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Automatic equipment design for modular process units

Introduction

In contrast to industrial sectors like the automotive industry, the plant design for unit operations applied in chemical and petro-chemical processes is often tailor-made. The design requires a high level of experience and engineering know-how and is time- and money consuming. One possibility to reduce planning expenses and the time to market is using a modular approach for the design of unit operations, especially for those, which are frequently installed in industrial processes. Furthermore, an increase of reusability of best-practise engineering know-how is achieved by using a modular plant concept. Plant modules in process engineering includes equipment (apparatus and machines), steel construction, foundations, close piping (piping and fittings), MSR technology used for the module-internal control loops [*Hady, 2013*].

Related to this module definition, a concept of automatic constructive equipment design for *Modular Process Units* (MPUs) was developed for rectification columns and associated apparatuses. The prototypical implementation of linking process simulation and the generation of 3D design models is realized in *MOSAICmodeling's PlantDesign* feature [*Fillinger et al., 2017*]. It enables the automatic source code generation for detailed 3D design models including norm-compliant equipment components, internal installations, platforms and ladders, structural elements, supports, and close piping including measurement and control devices. The source code of the MPUs can be imported to 3D CAD tools e.g. *E3D/PDMS* [*AVEVA*®, 2017].

Automatic equipment design

The constructive equipment design depends on a wide range of different determining factors. The following explanations and given examples are related to the detailed constructive equipment design of process units applied in rectification processes, as shown in Fig. 1.

Concept of automatic constructive equipment design

The basic dataset for the equipment design is examined during the basic engineering phase within process simulation and/or optimization. Results of this planning step are for example process variables like material and energy streams, the number of separation stages for columns, transfer areas of heat exchangers or the discharge heads of pumps which have a significant influence to the rough layout of the units. Process operation conditions (pressure, temperature) as well as the occurring media and chemical components affect the selection of steel grade and therefore have influence on the spatial characteristics of structural elements, too. For example, the calculation of apparatus shell thicknesses depend on process conditions (e.g. operating pressure) as well as on temperature-depended material parameters (e.g. yield strength) [*AD 2000-Merkblatt B1:2000-10, 2000*]. Flexible applicability of MPUs to the specialized requirements and constraints of chemical processes is achieved by providing various options for the detailed constructive design. Possible user selections for customization of the process units are types of pumps and heat exchangers, choice of internal types for columns (packing and tray options), supports, beams, and brackets for internals and piping, installation of demister, types of collectors and (re-)distributors, manholes diameters for maintenance, to mention only a few.

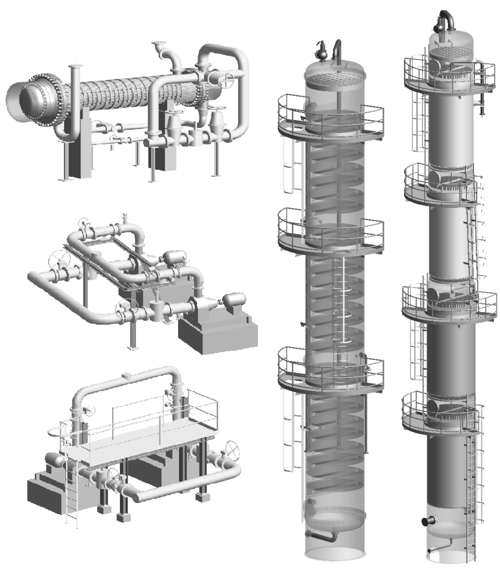

Fig. 1. Examples of automatically generated 3D Models for Modular Process Units (MPUs) in MOSAICmodeling - exported to AVEVA PDMS® 12.1 SP4

The 3D equipment models are created based on the constructive solid geometry method (CSG). With the CSG method, 3D shapes are constructed from simple parametrizable primitives like cylinders, cuboids or spheres, which are transformed and combined by Boolean operations (union, intersection, and difference) [*ISO 10303-42, 1994*]. The description of primitives is realized by characteristic variables, which are represented by parameters, equations or constraints. [*Foley et al., 1996*] All equipment components are assembled out of a set of defined primitives, as shown in Fig. 2. Spatial position and dimensions of these components are calculated automatically depending on the user specifications and calculations. For example, column norm diameter, wall and dished end thickness, and stress calculations for support beams are performed during the design procedure. In addition to the resulting spatial and geometric information of all components, process, plant, and planning data are included in the 3D data model of the MPU. Exemplarily, material selections, operation conditions, piping class information, types of internals, and site-specific information of the plant are included in the model. After importing the MPU model into a 3D CAD environment, all this information are available for further usage. Therefore, this approach allows the generation of intelligent 3D models including already all information from the planning procedure.

A prototypical implementation of the approach is realized within *MOSAICmodeling's PlantDesign* feature, which is described in detail in the following section.

MOSAICmodeling PlantDesign feature

MOSAICmodeling is a free, web-based modeling, simulation and optimization environment developed at the *Chair of Dynamics and*

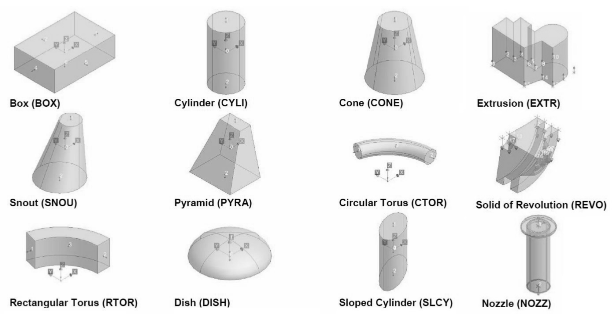

Fig. 2. Parametrizable geometric primitives [*AVEVA PDMS® 12.1 SP4*]

operation at the *Technical University* in Berlin. [*MOSAICmodeling, 2017*] It enables source code generation for a wide range of programming languages and simulation tools based on mathematical models written in *LaTeX*. The portfolio of functionalities contains various features, e.g. *Model Transformation and Analysis, CAPE OPEN Unit Operations and PlantDesign* [*Merchan et al., 2015*].

