

Full Length Research Paper

Anaerobic biodigestion in Indian batch-type biodigester, using poultry litter as substrate for the production of biogas

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Poultry litter is being produced in large quantities due to the accelerating growth of the broiler industry in recent years, which implies a greater energy dependence and cost of these systems. This study seeks to evaluate the capacity of an anaerobic batch biodigester to produce biogas from poultry litter. To this end, three tests were conducted: 1st: Poultry Litter + Water - [PL + W]1, 2nd: Poultry Litter + Water - [PL + W]2. 3rd: Description of treatments: Period of implementation: September 2013 to March 2014. T1 - Poultry Litter + Biofertilizer + Water, (PL+B+W) - of which: 28.25 kg of water + 28.25 kg of biofertilizer + 3.5 kg of litter. T2 - Poultry Litter + Biofertilizer (PL+B) - of which: 56.5 kg of biofertilizer + 3.5 kg of litter. T3 - Poultry Litter + Water (PL+W) - of which: 56.5 kg of water + 3.5 kg of litter. The results showed that the anaerobic biodigestion process was efficient in producing biogas in test 3, and that the three evaluated treatments produced different volumes of biogas, with the best treatment being the one that used a poultry litter associated with biofertilizer (T2 - PL+B), suggesting that the biofertilizer acted as a system that enabled the process, followed by the treatment that used poultry litter associated with biofertilizer and water (T1 - PL+B+W). The lowest values were observed in the third treatment, which used a mixture of poultry litter and water (T3 - PL+W).

Key words: Biogas, poultry, waste, biomass.

INTRODUCTION

The Brazilian broiler industry had an output of about 8 million tons of meat in 2014, which corresponds to 16.4%

of world production. With this, exports reached 1.8 million tons, increasing Brazil's share to almost a third of total

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foreign trade, with emphasis on the quantity of shipped cuts. The consumption of 35.1 kg of poultry per inhabitant per year is among the highest observed in developed countries (Anualpec, 2014).

As in other agricultural activities, broiler production generates a very large amount of waste (poultry litter and dead birds), which, if well managed, can not only become an important source of income and add value to the activity, but also turn into a model of sustainable production, which is increasingly becoming a market demand. To this end, a system will need to be adopted for the treatment of this waste in order to avoid possible contamination of the environment (Giroto and Ávila, 2003; Güngör-Demirci and Demirer, 2004; Angonese et al., 2006).

The biogas produced from the biodigestion of poultry litter can be used to heat the chicks by using equipment that burns the biogas and, consequently, produces heat, which is essential for the survival of these animals in the first two weeks of life. It can also replace electrical power in, for example: Lighting (lamps); water heating (for the sterilization of equipment, washing facilities, showers, etc.); stoves; grain milling, etc. (Silva et al., 2005).

Anaerobic biodigestion is a treatment system in which biomass is degraded to form methane (CH_4) and carbon dioxide (CO_2) in anaerobic conditions (Demirer and Chen, 2005). The methane produced can be used as a source of energy, replacing fossil fuels and thus adding value to production and decreasing the emission of carbon dioxide (Silva et al., 2005; Orrico et al., 2007; Santos et al., 2007). The advantages of the process are: Reduction of pathogenic micro-organisms and odors; occupation of a small physical space for the treatment of waste; and the easy control of the released gases or effluents from the process. In anaerobic processes, or in anaerobic biodigestion systems, the degradation of organic matter involves the activity of optional and required prokaryotic micro-organisms, whose species belong to the group of hydrolytic-fermentative bacteria, acetogenic bacteria that produce hydrogen and methanogenic archaea (Côté et al., 2006; Alvarez et al., 2006).

For the digestion of biomass from animal waste to be economically attractive, the physical and chemical properties of the waste must be compatible with the considered biodigester design. Thus, it is important to understand the principles of operation of most biodigestors to help in the selection and planning of the treatment model based on anaerobic biodigestion. The importance of this knowledge is related to the elevated production of methane and the rates of biogas production, which are dependent on the relative contribution of the waste and biodigester costs in the final costs of the biogas (Santos, 2001; Nishimura, 2009).

In environmental terms, the use of biogas represents an overall improvement in process efficiency. Since biogas is usually a residue of the decomposition process of organic matter, the benefits attributed to it are linked to

its intended use. The two main alternatives for the energetic exploitation of biogas are the conversion to electrical energy and its thermal use (Fisher et al., 1979; Alvarez et al., 2006).

