INTEGRATION OF PROCESS AND CONTROL SIMULATION INTO THE ENGINEERING PROCESS

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ABSTRACT

Testing of a chemical plant is done mainly during its start-up and commissioning phase and in general requires a considerable amount of time and money to correct hardware and software problems. Using model based plant simulation directly after completion of detailed plant engineering, the main testing and debugging could be done by simulated virtual plant thus reducing the time and cost of the start-up phase. This paper describes an approach to generate the required plant models automatically from a model catalogue in parallel to the engineering process.

INTRODUCTION

Simulation technology has become a widely used technique in all phases of the chemical engineering cycle, from process synthesis and conceptual design, through basic and detail engineering. It is also used in process control, monitoring and operator training (Schuler, 1995). Growing economical and ecological constraints require further tightening of the engineering cycle and thus demand the application of simulation technology during all design/development phases. The development of the necessary process models, however, requires highly sophisticated expert knowledge and is in general time-intensive. Over the last decade, this has lead to an increasing interest among research groups to develop methodologies for model generation based on computer-aided systems.
Advanced computer-aided modelling environments share at least some of the following characteristics:

- basic modelling objects, e.g. phenomena-based
- model representation with high abstraction to facilitate model re-use
- comprehensive data model to ease model maintenance
- implementation of work flows to facilitate reproducible modelling and automation of modelling tasks

(Stephanopoulos et al. 1990) and (Bieszczad 2000) focus on the development of a phenomena-based modelling language (MODEL.LA). Furthermore, the modeller is assisted in specifying the modelling problem and thus providing a basic work flow.
(Jensen and Gani 1999) describe a process-modelling tool (ModDev) which is composed of a knowledge-based system and a generic modelling language. Model abstraction is achieved by uniformly distributed regions (shells) and connections between those regions. Models for unit operations are derived by aggregation from those fundamental building blocks.
(Linninger et al. 2000) present an approach for computer-aided model generation and an associated environment (TechTool). This is based on a generic object-oriented (object inheritance framework) and phenomena-based mathematical language. Meta-modelling is employed to facilitate model re-use and adaptability of the framework and to achieve a purely declarative formulation of modelling problems.
(Tränkle et al. 2000) describe a process modelling tool (ProMot) that supports the modeller through an object-oriented modelling language and a graphical user interface. The modeller can build process models from basic structural or behavioral modelling entities through aggregation and/or inheritance by either means. Knowledge representation is provided by a frame definition language.
(Bogusch et al. 2001) describe a comprehensive framework (ModKit) aimed at supporting the entire model development process. A knowledge-based approach has been adopted for the model representation including phenomena-based objects. A data model aimed at chemical engineering data (VEDA team 1999) has been developed. Work flows have been implemented which allow for partial automation of modelling tasks.
(Fritz and Engell 1997) describe an architecture for the simulation of batch processes (BaSiS). The system is characterized by object-oriented components (model builder, simulator and output client), which provide the framework for the implementation of specific interfaces, e.g. for a specific simulator. Thus a substantial degree of flexibility with respect to the simulation task is achieved.
However, all these approaches are only suitable if CAE and simulation experts are available throughout the

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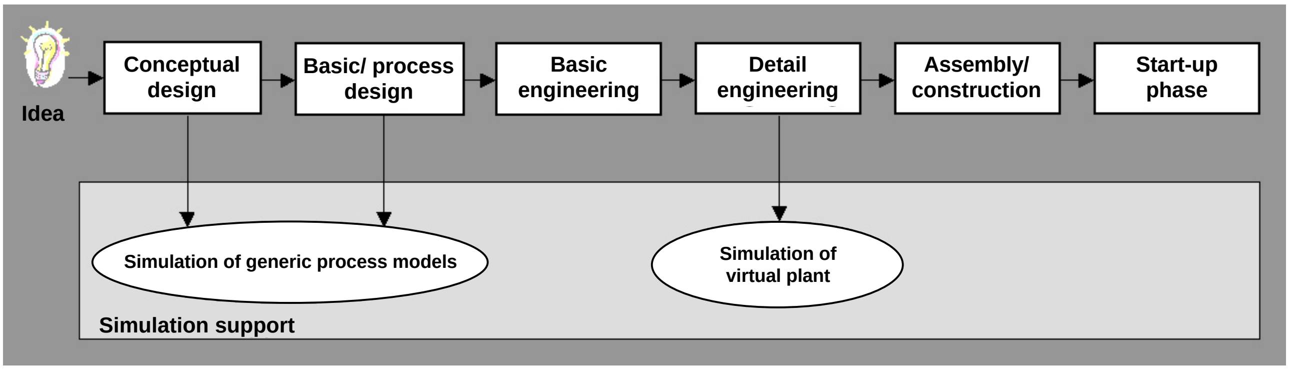

