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Application of Cleaner Production Methodology to Evaluate the Generation of Bioenergy in a Small Swine Farm

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The swine production is an animal husbandry activity of great commercial importance in Brazil although the 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. Against that background, the aim of this work was to apply the Cleaner Production (CP) methodology in a small swine farm with the purpose of identifying the bottlenecks of processes (considering environmental impacts) and propose sustainable and safe solutions. Based on the first results this research analyzed the economical and environmental feasibility of biogas production, due to the implementation of anaerobic digestions system. To achieve the first goal of this work, the authors developed a schematic flowchart of the process, then identified and evaluated the environmental impacts, to finally select the specific stages necessaries to implement CP actions. The main short and long term actions proposed were: the installations of a septic tank; the improvement of the drainage system; the installation of a hydrometer and a powered watch; the implementation of safety standards to storage chemical and medical products, the improvement of the residues management and the implementation of a biological treatment for the sewage which can be combined to a cogeneration system to produce electricity from the biogas. The technical feasibility study for the implementation of an efficient cogeneration system from the biogas has been developed considering three specific mathematics models (MM): 1st MM: Ratio between animal waste (manure generation) and amount of the biogas produced; 2nd MM: Ratio between the concentration of volatile solids (VS) from animal waste and amount of the biogas produced and 3rd MM: Empirical correlation between the amount of methane produced and the waste digested in the anaerobic reactor, considering influent Biological Oxygen Demand (BOD) value. The VS and BOD methods seem to be the most proper models and had close values for the predictions of biogas produced. According to these results the use of biogas for the energy cogeneration seems to be economically and environmentally practicable.

1. Introduction

The swine production is an animal husbandry activity of great commercial importance in Brazil. This activity employs approximately 1,000,000 people in the 26 federation states. Since 2001, Brazil has achieved the 4^{th} position of swine production with approximately 10 Mt/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 thousands farmers which work in a different range and type of production. However, 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. It is noteworthy that swine production is the mainstream activity of the small rural proprieties. In North and Northeast of Brazil the swine production is performed in traditional production practices and subsists as one of the mainstream activity of the small rural proprieties while in South, Southeast and Midwest regions it is predominant the

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industrial swine production. 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). The Cleaner Production arises as an important methodology since it considers the necessity of a more efficient use of raw materials and energy, the use of renewable sources of energy, the improvement of energy technologies and the reduction of emissions and pollutants (Bonila et al., 2010).

In this context, the use of the anaerobic digestion is considered promising for the energetic valorisation 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/sluge and at the same time can produce heat or electricity. It also reduces 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 (Lauwers et al., 2012).

Thus, the aim of this work was to apply the Cleaner Production (CP) Methodology in a small swine farm with the purpose of identifying the bottlenecks of processes (considering environmental impacts) and propose sustainable and safe solutions. Based on the first results this research analyzed the economical and environmental feasibility for the implementation of a cogeneration system from the biogas using the sewage of the swine production.

2. Experimental

2.1 Cleaner Production (CP) Program

This work was carried out in a small swine farm at Universidade Federal de Viçosa (University of Viçosa), Florestal, Brazil. In the present study a schematic flowchart of the process was made and then the environmental aspects and impacts were identified (Figure 1). In order to apply the Cleaner Production (CP) methodology, the aspects were evaluated and quantified (when possible). The evaluation considered the severity of the correlated impact and the application of the environmental legislation. Aspects which were severe and did not attend the legislation were considered significant and important for Cleaner Production analysis. Short and long term actions were proposed to avoid environmental impacts and improve sustainable solutions. Data collected is summarized in Table 1.

2.2 Prediction of Biogas production

From Table 1 it can be seen that the implementation of a cogeneration system from the biogas using the sewage of the swine production was considered a priority action in order to minimize the risk of water pollution, the consumption of energy and the smell. So, the present paper presents a technical feasibility study which was developed considering three specific mathematics models as follow.

