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# Modules in process industry – A life cycle definition

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ABSTRACT

The chemical and biochemical industry has to face the challenges of globalization, short product cycle times and volatile markets. Therefore, the lead time of development projects has to be shortened. Modules and module-based plant design are widely discussed to enable shorter time-to-market by reuse of engineering effort and standardization. In this paper general requirements on modules in process engineering and modules for particular applications in the chemical and biochemical industry are reviewed. This includes the impact of modules on the planning process and examples of realized modular equipment concepts. Based on this, a general terminology definition of 'modules' and of specific module types for the process industry is presented, whereas modules on various 'aggregation levels' are accounted. A 'block representation frame' stores information and tracks information fluxes along the whole process and plant life cycle and on different 'realization levels' from laboratory studies over miniplant validation to production plant design and operation.



## 1. Introduction

As a consequence of globalization, shorter time-to-market and more flexible production concepts are required in the chemical and biochemical process industry, hereinafter referred to as 'process industry', to stay competitive [1,2]. Utilizing 'modules' for plant design in the process industry has been discussed in literature to decrease the planning time due to reduced engineering effort [3,4]. Lier et al., Seifert et al. and Bramsiepe et al. have shown economically advantageous scenarios for chemical production in modular plants [5–7]. With modular plants an adaption of the production capacity to changing and less predictable markets is possible [2,8–10].

Nevertheless, a generally accepted module definition for the process industry still does not exist. This work aims at setting such a definition for the process industry including planning, construction, and operation, as well as information handling. First, a review and classification is given for module definitions already being stated in literature. Afterwards, concepts for modularization, module-based plant design and information handling are presented with respect to all phases of the life cycle and to all contributing disciplines of a process and production plant in the process industry.

### 1.1. Modules in the field of engineering

Generally in technical literature and particular in engineering science several definitions for modules exist. Each of these definitions states important requirements that can be used for developing a module definition for the process industry.

*Abbreviations:* BD, Block diagram with additional information; CAPD, Computer-aided plant design; CIP, Cleaning in place; DIN, German norm; EN, European norm; HMI, Human machine interface; HPLC, High performance liquid chromatography; I&E, Instrumentation and control engineering; ISO, International norm; MCSP, Modular and continuously operated small-scale plant; MIT, Massachusetts Institute of Technology; MEAR, Modular engineering and automation research; MRO, Maintenance repair and operation; NAMUR, User Association of Automation Technology in Process Industries; NPV, Net present value; P, Plant; PAT, Process analytics technology; PEA, Process equipment assembly; PEC, Process equipment container; PFD, Process flow diagram; P&ID, Piping and instrumentation diagram; PS, Plant section; UO, Unit operation.

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A building block for construction such as a LEGO™ brick is often applied as an illustration for standardized interfaces, which are essential for the combination of multiple modules to a larger modular assembly. However, according to Wiendahl et al., a module combines the aspects of providing standardized interfaces with a self-contained technical function [11]. Therefore, the function of a modular assembly of multiple modules results from the combination of the modules' functions. A module definition for so-called 'factory modules' in the metal processing industry is given by Wiendahl et al. [11]: “A module is a technically and organizationally limited area of the plant that fulfills a defined task in terms of company-internal or −external saleable goods and services. It is a standardized and self-functioning unit. As an autonomous operating element it should be able to be tested beforehand. All necessary flows of information, communication, material, energy, and staff are connected to a module via defined interfaces. The module has a defined degree of adaptability. Within planning, a module is reusable.”

Modules are common in further industrial branches. In the automotive industry a car's underbody is constructed using a front, floor and rear module [12]. In the electronic industry multiple modular concepts exist, such as a modular radio [13] or the design of various electronic products based on modules [14]. In the civil engineering sector the application of preassembled parts of houses, so-called building modules, are common to accelerate the construction [15].

