THE DEPLOYMENT OF BIODIGESTER SYSTEMS IN RURAL PROPERTIES

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ABSTRACT

Swine production has a strong impact on the national and international meat economy. However, this type of agribusiness generates solid and liquid wastes which impact the environment when deposited inadequately. An alternative for the treatment of these effluents would combine appropriate management of residual biomass to the digester system. Current study collects data to deploy a digester system on a rural property in Mambore PR Brazil, with a herd of 330 matrices. Further, 30,301.49 kg.day-1 in feces and urine and use of 15,673 m^3 of water were obtained. Daily volume of wastes estimated the amount of biogas within conditions of hydraulic retention time (HRT) of 22 days and 30 days, with temperature variation of biomass at 20°C, 25°C and 30°C. Electric energy produced was estimated at105,553.95 $kWh.year^{-1}$ with HRT of 22 days and 20°C. Under the above conditions, the biofertilizer produced amounted to 27,500 kg. Thus, the biogas produced could generate electricity to meet the needs of the farm and the bio-fertilizer produced could be used on crops or sold.

Keywords: swine production, biogas, bio-fertilizer.

ANÁLISE DA IMPLANTAÇÃO DE SISTEMAS BIODIGESTORES EM PROPRIEDADES RURAIS

RESUMO

A suinocultura é apresenta forte impacto na economia nacional e internacional de carnes. Este setor do agronegócio gera dejetos sólidos e líquidos que, quando depositados inadequadamente impactam o ambiente. Uma alternativa para o tratamento destes efluentes seria aliar um manejo apropriado da biomassa residual com sistema biodigestor. Deste modo, o objetivo do trabalho foi levantar dados para implantar um sistema biodigestor em uma propriedade rural em Mamborê-PR, com um plantel de 330 matrizes. Foi obtido o valor de 30.301,49 $kg.dia^{-1}$ de fezes e urina, e a utilização de 15,673 m^3 de água. O volume diário de dejetos possibilitou estimar a quantidade de biogás, considerando tempos de detenção hidráulica (TDH) de 22 dias e 30 dias, com a variação de temperatura da biomassa de 20°C, 25°C e 30°C. A estimativa da energia elétrica produzida foi de 105.553,95 $kWh.ano^{-1}$ com TDH de 22 dias e temperatura de 20°C. O biofertilizante produzido nestas condições foi de 27.500 kg. Assim, o biogás produzido poderia gerar energia elétrica para suprir as necessidades da propriedade e o biofertilizante produzido poderia ser utilizado nos cultivos da propriedade ou comercializado.

Palavras-chave: suinocultura, biogás, biofertilizante.

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INTRODUCTION

Swine production in Brazil has a highly relevant chunk in world market due to scientific and technological development in production that comprises health, nutrition, proper management, integrated production and above all the segment´s managerial improvement. Further, accountability in the minimizing environmental impacts has also been crucial for growth.

According to Almeida (2008), the system of biodigesters is an alternative for swine production wastes through the introduction of a source of renewable and sustainable energy and a solution for the environmental issues concerning waste. Souza et al. (2005) remark that the storage of swine wastes in anaerobic biodigesters comprises the harnessing of biogas mainly composed of methane, sulfur dioxide, ammonia, hydrogen sulfide and nitrogen. They have been employed as energy sources, frequently replacing natural gas (ASTALS et al., 2012; CAPPONI et al., 2012).

The deposition of untreated wastes in water bodies was a very common practice in Brazil prior to the publication of Law 9.605 of 12/02/1998, which deals with administrative punishment derived from behavior and activities against the environment (Law of Environmental Crimes). According to Fonseca et al. (2009), the law is so important that swine production became unfeasible without the adequate management of wastes. In other words, a new ethical position by producers was made mandatory in the wake of the impacts caused by the activity. According to Diesel et al. (2002), a farm with approximately 600 animals has the pollutant capacity of approximately 2100 people, with high levels of contamination of surface and underground water in the countryside and in towns.

