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Kinetic Studies of Biogas Generation Using Chicken Manure as Feedstock

Araştırma Makalesi / Research Article

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ABSTRACT

The gas generated by anaerobic fermentation of organic wastes is called biogas. Since it contains methane, it can be burnt and so it can be used as an alternative energy source. The production of biogas is an anaerobic treatment process, it is important to understand the basic biochemistry and microbiology of anaerobic systems. This study demonstrates the kinetic study to find out the best microbial kinetics which will be necessary for the design of an anaerobic fermenter. For this purpose, chicken manure and chicken manure with inoculation culture were used. Experiments were operated under mesophilic conditions in laboratory type glass fermenters each having a volume of ten liters.

Keywords: Biogas, renewable energy, chicken manure, microbial kinetics.

Tavuk Gübresi Kullanılarak Biyogaz Üretiminde Kinetik Çalışmalar

ÖZ

Organik atıkların anaerobik fermentasyonu ile oluşan gaza biyogaz denir. Biyogaz, metan içerdiğinden yanabilir ve alternatif bir enerji kaynağı olarak kullanılabilir. Biyogaz üretimi bir anaerobik arıtma sürecidir, anaerobik sistemlerin temel biyokimyasını ve mikrobiyolojisini anlamak önemlidir. Bu çalışma bir anaerobik fermentörün tasarımı için gerekli olan en iyi mikrobiyal kinetiği bulmak için kinetik çalışmayı göstermektedir. Bu amaçla, aşı kültürü ile tavuk gübresi ve tavuk gübresi kullanılmıştır. Deneyler, her biri on litre hacimli laboratuvar tipi cam fermenterlerde mezofilik koşullar altında çalıştırılmıştır.

Anahtar Kelimeler: Biyogaz, yenilenebilir enerji, tavuk gübresi, mikrobiyal kinetik

1. INTRODUCTION

The energy crisis in the last years resulted in the growth of researches and applications on the new energy sources. So, for the past two decades, many researches have been studied rapid depletion of fossil fuel resources and gradual climate changes resulted from excessive greenhouse gases emissions have increasingly attracted people’s attention, worldwide [1]. In today’s energy demanding life style, need for exploring and exploiting new sources of energy which are renewable as well as eco-friendly is a must [2]. Biogas production and utilisation is an emerging alternative energy technology [3]. Biogas is produced in different environments, e.g., in landfills, sewage sludge and biowaste digesters during anaerobic degradation of organic material [4]. Anaerobic digestion converts plant biomass, crop residues, animal manures, and other organic wastes into methane-rich biogas, which is widely used as a source of renewable energy [5]. Methane, which is the main component of biogas, is a valuable renewable energy source, but also a harmful greenhouse gas if emitted into the atmosphere. Methane, upgraded from biogas, can be used for heat and electricity production or as biofuel for vehicles to reduce environmental emissions and the use of fossil fuels [4].

Biogas generally contains between 40% and 70% methane, with the balance of the gas consisting of carbon dioxide and anywhere from 100 to more than 3000 ppmv of hydrogen sulphide (H_2S). Owing to the high levels of methane, biogas can be used as a heating fuel, and can even be used in an engine to generate electricity [6]. This process can be carried out at two different temperature ranges, namely mesophilic (35-40°C) and thermophilic (55-60°C) [7]. Conventional anaerobic digestion is carried out at mesophilic temperatures, that is, 35-37°C. Although thermophilic temperature range is worth considering because it will lead to give faster reaction rates, higher gas production, and higher rates of the destruction of pathogens and weed seeds than the mesophilic temperature range, it is more sensitive to environmental changes than the mesophilic process [8].

In order to fully model the anaerobic digestion process, the kinetics of bacterial growth, substrate degradation and product formation have to be taken account [9]. Markowski et al., used the Monod approach to find the

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optimal diameter of the two cylinder-separated stages of the reactor that maximizes the amount of biogas produced per unit of time [10]. Mathematical model based on the kinetic parameters obtained from the growth kinetics of separated acidgenic and methanogenic bacterial consortia has been developed by Biswas et al. [11]. Some researchers studied the chemical kinetics of the biogas production. Yusuf and Ify developed the chemical kinetics of biogas yield from the co-digestion of cow dung and water hyacinth. The use of first order kinetics and maximum biogas yield in reactor design may compliment other design approach available in literature [12]. Kinetic modeling revealed the reaction to generally proceeds by first order kinetics with respect to the substrate concentration was studies by Abdullahi et al. They obtained that, rise in both temperature and seeding parameters enhanced biogas production, with temperature effect outweighing by at least 25 % [13]. For the biogas fermentation co digestion salvinia molesta and rice straw in a batch anaerobic digesters at mesophilic range, Cone model was used to design the anaerobic batch digester volume and develop the kinetic model of volatile solid degradability rate by Syaichurrozi [14].

