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Methane Production by Anaerobic Digestion of Grain Dust in a Plug Flow Digester

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Abstract

Methane production from grain dust was studied using a 3 L laboratory-scale anaerobic plug flow digester. The digester was operated at; temperature of 35, 45, and 55℃; hydraulic retention time(HRT) of 6 and 12 days; and influent concentration(S_o) of 7.8 and 9.0 % total solids(%TS). With ten different operation conditions, this study showed the significant effects of temperature, hydraulic retention time, and influent concentration on methane production. The highest methane-production rate achieved was 1.903 (L methane) /(L digester)(day) at 55℃, 6 days HRT, and S_o of 7.8 %TS. A total of 3.767 L of biogas per day with a methane content of 50.57 % was obtained from this condition. The ultimate methane yield(B_o) was found to be a function of temperature and influent concentration, and was described as : B_o= 0.02907T-0.1263-0.00297(T-10)(%TS), where TS is the total solids in the liquid effluent, and T is temperature(℃). Our results showed that thermophilic condition is better than mesophilic for grain dust stabilization in an anaerobic plug flow digester.

Key Words : anaerobic digestion, biogas, grain dust, methane, plug flow digester

1. Introduction

The interest in anaerobic digestion of grain dust has been increased since a very useful fuel, methane gas, is formed upon digestion of organic matter. The normal composition of biogas emanated from anaerobic digesters ranges from 50 to 70 % of methane and a balance of 30 to 50 % of carbon dioxide(American Public Health Association, 1989). The methane produced from digestion can be commercially applicable or used for the farm operations and liquid effluent can be used as fertilizer.

Kinetic study has been performed to describe the anaerobic digestion(Chen and Hashimoto, 1978, 1980; Fu, 1984; Samson and Leduy, 1986). To evaluate the potential of anaerobic digestion, the methane digestion kinetics must be understood, and temperature, hydraulic retention time, and influent concentration must be determined to optimize the anaerobic system. Some environmental effects must also be examined.

Contois(1959) derived a model for bacterial growth. Later, using the model of Contois(1959), Chen and Hashimoto(1978) derived a substrate-utilization kinetic model to relate the specific growth rate to the substrate concentration. Fu(1984) used these kinetic equations to determine anaerobic digestion parameters of grain dust in a batchfed digester. the study applied these equations to evaluate the performance of an anaeobic plug flow digester.

This study includes the effects of digestion temperature, hydraulic retention time and influent concentration on methane production from grain dust using a plug flow digester. The experimental data will be used to predict methane production rates on a pilot- and a full-scale anaerobic fermentation systems of grain dust.

2. Materials and Methods

2.1. Materials

The grain dust contains a mixture of dust from corn, wheat, milo and other grains. The grain dust was pretreated by adding 9 wt% calcium hydroxide in order to maintain the pH at about 7.

7 dry wt% of calcium hydroxide gave a relatively high gas production rate, but 9 wt% showed both higher and better production rate than 7, 11, 13 wt%(Fu, 1984). This is due to the strong acidic buffer effect of the grain dust. Pretreated grain dust solution stabilized the digester and produced a larger amount of gas with higher methane content(Fu, 1984).

The wastewater was obtained from the Wastewater Treatment Plant. The microornism culture was preheated to the desired temperature for one day before starting the addition of feed. The feed rates were selected to provide hydraulic retention time of 6 and 12 days.

The laboratory digester with an approximate working volumes of 3 L was placed in a water bath and maintained at the desired temperature. The actual dimensions of the laboratory digester were obtained from a commercial digester of 1,700,000 L. Gas was collected in a plastic bag connected to the digester and gas volumes were measured by water displacement.

Table 1. Experimental scheme

Experiments												
Temperature (℃)	35				45				55			
Influent Solids Conc.(%)	7.8		9.0		7.8		9.0		7.8		9.0	
HRT (days)	6	12	6	12	6	12	6	12	6	12	6	12

2.2. Experimental Procedure

Table 1 shows the experimental scheme. Influent solids concentration of 7.8 % was taken from Fu(1984). From the batch-fed digester, Fu(1984) obtained the best gas production rate with this value from five different values of 2.6, 5.2, 7.8, 10.4, and 13.0 %. 9.0 % was taken to investigate the effect of higher solids concentration. The digestion unit was heated electrically and the temperature was maintained at the desired temperature by means of a thermostat in the water bath.