Biogas derived from biodigesters has been widely disseminated and studied worldwide. China expects that economic and technological development brings about the sale of the energy for distributors (CHEN et al., 2012), whereas in Vietnam the production of energy is highly viable due to the production of swine and to geographic conditions (THU et al., 2012).

The use of biodigesters for agroindustrial wastes produced on small farms has economic assets when installed and dimensioned correctly to attend requirements (MARTINS et al., 2011; CERVI et al., 2011; MARTÍ-HERRERO; CIPRIANO, 2012; CATAPAN et al., 2011). However, several risks exist in the production of biogas, comprising the release of copper, sulfadiazine, difloxacin (GUO et al., 2012), methane (REGUEIRO, et al., 2012; FLESCH, et al., 2011) in the atmosphere. Increase in the number and production of bacteria and viruses (SHI, et al., 2012) has also been reported. After the fermentation process and the production of biogas, a residue with high nutrient rates is released. Its application in plantations caused an increase in corn productivity (SOKCHEA; PRESTON, 2011; RODRÍGUEZ et al., 2011).

Improvements are caused by swine wastes with special reference to soil fertility (OLIVEIRA et al., 2011) and increase in the soil´s microbiological activities.

Current analysis comprises a data survey to study the viability in the deployment of a biodigester system for the production of biogas on a farm in Mamborê PR Brazil.

MATERIALS AND METHODS

Current study comprised a data survey on a farm in the municipality of Mamborâ PR Brazil. The 137.97 hectare-farm is devoted to swine production and agriculture and has a complete production cycle with a herd of 330 matrixes and an average 2.2 births/year. Each matrix averages 13 piglets.

Water used on the farm comes from a water source and sucker drinking troughs are used for the watering of animals. Swine nutrition, 5.5 tons/day, is prepared on the farm and consists of corn, soy meal, roughage (40kg $ton.^{-1}$), food supplement, mycotoxins-adsorbent as feed additives, Neobiotic-P325 (for the control of bacteria-caused dysentery) and Ivermectin (for the control of parasite and tapeworms).

Wastes currently pass through a system of treatment lakes following recommendations by the Environmental Institute of the state of Paraná (IAP), which consists of four lakes coated with a polyethylene geomembrane. The manure deposit is cleansed once a year and residues are arranged in hillocks close to the cultivation ground.

Four stages were employed to assess the amount of wastes from the swine production system.

Stage 1: The quantity of waste produced on the farm was calculated according to the swine herd. Total production of effluents comprises the sum of wastes, washing water from the pens and surplus from drinking troughs.

Total wastes were calculated by formula suggested by Oliveira (1993) and summarized in the column Manure + Urine (Table 1).

TABLE 1 – Estimates of swine wastes

Category	Manure ($kg.day^{-1}$)	Manure + Urine ($kg.day^{-1}$)	Liquid wastes ($L.day^{-1}$)
25-100 kg	2.30	4.90	7.00
Pregnant sows	3.60	11.00	16.00
Lactating sows	6.40	18.00	27.00
Males	3.00	6.00	9.00
Piglets	0.35	0.35	1.40
Mean	2.35	5.80	8.60

Source: Adapted by Oliveira (1993).

Water for cleansing and water loss from troughs were estimated following Perdomo et al. (2003), given in Table 2, employing rates of Complete Cycle Pig Production Unit (CCU).

TABLE 2 – Volume of water used for cleaning and water loss from troughs

Production system	Feces and Urine (L/matrix)	Cleaning (L/matrix)	Water loss from troughs (L/matrix)
SPU1	19.0	16.0	7.9
FPU2	6.8	2.8	1.3
CCU3	55.0	32.0	15.5

SPU[1]- Swine-Producing Units; FPU[2] - Finishing-Producing Units; CCU[3] - Complete Cycle Pig Production Unit. Source: Perdomo et al. (2003).

