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Biogas Production on a Small Swine Farm: Study of Prediction Using Different Models

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The use of the biodigestion is considered promising for the energetic valorisation of the sewage produced in swine farms. It is necessary to provide farmers with technical information that encourages the adoption of this technology and gives adequate and accessible data for the implantation of biodigesters. There are some calculators developed in European countries and in the United States that use simple inputs such as the type of the farming, the manure generation (dry solids content), the animal waste (animal.kg/day) and the technology used for the biodigester. These calculators also give relevant outputs such as biogas and energy production. In Brazil, this kind of calculator is not diffused and the information of biogas and energy production are often provided from government agencies. In order to evaluate the accuracy of the prediction of biogas using this accessible information to swine farmers (relation between the quantity of pigs or waste produced and the potential of biogas production), the main objective of this work was to compare these results with models based on physical chemical parameters measured in the swine sewage (Volatile Solids and Chemical Oxygen Demand) and also compare it with the biogas produced in a lab-scale biodigester. Results showed the models based on physical chemical parameters and the model based on quantity of growing pigs were coherent with results provided by lab-scale biodigesters. Models based on the quantity of farrowing pigs and the estimation of manure produced by the animals in the farm presented results without compatibility with all the others.

1. Introduction

Swine production is an animal husbandry activity of great commercial importance in Brazil. This activity employs approximately one million people in the 26 federation states. Since 2001, Brazil has achieved the 4th position of swine meat production with approximately 10 million t/y, just behind the Republic of China, the European Union and the United States of America (Dias et al., 2011).

The Brazilian swine production chain is formed by 50 thousand farmers that work in a different range and type of production. This activity has been mostly carried out in confined systems with controlled feeding and health care. Despite the economical relevance, Brazilian Environmental Organization considers the confined systems of low environmental quality and high polluter potential, since it generates a great amount of waste and consumes a high amount of water. The development of this industrial production showed the necessity of more advanced technologies seeking more efficiency and lower inputs consumption and the reduction of residues and wastewater (Souza et al., 2009). Figure 1 shows an example of the sewage collection and treatment of a small swine farm in southeast of Brazil, which does not provide any environmental control of the process. In this context, the use of the anaerobic digestion is considered promising for the energetic valorization of the waste produced in the swine process.

The biogas produced from the sewage is known as a waste-to-energy technology since it reduces the volume and hazardousness of the sewage/sludge and at the same time can produce heat or electricity. It also reduces

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the environmental impacts generated by improper waste disposition and generates an extra income for the farmers, in additional to provide improvement on sanitary standards in rural areas (Oliveira et al., 2011).

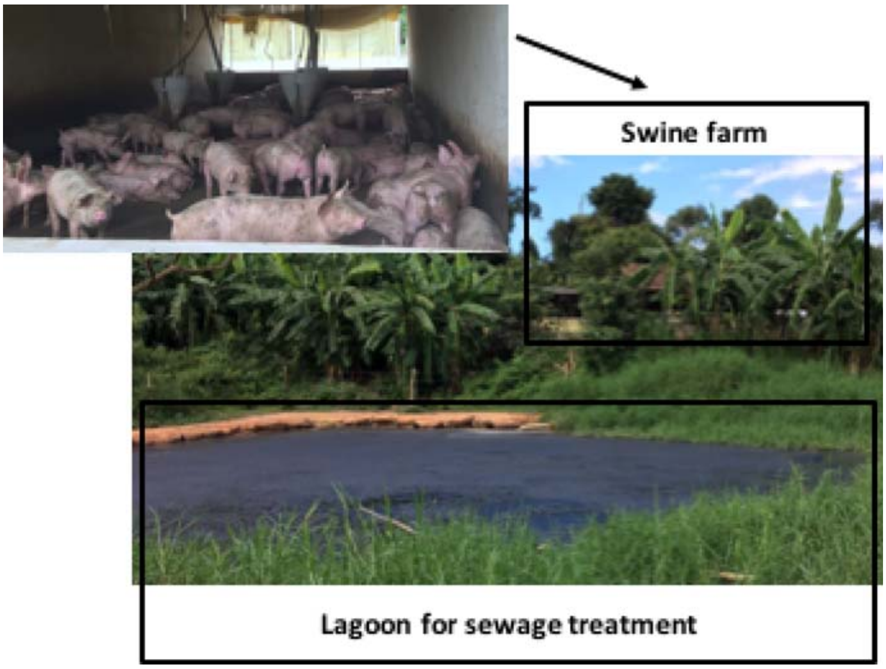

Figure 1: Sewage collection and treatment of a small swine farm in southeast of Brazil (photography from the author.)

