Micro- and Millireactors on the Upswing

Flow Chemistry: Well Proven, but not yet Implemented. What are the Reasons?

Flow chemistry, and in particular microreaction technology (MRT), is no longer a pure academic or R&D field — it is proven to run in production scale, even in world-scale tonnage. This means, micro- and millireactors have entered the final stage of establishing themselves in world-scale dimensions globally.

The main advantages of continuous operation in micro- and millireactors are ultra-fast mixing, highly efficient heat transfer, simple process control due to low system volume and high operational safety due to minimum hold-up. These properties of continuous flow reactors are particularly advantageous for fast, highly exothermic reactions with explosive or toxic substances; due to the safety risk, these processes are often difficult or impossible to handle in batch reactors.

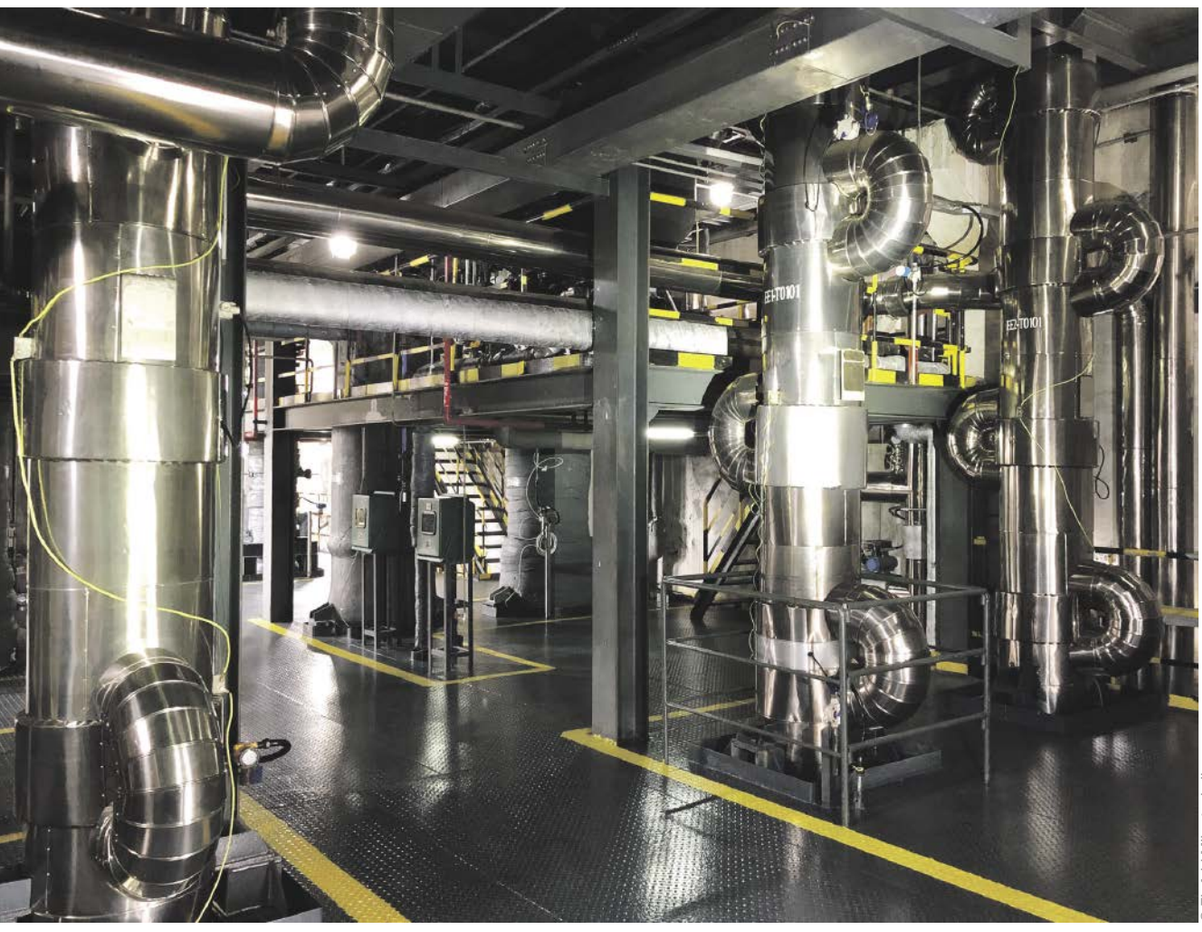
The economic benefits resulting from the technology are mainly due to the high yield and the low proportion of by-products, but also to the sustainable plant safety, lower energy consumption and a smaller carbon footprint.

