tce november 2008 www.tcetoday.com issue 809

tce

the chemical engineer
www.tcetoday.com
issue 809, november 2008

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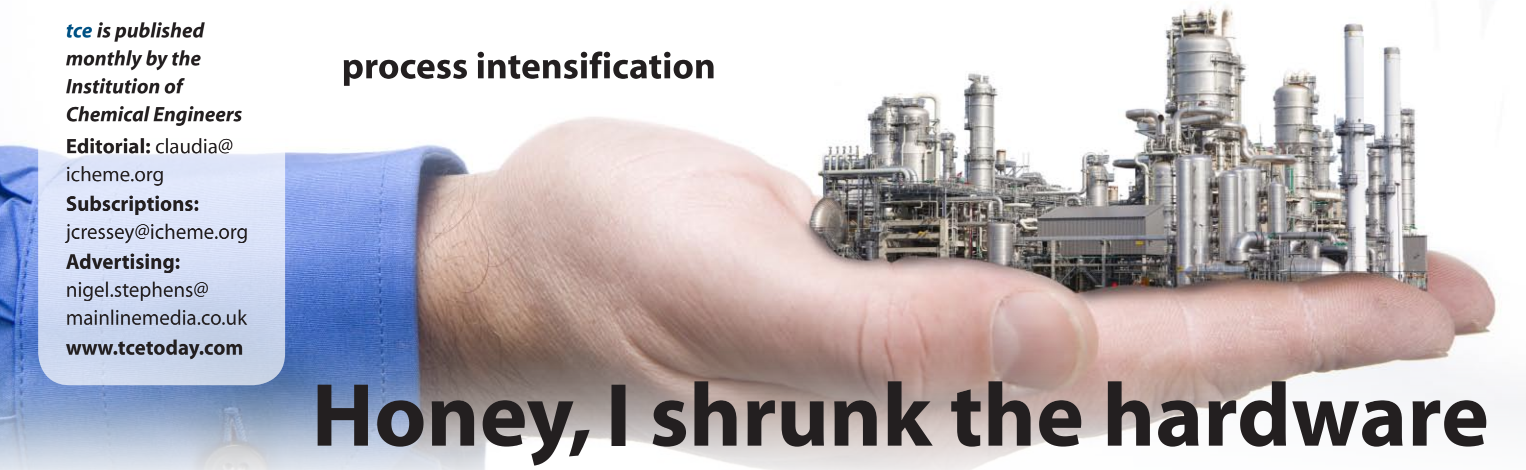
IChemE Awards 08

supplement

***tce* is published monthly by the Institution of Chemical Engineers**
Editorial: claudia@icheme.org
Subscriptions: jcressey@icheme.org
Advertising: nigel.stephens@mainlinemedia.co.uk
www.tcetoday.com



Honey, I shrunk the hardware

Microchannel reactors for Fischer-Tropsch processes can lead to mega benefits for biofuels production, say Derek Atkinson and Jeff McDaniel

OIL and liquid hydrocarbon fuels still provide the mainstay of today's energy economy. But change is in the air. World demand for petroleum is continually increasing, while world oil production has plateaued. Along with factors such as high oil prices, fears about fuel security and concerns about global climate change are encouraging the development of alternative fuels. This, in turn, is sparking a revival of interest in the Fischer-Tropsch (FT) reaction, a process first developed by Franz Fischer and Hans Tropsch in Germany in the 1920s and 1930s to produce liquid fuel from coal.

In the FT process synthesis gas, composed of a mixture of carbon monoxide (CO) and hydrogen (H_2), is converted into various forms of liquid hydrocarbons using a catalyst at elevated temperatures and pressures. Because they don't contain aromatics or sulphur-containing contaminants, the liquid fuels produced are typically of higher quality and burn cleaner than petroleum-based diesel and jet fuels, resulting in lower emissions of NO_x and harmful particulates.

In theory, any source of carbon can be used to generate the synthesis gas. The FT reaction is already used to produce liquid fuels from natural gas (via gas-to-liquid, GTL) on a large scale in Qatar, and is widely used to generate liquid fuels from coal (via coal to liquid, CTL). It can also be used to produce liquid fuel from biomass (via biomass to liquid, BTL).

