Application of Anaerobic Digestion Model 1 (ADM1) for Prediction of Biogas Production

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Abstract: Anaerobic Digestion Model 1 (ADM1), developed by the International Water Association (IWA) in 2002 is the first and most advanced model applicable for predicting biogas pro-duction and the dynamic processes involved. The model includes parameters after the dis-integration to define substrates in terms of carbohydrates (XCh), proteins (XPr), lipids (XLi) and inert (XI) fractions. Chemical Weender- van Soest analysis was performed to characterize substrates and batch experiments were performed using ANKOM Wireless gas sensor devices. The biogas production using chicken manure was monitored on hourly basis and further simulations were performed using the kinetic constants derived from the experimental results. The simulation program SIMBA® was used for the calculations. The results obtained showed a comparison with experimental data, both in terms of the calcu-lated amount of gas and in terms of the gas composition and was in very good agreement with the corresponding measured values. Use of ADM was thus determined to be reliable and beneficial in predicting the biogas production and the system dynamics.

Keywords: *Anaerobic Digestion Model1 (ADM1), Biogas, Chicken Manure, Simulation, Waste Management.*

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1 Introduction

Advancement in the field of renewable sources of energy has been elevated with the com-bination of enormous demands of energy, depletion of fossil fuels and increased awareness of global warming. Biogas, an age old realized concept produced by a large number of anaerobic microbial species offers an added advantage of organic waste management. Bio-gas mainly comprises of methane, an effective fuel, however on the other side it is a potent greenhouse gas has a warming potential over 20 times higher than carbon dioxide [7]. Utiliza-tion of this gas as an energy source than letting it add on to the issue of global warming, with an added advantage of han-dling waste and producing organic fertilizers as a by-product makes biogas a very attractive sustainable energy alternative. There is a rapid increase in the number of biogas plants in many parts of the world, Germany being the leader bearing nearly 6800 biogas plants in 2010 with an installed combined capacity of about 2.28GW of electrical power [3]. This further necessitates continual improvement in technology and in-creased understanding of the whole process of anaerobic di-gestion that enables biogas production.

Mathematical models are gaining popularity to facilitate de-sign, system analysis, opera-tional analysis, control and also to understand the complex systems and design the process. When the behavior of the process can be predicted, the pro-duction can be optimized and problems like process failures, reactor break down etc. can be prevented [2]. Anaerobic Di-gestion Model 1 (ADM1), developed by the International Wa-ter Association (IWA) in 2002 is the first and most advanced model applicable for predicting biogas production and the dynamic processes involved. The model includes kinetics for disintegration of ho-mogenous particles to carbohydrates, pro-teins and lipids, and hydrolysis of these particles to sugars, amino acids and LCFA. ADM 1 has been found to be a very useful tool for de-scribing existing systems and it has a capa-bility of giving insights into the process dynam-ics and impact of changing process, parameters such as feed concentration, temperature, substrate flow, inhibition during the process, pH changes etc. overall during the digestion process [6]. Despite of these motivations modeling has rarely been applied on an-aerobic digestion. ADM1 is not widely used due to the lack of implementation in a commercial program, and due to the low number of case studies [2]. However, the ADM1 model, used to simulate the anaerobic digestion process for waste man-agement and biogas production has proven to be efficient, cost effective and reliable as well.

In our present study, the application and reliability of ADM1 model was checked for pre-dicting the biogas production with chicken manure. Batch experiments were performed for de-termination of the experimental biogas production. The simu-lation program SIMBA®, a versatile software (toolbox of the simulation system MATLAB / SIMULINK) for the modeling and dynamic simulation of wastewater treatment plants and biogas plants was used for the calculations and the further the model predictions for biogas production were compared with the experimental data.

2. Materials and methods

2.1.1. Materials used

The Chicken manure tested as a substrate for biogas produc-tion was obtained from Chicken farms in the region of Lower Saxony, Germany. The sample was ground to favor a better and efficient degradation by the microbes and was sieved in order to remove peb-bles.

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2.1.2. Inoculum

Inoculum plays an important role in influencing the biogas production and hence it is nec-essary to obtain the specific substrate adapted inoculum. The starter inoculum with the active bacteria for the biogas production was obtained from a biogas plant operating with chicken manure in the region of Magdeburg, Germany.

