Future Production Concepts in the Chemical Industry

Continuous Manufacturing and Modularized Plant System Approach Could Make Chemical Production More Cost-Effectively

In the last few years, chemical and pharmaceutical industry companies are working on two major production concepts to further improve their production of chemicals, drugs, materials, or biotechnology products: continuous-flow and modularized production. The general goal of these activities is to more quickly produce at a higher quality, while being less wasteful.

Due to globalized and volatile markets, reduction of time to market is as essential as safe, resource-efficient, and flexible production. The chemical industry is facing an increasing demand from fast growing and vibrant markets such as China, India, or Brazil (maybe not as strong as expected, but still reasonable) and a trend to customize specialty and fine chemicals. This leads to high product varieties, which are produced either in small amounts or over a hundred tons per year.

However, what are the advantages and disadvantages of continuous production processes and modularized production systems? Are these production concepts really helpful for the whole industry, or do they only fit the production of bulk chemicals?

Traditional Batch Processing and Continuous Production Methods

When we examine traditional batch processing, scaling up a batch process is a long-term run and requires a lot of chemical engineering know-how and calculations, as well as experimental results from lab scale and pilot plant prototyping. Step by step, the production volume is increased until the final production plant is built. Every step is difficult and accounts for a high investment and increases time to market. In addition, that market foresight has a potentially high deviation rate, as time to market is too long.
The continuous-flow and modularized process approaches used to overcome the disadvantages of the batch process, and reduce the development time of a chemical or biotechnological production process from initial idea to market operation with simultaneous energy and resource efficiency, is a new paradigm in the chemical and pharmaceutical industry. It could also be used as an example in the agrochemical industry.

Numerous advantages are offered by continuous production methods: they have a smaller ecological footprint, the needed equipment is much smaller and easier to handle, process cycle times and operating costs are lower, and they have maximized quality control and a higher level of automation, which leads to less human interaction and allows for smarter and digitized process control for upcoming trends like the Internet of Things.

In addition, it must be kept in mind that depending on the produced chemical or biotechnological product, the usage of single-use equipment could be profitable, and overall, the needs for inventory and storage would be much lower.

For processes which are susceptible to contamination, like in pharmaceutical drug production, continuous processes together with real-time monitoring and regular sampling can easily clarify such contaminations, and allow discarding only a small amount of the product instead of the entire batch.

Another key component of continuous-flow production is that the process is fully integrated, which means the products of one reaction flow into the next through small-volume pipes. Thus, scientists and engineers in specialty and fine chemical companies can now use certain kinds of chemical reactions that are not feasible in batch processes such as very fast reactions, highly exothermic reactions, safety-relevant conversions like nitrations, or those which require specific light-impulse, UV-impulse, or high temperatures. This could open a completely new field of chemicals and drugs.

**Continuous Manufacturing and Modularized Plant Systems**

Listening to fine chemical and pharmaceutical companies, it sounds that it is only a matter of time when, for example, all major pharmaceutical drug producers have commercial-scale continuous manufacturing facilities.

For higher outputs, which may be needed in the specialty chemical industry, a single micro-structured or milli-structured reaction system sometimes does not fit. However, modularized plant systems, working with continuous manufacturing
methods as a key enabler, allow reacting quickly on increasing or decreasing market demands and are very suitable for the chemical process industry. The target behind modular plant systems is to use standard modules for continuous manufacturing. Therefore, modules and components must be integrated and multi-scalable to significantly accelerate modeling and process design. By using continuous manufacturing laboratory equipment with high similarity to the final process equipment, the detailed engineering of the final production facility can be realized with the chosen laboratory plant structure. The production facility is then built together by pre-configured modules. The wise combination of these components into modules, and the associated integrated information modeling from the process design to the initial operation, are essential cross-cutting activities. They reduce throughput times, while also optimizing the energy efficiency of the process.

To realize an efficient modular plant system, the mentioned integrated and multi-scalable reaction, separation, and other hardware modules are needed. It is only possible with these modules and components to transfer laboratory reactions directly into mass production, avoiding pilot projects and long adjustments of the chemical recipe. The development of scalable components supports the concurrent development of appropriate planning and hardware modules for recurring process steps, and frequently used components such as pumps, columns, reactors, infrastructure, etc. These modules must be integrated into a planning tool that supports the entire design process from early process development in the laboratory up to the 3-D plant model.

The modularization of these key components such as columns and pumps, as well as the data integration and data management through various phases in the plant design cycle, contribute significantly to an increased efficiency and reduced time to market, and allow for industry-wide use.

Furthermore, models of automotive industry supply chains can be adapted, which offer great potential for synergies and competitive advantages for specialty and fine chemicals companies. Thus, the continuous manufacturing and modularized plant system approach could lead to producing cost-effectively over the long-term from the start, just by offering the optimal balance between investments and operating costs, as well as future updates. It remains to be seen if this will be the standard in the chemical process industry.

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