Revista Brasileira de Zootecnia

ISSN 1806-9290
www.sbz.org.br

R. Bras. Zootec., v.41, n.11, p.2379-2383, 2012

Short Communication

Potential of biogas and methane production from anaerobic digestion of poultry slaughterhouse effluent

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ABSTRACT - The objective of this study was to evaluate the efficiency of anaerobic digestion on the treatment of effluent from poultry slaughterhouse. The experiment was conducted at the Laboratory of Waste Recycling from Animal Production/ FCA/UFGD. During four weeks, eight experimental digesters, semi-continuous models, were loaded and set according to the hydraulic retention time (HRT) of 7, 14, 21 and 28 days, and according to the solid fraction treatment, separated with 1 mm sieve or without separation. The average weekly production of biogas and methane as well as the methane concentrations, the potential production per amount of chemical oxygen demand (COD) added and reduced, the concentrations of N, P and K at the beginning and end of process, and the most likely numbers of total and thermotolerant coliforms were evaluated. For data analysis, a completely randomized design was performed in a 4 × 2 factorial arrangement (4 HRT: 7, 14, 21 and 28 days and separation with 1 mm sieve or without separation), with repetition over time. The highest production of biogas and methane was statistically significant for the HRT of 7 and 14 days (5.29 and 2.38 L of biogas and 4.28 and 1.73 L of methane, respectively). There was an interaction between HRT and the separation of the solid with sieve and the highest production was obtained in the treatment without separation. Similar behavior was observed for the potential production with a maximum of 0.41 m^3 methane.kg^{-1} COD added with an HRT of 7 days without separation of the solid fraction. The separation of the solid fraction is not recommended in the pretreatment of liquid effluent from poultry slaughterhouse, once the potential for production and production of methane and biogas were reduced with this treatment.

Key Words: chemical oxygen demand, total solids, volatile solids

Introduction

The poultry industry has increased its production due to the high commercial demand that has stimulated this sector which turned Brazil into the third largest broiler producer, with 10.9 million tons produced in late 2009 (UBA, 2009).

The generation of waste from the slaughtering of broilers has increased proportionally to the growth of production. According to Silva (2005), the amount of effluent generated is of about 15 liters for each slaughtered bird, which is characterized by containing a large amount of organic matter that is biodegradable, suspended and colloidal (Kobya et al., 2006), as well as microorganisms. Therefore, the previous treatment of this effluent is very important before its releasing into the environment (Kobya et al., 2006).

The use of anaerobic processes is widely practiced in the treatment of waste, since anaerobic microorganisms degrade the organic matter, which generates biogas and biofertilizer as final products (Lianhua et al., 2010; Nges, 2010). Biogas can be used for electricity and heat generation, and therefore by industrial or rural properties, bringing economic and environmental gains. The burning of biogas is beneficial for reducing the global warming potential, which was reported by data of UNFCCC (2006) as 21 for methane and 310 for nitrous oxide in regards to the pattern 1 that is referred as the carbon dioxide.

According to the environmental conditions, the performance of the digestion process may be delayed or unsuccessful due to the accumulation of fat and suspended solids in the digester, since a decrease in pH, particularly, causes a reduction in the methanogenic activity and biomass (Kobya et al., 2006). For this reason, several studies have recommend the previous separation of constituents with a high fat content, despite their higher heat capacity, and specifically, for waste from slaughterhouses, this separation might prioritize better biogas production within a shorter period of time, since the soluble constituents (mostly blood) require shorter periods for the digestion process.

Received May 24, 2011 and accepted August 1, 2012.
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Based on the assumptions, the objective was to evaluate the productions of biogas and methane, as well the reductions in the most probable number (MPN) of total and thermotolerant coliforms and chemical oxygen demand (COD), besides the characterization of bio-fertilizers (N, P and K) during the anaerobic digestion of the liquid effluent with and without separation of the solid in semi-continuous digesters timed in 7, 14, 21 and 28 days of the hydraulic retention.

