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Chemically pretreating slaughterhouse solid waste to increase the efficiency of anaerobic digestion

Cyntia R. Flores-Juarez, Adrián Rodríguez-García,* Jesús Cárdenas-Mijangos, Leticia Montoya-Herrera, Luis A. Godinez Mora-Tovar, Erika Bustos-Bustos, Francisco Rodríguez-Valadez, and Juan Manríquez-Rocha

Environmental Electrochemistry, CIDETEQ, S. C., P.O. Box 064, C.P. 76703, Parque Tecnológico Querétaro S/N, Sanfandila, Pedro Escobedo, Querétaro, Mexico

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The combined effect of temperature and pretreatment of the substrate on the anaerobic treatment of the organic fraction of slaughterhouse solid waste was studied. The goal of the study was to evaluate the effect of pretreating the waste on the efficiency of anaerobic digestion. The effect was analyzed at two temperature ranges (the psychrophilic and the mesophilic ranges), in order to evaluate the effect of temperature on the performance of the anaerobic digestion process for this residue. The experiments were performed in 6 L batch reactors for 30 days. Two temperature ranges were studied: the psychrophilic range (at room temperature, 18°C average) and the mesophilic range (at 37°C). The waste was pretreated with NaOH before the anaerobic treatment. The result of pretreating with NaOH was a 194% increase in the soluble chemical oxygen demand (COD) with a dose of 0.6 g NaOH per g of volatile suspended solids (VSS). In addition, the soluble chemical oxygen demand/total chemical oxygen demand ratio (sCOD/tCOD) increased from 0.31 to 0.7. For the anaerobic treatment, better results were observed in the mesophilic range, achieving 70.7%, 47% and 47.2% removal efficiencies for tCOD, total solids (TS), and volatile solids (VS), respectively.

[**Key words:** Anaerobic digestion; Chemical hydrolysis; Mesophilic conditions; Chemical pretreatment; Psychrophilic conditions; Slaughterhouse waste]

Problems related to the environmental contamination are some of the most important research topics due to their major impact on the sustainability and the continuity of plant, animal and human life. For example, increasing emissions of greenhouse gases like carbon dioxide (CO_2), methane (CH_4), and chlorofluorocarbons (CFCs) constitute the main cause of global warming, and a reasonable proportion of these emissions are related to the uncontrolled degradation of organic matter contained in the increasing amount of human produced wastes. Interestingly, anaerobic digestion is still the most attractive option for solid stabilization and volatile solid removal of organic matter contained in solid wastes (1).

Solid waste from slaughterhouses is especially problematic, because it consists primarily of ruminal and stomach content, viscera and blood. Due to its elevated concentration of biodegradable organic matter, this waste can be efficiently treated by anaerobic digestion (1), although the high content of lignocellulosic and refractory material causes the process to be relatively slow. For this reason, a good approach is to pretreat the solid waste which shortens the hydrolysis phase (2,3).

A variety of pretreatments focused on both the degradation of the organic fraction of organic wastes and increase the production of methane have been developed. Studies have been reported on mechanical, chemical and thermal primarily pre-treatments. Liao et al. (4) reported the positive effect of pretreatment of solid–liquid separation by screening prior to anaerobic digestion. Regarding chemical pretreatments, it has been mainly evaluated the use of alkali, polyacrylamide and acid such as HCl and H_2SO_4 (5,6). In terms of thermal treatments, the best results were obtained with temperatures between 100°C and 170°C (7). Gonzalez-Fernandez et al., (8) conducted a comparative study to determine the effect between the methods of mechanical and chemical pretreatment with either HCl or NaOH in pig manure. The best results were obtained with the alkaline pre-treatment, enhancing the biodegradability of the residue by 81.6% compared to 69.4% for the residue obtained pretreated with HCl. Heat treatments are still the most efficient option, however, the thermophilic pretreatment is more sensitive to environmental changes than the mesophilic pretreatment (9).

