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Biogas production from chicken manure at different organic loading rates in a mesophilic-thermopilic two stage anaerobic system

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This study investigates the biogas production from chicken manure at different organic loading rates (OLRs), in a mesophilic-thermophilic two stage anaerobic system. The system was operated on semi continuous mode under different OLRs [1.9 g volatile solids (VS)/L·d − 4.7 g VS/L·d] and total solid (TS) contents (3.0–8.25%). It was observed that the anaerobic bacteria acclimatized to high total ammonia nitrogen concentration (>3000 mg/L) originated as a result of the degradation of chicken manure. High volatile fatty acid concentrations were tolerated by the system due to high pH in the reactors. The maximum average biogas production rate was found as 554 mL/g VS_{feed} while feeding 2.2 g VS/L-d (2.3% VS − 3.8% TS) to the system. Average methane content of produced biogas was 74% during the study.

[**Key words:** Biogas production; Chicken manure; Two stage digestion; Anaerobic; Thermophilic]

Environmental pollution caused by poultry breeding industry can be controlled by anaerobic digestion of the wastes. Since the organic matter in the chicken manure is biodegradable, anaerobic digestion of these wastes can be considered as an alternative method to minimize the amount of waste and recover energy by the production of methane. Daily chicken excretion is between 80 and 125 g (wet)/chicken and excreta includes around 20–25% total solids (TS) and 55–65% volatile solids (VS) of total solids (1,2) that is a valuable source to produce energy.

The important features that prevent or slow down the digestion of chicken manure are low C/N ratio of the manure and high total ammonia levels originating from degradation of proteinaceous organic materials. The C/N ratio of chicken manure ranging between 8 and 10, is lower than the desired range of 15–30 (2–4). Co-digestion with a carbon rich substrate is recommended to improve biogas production from low C/N proportioned wastes (5–7). Ammonium; which is formed during the degradation of proteinaceous organic materials present in the chicken manure, can inhibit conversion of organic materials to biogas. Because of its high protein and amino acid content, chicken manure is rich in nitrogen (8). Environmental conditions such as pH, temperature, substrate type, TS and VS content of the substrate, hydraulic retention time (HRT) and acclimation periods etc. are the main factors affecting both the inhibition level in an anaerobic process under different total ammonium nitrogen (TAN) concentrations (9) and the rate of biogas production. There are several methods to improve biogas production rate of an anaerobic system: diluting the manure with water to reduce TS content, increasing temperature of the process, pre-treatment of the manure and co-digestion of manure with a carbon rich waste (10,11).

Predigestion, being biological pretreatment of organic materials that lasts between 1 and 2 days, is the first step of two stage systems in which increased acetate production take place at pH interval of 5.5–6.5 (12,13). Two stage systems are mostly used to improve volatile solid destruction and methane production in anaerobic processes. Hydrolysis and acidification of the organic materials take place in the first stage and in the second stage methanogens are free of intense high volatile fatty acid (VFA) production that may prevent their vital activity (14,15). Two stage anaerobic systems can be loaded up with higher TS content of input respect to one stage reactors as well (12,16). Temperature of the process environment is another important parameter that determines the fate of the anaerobic digestion. Thermophilic (50–55°C) anaerobic digestion is superior to mesophilic (37–40°C) digestion due to its advantages such as improved destruction of volatile solids and therefore improved biogas production and pathogen removal (17). However, thermophilic bacteria are more sensitive to environmental conditions and high TAN concentrations than the ones at mesophilic temperatures (18,19).

Chicken manure as well as animal manure cannot be treated sufficiently at higher TS loadings. It is reported that threshold value for chicken manure is 5% TS loading and a decrease in biogas production rate could be observed when TS was further increased (1,8). Bujoczek et al. (20) found out that digestion performance was not feasible at TS loadings higher than 10%. At TS values above 10%, a longer acclimation period was also needed. Even after a long acclimation period, inhibition of the anaerobic process could still occur. Bujoczek et al. (20) reported that optimum substrate bioconversion to methane from solid wastes was favorable at TS loadings between 4% and 6%. Most of the studies at which chicken manure were fed in various TS contents (10–25%) and OLRs, have

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TABLE 1. Characteristics of raw chicken manure.

Parameter	Raw CM
Water content (%)	75 ± 8
TS (% w/w)	24 ± 2
VS (% TS)	60 ± 5
TCOD (g/L)	178 ± 20
SCOD (g/L)	37 ± 5
TAN (g/L)	10.3 ± 1
Nitrogen (% TS)	5.28
pH	7.45
Carbon (%)	36.25
Phosphorus (%)	1.25

CM, chicken manure; TS, total solids; VS, volatile solids; TCOD, total chemical oxygen demand; SCOD, soluble COD; TAN, total ammonia nitrogen.

been carried out in batch (1,5,20) and/or single stage systems with HRTs of 20–30 days (10,21,22) at mesophilic temperatures. In this paper an alternative method is introduced on biogas production from chicken manure at varying OLRs in a mesophilic-thermophilic two stage anaerobic system.