The first model uses the ratio between animal waste (manure generation) and amount of the biogas produced. According to Oliveira and Higarashi (2006) one kilogram of manure can produce between 0.35 and 0.60 m^3 of biogas. In addition, the quantity of manure that each animal produces depends on their growth stage (Bonett and Monticelli, 1998). Hence, the animals were classified and counted in order to estimate the amount of biogas that can be produced.

The second model uses the ratio between the concentration of volatile solids from animal waste and amount of the biogas produced. One kilogram of volatile solids can produce 0.45 m^3 of biogas (Oliveira and Higarashi, 2006).The sewage produced each day was quantified and samples were collected and analysed in accordance with Standard Methods for the Examination of Water and Wastewater (APHA, 1995).

Finally, the third model consists 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):

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

where V_{CH4} is the quantity of methane gas produced (m^3/kg.BOD.d), E is the efficiency of waste utilization (0.6), Q is the volumetric flow rate of wastewater (m^3/day), S is the influent Biological Oxygen Demand (BOD kg/day) and P_x (Eq(2)) is the net mass of cell tissue into BOD.

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

where Y is the yield coefficient (0.06), k_d is the endogenous coefficient (0.03) and θ_c (14) is the mean cell residence time. The total volume of biogas produced can be estimated since it contains two-thirds methane.

2.3 Economical study for implementation of a cogeneration system

In the present work, the cost of the electrical energy produced by the cogeneration system was calculated considering the method described by Souza et al. (2004) and the results of the amount of biogas obtained according to section 2.2. The mathematic model considers the cost of the biodigester construction and maintenance (approximately USD 75.00/swine) and cost of the motor-generator system purchase (approximately USD 175.50/swine).
In this calculation, the appropriate operation and maintenance conditions were considered. It was admitted that all the biogas produced was completely consumed by the motor-generator, which may be operating in steps of 4, 6, 8, 10 and 12 h/d. It was also considered, as the discount rate used, 8 %/y (this is the rate of the Brazilian federal government for the financing of agricultural and livestock activities) and amortization of 10 y. The annual cost of the maintenance per year is approximately 4 % of the total investment.

3. Results and Discussion

3.1 Cleaner Production (CP) Program

The swine farm studied is considered small and has the maximum capacity for about 500 animals. At the moment of the investigation there were 323 pigs. A schematic flowchart of the swine production was the first step of this study to apply the Cleaner Production (CP) methodology, as show in Figure 1. As can be seen in Figure 1, 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. The consumption of the inputs (natural resources) and the release of this output (residues) are the environmental aspects that were evaluated considering the severity of the correlated impact and the application of the environmental legislation. These aspects are rarely quantified and the only one usually controlled is the sewage that is about 2,285.00 L/d (2.285 m^3/d).
According to data present in Table 1 the production/release of sewage, smell, health services residues and the consumption of water and energy are some examples of the aspects that were considered significant and a priority for Cleaner Production analysis, since they were severe and did not satisfy the applicable legal. As a consequence of these results short term actions such as: the installations of a septic tank; the improvement of the system of drainage; the installation of a hydrometer and a powered watch; the implementation of safety standards to storage of chemical and medical products and the improvement of the residues management were proposed to minimize environmental impacts. In addition the most comprehensive long term action proposed was the implementation of a biological treatment for the sewage which can be combined to a cogeneration system to produce electricity from the biogas.
Due to this fact it may be assumed the importance of a technical, economic and environmental feasibility study for the implementation of a bio digester and a cogeneration system to produce electricity from the biogas.

