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Towards the Development of a Training Simulator for Biorefineries

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Biorefineries are one of the future components for sustainable industrial production. They consist of highly interacting unit operations. In order to efficiently run biorefineries, sophisticated operational strategies and control mechanisms must be applied, which requires an intense training of plant operators and engineers. In order to train process handling and control a training simulator can be used. With this simulator also new control schemes and operational strategies may be tested prior to application in the real plant.
Towards the development of a training simulator for a full biorefinery three single unit simulators, i.e. for bioethanol fermentation, a distillation process and a biomass power plant have been created. A new software structure, using router technology in combination with the open source script software AutoHotkey enables the combination of the single unit simulators to form a complex interacting process.
The presented biorefinery simulator offers a new methodology for the training of plant operators as well as the development and testing of complex “whole plant” process operation and management strategies.

1. Introduction

Biorefineries will play an important role in future industrial production. As they utilize different types of biomass as their key substrates, they are supposed to contribute significantly to a sustainable economy. Biorefineries are grouped into several types according to the products being produced, the biomass sources utilized or the technologies used. Examples are biorefineries producing bioethanol, biorefineries utilizing the green (wet) parts of plants (green biorefineries), lignocelluloses biorefineries based on the utilization of wood, or two platform biorefineries using thermo-chemical technologies for the degradation of biomass and fermentations for the conversion of the substrates to valuable products or intermediates (Kamm et al., 2010).
However, the general structure of all biorefineries is rather similar and consists of four interacting parts. ***Up-stream*** processing is needed to convert the biomass into intermediates that can be utilized further in the biotechnological or chemical ***conversion processes***. The products are either part of the untreated biomass or have been produced in the conversion processes. In both cases, they need to be separated and purified, which is often called ***down-stream*** processing. In addition, energy must be

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provided to run the process, and waste-water must be treated to ensure sustainable production (***utilities***).
Due to the high interaction between the individual unit operations of a biorefinery, sophisticated operational strategies and control schemes are required for their optimal and sustainable operation.
A further challenge for plant operation arises from seasonal changes in biomass composition. Thus, a high flexibility in biorefinery operation is required. A high flexibility in plant operation not only requires intelligent control schemes, but also a very good education of plant personnel and operators. A training simulator can help to instruct these persons riskless and at a good price level. Wrong decisions do not have severe security-related or financial effects.
Generally, training simulators may be used to

- investigate several process control strategies,
- simulate start-up and shut-down processes,
- practise disturbances or accidents,
- learn the handling of process control systems and of the simulated process itself, and to
- develop and test new control and automation concepts (Blesgen, 2009).

In the subsequent sections, we will describe the general structure of a training simulator for a biorefinery. Some integrated individual simulators for unit operations such as a fermentation unit, a distillation column and a biomass power plant simulator will also be described.

2. Structure of the biorefinery simulator

The biorefinery simulator outlined here is based on dynamic mathematical models for the unit operations bio-ethanol fermentation and distillation as well as the unit operations within the biomass power plant (Kuntzsch, 2010).
The unit operations were modelled using sets of differential and algebraic equations based on dynamic mass balances and process kinetics, which dynamically calculate important state variables such as temperatures, flow rates and media compositions in the relevant process parts (i.e. fermentation unit, bottom and top of the distillation column). The models were implemented into a FORTRAN source code and compiled with the eStIM-software package – developed at the Technical University Hamburg-Harburg and the University of Applied Sciences Bremen – into an executable program. The operational reliability of each sub-model was tested in order to verify its qualitative and quantitative functionality.
After successful completion of the tests, dynamic link libraries (DLL) were compiled and implemented into the process control software WinErs (Schoop, 2012). In WinErs the individual models were combined and supplemented by WinErs-control structures to form an overall-process model. Additionally, graphical user interfaces (GUI) were designed, on which the user can adjust process control parameters such as for pumps, valves etc. and gain information about relevant state variables.