Total volume of effluents produced on the farm was the sum of manure plus urine ($kg.day^{-1}$), following Table 1, plus water volume in cleaning and water loss from troughs calculated in Table 2.

Stage 2: Equations proposed by Chen & Hashimoto (1980) were applied to quantify the biogas to be produced on the farm.

The kinetic coefficient (k) for swine wastes was calculated by Equation (1), (CHEN; HASHIMOTO, 1980), where S_0 is the concentration of volatile solids (VS) in $kg.m^{-3}$.

S_0 was calculated by assay performed in the Water and Drainage Laboratory of the Universidade Tecnológica Federal do Paraná, campus of Campo Mourão PR Brazil, with a sample of swine effluents from the farm under analysis, in triplicate. Total solids, fixed and volatile solids, were determined by methodology by Piveli and Kato (2005).

$$k = 0.5 + 0.0043.e^{0.0051.S_0} \quad (1)$$

Maximum specific growth rate (μm) was given by Equation 2, proposed by Hashimoto et al. (1981), in which T is the temperature of the biomass, namely, 20°C, 25°C and 30°C.

$$\mu_m = 0.013.T - 0.129 \quad (2)$$

Equation 3 was employed to obtain rate of methane production Yv (m^3 of CH_4 of the digestion chamber.day^{-1}). Maximum methane production rate, B_0, (m^3 of CH_4. kg^{-1} of VS) for calculations was 0.516 m^3 of CH_4/kg of VS (MOLLER et al., 2004); 22 and 30 days were employed for hydraulic retention time (HRT).

$$Y_V = \frac{B_0.S_0}{RTH}\left(1 - \frac{K}{HRT\mu_m - 1 + K}\right) \quad (3)$$

where, Yv is the methane production rate (m^3 of CH_4 of the digestion chamber.day^{-1}), B_0 is the maximum rate of methane production (m^3 of CH_4. kg^{-1} of VS), S_0 = VS concentration of effluent (kg.m^{-3}), HRT is the hydraulic retention time (days), μm is the specific growth rate (day^{-1}) and k is the kinetic coefficient (adimensional).

Biogas estimates were calculated by Equation 5, taking into consideration 65% of the methane in the biogas (NISHIMURA , 2009).

$$Production\ of\ biogas = \frac{Y_V}{0.65} \quad (4)$$

where biogas production is given by

$$m^3 biogas.m^{-3}\ of\ the\ digestion\ chamber.dia^{-1}$$

Stage 3: Electric energy was estimated from the produced biogas by rate proposed by Coldebella (2006), with a calorific power of 6.5 kWh.m^{-3} and a 21% efficiency of the equipment.

Stage 4: Amount of biofertilizers was estimated by the quantity of matrixes on the farm, using formula proposed by Konzen (1983), with each twelve matrixes producing 1000 kg of biofertilizers daily.

RESULTS AND DISCUSSION

Production of wastes

The quantity of wastes produced per kg.day^{-1} unit was calculated by rates on Table 1, according to swine growth phases on a complete cycle farm (Table 3).

TABLE 3 – Production of wastes and urine

Category	Production of animal manure+urine (kg.day^{-1})	Number of Animals	Total
25-100kg	4.90	2.700	13,230
Pregnant sows	11.00	330	3.630
Lactating sows	18.00	80	1.440
Piglets	6.00	2.000	12.000
Males	0.35	4	1,40
		Total	30.301

Production was calculated at 30,301 kg.day^{-1} in manure and urine for a complete cycle stock. Oliveira (1993) enhances that the amount of urine is the greatest variant in the calculation of wastes since it directly depends on the intake of water by the pigs.

According to Konzen (1983), average production of liquid wastes per swine was 8.6 liters.day^{-1}. Based on the above rate to calculate the production of liquid wastes, 43,980 liters.day^{-1}or 43.98 m^3.day^{-1} were produced for a herd of 5114 pigs, disregarding breeding phases.

