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Biogas from poultry waste—production and energy potential

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Abstract The objective of this study was to evaluate the effect of heat treatment on poultry litter with different levels of reutilisation for potential generation of biogas in experimental biodigesters. Chicken litter used was obtained from two small-scale poultry houses where 14 birds m^{-2} were housed for a period of 42 days per cycle. Litter from aviary 1 received no heat treatment while each batch of litter produced from aviary 2 underwent a fermentation process. For each batch taken, two biodigesters were set for each aviary, with hydraulic retention time of 35 days. The efficiency of the biodigestion process was evaluated by biogas production in relation to total solids (TS) added, as well as the potential for power generation. Quantified volumes ranged from 8.9 to 41.1 L of biogas for aviary 1, and 6.7 to 33.9 L of biogas for aviary 2, with the sixth bed reused from both aviaries registering the largest biogas potential. Average potential biogas in m^3 kg^{-1} of TS added were 0.022 to 0.034 for aviary 1 and 0.015 to 0.022 for aviary 2. Energy values of biogas produced were calculated based on calorific value and ranged from 0.06 to 0.33 kWh for chicken litter without fermentation and from 0.05 to 0.27 kWh for chicken litter with fermentation. It was concluded that the re-use of poultry litter resulted in an increase in biogas production, and the use of fermentation in the microbiological treatment of poultry litter seems to have negatively influenced production of biogas.

Introduction

The livestock production sector is a competitive chain aimed at high productivity and profitability, growing every year in the number of animals slaughtered and sold. One of the sector's highlights is the poultry industry. Brazil ranks second in the world in broiler production, behind only the USA, in addition to maintaining the position of world's largest exporter since 2004 (ABPA 2016).

Development within the poultry industry is due to several factors. One such factor is the growth rate of broiler chickens, which over the years has become shorter due to improvements achieved in genetics, nutrition and productive environments. Currently, the production cycle is approximately 42 days, with some variation, depending on the consumer market. Due to these improvements, the animals can convert food into meat production due to the high consumption of energy feed (de Oliveira et al. 2006). However, high feed intake and intensive management generate significant amounts of high organic waste load.

The composition of waste from poultry farms is characterized by the presence of dead animal carcasses and primarily chicken litter, which is an absorbent material distributed over the paving of the sheds that serves as a bed to the birds (Suzuki et al. 2012). This material at the end of the production cycle consists of excrement,

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bird feathers and feed scraps, presenting characteristics with high pollution potential.

As an alternative to help reduce the environmental impact and production costs of poultry activity, many producers employ the reutilisation of poultry litter for several consecutive batches (Costa 2009). This re-use of poultry litter increases the concentration of micro-organisms, which can cause health problems (da Virtuoso et al. 2015). In this sense, it is essential to adopt a pretreatment of poultry litter during the fallow period to avoid problems with the next batch (Otutumi et al. 2013). Among the processes applied to reduce pathogens in poultry litter during fallow periods is fermentation.

According to Avila et al. (2007), fermentation is characterized as the natural process of decomposition of organic matter by micro-organism activity, culminating in the production of heat, water vapour and carbon dioxide. The main objective in the fermentation of chicken litter is to reduce the concentration of undesirable micro-organisms, which provides a healthier environment to the chickens that will be housed in subsequent batches.

However, when the possibility of maintaining the bed for housing poultry does not exist, removal is necessary, and this waste is generally intended for application to soil, although if applied inappropriately, it can become an environmental liability.

One possible waste treatment method to reduce the risk of pollution is through the process of biodigestion (Costa et al. 2012). In this process, anaerobic bacteria in an environment devoid of oxygen (biodigester) degrade organic matter, resulting in the production of biogas and biofertiliser as by-products (Holm-Nielsen et al. 2009). These by-products can be used as sources of income, adding value to the business, making the activity a sustainable production model.

Thus, through the biodigestion process, the farmer can produce fuel with high energy output which can be used to generate electricity, heat or drive mechanical devices and satisfactorily recycle waste material from the farm which contributes to the reduction of environmental impacts generated during the production process. In addition, at the end of the digestion process the farmer will have a stabilized biofertiliser for use on the property or for sale (Roshani et al. 2012). According to LAZOR et al. (2010), other advantages in using biodigestion are odour control and reduction of greenhouse gas emissions.

Therefore, this study sought to quantify the production of biogas in biodigesters developed at an experimental scale that were fed waste originating from poultry, and to evaluate whether the use of fermentation as a pretreatment interfered with the biodigestion process. This study also sought to assess the biogas production potential and potential power generation of poultry litter from different stages of reutilisation.

Methods

Local

The experiment was conducted at the Sinop campus of the Universidade Federal de Mato Grosso, located in Sinop - MT, during the period January 2015 to July 2016. The geographical coordinates are latitude 11.98° S and longitude 55.56° W, where there is an average annual temperature of 24 °C and an altitude of 371 m.

Reduced scale models of poultry shed

Two reduced scale model poultry sheds were constructed for research development, specifically for the production of waste to be used in the anaerobic biodigestion process.

The two model sheds were constructed at a distorted scale (1:10), both with identical dimensions of 3.20 m long, 1.40 m wide and 1.80 m high. The support structures used were solid timber joists with the side guard rails and the east-west sides built with masonry.

Fibre cement tiles (0.006 m) were used as roofing on the model sheds, supported by a timber structure. Plastic canvas curtains were installed along the north-south sides of the model sheds. The aviaries were oriented in the east-west direction.

