Determination of the equilibration concentrations of substances during recirculation of process water in anaerobic digestion plants

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Abstract

A mathematical model for the estimation of the fermenter performance as a function of feeding and mashing strategies is proposed. The model is based upon mass balances without the demand of dynamic parameters. The investigated substrates were silages of maize, grass and rye and they are mashed with different amounts and compositions of recirculated process water, retentate and fresh water. Fermenter performance was calculated with special interest in inhibition by ammonium, the biogas yield and the required amount of liquid for mashing. The model works in a plausible way and shows a good agreement with analytical data.

key words: anaerobic digestion, renewable resources, recirculation, modeling

1 Introduction

For the Fermentation substrates rich in dry matter the addition of liquids is required in order to get the mass flow suitable for pumping and agitating [10, 14]. Manure is convenient for mashing due to its low content of solids, its high buffer capacity and the additional biogas produced [13]. However, manure has to be delivered. Alternatively, fresh water can be applied to mash the substrates although this is neither economically nor ecologically advisable. Another way of lowering the dry matter content of the fermenter is to mash the substrates with the liquid part of the digestate. However, this process water has the potential to cause inhibition or in the worst case process breakdown because of its dissolved chemical compounds like ammonium, heavy metals or hydrogen sulfide, which can rise to critical levels after accumulation. Besides, the press water contains a solid fraction, so the demand of liquid need for mashing is higher than the required amount of fresh water. As a result the hydraulic retention time (HRT) decreases. It is necessary that this parameter is high enough to prevent a washout of slowly growing microorganisms (MO) [6, 11]. By implication of a short HRT the substrates are incompletely degraded. Under these conditions a stable process and microbial community cannot be formed [4] and the biogas yield is low [6].

Inefficient fermenter performance can be attributed to a disturbance in the microbial interactions [1]. Usually this kind of inhibition is reversible if the reason has been found and adjusted. In principle all macro- and microelements are nontoxic; partially stimulating to MO and sometimes essential for their growth and a stable fermentation [2, 8, 12]. However, If a threshold is exceeded the resulting inhibition can cause a process breakdown [2, 7]. A complete lack of certain trace elements can have a negative effect on anaerobic digestion [9].

By virtue of the economic impact of a stable process and the produced quantity and quality of the biogas [3], a model for calculating the fermenter performance as a function of different feeding and mashing situations was developed. The initial data for modeling was provided by NAWARO® BioEnergie Park "Güstrow" GmbH. The primary use of the model is the estimation of negative effects caused by new substrates and mash strategies. Beforehand modeling fermenter performance helps to prevent overloading the process.

2 Materials und Methods

2.1 Biogas Plant

The modeled data was compared with the fermenter data. Fermenter samples were took from the NAWARO® BioEnergie Park "Güstrow" GmbH. The biogas plant in this location produces biogas in natural gas quality and is fed into the gas network of ONTRAS since June 2009. The plant has a thermal power of 50 MW.

2.2 Analyses

Samples for the control of the modeled parameters were taken over 7 weeks from one fermenter of the BioEnergie Park Güstrow and analyzed by the Landwirtschaftlichen Untersuchungs- und Forschungsanstalt (LUFA) part of Landwirtschaftsberatung Mecklenburg-Vorpommern (data not shown).

2.3 Model implementation

The equations were implemented by the programs MATLAB VersionR2009b and MS EXCEL.

