Effect Of Co-Digesting Pig Slurry With Maize Stalk On Biogas Production At Mesophilic Temperature

Ademola Oyejide ADEBAYO
Department of Agricultural Engineering,LAUTECH, Ogbomoso, Oyo State, Nigeria
aoadebayo57@lautech.edu.ng`
ademolaadebayo1@yahoo.com
(Corresponding author)

Simeon Olatayo JEKAYINFA
Dept. of Agricultural Engineering LAUTECH, Ogbomoso, Oyo State, Nigeria
jekaysol@yahoo.com

Bernd LINKE
Leibniz-Institute for Agricultural Engineering (ATB), Max-Eyth-Allee100, D - 14469 Potsdam, Germany
blinke@atb-potsdam.de

***Abstract*—The present energy crisis has stimulated various research programmes to evaluate energy potentials of renewable energy sources. To this end, the effect of co-digesting pig slurry with maize stalks was studied in a fed-batch reactor at mesophilic temperature (37^{o}C) for 36 days. The digester was fed with pig slurry-maize stalk mixtures calculated for the selected ratios based on the volatile solid (VS) concentration of the selected substrates. The co-digestion of pig slurry/ maize stalk at ratios 1:0, 3:1, 1:1 and 1:3 gave biogas yields of 176.77, 253.80, 261.45 and 340.38 l_N/kg_{oDM} respectively while the methane yields were 136.33, 177.31, 187.91 and 232.80 l_NCH_4/kg_{oDM} respectively. At the same ratios, using the fresh mass of the selected substrates, biogas yields of 16.49, 27.64, 34.20 and 55.71 l_N/kg_{FM} were obtained for pig slurry-maize stalk while the methane yields from the fresh mass for the same ratios were 12.72, 19.31, 24.58 and 38.10 l_NCH_4/kg_{FM} respectively. Co-digestion of pig slurry with maize stalk was found to have methane concentrations of 77.12, 69.86, 71.87 and 68.40% at pig slurry/maize stalk ratios of 1:0, 3:1, 1:1 and 1:3 respectively. The study revealed that co-digesting pig slurry with maize stalk at ratio 1:3 is optimum for biogas production (yields).**

Keywords—Co-digestion, pig slurry, maize stalk, batch experiment, mesophilic temperature

I. INTRODUCTION

Anaerobic digestion is a complex biochemical process carried out in a number of steps by several types of microorganisms in the absence of oxygen. Methane and carbon dioxide are the principal end products, with minor quantities of nitrogen, hydrogen, ammonia and hydrogen sulphide. The breaking down of biodegradable materials in the absence of oxygen produces biogas suitable for energy conversion (Chae *et al.,* 2002, Vindis *et al.,* 2009, Wei, 2007).

Anaerobic processes have many advantages over the corresponding aerobic processes, such as low consumption of energy and low sludge production, smaller space requirements and lower overall costs (Demirel and Yenigun, 2002; Ahn *et al*., 2001; Ligero *et al*., 2001; Lema and Omil, 2001). Anaerobic route has an obvious advantage in that it produces methane, a combustible gas with a high calorific value (24MJ/m^3). Anaerobic digestion consists of several inter-dependent, complex sequential and parallel biological reactions, during which the products from one group of microorganisms serve as the substrates for the next, resulting in transformation of organic matter mainly into a mixture of methane and carbon dioxide. Anaerobic digestion takes place in four phases: hydrolysis/ liquefaction, acidogenesis, acetogenesis and methanogenesis. Biogas generally composes of methane,CH4, (55-65%), carbon dioxide, CO2 (35-45%), nitrogen, N2 (0-3%), hydrogen, H2 (0-1%), and hydrogen sulphide H2S (0-1%), (Chomchat *et al.,* 1984; Milono *et al.*, 1981).