Given the importance of the anaerobic digestion for the sewage treatment, it is necessary to provide farmers with technical information that encourages the adoption of this technology and gives adequate and accessible data for the implantation of biodigesters and consequently cogeneration system. There are some calculator developed in European countries and in the United States which use simple inputs such as the type of the farming, the manure generation (dry solids content), the animal waste (animal.kg/day) and the technology used for the biodigester. These calculators also give relevant outputs such as biogas and energy production (Kythreotou et al., 2014).

In Brazil, this kind of calculator is not diffused and the information of biogas and energy production are often provided from government agencies, such as Embrapa (Empresa Brasileira de Pesquisa Agropecuária). Often, the literature available spread the relation between the number of animals such as growing pigs (Dias et al., 2011) or farrowing pigs (Sobestiansky et al., 1998) and the potential of biogas yield. It is also found the relation between biogas and the quantity of biomass to be fed in the biodigester (Ministério da Agricultura Pecuária e Abastecimento, 2016). For example, each m^3 of biomass from swine farms can produce 0.35-0.60 m^3 of biogas (Oliveira and Higarashi, 2006). Despite the relations stated, it well known the biogas yield can vary as a consequence of farm’s productive process such as the use of water, the growth stage of the animals and kind of feed (Moller et al., 2004). Biogas yield is also dependent of the operational parameter such as pH, temperature and hydraulic retention time (Yadvika et al., 2004). Hence, It can be seen that such information spread to farmers is not straightforward, it is superficial and it may not provide a view of the economic advantages due to the implantation of biodigesters for energy purposes.

The main objective of this work was to compare the results of biogas yield based on this accessible information to swine farmers with the results obtained with physical chemical parameters measured in the swine sewage such as Volatile Solids [6] and Chemical Oxygen Demand [7] and also compare them with the biogas produced in a lab-scale biodigester. The present research was based on the case study method, in a small swine farm typically found in Brazil. It is expected that this comparative study may provide critical evaluation of the information provided to farmers in order to encourage a study of a Brazilian simple calculator, which is an important tool to improve the use of the biodigesters.

2. Experimental

2.1 Case Study

The evidence for this study were collected from observations, interviews, review of documentation and data collection. The investigations were based on a specific case which consists of a small swine farm at Florestal city, Brazil. Documents analysed consisted of a schematic flowchart of the process, the waste characterizations and swine accounting. Data for the study were also collected from interviews with the workers, which were held at the study site. All the information was opposed to observations of the activity on the property to enable validation of data presented by the interviewee and provide a safer view of the research objects.

2.2 Biogas Prediction

In this research, it was used five different models to estimate the biogas production. The first three models just used the information presented in the literature accessible for farmers and the quantity of pigs (and respectively stage) counted in the farm (Table 1). Hence, the first model considered the quantity of growing pigs and their relation between biogas production: one animal (of about 90 kg) estimates 0.24 m^3 of biogas each day in the farm (Dias et al., 2011). The second one used the quantity of farrowing pigs: 1 animal estimates 1 m^3 of biogas each day in the farm (Sobestiansky et al., 1998).
The third model considered the information of manure production according to the swine growth stage presented by Bonett and Monticelli (1998) and shown in Table 1. This model used the values of kg of manure generation expected each day, the estimated Volatile Solids (VS) content in the manure (70 wt%) and the relation between VS and amount of the biogas produced: one kilogram of volatile solids can produce 0.45 m^3 of biogas (Oliveira and Higarashi, 2006).
The fourth and fifth models were based on physical chemical parameters measured in the swine sewage of the farm. Sewage samples were collected (one sample of 2 liters of residue from growing pigs) and analysed in three different months.
The fourth model used the same relation between the concentration of volatile solids and amount of the biogas produced as in the third one, however it considered the experimental values of VS. (Oliveira and Higarashi, 2006).
Finally, the fifth model consisted of the empirical correlation for the amount of methane produced and the wastewater digested in the anaerobic reactor as follow in Eq (1) (Bhattacharyya and Banerjee, 2007):

$$V_{CH_4} = (0.35)\times(EQS_i - 1.42P_x) \quad (1)$$

where V_{CH_4} is the quantity of methane gas produced (m^3/kg.COD.day), E is the efficiency of waste utilization (0.6), Q is the volumetric flow rate of wastewater (m^3/day), S_i is the influent Chemical Oxygen Demand (COD kg/day) and P_x is the net mass of cell tissue, as presented in Eq (2):

$$P_x = \frac{YQ(ES_i)}{1+k_d\theta_c} \quad (2)$$

where Y is the yield coefficient (0.06), k_d is the endogenous coefficient (0.03) and θc (40) is the mean cell residence time. The total volume of biogas produced could be estimated since it contains two-thirds methane.