In present study, biogas production from chicken manure was investigated. Microorganism growth kinetics and substrate consuming and gas production rates should be determined to design an anaerobic fermenter. So, in order to obtain kinetic model of the microorganisms, the results of the experiments done with chicken manure and chicken manure with inoculation culture were tested to the six different microbial kinetics indicated in literature. The best fitted model relating the specific growth rate of microorganisms was determined by using nonlinear regression method.

2. MATERIAL and METHOD

The laboratory set up is consisted of a rectangular prism heating room, control elements and fermenters. An agitation system has two electrical motors and constructed to mix the fermenter contents. The compositions of the produced biogas was measured using infra-red gas analyzer purchased from Geotechnical Instruments, U.K. The details of the experimental set-up can be found in literature [15,16].

During the experiments chicken manure and chicken manure mixed with inoculation culture was used as organic matter. Inoculation culture was maintained from an anaerobic wastewater treatment system of a yeast factory in Izmir. The amount of produced biogas and its compositions were recorded daily. By this way, the produced biogas amount in grams were calculated with respect to time. Standard methods given in literature [17] were used to calculate the initial substrate (S_0) and microorganism (X_0) amounts, as the organic contents of solid waste and inoculum sludge. The operating conditions and the calculated values was given in Table 1.

3. **KINETIC STUDY** (MICROORGANISM GROWTH KINETICS)

There exist two ways to investigate the kinetics of microorganisms growth. First one is measuring the substrate concentrations during experiment [18]. However, measuring substrate concentration is bothering and requires long time. Second way is measuring the gas production rates during experiments. This method is easier then the first one and also measuring time is shorter [16]. Firstly material balances should be written around the batch fermenter.

Microorganism Balance: Accumulation=Net growth;

$$dX/dt = \mu X \quad (1)$$

Substrate Balance: $dS/dt = -\text{consumed}$ (2)

Substrate consumption rate can be written using the growth yield constant for microorganisms as follows:

$$-\frac{dS}{dt} = \frac{\mu X}{Y} \quad (3)$$

Then by using Equations 1 and 3

$$Y = -\frac{dX}{dS} \quad (4)$$

is obtained.

After Equation (4) is integrated using initial conditions and applying total material balance, Equation (5) is obtained. The details of the calculations can be found in literature [9, 10].

$$\frac{dS}{dt} = -\alpha\frac{dG}{dt} \quad (5)$$

The specific growth rate equations used in modeling studies are given in Table 2. An example of the procedure in the development of the mathematical models is given step by step in [16]. Equation (6) is derived for the mass gas production rate of Contois Equation and it includes three kinetic parameters (μ_m, B, K).

Table 1. Specifications of manure and inoculation culture

Material	Volume (L)	Inoculation (mL)	Dry Solid (%)	Organic Dry Solid (%)	S_0 (g)	X_0 (g)
Chicken manure	7	-	26.975	33.7	281.77	-
Inoculation	7	20	10.9	51.42	281.77	1.121

$$\frac{dG}{dt}=\frac{1}{Y\alpha}\left[\frac{\mu_m(S_0-\alpha G)(X_0+Y\alpha G)}{BX_0+S_0+\alpha G(K-1)}\right] \quad (6)$$

manure was calculated using the volumetric gas production rates for the experiments. Gas production rate (dG / dt) is calculated by taking the first derivative G using the method of numerical differentiation. The results

Table 2. Specific growth rate (model) and derived equations

Name	Model	Derived equation
Monod Equation	$\mu=\mu_m S(K_s+S)^{-1}$	$\frac{dG}{dt}=\frac{\mu_m(S_0-\alpha G)(X_0+Y_0+Y\alpha G)}{Y\alpha(K_s+S_0\alpha G)}$
Monod Equation With Decay Rate	$\mu=[\mu_m S(K_s+S)^{-1}-b]$	$\frac{dG}{dt}=\frac{1}{Y\alpha}\left[\frac{\mu_m(S_0-\alpha G)}{K_s+S_0-\alpha G}-b\right](X_0+Y\alpha G)$
Contois Equation	$\mu=\mu_m S(BX+S)^{-1}$	$\frac{dG}{dt}=\frac{1}{Y\alpha}\left[\frac{\mu_m(S_0-\alpha G)(X_0+Y\alpha G)}{BX_0+S_0+\alpha G(K-1)}\right]$
Contois Equation With Decay Rate	$\mu=[\mu_m S(BX+S)^{-1}-b]$	$\frac{dG}{dt}=\frac{1}{Y\alpha}\left[\frac{\mu_m(S_0-\alpha G)}{BX_0+S_0+\alpha G(K-1)}-b\right](X_0+Y\alpha G)$
Substrate Inhibition	$\mu=\mu_m[1+(K_s/S)+(S/K_i)]^{-1}$	$\frac{dG}{dt}=\frac{\mu_m}{Y\alpha}\left[\frac{X_0+Y\alpha G}{1+\frac{K_s}{S_0-\alpha G}+\frac{S_0-\alpha G}{K_i}}\right]$
Substrate Inhibition With Decay Rate	$\mu=\mu_m[1+(K_s/S)+(S/K_i)]^{-1}-b$	$\frac{dG}{dt}=\frac{1}{Y\alpha}\left[\frac{\mu_m}{1+\frac{K_s}{S_0-\alpha G}+\frac{S_0-\alpha G}{K_i}}-b\right](X_0+Y\alpha G)$

