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Energy potential of poultry litter for the production of biogas

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Poultry litter, a waste product from broiler farming, can be transformed into biogas when subjected to anaerobic biodigestion. This study proposes to evaluate the potential of poultry litter for energy generation in order to meet the energy demands of the poultry production chain in the southwest region of the state of Parana - Brazil, when used as a substrate for the production of biogas. Based on the volumes of biogas produced, the viability of biogas production was determined. The results reveal that the anaerobic biodigestion process was efficient in biogas production. It was also possible to determine that the use of poultry litter in biogas production is viable, since the raw material for its production is available in the entire southwest region of Paraná. The presentation of the three treatments proved to be important, because in the three systems the production of significant quantities of biogas was possible, constituting a potential replacement for non-renewable fuel sources derived from petroleum.

Key words: Biogas, energy, waste, biomass.

INTRODUCTION

As in any economic activity, the production chain in broiler farming generates industrial and rural sub-products that have environmental impacts. The inappropriate management of poultry waste affects the rivers and groundwater supplying both rural and urban environments, potentially causing ecological imbalances, spreading pathogens and contaminating drinking water with ammonia, nitrates, phosphates and other toxic elements. Mitigating these risks is increasingly becoming a requirement for poultry farmers (Almeida and Navarro, 1997).

Since its activities involve high energy consumption

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and waste production, the broiler industry can convert its waste into energy - as happens in the sugar-ethanol industry with the sugarcane vinasse and bagasse. The sub-product of poultry farming, the "poultry litter", is of extreme importance in the poultry production chain in the southwest region of Paraná - Brazil. Poultry litter is made up of a mixture of excretions (feces and urine) with the substrate used to receive and absorb the moisture from these excretions (wood shavings, sawdust, straws from cereals, chopped hay, etc.), feathers and skin flakes from the birds, and food remnants that fell from the feeders. The purpose of the poultry litter is to avoid direct contact of the bird with the floor, to serve as a substrate for the absorption of water and incorporation of feces and feathers, and to contribute to the reduction of temperature fluctuations in the shed. The poultry litter has a significant energy potential that can be made available as biogas through anaerobic biodigestion, contributing to the increased economic attractiveness of the activity (Rodrigues, 1997; Bellaver and Palhares, 2003).

Poultry litter is being produced in large quantities due to the accelerating growth of the broiler industry in recent years, based mainly on the development of shed technology, which implies a greater energy dependence and cost of these systems (Rocha et al., 2008).

In addition to the environmental impacts, the energy issue is another challenge of strategic importance to the world economy, one that directly affects the poultry production chain in the southwest region of Paraná - Brazil. In the poultry production chain, energy costs are highly significant, highlighting the great demand for energy in both the slaughter and processing units and in the chicken farms themselves (Fiorentin, 2005; Uba, 2014).

The biogas produced in bio-digesters consists essentially of 60 to 70% methane (CH_4) and 30 to 40% carbon dioxide (CO_2), in addition to traces of O_2,N_2, H_2S, etc., that for organic waste. In the biodigestion of fatty substances, the gas may contain up to 75% methane, and methane is the biogas component that has fuel properties, serving, for example, to power engines with a quite similar performance as those powered by natural gas or liquid fuels. The difference lies in the economic and environmental aspects, given that biogas is one of the by-products of the processing of organic waste, producing less solid sulfur-based waste (Lusk, 1998; Jonsson, 2004; Kapdi et al., 2005).

Methane has a calorific value of 9,100 kcal/m^3 at 15.5°C and 1 atm, its flammability occurs at mixtures of 5 to 15% with air. Biogas, on the other hand, has a calorific value ranging from 4,800 to 6,900 kcal/m^3 due to the presence of other gases than methane. In terms of energy equivalence, 1.33 to 1.87 and 1.5 to 2.1m^3 of biogas is equivalent to 1 L of gasoline and diesel, respectively. In comparison, natural gas is made up for 88% of methane (Kirb and Biljetina, 1987; Ross et al., 1996; Ferrer et al., 2004; Epe, 2007).

The potential for harnessing the energy from biogas depends, above all, on the economic viability of integrated projects for the production, collection and use of biogas. To assess the economic viability of projects, first the costs of investment, operation and maintenance for each specific project, in addition to the revenue obtained through the sale of energy or cost savings, need to be considered. In this case, the final use of the biogas is the determining factor, since all the economic parameters depend on the use of the fuel, be it for the production of heat, electricity, co-generation or simply for the sale of gas (Murphy et al., 2004; Persson et al., 2006).