A variety of alkaline pretreatments have been reported for the solubilization of biopolymers (proteins, polysaccharides, nucleic acids and lipids). For instance, a comparative study of the effect of pretreating with two alkalis, NaOH and CaO, on the degradation of residual sludge was carried out, obtaining better results with NaOH, using a dose of 0.5 g NaOH per g of volatile suspended solids (VSS) (10). Lopez et al. (11), on the other hand, studied the effect of the addition of $Ca(OH)_2$ to municipal solid wastes and determined that the optimum alkali dose was 62 mg $Ca(OH)_2$/L with a contact time of 6 h. They obtained an 11.5% of solubilization of chemical oxygen demand (COD).

* Corresponding author. Tel.: +52 442 2116046; fax: +52 442 2116001.
E-mail addresses: arodriguez@cideteq.mx, adrian_r_g@hotmail.com (A. Rodríguez-García).

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Our research was focused on facilitating the treatment of slaughterhouses waste, which is extremely difficult to degrade because of its high organic content. Based on the studies cited above, we decided to try to accelerate the anaerobic digestion process by solubilizing the organic matter with an alkaline pre-treatment of the waste, which increases the hydrolysis of the substrate, thereby accelerating the first stage of anaerobic digestion process. In this work, we achieved a 28% of solubilization in three days, increasing it to 7460–9500 mg/L for an organic load of 50 g/Kg. Concerning the effect of temperature on COD removal for slaughterhouse waste, we performed literature search, failing to find published information evaluating the COD removal of both psychrophilic and mesophilic conditions. Then we tried to accelerate the methanogenic phase of the anaerobic digestion process by increasing the operating temperature, testing the treatment of the pretreated waste by anaerobic digestion in both the psychrophilic range (at room temperature) and the mesophilic range, at 37°C. In order to evaluate the effect of pretreatment study on the productivity of biogas through anaerobic digestion, the same tests were performed on a substrate without pretreatment (control).

MATERIALS AND METHODS

Substrate The weight percentage for each component of the slaughterhouse waste studied was determined according to a previous work (12), and was 80% ruminal content, 11% blood and viscera, and 9% manure. Additional waste characterization experiments were carried out according to standard methods (13), adapted to waste with both a high organic load and high solid load. These data are presented in Table 1.

Pretreatment Chemical pretreatment was carried out by adding NaOH to the waste with the goal of increasing the hydrolysis rate as well as the soluble fraction of COD. In order to quantify the effect adding the alkali, doses of NaOH were added ranging from 0.1 to 0.7 g per g of VSS. A contact period of 24 h between the residue and the NaOH was defined and constant agitation conditions were maintained during this time using a magnetic stirrer working at 150 rpm. The pretreatment experiments were performed at room temperature (18°C average). The solubilization rate was calculated from the relationship (sCOD/tCOD) where sCOD and tCOD correspond to soluble and total chemical oxygen demand, respectively.

Anaerobic digestion After the slaughterhouse waste was pre-treated, increasing its soluble COD value, we processed this pre-treated waste by anaerobic digestion at two different temperature ranges: psychrophilic (room temperature, 18°C average) and mesophilic (37°C), to study the effect of the temperature on the removal of COD, total solids (TS) and volatile solids (VS).

A series of experiments were performed in two Upflow Anaerobic Sludge Blanket (UASB) laboratory scale digesters, (reactors 1 and 2), each having a working volume of 6 L. The first one was operated at room temperature (18°C average) and the other operated at a controlled temperature of 37°C. The experiments were performed in batch mode, having a total duration of 30 days. The hydraulic retention time (HRT) for both experiments was kept constant for 30 days resulting in a solid loading of 1.42 g TS/L day and an organic load of 1.72 g tCOD/L day. Mixing was maintained by recirculating the biogas produced inside the reactors. Table 2 shows the operational conditions at the beginning of the experiments.

Inoculum An anaerobic seed sludge collected from an operating UASB reactor was used to inoculate the digesters. The seed sludge had total suspended solids (TSS) and VSS concentration of 83.4 and 62.4 g/L respectively. 1 L of anaerobic seed was added with a specific methanogenic activity of 1.32 g COD per g of VSS per day.