Material and Methods

The study was conducted at the Laboratory of Waste Recycling from Animal Production at the College of Agricultural Sciences at Universidade Federal de Grande Dourados. The poultry waste used to supply the digesters was untreated effluent from a slaughterhouse (Table 1) located in Dourados city, which was generated during slaughter and processing of broiler carcasses.

Prior to the beginning of digester loading, an inoculum was prepared with cattle manure and untreated effluent from broiler slaughterhouse. The inoculum was determined when it reached the stability in a methane concentration of 80% and then was added into the digester for the first loading, which corresponded to 15% of total volume of digester in order to avoid any delay at the beginning of biogas production.

The bio-digesters used for the trial were horizontal tubular and semi-continuous-feeding type (Figure 1). These digesters were filled in accordance with the hydraulic retention times (7, 14, 21 and 28 days) and also according to the treatment of organic solid (separation with 1 mm sieve and no separation). Then, the volume of daily load was determined according to the capacity of each digester (average capacity of 36.71 liters) and retention time.

The digesters are composed of two distinct parts: the container with the material in fermentation and the gas tank. The digesters were protected from sunlight and rain and maintained under room temperature without any control of external temperature.

During the anaerobic digestion trial, the influence of different hydraulic retention times (7, 14, 21 and 28) and the separation or no separation of the solid fraction and their interaction were assessed through the yields and potential of production of biogas and methane, according to the amount of COD added and reduced, and the characterization of the sieved or unsieved affluent and biofertilizers produced in different conditions.

The volume of biogas produced per day was determined by measuring the vertical displacement of the gasometers, and multiplying by their cross-sectional area. After each reading, the gasometers were zeroed using the record of discharge of biogas. All gas volumes reported were corrected to 20 ^{o}C and 1 atm condition as described by Caetano (1985). The potential of biogas and methane productions were calculated by dividing the output values by the amounts of COD added and reduced in the digesters.

Biogas composition was determined using a Finigan GC-2001 gas chromatograph equipped with Porapack Q columns and molecular sieve, and a thermal conductivity detector.

The amount of total solids (TS), volatile solids (VS), MPN of total and thermotolerant coliforms and COD were determined through methodology described by APHA (2005).

Samples of inputs and outputs of digesters were collected on a weekly basis in order to measure N, P and K levels (calculated based on total solids). Nitrogen was determined as described by Silva (1981). The phosphorus and potassium were determined by the colorimetric method, as quoted by Malavolta (1989), using a spectrophotometer.

A completely randomized design was performed in a 2 × 4 factorial arrangement, four HRT (7, 14, 21 and 28 days) and separation or non-separation of the solid fraction, with repetition over time (4 weeks).

Table 1 - Characterization of poultry slaughterhouse effluent

Component	Concentration
Total solids (mg/L)	2000
Volatile solids (mg/L)	1800
pH	6.7
Total coliforms (MPN per mL of effluent)	2.40×10^{10}
Thermotolerant coliforms (MPN per mL of effluent)	7.70×10^{9}
Ammoniacal N (mg/L)	164.5
Total P (mg/L)	18.1
K (mg/L)	83.6
Chemical oxygen demand (mg O_2/L)	2319.0

MPN - most probable number.

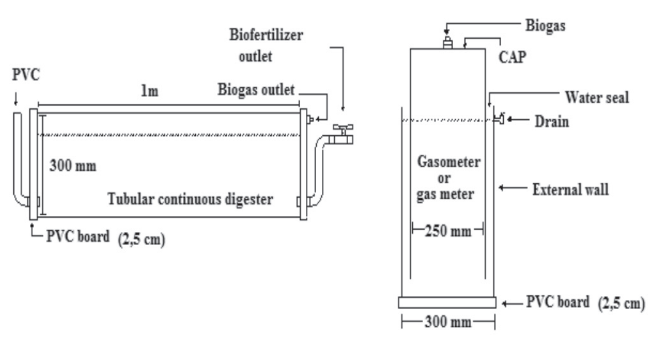


Figure 1 - Schematic representation of a tubular continuous digester of lab bench and gasometer.

The results were submitted to ANOVA considering the use or nonuse of sieve, the hydraulic retention times and the interaction between them as sources of variation, tested at 5% probability by Scott-Knott's test using statistical software SISVAR.