Chicken flock batches

The housing of different batches of broilers started on January 17, 2015 and ended on June 22, 2016, totalling seven consecutive batches of chicken flocks.

Each shed housed broilers of Cobb 500™ lineage and mixed sexing with a stocking density of 14 birds m^{-2}. The production cycle consisted of broilers up to 42 days old, and the intervals between each batch were at least 15 days of fallowing. The birds received food and water ad libitum, with the ration provided in accordance with the recommendations for each phase of bird

life as shown by Rostagno et al. (2011). The absorbent material utilized as bedding within both aviaries was rice husk, and was added up to 20 cm thick.

In order to reduce the microbiological load that builds when reusing chicken litter, the chicken litter from one shed (aviary 2) underwent a thermal pretreatment process through bed fermentation, carried out during fallow periods between batches. The other shed (aviary 1) was used as the control and did not receive fermentation pretreatment during the experiment.

In the fermentation process performed, the chicken litter remained distributed throughout the aviary and was covered with PVC plastic sheeting. To significantly reduce the microbial load in the fermentation method, it is required to keep litter covered with plastic sheet for 10–12 days (Silva et al. 2007; Macklin et al. 2006). In this experiment, a fermentation period of 10 days was used, since the interval between chick batches were 15 days. Therefore, 10 days were dedicated to fermentation, and 5 days were used for bed ventilation in order to reduce ammonia concentration. It is important to notice that fermentation period of 10 days is the common practice in Brazilian broiler houses.

Experimental biodigesters

For the construction of the experimental biodigesters, four plastic drums were used with capacity to hold 50 L of substrate for fermentation. The lids were sealed with epoxy resin and silicone type glue and a hole drilled in each lid to connect the manometer.

To measure the pressure of the biogas generated in each biodigester, a manometer with "U" shaped tube was used. One end of the manometer was connected to the biodigester with the other end in contact with atmospheric air (Fig. 1).

Testing the biodigesters

After removal of the first batch of chickens, a portion of litter from each aviary's bed was collected, mixed with water and co-substrate inoculant (dairy cattle manure) and added to the biodigester. This process was carried out in duplicate for the two scale model sheds, i.e. four biodigesters commenced fermentation simultaneously, two in each aviary. The same process was performed at the end of the second, third, fourth, fifth, sixth and seventh consecutive batches.
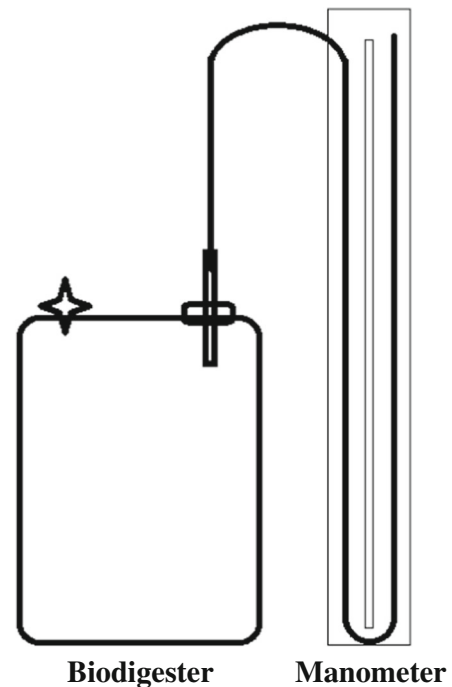

Biodigester   Manometer

Fig. 1 Complete system of anaerobic biodigestion, consisting of biodigester and manometer

To supply the biodigesters, the mixture was prepared with the same ratio as used by Aires et al. (2010), whereby each biodigester was filled with a mixture composed of 3 L of broiler bed, six parts of distilled water (18 L) and three parts co-substrate inoculant (9 L), totalling ten parts by volume (30 L) in each digester.

After anaerobic biodigestion of the bed from the first batch of chickens, the co-substrate inoculant used in proceeding biodigesters was always the effluent (output) of the previous anaerobic biodigestion. Demirci and Demirer (2004) and Onofre et al. (2015) state that the use of inoculants in conjunction with poultry litter can have beneficial effects on the production of biogas.

The hydraulic retention time for the mixture adopted in this experiment was 35 days for all tests. According to Arruda et al. (2002), an average of 30 to 45 days is sufficient for conversion of organic material to biogas. The biodigesters remained under ambient conditions inside a shed, in absence of direct sunlight and rain.

Determination of total and volatile solids levels

The initial and final levels of total and volatile solids mixture in the biodigesters was determined by

gravimetric testing according to the methodology described in *Standard Methods for Examination of Water and Wastewater* (APHA 2012). These values were later used to determine the relationship between the volume of biogas produced against mass of total solids added and reduction of volatile solids in the mix.

Biogas production

Monitoring of biogas production was performed daily. As biogas accumulation occurred within the biodigester, internal gas pressure was recorded as indicated by the pressure gauge. After each reading, the systems were disconnected from the biodigesters and biogas produced was then discharged.

The volume of biogas produced in each biodigester was calculated according to the methodology used by Aquino et al. (2007), with correction of biogas volume to the normal conditions of pressure and temperature of 1 atm and 20 °C performed using the equation resulting from the combination of Boyle's law and Gay-Lussac's law, Eq. 1.

$$V_0 = P_1.V_1.T_1^{-1}.P_0^{-1}.T_0 \tag{1}$$

where,

V_0 is the fixed volume of biogas (m³);
P_0 is the average atmospheric pressure in Sinop (1 atm);
T_0 is the corrected biogas temperature (293.15 K);
V_1 is the volume of biogas measured (m³);
P_1 is the biogas pressure measured at pressure gauge (atm);
T_1 is the biogas temperature at time of reading (K).