3 Model description

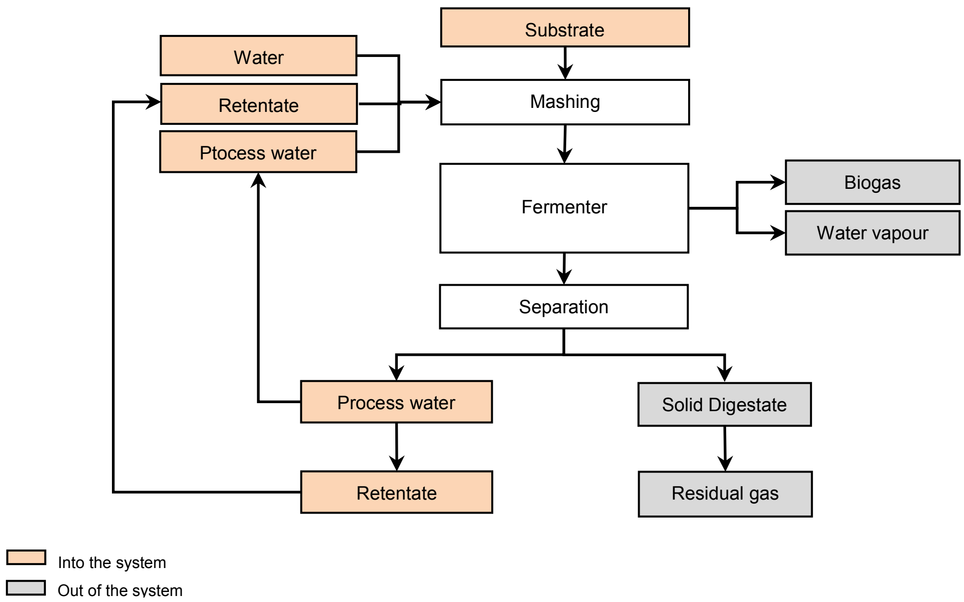

Fig. 1: Scheme of the modeled fermentation process

The model is schematically shown in Figure 1. Variable substrates compositions modeled to one substrate flow and mashed with different amounts of water or the liquid part of the digestate (retentate or press water). According to the ingredients of the substrates and their bioavailability the biogas yield is calculated. The digestate enters the separation step and provides the required liquid. The amount of the residual gas is calculated, too.

It is known that biogas yield decreases with increasing crude fiber and ash content of the substrates [16]. This relation is included by the parameter of the fermentable organic matter (FOM) [16] as a fraction of the total solids (TS). From the FOM, the amount of organic matter (OM) that is available to the MOs to form biogas is calculated under optimal circumstances. A fraction of the FOM is not be degraded and thus recirculated with the press water. This second fermentation of the organics will produce some extra biogas [15]. The residual TS persisting degradation remains in the fermenter and defines its TS-content. A fraction of this inert fermenter TS is recirculated with the process water. This fact is accounted for by the degradation rate, and calculated from the in- and out-concentration.

The amount of water needed to bring the TS-content of the fermenter to the required level is determined by the demand of the MOs, the water vapour, which is lost with the biogas and the water content in the substrates. During substrate degradation the bounded water is released to the fermenter thus lowering the initial TS. The water required by the MOs to maintain their cellular functions can approximated with an equation established by Buswell and Boyle [10] and is normally used to determine the theoretical biogas yield. The amount of the alternative liquids needed for mashing is calculated with an iterative approximation starting with the required amount of water.

The calculation of the concentration of ammonium is important because of its inhibitory effect. Ammonium is released during reductive substrate degradation. It is in a pH dependent equilibrium with ammonia as described by the dissociation constant K_B. Ammonia in turn diffuses according to the law of Henry to the gas phase and is removed from the liquid phase. A fraction of ammonium is recirculated within the press water or retentate. The final concentration of ammonium and ammonia is defined by the in- and out-flows of the fermenter.

4. Results and discussion

4.1 Comparison of the model and the analyses

The measured TS, OM and ammonium concentrations are in good agreement with calculated data (Figure 2). However, the model tends to underestimate the concentrations of TS and OM. This is a consequence of the fact that model parameters stay constant during the time. Inhibiting reactions are not considered. A variation may also result from manual liquid handling during mashing

In contrast the amount of ammonium is overestimated since a portion of all nitrogen is used by the MOs for cellular processes. It is also assumed that only this part of that nitrogen is released as ammonium that corresponds to the amount of the degraded substrates.

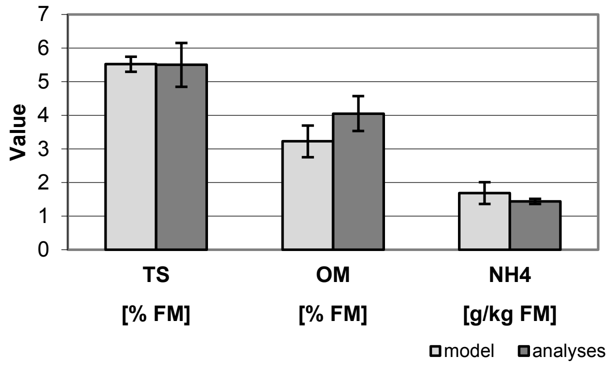

Fig. 2: Comparison of the modeled (n=5) and analyzed (n=7) data of the fermenter

The calculated biogas yield ranges between 9.197 to 15.902 m³ while the measured data in Güstrow ranges from 9.813 to 12.119 m³. The biogas yield is calculated by the FOM of the substrates. It should be noted that the probed fermenter did not run under full load.

4.2 Simulation of different feeding and mashing strategies

The simulation was done for the mono fermentation of maize and for a mix of substrates consisting of 40% whole plant silage of maize, 30% whole plant silage of rye and 30% of grass silage. Liquids used for mashing were 100% fresh water or 100% press water.

