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Original article

Power generation potential in posture aviaries in Brazil in the context of a circular economy

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ABSTRACT

This work investigated the composition and volume of biogas produced from the anaerobic biodigestion of laying hen manure from poultry farms in Itanhandu-MG, Brazil. We then used this gas to generate energy. The experiments characterized the biogas quantity and composition at different temperatures, with total solid contents of 6%, 9%, and 12% of total solids (TS). The biogas production and power calculation were compared to the proposed methods by the Environmental Company of the State of São Paulo (CETESB, as acronym in Portuguese) in the effluent software 1.0 (CETESB, 2006). In addition, after hydraulic detention time (HRT) treatment, we compared the parameters related to the content of the organic matter present in substrates and effluent to verify the degree of degradability. The biogas production rates were assessed as volatile solids (VS) basis as $0.72\ m^3\ kg_{VS}^{-1}$ (6%), $0.42\ m^3\ kg_{VS}^{-1}$ (9%) and $0.34\ m^3\ kg_{VS}^{-1}$ (12%). Regarding the 6% of TS, the maximum, average and minimum values of CH_4 were 70.9%, 62.5% and 49.2%; the 9% values were 68.8%, 62.9% and 43.9%; the 12% values were 77.6%, 72.2% and 66.2%, respectively. If all Brazilian poultry farms used manure to generate energy, it would be possible to generate 1.277 TW h $year^{-1}$.

Introduction

In agribusiness, there are many studies related to biogas production from the manure of swine, cattle and poultry industry as shown by Aires and Lucas Júnior [1], Hansen et al. [26], and Gaspar et al. [24].

In accordance with the municipal livestock survey of the Brazilian Institute of Geography and Statistics, IBGE [47], approximately 221.8 million laying hens were housed in Brazil. The southeast region is the largest producer. In addition, according to the IBGE [47], 2.74 billion dozen eggs were produced in Brazil from 129.42 million birds. The municipal livestock survey of IBGE [47] found the ten cities that stood out in terms of egg production. The municipality of Itanhandu-MG, Brazil had 4,080,000 birds in 2013. Mendes [30] classified the properties of poultry farms in terms of number of animals based on the Brazilian Institute of Geography and Statists (IBGE, as acronym in Portuguese) regarding their number of fowls varying between more than 500,000 units to 10 units.

According to Messenger/ISWA [31], there are significant opportunities to exploit, capture, and use secondary raw materials. Organic materials (OM) are generally renewable and play a huge role in the circular economy. They can produce low-value products (e.g., soil amendments), but also medium-value products such as biogas. Therefore, the goal of this study was to make this segment more sustainable and meet the Brazilian National Policy on Solid Waste (NPSW) recommendations as described by Law nº. 12,305/2010 [9] and regulated by Decree nº. 7404 [10]. Barros et al. [6] evaluated energy generation from landfill biogas via thermal biogas plants, and their results revealed that this kind of energy would be economically viable only in cities over 200,000

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people. Such values represent only a small percentage (0.00020% in 2010 and 0.44496–0.81042% in 2030) of the projected energy generation from residual fuels in accordance with the National Energy Balance plan created by the Mines and Energy Ministry of Brazil/MME/EPE [12]. Santos et al. [40] analyzed the economic viability and energetic potential of energy generation by biogas from anaerobic wastewater treatment plants, and their results indicated economic viability only for cities with a population greater than 300,000. In these situations, the energy potential could supply nearly 0.25% of the residual fuels according to the Brazilian Ministry of Science and Technology.

Several authors have described anaerobic biodigestion as a sequential process that occurs in a microorganism's symbiosis [44,38,16,5]. The optimum temperature is 35 °C (mesophilic range), but 50–60 °C (thermophilic range) produces more biogas [42,28,50,16]. Methane production was calculated by Sobel and Muck [42] by comparing among different reactors and according to these authors, energy production via dairy cow manure is mesophilic under anaerobic reactions. The methane yield (Y) is on average $0.152\ m^3 kg^{-1}_{VS_{added}}$ and ranged between 0.091 and $0.207\ m^3 kg^{-1}_{VS_{added}}$. The maximum average rate of biogas production found by Dalkilic and Ugurlu [20] was 554 ml $g^{-1}_{VS_{added}}$, with a supply 2.2 VS $L^{-1}\ d^{-1}$ (2.3% VS–3.8% TS) for the system of the chicken manure biodigestion; the average methane content from biogas was 74%. In order to presents some specifies of poultry posture manure some studies are presented, because of its differences from other animal's manure, even from chicken manure as well as due to the fact that there are not enough studies regarding this type of waste.