Results and Discussion

The largest productions of biogas and methane (Table 2) ($P<0.05$) were obtained in the treatment without separation of the solid fraction and shorter HRT (7 and 14 days). The liquid effluent without the solid fraction was less efficient at the production of biogas and methane, which resulted in lower values, representing only half of the values that were obtained in the treatment without separation of the solid fraction.

The results of the potential of biogas production per kilogram of COD added or reduced showed that the substrates under the shorter hydraulic retention times (7 and 14 days) achieved the highest yield ($P<0.05$), regardless of the separation of the solid fraction. When comparing the production parameters by manual separation of solid fraction, it was found that the highest yield was achieved by the treatment without separation of the solid fraction with a HRT of 7 days for COD added and in the period of 7 and 14 days taking into account the amount of COD reduced.

Similar result was found in the analysis of the production of methane per kg of COD added and reduced, since the highest production was achieved ($P<0.05$) in the treatment without separation of the solid fraction and HRT of 7 days (0.41 m^3 methane.kg^{-1} of COD added and 1.79 m^3 methane.kg^{-1} of COD reduced). The average estimate provided by the CEC (Centre for Energy Conservation), cited by Brondani (2010) for development of proposals in regards to carbon trade, is a production of 0.35 m^3 methane per kg of COD added to the digester. This estimated amount is related to a methane potential production which ensures profits for the producing unit. Based on this estimate and analysis of the results (Figure 2), it is possible to recommend the anaerobic digestion process for recycling of effluent generated in the poultry processing plant, particularly when handled within the retention times of 7 days and without sieving to separate small solid fractions.

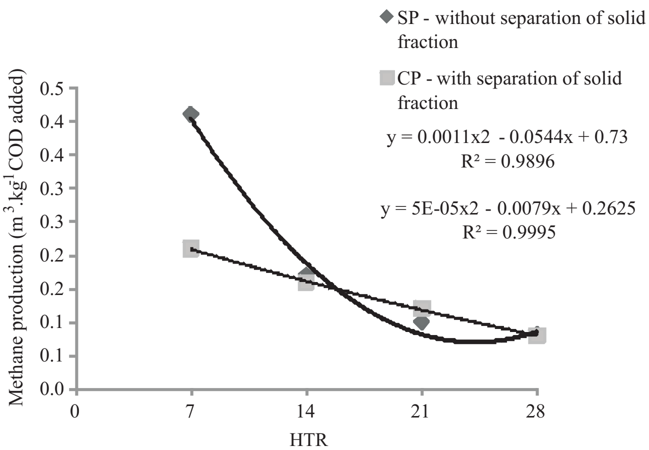
These results corroborate those described by Luste & Luostarinen (2010), stating that the use of sieves as method of pretreatment reduces the biogas production, once a highly degradable fraction is lost during the process. Thus, it was observed that the behavior of the results showed that the separation with sieves of the substrates reduced the production of methane and biogas, and hence their potential when compared with the non-treated wastewater that provided higher production of biogas and methane due to its high content of organic material in the solid fraction, as well as its high nitrogen content, especially from blood and animal tissue that are easily degraded under the anaerobic digestion process.

Also in regards to the waste quality, it was observed that the use of poultry slaughterhouse effluent as a non-treated substrate presented a reducing and subsequent increase in the potential of methane production from the COD added or reduced (Figures 2 and 3). These values can be attributed to heterogeneity of the material due to, as discussed

Table 2 - Concentrations of methane, productions, potential of biogas and methane productions and reductions of effluent constituents

