**The transformation of the chemical and pharmaceutical industry is taking place in the industry's reactors, fermenters and plants. Innovation is therefore in demand.**

*Chemical reaction engineering lies at the interface between chemistry and process engineering. Anyone talking about scaling up processes, electrification or the use of hydrogen must automatically consider reaction technology: it determines the reaction conditions, regulates what takes place where and when, ensures energy efficiency and influences product properties.*

According to experts, three trends are currently making themselves particularly felt in reaction technology:

* Integrated product and process design based on a fundamental understanding of reactors and reactions
* Process diagnostics based on models, operando investigations and process data
* Electrification of chemical conversion processes and large-scale implementation of electrochemical and chemical energy storage

New diagnostic methods, a better understanding of processes and the customised production of reactors and components, for example with the help of 3D printing, make it possible to provide new equipment that meets the requirements arising from innovative processes.

**From laboratory to industrial process**

Increasingly, the most seamless possible path from the initial idea to the laboratory reactor to the large-scale process is being sought in order to avoid bottlenecks during scale-up and quickly bring new processes into application. Various diagnostic and modelling methods help here. Even on a laboratory scale, the reactors are extensively instrumented so that precise control over reaction conditions such as temperature, partial pressures, throughput times, etc. is possible. In addition, easily configurable process control systems are available to automatically operate today's often parallelized reactor systems over extended periods of time. Automatic data acquisition and processing facilitates the interpretation of experimental results and forms the basis for the continuous scaling of processes.

The more precisely stoichiometry, thermodynamics, kinetics, transport phenomena and relevant safety data are known, the better the performance in the process in industrial scale can be predicted. These parameters can be used to calculate reaction times and heat or electricity consumption or production. If transport processes are taken into account, the reactor can be designed in such a way that the reaction can be carried out safely and with high yields. Miniplant studies are essential for this, as recycling flows and operation under partial load and during start-up and shut-down of the reaction must also be taken into account when designing and analysing the process. With the help of a good model, the process can be transferred directly to the production plant scale. In practice, however, a pilot plant is often interposed in order to further reduce the risks during scale-up.

**Big process in small structures?**

However, the goal is not always the largest possible reactor. This is demonstrated by another important research trend, flow chemistry. It opens up new avenues for catalytic reactors and production techniques. Nanoparticles and other functional materials can be produced in microfluidic reactors with precisely defined properties. Such reactors also enable better heat and mass transfer. Microstructured reactors are characterised by internal structures of ten to several thousand micrometres. In such structures, liquids can be heated or cooled within milliseconds.

Microstructured production plants are also currently being developed, for example to produce synthetic hydrocarbons or high-quality power-to-X chemicals using renewable energy. Thanks to their excellent heat transfer, they enable high space-time yields with high selectivity, precisely controlled product quality and a long catalyst service life. If they have a modular design and can be ramped up and down quickly, they are particularly interesting for decentralised use at the point of energy generation. Several companies, including Ineratec, are therefore already thinking ahead: they not only want to use microstructured reactors in development, but also expand them into commercial production plants.

Developments in microstructured reactors in recent years have shown that the intensification of heat exchange in production processes was initially primarily limited to, but also driven by, single-phase systems. In principle, microstructured reactors can also be used for multiphase systems. Effects such as surface tension, wetting or non-uniform flow behaviour in parallel channels complicate the industrial application of microreactors.

For large-scale production, an integrated scale-up concept is required to ensure the necessary flow rate while only minimally increasing the diameter of the channels. This preserves the advantages of microreaction technology, such as the high mixing rate, excellent heat transfer and targeted process control. The desired throughput can be realised, for example, by a parallel connection of channels to a channel bundle in the reactor.

In 2016, Shaoxing Eastlake Hi-Tech Co. Ltd. commissioned the first large-volume production reactor based on microreaction technology for the production of an ingredient for agricultural applications in China. Three of these reactors are now running continuously with an overall throughput of 30,000 tonnes per year.

**Between stirred tanks and hybrid processes**

The development of new processes and the development of apparatus technology for the construction of chemical reactors go hand in hand. Today, the range of apparatus and reactor designs is as broad as the product portfolio of chemical plants. Due to its flexibility, the stirred tank is still the most widely used reactor type. However, the spectrum of technologies ranges from classic fixed-bed reactors with molten salt or evaporative cooling to heat exchange reactors, bubble columns, jet reactors, nozzle and fluidised bed reactors, high-temperature reactors and more complex apparatus such as microstructured, electrochemical and kneader reactors as well as hybrid systems such as reactive distillation, extraction or gas scrubbers.

Although the stirred tank is one of the oldest chemical reactor designs, it is still constantly being improved. New solutions such as flexible baffles and other modifications have been developed for the "inner workings" of enamelled stirred tanks, which have significantly improved the flexibility and energy efficiency of gas-liquid systems despite the otherwise limited production potential of enamelled devices.

In order to increase heat exchange, heat exchanger plates can be introduced into the stirred tank, which offer larger exchange surfaces than internal heat exchange coils. This allows exothermic reactions, such as suspension hydrogenation, to be better controlled. Salt bath reactors are conventional fixed bed reactors for exothermic, heterogeneously catalysed gas phase reactions at high temperatures. They are used, for example, for partial oxidations, such as in the synthesis of acrylic acid.

If the demands on heat exchange or temperature control are higher, so-called heat exchange reactors can be used. Based on plate or tube bundle heat exchangers, they enable very high heat exchange rates for single-phase systems.

**Challenges from the application**

The new industrial processes, the change in the energy and raw material base and the pursuit of economic efficiency will continue to pose challenges for reaction technology in the coming years. Particularly in view of the trends towards bio-based and recycled raw materials, whose composition and physical properties vary considerably more than those of conventional petrochemical raw materials and which typically contain far more impurities, reactors must be optimised as far as possible on the one hand, but also robust enough to cope with changing conditions on the other.

For example, some biotechnological processes require large reactor volumes of more than 1,000 m³ and simultaneously high specific mass transfer rates. For a conventional aeration system, motor outputs of more than 10 MW are then quickly required, which is difficult to realise mechanically. The development of hybrid gassing technologies and new ways of dissipating heat could help to bring such processes into industrial application more quickly.

In the production of new gene and cell therapeutics, on the other hand, which are highly individualised, all reaction steps should take place in a small space close to the point of care – the pharmaceutical factory in a compact, mobile “chest” would be a possible goal here.

As diverse as the applications are, as innovative are the solutions that reaction engineers develop and for which the plant engineers and equipment manufacturers provide the equipment. In view of the numerous new developments, much can still be expected in the coming years.

*This ACHEMA trend report is based on the Roadmap Chemical Reaction Engineering, 3rd edition 2023,* [*https://dechema.de/Roadmap\_Reaction\_Engineering-path-123211,124930.html*](https://dechema.de/Roadmap_Reaction_Engineering-path-123211%2C124930.html)

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