And yet, due to various reasons, MRT has not achieved the status of implementation, for instance, in fine chemicals and active ingredients production that one might expect — at least not in Central Europe.

At an online roundtable event hosted by CHEManager, a group of industry experts with a diverse range of professional backgrounds, thus bringing technologic as well as economic expertise to the virtual table, discussed those reasons and various business and production aspects of MRT.

Microreaction Technology

MRT replaces the discontinuous batch process with a continuous process in which reactions take place in structures with a reduced size. The main components are mixers with excellent mixing speed and heat exchangers with high heat-transfer capacities. This results in improved process conditions and significant miniaturization of reactive volumes. The excellent mixing and temperature control with hardly measurable temperature gradients over the whole reaction volume cannot be achieved in a classical batch reactor. Due to the exact controllability of the reaction process, the reaction parameters can be better adjusted, resulting in higher product quality and better yields.



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Drawbacks and Hurdles

Why are many chemicals manufacturers still foot-dragging when it comes to investing in and implementing MRT? Five topics emerged from the expert discussion: In addition to technology, the cost side plays a decisive role, and regulatory aspects, mindset as well as know-how in the chemicals companies need to be improved.

In addition to the technical imperative to support the continuous improvement process through technical progress, there is always the economic imperative in business practice: costs and benefits must be in balance. However, there are examples that prove the technology to be economical, for instance in China.

The MRT Lighthouse Project

Shaoxing Eastlake High-Tech, an established Chinese agrochemical ingredients producer located near Shanghai, invested heavily in the technology. In 2016, the company, founded in 1990, commissioned a millireactor which was designed, manufactured and supplied by Ehrfeld Mikrotechnik. The German company develops micro- and millireactors from laboratory up to production scale. The continuously operated Miprowa production reactor at Shaoxing Eastlake with a capacity of up to 10,000 t/a is using milli structures on a production scale and was designed for a highly exothermic alkoxylation reaction. It replaced more than 20 batch reactors while doubling the original capacity. This millireactor was the first visible lighthouse project for the use of MRT on an industrial scale.

According to Jessen Gu, Board Member of Shaoxing Eastlake High-Tech, the entire process — from the first trials to the commissioning of the production plant — took the company less than four years. Since then, the processes have been running continuously and the company has accumulated a lot of knowledge about the technology/process. And Ji Sheng, General Manager of Shaoxing Eastlake Hi-Tech, confirmed that MRT is a safe, sustainable and efficient large-scale production technology.

In November 2018, Shaoxing Eastlake implemented two additional millireactors of the same size, thus tripling their production capacity at its Shaoxing site to 30,000 t/a. The company recovered its first investment in MRT within almost one year.

Joachim Heck, Managing Director of Ehrfeld Mikrotechnik, explained that one important advantage of MRT is the yield increase, which means the generation of fewer by-products and less waste within the production processes, thus reducing the efforts and costs for downstream processing. This can also lead to a significant contribution to climate protection and reduced energy demand for chemical and pharmaceutical processes overall. As energy costs for separation of by-products during downstream processing can make up between 40% and up to 80% of total cost, this can make a significant difference.

Heck explained that millireactors in production are forecast to be reaching a throughput capacity of more than 100,000 t/a. "With the achievement of this capacity, the proof of concept for establishing micro-/millireactors as process technology will be fulfilled," said Heck.