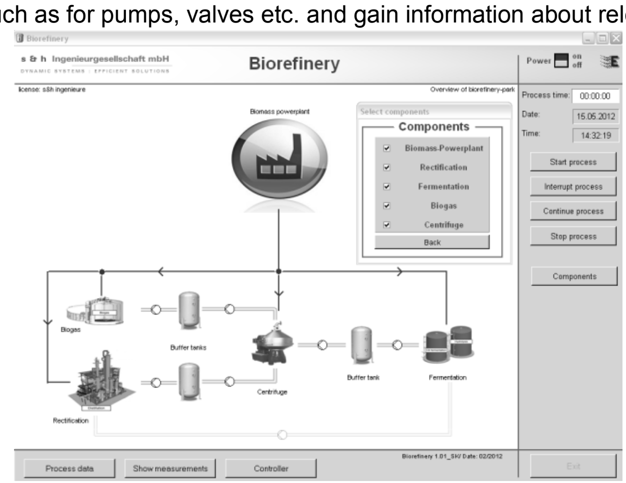

Figure 1: Main GUI of the master project “Virtual Biorefinery”. The desired components can be selected in a sub-window “Components”

A set of appropriate DLL's, WinErs-based control structures and graphical user interfaces form a single unit training simulator, i.e. for fermentation or distillation.
The single-unit simulators may be used as stand-alone training tools. In order to combine the single-unit simulators to a full plant biorefinery simulator, a master project was defined that combines and controls the single-unit simulators. A WinErs built-in router driver is used to organize efficient communication between the individual simulators and the master project.
The master-project generally acts as a *"communication management project"*. In biorefineries the individual main time constants of the unit operations may be very different. In case of a biorefinery the bioethanol fermentation may be a "slow" process and the distillation column a "fast" one. In training sessions it might be helpful to reduce training duration by accelerating slow processes. Thus, for an efficient training individual processes may be run with different time scales. This requires an intelligent time-conversion mechanism, which we implemented into the master project.
In future versions of the biorefinery simulator the master and slave system will be used to introduce trainer stations, where a trainer may observe the trainees and their processes and has got the opportunity to intersperse failures (e.g. blocked valves). For this purpose user rights on individual signals (read, write, and read/write) are allocated.
In order to organize direct calling of graphical user interfaces between individual simulator projects the software AutoHotkey (2012) was used which allows writing scripted commands in executables. These files can be executed by WinErs, so that a quasi sub-structure within an overall project "Virtual Biorefinery" is simulated. Although running different stand-alone simulators, the user has the impression of using just one complex simulator (Figure 1). This also enables a distributed structure of simulators (even to different PCs) which may be used to overcome computing power limitations.

3. Power plant, fermentation and distillation simulators

Efficient training may also require the possibility to run single-unit simulators independent of each other. In order to reduce training time for the handling of the simulators, a general structure for graphical user interfaces was developed (Figures 2, 3, 4). The main part of the GUI illustrates the simulated process in a simplified P&ID flow chart. Aggregates like pumps and valves can be de-/activated directly via this screen. Important states can also be seen here.
Further screens showing process data (historical, online, and simulated sampling) can be chosen from submenus at the bottom of the control screen. At the right hand side of the GUI, process control options are positioned. Here, the process can be interrupted, continued or accelerated, and starting conditions may be defined, etc.
When combining single-unit simulators to a biorefinery, interface push-buttons directly in the process control sheets call the corresponding process control sheets of the related unit operations. In the following paragraphs, three single-unit simulators are shortly described.