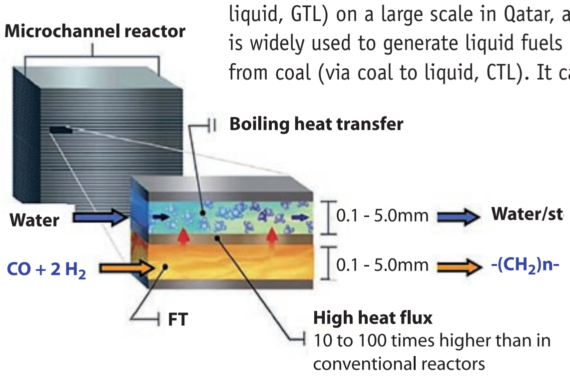


Figure 1: In a microchannel reactor, a single reactor module consists of many hundreds of rows of microchannels each containing large numbers of parallel microchannels. The orientation and size of the channels within each row is determined by the application, adjacent rows of channels potentially having very different duties. (Courtesy of Velocys)

sustainable biofuels

Biofuels have attracted much interest as an environmentally-friendly substitute for petroleum-based transport fuels. Biofuels based on vegetable oils will probably be the major technology for meeting the EU goal of having 5.75% in fuels by 2012. But to meet the goal of 10% biofuels by 2020 it will be necessary to look for alternative methods for producing biofuels from different types of biomass – not least because existing first-generation biodiesel uses food crops as a feedstock. There are concerns that this could lead to food shortages and promote destruction of the rain forests. In contrast, second-generation biodiesel produced via FT will rely on waste feedstocks, such as potato waste, animal waste, corn stover and ligno-cellulose waste from trees.

Although the BTL technology needed to produce second-generation biofuels exists, the FT processes used to produce it need to be optimised to make them economic. Because biomass isn't very dense – as a rule of thumb it takes one ton of biomass to produce one barrel of liquid fuel – it can't be transported over long distances to production facilities. This means that the facilities must be relatively small, producing around 500–2000 bbl/d, compared to 30,000–140,000 bbl/d for a GTL plant. This depends on developing better catalysts, intensifying the BTL process, and developing small-scale FT reactors. We believe new reactor designs combined with more efficient, optimsed FT catalysts are the key to successful BTL process intensification. To achieve this, reactor designers and catalysts developers must work closely together.

microchannel reactors: small and perfectly formed

Microchannel reactors are potentially the best candidates for producing second-generation biofuels. While large conventional BTL plants would need to process biomass feedstocks of 10,000 t/d in order to produce 10,000 bbl/d of fuel, small microchannel FT reactors can operate economically when processing just 500–2000 t/d of waste.

The secret of their success is down to the fact that they offer a way to reduce the size and cost of the chemical processing hardware, while still enabling efficient and precise temperature control, leading to higher throughput and conversion. Like the microelectronics technology that revolutionised the computer industry, microchannel technology shrinks processing hardware, while at the same time improving its performance.

For a start, plant size is small: microchannel reactor assemblies have diameters of around just 1.5 m. Capital costs are relatively low compared to conventional reactor systems such as slurry beds, and the reactors can be operated with a minimum of staff. The microchannel FT reactor design is also very flexible. The basic building blocks consist of components with parallel microchannels, which are arrays of channels with diameters in the 0.1–5.0 mm range (see Figure 1). Their modular structure means that maintenance and catalyst replacement can be carried out by replacing individual modules, rather than requiring the prolonged shutdown of the entire system.

A great advantage of microchannel reactors is their capability to handle huge volumes of feedstock and their ability to produce high quality, energy-dense fuel from a wide variety of resources, including waste wood, energy crops and municipal solid waste.

In terms of productivity – defined as bbl/d of FT product per ton of reactor mass (bbl/d/t) – microchannel FT reactors far outstrip their conventional cousins. For example, Velocys' microchannel FT reactor assembly, which has an output of 360 bbl/d, exhibits reactor productivities in the range of 12 bbl/d/t. In contrast, Shell's Bintulu and Pearl GTL FT reactors with outputs ranging from 3500–6000 bbl/d have reactor productivities that range from around 3–5 bbl/d/t, and Sasol/QP's Oryx FT plant has a reactor with an output of more than 12,000 bbl/d, with a productivity of around 8 bbl/d/t.