Anaerobic digestion of the large quantities of municipal, industrial and agricultural solid waste can provide biogas as well as other benefits such as reduction in waste volume, the production of bio-fertiliser and valuable soil conditioners (Edelmann *et al.,* 2000; Grommen and Verstraete, 2002; Lema and Omil, 2001; Lettinga, 2004). Several researchers have used various wastes in producing biogas. For example, solid municipal wastes (Igoni *et al.,* 2008; Ojolo *et al.,* 2008; Nordberg and Edstron, 2005), fruit and vegetable processing wastes (Sumitradevi and Krishna, 1989; Mata *et al*., 1993), animal wastes (Adebayo *et al.,* 2015, Itodo and Kucha, 1998; Zuru *et al*.,1998; Sadaka and Engler, 2000) and Water hyacinth (Lucas and Bamgboye, 1998; Patil *et al.,* 2011). Others worked on co-digestions of animal wastes and crop residues (Adebayo *et al*., 2013, 2014, 2015, Riano *et al.,* 2011, Wu *et al.,* 2010; Xie *et al.,* 2011, Ogunwande *et al.,* 2013). Co-digestion has been established to improve biogas production (Adebayo *et al.,* 2013, 2014a, 2014b, Adelekan and Bamgboye 2009). However, information on the co-digestion of pig manure with maize stalks at different ratios with the purpose of boosting the biogas production capability of pig manure has not been exhaustively expunged. This study aimed at determining the biogas production potentials of pig slurry co-digested with maize stalk in a fed batch reactor at mesophilic temperature.

1. Materials and Methods

2. Materials and Methods

2.1 Sources of organic materials

Maize plants were harvested from the Institute for Animal Breeding and Animal Husbandry (ABAH), Ruhlsdorf / Grosskreutz, Germany and the cobs were separated for experimentation. Pig slurry was also obtained from the same institute (ABAH).

2.2 Methodology

All samples were kept in the laboratory at a +3°C after size reduction prior to feeding into the digester. The amount of substrate and seeding sludge weighed into the fermentation bottles were determined in accordance to German Standard Procedure VDI 4630 (2004) using the equation 1:

$$\frac{oTS_{substrate}}{oTS\ seeding\ sludge} \leq 0.5 \qquad (1)$$

Where:

oTS $_{substrate}$ = organic total solid of the substrate and;

oTS $_{seeding\ sludge}$ = organic total solid of the seeding sludge (the inoculum)

The batch experiment was carried out in a lab-scale bottles with two replicates as described by Linke and Schelle (Linke and Schelle, 2000). A constant temperature of 37°C was maintained through a thermostatic cabinet heater (Plate 1). Anaerobically digested material from a preceding batch experiment was used as inoculum for this study. The chemical and thermal properties of the substrates used and that of the inoculum were determined in the laboratory using standard methods (Table 1). Vessels (0.9 litre capacity) were filled with 800g of the stabilized inoculum. The substrates fed into the digestion bottles were calculated using equation (3). Pig slurry / maize stalk mixtures of 56.9, 42.60, 34.05 and 28.35 g were loaded for ratios 1: 0, 3:1, 1:1 and 1:4 respectively. These calculated amounts of the substrates (using equation 3) were added to 800g inoculums to ensure compliance of the oDM feedstock to ODM inoculum ratio being less or equal 0.5 as recommended in VDI 4630 (equations 1 and 2). Two digestion vessels were also filled with 800g of inoculums only as control. The biogas produced was collected in scaled wet gas meters over a defined period of 36 days. This duration of the test fulfilled the criterion for terminating batch anaerobic digestion experiments given in VDI 4630 (daily biogas rate is equivalent to only 1% of the total volume of biogas produced up to that time). The volume of the gas produced was measured and recorded daily through the gas collector. Besides, other gas components, methane (CH_4) and carbon dioxide (CO_2) contents were determined four times during the batch fermentation test using a gas analyser GA 2000. The tests were conducted in two replicates. Plate 1 shows the set up of the batch experiment conducted at mesophilic temperature (37^{o}C).