2.3 Lab-Scale Biodigester

Two lab-scales biodigesters were operated for forty days using swine sewage collected from growing pigs as substrate (sample from November/2016). The batch digestion tests were carried out in Kitasatos flasks with a working volume of 750 mL. The biodigester were kept in a thermostatic water bath maintained at a mesophilic temperature (35 ± 1°C). Each digester received 50 mL of seed sludge for startup and 700 mL of swine sewage. The collection of the methane was done with the use of vessel containing sodium hydroxide solution which was displaced as the gas gets collected. Methane production was measured daily and values converted to Normal Conditions and biogas volume (biogas presents two-thirds methane). Volatile Solids and COD were measured at the biodigesters feeding and they were determined using standard techniques (APHA, 1998).

3. Results and discussion

The activities developed where today is located the Federal University of Viçosa (UFV- Florestal), began in 1939. The activity of pig breeding began in undetermined date, in order to meet the university restaurant needs. The keeping of pigs is made in the intensive system and includes all phases of the animal's life cycle: breeding, rearing and fattening. The swine farm studied is considered small and has the maximum capacity for about 500 animals.

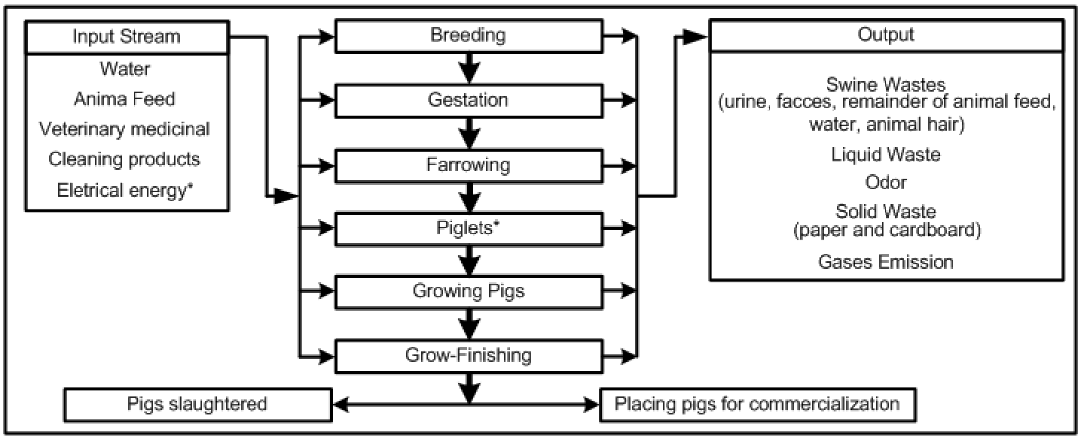

Figure 2: Schematic flowchart of Swine Production (Leite et al., 2014)

A schematic flowchart of the swine production is shown in Figure 2. As it can be seen this process has inputs such as water, energy, animal feed and veterinary medication and also has important outputs such as sewage, smell and health services residues.

Sewage release in the only environmental aspect quantified in the farm and it is about 2,500 L/day (2.5 m^3/day). Considering the implementation of a conventional biodigester (without biomass retention mechanism) (Chernicharo, 2007), animals quantification and the sewage release and characterization are the main inputs for biogas prediction used in this work.

In order to apply the first three models and estimate the biogas this swine farm may produce, the pigs were counted and classified into breeding (3), gestation (33), farrowing (6), piglets (71), growing pigs (134). As can be shown in Table 1, the swine farm totalizes 247 animals that can produce about 500 kg of manure each day. According to the 1st model the presence of 134 growing pigs suggests the farm may produce 32 m^3 of biogas. Likewise, using the 2nd model and the amount of farrowing pigs as reference, the farm may produce 6m^3 of biogas. Finally, from the third model, 500 kg of manure have around 350 kg of VS that may produce 157 m^3 of biogas each day.