Figure 1: Simulation Support During the Engineering Process of a Chemical Plant

whole design cycle. Therefore, for all phases of process engineering, where such experts are not available (which is frequently the case in small or medium sized industrial companies), new ways have to be found and new tools developed to support the planning process by simulation. Also, all but one of the above approaches concentrate on the early phases of the engineering process and tend to support simulation for conceptual design, Fig. 1. The approach proposed in this paper is aimed at the later phases of the engineering process and particularly at the detail engineering phase in which the final specification of parts and components is done by project engineers without specific modelling and simulation expertise. After completion of the detail engineering, all information is prepared for the construction and assembly of the plant. The functionality of the plant, however, is not usually tested until the start-up phase, during which time, all hardware and software problems become obvious and must be resolved in a time and money intensive debugging procedure. By simulation of the plant, the test and debugging phase could be shifted back to the end of the detail engineering phase where in principal all required technical information for the building of the plant has been compiled. Currently, however, this information cannot yet be transformed automatically into a simulation model of the plant which could be used by the planning engineer for test purposes. This paper outlines a general approach for the automatic generation of plant simulation models in parallel to the engineering process based on a component model catalogue, not requiring specific modelling expertise of the planning engineer to run a simulation. Based on such models, testing and debugging could become available to the planning engineer, on the simulated virtual plant before the real plant is built, thus reducing time and cost during the start-up phase.

GENERAL CONCEPT

After completion of detail engineering all components of the plant are completely specified: So e.g. the planning engineer has chosen a pump with its typical characteristics from the catalogue of a specific manufacturer. In order to simulate the functionality of the pump for the process planning engineering or the control planning engineering disciplines, specific simulation models must be made available. These should allow the simulation of the flow through the pump depending upon the fluids and pressures, for the process engineer. Likewise, the dynamic response of the flow to a change of the driving input, would often be required by the control engineer etc.. In electrical engineering, especially for printed circuit board (PCB) design, simulation models of electrical components are provided by the suppliers, often before the silicon itself becomes available and can be used to simulate the function of the electrical circuit during the board design. Such a systematic approach is still missing in chemical and mechanical engineering. The intriguing idea to get the simulation models from the component suppliers in order to distribute the effort for the creation of the simulation model is one basic principle for the automatic model generation concept proposed here, see Fig. 2.

Let us assume for a moment that such a systematic model collection methodology exists and that all required component models are stored in the CAE system for process engineering in a simulation model catalogue. In parallel to the selection and specification of components for the plant during detail engineering, a plant simulation model could now be automatically aggregated from the component simulation models – and this idea forms the other basic principle for the automatic model generation concept proposed in this paper, see Fig. 2.

Although the general idea is simple, the realisation of such a modelling concept requires the solution of a number of complicated tasks. In order to restrict the complexity the following description concentrates on models for the process and control engineer which allow them to test the respective functionality of the plant that is of interest to them. Other modelling aspects are excluded for the moment but may be added later.