### 1.2. Module terminology for the process industry

Based on the general considerations and examples from other industrial branches, a general module terminology for the process industry is proposed: 'Modularization' refers to a procedure, where a complex setup is defined by modules. A 'module' is regarded as an unmodifiable element during planning and realization of assemblies with modules. An assembly consisting of two or more modules is then regarded as 'modular'. A module represents or provides a dedicated function for the process and is reusable during planning or realization of modular plants in the process industry. Therefore, planning elements, such as a process flow diagram (PFD), a piping and instrumentation diagram (P&ID), a 3D layout, and realized equipment can be considered as modules. 'Module-based plant design' is regarded as the selection and arrangement of multiple modules to a process plant, which transforms raw materials to products.

### 1.3. Requirements on a concept for modularization, module-based plant design and information handling in the process industry

As pointed out in the introduction, the utilization of modules in the process industry aims at decreasing time-to-market by shortening project times. This can be achieved due to the reusability of modules [11,16], enabling the reduction of engineering effort. In contrast to this, conventional process engineering often results in individual solutions. The documentation of such solutions does not allow for predicting whether existing designs can be reused in another project with different requirements. Existing designs are characterized by type of equipment, piping, instrumentation, material, dimensions, simulation models, function descriptions and experience reports if those are available. The project requirements are characterized by process parameters such as capacity, temperature, pressure, physical/chemical properties, e.g. density, heat capacity, process kinetics, and further constraints, e.g. given by legal regulations, and the site location.

A plant design approach using modules which makes engineering knowledge available for reuse needs new concepts. Equipment modules for a certain functionality have to be characterized with mathematical models in order to describe the equipment performance under given process conditions and thus its capability. This allows for a comparison between process requirements and equipment capabilities, the so-called 'matching' and thus for a selection and configuration of suitable equipment. For proper matching, information on project requirements and equipment capabilities has to be structured and made available for comparison. Thus, modularization in the process industry has to cover both planning procedures and equipment design by means of suitable data models and information technologies [4].

First concepts have been developed e.g. at INVITE GmbH research center [4,17,18] for flow reactors to match existing designs with requirements of new projects. Similar approaches for heat exchangers [19] and coiled tubular devices for single and multiphase processes [20,21] are under current investigation. Due to the fact that these concepts are presently not available in full coverage for required applications in the process industry, reasonable reuse of engineering achievements is not possible, yet.

Modularization and utilization of modules in module-based plant design should not be limited to product classes, production capacities or to a process mode, e.g. batch or continuous. It requires applicability from first laboratory trials during product development up to construction, operation and optimization of a production plant. This does not necessarily mean that equipment modules being chosen for small-scale studies in process development have to be of the same equipment type being applied later in production. Instead, scale-up concepts are required to perform the transformation from small-scale to production scale.

To maximize the benefit of modularization, all knowledge generating steps throughout planning and project realization need be covered by a structured data and information handling, making engineering knowledge reusable and information fluxes traceable throughout the life cycle.

Information handling should cover the specific views of all parties being involved in the development process and production life cycle, see Fig. 1. Beside the chemical product development, technical development of the process, and plant design managerial aspects such as market analysis, business and product strategy, or regulatory affairs have to be considered, as these aspects set important presettings and requirements for a development and investment project.

## 2. State of the art – modularization approaches in the process industry

Modularization approaches in the process industry started at the end of the last century. In 1980 Stephanopoulos et al. designed modular heat exchanger networks [23]. Their concept was based on shell-and tube heat exchanger modules with discretely defined exchange areas, as tube number and diameter were fixed and the tube length and the number of passes was varied in optimization to identify suitable modules. Afterwards, parallel and series arrangements of the optimal modules were investigated to setup the heat exchanger network.

For plant construction, transportable parts of the plant have been defined as modules. In 1985 Mecklenburgh [24] pointed out the key advantage of these module types to be the opportunity to manufacture plant sections under controlled conditions. This is especially reasonable for plants that shall be erected in remote areas, e.g. with difficult climate, in locations with limited local construction work force or in countries with difficult labor conditions. In 1990 Hesler presented small skid-mounted modules, such as reactor modules and a saline water conversion plant as an example for large modules on a plant section level [25]. Further large-scale process section based plants are a refinery and a methane plant, which were presented by Glaser et al. and built by C-E Lummus [26].