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Anaerobic Co-digestion of Sewage Sludge with Food Waste: Kinetic Models

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ABSTRACT

Large quantities of waste activated sludge can be produced with the growth of wastewater treatment plants. Anaerobic technology allows to co-digestion of nutrient-rich and high COD-containing wastes. The aim of this study was to investigate the effects of anaerobic disintegration of wastewater treatment plant sludge (WS) and vegetable wastes (VW). Batch experiments were performed under mesophilic conditions (37 ± 1°C) and eleven different VW / WS ratios and methane production potentials were evaluated by standard BMP test. The logistic model and modified Gompertz model were used to estimate methane yield and evaluate kinetic parameters. It was shown that the systems more stabled where VW and WS are fragmented together Modified Gompertz model (R2: 0.884-0.999) showed a better fit to the test results. As a result, according to the characterization of the sludge from the wastewater treatment plant, it is recommended that the sludge be dried and evaluated as well as the integrated management of the sewage sludge with organic wastes (vegetable waste).

1. INTRODUCTION

It is important for integrated waste management that organic wastes in solid wastes are mixed with domestic and/or urban sludge for different purposes (composting, anaerobic digestion, etc.). Integrated waste management applications are regular storage, incineration, compost (fertilizer support), energy production and discharge to the sea. One of the options offered to improve the anaerobic degradability of organic wastes is the co-digestion of different types of organic wastes [1]. Nowadays and in recent years, due to a better understanding of the limitations and possibilities of anaerobic treatment, the disintegration process of different types of wastes has become a developing technology [2]. In order to supply nutrient requirements and increase biogas yield, a second substrate is used [3]. However; it is necessary to know the wastes to be used in the applications where the co-digestion process will be applied and the appropriate mixing ratios of these wastes [4].

This technology is an environment-friendly and energy-saving method for controlling high-strength organic wastes. Using anaerobic technology, the nutrient-rich and high COD containing wastes allow more favorable carbon/nitrogen/phosphate ratios (C/N/P) that can be achieved by co-digestion together.

In this study, eleven different ratios of sewage sludge and vegetable wastes were investigated in order to increase the biogas production of anaerobic parts of urban wastewater treatment sludge. 100%:0%, 10%:90%, 20%:80%, 30%:70%, 40%:60%, 50%:50%, 60%:40%, 70%:30%, 80%:20%, 90%:10%, 0%:100% ratios were added and methane production potentials were evaluated by standard BMP test. In addition, experimental data were examined for compatibility with modified Gompertz and Logistic models.

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2. MATERIAL AND METHODS

The use of wastewater treatment plant sludge (WS) as the primary substrate and the use of vegetable wastes (VW) as an additional substrate in anaerobic digestion were examined. Batch experiments were carried out in laboratory-scale serum bottles of 500 ml volume. The effect of the ratios of substrate used in anaerobic digestion on biogas production and COD removal was investigated. In addition, the results of the anaerobic digestion process were adapted to kinetic models. Logistics and the modified Gompertz model was used for this.

Experiments were performed using 500 ml serum bottles filled with 300 ml of the substrate. In batch anaerobic experiments, the 500 ml glass serum bottles were tightly closed and the experiments were performed in an incubator operating at 37°C. Each serum bottle was prepared by adding the calculated amount of anaerobic sludge to provide a sludge concentration of 5000 mg/L MLVSS. After the anaerobic seed sludge brought from İzmir Pakmaya industry was added to the bottles, WS and VW were added in certain proportions as carbon source and the required Vanderbilt mineral medium were added to the bottles for macro and micronutrients. The inorganic composition of the mineral medium used in all batch studies is given as an mg/L [5]. NaHCO3 was used as the pH buffer. The experiments were carried out in a shaking incubator with temperature control at 37°C (Fig. 1). The amount of biogas produced was measured periodically. Serum bottles were operated at a speed of 150 rpm, the bottles were removed from the incubator at specified intervals. Chemical oxygen demand (COD), total suspended solids (TSS), volatile suspended solids (VSS), pH, alkalinity, total gas, and methane values were measured.

