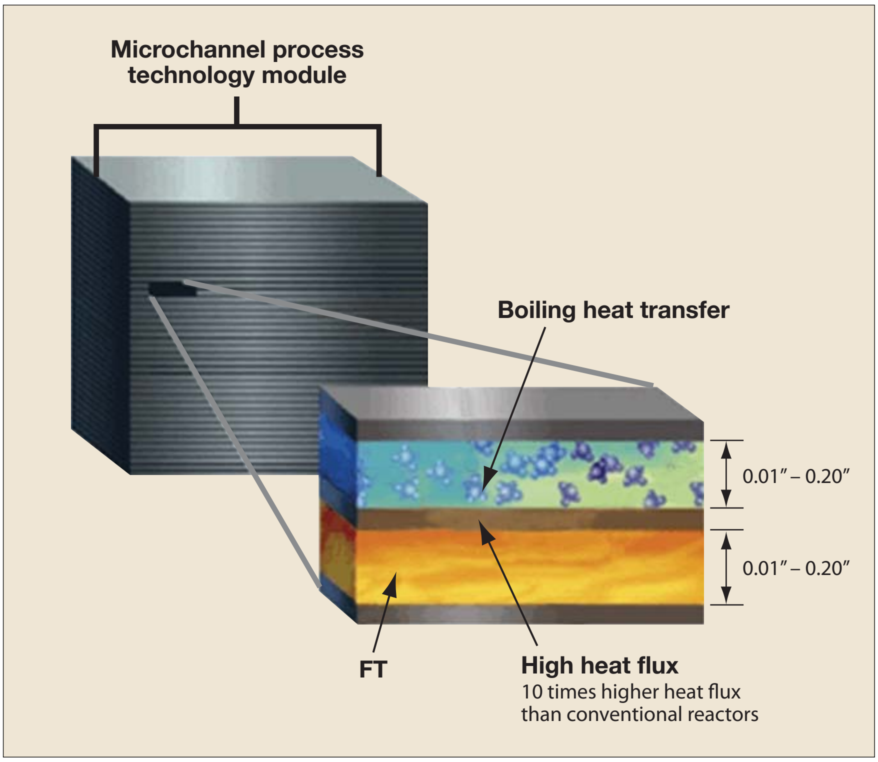

Figure 2 In a microchannel reactor, a single reactor module consists of hundreds of rows of microchannels each containing large numbers of parallel microchannels. The orientation and size of the channels within each row is determined by the application, adjacent rows of channels potentially having different duties *Courtesy: Velocys*

Reduced dimensions

Microchannel process technology is a developing field of chemical processing that enables rapid reaction rates by minimising heat and mass transport limitations, particularly in highly exothermic or endothermic reactions. This is achieved by reducing the dimensions of the reactor systems. In microchannel reactors, the key process steps are carried out in parallel arrays of microchannels, each with typical dimensions in the range 0.1–5mm (see Figure 2). This modular structure enables reduction in the size and cost of the chemical processing hardware.

When microchannel technology is employed, plant size is small. Conventional FT reactors are up to 60m tall. In contrast, microchannel reactor assemblies are roughly 1.5m in diameter, have a low profile and sit horizontally. Their modularity and productivity make them convenient for use in small-scale biofuels production plants, and also opens up the possibility for their use on offshore platforms to produce liquid fuel via gas to liquids (GTL) processes.

Microchannel FT reactor design is also flexible. For example, where increasing the size of conventional reactors normally requires plant designers to increase the size of each reactor unit, which alters flow and reaction dynamics in the reactor, the modular structure of microchannel reactors means that increasing plant size to build demonstration or even commercial-sized plants can be done by “numbering up”. This involves simply adding more reactors with the same dimensions. In conventional FT plants, scaling up typically

Microchannel technology offers enhanced heat and mass transfer

	Microchannel	Conventional
Heat transfer, W/cm^2		
Convective 1–20	<1	
Boiling	1–20	<1
Mass transfer (contact time in seconds	0.001-0.3	1–10
Selectivity, %C$_5$+	78–82	81–94
Selectivity, %CH$_4$	<10	No information available
Alpha ratio	0.89–0.92	>0.9
Contact time, ms	<250	No information available
Catalyst life, years	Not yet determined	2

Sources: Velocys test data and estimates from Nexant

Table 1

involves a lot of fabrication in the field, as well as respecification of reaction conditions and plant components. This can be both expensive and time-consuming. In contrast, microchannel reactors can be shop-fabricated, so microchannel-based plants can be constructed more quickly and easily, thus reducing setup costs and the risks associated with scaling up in conventional reactors.