Biogas emissions into the atmosphere have negative impacts on the environment and society since it contributes to the further intensification of the greenhouse effect through methane emissions into the atmosphere. In addition, it causes unpleasant odors through the emission of putrid and toxic gases due to the concentration of sulfur compounds in the gas, in addition to a small, but not negligible presence of bacteria responsible for the anaerobic digestion of organic waste (Costa, 2006). When converted into electrical energy, the advantages of the use of biogas are related to the avoided emissions through the generation of electrical power using a renewable source, the efficiency of conversion systems and the reduction of dependence on energy from the network, reducing local overload (Oliveira and Ribeiro, 2006).

Biogas has several applications in energy. Although its main application is as a fuel in an internal gas combustion engine that powers an electric generator, it can be directed to other purposes. Among these other applications, one could highlight the use of biogas in gas-fired heaters for the production of hot water for environmental conditioning or heat processing, in the drying of grain in rural properties, in the drying of sludge at waste water treatment stations, in the burning in boilers, in the heating of pig farms, in vehicular use, and in gas lighting, among others (Pecora, 2006). Biogas is composed, for the most part, by two gases: methane, which is its energy constituent, and carbon dioxide, since about 95% of the volume is composed of these two gases (Silva et al., 2005).

The harnessing of energy from biogas does not only contribute to the preservation of the environment, it also brings benefits to society by promoting the use or reuse of "disposable" and/or low-cost resources, by reducing our dependence on fossil fuels through a greater variety in fuels, by enabling the generation of decentralized power, by increasing the supply of power, by enabling the generation of local jobs, by reducing odors and toxins in the air, by reducing the emission of pollutants through the substitution of fossil fuels, by helping in making Landfill and Waste Treatment plants economically viable, by optimizing the use of local resources, and by increasing the viability of basic sanitation in the country, enabling the technological development of Sanitation and Energy companies (Ross et al., 1996). In this context, this study evaluated the capacity of an anaerobic batch biodigester to produce biogas from poultry litter.

MATERIALS AND METHODS

This study followed the methodology described in Caetano (1991) and adapted it to this work, in which a batch-type biodigester with a

Table 1. Yield at every 7 days (m³/kg of biomass) of biogas for the batch-type biodigester filled with poultry litter and with the addition of water.

RTD*	[PL+W]1	[PL+W]2
0	0	0
7	0.0123	0.0093
14	0.0172	0.0134
21	0.0234	0.0212

*Retention time in days.

capacity of 60 L was used, filled one time for each one of the experiments, keeping it in fermentation for the desired period, with the material being discharged after the end of the effective period of biogas production. The biodigester was developed by LACTEC - Institute of Technology for the Development of Paraná - Curitiba - Paraná - Brazil, and was intended for teaching purposes. It was adapted for the application of the methodology of this study.

The poultry litter was obtained from a conventional chicken production barn of 1,200 m² installed in a rural property located at the geographic coordinates 25° 44' 06" S and 53° 04' 52" W in the municipality of Dois Vizinhos - Paraná - Brazil. Three batches of litter from chickens reared for 40 days, on average, were used.

The tests were carried out between the months of May 2012 and March of 2014, with a minimum temperature of 15°C and a maximum of 37°C, according to Simepar. During this period, the following tests were performed: 1st test: Poultry Litter + Water - [PL + W]1. Implementation period: May to September to November 2012. 30 Kg PL + 30 kg W. 2nd test: Poultry Litter + Water - [PL + W]2. Period of implementation: October 2012 to March 2013. 15 kg PL + 45 kg W. 3rd test: Description of treatments: Period of implementation: September 2013 to March 2014. T1 - Poultry Litter + Biofertilizer + Water, (PL+B+W) - of which: 28.25 kg of water + 28.25 kg of biofertilizer + 3.5 kg of litter. T2 - Poultry Litter + Biofertilizer (PL+B) - of which: 56.5 of biofertilizer + 3.5 kg of litter. T3 - Poultry Litter + Water (PL+W) - of which: 56.5 of water + 3.5 kg of litter.

The experiments were carried out for a period of 56 days and the volumes of biogas produced were observed by means of a piston every 7 days, recording the values and quantifying the average biogas produced.

The potential for biogas yields was calculated using the total production data and the quantities of material *in natura*. The values were expressed in cubic meters of biogas per kg of substrate used (m³/kg).

RESULTS AND DISCUSSION

The obtained results showed that the two models sized and characterized as tests [PL+W]1 and [PL+W]2 proved to be unviable from the point of view of the biogas production process. This data can be seen in Table 1.