Wastes in drinking troughs and the cleaning of pens require water consumption which, when added to manure, forms the effluent of the breeding system. The rates of the producing unit given in Table 2, with 330 matrixes, provided a total of 15.673 m^3.day^{-1} with regard to water used in cleaning and to water loss from troughs.

Total volume of wastes produced on the farm is the sum of the production of wastes produced in kg.day^{-1} plus cleaning water and water loss from troughs in m^3.day^{-1}.

Estimates of biogas and electric and electric energy production

Estimates of biogas were performed by equations by Chen & Hashimoto (1980), with variations (HRT, temperature of biomass, volatile solids, number of animals and volumes of wastes) which were taken into account in the calculations for biogas results.

For the calculation of kinetic energy (k) by Equation 1, the concentration rate of volatile solids is required, or rather, 6.73 kg.m^{-3} as mean of triplicates obtained from the assay of a sample collected at the entrance of the effluent to the manure deposit, with $k = 0.5045$ (adimensional).

Rate is low when contrasted to the rate of volatile solids given by other authors. Instruction 105006 of IAP, published on 5/1/1998, for example, suggests minimum and maximum rates for physical and chemical parameters for crude wastes of swine production, taking Konzen (1983) as reference in which 8429 mg.L^{-1} (8429 kg.m^{-3}) is the minimum for volatile solids. Oliveira & Higarashi (2006) enhance that the dilution degree is a direct influence on total solid rates and consequently on volatile solids. The authors used a variation between 10 and 75 kg.m^{-3} to calculate biogas rates in their assays. The rate obtained by the assay in the calculation of the kinetic coefficient (k) was maintained since there were only slight differences given by authors, coupled to some factors, such as the dilution by loss of water and higher consumption of water between December and February, coinciding with the period of sample collection which may have affected the sample´s mean rate (MONDARDO et al., 2011; ARAÚJO et al., 2012).

Table 4 shows results from Equations 2, 3 and 4 proposed in the methodology.

TABLE 4 – Rate of growth and production of methane and biogas.

		Production of methane (m^3)		Production of biogas ($m^3.m^{-3}$ digestion chamber.day^{-1})	
Temperature of biomass (°C)	μm (day^{-1})*	HRT** 22 days	HRT 30 days	HRT 22 days	HRT 30 days
20	0.131	0.208	0.099	0.321	0.152
25	0.196	0.218	0.105	0.335	0.161
30	0.261	0.222	0.108	0.342	0.166

μm*: specific growth rate.
HRT**: hydraulic retention time.

Increase in the temperature of the biomass from 20°C to 30°C, methane (m³) and biogas production increased HRTs. According to Coldebella (2006), temperature is the most important factor in the production of biogas since it affects directly biological activity of microorganisms. In fact, a temperature of 35°C is the best environment for anaerobiotic microorganisms.

When HRT rates of 22 days are compared with those of 30 days for the production of methane, there is a 51.35% decrease in HRT of 30 days and a 51.46% decrease in the production of biogas for biomass at 30°C. Decrease occurs since the speed of biological reactions at high temperatures is more intense, with less HRT (COLDEBELLA, 2006). Cortez et al. (2008) insist that the production of biogas doubles for every 10°C increase, between 15°C and 35°C. High temperatures increase biological reactions, with a more efficient performance in a lower detention time. They also underscore that most biodigesters work within a mesophilic range between 20°C and 35°C.

The digestion chamber volume was also calculated, following Kunz & Oliveira (2008), who take into consideration HRT/day multiplied by the daily discharge of wastes ($m^3.day^{-1}$) on the farm.

A rate was obtained from a 660 m^3 digestion chamber for the farm under analysis, taking into consideration HRT of 22 days and a discharge of approximately 30 m^3 of wastes per day.

