



More than meets the eye

Despite their modest size, microreactors can outperform traditional reactors that are hundreds or thousands of times larger

CLAY BOSWELL/NEW YORK

PRESSED BY margin shrinkage and environmental considerations to streamline costs and reduce environmental damage, many of the biggest names in chemicals and consumer products are developing applications for microreactors. Some companies are already using them for production.

Microreactors are even being developed for the production of bulk chemicals such as methanol and ethylene oxide (EO).

It might seem counterintuitive that something called a microreactor could produce 10,000 tonnes/year of a specialty chemical,

much less contribute meaningfully to a commodity market, but microreactors are not a batch technology. Because they employ flow chemistry, a continuous process, the principles governing their operation and economics are fundamentally different.

GROWING INTEREST

Like petrochemical plants – the chemical industry's most intensive flow processing users – microreactors do chemistry in tubes. But while a typical hydrocracking reactor might have a diameter of 4m, microreactor tubes range between 10 microns and 5mm.

Because reactions in these narrow spaces

tend to be extremely fast, the channels, as they are called, are also quite short. Issues related to mixing – heat transfer, mass transfer and hydrodynamics – that slow transformations and allow side reactions in large reactors are effectively eliminated in microreactors, where mixing is essentially instantaneous, hence the speed. Reaction kinetics become the only limiting factor.

A growing number of chemical manufacturers are trying to exploit the associated advantage, including Swiss-based Clariant, SAFC (a subsidiary the US's Sigma-Aldrich), BASF and Evonik Industries, both German, DSM and US-based DuPont, and pharmaceutical companies Schering-Plough of the US, France's Sanofi Aventis, Roche, of Switzerland, GlaxoSmithKline, Novartis and AstraZeneca, all UK headquartered. Even US consumer products giant Procter & Gamble has worked with them.

Dutch fine chemical producer DSM,

which has used a microreactor developed by US-based Corning to produce more than 25 tonnes of a nitration product under current Good Manufacturing Practice conditions in four weeks, will receive a Corning reactor capable of over 100 tonnes/year of the product later this year.

Siegfried and Lonza, both Swiss, PCAS and Isochem, both French, and Schering-Plough have also tested technology from Corning, which is developing reactors for "several other major customers," as well, according to Gary Calabrese, vice president, science and technology at Corning.

Other developers of microreactor technology include Micronit Microfluidics and Future Chemistry, both Dutch-based, Ehrfeld Mikrotechnik BTS, part of German-based Bayer Technology Services, Uniqsis, and Velocys, both US, the Anglo-American Syrris and Germany's Institut für Mikrotechnik Mainz (IMM).

The devices supplied by these companies differ in various respects. For example, Corning's microreactors feature relatively large channels in the millimeter range, which can increase throughput and reduce clogging. They could actually be called millireactors, and indeed the company prefers the term "Advanced Flow" reactor technology.

However, certain advantages are common to all microreactors: improved selectivity and reliability, safety, cost savings and greater speed to market.

More selective and reliable chemistry results from greater process control. Flow rate, channel length and extremely efficient heat transfer can all be adjusted in microreactors to optimize reaction time and temperature. One benefit is less waste, which in turn lowers costs. In some cases, the products' higher purity may allow the elimination of purification steps.

Costs also benefit from greater safety, the result not only of greater process control, but also of small reactor volume, which minimizes the impact of mishaps.

When expensive cryogenic reactors or explosion-proof facilities can be replaced with microreactors, costs are reduced, notes Andreas Weiler, global business director at US-based SAFC, which uses microreactors to produce about 50 commercial products of up to multikilogram quantities. Costs may be further reduced by the smaller footprint, he adds. "Although a sizeable collection vessel will still be required and further work-up and purification procedures are often needed, the space and equipment require-

ments for the reactors themselves are lower."

Microreactors also simplify scale-up, shortening time to market. Batch processes must often be altered considerably in the transfer to large-scale production, microreactor processes can proceed largely unmodified. Instead, they can "numbered up," or run in parallel in multiple microreactors.

"Usually in scale-up, modeling is not too predictive," explains Volker Hessel, head of the department of chemical process technology at the IMM. "Here you have very regular flows. You can predict some of the behavior, and you use the same units throughout the development chain – ideally. In practice, this is somewhat different, but it is still a major improvement. You don't have to reinvent the wheel, as is done now."

Microreactors not only improve established transformations, but also facilitate more difficult or novel chemistries.

"At SAFC, we are finding that continuous microreactors allow us to carry out a number of useful reactions that simply would not be possible in a batch reactor," says Weiler. "Depending on the process and batch size, they can also be more cost-effective for reactions that already run well in a batch reactor."

"You don't have to reinvent the wheel, as is done now"

Volker Hessel, head of chemical process technology, Institut für Mikrotechnik Mainz

Calabrese agrees. "The unique integration of heat control with the reaction layers enables new chemical paths not approachable with traditional batch technology, and the continuous process provides for effective management of unstable intermediates," he says. Hessel is methodically exploring the expanded range of chemistries possible in microreactors. He employs harsh conditions such as high temperature and pressure to access "novel process windows" in which reaction rates are much higher. "We go to the limits to release the true chemical potential," Hessel explains.

BULKING UP

Most applications being developed for microreactors involve specialty chemicals, fine chemicals and pharmaceuticals, but Velocys, a US-based company recently acquired by UK-based Oxford Catalysts,

is focused on bulk chemicals. Among its partners are US-based Dow Chemical and Japan-based Toyo Engineering.

"Most microreactor companies offer small-scale microreactors without catalysts that process liquid phase flow," explains Laura Silva, director, IP and licensing, at Velocys and Oxford Catalysts. "In contrast, Velocys microchannel reactors can incorporate heterogeneous catalysts or sorbents." They can also process large amounts of material at high temperatures and pressures.

Applications of Velocys' technology include ethylene via oxidative dehydrogenation of ethane; dimethylether (DME) from synthesis gas (syngas); the Fischer-Tropsch (FT) process; steam methane reforming; hydrocracking; higher alcohols from syngas; and production of methanol, styrene, vinyl acetate monomer (VAM), formaldehyde and EO.

Microreactors will not replace large petrochemical complexes, but there are circumstances where their size and portability are more beneficial than economies of scale. It is not cost-effective to transport biomass long distances for conversion to fuel, hence Velocys' biomass-to-liquids (BTL) project.

Last year, Velocys demonstrated a 2 gallon/day BTL microreactor using a new, highly active FT catalyst developed by Oxford Catalysts. The device operated for more than 3,000 hours and achieved productivities of over 1,500kg/m³/h. Standard fixed-bed FT reactors typically operate at around 100kg/m³/h, and slurry bed FT reactors at around 200kg/m³/h. A larger-scale demonstration will take place later this year at the Wright-Patterson Air Force base in Ohio, US.

Challenges remain, such as integration of online control, integration of isolation, solids handling and cost, says Harmen Lelivelt, sales engineer at Micronit Microfluidics. A complete lab unit might cost €10,000–70,000 (\$13,000–90,000), but a dedicated production plant runs from €100,000–500,000, he says.

However, microreactor technology clearly has momentum. Hessel says it may be another 10 years before microreactors are considered a regular tool, but he expects one-fifth of processes to employ them. Lelivelt sees growing interest among research and development groups and gradual acceptance and implementation by industry. "It will be an important [tool]," he says, "one that will certainly claim its place in chemical technology." ■

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