The wastewater and the feed were housed in an incubator at a desired temperature for one day and one hour, respectively, before being fed to the digester. This prevented a temperature shock when added. The digester was fed daily by discharging a calculated amount of the digester content. Then the fresh feed was added at approximate amounts. The slurry, which was discharged from the digester, was analyzed for total solid (TS), fixed solid (FS), volatile solid (VS) and pH. The gas collection bag was attached to the digester for measuring the total gas volume. While the gas volume was being measured, 1 ml gas sample was withdrawn with a syringe and analyzed for methane and carbon dioxide contents. The experiments were continued for a period of at least 5 days after the digestion process had reached a steady state with respect to the gas production and the VS concentration.

2.3. Analyses

Analyses were conducted following the Standard Methods(American Public Health Association, 1989). The total solids concentration was determined by drying a 100 ml sample at 103~105℃ in an oven, overnight. Volatile solids concentration was estimated by determining the weight losses at ignition at 550℃ for one day by a muffle furnace. pH was measured by a digital pH meter, and was standardized before use with pH 4 and 10 buffer solutions. The produced biogas was collected and measured by the Cole-Parmer collection bag. Gas analyses were performed with a gas chromatograph, and the output was recorded with an integrator.

2.4. Backgrounds

Experimental results were evaluated using the following equations. These equations were derived by Chen and Hashimoto(1978).

$$B = B_0 \left[1 - \frac{K}{\theta/\theta m - 1 + K} \right] \quad \cdots (1)$$

$$\theta = \theta m + \theta m K \left[B / (B_0 - B) \right] \quad \cdots (2)$$

$$Vv = \frac{B\, S_0}{\theta} = \frac{B_0\, S_0}{\theta} \left[1 - \frac{K}{\theta/\theta m - 1 + K} \right] \quad \cdots (3)$$

where B is methane yield denoted by the liters of methane at STP produced per gram of volatile solids added to the digester; B_0 is ultimate methane yield denoted by the liters of methane at STP per gram of volatile solids produced at infinite retention time; Vv is the volumetric methane production rate in (volume methane) / (volume digester)(time); So is the total influent VS concentration, K is kinetic parameter; θ is hydraulic retention time in (day); and θm is minimum hydraulic retention time in (day).

Equation (2) shows that the plot of θ vs. $B/(B_0-B)$ yields a straight line with the intercept equal to θm and the slope equal to K θm. Therefore, equation (2) can be used to determine the kinetic constant K.

3. Results and Discussion

The experimental results are summarized in Table 2. The values in Table 2 are average of 5 days after steady state. The steady state values are arranged for each reaction temperature, influent concentration and hydraulic retention time.

The results in Table 2(a) indicate that biogas production rate at an HRT of 6 days is better than that at an HRT of 12 days. This result reveals that higher loading rates can produce more biogas.

At a longer retention time, fewer volatile acids are produced by the acid formers because of low volatile solids loading rate, and the methane formers with a longer retention time digest more carbon dioxide to maintain their metabolism than those with a shorter retention time. This can explain the reason why methane content with a longer retention time is higher than that of a shorter retention time as shown in Table 2(b). According to the data in Table 2(b), the range of the percentage methane content is between 45 and 60. This shows that