The meteorological data required to estimate the volume of biogas was obtained from the automatic weather station installed at the Sinop campus of UFMT.

Biogas production potential was calculated using the total output data and added amounts of total solids (initial) in the biodigesters, in addition to the amounts of reduced volatile solids during the process of anaerobic biodigestion. The values are expressed as L of biogas (accumulated production in each test) and in $m^3 \, kg^{-1}$ of initial total solids.

Estimated energy potential of generated biogas

Concentrations of methane (CH_4) and hydrogen sulphide (H_2S) within the biogas produced were recorded with the aid of a portable 4-gas detector. Readings were taken at the time that storage systems were disconnected from biodigesters and biogas produced was discharged.

Analysis of energy potential from biogas generated within the experimental scale model biodigester was estimated by means of the biogas energy calculation produced using Eq. 2.

$$E = Q.PCI \tag{2}$$

Where:

E   is available energy (kWh);
Q   is the accumulated volume of biogas produced in each test performed (m³ batch⁻¹);
PCI   is the lower calorific value of biogas (kWh m⁻³).

Statistical analysis

Descriptive statistics were used to analyse the following variables: total solids (TS) and volatile solids (VS) levels, accumulated biogas production, biogas produced per kg of added total solids (initial) and energy potential of biogas produced in each test.

Results and discussion

Levels of total solids (TS) and volatile solids (VS)

Levels of total solids (TS) and volatile solids (VS) in kg, at the beginning and end of the anaerobic biodigestion process, as well as reductions in VS levels, in %, for the different chicken litter batches without fermentation (aviary 1) and with fermentation (aviary 2) are shown in Table 1.

Total solids (TS) were plotted, from initial concentrations through to the last reutilisation of broiler bed with and without fermentation, with the highest TS concentrations found from the seventh batch of chickens, both in the chicken litter substrate produced without fermentation (aviary 1), and the chicken litter substrate with fermentation (aviary 2). This increase was

Table 1 Total solids and volatile solids concentrations and reduction of VS, in percentage, for the different chicken litter batches without fermentation (aviary 1) and with fermentation (aviary 2)

Total bird upbringing	Aviary	Total solids		Volatile solids		
		Range of initial TS kg	Range of final TS kg	Range of initial VS kg	Range of final VS kg	Range of reduced VS %
7	1	0.39–1.96	0.29–0.90	0.32–1.12	0.09–0.43	10.61–69.28
	2	0.47–1.83	0.37–0.88	0.32–1.03	0.10–0.51	12.51–52.05

possibly due to the accumulation of excrement, bird feathers and feed remains in each subsequent reuse of beds. In analysing the range of final concentrations of total solids (TS), it can be seen that there was a reduction in all tests. This variability, according to Xavier and Lucas Junior (2010), can be attributed to differences in the TSs of chicken litter that were included in equal amounts in treatments at different times of the year and the inoculum used.

Regarding the percentage level of volatile solids, the largest reduction was achieved in the beds from seven batches of poultry, reducing 69.28% of VS for the chicken litter substrate without fermentation and VS reduction of 52.05% for the chicken litter substrate with fermentation. According to Costa et al. (2013), the higher the reduction value of solids, the more efficient the breakdown and conversion of organic matter will be, resulting in higher biogas production. The different range of values in VS reduction in both systems can be attributed to sedimentation of the substrate in the biodigester, as the biodigester did not have a mechanical stirrer.

According to Wohlgemut (2009), the initial and final levels of volatile solids from biodigester substrate can demonstrate the efficiency of the process. Barros et al. (2004) state that the higher the level of VS, the higher the rate of biodegradation.

Mari et al. (2014) evaluated the capacity of solids removal and production of biogas from a new model of upflow anaerobic digester developed in Brazil. The anaerobic digester was loaded with cattle manure and a hydraulic retention time of 30 days. The treatment process resulted in an average reduction of $24.78 \pm 21.44\%$ for volatile solids.

Farias et al. (2012), using waste from laying hens in batch type biodigesters with 22 days hydraulic retention achieved a reduction in VS levels of approximately 20%. dos Santos (2001), in evaluating the anaerobic

biodigestion of chicken litter (wood shavings), obtained a reduction in VS levels of 41.27 and 41.95% in beds of first and second reutilisation, respectively.

Quantification of biogas production

It was found that during the experimental period, there was biogas production from poultry litter material in all tests performed, confirming the potential of poultry manure for this purpose, as evidenced by the literature. Biogas production was noted in all the tests through the presence of the characteristic odour of H_2S close to the biodigesters, and also by the filling of the gas storage systems. The quantities of accumulated biogas produced during the experimental period of testing of poultry litter with no fermentation (aviary 1) and with fermentation (aviary 2) reutilised over seven batches can be seen in Fig. 2.

It was observed that with the increased number of poultry litter reuse, the volume of biogas produced showed higher values, as observed by Fukayama et al. (2009). This demonstrates that biogas production potential rises with increased number of poultry litter reuses.

Quantified biogas volumes ranged from 8.9 to 41.1 L for aviary 1 (beds without fermentation pretreatment during fallow periods) and 6.7 to 33.9 L for aviary 2 (beds with fermentation), with the largest potential for biogas production registered with chicken litter from seven batches of chickens about the same in both aviaries.