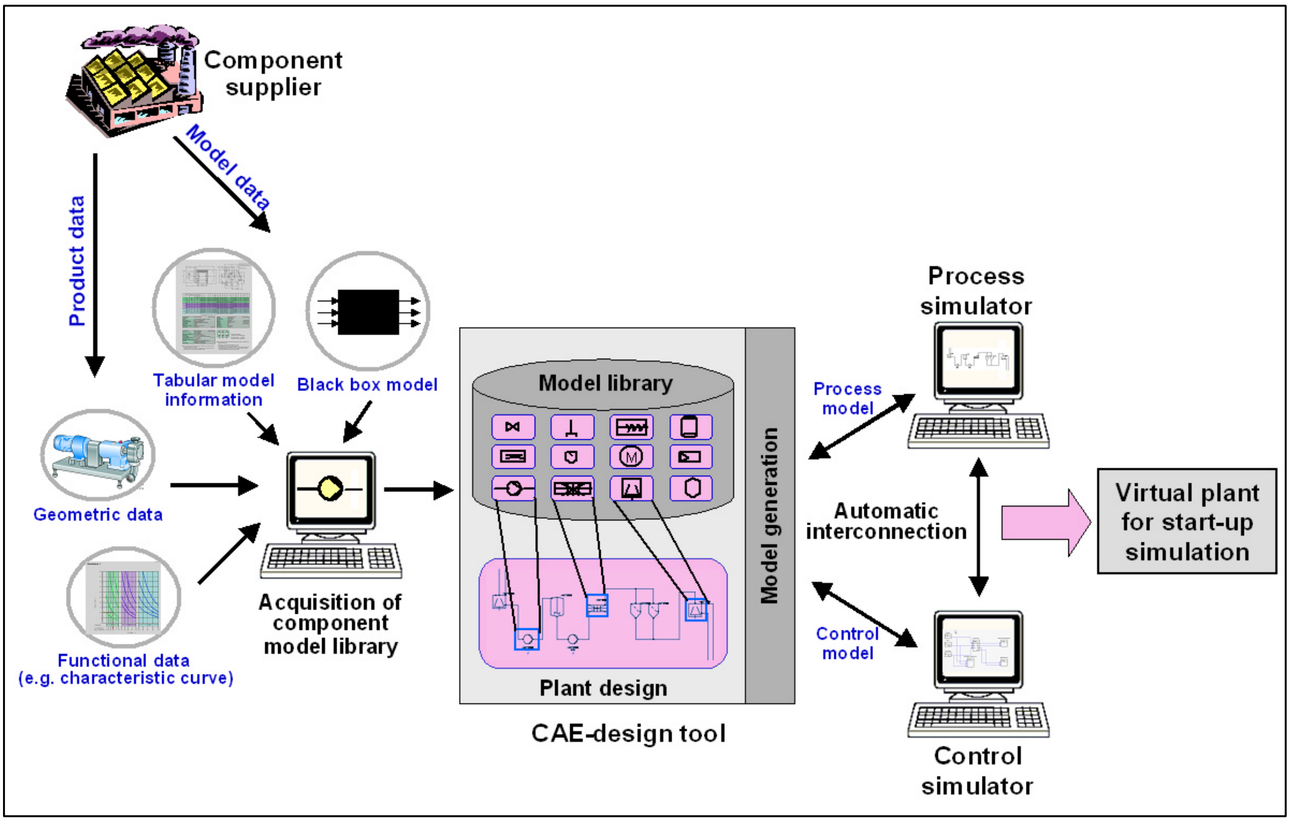

Figure 2: General Concept for Model Catalogue Based Simulation

TASKS AND REQUIREMENTS

For the proposed approach, the following tasks and requirements will be considered:

- structure of the component models
- quality of the component models
- organisation of the model catalogue according to model aspects such as model type and storage format
- automatic model aggregation within a process engineering CAE tool

Component Model Structure

Component models should be provided by the component suppliers. In order to make this possible two principal approaches can be taken:

(1) Table based models. A generic model is defined for each component class with a prescribed structure and parameterisation. In order to acquire the component model information, the supplier must only provide the parameterisation for his specific component which could be collected using templates. This would simplify the modelling task for the supplier but would require the generation of generic models for all necessary component classes – a considerable work load.

(2) Black box models. An input/output structure is defined for each component class with prescribed signal types. The suppliers provide a black box model for the defined input/output model structure – this would require an explicit model designed by the supplier, but would require a relatively small effort for the definition of the input/output structure, for the required component classes. The problem here is to define a compatible exchange format for such black box models (DLLs, models for specific simulators etc.).

In a prototypical implementation of the approach presented in this paper, both model types have been taken into account. No matter which approach is used, the principal question arising is how models for significantly different simulation aspects – be they for process simulation or control simulation – can be combined efficiently in the model catalogue to support all required simulation tasks.

Component Model Quality

The quality of component models is inextricably linked to the process model performance and is determined by the validation of the process models for the envisaged simulation task. The validity of the models can be characterized by the experimental or theoretical conditions under which these models were derived. These conditions and model characteristics form an integral part of the model description and have to be supplied by the model developer. The range of validity of a model can be expressed in the form of declarations and in terms of valid model parameters and input signals, for example. Declarations regarding valid process conditions have to be brought to the attention of the process engineer during component specification, e.g. requiring confirmation. Invalid model parameters can be rejected during model specification. Thus only valid parameters can be specified. During a simulation run invalid input signals can be handled with alerts and automatic interruption of the simulation. These procedures provide different degrees of control with respect to the quality of simulation models.

Organisation of the Model Catalogue

All kinds of process models and control models have to be collected in the model catalogue. According to their nature, these models reflect different aspects of the process – the process models concentrate on flows, temperatures or compositions of flows whereas the control models represent the dynamic interaction of all kinds of signals for control. For the storage of such simulation models the following alternatives can be chosen:

(1) General model description language. By choosing a description language like XML the models could be formulated and stored independently from any specific simulator format. For the simulation, however, such models have to be converted to the format of the simulator used.
(2) Simulator specific model format. Having specified standard simulation tools, the models could be stored in the specific formats of the simulators. Thus, the models can be directly used for simulation, though only for the specified simulator. For other simulators the models must be converted.