According to Oliveira (2005), in the case of a herd of 161 matrixes in a complete cycle with 13.64 m^3 of wastes, the results revealed the need of a 300 m^3 digestion chamber. The above shows that rates estimated for the farm may also be used in other studies on the volume of the digestion chamber. To estimate the energy produced from the biogas (Table 5), biogas with a 50 – 80% methane rate was taken into consideration, with a heating power of 6.5 $kWh.m^{-3}$ with a 21% efficiency in co-generation systems (COLDEBELLA, 2006).

TABLE 5 – Estimates for the production of electric energy on the farm under analysis

Production of biogas $m^3.day^{-1}$	Production of biogas $m^3.year^{-1}$	Heating power $kWh.year^{-1}$	Efficiency (21%) $kWh.year^{-1}$
0.321	77328.9	502,637.85	105,553.95

* HRT=22 days; T=20 °C

According to Lima (2007), an increase in the daily production of biogas within a swine production system recommends an increase in daily feed load of volatile solids for rates between 55 and 65 kg per m^3 of biomass, reduction of retention time to 22 days and an increase in biomass temperature to 35ºC.

To calculate the production of electric energy, the production of biogas with HRT for 22 days, at a temperature of 20 °C, was employed, since, according to Oliveira (2005), the temperature range for biomass lies between 20 and 25°C in the states of the southern region of Brazil. A total 105,553.95 $kWh.year^{-1}$ was obtained. Since yearly intake of the farm for 2013 was 82,802 $kWh.year^{-1}$, the farm would be self-sufficient in electric energy, with an excess in electric energy. The analysis of costs in the deployment of a biodigester system on the farm is thus justified.

According to Lima (2007), the Brazilian swine herd produces sufficient wastes to generate approximately 4 million $m^3.day^{-1}$ of biogas. If a mean month consumption of 170 kWh is considered, the electric energy produced from Brazilian swine production may attend to more than 350,000 homes.

CONCLUSION

Results on data survey with regard to swine production reveal that farmers who adopt the biodigester system featuring a 660 m^3 digestion chamber, biomass temperature at 20°C and 22-day HRT, would be receiving the energy required for the running of the farm and may also sell the surplus. They would also be employing biofertilizers for the improvement of the plantation´s productivity and thus employing economic and environmental alternatives.

Monitoring the effluent´s physical and chemical characteristics (BOD, COD, total phosphorus, pH, fixed solids, volatile solids and total solids), biomass temperature, HRT and the effluent´s dilution will warrant economic and environmental efficiency of the biodigester system.

It is highly necessary that in a future assay the costs for the installation of the system, the conversion of biogas into electric energy and the time necessary for investment gains would be analyzed and calculated.

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REFERENCES

ABUBAKER, J.; RISBERG, K.; PELL, M. Biogas residues as fertilisers - Effects on wheat growth and soil microbial activities, *Applied Energy*, v. 99, p.126–134, 2011.

ALMEIDA, G. V. B. P. Biodigestão Anaeróbica na Suinocultura. 2008. 54f. Trabalho de Conclusão de Curso (Graduação) - Curso de Medicina Veterinária. Centro Universitário das Faculdades Metropolitanas Unidas, UniFMU; São Paulo-SP, 2008. Available at <http://arquivo.fmu.br/prodisc/medvet/gvbpa.pdf>. on 25/11/2013.

ARAÚJO, I. S; OLIVEIRA, J. L. R.; ALVES, R. G. C. M.; FILHO, P. B.; COSTA, R. H. R. Avaliação de sistema de tratamento de dejetos suínos instalado no Estado de Santa Catarina. *Revista Brasileira de Engenharia Agrícola e Ambiental*. v.16, n.7, p.745–753, 2012.

ASTALS, S.; NOLLA-ARDÈVOL, V.; MATA-ALVAREZ, J. Anaerobic co-digestion of pig manure and crude glycerol at mesophilic conditions: Biogas and digestate. *Bioresource Technology*, v.110, p.63–70, 2012.