A slight difference in biogas production between aviaries 1 and 2 was observed. This suggests that the fermentation pretreatment process performed only in aviary 2 stabilized part of the organic material which would otherwise be decomposed in the biodigestion process, thus the different total volume of biogas produced. This is supported by the work of Orrico Junior et al. (2010), which found that in the pre-fermentation

Fig. 2 Volume of biogas produced in biodigesters filled with poultry litter without fermentation (*1*) and with fermentation (*2*) in seven consecutive batches of chicken production (volume corrected for 20 °C and 1 atm)
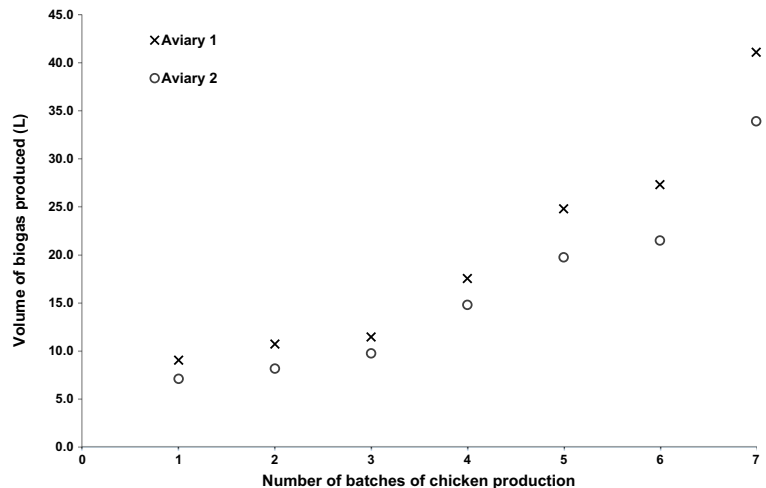
period, there were significant losses of carbon and nitrogen from the material, which reduced potential biogas production from the original bed.

Thus, in terms of demonstration, a commercial poultry shed with dimensions of 150 m length, 12 m width and a bed of 20 cm thickness, could potentially generate approximately 4932 m^3 of biogas without bed fermentation, and approximately 4068 m^3 of biogas with bed fermentation during fallow periods, considering poultry litter removal after 7 cycles of chicken rearing.

In a study on ruminant waste (cattle and buffalo) and monogastric waste (laying hens and pigs), Micalli Junior et al. (2009) conducted 42 days of biodigestion and produced 2.9 L of biogas from the treatment with bird waste, and 2.5 L from the treatment with poultry manure and cattle manure in 60 L of substrate. All of these volumes were lower than those found in this study for all tests on poultry litter with, and without fermentation, in 30 L of substrate, at every stage from the first to the seventh batch of chicken rearing on the same bed.

According to Amaral et al. (2004), the best factor used to reflect the potential biogas production of a certain biomass is one that expresses biogas production as per kg added total solids (initial); this eliminates the interference of water content present within the biomass. Evaluating biogas production in relation to the mass of total solids (TS) added to each test (Fig. 3), it was found that the higher values were obtained from the tests performed using the aviary 1 bed (without bed fermentation) in every batch of chicken rearing in this experiment.

However, the relationship did not show a positive correlation, as although the volume of chicken litter added in each biodigestion process was constant (3 L);

the total solids added varied according to the number of bed reuses. Biogas production in m^3 per mass of total solids (TS) added during the experimental period for the tests performed on chicken litter with no fermentation (aviary 1) and with fermentation (aviary 2) reused for 7 cycles of chicken rearing can be seen in Fig. 3.

Cubic metres of biogas per kg of TS added ranged from 0.022 to 0.034 for aviary 1 (bed without pretreatment and fermentation during fallow periods) and 0.015 to 0.022 for aviary 2 (bed with fermentation), with the largest potential biogas production per kg of TS added recorded with the bed from four batches of chicken rearing for aviary 1, and the highest values for aviary 2 were obtained with beds from four to five batches of chicken rearing, and resembles the visual values.

Orrico Junior et al. (2010), using beds with chicken carcasses previously composted in batch type biodigesters for 14 weeks obtained values of 0.135, 0.153 and 0.135 m^3 of biogas per kg of TS added, respectively, to biodigester 1 (7.4 kg of dead birds and pre-composted chicken litter), biodigester 2 (7.2 kg of dead birds and pre-composted chicken litter) and biodigester 3 (8.3 kg of dead birds and pre-composted chicken litter). According to these authors such differences in values can be attributed to different substrate composition and hydraulic retention time which was 98 days, while this study was 35 days.

Xavier and Lucas Junior (2010) evaluated additions of different inoculum proportions in the anaerobic biodigestion of dairy cattle manure and obtained 0.210, 0.218 and 0.258 m^3 of biogas per kg of TS added to 20, 30 and 40% of inoculum, respectively, in biodigester substrates.