3.1 Biomass power plant simulator

The biomass power plant simulator is based on a real plant, which is currently under construction in Emlichheim, Germany. The simulator is a tool for the training of future plant operators in process control system handling. Basically, a power plant consists of several different heat exchanger units (with/without phase exchange, different types of fluids) along the feed water and steam cycle plus additional units like the turbine, feed water storage tank, pumps etc.
For the biomass power plant simulator a generalized dynamic heat exchanger model was developed, that represents the different types of heat exchangers. The model has been thoroughly tested in order to prove its function through stationary, instationary and transient states. The simulation results were graphically evaluated according to qualitative and quantitative aspects (Figure 2). Further models (representing the turbine, incineration, feed water tank and pump) were developed and implemented in WinErs to form an overall process model.
The developed simulator can be run either in real-time or in accelerated mode. The handling is easily carried out with the developed process GUI and further sub menus. The most important state variables, like e. g. temperatures or derived quantities like the power generation efficiency can be seen directly on

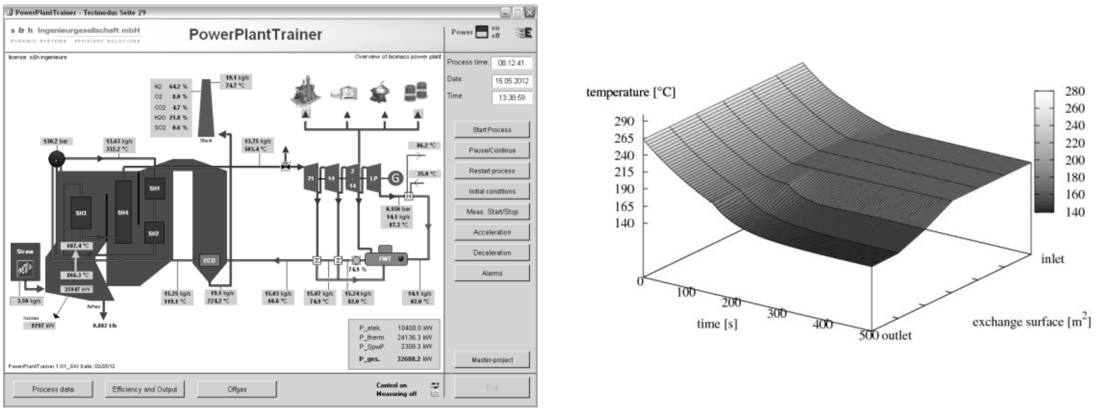

Figure 2: Left-side: Main GUI of the power plant simulator, based on a P&ID-chart of the steam cycle. The simulator might be coupled to the other simulators (rectification, bioethanol fermentation etc.) using the push-buttons on the upper right side of the control scheme. Right-side: Temperature changes vs. time and heat exchanger surface in a condenser. Steam is entering the condenser at 265 °C, cooling down to condensation temperature at 195 °C and cooling further down until complete condensation occurs (Kuntzsch, 2010)

the main GUI (trends, drifting, and plant behaviour). The GUI also allows operator actions to control the power plant process. Control structures and controllers have been designed and implemented using the functionality of the process control system WinErs.
Trainees may also investigate effects of poorly adjusted controller parameters in the simulator. In order to further support the operator training, the actual values of state variables are shown in clear and descriptive sub-windows. The trainees get insight into the dynamically changing process states and thermodynamic steam properties.
Influences of different straw qualities on the overall process performance are accounted for in the simulation and may be investigated by running different scenarios. A varying straw quality may lead to changing temperatures, mass flows, exhaust air quality, and to the produced amount of ashes. Thus, a training task with the biomass power plant simulator could be to adapt important process controls, such as mass flows in the steam cycle or the straw feed rate to varying straw qualities and power demands.
The visualization of measured data takes place using WinErs functions. WinErs also offers functionality for the export of states, signals, initial conditions, etc. into Microsoft Excel. Thus, simulation results from certain trainings may also be presented and evaluated using common spreadsheet software.
The power plant simulator can “deliver” steam and electric power to other processes of the biorefinery. A direct connection to the other simulators in the aspired biorefinery has been implemented on the main GUI (Figure 2).

3.2 Bioethanol fermentation simulator

The bioethanol fermentation training simulator was originally developed by Hass (2005). It includes a model describing important metabolic properties of the ethanol producing yeast *Saccharomyces cerevisiae*. The model was verified using data from a 10 L laboratory-scale pilot fermenter (Figure 3). The main purpose of the simulator is the training of plant operators with respect to process control strategies for biotechnological processes.