2.2. Characterization of complex substrates

The considered substrate, chicken manure was tested for the organic content using the well-established Weender analysis and van Soest method [4] [8] [11]. The fractionation of the organic matter was thus determined in terms of raw lipids (RL), raw protein (RP), raw fiber (RF) and N-free extract (NfE) [5]. The carbohydrate content of the substrate was the sum of raw fiber (RF) and N-free extract (NfE). The content of starch, cellulose and hemi-cellulose and lignin was determined by analysing the Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF) and Acid Detergent Lignin (ADL) content.

2.3. TS and VS 3

Total solids (TS) are determined as per the procedure mentioned in VDI 4630[9]. This is performed by drying the substrate sample at 105°C f or 4-5 h and further calculations are performed as detailed in the standard procedures.

The Volatile Solids (VS) were determined by burning the sample at 600°C for 4 hours and the standard procedures were followed for the calculations.

2.4. FOS/TAC

The FOS/TAC is the German abbreviation that expresses the ratio of the free volatile fatty acids (FOS) to the existing buffering capacity (TAC) [10]. This enables a more accurate assessment of the pH value and hints at the stability of the system in terms of acidity and alkalinity. The FOS/TAC values are determined using the automatic Hach Lange Biogas Titration Manager. This is based on a method in which acid consumption per change of pH value is measured between titration end points.

2.5. Batch experiments

Batch experiments were prepared in accordance with VDI 4630 (VDI, 2006). Since the duration of the batch tests depend on the inoculum concentration and activity of the inocu-lum [1], 20% of the reactor's overall mass was substrate while the rest comprised of the tested inoculum. This attempt was to ensure an authentic biogas power plant feeding sce-nario. Batch reactors were performed in bottles with volume of 1100ml and 400g of inocu-lum was mixed with 100g of wet weight substrate. The bottle contents were incubated in a water bath at 38oC. Reference or zero samples were prepared with 100g of distilled water instead of substrate and mixed with the inoculum and the tests were performed for 15 days. The batch reactor bottles were placed on water bath for nearly 30min to facilitate removal of air and this method was found to be comparable to nitrogen flushing method, hence was relied on. After incubation and activating the inoculum, the reactors were closed tightly to begin the experiments. Biogas production was measured hourly with an ANKOM's (N1v0, 4RF2; RFS#194) gas production system and the readings were transmitted electronically to a computer. These pressure values were further used to calculate the biogas production yield. The batch reactors were prepared in triplicates and average values were presented.

2.6. Simulation

The calculations were performed by using SIMBA®. Th is simulation program is a versa-tile software (toolbox of the simulation system MATLAB / SIMULINK) for modeling and dynamic simulation of biogas plants and waste water treatment plants. The data derived from experiments were used to derive the kinetic constants and this was done by a numeri-cal adjustment of the experimental data according to the Nelder-Mead simplex method by mathematical minimization squares of the errors of experimental and calculated data.

3. Results and discussion

3.1. TS and VS

The starting inoculum provided from the biogas plant had a TS value of 9.8% and the VS content of 76.9%.

3.2. FOS/TAC

The FOS/TAC content of only substrate, i.e. chicken manure mixed with water was deter-mined to be 2.06. A FOS/TAC value of 0.3 represents a limiting value. The value of less than 0.3 indicates the degradation proceeding without any inhibition. A value of ≥ 0.3 in-dicates the process might be retarded due to hyper acidity in the digester. A value above 0.6 indicates an over feeding of substrate that might result in breakdown of the reactor.

The FOS/TAC value on day 1 of the experimental run was determined to be 0.2 and it was found to remain nearly constant maintained between 0.19-0.2 (Fig. 1), thus implying stable conditions in the batch reactor with the substrate.

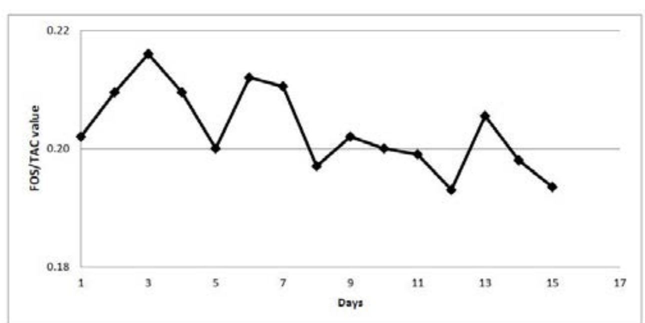

Fig.1. FOS/TAC ratio displaying the ratio of the volatile organic acids to the alkaline con-tent in the reactor during the experimental run.