Fig. 3 Average potential biogas production per kg of total solids added to biodigesters supplied with poultry litter without fermentation (*1*) and with fermentation (*2*) in seven consecutive batches of chicken production (volume corrected to 20 °C and 1 atm)
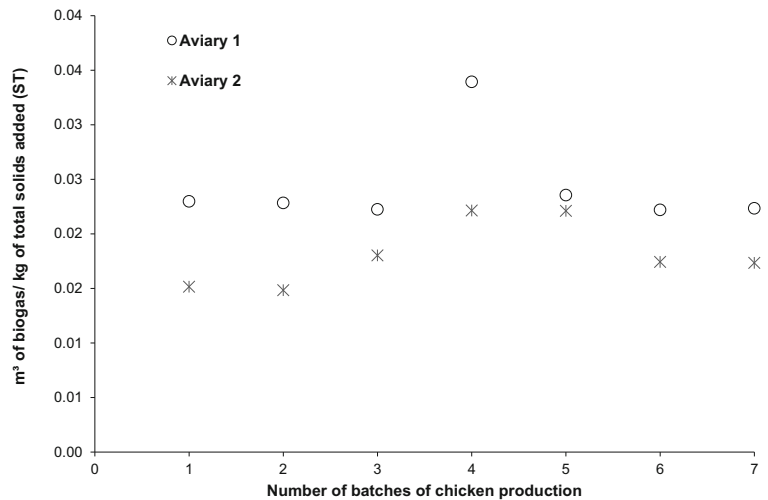
Costa et al. (2013) conducted a study to assess the inclusion of bioremediators (microorganism catalysts in the biodegradation rate) in the anaerobic biodigestion process of cattle manure and abattoir refrigerator wastewater in batch biodigesters. They considered four treatments. The average potential biogas production per kg of total solids added was 0.1083, 0.0685, 0.0777 and 0.0132 for T1, T2, T3 and T4, respectively.

When using continuous biodigesters filled with dairy cattle manure and 30 days of hydraulic retention, Amaral et al. (2004) recorded 0.1162 m^3 of biogas production per kg of total solids added for the Indian model and 0.1232 for the Chinese model biodigester.

Energy potential of generated biogas

According to Ozturk and Demirciyeva (2013) methane is the gas of most interest in biogas mixtures, with the higher the percentage, the higher the biogas' calorific value. Methane concentrations present within biogas produced in the experiment are shown as percent values in Fig. 4.

According to Suzuki et al. (2012), generated biogas can be considered of high enough quality to be used in internal combustion engines when methane concentration is at least 60%. Lower values would promote engine malfunction, system failures and ignition difficulties. The average values of methane concentration obtained were satisfactory and showed a positive correlation with the number of bed reuses, which agrees with the values mentioned in the literature. This trend is natural, probably through the increased concentration of organic matter with each reuse of poultry litter. Values obtained from aviary bed were slightly higher than values from aviary bed 2 from the fourth batch of chicken litter, suggesting a negative influence from the previous use of the fermentation process on beds to the biogas produced in the anaerobic biodigestion.

dos Santos (2001) performed 30 days of fermentation for biogas from broiler litter substrates with 15% inoculum, and observed CH_4 levels around 65%. Aires et al. (2010) recorded an amount of 64.87% CH_4 when performing biodigestion using water and inoculum, separation of the solid fraction, 21 days of hydraulic retention and broiler beds after their 3rd cycle of reuse.

Estimates of generated biogas energy potential from the experimental biodigester with 30 L of substrate from unfermented poultry litter (aviary 1) and fermented poultry litter (aviary 2) were based on methane levels and its respective lower heating value. Energy values of produced biogas calculated based on the calorific value were 0.06, 0.07, 0.08, 0.13, 0.19, 0.22 and 0.33 kWh, respectively, for the batches of first, second, third, fourth, fifth, sixth and seventh cycle of reuse in chicken rearing on bed material without fermentation, and 0.05, 0.05, 0.07, 0.10, 0.14, 0.17 and 0.27 kWh for the batches of first, second, third, fourth, fifth, sixth and seventh cycle of reuse in chicken rearing on bed material with fermentation.

Hydrogen sulphide levels were also determined. According to Haas (2013), despite the presence of H_2S within biogas in small quantities, it is the principal contaminant due to its toxic and corrosive properties that limit the use of biogas in certain cases. Galbiatti et al. (2010) state that in the evaluation of waste produced from biogas, the volume and quality of biogas generated should be considered. Hydrogen sulphide

Fig. 4 Concentration of Methane (%) in biogas produced from broiler litter reused in different batches
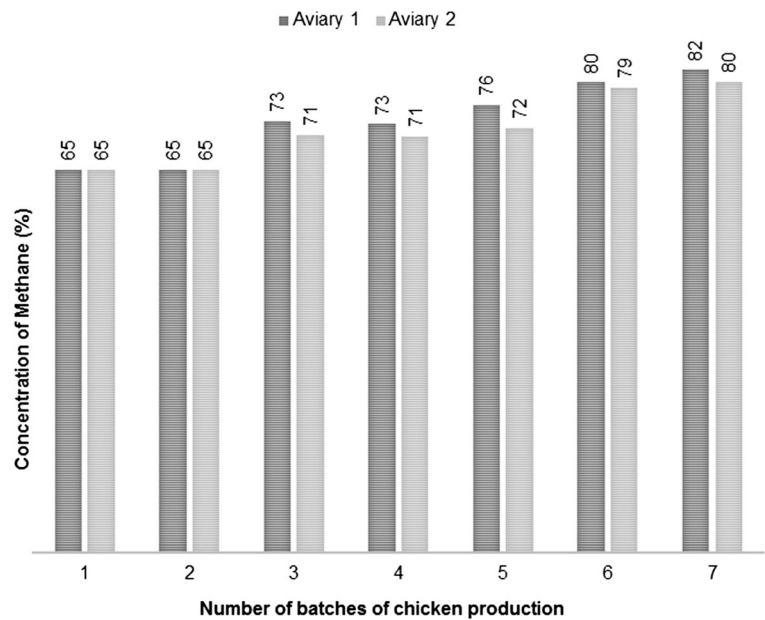
levels for the tests performed (Fig. 5) were within the range indicated by Rasi et al. (2007) of 32–169 ppm, which is the range commonly found in biogas. It was observed that in all tests performed, H$_2$S levels were slightly higher for aviary 2 (beds with fermentation during fallow periods).