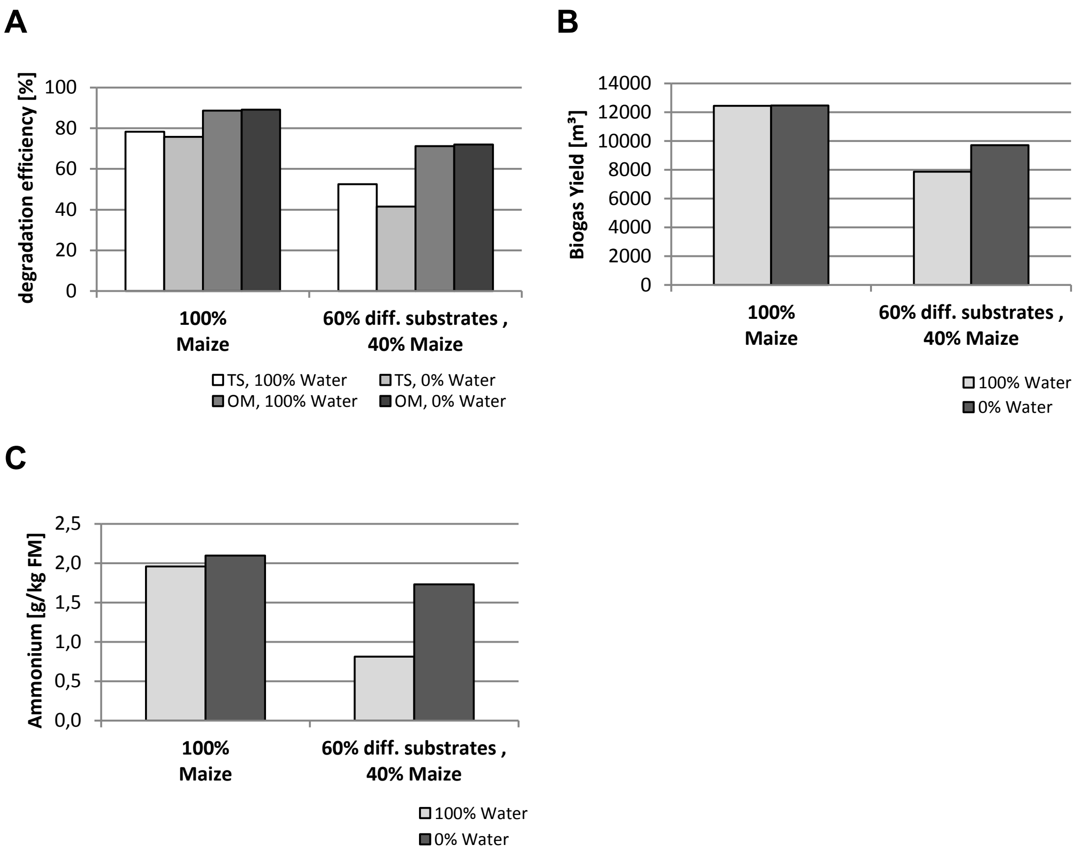

Fig. 3: Results of modeling two feeding situations A) reduction of the total solids and the organic matter after fermentation B) biogas yield C) final concentration of ammonium

With its low crude fiber and ash content Maize is very usable by the MOs. As a result the required amount of liquids is low and the HRT is very high. The reduction of dry matter is better when water is used for mashing, because press water includes an additional TS fraction which cannot be degraded. A degradation efficiency of 75-80% is suitable for an economic operation [8, 3] because a complete degradation would need too much time. The reduction of the OM-content is rising when recirculated process water is used. This is caused by a second degradation with an extension of the effective HRT, thus increasing biogas yield. Due to the good degradation of maize silage, the ammonium levels are very high, but still not pass thresholds [12, 5].

The addition of grass silage with its crude fiber and ash content ratio decreases the HRT to 30 or 40 days so that the degradation efficiency falls to 50% or 40% when using process water. The double digestion has an additional positive effect on the reduction of the OM - also seen in the slight increase of the biogas yield - but it is not comparable to that of the mono fermentation of maize silage. The concentration is low because just a small amount of nitrogen is released by the substrates due to the bad degradation rate. Using press water increases the ammonium level but do not pass thresholds.

5. Conclusion

The developed model produces a good prediction of the progression and efficiency of fermentation. Predicted liquids need for mashing are realistically as judged from the experiences of NAWARO® BioEnergie Park “Güstrow” GmbH. Thus the program supports operational decisions and the assessment of new procedures.

The program works without dynamic parameters. Thus, only few measured data points are required for initialization. The agreement of predicted with measured values is sufficient. Without including specific microbial values the pH, the compositions of the acids in the fermenter and the content of methane in the biogas cannot be estimated.

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