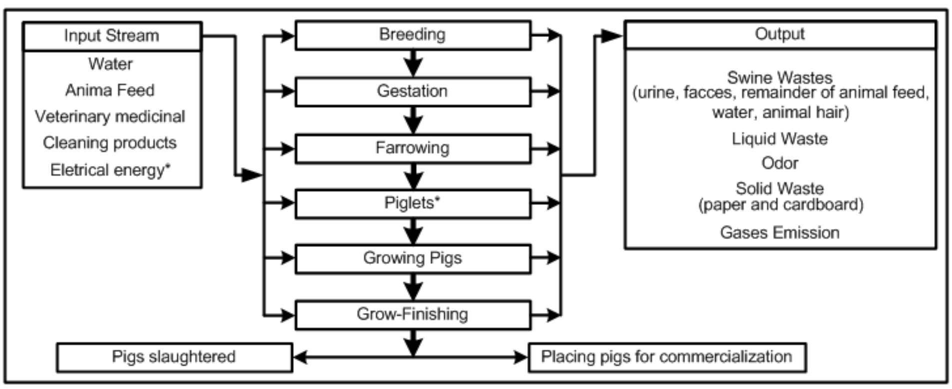

Figure 1: Schematic flowchart of Swine Production

Table 1: Data collected for Cleaner Production analysis and actions proposed

Aspect	Impact	S=?	Analysis of L.R		Focus of CP (priorities)	Short-term proposals	Long-term proposals
			Have L.R?	Satisfy L.R?			
Biological effluent generation	Pollution of soil and water	Yes	Yes	No	1	Septic tanks; Drainage system	System of wastes collection with inclination; Biological treatment for the sewage
Consumption of water	Depletion of natural resources	Yes	Yes	No	1	Hydrometer	Drinkers more efficient
Consumption of energy	Depletion of natural resources	Yes	No	-	1	Powered watch	Transparent roof to higher luminosity and heat; Cogeneration system to produce electricity from the biogas Appropriate facilities for use of space and with natural light
Consumption of medical and chemical products	Pollution of soil and water	No	No	-	2	Storage following safety standards	Ensures good sanitation conditions of the farm and presence of veterinary professional
Waste generation (health services residues)	Pollution of soil and water	Yes	Yes	No	1	Direct to incineration	Not apply
Release of gases (smell)	Discomfort of the population	Yes	No	-	2	Cover the boxes of effluent	Biological treatment for the sewage

*S=?: Aspect considered severe?; R.L: legal requirements; CP: Cleaner Production

Table 2: Experimental values of biogas (m³/day) in samples and Electrical Energy Cost (USD/m³ of biogas) calculated.

Mathematic Model	Biogas Production			Electrical Energy Cost (C_e)*		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
1st Manure Generation	345.0	432.2	519.4	290.1	289.1	288.5
2nd Volatile Solids	3.1	13.8	33.2	377.3	377.3	335.6
3rd Biological Oxygen Demand	7.7	23.3	50.5	306.9	357.0	318.3

* Values considered the 10 years of amortisation and 6 hours/day operation time

3.2 Prediction of Biogas production

The present work reports the results of the biogas estimated from the relations between 1st manure generation; 2nd Volatile Solids and 3rd Biological Oxygen Demand consumed and the amount of gas produced, as can be seen in Table 2.

In order to estimate the biogas from the relation manure/biogas produced (1st), the animals were counted and classified into Breeding/Gestation (33), Farrowing (82), Piglets (71), Growing pigs/ Growth finishing (137). The swine farm totalizes 323 animals that in accordance with Bonett and Monticelli (1998) produce about 986 kg of manure each day. This quantity may produce at least 432.2 and the maximum of 519.4 m³ of biogas (Oliveira and Higarashi, 2006).

Afterward, the Volatile Solids (VS) and the Biological Oxygen Demand (BOD) of the sewage were quantified in order to apply the second and third models proposed. The samples were collected and analysed during December/2013 and January/2014. VS content varied between 13,378.3 and 32,310.0 mg/L and BOD varied between 15,098.2 and 32,652.0 mg/L. Although the variation of the results is large, they are appropriated to swine sewage. This variation reflects the influence of the swine growth stage, the use of water for sanitation and health care and also the rainfall period (Souza et al., 2009).