Table 2. The steady state values of the experiments

HRT	T	%TS	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
12	35	7.8	1.927	56.87	1.135	7.07	0.74	48.35	51.65	73.62	0.215
12	35	9.0	1.847	53.66	0.991	6.73	1.15	42.80	57.20	66.97	0.162
12	45	7.8	2.300	54.61	1.258	7.30	0.89	46.89	53.11	71.87	0.237
12	45	9.0	2.099	49.16	1.032	7.03	0.97	47.26	52.74	72.41	0.169
12	55	7.8	2.859	55.08	1.575	7.12	0.64	51.26	48.74	76.39	0.297
12	55	9.0	2.225	53.40	1.188	7.14	1.02	44.76	55.24	69.50	0.194
6	35	7.8	2.576	52.31	1.372	7.12	0.97	38.46	61.54	60.47	0.129
6	35	9.0	2.302	46.58	1.072	6.75	2.20	36.20	63.80	56.14	0.088
6	55	7.8	3.767	50.57	1.903	7.00	1.94	37.01	62.99	57.98	0.180
6	55	9.0	2.834	46.77	1.326	6.91	2.24	38.10	61.90	59.86	0.108

HRT : Hydraulic Retention Time, day
T : Temperature, ℃
%TS : Percent Total Solids, (g TS)/(100 ml sludge)
(a) Volumetric Biogas Production Rate, (L)/(L diges -ter)(day)
(b) Percent Methane Content, (%)
(c) Volumetric Methane Production Rate, (L)/(L diges -ter)(day)
(d) pH
(e) Total Solids Concentration, (g)/(100ml sludge)
(f) Fixed Solids Concentration after Digestion, (%TS after digestion)
(g) Volatile Solids Concentration after Digestion, (% TS after digestion)
(h) Volatile Solids Reduction, (%)
(i) Methane Yield(B), (L)/(g VS added)

the percentage methane content of this study is lower than the literatures(Biomass Energy Institute Inc., 1978; Chen and Hashimoto, 1980). This is mainly because of the shorter retention time, and the retention time also affected the volatile solids reduction in Table 2(h).

The fact that the methane content of the biogas did not differ greatly from run to run in Table 2(b) results in similar trends in the production rates of biogas (Table 2(a)) and methane (Table 2(c)).

Table 2 shows that better and highest gas production was observed at 7.8 % influent concentration and 55℃. This well agrees the result of Fu(1984). The highest methane production rate was 1.903 (L methane)/(L digester)(day) at 55℃, 6 days HRT and 7.8 % TS. It then decreased at 45℃, and at 35℃ the production rate was the lowest. This indicates that thermophilic digestion of grain dust has better performance than mesophilic digestion in a plug flow digester.

Because of the strong acidic buffer effect of the grain dust, grain dust was pretreated to produce a more suitable pH for the digestion. By adding 9 wt% of calcium hydroxide to the grain dust mixture before feeding it to the digester, pH of the digester was maintained at about 7. These efforts are shown in Table 2(d) that the steady-state pH values are 6.73-7.30. McCarty(1964) reported that methane production proceeds quite well as long as the pH is maintained between 6.6 and 7.6, with an optimum range between 7.0 and 7.2. pH values at 7.8 % in this study are within the optimum range except at 45℃ and 12 days HRT. The higher influent solid concentration gives a lower pH value except at 12 days and 55℃. This is probably because of accumulated volatile acids which were not converted to methane.

The results in Table 2(e) indicate that total solids concentration increased as the influent concentration increased. Table 2(g) shows that percent volatile solids are higher at an HRT of 6 than at 12. As indicated previously, at a longer retention time more methane formers can be converted from acids to biogas. The values of volatile solids concentration after digestion in this study were higher than those of most digesters ranging from 45 to 50 %(Eckenfelder and Santhanam, 1981).

Stabilization can be explained in terms of the reduction of volatile solids. This study showed a good performance in volatile solids reduction (Table 2(h)). The values obtained at the 7.8 %TS in this study are higher than 50-60 % at the 7.8 %TS of Fu(1984). Fu(1984) obtained 45-58 % at the 10.4 %TS.