Afterward, the Volatile Solids (VS) and the Chemical Oxygen Demand (COD) of the sewage were quantified in order to apply the fourth and fifth models proposed. Solid Volatile content were between 16.3 and 34.7 g L^{-1} and COD content were between 12.5 and 20.7 g L^{-1}. The results of chemical analysis are in accordance with the values obtained in other swine farms [2]. Table 2 presents the results of SV, COD and the biogas prediction that was calculated considering the flow rate of 2.5 m^3/day of swine sewage. According to Table 2, biogas prediction varies in the months between 18.3 and 39.6 m^3/day and the results are coherent with organic matter available (represented by SV and COD).

The two batch biodigestion tests, with 700 mL of swine sewage produced 5.1 and 5.8 liters of methane, that correspond to 0.428±0.039 m^3 CH_4/kg VS added. Similar results, around 0.40 m^3 CH_4/ kg VS added, were reported under batch conditions at a mesophilic temperature (Moller et al., 2004). Considering the lab-scale biodigesters results and the sewage flow rate (2.5 m^3/day), the methane and the biogas yield could be estimated as 19.5 and 29.0 m^3/day, respectively,

Table 1: Manure generation (kg/day) from Intensive animal farming at UFV Florestal

Stage Production	Confined Animal	Manure (kg/animal)	Manure (kg/day)
Gestation	33	3.6	118.8
Farrowing	6	6.4	38.5
Piglets	71	0.35	24.85
Growing pigs	134	2.3	308.2
Breeding	3	3	9
∑	247	15.65	499.45

Table 2: Volatile Solids (VS) and the Chemical Oxygen Demand (COD) measured in the swine sewage and their biogas prediction.

Sewage Sample	Fourth Model		Fifth Model	
	VS (g L^{-1})	Biogas Prediction (m^3/day)	COD (g L^{-1})	Biogas Prediction (m^3/day)
1(May/2016)	16.3± 0.7	18.3	13.9± 2.0	26.2
2(September/ 2016)	34.7± 1.6	39.6	20.7± 1.8	39.0
3(November/2016)	18.2± 0.4	20.5	12.5± 1.8	23.5

Table 3 summarizes the values of biogas prediction, according to each model proposed. It also presents data collected to these estimation, the deviation from the values obtained with the lab-scale biodigester and the respectively references. The results in Table 3 suggest the values for biogas yield predicted from the models based on physical chemical parameters are more coherent with biogas yield predicted from lab-scale biodigester. Also, the first model, which considered the quantity of growing pigs, present a closer value although it over estimates the amount of biogas that might be produced. The 2nd and 3rd models presented results without compatibility with all the others.

4. Conclusions

The model based on the quantity of growing pigs presented coherent value of biogas yield although it over estimated it. Models based on the quantity of farrowing pigs and the estimation of manure produced by the animals in the farm presented results without compatibility with all the others. They may compromise the economic study for implementation of biodigesters and cogeneration system. The use of physical chemical parameters measured in the sewage such as Volatile Solids and Chemical Oxygen Demand provided reliable results of biogas yield when compared to lab-scale test. Moreover, these chemical parameters associated with the information (inputs and outputs) from the swine production are important to design and improve biodigesters. They may provide information to be used by the (small) farmers, typically found in Brazil and may be important data to be considered to draft a simple calculator.

Table 3: Values of biogas prediction, according to each model proposed.

Model	Data		Biogas prediction (m^3/day)	Deviation from experimental value	Reference
	Swine Farm	Chemical Analysis			
1st (Growing pigs)	134 animals	-	32	+ 10 %	Dias et al., 2011
2nd (Farrowing pigs)	6 animals	-	6	- 79%	Sobestiansky et al., 1998
3rd (Manure generation from total pigs and SV)	247 pigs; 500 kg (manure)/day	-	157	+ 441%	Bonett and Monticelli, 1998; Oliveira and Higarashi, 2006
4th (Volatile Solids Content)	2,500L (sewage)/day	18.2 g L^{-1}VS	20.5	- 29%	Oliveira and Higarashi, 2006
5th (Chemical Oxygen Demand Content)	2,500L (sewage)/day	12.5 g L^{-1}DQO	23.5	- 19%	Bhattacharyya and Banerjee, 2007
Lab-Scale biodigester (experimental value)	2,500L (sewage)/day	CH_4 volume	29.1		

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