CAPPONI, S.; FAZIO, S.; BARBANTI. L. CO_2 savings affect the break-even distance of feedstock supply and digestate placement in biogas production, *Renewable Energy*, v.37, p.45-52, 2012.

CATAPAN, A.; CATAPAN, D. C.; CATAPAN. E. A. Alternative forms of electricity generation from the biogas: An approach to the cost of generation of energy, *Custos e @gronegócio on line*. v. 7, n. 1 - Jan/Apr - 2011.

CAVALCANTI, M. *Mercado de crédito de carbono e a atividade suinícola: uma análise de projetos e regiões do Brasil 2010*. In: CONGRESSO NACIONAL DE EXCELÊNCIA EM GESTÃO, 7, 2011. Rio de Janeiro, RJ. Anais... Rio de Janeiro: CNEG. Available at : <http://www.excelenciaemgestao.org/Portals/2/documents/cneg7/anais/T11_0351_1740.pdf>. on 11/1/2014.

CERVI, R. G.; ESPERANCINI, M. S. T.; BUENO, O. C. Viabilidade econômica da utilização do biogás produzido em granja suínícola para geração de energia elétrica, *Engenharia Agrícola*, Jaboticabal, v.30, n.5, p.831-844, set./out. 2010.

CHEN, Y. R.; HASHIMOTO, A. G. *Substrate Utilization Kinetic Model for Biological Treatment Processes.* Biotechnology and Bioengineering, 1980.

CHEN, L.; ZHAO, L.; REN, C.; WANG, F. The progress and prospects of rural biogas production in China. *Energy Policy*, v. 51, p.58-63, 2012.

COLDEBELLA, A. Viabilidade do uso do biogás da bovinocultura e suinocultura para geração de energia elétrica e irrigação em propriedades rurais. 2006. 74 f. Dissertação (Mestrado em Engenharia Agrícola) –Programa de Pós-Graduação em Engenharia Agrícola, Universidade Estadual do Oeste do Paraná, Cascavel-PR, 2006. Available at : <http://tede.unioeste.br/tede/tde_busca/arquivo.php?codArquivo=92>. On 25/11/2013.

CORRÊA, J. C.; NICOLOSO, R. S.; MENEZES, J. F. S.; BENITES, V. M.; Critérios técnicos para recomendação de biofertilizande de origem animal em sistemas de produção agrícolas e florestais. Comunicado Técnico 486, Embrapa/Suínos e Aves. Concórdia-SC, julho 2011. Available at : <www.cnpsa.embrapa.br/sgc/sgc_publicacoes/publicacao_v4d91o4i.pdf>. on 11/2/2014.

CORTEZ, L. A. B.; LORA, E. E. S.; GÓMEZ, E. O. Biomassa para energia. Campinas -SP. Ed. UNICAMP, 2008. 732 p.

DIESEL, R; MIRANDA, C. R.; PERDOMO, C. C.; Coletânea de tecnologia sobre dejetos suínos. Concórdia EMBRAPA, 2002 31p. EMBRAPA-CNPSA. Documentos, 14. Available at: <http://docsagencia.cnptia.embrapa.br/suino/bipers/bipers14.pdf>. on 25/7/2013.

FLESCH, T. K.; DESJARDINS, R. L.; WORTH, D. Fugitive methane emissions from an agricultural biodigester. *Biomass and Bioenergy*, v.35, p.3927-3935, 2011.

FONSECA, F. S. T.; ARAÚJO, A. R. A.; HENDGES, T. L. *Análise de viabilidade econômica de biodigestores na atividade suinícola na cidade de Balsas-Ma, um estudo de caso*. In: SOCIEDADE BRASILEIRA DE ECONOMIA ADMINISTRAÇÃO E SOCIOLOGIA RURAL, SOBER, 47. Porto Alegre, 26 a 30 de julho de 2009. Anais eletrônicos...SOBER, Porto Alegre, 2009; Available at:<http://www.sober.org.br/palestra/13/687.pdf>. on 30/10/2013.