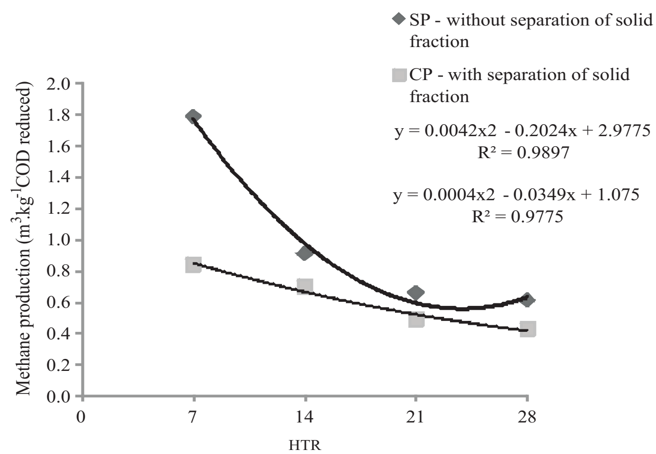
Variables	HRT 7		HRT 14		HRT 21		HRT 28		CV (%)
	SP	CP	SP	CP	SP	CP	SP	CP	
Concentration of methane (mL/L)	752.0Aa	696.0Ab	724.0Aa	717.0Aa	705.0Aa	714.0Aa	738.0Aa	717.0Aa	4.19
Average weekly production of biogas (L)	5.69Aa	2.93Ab	2.38Ba	1.84Bb	1.58Ca	1.25Ca	1.21Ca	1.02Ca	11.5
Average weekly production of methane (L)	4.28Aa	2.04Ab	1.73Ba	1.32Bb	1.12Ca	0.90Ca	0.89Ca	0.73Ca	15.6
m^3 biogas.kg^{-1} COD added	0.55Aa	0.31Ab	0.24Ba	0.22Ba	0.15Ca	0.28Ba	0.12Ca	0.12Ca	14.5
m^3 biogas.kg^{-1} COD reduced	2.37Aa	1.19Ab	1.26Ba	0.98Ab	0.94Ca	0.68Bb	0.81Ca	0.59Ba	15.1
m^3 methane.kg^{-1} COD added	0.41Aa	0.21Ab	0.17Ba	0.16Ba	0.10Ca	0.12Ca	0.08Ca	0.08Ca	16.5
m^3 methane.kg^{-1} COD reduced	1.79Aa	0.84Ab	0.91Ba	0.70Ab	0.66Ca	0.49Ba	0.61Ca	0.43Ba	16.9
				Reductions (%)					
Total solids	63.58Aa	57.97Ab	64.99Aa	60.88Ab	64.86Aa	53.84Bb	65.28Aa	53.51Bb	5.14
Volatile solids	63.00Aa	58.46Aa	64.93Aa	60.11Aa	66.76Aa	60.78Aa	70.44Aa	61.51Ab	7.78
Chemical oxygen demand	84.8Aa	69.4Bb	83.3Aa	78.4Ba	83.3Aa	73.5Aa	85.9Aa	82.4Aa	5.95
N	17.1Aa	16.7Aa	13.0Aa	16.7Aa	13.0Aa	12.5Aa	8.7Aa	12.5Aa	16.76
P	73.33Aa	90.2Aa	78.23Aa	81.2Aa	81.7Aa	86.6Aa	72.9Aa	88.2Aa	10.70
K	27.6Aa	21.6Ba	21.8Aa	24.2Ba	14.9Ba	22.1Ba	13.8Bb	48.5Aa	14.82
Total coliforms	99.99	99.99	100	99.99	100	100	100	100	-
Thermotolerant coliforms	100	100	100	100	100	100	100	100	-

HRT - hydraulic retention time; CP - with separation of solid fraction; SP - without separation of solid fraction; CV - coefficient of variation.
Capital letters compare results according to the hydraulic retention times and lower case letters compare the results according to the separation of the solid.
Means followed by different letters differ by Scott-Knott's test ($P<0.05$).



COD - chemical oxygen demand; SP - without separation of solid fraction; CP - with separation of solid fraction; TS - total solids; HRT - hydraulic retention time.

Figure 2 - Potential of methane production ($m^3.kg^{-1}$ COD added) in semi-continuous digesters managed at different HRT (7, 14, 21 and 28 days) with or without separation of the solid fraction.



COD - chemical oxygen demand; SP - without separation of solid fraction; CP - with separation of solid fraction; TS - total solids; HRT - hydraulic retention time.