heat handling

This sterling performance is largely down to the process-intensified design, which results in massively enhanced heat and mass transfer capabilities (see Table 1). Conventional reactor systems rely on the use of massive hardware to manage the heat in FT reactions and 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 ideally suited for carrying out both highly exothermic catalytic reactions, such as FT synthesis, and highly endothermic reactions, such as methane reforming, 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 conversions. Microchannel reactors exhibit conversion efficiencies in the range of 70% per pass. By comparison, conventional reactor systems typically operate at conversion efficiencies of only 50% per pass.

catalysts: improved and optimised

Taking advantage of these high conversion efficiencies 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. A new FT catalyst developed for this purpose by Oxford Catalysts allows operators of microchannel reactors to achieve productivities (defined as $kg/m^3/h$) that are orders of magnitude higher than for conventional systems. For comparison, fixed-bed reactors typically operate at catalyst productivities of 100 $kg/m^3/h$, while slurry-bed reactors operate at productivities of around 200 $kg/m^3/h$. In contrast, the use of the new catalyst makes it possible to achieve productivities of over 1500 $kg/m^3/h$.

The same catalyst will also be of great benefit for use in conventional FT systems, since another key feature of the catalyst is exceptional stability (see Figure 2). This stability means that both microchannel reactors and conventional systems will be able to operate for longer without resorting to elevated temperatures – which accelerate the decay in catalyst activity – in order to maintain productivity. The key to the improved performance of Oxford Catalysts' FT catalyst lies in a new patented catalyst preparation method, known as organic matrix preparation, OMX (see box).

closer than you think

Although the FT reaction has been around for many years, there are just seven FT plants in operation worldwide, and these are used for producing liquid fuels, lubricant feedstocks and industrial waxes from coal or gas on a large scale. Use of FT to produce second-generation biofuels, economically, and on a small-distributed scale, presents new challenges. Some experts believe that we may have to wait as long as 5–10 years before commercial production of second-generation biofuels becomes viable.

From both the environmental and commercial perspective, existing BTL processes are not suitable for the production of second-generation biofuels. However, we believe that by working closely together to optimise and intensify the FT process, catalyst developers and microreactor designers could ensure that the distributed production of second-generation biofuels becomes both a viable economic reality and a practical way to reduce carbon emissions, much sooner. **tce**

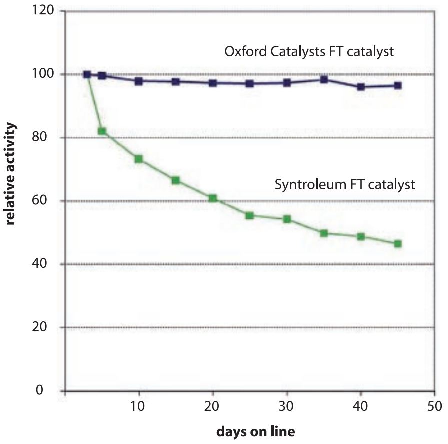
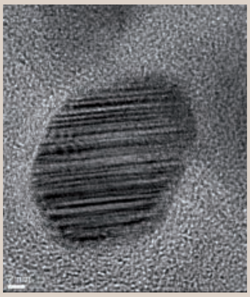


Figure 2: Comparison of deactivation rates between Oxford Catalysts new FT catalyst and a catalyst used in the Syntroleum FT process (data on this catalyst supplied by the FT process licensor, Syntroleum)

	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

Table1: Comparison of heat and mass transfer capabilities



Transmission electron microscope picture of the FT catalyst produced using the OMX method (photo courtesy of Oxford Catalysts)

The OMX method

The level of catalyst activity is related to its surface area, which 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 – will be reduced. If too small, the catalyst becomes unstable. The aim is always to produce a catalyst crystal size that is just right.

The OMX method combines the metal salt and an organic component to make a complex that effectively stabilises the metal. On calcination, combustion occurs that fixes the crystallites at this very small size. Since the calcination is quick, the metal crystallites do not have time to grow, and hence remain at the ideal size. This is important because the improvements in catalyst performance are down to the fact that the OMX method produces crystallites in the 8–15 nm range that exhibit a terraced surface (pictured). These are both features that enhance 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.

Aside from their higher activity, the FT catalysts produced using OMX have a longer life, and the need for precious metal promoters on the catalysts can be reduced, or in some cases, eliminated (see for example, ***tce*** March 2008, pp46–47), while still retaining or even exceeding the benefits of traditional catalysts. Oxford Catalysts are now working to scale up the OMX process to make it possible to supply formed catalysts in commercial quantities.

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