This work proposes to use waste from poultry farms (anaerobic biodigestion of poultry manure) for biogas generation and its conversion into electrical energy through generators use. Through experiments and simulations, this study seeks a technical and economic approach to energy use from the residual biomass of laying hens in Itanhandu-MG.

The poultry posture manure

According to Augusto [3,4], the manure from the poultry (Table 1) is richer in nutrients than other domestic animals. It contains a mixture of solid and liquid waste. It comes from poultry raised on concentrated feed and has high levels of nitrogen, phosphorus and potassium. Chicken manure has two to three times more nutrients than mammalian manure [3,4]. The high nitrogen content in hen manure can damage plants if not properly treated before use as a fertilizer, but it is a very valuable material from a biological point of view. Poultry manure contains organic matter and dissolved particles such as polysaccharides, lipids, proteins, volatile fatty acids, and high number of inorganic components. Table 2 presents the biogas composition.

Moreng and Avens [33] quantified hen's excrement as being 120 g $bird^{-1}\ day^{-1}$. Thus, for every 100,000 hens, 12 tonnes of manure is produced. According to Silva and Lucas Júnior [41], hens may produce 140 g $bird^{-1}\ day^{-1}$ of manure.

Table 1
Composition N P K chicken manure.

Author	N (%)	P (%)	K (%)
Augusto [4]	0.46	1.32	0.72
Santos [39]	6.9	3.5	2
Figueroa et al. [23]	6.9	3.5	2

Table 2
Composition of the biogas from landfill and from digesters. Source: adapted from Monteiro et al. [32].

Composition	Landfill	Biodigesters
Methane	45%	65%
Range of methane	35–65%	60–70%
Hydrogen	0 to 3%	0
Carbon dioxide	40%	35%
Nitrogen	15%	0.20%
Range of nitrogen	5 to 40%	–
Oxygen	1%	0
Range of oxygen	0 to 5%	–
Hydrogen sulfide	<100 ppm	<500 ppm
Range of hydrogen sulfide	0–100 ppm	0–4000 ppm
Ammonia	5 ppm	100 ppm
Chlorine	20–200 mg m^{-3}	0–5 mg m^{-3}
Siloxine	12.9 μg g^{-1}	–

Methodology

The methodology included biodigester construction, substrate characterization and quantification, volume parameter measurements including biogas temperature and pressure, and determination of methane potential generation by anaerobic digestion by its quantification from measurements in experiments. The site was a poultry farm in Itanhandu, Minas Gerais, Brazil. The aviary has 2,000,000 birds distributed in three farms.

Three experiments were performed with a 3.3 L biodigestor with 2.1 L coaxial annular gasometers. Three dilutions were made with fractions of 6%, 9%, and 12% of total solids in the substrate.

The installations used for substrate analyses took place on the Laboratory of Solid Waste, Hydrogeology and Water Quality (LABRES, as acronym in Portuguese) and on the Sanitation Laboratory, both from The Natural Resources Institute (IRN, for its acronym in Portuguese) of the Brazilian Federal University of Itajubá (UNIFEI, for its acronym in Portuguese) was used. We used manure from the automated production sheds with mechanized collection.

Biodigester with thermal control without agitation

The anaerobic upflow biodigesters were mounted based on the model proposed by Souza [43] with some adaptations in accordance with Price and Cheremisinoff [36]. The connection between the reactor and gasometer of biodigesters was prepared based on Parajuli [35].

The sample was loaded into the biodigestors with excrement from shed number 3. This cohort contained HiSex Brown breed hens fed with type 2 posture in the abovementioned poultry farm. Waste was collected with a shovel and a mechanical treadmill. In the LABRES IRN-UNIFEI laboratory, waste weighing was performed and was destined for each biodigestor. Finally, it was loaded into the biodigestor for a batch system. Before load filling into the biodigester, the waste was diluted in water. The biodigestion was conducted in Itanhandu-MG, Minas Gerais, Brazil.

The proportion was adopted as 6% of total solids (TS) due to the assumption by Lucas Júnior [27] and Augusto [4] who showed that 6% TS would be the ideal concentration for agroforestry waste biodigestion. The solid content analysis of this TS percentage in waste followed the APHA [46] methodology. It matched the average percentage of 30% (dry base mass) in solid material in manure. This was similar to that reported by Lucas Júnior [27], Augusto [4] and Gomes et al. [25] who described a moisture content of 70%, 60–80% and 70–75%, respectively.

A blender was used to ensure a homogenous substrate. There was sludge from WWTP addition early in charge of the biodigesters. The HRT was adopted for in average 100 days (6%, 97 days;