Figure 3 - Potential of methane production ($m^3.kg^{-1}$ of COD reduced) in semi-continuous digesters managed at different HRT (7, 14, 21 and 28 days) with or without separation of the solid fraction.

previously, a significant amount of components with rapid degradation (muscle tissue) in the initial substrate, as well as a high amount of long-chain fatty acids that may be formed from the digestion of these components and thus cause a reduction in the biogas production and thus methane (Chen et al., 2008). Once this situation is characterized, the normal production is restored after a period of adaptation of microorganisms inside the digester, but the peak of production is not reached and, as was shown, the values are lower than or equal to the half of the expected value of 0.35 m^3 of methane per kg of COD added to the digester, thus indicating that the anaerobic digestion of this residue is a feasible way of recycling if it is managed in 7 days of HRT; however, in all conditions of HRT over 7 days, it will represent an important method of treatment, although it generates a lower amount of methane.

Despite the large amount of COD that was reduced in the biofertilizer (maximum value of 419 mg O_2/L), this is not classified as a safe value (CONAMA, 2005) for using as fertilizer for plants of direct consumption, such as vegetables, which is around 6 mg O_2/liter (Table 2). In addition, the great reductions of COD content reinforce the recommendation that the effluent from poultry slaughterhouse must remain in anaerobic digestion for at least 7 days, ensuring the reduction of organic load in the biofertilizer and the increase of methane production.

There was no significant difference (P>0.05) in the pH of biofertilizers from the digesters with different hydraulic retention times (7, 14, 21 and 28 days) and with and without separation of the solid fraction. The pH values are expressed respectively by the average values of 7.0, 7.0, 7.1, 7.0, 7.0, 7.2, 7.1 and 7.3.

The greater reduction of VS and TS (%) (P<0.05) occurred according to the longer retention times and then were decreasing proportionally to the HRT (Table 2). Also, it is observed that the separation of the solid fraction reduced the degradation rate of the liquid effluent. The greater reduction in the treatment without separation of solid fraction may be related to the larger amount of nutrients available in it.

The biodegradability of the waste was not influenced (P>0.05) with respect to hydraulic retention times and separation of the solid fraction, presenting the highest value (0.70 g. $SVadded.g^{-1}SVreduced$) similar to that found by Ogejo & Li (2010) (0.81 g. $SVadded.g^{-1}SVreduced$). These values represent the capacity of the liquid effluent to be degraded and thus produce biogas, which characterizes the efficiency of the process, even in the shortest hydraulic retention times.

An increase of N, P and K concentrations (Table 2) was expected in the produced biofertilizers when compared with the initial concentration in the material used to supply of digesters, since in general, during the anaerobic digestion, most of carbon is lost in the form of CH_4 and CO_2, causing the concentration of other nutrients. However, opposite behavior was observed, in which a representative reduction of these concentrations occurred. This reduction may be associated with the particular physic-chemical removal by precipitation of these compounds. Similar results were obtained by Vivan et al. (2010), who studied effluent from swine production in biodigesters and waste stabilization lagoons and found losses of 98.6% of phosphorus and 89.8% of total nitrogen, attributed mainly to precipitation and volatilization of N, respectively.

The analysis of most probable numbers of total and thermotolerant coliforms in biofertilizers along with the chemical oxygen demands demonstrated the efficiency of digestion in the treatment of the material.

There were reductions in the rates of MPN of total and thermotolerant coliforms over 99%, which represents the efficiency of anaerobic digestion in the reduction of indicator microorganisms of fecal contamination. According to this result, the HRT influenced the greater reductions that were presented, and the numbers of coliforms counted in biofertilizers did not exceed the recommended limits for the rivers from class 2 classified for aquaculture or recreation, as stated in CONAMA (2005), which establishes a maximum of 1000 thermotolerant coliforms per 100 mL of effluent.

Conclusions

The separation of the solid fraction of the liquid effluent from poultry slaughterhouse influenced the lower values of production and the potential of methane and biogas production for the retention times of 7 and 14 days when compared with the digestion of the non-treated wastewater. Thus, the use of 1 mm sieve to separate the solid fraction of the liquid effluent from slaughterhouse is not recommended for biogas production.

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