3.3. Characterization of complex substrates

The substrate composition determined by Weender Analysis based on TS is shown in Ta-ble 1.

Table I shows the results of the substrate composition of chicken manure determined by extended Weender Analysis.

Sl no.	Type of Analysis	Amount in sample
1.	ADF- Acid Detergent Fibre	39.7g
2.	ADL- Acid Detergent Lignin	11.1g
3.	CF-Crude Fibre	26.5g
4.	NDF-Neutral Detergent Fibre	44.3g
5.	Fat	9.1%

The carbohydrate composition was further calculated. The Starch content was determined to be 6.6 %, a hemicellulose content of 4.6 % and a lignin content of 11.1% TS.

3.4. Biogas production

The biogas potential of the chicken manure mixed with straw was observed for 15 days. Fig. 2 shows the experimental re-sults of biogas production of 4.6L in batch reactors with 20% substrate mixed with 80% inoculum. The average result of the experiments performed in triplicates is presented.

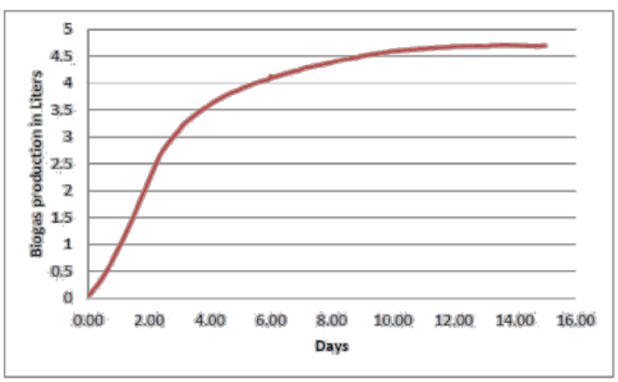

Fig.2. Graph of biogas production with chicken manure

3.5. Simulation

Modeling of the dynamic simulation was performed using Simba® and the kinetic con-stants were derived for regression analysis. The data derived from experimental results were needed for the input parameters for performing the simulation using ADM1 model. A real time biogas plant fed continuously with chicken manure every hour was designed us-ing the model. The protein, lipid, carbohydrates, inert fractions, their rate of hydrolysis etc. were derived (refer Appendix 1). Using the information such as TS, VS, Total Nitrogen, Ammonium content, dimensions, volume, substrate feeding etc. as in the batch experimen-tal set up, a biogas plant model was created and experimentally determined fractions by Weender analysis were transferred to the model.

Simulation was initially performed using the unchanged An-aerobic Digestion Model No.1 version (in SIMBA called ―adm1xp‖). Care is taken to increase the ammonia content in the model since chicken manure is an ammonium rich sub-strate and these changes showed very encouraging results. The total biogas yield predicted by the model for the large scale biogas plant operating on chicken manure on a continu-ous basis was 8444[m3/d] or 3082056.5 [m3/a]. The methane content was derived to be 57% and a carbon dioxide con-tent of 43% was predicted for the biogas plant.

4. Conclusion

The Anaerobic Digestion Model 1 is an effective tool for pre-diction of biogas production yield and composition. This model can be successfully used for designing biogas plants and understand the processes involved with any type of or-ganic materials once the sub-strate characterization is per-formed and the parameters are fed to the model. Chicken ma-nure, a commonly found waste can be used as a favorable substrate for biogas production. Easy laboratory experiments can be used to scale up real time biogas plants using the ADM1 model which proves to be reliable and helps save time and money by eliminating the need to perform large scale ex-periments that need months and tons of substrates to op-erate.

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Appendix 1.

Input data derived from the experiments for the ADM1 model parameter	Value
Total Amount (Xc)	120 kg COD / m3
Protein fraction of Xc	0.22
Lipid fraction of Xc	0.12
Carbohydrate fraction of Xc	0.31
Inert fraction of Xc	0.36
Disintegration rate (k_dis)	4.8514 d-1
Rate of hydrolysis of carbohydrates (k_hyd_CH)	0.7601 d-1
Rate of hydrolysis of lipids (k_hyd_LI)	0.5296 d-1
Rate of hydrolysis of proteins (k_hyd_PR)	0.7626 d-1