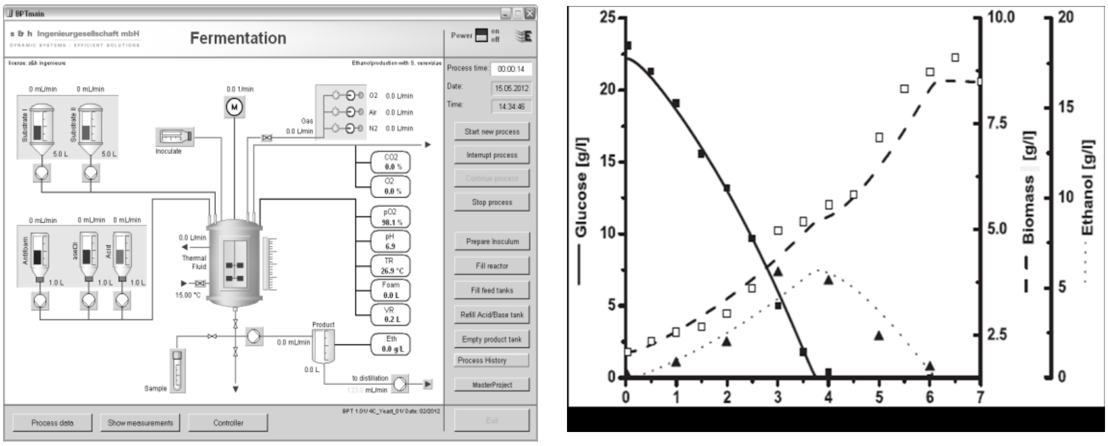

Figure 3: Left-side: Main GUI of the bioethanol fermentation simulator. In the bottom-right corner of the process control scheme the connection to the rectification simulator is realised with an interface push-button. Right-side: Measured (symbols) and simulated (lines) concentrations of glucose, ethanol and biomass (Hass, 2005).

According to the described GUI-design strategy a graphical user interface was developed (Figure 3). The ethanol containing cultivation broth, produced with this simulator, can be fed to the distillation plant simulator via a pump and storage tank.

At present, additional biotechnological models are under development, which shall be included in the simulator. More detailed information on properties of the simulator can be gained in Hass, 2005.

3.3 Rectification / Distillation simulator

The rectification simulator was initially developed to train students. Using the simulator the students are trained for improved handling of a WinErs-controlled laboratory distillation plant prior to the real laboratory exercise. The core simulator models are based on dynamic mass and energy balances, heat transfer kinetics and vapour-liquid equilibrium relationships. The distillation simulator basically comprises three models: one for the reboiler, one for the distillation column and a model for the condenser on the top of the column. Appropriate controllers were designed using WinErs.