Since the proposition is to provide a treatment system that has energy self-sufficiency in poultry farming as main advantage, an understanding of the energy consumption in this activity is essential for the proper planning of the treatment system so as to detect if it will be able to achieve self-sufficiency or simply contribute to a decline in the consumption of external power (Broughton et al., 1998).

As such, this work seeks to evaluate the energy potential of the poultry litter produced in the southwest region of Paraná used as substrate for the production of biogas.

MATERIALS AND METHODS

This study followed the methodology described in Caetano (1991) and adapted it to this work, in which the employed biodigester was of the Batch type with capacity of 60 L, which was filled one time in each 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 m^2 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 substrate used to line the floor was *pinus* sawdust and the thickness of the initial litter was approximately 12 cm, a volume that increased with the placing of new substrates on top of the others for subsequent production cycles. For the purposes of the experiment, however, the litters of the third batch were used. One (01) Indian batch-type biodigester was filled. 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 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.

Biogas production was quantified according to the observed accumulation in production, with monitoring being carried out daily and a reading being taken at least every 07 days.

The reading was taken by measuring the vertical displacement of the gasometer through a ruler fixed to the biodigester, located next to the bell. After each reading, the gas meters were zeroed using the biogas discharge valve.

The data was submitted to analysis of variance (ANOVA), and the means and standard deviations were calculated, through which it was possible to compare one data set at the same time. The means obtained for the three different treatments were compared by Tukey's test. A significance level of 5% ($P< 0.05$) was used for all analyses.

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. 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. According to the data obtained, 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). The average potential of biogas yields in trial 3 are presented in Table 1, in m^3 of biogas per kg of dry matter.

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 + 643.20 m^3 for PL+B+W, PL+B and PL+W, respectively, totaling approximately 6,540 m^3.

When calculating the percentages of each of the three treatments of the 3rd trial 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. So considering that the three treatments evaluated in this study showed production of biogas, with treatment T2 being the most viable, producing a volume of biogas in the period of 3,284.80 m^3/kg of poultry litter biomass, it is possible to determine the energy capacity of the poultry litter produced in the southwest region of Paraná - Brazil.

Considering that the three scaled and monitored experiments produced values varying between 0.643 to 3.284 m^3/kg of poultry litter, the following calculations will use the lowest values, taking into account that several variables can interfere with the biogas production process. To perform this calculation, the methodology described by Mahadevaswamy and Venkataraman (1986) was taken into account, where: *CPB= Mscf 0.643* m^3*of biogas/kg of dry poultry litter matter.*

As such, a CPB *(Capacity for Producing Biogas)* = 0.643 m^3/kg of poultry litter for 51,219,177 kg of poultry litter in the 38 municipalities in the southwest region of Paraná / year (Amsop, 2014), will potentially yield a volume of 32,933,931 m^3/year in biogas. It should be noted that this is the lowest estimated value, considering only the lowest values of the performed trials.

If we were to consider the three treatments, the volume would be much higher, since the production of biogas in treatment 1 and 2 were significantly higher than those in treatment 3. These data can be seen in Table 2.

Taking into consideration the values presented in Table 2, and using the calorific value of the produced biogas, one can estimate the savings in the use of other fuels by using the equivalence of 0.61 L of gasoline, 0.58 L of kerosene, 0.55 L diesel oil, 0.45 kg of cooking gas, 1.5 kilos of wood, 0.79 L of hydrated ethanol and 1.43 kWh of electricity for each m^3 of biogas (Ferraz and Mariel, 1980; Sganzerla, 1983; Nogueira, 1986; Santos, 2000). These data can be seen in Table 3.

The data presented in Table 3 show the viability of using poultry litter for biogas production, since the raw material for its production is available in the entire southwest region of Paraná. The presentation of the three treatments proved to be important, because in the three systems the production of significant quantities of biogas was possible, constituting a potential replacement for non-renewable fuel sources derived from petroleum.

One can observe that it is possible to save up to 117,624,599 kWh of electrical energy; 132,880,509 liters of hydrated ethanol; 252,304,765 cubic meters of firewood; 75,691,429 kg of cooking gas, considering that each gas canister has a capacity of 13 kg of gas, this would imply savings of 5,822.41 gas bottles. In addition, the savings would be equivalent to 92,511,747 liters of diesel oil; 97,557,842 L of kerosene and 102,603,937 L of gasoline.