Data present in Table 2 suggest that the second and the third models are more reliable since they have close values and they consider the chemical relations between organic matter content and the quantity of biogas produced. Although the first model is the most common and simple, it may bring an overestimated value of biogas production and compromise the economical study for implementation of a cogeneration system.

3.3 Economical study for implementation of a cogeneration system

For a carrying out of the feasibility study of the implementation of a cogeneration system from the biogas it was considered the: investment return; energy production; investment of the cogeneration system (construction, acquisition and maintenance) and amortization investment. It was admitted that all the biogas produced was completely consumed by the motor-generator, which may be operating in steps of 4, 6, 8, 10 and 12 hours/day.

From Figure 2 it possible to see that longer the operating time of the motor-generator system, the minor is the cost of electrical energy production and consequently faster will be the return on the investment. In the

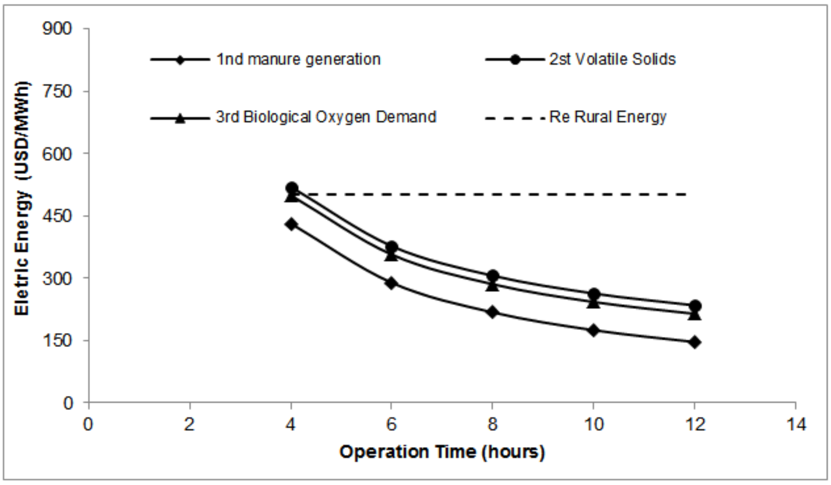

Figure 2: Comparison of the electric energy cost (USD/MWh) considering the calculation of energy production in 4, 6, 8, 10 and 12 h/d operation time and the rural energy provide from electricity concessionaire

case studied, the rural energy provided from electricity concessionaire costs 500 USD/MWh. The cost of the energy produced from the biogas is just slightly larger compared with the cost of rural energy when the motor-generator operates 4 h/d. However for the operation time greater than 6 hours/day the energy produced from the biogas is lesser compared with the cost of rural energy, as can be seen in Table 2. Even though the values estimated for the biogas production are different they contribute little in the variation of the energy cost when energy production is short (4 hours/day operation) since the input of the motor-generator system is predominant compared to the operation cost.

4. Conclusion

The application of Cleaner Production (CP) Methodology leads to important actions that may be considered in the swine farm. It will bring environmental benefits and it will also improve the performance in product quality and working condition. However, this program itself might not be successful without an environmental managements system systematized in the organization and the commitment of the leaders and all the staff. According to CP program the implementation of a cogeneration system from the biogas using the sewage of the swine production was considered strategic in order to minimize the risk of water pollution, the consumption of energy and the smell. SV and BOD methods were considered more reliable to estimate biogas production from the swine waste. The use of the relation between animal waste (manure generation) and amount of the biogas produced should be used with precaution since it may overestimate the value of biogas production. Economical study for implementation of a cogeneration system indicates positivity the use of the biodigester combined with the motor-generator to provide energy in rural areas. The biogas/energy produced from the sewage is known as an important waste-to-energy technology that must be encouraged in Brazil.

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