GUO, J.; OSTERMANN, A.; SIEMENS, J.; DONG, R.; CLEMENS, J. Short term effects of copper, sulfadiazine and difloxacin on the anaerobic digestion of pig manure at low organic loading rates. *Waste Management*, v.32, p.131–136, 2012.

HASHIMOTO, A. G.; CHEN, Y. R.; VAREL, V. H. *Theoretical aspects of Methane Production: State of The Art.* In: LIVESTOCK WASTES: A RENEWABLE RESOURCE, ASAE, 1981.

INSTITUTO AMBIENTAL DO PARANÁ. Instrução Normativa 105.006. de 05 de janeiro de 1998. Licenciamento e/ou autorização de ambiental de empreendimentos de suinocultura. Instituto Ambiental Paranaense. Available at <http://www.iap.pr.gov.br/arquivos/File/Legislacao_ambiental/Legislacao_estadual/Instrucao_normativa/IN_105006_2004.pdf>. on 29/1/2014.

KONZEN, E. A. Manejo e utilização dos dejetos de suínos. Concórdia: EMBRAPACNPSA, EMBRAPA-CNPSA. Circular Técnica, 6, 1983.

KUNZ, A.; OLIVEIRA, P. A. V. de; Uso de biodigestores para tratamento de resíduos animais. Embrapa/Suínos e Aves. Concórdia-SC, junho 2008. Available at <http://www.infoteca.cnptia.embrapa.br/bitstream/doc/444153/1/CUsersPiazzonDocuments17238.pdf>. on 10/2/2014.

LEI n° 9.605, de 12 de fevereiro de 1998. Dispõe sobre as sanções penais e administrativas derivadas de condutas e atividades lesivas ao meio ambiente, e dá outras providências. Diário Oficial [da] República Federativa do Brasil, Brasília, DF, 12 fev. 1998. Available at: <http://www.planalto.gov.br/ccivil_03/leis/l9605.htm>. on 20/11/2013.

LIMA, P. C. R. Biogás da suinocultura: uma importante fonte de geração de energia. Biblioteca Digital da Câmara dos Deputados, Brasília-DF, 2007. Available at <http://bd.camara.leg.br/bd/bitstream/handle/bdcamara/1724/biogas_suinoculltura_lima.pdf?sequence=4>. On 16/1/2014.

MARTÍ-HERRERO, J.; CIPRIANO, J. Design methodology for low cost tubular digesters. *Bioresource Technology*, v.108, p. 21–27, 2012.

MARTINS, F. M.; OLIVEIRA. P. A. V. Análise econômica da geração de energia elétrica a partir do biogás na suinocultura. *Engenharia Agrícola*, Jaboticabal, v.31, n.3, p.477-486, maio/jun. 2011

MINISTÉRIO DA AGRICULTURA PECUÁRIA E ABASTECIMENTO. Secretaria de Defesa Agropecuária. Instrução Normativa n° 25 de 23 de julho de 2009. Estabelece as normas sobre as especificações e as garantias, as tolerâncias, o registro, a embalagem e a rotulagem dos fertilizantes orgânicos simples, mistos, compostos, organominerais e biofertilizantes destinados à agricultura. Diário Oficial [da] República Federativa do Brasil, Brasília, DF, n. 142, 28 jul. 2009. Seção 1, p. 20. Available at: < http://www.agricultura.pr.gov.br/arquivos/File/PDF/in_25_09.pdf>. On 11/2/2014.

MOLLER, H. B.; SOMMER, S. G.; AHRING, B. K. Methane Productivity of Manure, Straw, and Solid Fractions of Manure. *Biomass and Bioenergy,* 26, 2004 p. 485-495.

MONDARDO, D.; CASTAGNARA, D. D.; OLIVEIRA, P. S. R. DE; ZOZ, T.; MESQUITA, E. E. Produção e composição químico-bromatológica da aveia preta fertilizada com doses crescentes de dejeto líquido suíno. *Revista Ciência Agronômica*, v. 42, n. 2, p. 509-517, abr-jun, 2011.