It is important to stress that there are several technologies for the conversion of biogas into other forms of energy. When there is a mixture of air and biogas in a process called controlled combustion, the chemical energy contained in the biogas molecules is converted into mechanical energy. The mechanical energy is converted into electrical energy through an alternator (Synchronous Generator).

Cogeneration (combined generation of heat and power) and trigeneration (combined generation of heat, electricity and cold) are important alternatives for the use of energy, since these conversion processes allow for the reuse of residual thermal energy, increasing energy efficiency. Generating electrical energy from biogas has advantages

Table 1. Yield at every 7 days (m^3/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. * Means followed by the same letter horizontally do not differ by Tukey's Test at the level of significance of 5%. [3] m^3 of biogas/kg of biomass.

Table 2. Biogas production capacity of the southwest region.

Treatment	Total volumes (m^3/year)
T1	136,344,271
T2	168,203,177
T3	32,933,931

Table 3. Equivalent use of biogas in relation to other sources.

Fuel type	T1 - PL+B+W 136,344,271 m^3/year	T2 - PL+B 168,203,177 m^3/year	T3 - PL+W 32,933,931 m^3/year
Gasoline (L)	83,170,005	102,603,937	20,089,697
Kerosene (L)	79,079,677	97,557,842	19,101,679
Diesel Oil (L)	74,989,349	92,511,747	18,113,662
Cooking Gas (kg)	61,354,921	75,691,429	14,820,268
Wood (m^3)	204,516,406	252,304,765	49,400,896
Hydrated Ethanol (L)	107,711,974	132,880,509	26,017,805
Electricity (kWh)	95,345,644	117,624,599	23,030,720

from strategic, economic, environmental and social perspectives. Among these advantages, the following could be highlighted; (i) decentralized generation, which avoids investment in transmission due the proximity with charging points; (ii) use of cheap fuel (process waste) that is available on site; (iii) (renewable) biomass energy, low emission of pollutants, contributing to the mitigation of the greenhouse effect; and (iv) potential use of resources that were previously reserved for the payment of electrical power utilities, in actions for the social development of the region. The main technologies to convert biogas energy into electricity are gas turbines and micro-turbines.

It should be noted that according to Silva et al. (2005), biogas is typically stored at low pressure and can be used in heat generation equipment, such as stoves, furnaces, thermal radiation heaters, etc. A substantial part of the equipment using biogas is still empirically adapted, but with the increase in the number of biodigesters, driven by projects related to the clean development mechanism (CDM), a rapid evolution in the quality of the burners and engines offered on the market is expected.

One should consider that the increasing technological sophistication and industrial activity in modern society has become possible thanks to the various forms of energy available. The dependence of the agricultural sector on fossil fuels is a question that deserves to be discussed. Fuel consumption from this source represents approximately 60.5% of the energy consumed in the agricultural sector. Their high price, future shortage and the environmental contamination caused by their use, are issues of economic and environmental importance.

Another aspect to be considered is the wasted energy when agro-industrial waste is not harnessed, in addition to the environmental pollution caused by its uncontrolled disposal in these environment. One cannot fail to mention the opportunities that the responsibilities for reducing greenhouse gas emissions taken up by countries through the signing of the Kyoto Protocol and the Clean Development Mechanism, offer for the growth of developing countries.

Conclusion

The obtained results reveal the viability of using poultry litter for biogas production, since the raw material for its production is available in the entire southwest region of Paraná. The presentation of the three treatments proved to be important, because in the three systems the production of significant quantities of biogas was possible, constituting a potential replacement for non-renewable fuel sources derived from petroleum. The biogas yield estimates from poultry litter revealed that a large energy potential is being left unused in the broiler production chain of the southwest region of Paraná - Brazil. The energy from biogas can make the activity more competitive in the region, thereby compensating for the difficulty in obtaining the main inputs for the activity (corn and soybeans). The harnessing of the poultry litter will result in gains of a: (i) economic nature: the energy generated decreases the cost of production with the possibility of selling the energy to the utility; (ii) environmental nature: the treatment of bird waste through anaerobic biodigestion prevents the contamination of rivers and springs with the toxic substances existing in the poultry litter. Additionally, the use of biogas avoids the emission of methane (CH_4) into the atmosphere, contributing to the mitigation of the greenhouse effect; and (iii) social nature: Resources that were previously intended for the payment of energy consumed in the activity, can now be redirected to other purposes, improving the quality of life of people who are directly connected with the activity and also increasing the circulation of money in the region, stimulating sectors of the economy, such as trade.

The study also showed that the electrical power available from biogas generated from poultry litter across the production chain represents around 117,624,599 kWh of electrical power.

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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