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Application of Anaerobic Digestion Model No. 1 for describing an existing biogas power plant

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ABSTRACT

Pragmatic approach was adopted in order to reduce the amount of parameters necessary for determination, prior to simulation with Anaerobic Digestion Model No. 1 (ADM1). As a result common kinetic constants describing hydrolysis phase, applicable for a wide range of substrates, were determined and tested. Afterwards, this simulation methodology was tested against industrial scale biogas power plant, with 7 dam^3 fermenter size, and feed with cattle manure and food waste. The result confirmed the applicability of ADM1 with modified kinetic constants in describing an existing biogas power plant.

1. Introduction

Renewable energy sources became significant topic of research over last years, due to increased interest in environmental issues. An already identified solution to directly substitute natural gas or liquefied petroleum gas is biogas, since it can be further upgraded to become clean vehicle fuel, or can be directly utilized in combined heat and power units (CHP). Substrates used for biogas production through anaerobic digestion, like manure and waste, are an additional advantage of biogas application over conventional energy sources, since biogas production is also a waste treatment technology. Taking under consideration all the benefits coming from biogas production, it is not surprisingly that number of biogas plants is growing [1]. As a consequence, there is a need of a tool for precise design of biogas plants, ensuring an optimal usage of available substrates, along with identifying potential of optimization of existing biogas power plants. Consequently, a reliable simulation model based on biochemical fundamentals is necessary.

International Water Association's (IWA) Task Group developed the Anaerobic Digestion Model No. 1 (ADM1) in year 2002 [2], and since then it is already the universally applicable model for biogas simulations [3–10]. ADM1 includes 31 processes, where 19 of them are differential and 12 are algebraic equations, and 33 groups of fractions, where 24 of them are the dynamic states variables. As a result 4 stages of anaerobic degradation are represented, and additionally decay and growth of separate biomass fractions is also incorporated [2,11].

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Following the approach of Biernacki et al. [12], where the International Water Association's (IWA) ADM1 was used with the initial biomass disintegration and hydrolysis phase's parameters improved, it will be shown here that ADM1 is capable of describing the biogas production rate and composition of industrial size biogas power plant. In addition, since a pragmatic approach was adopted, it was intended to reduce the amount of parameters necessary for determination, prior to modelling with ADM1. Consequently, it was decided, that the number of kinetic constants to be determined for each new substance will be reduced from 4 parameters (kinetic constants for disintegration, hydrolysis of proteins, hydrolysis of carbohydrates, and hydrolysis of lipids) to 1 kinetic constant for disintegration (KCD). Therefore, the common kinetic constants (CHC) describing the hydrolysis phase (k_{hyd_ch}, k_{hyd_li}, k_{hyd_pr}) were found, leaving out only the KCD for an individual evaluation. This approach is based on the ADM1's indication [2], presented in Table 1, where for substrates like cattle manure, pig manure and food waste the common ADM1's values are recommended, and only the KCD is individually adjusted.

Furthermore, Schoen et al. [7,8] also determined KCD's during calibration of the model, leaving out hydrolysis constants. In addition to that, Wichern et al. [9] observed that kinetic constants of hydrolysis are less sensitive parameters for agricultural substrate, in contrast to KCD, therefore he reduced KCD to 0.05 d^{-1} for a mixture of cattle manure and fodder for cows. Besides, Wichern et al. [10] continued with this approach for grass silage, where he increased the KCD to 1 d^{-1}, again confirming the individual character of KCD. On the other hand, one value for all 3 hydrolysis kinetic constants, equalled to 0.31 d^{-1}, for cattle manure and energy crops, was successfully used by Lübken et al. [6], where he stated that different hydrolysis constants did not improve simulation results.

The main intention of this research is application of ADM1 for describing an existing biogas plant, in order to verify the ADM1's preparation methodology, and also verification of the determined CHC.

2. Material and methods

2.1. Analysis of existing biogas power plant

As an existing biogas power plant, our partner EWE Wittmund Biogas Power Plant (Wittmund, Lower Saxony, Germany) was chosen. The plant was built in 1996 and it consists of 2 parallel fermenters, each 3.5 dam^3, with an average hydraulic retention time of 20 days. The average, summarized for both reactors, input of 180 m^3 d^{-1} of manure and 100 m^3 d^{-1} of organic waste results in ca. 4.57 dam^3 d^{-1} averaged cumulative biogas production, during the assessment period. The produced gas is measured from the cumulative gas flow, together with it's composition using an infrared sensor. This biogas is converted in combined heat and power (CHP) units to electricity and heat. Before, the delivered industrial organic waste is collected in an underground tank (1.9 dam^3), and the manure is fed directly to the mixing tank (620 m^3), where both substrates are mixed to obtain a consistent mixture. This mixture is then kept for minimum 1 h at 70 °C in one of the 3 hygienization tanks (30 m^3), before feeding into the fermenters [15].

The data were collected from the 19.03.2012 until 15.04.2012 (28 days). On each day samples were collected three times per day (morning, midday, afternoon), and then mixed together, as it is described in the German Industry Norm (DIN) 38402 [16], attachment 11: "sampling of waste water". In addition, operator of the plant each day recorded basic data about the plant: pH in each reactor, temperature in each reactor, substrate delivery, biogas production, biogas composition, and operational failure/disorder. However, in this simulation only the raw substrates were analysed and used for the final modelling, in order to follow the pragmatic approach of simulating existing biogas power plant, based only on the raw substrates.

Collected substrates were tested in a batch scale, in order to determine the kinetic constants and evaluate it's activity. Because the substrates were collected over a longer period of time, the batch experiments were also employed for verification of substrates activity fluctuation. In addition to the both substrates used at the EWE Wittmund biogas power plant, chicken manure (CM) collected from local farmer was also analysed. The experimental procedure is in accordance to VDI 4630 [17], with 2 modifications. The first modification includes the experiment's duration, which was shortened to 16 days, because obtaining the kinetics of biogas build up was of author's core attention. In addition to that, for batch experiments only 1% mass fraction consists of CM or substrates used at the EWE Wittmund biogas power plant, in order to guarantee a genuine biogas power plant situation, therefore it was found rational to decrease length of the experiment. The second modification applies to measuring principle. Despite described in VDI 4630 [17] eudiometers, state of the art wireless gas production measuring devices acquired from company ANKOM (N1v0, 4RF2; RFS#194) were used, allowing hourly automated measurements of the total biogas production.

2.2. Characterization of complex substrates

As indicated already by other authors [3–6,9,10] a very good method for transferring substance characteristics into ADM1's environment is with use of Weender analysis and van Soest extension [18] described in Ref. [19]. Following the already proposed and extensively described methodology of transferring experimental results from Weender/van Soest analysis into the ADM1 environment [3,12], the crucial ADM1 fractions were calculated for cattle manure, food waste, and chicken manure, and are listed in Table 2, together with the results of the Weender analysis with van Soest extension.

2.3. Parameters used in the modelling

The ADM1's stoichiometric parameters and dynamic state variable values remained mainly original, in order to follow the pragmatic approach. Incorporation of the new inert decay products fraction (X_P), which's formation is described by a decayed biomass factor (f_P) proposed by Wett et al. [20], acknowledged by Koch et al. [3], and implemented by IFAK [11]