Lazor et al. (2010) evaluated the biodigestion of chicken waste with cooking oil and 14 days of hydraulic retention and recorded hydrogen sulphide levels of 104 ppm of within the biogas produced. In evaluating biogas production potential using effluent from a sewage treatment plant, Zilotti (2012) obtained results of an

average level of 210.8 ppm hydrogen sulphide in the biogas.

Application

Based on the dimensions of a commercial poultry shed (150 m long, 12 m wide, 20 cm thick bed) and taking into account using the same bed for six consecutive production cycles, with each cycle having a chicken population for a period of 42 days, one can estimate the biogas potential from reused poultry litter based on the values obtained in this study, and taking into account

Fig. 5 Hydrogen sulphide levels (ppm) in biogas produced from poultry litter reused for seven consecutive cycles of broiler rearing
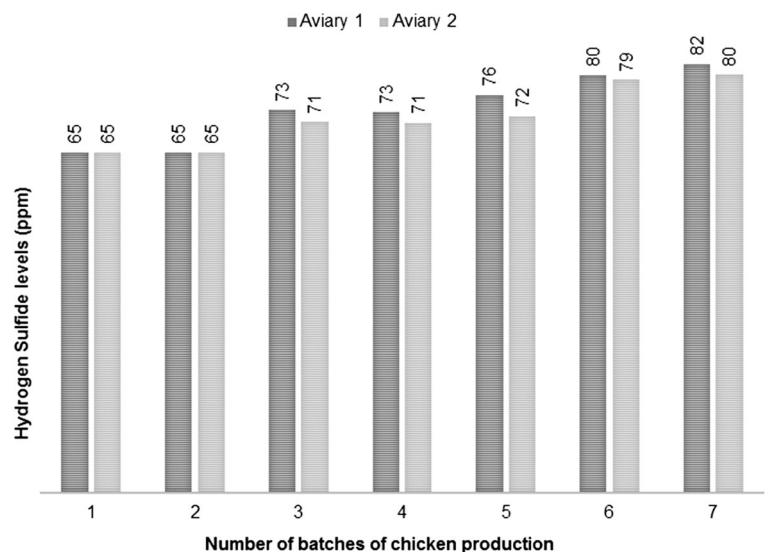
that biogas production from the aviary 1 bed (no fermentation in fallow periods) was slightly higher.

An aviary of this size produces a total volume of 450 m^3 of chicken litter. A viable alternative in the production of biogas for power generation would take only 1/6 of the volume of poultry litter at the end of each production cycle to be allocated to the biodigesters and produce biogas to be used as a substitute for traditional fuels and electricity used in successive production cycles, thereby increasing the viability of the biodigester and power generation.

Thus, at the end of the first batch of chickens, 75 m^3 of chicken litter would be removed from the aviary for the biodigesters, with the remainder to be reutilised in subsequent batches. The remaining bed should be topped up with 75 m^3 of new bed to maintain a 20-cm bed thickness, and continue this process until the sixth batch.

Under these conditions, it appears that each process of biodigestion with 75 m^3 of bed would produce: 222.5, 275, 287.5, 437.5, 687.5 and 625 m^3 of biogas for bed portions after the first, second, third, fourth, fifth and sixth batch of chicken rearing cycles, respectively. Using the equivalence cited by Tessaro et al. (2015), wherein 1 m^3 of biogas is equivalent to 0.61 L of gasoline, and considering the biogas would be used to generate electricity, heat or drive mechanical machinery for a 42-day duration of subsequent batches, equivalent amounts of gasoline obtained would be approximately 136, 168, 175, 270, 381 and 419 L. After completion of the first cycle, 1 year and beginning of the second year, each portion of the bed would have gone through at least 6 cycles of production.

Biogas produced from biodigestion of poultry litter can be used in simple gas burners for the heating of chicks, essential for the first 2 weeks of the production cycle, in addition to fuelling biogas generators that could run power systems, lighting and ventilation of farms, thus demonstrating the feasibility of using poultry manure in biogas production, and this may primarily replace non-renewable fuels such as petroleum.

According to Nägele et al. (2017) for the energy utilization of the biogas without damage to the energy generation or heating systems, the hydrogen sulphide must be removed. The methods that may be employed are the injection of air into the gas phase within the biodigester or the use of chemicals in the liquid phase to inhibit H_2S formation. Biogas can also be treated directly using water absorption, chemical absorption, activated carbon adsorption, membranes, biological filters and the use of iron sponge.

Conclusion

It was observed that the anaerobic biodigestion process was efficient in producing biogas, and the number of bed reuses that generated a greater accumulated amount of biogas was the fifth, demonstrating an increase in biogas production from poultry litter beds that have a greater number of reuses. Additionally, it was observed that the use of fermentation as a microbiological treatment of beds showed lower results in biogas production, shown by reduced biogas production when fermentation was used compared to production without fermentation.

The estimate of energy potential from the produced biogas demonstrates the potential of poultry manure in the energy aspect. The production of CH_4 (%) increased with greater amounts of bed reuse and without pretreatment and fermentation, with the highest levels found in the aviary 1 bed. Hydrogen sulphide content showed a positive correlation with greater numbers of bed reuse in both aviaries, with the levels obtained from aviary 1 being higher in all biodigestion tests.