One can observe through these tests that anaerobic digestion proved to be slow at the beginning for the production of biogas, thus presenting a lag phase that was too long, exceeding 15 days. These two batches were therefore shut down after 21 days, with yields of 0.0234 and 0.0212 m³ of biogas with the treatments [PL+W]1 and [PL+W]2, respectively. It should be noted

that these trials only had two repetitions, which means no statistical program could be applied to them.

The test characterized as number 3 proved viable and capable of being used as a model in the use of biomass that is basically made up of poultry litter. The discussion of this work is therefore based on this trial, in which three characteristic treatments were adopted. The average potential of biogas yields in trial 3 are presented in Table 2, in m³ of biogas per kg of dry matter.

According to the results obtained in Table 2 and shown in Figure 1, higher yields of biogas can be observed when the digester is filled with poultry litter + biofertilizer when compared to digesters filled with poultry litter + biofertilizer + water and poultry litter + water. The mixture that produced the least biogas was the mixture poultry litter + water mixture (T-3). This behavior was observed during the entire process.

When the means obtained in the three treatments are compared, one can observe that treatment T2 proved to be superior in the production of biogas, at the level of 5% through the Tukey test, compared to the two other treatment methods (T1 and T3) for the period under evaluation, since the mean values were 0.4106±0.0128, 0.3264±0.0243 and 0.0804±0.0023 m³ of biogas per kg of biomass added to the process for each one of the assessments, respectively. The data relating to the volumetric biogas yields are presented in Figures 1 and 2.

Considering the results obtained with the treatments, one can see that the treatment PL+B produced a greater quantity of biogas during the 56 days and showed a peak of biogas production at 42 days with a drop in production after 49 days, a drop in production that lasted until the end of the process. At the end of the process this treatment presented a kinetics equal to $y = -0.0004x^2 + 0.0312x - 0.159$ with a correlation coefficient $R^2 = 0.9641$.

It should be pointed out that the time variable was important in this analysis, since the volumes of produced biogas increased over time. This becomes important because an understanding of the range with the highest biogas yields in a given time period is crucial for the dimensioning of the utilization of the generated biogas.

One can see that the other two treatments showed the same behavior, but with production starting a little later and with the treatment PL+B+W only reaching the volumes recorded in the treatment PL+B after around 14 days. As such, the kinetics regarding treatments PL+B+W and PL+W, which represent the behavior of each treatment and are expressed through polygonal adjustments curves, were $y = -0.0004x^2 + 0.0312x - 0.159$ with $R^2 = 0.9641$ and $y = -0.0002x^2 + 0.0142x - 0.0904$ with $R^2 = 0.7944$, respectively. The treatment that produced the lowest amount of biogas was PL+W.

The determination coefficient R^2 is the percentage of the variation in the dependent variable explained by the independent variable. It should be clarified that the closer R^2 is to 1.0, the lower the difference between the actual

Table 2. Yield at every 7 days (m³/kg of biomass) of biogas for the batch-type biodigester filled with poultry litter and diluted with biofertilizer and water.

RTD ¹	PL+B+W	PL+B	PL+W
7	0.0482	0.1242	0.0161
14	0.1684	0.1875	0.0183
21	0.3682	0.3745	0.1285
28	0.3823	0.5289	0.1546
35	0.4230	0.5529	0.1573
42	0.4554	0.5593	0.0862
49	0.4420	0.5293	0.0558
56	0.3251	0.4286	0.0265
Mean ²	0,3264±0,0243A	0,4106±0,0128B	0.0804±0.0023C
Total for the period ³	2,611	3,284	0,643

¹ Retention time in days. ²Means followed by the same letter horizontally do not differ by Tukey's Test at the level of significance of 5%. ³ m³ of biogas/kg of biomass.

