Online - Simulation of Anaerobic Digestion – An Example for Modeling & Control of Complex Bioprocesses

University of Natural Resources and Applied Life Science, Vienna

Alexandra Wolfsberger, Susanne Beisteiner and Peter Holubar*
Institute of Applied Microbiology, University of Natural Resources and Applied Life Sciences Vienna, Muthgasse 18, A-1190 Vienna, AUSTRIA
*Corresponding Author: peter.holubar@boku.ac.at, *Tel.: 0043/(0)1/36 006 6212*

Introduction

In the last years the sustainable use of crops became interesting. Not only to be used for energy- and fertilizer-production, but for the production of bio-chemicals in industrial scale (e.g. lactic acid). By the example of an online-simulation of the anaerobic conversion of maize silage into biogas, we want to demonstrate the tools already at hand for optimization even of very complex bioprocesses.

To make the anaerobic digestion (AD) of biomass not only economically attractive, but also to solve certain problems - e.g. low methane content, self heating, odor problems– the fermentation process itself has to be optimized. This can be achieved with an advanced process control. But to implement an effective control tool, a good knowledge of the AD process is necessary. A so called "Virtual Laboratory" (VL) – a software training tool - is therefore thought as an instrument to provide users with more and detailed insight into the AD process. Basis of the VL is the Anaerobic Digestion Model No.1 (ADM1) (Batstone et al., 2002). The ADM1 is a mathematical model describing the AD process.

Results

To consider the high amount of cellulose in the substrates, the ADM1 (Figure 1) was extended with a second hydrolysis rate for carbohydrates (Equation (1)). Further the sulphate reduction process was implemented. Here 9 extra state variables, 8 new process rates, 2 gas transfer rates and two extra inhibition constants were implemented.

$$\frac{dX_{ch\_s}}{dt} = \frac{q_{in}}{V}\left(X_{ch\_s,in} - X_{ch\_s}\right) + f_{ch\_s\_xc} * k_{dis} * X_c - k_{hyd\_ch\_s} * X_{ch\_s} \qquad (1)$$

Four completely stirred tank reactors were operated with maize silage. The results of several months of operation are used for model validation and calibration. Further data are gained from project partners and from literature.

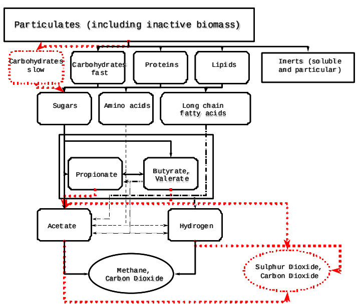

Figure 1: Structure of the adapted ADM1. Shows the changes compared to the original model.

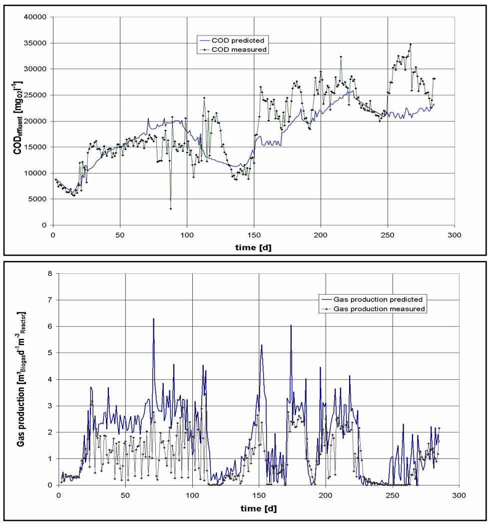

Figure 2: Modelling results of the adapted ADM1 during the training phase. The COD (measured and predicted) showed a correlation of 0.79 and for the gas production of 0.69 was calculated.

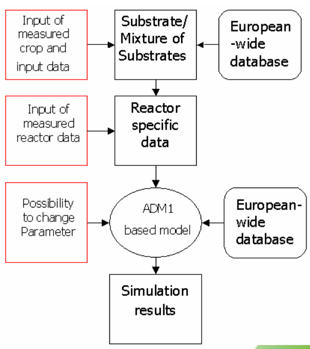

Figure 3: Structure of the Virtual Laboratory 1.1. The VL is organized in several levels. Options marked red in the flow sheet are not available in the Version 1.1, but will be available in later Versions.

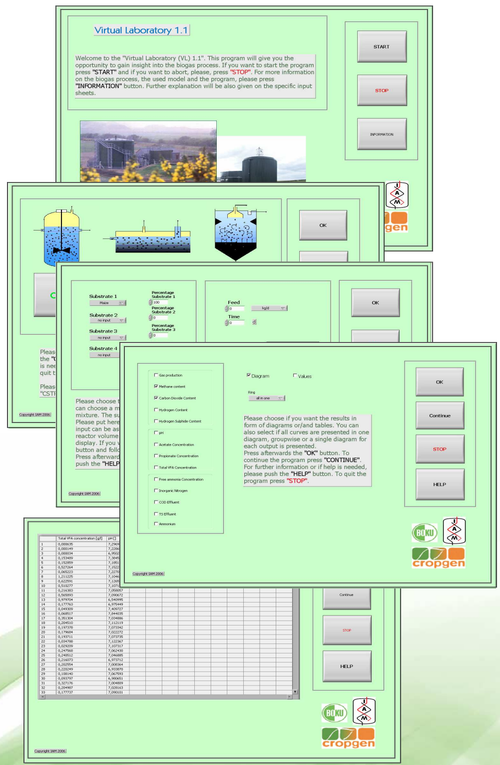

Figure 4: Screenshots from the VL 1.1

Conclusions

Result of this work is an online tool that gives the possibility to gain first experiences with modelling and simulation of a complex biological process. It provides also a strong tool to impart knowledge about the AD process.

The ADM1 should serve, in an adjusted form, as basis for this VL. The adaptation covers the consideration of a high cellulose content, as energy crops are used as substrate and an extension for the sulphate reduction process. For model calibration (Figure 2) the differential equation system of the adapted model was solved with a differential equation solver (ODE15s Solver from MATLAB® R2006a).

The VL Version 1.1. consists of different layers for substrate choice and characterization of the used reactor. After the selected case is modelled, the output of the model is presented in form of diagrams and tables (Figure 3 and Figure 4).

Reference

D.J. Batstone, J. Keller, I. Angelidaki, S.V. Kalyuzhnyi, S.G. Pavlostathis, A. Rozzi, W.T.M. Sanders, H. Siegrist, V.A. Vavilin, 2002, The IWA Anaerobic Digestion Model No. 1 (ADM1), IWA Publishing, London

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