References

Aires, A. M. A., Lucas Junior, J., Fukayama, H. E., Machado, R. C., & Guidolin, F. G. D. (2010). Biodigestão anaeróbia da cama de frangos de corte com ou sem separação das frações sólida e líquida sobre a produção de biogás e a qualidade do biofertilizante. *Engenharia Agrícola, 30*(2), 212–223.

Amaral, C. M. C., Amaral, L. A., Lucas Junior, J., Nascimento, A. A., Ferreira, D. S., & Machado, M. R. F. (2004). Biodigestão anaeróbica de dejetos de bovinos leiteiros submetidos a diferentes tempos de retenção hidráulica. *Ciência rural, 34*, 1897–1902.

American Public Health Association. (2012). *Standard methods for examination of water and wastewater. (1496p). 22nd*. Washington: APHA/AWWA/WEF.

Aquino, S. F., CHERNICHARO, C. A. L., FORESTI, E., SANTOS, L., & MONTEGGIA, L. O. (2007). Metodologias para determinação da atividade metanogênica específica (AME) em lodos anaeróbios. *Revista Engenharia Sanitária e Ambiental, 12*(2), 192–201.

Arruda, M. H., Amaral, L. P., Pires, O. P. J., & Barufi, C. R. V. (2002). Dimensionamento de Biodigestor para Geração de Energia Alternativa. *Revista científica eletrônica de agronomia, 1*(2), 1–8.

Associação Brasileira De Proteína Animal (ABPA). (2016). *Relatório Anual ABPA 2016*. Mercado Mundial. São Paulo, Brasil. < http://abpa-br.com.br/storage/files/versao_final_para_envio_digital_1925a_final_abpa_relatorio_anual_2016_portugues_web1.pdf >. Accessed 29 July 2016.

Avila, V. S., Abreu, V. M. N., Figueiredo, E. A. P., Brum, P. A. R., Oliveira, U. (2007). Valor Agronômico da Cama de Frangos após Reutilização por Vários Lotes Consecutivos - Concórdia: Embrapa Suínos e Aves. Embrapa Suínos e Aves. *Comunicado Técnico, 466*, 4 p.

Barros, R. M., FILHO, G. L. T., NASCIMENTO, Y. D. S., GUSHIKEN, E., CALHEIROS, H. C., de Silva, F. G. B., & Júnior, A. S. (2004). Estudo da produção de biogás da digestão anaeróbia de esterco bovino em um biodigestor. *Revista Brasileira de Energia, 15*(2), 95–116.

Costa, L. V. C. (2009). Aproveitamento de resíduos da suinocultura e avicultura: potenciais para produção de biogás e biofertilizante. *Pubvet, 3*(10), Art#538.

Costa, L. V. C., MOGHRABI, J. A., SAGULA, A. L., & Del Junior, J. (2013). Tratamento anaeróbio da água residuária de frigorífico com uso de biodigestores: utilização de remediadores biológicos para produção de biogás. *Brazilian Journal of Biosystems Engineering, 7*(2), 77–85.

Costa, L. V. C., Sagula, A. L., & Lucas Junior, J. (2012). Uso de remediadores biológicos na biodigestão anaeróbia da cama de frango de corte. *Revista Brasileira de Engenharia de Biossistemas, 6*, 71–78.

da Virtuoso, M. C., Silva, de Oliveira, D. G., de Dias, L. N. S., de Fagundes, P. S. F., & de Leite, P. R. S. (2015). Reutilização da Cama de Frango. *Revista Eletrônica Nutritime, 296*(12), 3964–3979.

de Oliveira, G. A., de Oliveira, R. F. M., Donzele, J. L., Cecon, P. R., Vaz, R. G. M. V., & Orlando, U. A. D. (2006). Efeito da temperatura ambiente sobre o desempenho e as características de carcaça de frangos de corte dos 22 aos 42 dias. *Revista Brasileira de Zootecnia, 35*(4), 1398–1405.

Demirci, G. G., & DEMIRER, G. N. (2004). Effect of initial COD concentration, nutrient addition, temperature and microbial acclimation on anaerobic treatability of broiler and cattle manure. *Bioresource Technology, 93*, 109–117.

Farias, R. M., Orrico Junior, M. A. P., Orrico, A. C. A., Garcia, R. G., Centurion, S. R., & Fernandes, A. R. M. (2012). Biodigestão anaeróbia de dejetos de poedeiras coletados após diferentes períodos de acúmulo. *Ciência Rural, 42*(6), 1089–1094.

Fukayama, E. H., Lucas Junior., J., Aires, A. M., Silva, A. A., Oliveira, R. A. (2009). Produção de biogás utilizando cama de frangos de corte. In: *1 SIMPÓSIO INTERNACIONAL SOBRE GERENCIAMENTO DE RESÍDUOS DE ANIMAIS SIGERA*, 8.

Galbiatti, J. A., Caramelo, A. D., Silva, F. G., Gerardi, E. A. B., & Chiconato, D. A. (2010). Estudo qualiquantitativo do biogás produzido por substratos em biodigestores tipo batelada. *Revista Brasileira de Engenharia Agrícola e Ambiental, 14*(4), 432–437.

Haas, L. B. (2013). *Desenvolvimento de um filtro para a remoção de H_2S de Biogás. Dissertação (Mestrado) – Universidade Estadual do Oeste do Paraná* (p. 45). Cascavel: UNIOESTE.