For the prototypical realisation, the second alternative was chosen to avoid the need for the definition of a general model format and a conversion utility.

Process Engineering CAE Tool and Automatic Model Aggregation

During basic and detail engineering of a chemical plant in general, an object tree is generated in the process engineering CAE system, reflecting among other information, the connections of the planned components and their parameterisation. The stored engineering information must be augmented by a reference to all required component simulation models, including their connections to other component models (I/O references) and parameterisations. The model I/O references reflect not only the connections within one simulation world (process or control) but also the interaction of process and control simulation worlds: A pump may be directly driven by a control input which is generated in a control scheme and the reaction of the flow to a change of the control input is generated by the process simulation. The changing flow may be measured by a flow sensor and transferred to the control scheme thus closing the control loop via the process model. This leads to an automatic integration of process and control simulation. The process simulator serves as process model for the control simulator whereas the control simulator provides the necessary control actions for the process simulation.

IMPLEMENTATION CONCEPT

An object oriented CAE tool for process planning - Comos PT - serves as the basis for the integration of process and control simulation into the engineering process. The simulation of process models is carried out with the process simulator gPROMS, the block oriented simulator Matlab/Simulink serves as simulation tool for control models, see Fig. 3. Within Comos PT component model libraries are stored as a basis for (chemical) process simulation (with gPROMS) and control simulation (with Simulink). During the planning process within Comos PT component model objects are arranged and specified for process and control system equipment, containing all relevant model parameters and connection information. To allow the aggregation of simulation models, references to the model library with process models for gPROMS and control models for Matlab/Simulink are added to the Comos PT model objects. Once the engineering process has been