Quantitative evaluation of the results gained in batch anaerobic digestion tests included the following steps: standardizing the volume of biogas to normal litres (1_N); (dry gas, t_0=273 K,p_0=1013hPa) and correcting the methane and carbon dioxide contents to 100% (headspace correction, VDI 4630). Readings were analysed using Microsoft Excel spread sheet together with "Table curve" computer software. Accumulated biogas yields over the retention time were fitted by regression analysis using Hill-Kinetic equation in order to determine the maximum biogas and methane potentials of the selected substrates.

The amount of substrate fed into the digester was calculated using equation (2).

$$oTS\ substrate \leq \frac{oTS_{seedingSludge}}{2} \qquad (2)$$

Equation (2) can be modified to read

$$p_i = \frac{m_i . c_i}{m_s c_s} \qquad (3)$$

(3)

Where

p_i= mass ratio=2 ; m_i= amount of inoculum, g

c_i=Concentration of inoculum, oDM in % Fresh mass

m_s= amount of substrate,g

c_s= Concentration of substrate, oDM in % fresh mass

Plate 1: Experimental set up for batch digestion

Readings of the gas production (ml), air pressure (mbar), gas temperature (^{o}C) and time of the day were taken on daily basis throughout the period of the experiment. The gas was analysed with the use of gas analyser GA 2000 at least twice per week for the four weeks of the experiment. Biogas production and gas quality from pig slurry (PS) and maize stalks (MS)were analyzed in batch anaerobic digestion test at 37°C according to German Standard Procedure VDI 4630 (2004). The gas factor was calculated as well as the fresh mass biogas and methane yield with the volatile solid biogas and methane yields also determined on daily basis. The amount of gas formed was converted to standard conditions (273.15 K and 1013.25 mbar) and dry gas. The factor was calculated according to equation 3.

$$F = \frac{\left(p - P_{H_2O}\right).T_o}{(t + 273.15).p_o} \quad (4)$$

Where

T_o= 273.15 °C (Normal temperature)
t= Gas temperature in °C
P_o= 1013.25 mbar (standard pressure)
P= Air Pressure

The vapour pressure of water P_{H_2O} is dependent on the gas temperature and amounts to 23.4 mbar for 20°C. The respective vapour pressure of water as a function of temperature for describing the range between 15 and 30°C is given as in equation 4

$$P_{H_2O} = y_o + a.e^{b.t} \quad (5)$$

Where:
y_o = -4.39605; a = 9.762 and b= 0.0521
The normalized amount of biogas volumes is given as

$$Biogas[N\,ml] = Biogas[ml] \times F \quad (6)$$

Normalized by the amount of biogas, the amount of gas taken off of the control batch is given as

$$Biogas[N\,ml] = (Biogas[Nml] - Control[Nml]) \quad (7)$$

The mass of biogas yield in standard liters / kg FM fresh mass (FM) is based on the weight
The following applies:
1 standard ml / g FM=1 standard liters / kg FM = 1 m^3 / t FM

$$Mass\,of\ biogas\ yield = \sum \frac{Biogas[N\,ml]}{Mass[g]} \quad (8)$$

The oDM biogas yield is based on the percentage of volatile solids (VS) in substrate

$$oDM\ biogas\ yield = \sum \frac{Biogas[N\,ml).100]}{Mass[g].VS[\%FM]} \quad (9)$$

$$CH_{4corr.} = \frac{CH_4[vol\%].100}{(Mass[g] + CO_2[vol\%])} \quad (10)$$

$$Fresh\,Mass\,Methane\ yield = \frac{Fresh\,mass\,biogas\ yield \times CH_{4corr.}}{100} \quad (11)$$

$$oDM\ Methane\ yield = \frac{oDM\ biogas\ yield \times CH_{4corr.}}{100} \quad (12)$$

2.2 Substrates and Analytical Procedures

Samples of pig slurry (PS) and maize stalks (MS) were investigated for Fresh matter (FM), organic Dry Matter (105°C), Organic Dry Matter in % fresh mass, pH, NH_4-N and Conductivity, C (Table 1). The inoculum for the batch anaerobic digestion tests was also analyzed for the following parameters DM, ODM, pH, organic acids and the electrical conduction. All analyses were performed according to German standard methods (Linke and Schelle, 2000).