Modular construction also makes the plants more durable and easier to service because maintenance and catalyst replacement can be carried out by replacing individual modules, rather than requiring a prolonged shutdown of the entire system. Finally, the overall capital costs associated with FT microchannel reactors are relatively low compared to conventional reactor systems such as slurry beds.

Process intensification

The performance of microchannel reactors is attributable to their process-intensified design, which results in enhanced heat and mass transfer capabilities (see Table 1). Conventional reactor systems rely on the use of bulky hardware to manage the heat in FT reactions, and they have relatively small heat transfer areas per volume of catalyst. In contrast, in microchannel reactors, each reactor block has thousands of thin process channels filled with FT catalyst, which are interleaved with water-filled coolant channels. As a result, they are able to dissipate the heat produced from the exothermic FT reaction much more quickly than conventional systems.

This makes them suitable for carrying out both highly exothermic catalytic reactions, such as FT synthesis, and highly endothermic reactions, such as steam methane reforming (SMR), in which heat must be efficiently transferred across reactor walls in order to maintain an optimal and uniform temperature, to maximise the catalyst activity and prolong catalyst life. This allows microchannel reactors to operate at much higher throughput and productivity.

As a result, microchannel process technology is looking like a breakthrough not only for small-scale FT, but also for a large number of chemical and process systems that involve thermal processing. They include, for example, ethane cracking, hydrocracking, SMR, ethylene oxidation, separations, mixing and emulsification, catalytic processes, gas processing for operations such as hydrogen production, and integrated and multiphase systems.

Catalysts improved and optimised

Another reason for the increased throughput per unit volume in microchannel reactors is that they enable the use of more active catalysts. Catalysts play a key role in the FT process. Taking advantage of the high productivity of these reactors in BTL processes requires the right FT catalyst for the job. In order to boost conversion rates to an economic level, microchannel reactors require an FT catalyst with an exceptional level of activity.

An FT catalyst developed by Oxford Catalysts enables operators of microchannel reactors to achieve productivities (defined as kg/m^3/h) that are orders of magnitude higher than for more conventional systems (see Figure 3). A demonstration carried out by Velocys in 2008 in a nominal two-gallon per day microchannel reactor that operated for more than 4000 hours using the new catalyst achieved productivities of more than 1500 kg/m^3/h. In contrast, fixed-bed reactors typically operate at 100 kg/m^3/h, while slurry-bed reactors operate at 200 kg/m^3/h.

The key to the improved performance of the new FT catalyst is in a patented catalyst preparation method, known as organic matrix

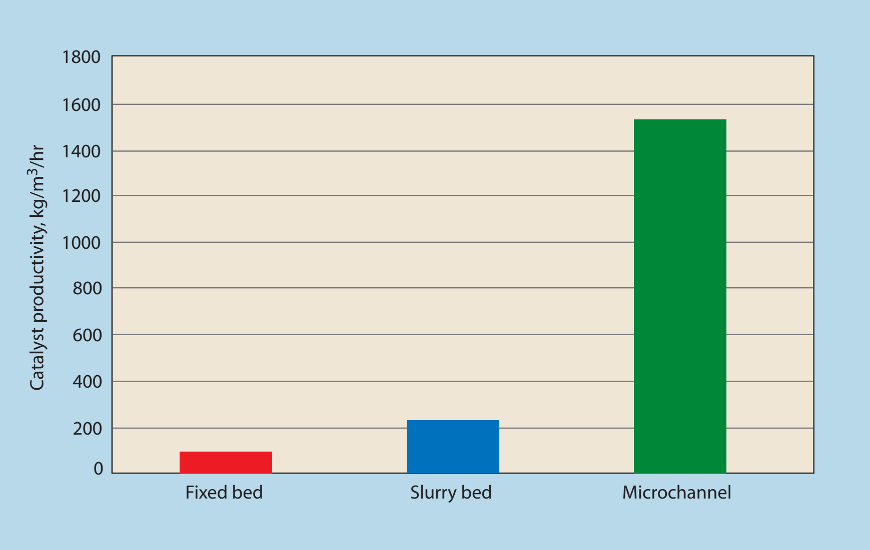

Figure 3 Productivity of conventional FT catalysts in fixed-bed and slurry reactors, compared to productivity of the Oxford Catalyst FT catalyst in a microchannel reactor