Ehrfeld's next two reference reactor are scheduled to be commissioned in 2023: these consist of six modular stages with a volume of 80 l each and will have a throughput of 20,000 t/a. But despite the existence of such lighthouse projects, the use of MRT varies widely across the globe. In Ehrfeld's experience, the establishment of MRT in Europe and the USA is still progressing slowly. In contrast, MRT is advancing much faster in China, as evidenced by the strong growth of Ehrfeld's subsidiary in Shanghai.

One reason may be that new industrial parks for greenfield chemical plants are currently being established in China and that the use of the latest innovative technology is mandatory.

Shizhe (Steven) Tian, Chief Scientist at Shaoxing Eastlake, said that some months ago, the Chinese government issued a catalogue in which they encouraged 32 technologies—and MRT was on number one.

Regulatory Environment

Claudia Barkowsky, representative of the German Mechanical Engineering Industry Association (VDMA) in Beijing, China, explained that the Chinese government is doing a lot to promote especially technologies that are not yet available in China, or even future technologies that are not yet fully developed.

Regulations such as the „Foreign Investment Catalogue" list industries and technologies that are explicitly encouraged in the Chinese market and those that are more restricted. The „Catalogue for Industrial Restructuring Guidelines", revised two years ago, specifies which industries and technologies should be promoted and which should be phased out. MRT is one of the technologies that is promoted, although not on a large scale.

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>
> Jessen Gu, Board Member, Shaoxing Eastlake High-Tech

"Promoted technologies can be introduced and established by companies—including foreign ones—with lower regulatory and tax costs and simplified approval procedures," Barkowsky said. This is an important reason why both the chemical and pharmaceutical industries are growing at a rapid pace in China.

Also, in a highly regulated environment like the manufacture of medicines and their active ingredients the introduction and qualification of novel synthesis technologies takes time and is costly. Therefore, many manufacturers refrain from changing their established and audited production methods and stay with their batch reactors for the synthesis of new molecules—at least in Europe and the US.

Heck explained: "MRT is not suitable for multi-purpose production as it is a dedicated reactor. Nevertheless, you could set up a production process installing multiple—smaller—MRT units in parallel, that could be used, for example, for the custom synthesis of complex molecules. But there are also projects in an early phase with specific reactors that use continuous processes with multiple synthesis steps. In general, we see that the use of flow chemistry is picking up in custom manufacturing, even for pharma customers."

Mindset

In addition, especially in China more and more conferences are addressing MRT, and both regulators and industry associations are becoming increasingly aware of the technology. Quan Liu, General Manager of Ehrfeld Process Technology in Shanghai, added that in China flow chemistry is mentioned as one of the most important technologies for the coming years, especially for hazardous reactions like nitration.

Compared to Europe and the US, it seems that China is more open-minded, motivated and willing to adopt new, innovative technologies, Heck said. In his opinion, China is a leader in the introduction of new technologies. "Another aspect is that in the last decade, the market leaders, especially in Europe, were waiting until start-ups or SMEs had established new technologies on the market and only then adopted them. China handles this differently," he added. "According to my experience, the most decisive point for entering MRT is that top-down decisions of the management are necessary to embrace this technology and to build it up from lab to production scale. A bottom-up decision for this technology normally doesn't work," Heck explained.

That's why lighthouse projects as the one at Shaoxing Eastlake and other successful implementations of MRT need to get as much visible in the industry as possible. And they probably will.

"As China—compared to Europe and the US—is not attached to established technologies it is more flexible in the adoption of new ones," Barkowsky said. "There is no need for a change of mindset in China."

Based on the experiences with the lighthouse project at Eastlake, Gu said, the company believes that the continuity of the manufacturing process and the environment-friendly production technology together with the high efficiency of engineering equipment will be the three key factors for the manufacture of high-quality chemical products in the future.

He strongly believes that MRT is the most effective technology to enter new or more applications in the coming years. In China, there are already companies using MRT to produce difficult intermediates, replacing other technologies.

These products can then be used, for example, in lithium batteries or other energy sources. With the use of MRT, the chemical industry is not only consuming energy, but can support—at least to some extent—the generation of new energy.

Ralf Kempf and Michael Reubold, CHEManager