Analytical methods The feed and effluent samples were analyzed for tCOD, sCOD, TS, VS, TSS, VSS, pH, volatile fatty acids (VFA), partial alkalinity (PA), total alkalinity (TA), and ammoniacal nitrogen (NH_4–N) according to standard methods (13). Continuous biogas production was measured through a system based on volumetric displacement using a 1 M NaOH. This solution was replaced when the pH value fell below 12.

TABLE 1. Waste characterization parameters.

Parameter	Value
pH	4.8 ± 0.24
Total COD (g/Kg)	215.90 ± 8.81
Total Kjeldahl Nitrogen (g/Kg)	7.01 ± 0.10
Total solids (g/Kg)	179.10 ± 11.73
Volatile total solids (g/Kg)	149.10 ± 7.98
Total suspended solids (g/Kg)	156.10 ± 3.40
Volatile suspended solids (g/Kg)	129.70 ± 8.00
Alkalinity (mg $CaCO_3$/L)	<0.5

TABLE 2. Operational parameters for the digesters at the beginning of the experiment.

Operational conditions	Test at 18°C	Test at 37°C
Volume (L)	6	6
HRT (days)	30	30
Solid load (kg TS/m^3 d)	1.42	1.42
Volumetric organic loading (Kg COD/m^3 d)	1.72	1.72
Temperature (°C)	Room T	37

RESULTS AND DISCUSSION

Waste pretreatment NaOH pre-treatment of the waste under study was carried out as described in the experimental section using different concentrations of alkali. As shown in Fig. 1a, the sCOD values increased in proportion to the concentration of NaOH, and reached 194% of the initial value, as expected.

Since the minimal dose of NaOH that produced the maximum change in sCOD was 0.6 g NaOH per g of VSS, this value of alkali concentration was set for the forthcoming experiments.

Consistent with this assumption, soluble COD increased from 13,526 mg/L for the waste without pretreatment, to 39,798 mg/L

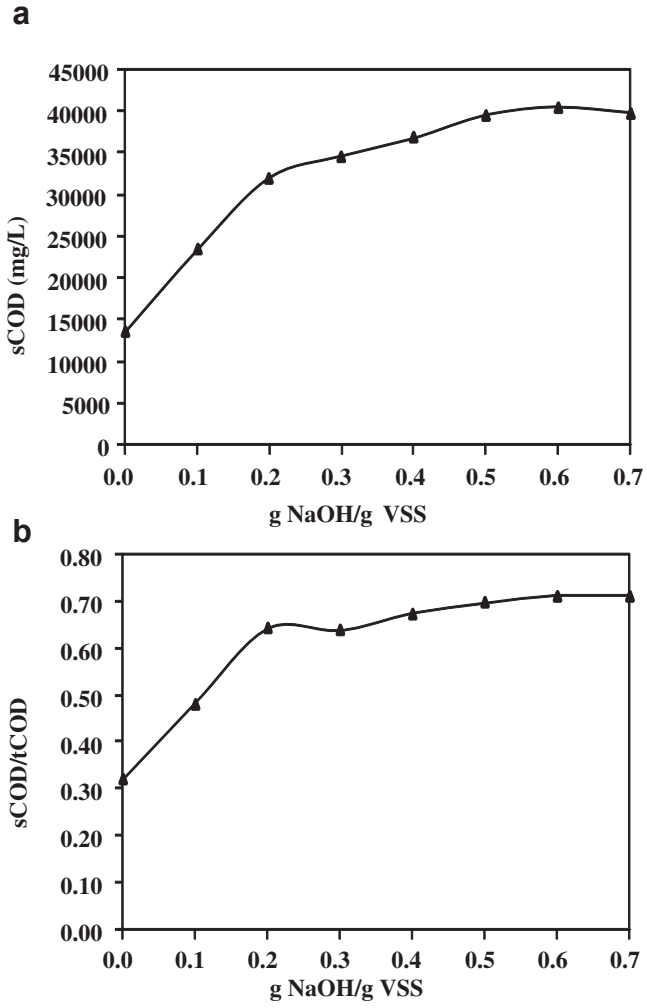

FIG. 1. (a) COD solubilization and (b) sCOD/tCOD ratio after the pretreatment with NaOH.