A. Results and Discussion

3. Results and Discussion

Table 1 shows the results of the chemical analysis of the selected substrates before digestion. Figures 1-4 show the fresh mass biogas yields, fresh mass methane yields, organic dry matter biogas yields and organic dry matter methane yields from the co-digestion of pig slurry with maize stalks. In the co-digestion of pig slurry with maize stalk under mesophilic condition (37°C), the fresh mass biogas yields at ratios 1:0, 3:1, 1:1 and 1:3 were found to be 16.49, 27.64, 34.20 and 55.71 l_N/kg_{FM} respectively with the fresh mass methane yields for the same combinations being 12.72, 19.31, 24.58 and 38.10 l_NCH_4/kg_{FM} respectively (Figures 1 and 2).

In the same vein, the biogas yields (oDM) of pig slurry co-digested with maize stalk at the same ratios were found to be 176.77, 253.80, 261.45 and 340.38 l_N/kg_{oDM} while the methane yields (oDM) were respectively found to be 136.33, 177.31, 187.91 and 232.80 l_NCH_4/kg_{oDM} when experimented at mesophilic temperatures (Figs. 3 and 4). The methane concentrations were found to be 77.12, 69.86, 71.87 and 68.40% at pig slurry/maize stalk ratios of 1:0, 3:1, 1:1 and 1:3 respectively. The C/N ratio of maize stalk (54:1) which indicated a high carbon content and low nitrogen content was compensated for by the low C/N ratio of pig slurry (16:1) and thereby influenced the biogas and methane yields. The results showed that co-digestion of pig slurry with maize stalks at ratio 1:3 produced the maximum biogas and methane when compared to the results obtained at the other two combinations which means that for better yield, it is better to co-digest at this ratio (1:3).

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Table 1: Chemical and thermal properties of the selected substrates

Parameter	Analysis		
	Pig Slurry	Maize Stalk	Inoculum
Dry Matter, DM (105°C)-%	12.33	45.54	2.21
Organic Dry Matter (oDM, %DM)	75.68	90.75	60.06
Organic Dry Matter (%FM)	9.33	41.33	1.33
NH_4-N (g/kgFM)	4.33	<2	1.02
Crude Fibre (%DM)	-	39.07	-
Conductivity (ms/cm)	21.9	0.911	14.36
pH	7.98	6.40	7.95
Fat (% DM)	-	1.61	-
Potassium (% DM)	3.87	1.22	15.50
Ethanol (g/l)	<0.02	<0.04	<0.04
Propanol	<0.02	<0.04	<0.04
Total Acetic Acid	11.49	0.17	0.33

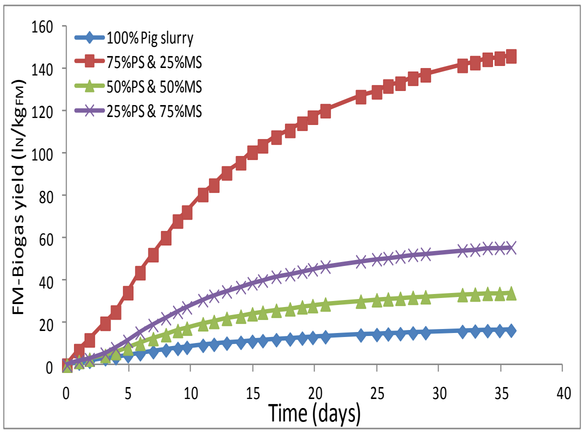

Figure 1: Fresh-mass biogas yields of pig slurry co-digested with maize-stalk at 37°C