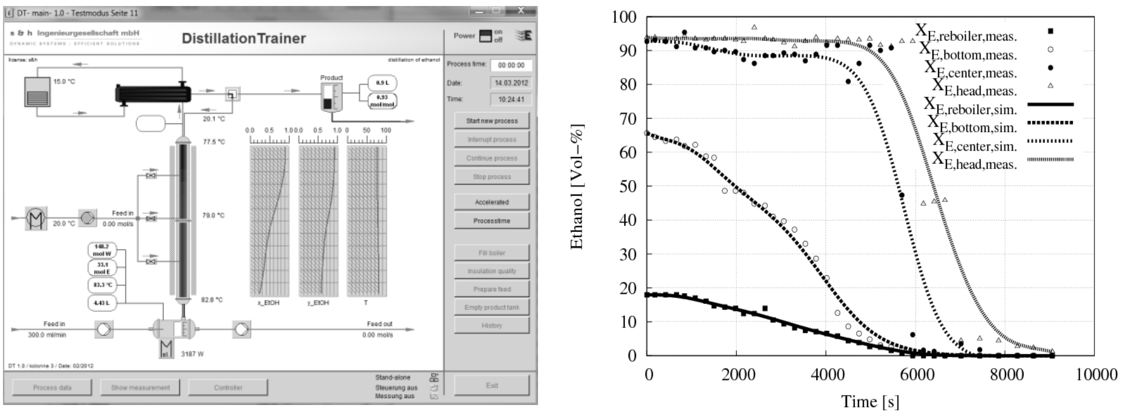

Figure 4: Left-side: Main GUI of the distillation simulator. In the middle-left position of the rectification column the connection to the bioethanol fermenter simulator is realised with an interface push-button. Right-side: Measured data (symbols) and simulated values (lines) of compositions in the head, centre, bottom of the column and the reboiler over time in a complete batch-distillation cycle of a water/ethanol mixture (right-side)

The distillation simulator may be used for the training of batch, as well as continuous rectification processes. The comparison of liquid composition curves from a real batch process to simulated profiles illustrates a reasonably good agreement between simulated and experimental data (Figure 4). For training purposes it is of particular importance, that the dynamics of the process, including start up (heating up) and shut down (cooling down) as well as the production phase can be described by the simulator.
Again, the graphical user interface has been developed according to the general GUI-design strategy for the biorefinery (Figure 4). The feed to the plant may be fed at three different positions on the column as well as to the reboiler (in particular for batch mode operation). The trainees may adjust feed and pumping rates, heating power as well as the reflux ratio according to the requirements of the simulated process. For didactical reasons the composition of liquid and vapour as well as the temperature curve in the column are shown on the main screen. Some additional graphs visualizing dynamically changing properties were included (i.e. boiling curve, or McCabe-Thiele-Diagram, not shown). As a special feature, the influence of different thermal column insulations on the process may also be investigated by the trainees.
The process simulator also offers the opportunity to develop a reflux controller and test different parameters for optimal results.

4. Concluding remarks

The presented simulators have been used for the training of different groups of students as well as in industrial training schemes. The single-unit simulators for fermentation and distillation significantly improve the capabilities of the trainees to run and evaluate the performance of real fermentation and distillation processes. Furthermore, in a pilot student training it has been observed that in particular the parallel operation of single unit operations combined to a full process (like a simplified biorefinery) is a new challenge, which cannot be addressed in a sufficient manner by conventional teaching methods. The presented biorefinery simulator offers new ways for an improved academic as well as industrial training.
Furthermore, from the findings of the operation of these simulations, first approaches for the optimization of the process management have been derived, thus illustrating the potential of the simulator in assisting process control scheme development. In future work the simulator will be further upgraded by the integration of additional processes like centrifugation for cell separation, membrane separation for further purification of bioethanol, a biogas production unit and a biogas purification unit.

5. References

AutoHotkey, 2012, Fast scriptable desktop automation with hotkeys <www.autohotkey.com>, Accessed 19.05.2012.

Blesgen A., 2009, Development and application of an interactive real-time training simulator for a biogas plant (in German), Ph.D. Thesis, University Bremen, Bremen, Germany.

Hass V.C., 2005, Improvement of process engineering education using the „Virtual Bioreactor“ (in German), Chemie Ing. Technik, *77*, 161 – 167.

Kamm B., Gruber, P.R., Kamm, M. (Eds.),2010, Biorefineries – Industrial Processes and Products. Wiley-VCH Verlag, Weinheim, Germany.

Kuntzsch S.; Kuhnen F.; Blesgen A.; Hass V.C. , 2010,Development of a modular training simulator for biomass power plants. In: Proceedings of the 19th International Congress of Chemical and Process Engineering (CHISA 2010) and 7th European Congress on Chemical Engineering (ECCE 7), CD-ROM of Full Texts (Paper: 509), 28th August to 1st Sept. 2010, Prague.

Schoop K.M., 2012, Helpdesk PCS-Software WinErs, <www.schoop.de>, Accessed 15.05.2012