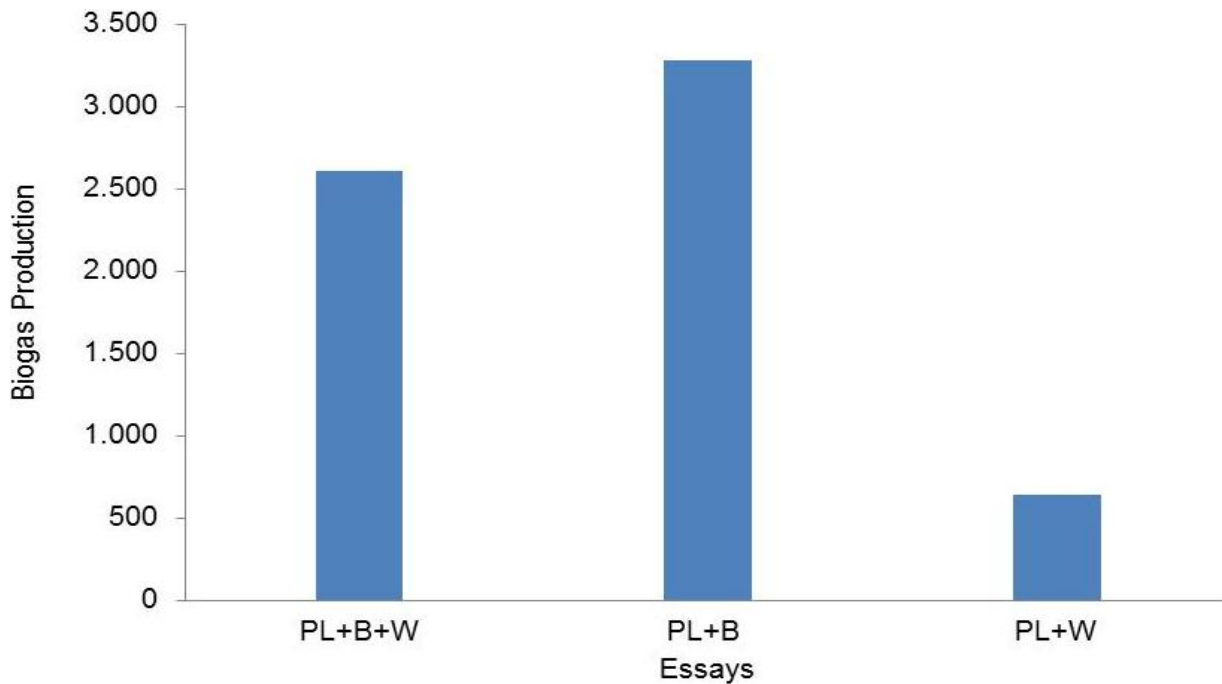


Figure 1. Cumulative biogas yields for each treatment during the process.

data and the points on the behavior fitting curve or the kinetic behavior of the variable.

In a general analysis regarding the total values for biogas yields, one can see that the volumes of the three treatments reached 2,611.20 + 3,284.80 + 0643.20 m³ for PL+B+W, PL+B and PL+W, respectively, totaling approximately 6,540 m³.

When calculating the percentages of each of the treatments in relation to the total volume of biogas produced in the three experiments, one sees that the treatment PL+B+W produced 40%, the treatment PL+B

produced 50%, and treatment PL+W produced 10% of the biogas.

The values point to the influence of the period on the yield potential for biogas found in this experiment and is similar to the studies by Ortolani et al. (1991) who found highly significant differences for the biogas yield potential means between three tests.

Through the visualization of the behavior in the fitting curves related to the volumes of biogas of the treatments, it is possible to plan a system that meets a certain energy demand. The anticipation of peak biogas production in