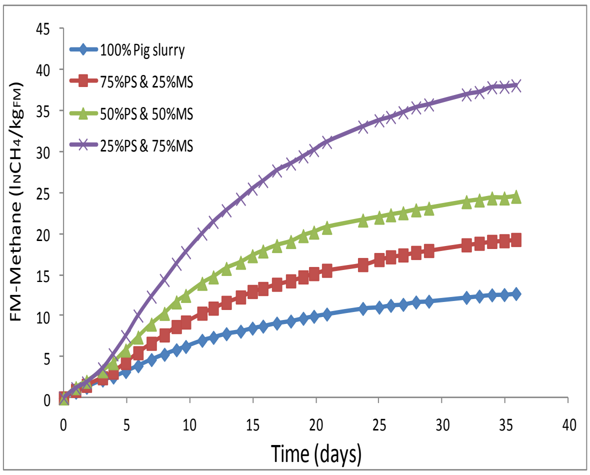

Figure 2: Fresh-mass methane yields of pig slurry co-digested with maize-stalk at 37°C

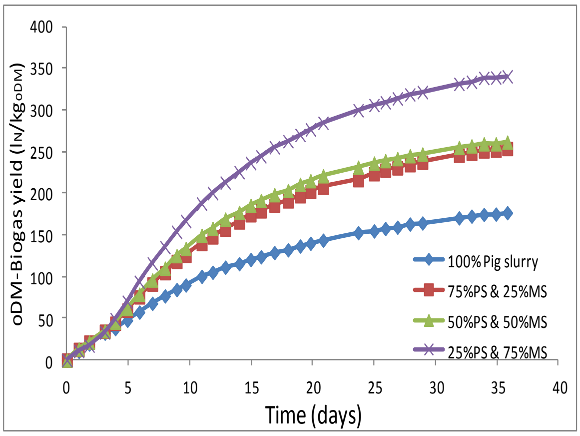

Figure 3: oDM biogas yields of pig slurry co-digested with maize-stalk at 37°C

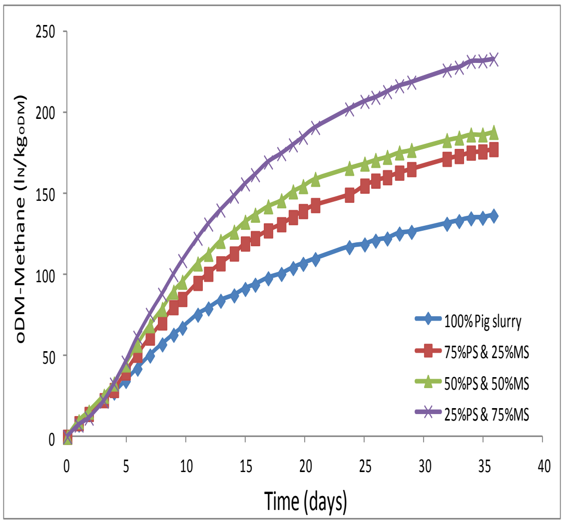

Figure 4: oDM methane yields of pig slurry co-digested with maize-stalk at 37°C

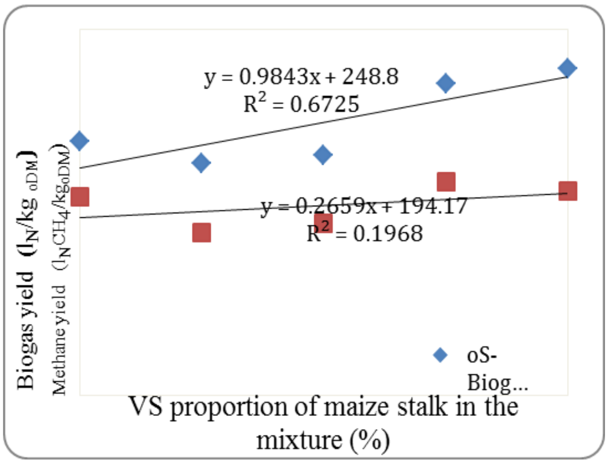

Figure 5: Co-digestion of pig slurry with maize stalk

Conclusion

The study has shown that Co-digestion of pig slurry with maize stalk at mesophilic temperature led to increase in both biogas and methane yield. Also, co-digestion ratio of 1:3 of pig slurry and maize stalks was adjudged the best in terms of biogas and methane yields.

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