Vanderbilt mineral media components and quantities [5] were added to serum bottles. The solid tests of anaerobic sludge were determined according to standard methods [6]. COD measurements and bicarbonate alkalinities were performed by the titrimetric method according to standard methods.

Fig.1. *Experimental anaerobic batch study in shaking temperature control incubator*

2.1. Kinetic study

In anaerobic digestion, microorganisms directly affect growth rate and methane production rate. In this study, the SPSS 23.0 program was used to calculate growth curve parameters from growth curves. For the transformation to the mechanical model, biological meaningful parameters can be obtained with the help of the first and second derivatives [7]. The model with the highest coefficient of determination (R^2) was chosen as the most suitable model.

The Gompertz equation is similarly used in sigmoidal growth curves [7]. The modified Gompertz model is widely used for biogas [8]. The logistics equation was used in sigmoidal growth curves and for cumulative methane/biogas production [8,9]. Where; y is the size at time t, t; time, a; asymptotic size, c; growth constant, b; initial growth constant of the living organism, e is 2.71828. Modified Logistic and Modified Gompertz models are shown in Table 1. Where; A is maximum methane production quantity (mL/g VS); λ is delay time (days); µm is a specific methane production rate (mL/gVS); t is time (days) and e is 2.71828.

Logistic model	$y = a\ (1+exp(b-ct)^{-1}$	(1)
Gompertz model	$y = aexp(-exp(b-ct))$	(2)

Table 1. *Modified Gompertz model and Modified Logistic models [7]*

Models	Equations
Modified Logistic	$y = \frac{A}{\left[1 + e^{\frac{4\,\mu_m(\lambda - t)}{A} + 2}\right]}$
Modified Gompertz	$y = Ae^{\left(-e^{\left[\frac{\mu_m e(\lambda - t)}{A} + 1\right]}\right)}$

3. RESULTS AND DISCUSSION

Figure 2 shows the COD removal of single and mixtures of sewage sludge, inoculum sludge and vegetable waste over time. Since organic carbon in sewage sludge is lower, biogas production increased with COD removal as the vegetable waste residue increases (up to 70%) in mixtures where inoculum and vegetable waste are rich in organic matter. In different studies in the literature, it has been observed that the potential of biogas production of co-substrate increases [2,5]. Kim et al. [10] were also evaluated the anaerobic degradability together of food waste and treatment sludge.