Holm-Nielsen, J. B., Seadi, T. A., & Oleskowicz-Popiel, P. (2009). The future of anaerobic digestion and biogas utilization. *Bioresource Technology, 100*, 5478–5484.

LAZOR, M., Hutˇnan, M., Sedláˇcek, S., Kolesárová, N., & Špalková, V. (2010). Anaerobic co-digestion of poultry manure and waste kitchen oil. In J. Markoš (Ed.), *In proceedings of the 37th international conference of Slovak Society of Chemical Engineering* (Vol. 37, pp. 1399–1406). Slovakia: Tatranské Matliare.

Macklin, K. S., Hess, J. B., Bilgili, S. F., & Norton, R. A. (2006). Effects of in-house composting of litter on bacterial levels. *The Journal of Applied Poultry Research, 15*(4), 531–537.

MarI, A. G., SECCO, D., Kunz, A., Edwiges, T., Mari Junior, A., Frigo, E. P., & Alves, H. J. (2014). Performance of up-flow anaerobic digester in solids removal and biogas production. *Journal of Food, Agriculture & Environment, 12*(2), 1135–1139.

Micalli Junior, J. R., Galbiatti, J. A., Perez, H. L., Ragazzi, M. F., Gabiatti, R. (2009). Produção de biogás a partir de dejetos de ruminantes e monogástrico com e sem inóculo. In: *VI Congresso de Meio Ambiente da AUGM*.

Nägele, H. J., Steinbrenner, J., Hermanns, G., Holstein, V., Haag, N. L., & Oechsner, H. (2017). Innovative additives for chemical desulphurisation in biogas processes: A comparative study on iron compound products. *Biochemical Engineering Journal, 121*, 181–187.

Onofre, S. B., Abatti, D., Refosco, D., Tessaro, A. A., Onofre, J. A. B., & Tessaro, A. B. (2015). Anaerobic biodigestion in Indian batch-type biodigester, using poultry litter as substrate for the production of biogás. *African Journal of Agricultural Research, 10*(31), 3056–3061.

Orrico Junior, M. A. P., Orrico, A. C. A., & Lucas Junior, J. (2010). Biodigestão anaeróbia dos resíduos da produção avícola: cama de frangos e carcaças. *Engenharia Agrícola, 30*(3), 546–554.

Otutumi, L. K., Previato Do Amaral, P. F. G., Piau Junior, R., de Moura, D. J., de Carvalho, T. M. R., Dalberto, J. L., & de Brito, B. G. (2013). Efeito de micro-organismos benéficos no tratamento da cama de frango. *Arquivos de Ciências Veterinárias e Zoologia, 16*(2), 121–127.

Ozturk, B., & Demirciyeva, F. (2013). Comparison of biogas upgrading performances of different mixed matrix membranes. *Chemical Engineering Journal, 222*, 209–217.

Rasi, S., Veijanen, A., & Rintala, J. (2007). Trace compounds of compounds of biogás from different biogás production plants. *Energy, 32*, 1375–1380.

Roshani, A., Shayegan, J., & Babaee, A. (2012). Methane production from anaerobic co-digestion of poultry manure. *Journal of Environmental Studies, 38*(62), 22–24.

Rostagno, H. S., Albino, L. F. T., Donzele, J. L., Gomes, P. C., Oliveira, R. F., Lopes, D. C., Ferreira, A. S., Barreto, S. L. T.,

& Euclides, R. F. (2011). *Tabelas brasileiras para aves e suínos: composição de alimentos e exigências nutricionais de aves e suínos* (3ªedição ed.p. 252). Viçosa: UFV.

Santos, T.M.B. dos (2001). *Balanço energético e adequação do uso de biodigestores em galpões de frangos de corte.* Tese (Doutorado em Produção Animal) - Faculdade de Ciências Agrárias e Veterinárias, Universidade Estadual Paulista, Jaboticabal, 167p.

Silva, V. S., Voss, D., Coldebella, A., Bosetti, N., & Avila, V. S. (2007). Efeito de Tratamentos Sobre a Carga Bacteriana de Cama de Aviário Reutilizada em Frangos de Corte. *Comunicado Técnico, 467,* 4.

Suzuki, A. B. P., Feiden, A., Ernandes, D. M., Martins, G. I., & Faria, R. A. P. (2012). Utilização de manipueira juntamente com sólidos da cama de aviário em biodigestores para geração de biogás. *Ambiência - Revista do Setor de Ciências Agrárias e Ambientais, 8*(3), 809–820.

Tessaro, A. B., Tessaro, A. A., Cantão, M. P., & Mendes, A. A. (2015). Potencial energético da cama de aviário produzida na Região Sudoeste do Paraná e utilizada como substrato para a produção de biogás. *Revista em Agronegócio e Meio Ambiente, 8*(2), 357–377.

Wohlgemut, O. (2009). *Co-digestion of hog manure with glycerin to boost biogás and methane production.* Dissertação (Mestrado em Ciências), Faculdade de Estudos de Pós-Graduação, Universidade de Manitoba, Winnipeg, 90 p.

Xavier, C. A. N., & Lucas Junior, J. (2010). Parâmetros de dimensionamento para biodigestores batelada operados com dejetos de vacas leiteiras com e sem uso de inóculo. *Engenharia Agrícola, 30*(2), 212–223.

Zilotti, H. A. R. (2012). *Potencial de produção de biogás em uma estação de tratamento de esgoto de Cascavel para a geração de energia elétrica.* Dissertação (mestrado) - Cascavel, PR: UNIOESTE, 52 p.