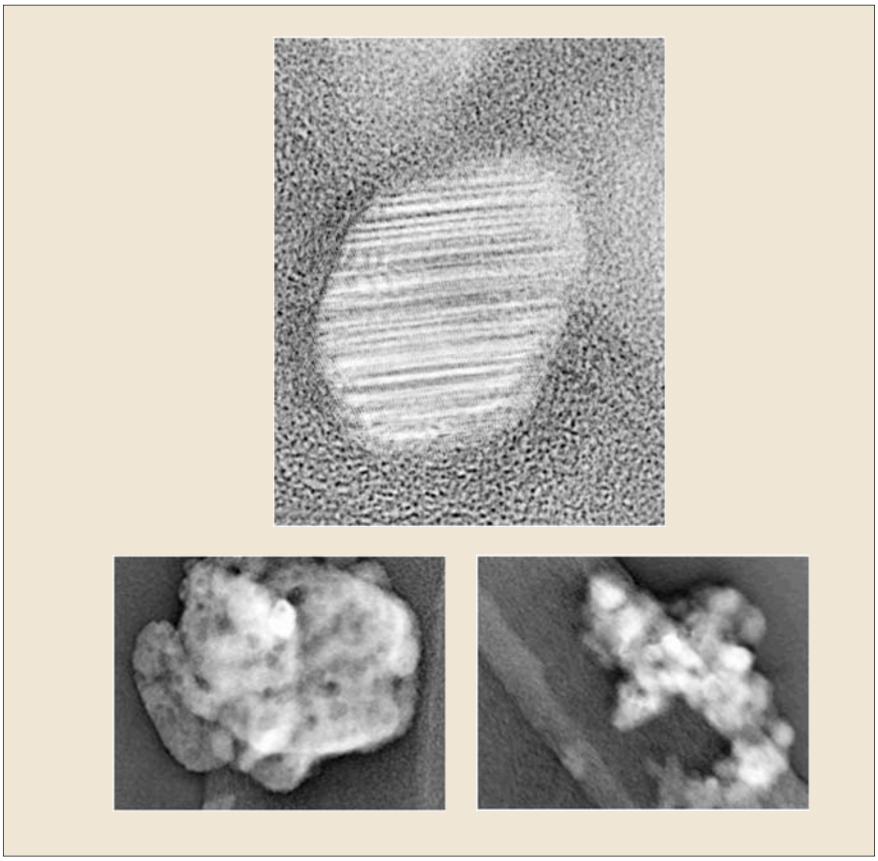

Figure 4 Transmission electron microscope picture of the FT catalyst produced using the OMX method

combustion (OMX). The OMX method combines the metal salt and an organic component to make a complex that effectively stabilises the metal. On calcination, combustion occurs to fix the crystallites at a very small size and in a very narrow range. Since the calcination step is quick, metal crystallites do not have time to grow and hence remain at an appropriate size for these types of catalytic reactions. This is important, because the level of catalyst activity, selectivity and stability is related to the surface area of the catalyst. This, in turn, is related to crystal size, so producing catalysts with the optimal crystal size for a given application is a key goal for catalyst developers. The big challenge lies in achieving the right balance between catalyst activity and stability. If the crystal size is too large, the catalyst activity and, hence, conversion rates are reduced. If too small, the catalyst becomes unstable.

The OMX method produces crystallites that exhibit a terraced surface (see Figure 4), which enhances catalyst activity. OMX also produces fewer very small crystallites that could sinter at an early stage of operation. This results in greater catalyst stability. Less stable crystallites tend to deactivate quickly, reducing the activity of the catalysts.

The method can be used to produce supported base metal catalysts for applications other than those produced for FT. Evaluations indicate that catalysts prepared via OMX perform better than catalysts containing the same metals but prepared using standard methods, such as mechanical milling, wet or dry impregnation, or via sol-gel or co-precipitation in a range of base metal catalysed reactions. Aside from their higher activity, the catalysts have a longer life and the need for precious metal promoters on the catalysts can be reduced, or in some cases eliminated, while still retaining or even exceeding the benefits of more conventional catalysts.

Microchannel technology shrinks processing hardware, while at the same time improving its performance

Work is currently in hand to scale up the process to make it possible to supply formed catalysts in commercial quantities.

Scaling down

An essential characteristic required for distributed biofuels production is the ability to operate efficiently on a small scale. Microchannel technology shrinks processing hardware, while at the same time improving its performance. As well as improved heat transfer properties and higher energy efficiency, microchannel design enables optimal temperature control across the catalyst bed, which maximises catalyst activity and life by preventing the formation of hotspots. It also results in higher reactor productivity as well as increased economies of scale and increased yields of target products. The reduction in the reactant residence time achieved using microchannel reactor technology also means inherently safer operation.

Another advantage of microchannel reactors is their capability to handle large volumes of feedstock and their ability to produce quality fuels from a variety of resources, including waste wood and municipal solid waste. In terms of productivity, they far outstrip more conventional designs and could help enable the distributed production of next-generation biofuels to become a viable economic reality and a practical way to reduce carbon emissions in the near future.

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