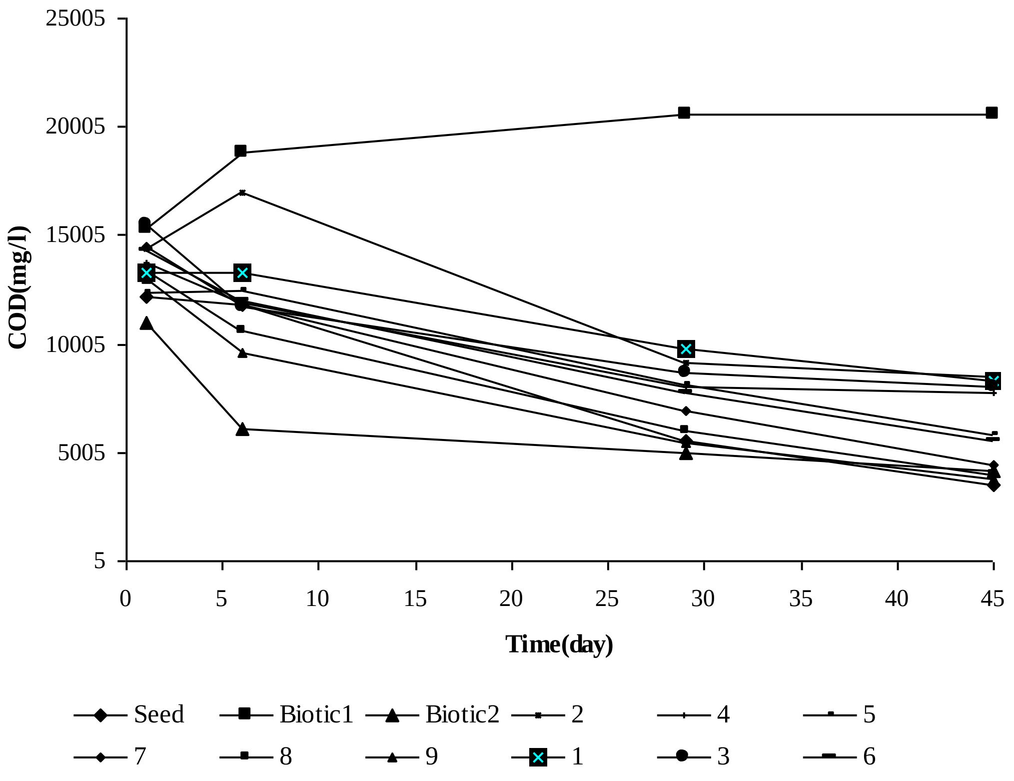

Fig. 2. COD removal of single and mixtures of sewage sludge, inoculum sludge and vegetable waste versus time.

In Figure 3, it was found that biogas production increased while COD removal and biogas production was stabilized as the degradable organic matter was consumed after a certain time. In order to monitor anaerobic degradation during the experimental period, pH, alkalinity, Total Solids (TS), TSS, VSS experiments were observed for different the experiment sets in the batch system and pH was observed to remain in the desired range of alkalinity for anaerobic degradation (Figs. 4-5). As it can be understood from the TSS and VSS experiments, it was observed that the organic matter was initially increased slightly and then decreased and stabilized.

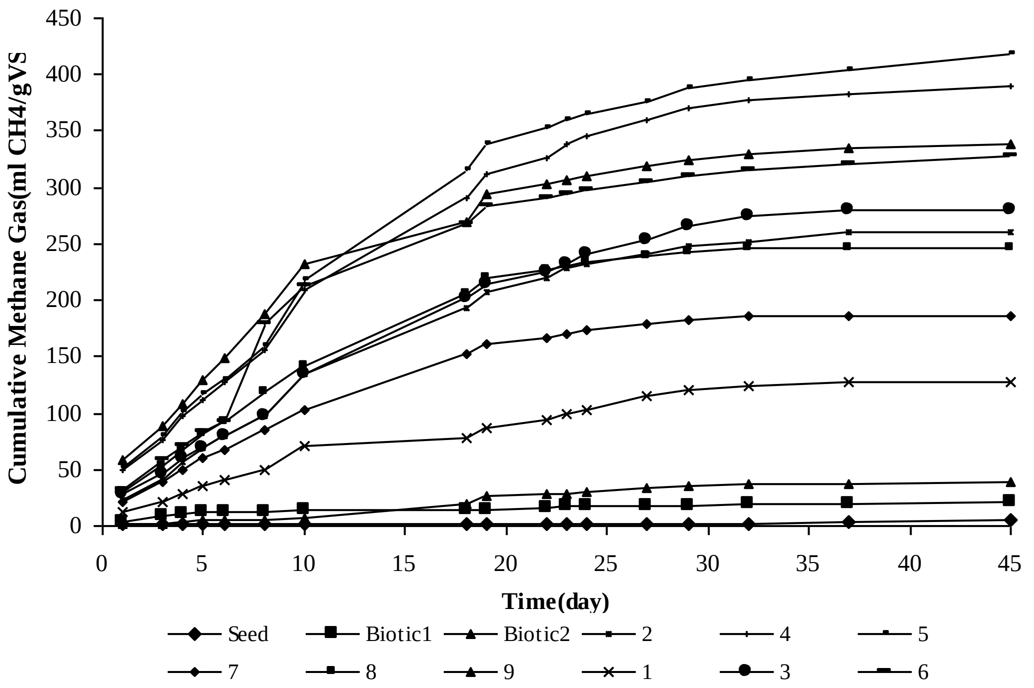

Fig. 3. Variation of Cumulative Methane Gas (ml CH4 / gVS) with different VW and WS values versus time