4. RESULTS and DISCUSSION

The model equations for gas production for all specific growth rates presented in Table 2 are derived by using the same method and can be seen also in Table 2. The mass of gas produced by the fermentation of chicken manure was calculated using the volumetric gas production rates for the experiments. Gas production rate (dG / dt) is calculated by taking the first derivative G using the method of numerical differentiation. The results were applied to the model equations presented in Table 2 using nonlinear regression technique and the best fit model relating the specific growth rate of microorganism for each waste was determined. The results of the modeling studies and the kinetic parameters obtained from the best model equation for the waste are presented

Table 3. The kinetic parameters calculated for the best fit model equations.

Waste	Best fit model equation	Kinetic parameters						
		α	**μ_m**	**B**	**K**	**b**	**K_s**	**K_i**
Chicken manure	Contois equation with decay rate	7	0.3	15	1	0.5	-	-
Chicken manure with inoculation	Substrate inhibition	7	0.7	-	-	-	236.91	100

in Table 3. Figure 1 and Figure 2 shows the results of the experimental study and model equations for the best fitted models.

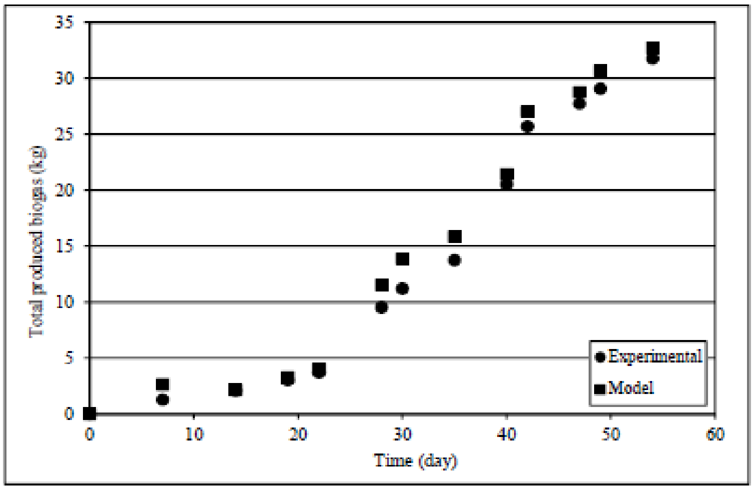

Figure 1. Results of the experimental study and model equation for chicken manure.

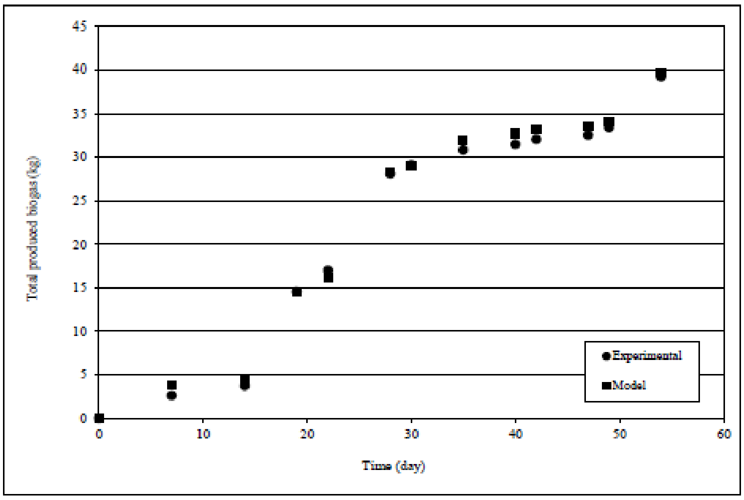

Figure 2. Results of the experimental study and model equation for chicken manure with inoculation rate

5. CONCLUSION

In order to investigate the correlations between substrate concentrations and gas production rates, the equations presented in Table 2 were derived. For the organic matters used in the experiments which were chicken manure and chicken manure with inoculation culture the kinetic models were determined. For chicken manure contois equation with decay rate was obtained as best fitted model whereas for chicken manure with inoculation culture substrate inhibition was obtained. Degree of integration between the experimental and model results were quite well as shown in Figure 1 and Figure 2. Also, related kinetic parameters were calculated.

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NOMENCLATURE

B	coefficient of Contois Equation	(-)
K_i	inhibition coefficient	(g/L)
K_s	saturation concentration	(g/L)
S	substrate concentration	(g/L)
X	microorganism concentration	(g/L)
Y	growth yield of microorganism	(g/g)

Greek Letters

μ	specific growth rate of

	microorganism	(day^{-1})
μ_m	maximum specific growth rate	(day^{-1})

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