The *Workflow* within *PlantDesign* is shown in Fig. 3. It starts with the selection of a standardized *Modular Process Unit* (MPU) for rectification processes. Up to now, the *PlantDesign* library includes columns, pumps, heat exchangers and vessels. Simulation and optimization results from *MOSAICmodeling*, such as process and operating conditions, can be embedded directly to the MPU model via an interface in it's simulation functionality [*Fillinger et al., 2017*]. Simulation data from other software can be integrated via an appropriate data interface or entered manually via the graphical user interface of *MOSAICmodeling Plant Design*. Exemplarily, a part of the graphical user interface (GUI) of *Plant Design* is illustrated in Fig. 4.

Besides simulation data, norm and manufacturer data of plant components as well as technical and heuristic rules for the apparatus design and the installation are available to perform the constructive design. Access to this information is given via a SQL database. Depending on the input data of the user, the database queries are performed automatically and the returned results are further processed within the internal calculations for the constructive design. Norm data refer mainly to component geometries (e.g. flanges, platforms and ladders, supports), material properties or constructions of process units (e.g. heat exchanger, vessels). Manufacturer data is primarily used for internals (properties of packing or tray types, collector-distributor systems). Heuristic rules are applied especially to achieve a suitable arrangement of the components with regard to plant operability (e.g. distances between nozzles and internals) or feasibility to install and maintain equipment and piping (e.g. manhole arrangements, access ways, space for welds). Input data is used to process and calculate automatically the dimensioning, positioning and orientation in space of every plant component. Calculated dimensions within the design of columns are for example the height of single packing segments or the tray geometries, the dimensions of the skirt or tubular support, the number and positions of required collector-distributor systems, and finally the total height of a column. These dimensions have a major influence on the positions of nozzles, which are connection points of the MPUs to further plant sections.

Finally, the source code of the MPU is generated, which can be imported directly to 3D CAD software like *AVEVA® E3D/PDMS*. The result is a 3D representation of the MPU, as shown exemplary in Fig. 1, including all underlying specifications in form of attributes.

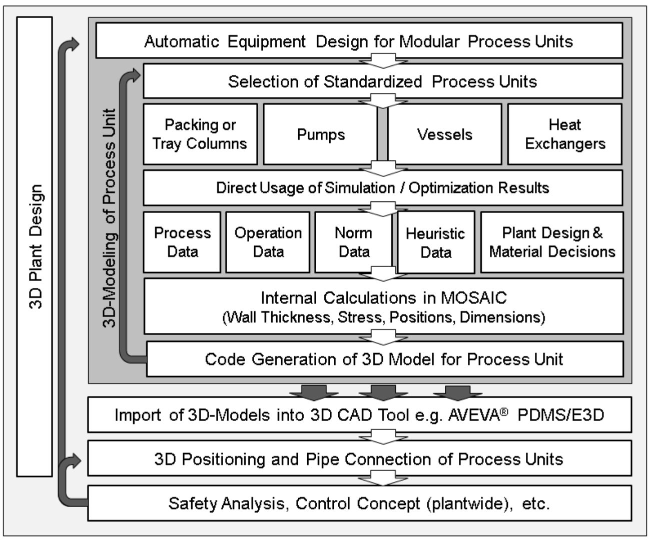

Fig. 3. *PlantDesign Workflow* in *MOSAICmodeling*

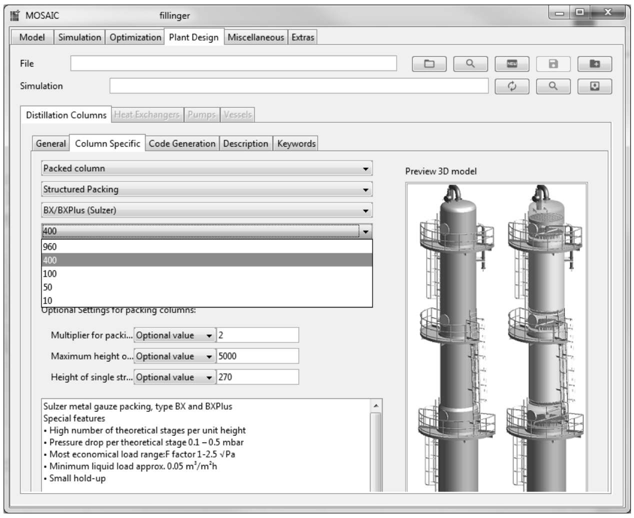

Fig. 4. Graphical User Interface of *MOSAICmodeling PlantDesign – Column Specific Settings*

Conclusions

Efficient plant engineering requires a wide range of specialized software tools used by the experts of the involved trades. The linking of process simulation, automatic design and generation of 3D design modules realized within the *MOSAICmodeling* environment enables a reduction of planning time, costs, and data transfer errors. The design of the MPUs is individually adaptable to the process data, operating conditions, material selection and constructive design requirements. The plant design is based on best-practice engineering solutions and proven heuristic know-how. It improves the reusability of the complete engineering starting with the process simulation and optimization and ending with the detailed constructive design.

Improving the interoperability between software tools is of great significance for the digitalization in process industries. For this reason, future research is dedicated to the development of platform-independent, standardized 2D-3D- and 3D-3D-plant data exchange formats with compliance to the standards [*ISO 15926, 2004-2013*]. This standard contains recommendations for the data management for the entire life-cycle of petro-chemical plants.

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