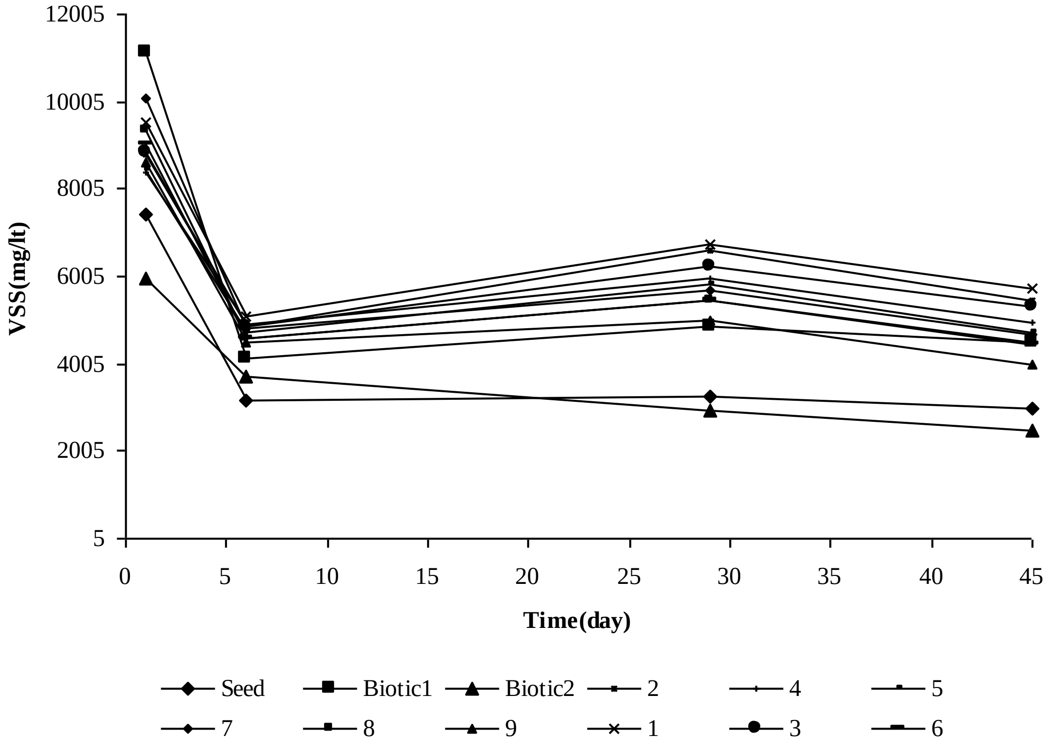

Fig. 4. Variation of Volatile Suspended Solid (VSS) (mg/L) at different VW and WS values versus time