MATERIALS AND METHODS

Mesophilic acidogenic–thermophilic methanogenic two stage anaerobic system Two stage mesophilic acidogenic–thermophilic methanogenic anaerobic reactor system used in this study consisted of glass vessels with working volumes of 0.5 L (acidogenic) and 2.5 L (methanogenic) respectively. The acidogenic reactor (RA) was operated under mesophilic conditions (37 ± 2°C) and methanogenic reactor (RM) was operated under thermophilic (53 ± 2°C) conditions. Heating and the mixing of the reactors were achieved by using the hot plate magnetic stirrers. Reactors operated under 12 days of HRT that of 2 days for RA and 10 days for RM reactors. During the start up period of the reactors, nitrogen gas was pumped to the reactors and strictly anaerobic conditions were maintained in the reactors. The system was operated on semi continuous mode by feeding and decanting once a day. No external chemicals were used to control pH values of the reactors. The anaerobic digested sludge used as inoculum in this study was taken from an anaerobic CSTR operated at mesophilic temperature (37°C) in Tatlar Wastewater Treatment Plant located in Tatlar, Ankara region. To acclimatize the seed to the thermophilic condition, it was placed in RM and was exposed to a gradual temperature increase until the temperature was 53°C. After observing a significant biogas production from RM, it had been operated as a single stage reactor until the acidogenic reactor was prepared. Acidogenic reactor was set up by placing the effluent of RM to the RA first and later on it was operated under the conditions of 37°C with HRT of two days. The system was operated under five different OLRs ranging from 1.9 g VS/L·d to 4.67 g VS/L·d. The chicken manure was diluted in order to maintain a TS content ranging between 3.0% and 8.25%. The system feeding was accomplished manually by removing 250 mL manure/day from acidogenic reactor and adding it to methonogenic reactor with a scaled plastic syringe.

Characteristics of chicken manure Fresh raw chicken manure was delivered from an egg production facility having 850 thousands laying hens. The characteristics of raw chicken manure are depicted in Table 1. It had 24 ± 2% TS (60 ± 5% being volatile) with a total COD of 178 ± 20 g/L. NH_4^+ concentration was 10.3 ± 1 g/L. Raw manure was blended with a hand blender after adding significant amount of distilled water. Lastly manure was screened before diluting to desired amount of TS content. The VS content of the feed ranged from 65 to 75%. Characteristics of raw chicken manure are given in Table 1.

Analytical methods The system performance was tested by measuring biogas and methane productions, VS and TS reductions, ammonium concentration, acetic acid concentration and pH. Biogas production of the system was determined daily by displacement of water in a scaled measuring cylinder. Methane content (CH_4) of biogas was measured according to Orsat Method in which KOH solution of 40% by mass was used to absorb CO_2, NH_3 and H_2S (23). Total solids and volatile solids analysis were conducted according to standard methods (24). Volatile fatty acid (as acetic acid) and total ammonia nitrogen were analyzed by Hach Lange Cadas 200 model spectrophotometer using commercially available testing kits (Hach-Lange LCK 365 and LCK 302, respectively). pH and temperature of the two stage system were also measured daily.

RESULTS AND DISCUSSION

The aim of this study was to evaluate the feasibility of biogas production from chicken manure in a mesophilic acidogenic –thermophilic methanogenic two stage anaerobic system under different OLRs. Hydrolysis and aceticlastic methanogenesis are often considered as the rate limiting steps for the anaerobic digestion of organic solids. Limiting step changes due to substrate type, OLR, HRT and temperature of the process (25,26). By using two stage system it is possible to reduce the HRT and reactor volumes, and increase the volatile solid (VS) loading rate, improve the VS destruction efficiency, reduce the inhibition effect of TAN and therefore, enhance the methane production and improve the process stability. Operation of the methane reactor at thermophilic condition can further improve the reaction rate and lower the HRT. Therefore in this study, unlike most of the two stage reactor configurations (thermophilic acidogenic–mesophilic methanogenic),

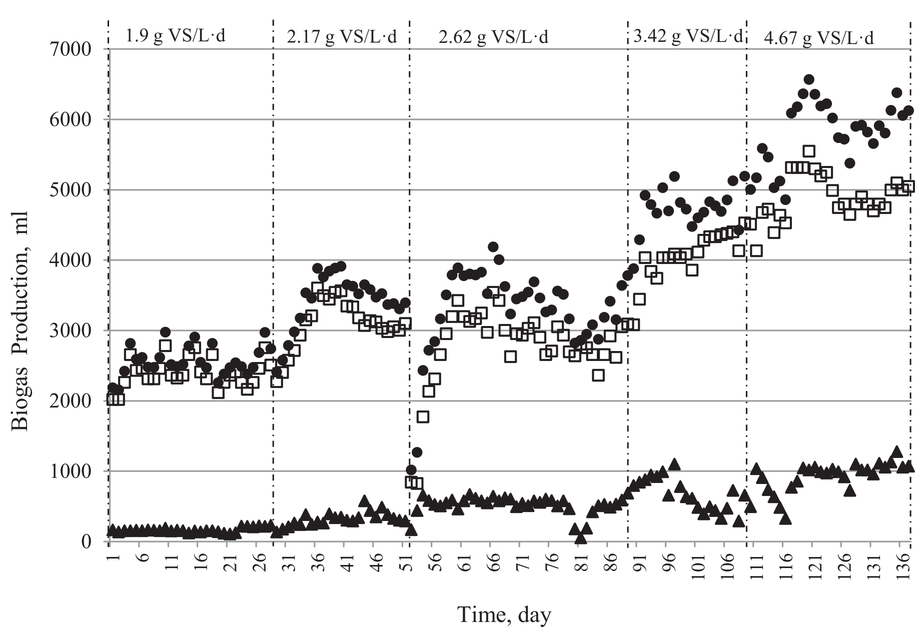

FIG. 1. Biogas production of RA (closed triangle) and RM (open square) and the total (closed circle).