NISHIMURA, R.; Análise de balanço energético de sistema de produção de biogás em granja de suínos: implementação de sistema computacional. 2009. 84 p. Master´s Dissertation in Electric Engineering - Universidade Federal do Mato Grosso do Sul, Campo Grande-MS, 2009.

OLIVEIRA, P. A. V. Manual de manejo e utilização dos dejetos de suínos. Concórdia-SC: EMBRAPA, 1993. 188p. EMBRAPA-CNPSA. Documentos, 27.

OLIVEIRA, P. A. V. Projeto de biodigestor e estimativa da produção de biogás em sistema de produção. Comunicado Técnico 417. Concórdia –SC: EMBRAPA, 2005. Available at <http://ainfo.cnptia.embrapa.br/digital/bitstream/item/86221/1/DCOT-417.pdf>. on 10/2/2014.

OLIVEIRA, S. V. W. B.; LEONETI, A. B.; CALDO, G. M. M.; OLIVEIRA, M. M. B. Generation of bioenergy and biofertilizer on a sustainable rural property, *Biomass and Bioenergy*, v.35, p. 2608-2618, 2011

OLIVEIRA, P.; A. V., HIGARASHI, M. M.; Geração e utilização de biogás em unidades de produção de suínos. Embrapa Suínos e Aves, Concórdia SC, 42p., 2006. Available at: <http://www.infoteca.cnptia.embrapa.br/bitstream/doc/856124/1/doc115.pdf>. on 27/1/2014.

PERDOMONO, C. C; OLIVEIRA, P. A. V; KUNZ, A. Sistemas de Tratamento de Dejetos Suínos: Inventário Tecnológico. Embrapa Suínos e Aves. Concórdia-SC, 2003.

PIVELI, R. P.; KATO, M. T.; Qualidade das águas e poluição: aspectos físico-químicos. Associação Brasileira de Engenharia Sanitária e Ambiental-ABES, São Paulo-SP, 2005.

REGUEIRO, L.; CARBALLA, M.; ÁLVAREZ, J. A.; LEMA, J. M. Enhanced methane production from pig manure anaerobic digestion using fish and biodiesel wastes as co-substrates, *Bioresource Technology*, v.123, p. 507–513, 2012.

RODRÍGUEZ, L.; SALAZAR, P.; PRESTON, T. R. Effect of a culture of “native” micro-organisms, biochar and biodigester effluent on the growth of maize in acid soils. *Livestock Research for Rural Development*, v.23, n.10, p.1-7, 2011

SHI, J. C.; LIAO, X. D.; WU, Y. B.; LIANG, Y. B. Effect of antibiotics on methane arising from anaerobic digestion of pig manure. *Animal Feed Science and Technology*, v. 166–167, p. 457–463, 2011.

SOUZA, C. F.; JUNIOR, J. de L.; FERREIRA, W. P. M. Biodigestão Anaeróbia de dejetos suínos sobre efeito de três temperaturas e dois níveis de agitação do substrato. *Revista Engenharia Agrícola*, Jaboticabal-SP, v.25, n.2, p. 530-539, maio/ago. 2005.

SOKCHEA, H.; PRESTON, T. R. Growth of maize in acid soil amended with biochar, derived from gasifier reactor and gasifier stove, with or without organic fertilizer (biodigester effluent). *Livestock Research for Rural Development*, v.23, n.4, p.1-7, 2011.

THU, C. T. T.; CUONG, P. H.; HANG, L. T.; CHAO, N. V.; ANH, L. X.; TRACH, N. X.; SOMMER, S. G. Manure management practices on biogas and non-biogas pig farms in developing countries e using livestock farms in Vietnam as an example, *Journal of Cleaner Production*, v.27, p.64-71, 2012.