Equation (1) was used to determine B_o. Since the plot of B vs. $1/\theta$ was found to be linear, linear regressions were used to determine the intercept Bo. After determining Bo, linear regressions of θ vs. $B/(B_o-B)$ were used to find θm and K, according to equation (2). The average values of θm (3.57 days) and K (0.997) permitted another linear regression which showed B_o to be a function of temperature and influet concentration, and was described by:

$$B_o = [\ 0.02907\ T - 0.1263 - 0.00297\ (\ T - 10\ )\ (\ \%\ TS\ )\ ] \quad \cdots\cdots (4)$$

and equation (1) gives the gas production, B, as a function of temperature, influent concentration (S_o) and hydraulic retention time :

$$B = [\ 0.02907\ T - 0.1263 - 0.00297\ (\ T - 10\ )\ (\ \%\ TS\ )\ ] \times [\ 1 - (\ K / (\ \theta/\theta m - 1 + K\ )\ )\ ] \quad \cdots\cdots (5)$$

where T is temperature between 35 and 55℃, and (%TS) is influent concentration between 7.8 and 9.0 %.

Equation (4) gives six ultimate methane yields (B_o): 0.312 (at 35℃, 7.8 %TS), 0.371 (at 45℃, 7.8 %TS), 0.430 (at 55℃, 7.8 %TS), 0.223(at 35℃, 9.0 %TS), 0.246(at 45℃, 9.0 %TS), and 0.270 liters methane / gram Volatile Solid added (at 55℃, 9.0 %TS). The highest B_o value of 0.430 liter methane/gram VS added at 55℃ and 7.8 %TS is lower than that of Fu (Bo=0.482)(1984) and swine (0.5), but higher than that of beef (0.35) and municipal wastes (0.27).

Figure 1 shows variations of methane yield with temperature for different influent concentrations and hydraulic retention times. The experimental results of Fu's(1984) showed 5-20 % relative differences between experimental and calculated methane yield with equation (5) at 7.8 %TS. This may indicate that equation (5) is applicable to influent concentrations around 7.8

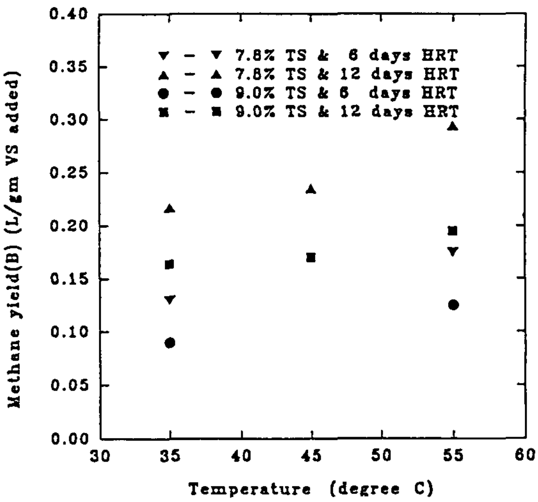

Fig. 1. Methane yield with Temperature for Different So & HRT

%TS. Equation (5) also showed that the calculated B values had relative errors of 0-3 % except a maximum error of 10 % at 45℃, 6 days HRT, and 7.8 %TS

The kinetic parameter (K) 0.997 by linear regressions is lower than the range of 1.61-12.67 of Fu(1984), but it moderately agrees with the range of 0.96-1.56 of Morris(1976) who used dairy waste, and all other data from Chen and Hashimoto(1978). The minimum hydraulic retention time (θm) 3.57 days by linear regressions agrees well with the values of 3.03-3.57 of Morris(1976) and about three days of Chen and Hashimoto(1978).

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플러그 흐름 소화기 속에서 Grain Dust의 혐기성 소화에 의한 메탄가스 생산

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3리터의 실험실 크기의 플러그 흐름의 혐기성 소화기를 사용하여 grain dust로 부터 메탄가스를 생산하였다. 이 실험에서 사용한 소화기는 온도(35, 45, 55℃), 체류 시간(6, 12일), 초기농도(7.8, 9.0% Total Solids)의 함수로 10가지 조건에서 실험이 행하여 졌는데, 실험 결과 55℃, 6일 HRT, 7.8%TS 에서 가장 높은 메탄가스를 생산하였으며, 실험결과를 토대로 메탄가스생산 관계식을 제시하였다. 또한, 위의 실험의 조건에서는 thermophilic 의 경우가 mesophilic 경우보다 메탄가스 생성이 좋은 것으로 나타났다.