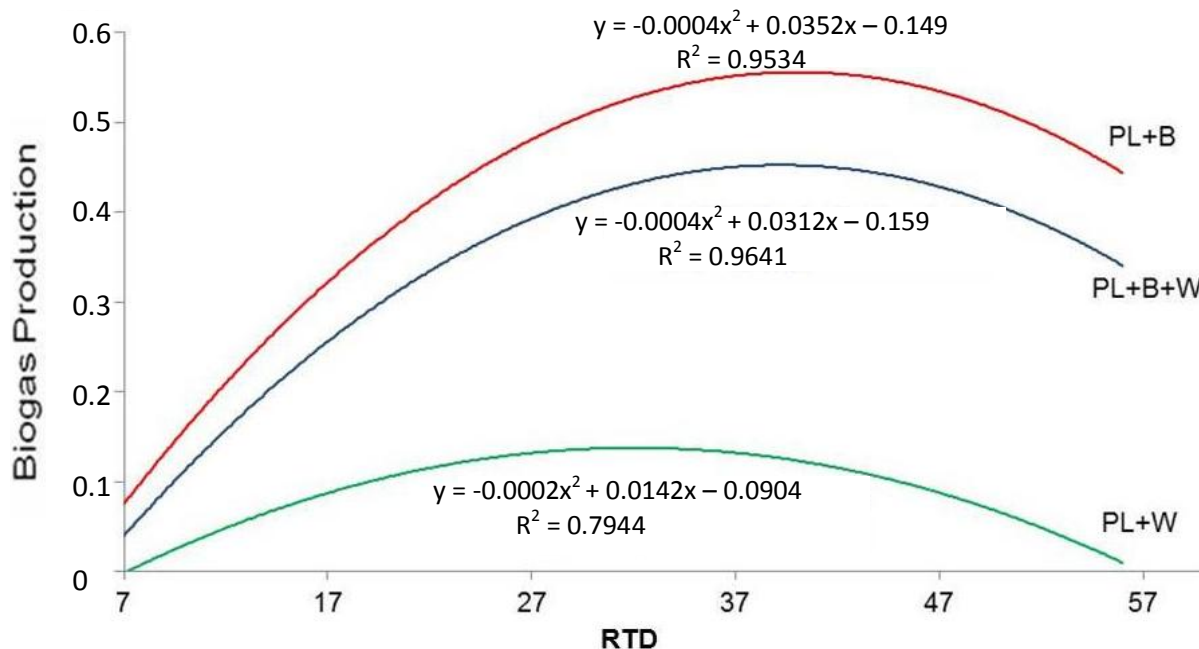


Figure 2. Kinetics of the second-degree polynomial behavior of the systems during the process. Equations are followed by the determination coefficient for each treatment R^2 .

treatment PL+B can be clearly seen in Table 2. This is probably due to the addition of biofertilizer in association with the poultry litter, accelerating the stages of anaerobic biodigestion and increasing the speed of biogas production.

In order to plan the production of biogas for power generation, the areas with the most expressive biogas production in the curves should be considered so as to prevent a lack of energy production when the demand for it is high. For example, proper planning should be used when using anaerobic biodigestion of poultry litter for the production of biogas, taking into account the stages of higher biogas production in relation to the batches of poultry, thus increasing the viability of the biodigester and the generation of energy.

Under these conditions, it is clear that the best treatment was the one that used poultry litter associated with biofertilizer, followed by the treatment that used poultry litter associated with biofertilizer and water. The lowest values were observed in the third treatment, which used a mixture of poultry litter and water.

It should be noted that the addition of poultry litter to anaerobic digestion reduces the conversion efficiency of other bird waste products into biogas. Some authors, however, have reported high potential for the production of biogas. In this respect, Webb and Hawkes (1985) operated a biodigester with poultry litter (manure + sawdust) and observed a production of biogas which yielded 0.245 to 0.372 m³ of biogas per kg of added biomass. These values are similar to those obtained in this work.

Magbanua Junior et al. (2001) tested anaerobic digestion using poultry waste supplemented with biofertilizers from pigs and cattle in various proportions. They concluded that the waste that received the biofertilizers from pigs, cattle and birds together produced more biogas compared with the waste (poultry litter) from birds alone. These data are in alignment with the data obtained here, which showed the same behavior. This behavior is based on the use of micro-organisms present in these different materials, which act as inoculants that activate the system more rapidly.

It should be emphasized that the biogas is formed by a mixture of gases produced during the fermentation process. The main gaseous components of the biogas are methane and carbon dioxide. Methane is an excellent fuel and the greater the methane content, the purer the biogas (Magalhães, 1986; Santos, 1992; Sanchez et al., 2001).

Given that poultry litter is produced at time intervals, that is, its availability is not continuous due to the mode of production, and considering its physical and chemical characteristics, such as a high solid content, low moisture and particle size, the ideal biodigester for its anaerobic digestion is a batch-type biodigester, which may be managed in the battery form or sequentially. The disadvantage of the management in battery form is related to the speed of fermentation of the litter, which is slow, making the harnessing of the biogas more difficult (Magellan, 1986; Santos, 2001).

It may be necessary for the poultry litter to undergo a pre-treatment before being added to the biodigester, the

most recommended would be a grinding step since the wood shavings may be too large and this can reduce the efficiency of the micro-organisms. Looking at the moisture content of the litter, it is necessary to add water to decrease the solid content and dilute its content (Santos, 1992, 2001).

The function of the inoculum is to speed up the process, mainly due to the high contents of cellulose and lignin, materials that are hard to digest and that are present in the litter. The inoculum may consist of already biofertilized manure from cattle, poultry, pigs, etc., which contains a large microbial flora of acetogenic and methanogenic bacteria that are fundamental for digestion (Santos, 1992; Steil, 2001; Zhu et al., 2004).

Conclusion

The anaerobic biodigestion process was efficient in producing biogas in test 3, and the three evaluated treatments produced different volumes of biogas, with the best treatment being the one that used poultry litter associated with biofertilizer (T2 - PL+B), suggesting that the biofertilizer acted as a system that enabled the process, followed by the treatment that used poultry litter associated with biofertilizer and water (T1 - PL + B + W). The lowest values were observed in the third treatment, which used a mixture of poultry litter and water (T3 - PL + W).

Conflicts of Interest

The authors declare there are no ethical, publishing of financial conflicts of interest regarding the data of this study.

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