Modularization Paves the Way to “Process Industry 4.0”

Modular Plant Engineering Offers Tremendous Technological and Economic Potential

Individualization does not only apply to cars, clothes or your breakfast cereals. The chemical and pharmaceutical industry is also facing an increasing demand for customized products. The resulting short development and product life cycles are a challenge to conventional plant concepts. Modular plants are globally on the rise in order to meet the changing customer expectations.

They allow for flexibility in terms of production capacity (e.g. by “numbering up” or parallelization), product variety (by changing reaction modules or downstream processing steps), raw materials and location (e.g. mobile modules). Broadly available standardized modules increase competitiveness, especially if they are used by many companies and are thus produced in large numbers at low cost.

Modularization from the Planning Phase on

The benefits from modularization can be reaped right from the planning phase. Reusing engineering information and closed data handling throughout the projects phases can lead to an accelerated engineering phase and shorter time to market. To achieve this goal the utilization of a standardized modular planning workflow is essential prior to physical modularization.

In order to achieve versatile continuous production units and to enable decentralized production, a physical modularization of process plants can be applied. Module definitions will then be performed such that functions specified in PED definition (see following section) are maintained. This physical modularization can take place on the apparatus, plant or logistics level on site as well as in the production network. If a physical modularization is desirable, the compatible modules are constructed as adaptable units and are assembled to form multi-purpose plants. During the following operation, the exchangeability of single modules simplifies maintenance and service and reduces changeover times.
Operational data obtained during production can be directly used by the plant engineer to define maintenance strategies and to optimize already planned modules for prospective projects. Following the production phase, the plant will be dismantled while information and physical components can be reused.

This ensures continuous improvement and the reapplication of operational experience.

**Physical Modularization: Modul Follows Function**

To implement a systematic modularization approach from the process development to the dismantling of the plant, a process is first virtually divided into equipment groups that belong to the same part of the process. This reduces the complexity of a process and creates reusable building blocks. All planning documents required for the construction of such modules are merged in functional process units that are called Process Equipment Design modules (PED) which are saved in databases. A PED incorporates at least one main equipment item, providing the desired unit operation together with all needed peripheral components. Within each PED the main equipment items can be exchanged to adapt to different operating conditions. Each PED is stored as a database element containing all information and documents.

PEDs should be accompanied by simulation models, which allow for the configuration of modules, starting from a description of the PED functionality. The PEDs are then categorized in functional units, the process and service units. Process units are in direct contact with reactants, process or waste streams (e.g. storage and dosage, reaction, downstream, formulation, and packaging). Service units have supporting functions for one or more process units such as utility and energy supply, and do not have direct contact to the process streams. This distinction and the related database should allow for different reuse scenarios to speed up the time to market.

Single PEDs can be combined to form a Process Plant Design (PPD). The PPD conforms to the scope of performance of a modular plant and comprises all documents that are needed for a successful construction and operation. It defines the positions and connections between PEDs and virtually represents the desired process.

**Modular Equipment Is at the Core**

To enable an efficient, yet versatile production environment, the availability of reliable process equipment for industrial small-scale processing is a fundamental
prerequisite. This includes validated model descriptions for process-intensified equipment as well as robust devices providing industrial grade reliability.

Physical modularization is suitable for multiproduct/multi-purpose plants, in which frequent reconfigurations of the process structure are common between product campaigns. Additionally, an integration of small scale continuously operated equipment into pilot or multi-purpose batch plants can be realized to enable highly efficient hybrid production concepts. In this case, the plant consists of individual Process Equipment Assemblies (PEAs). A PEA represents the physical implementation of a PED, following additional geometrical and technical design guidelines, to ensure compatibility of independently planned modules. During the following operation, the exchangeability of single modules simplifies maintenance and service and reduces changeover times.

**Plant in a Container**

The connection of various PEAs to a production plant is described by the Process Equipment Frame (PEF). The PEF contains the geometric conditions and safety-related specifications of the installation environment and covers the supply of all PEAs. Containing the overall process control system of arranged PEAs, the PEF is considered as an independent production unit. For standalone or decentralized production scenarios, the integration of PEAs into a PEF can be performed in modified freight containers, which can provide a fully integrated infrastructure to build up a mobile and reconfigurable production environment, requiring only basic utility supply on site.

To take full advantage of intensified continuous processes, key steps must be taken towards long-term stable, tightly controlled and fully automated production. In this context, process analytical technologies (PAT) play a crucial role. Based on their information the critical process parameters (CPP) can be monitored, controlled, and optimized in order to achieve the desired product output quality or to detect changes in critical quality attributes (CQA).

To enable an efficient implementation of PAT tools, the required measuring methods (including appropriate measuring/sampling points) should be defined at an early planning phase. Ideally, the same analysis methods are applied throughout process development and scale-up from lab to pilot or production scale. This makes an accelerated implementation of PAT tools possible.

Prerequisites for modular plants are a deeper understanding of micro reaction technology, process intensification, and continuous production – all areas that have seen tremendous research efforts and – not least – public funding over recent years.
Research projects such as F³ Factory or the ENPRO initiative have proven that the modularization approach is feasible and can be implemented. The vision of the F³ Factory project was a radical modular approach for a rapid process development and the implementation of novel flexible and sustainable processes with an improved Capex and OpEx. In the successful case studies, the potential of intensification and modularization for the chemical industry was demonstrated. During the project first design guidelines and standards were applied that enhanced the flexibility of a production plant by exchangeable PEAs.

**Standardization Is Key**

Building modular plants is a completely new approach. In order to reach the goal of a completely modular designed and built plant, a lot of effort especially regarding the standardization of equipment and automation technology is still necessary.

A key prerequisite for the modular approach will be the development of standard solutions for problems occurring repeatedly and the definition of guidelines for designing new PEDs. Examples for standard applications are storage, dosing or mixing. These typically do not represent competitive knowledge and can be developed in a joint effort by multiple companies and manufactured by suppliers. This could substantially reduce plant manufacturing costs. On the other hand, PEDs will have to be designed individually or existing PEDs need to be modified, either because no suitable PED is available, or because certain boundary conditions make individual design inevitable.

Interfaces are required to interconnect PEAs among one another and to local infrastructure. These interfaces have to match the requirements of a large variety of potential processes. This can only be achieved with flexible interfaces suitable for adaption to local boundary conditions. Even though interfaces have to be standardized for connections frequently applied, a certain degree of freedom is still needed to adapt the interface to local requirements. This will allow for a quick PEA installation and plant reconfiguration in multi-purpose plants. In cases of frequent exchange, rigid interfaces are required that allow for quick PEA connection and disconnection. However, this may cause substantial additional costs. It will thus be important to find a reasonable compromise between standardization and flexibility.

**Autor(en)**

Dechema

**Kontaktieren**

*Dechema e.V.*