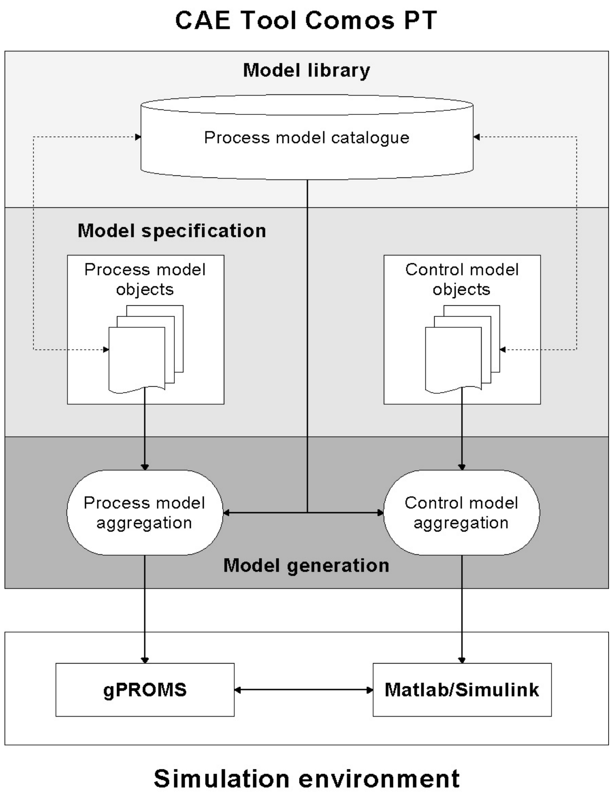

Figure 3: Generation of Specified Process Models from the Model Catalogue

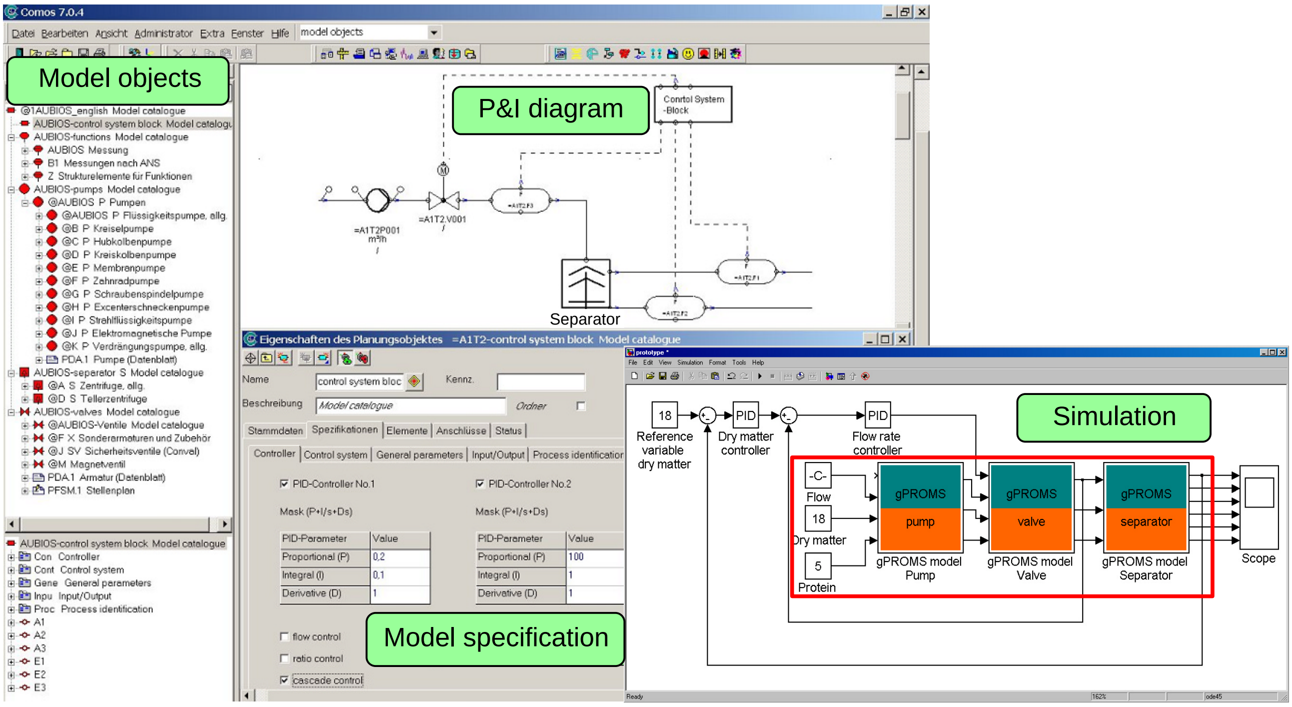

Figure 4: Application Example: Process Planning in Comos PT and Associated Simulink and gPROMS Simulation

completed the aggregation to the resulting plant simulation models and the parameterisation of the component simulation models can be done on the basis of the specified Comos PT model objects and their I/O connections according to Fig. 3.

APPLICATION EXAMPLE

The proposed concept was tested for the separation step of a fresh cheese production process, in a prototypical implementation. In this step a disk stack centrifuge (separator) separates the coagulated milk into sour whey and fresh cheese. The fresh cheese production is a batch process and the separation is prone to disturbances that influence the separation efficiency, especially at the end of the cycle. In order to maintain constant product quality a control strategy for dry mass and protein content of the fresh cheese is required. For the separation components simulation models have been developed for the component model library in Comos PT as required for simulation with gPROMS and Matlab/Simulink, respectively. During the design of the separation process and its control scheme within Comos PT the model objects are arranged and specified in the P&I diagram and the corresponding object tree. Based on this information the aggregation of the simulation models for gPROMS and Matlab/Simulink is done, at present still manually, in the near future by an automatic model generator utility. Fig. 4 shows on the left, the Comos PT interface with the model objects, flow chart and model specifications and on the right, the aggregated simulation models in the Matlab/Simulink environment. The gPROMS process models are integrated as special blocks in the Matlab/Simulink environment.

Thus, the planned configuration of the separation process and its control system can be simulated by the planning engineer without specific modelling or simulation expertise.

CONCLUSIONS

The integration of simulation into the engineering process for chemical plants allows, in general, the optimization and testing of the designed process at an early stage. The proposed catalogue based modelling approach aims at the simulation of the planned plant directly after completion of plant engineering, such that the plant's functions can be tested and debugged before it is built, yielding considerable time and money saving for the plant start-up phase. The required simulation models for the plant components should be collected directly from the component suppliers to distribute the effort for the component model generation. The plant simulation model is aggregated in parallel to the engineering process, making use of the information provided during the standard engineering process. Using this concept, plant simulation may become available in the future as standard test and debugging tool for the normal planning engineer without the need to become a modelling or simulation specialist.

Future work will include the development of an automatic model aggregation utility (model generator), with due regard to the generalization of the model generation systematic. The integration of more detailed simulation models (perhaps as complex as CFD models) will be considered. Industrial process realizations will be investigated, (e.g. by replacing the Matlab/Simulink simulation by the emulation of an industrial process control system), in order to create a simulation environment as close to reality as possible for the planning engineer.

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