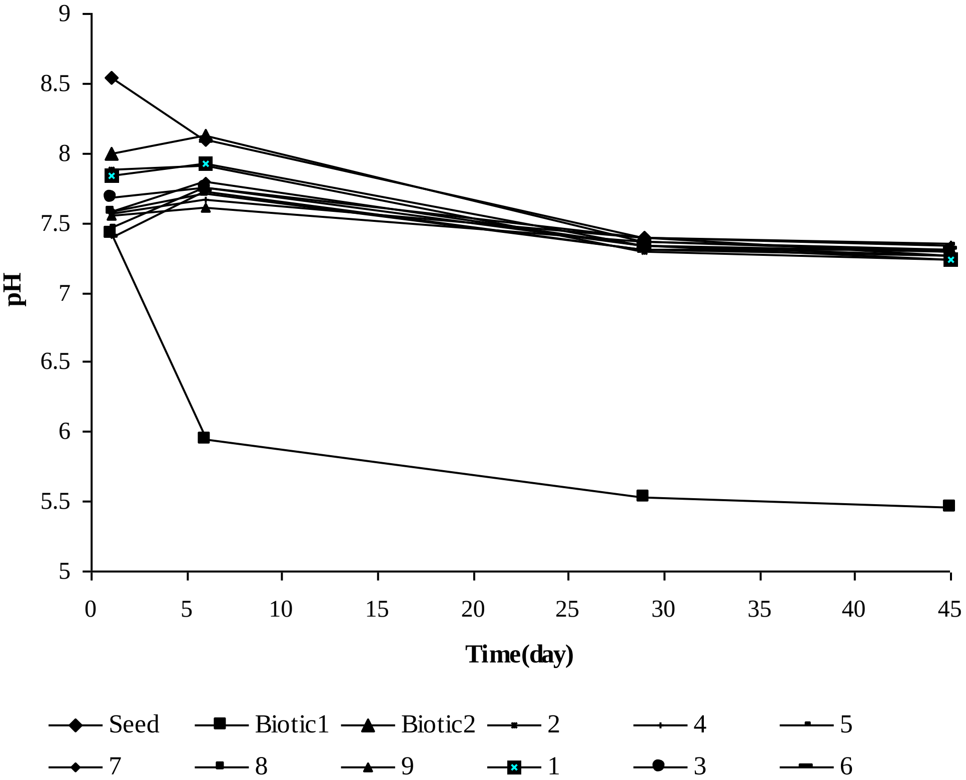

Fig. 5. Variation of pH at different VW and WS values versus time

Table 2. *Results from modified Gompertz and Logistic kinetic*

	Biotic 1 (100% VW)	Biotic 2 (100% WS)	1	2	3	4	5	6	7	8	9
Modified Gompertz model											
λ (days)	-13.30	4.67	-2.75	-0.43	-0.79	-1.51	-1.10	0.56	-1.05	-0.87	-2.18
μ (mL/g VS.d)	0.56	1.68	4.39	12.05	11.61	16.98	18.79	21.16	9.52	13.42	18.14
A(mL/g VS)	20.71	40.95	137.06	264.21	289.54	394.68	415.35	314.38	188.91	250.03	331.00
R^2	0.884	0.992	0.979	0.998	0.998	0.998	0.998	0.989	0.999	0.999	0.993
Modified Logistic model											
	Biotic 1 (100% VW)	Biotic 2 (100% WS)	1	2	3	4	5	6	7	8	9
λ (days)	-17.56	6.42	-2.63	-0.26	-0.50	-1.56	-1.02	1.31	-1.12	-0.92	-2.41
μ (mL/g VS.d)	0.45	1.84	4.17	11.43	11.20	16.03	17.93	23.57	8.94	12.71	17.22
A (mL/g VS)	20.7	38.57	132.56	257.03	280.20	383.96	403.13	305.20	184.50	244.55	323.47
R^2	0.876	0.996	0.973	0.994	0.995	0.995	0.996	0.985	0.996	0.997	0.987

The kinetic parameters of the modified Gompertz and modified Logistics model are given in Table 2. According to the Modified Gompertz model, R2 values of 11 reactors, which were formed by considering different parameters, varied between 0.884 and 0.999. According to the modified logistic model, these values varied between 0.876 and 0.996. Reactors 7 and 8 were the most compatible with the modified Gompertz and logistic model. The kinetic constant of lag phase (λ) shows that the lag time needed by bacteria to adapt to the substrates [11]. The lag phase ranged among -13.30 and 0.56 days in the Modified Gompertz model. In the modified Logistic model, the lag phase ranged from -17.56 to 1.31. The negative values of the λ show that anaerobic bacteria do not need the time for activation. This is a desirable condition for fast production. In previous studies, cumulative biogas production was examined for its applicability for the modified

Gompertz model [12,13]. In some studies, the modified Gompertz function model was compared with the modified Logistic function model [14].

4. CONCLUSIONS

As a result, according to the characterization of the sludge from the wastewater treatment plant, it is recommended to evaluate and dry the sludge as well as to provide integrated management of the treatment sludge with organic wastes (vegetable waste). It was determined that COD removal efficiency, VSM removal efficiency, methane production, and total reaction rate constant increased by increasing the amount of vegetable waste added to the treatment sludge for together the anaerobic degradability of sewage sludge and vegetable wastes. Among the mixture samples, the highest Cumulative Methane Gas production was obtained from 50%:50% VW/WS mixture ratio with 417.32 ml CH_4 / gVS.

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