valorisation of Piggery Sludge to Biogas to Bio-Solids Through Anaerobic Digestion

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Abstract

The potential to recover biogas and biosolids from piggery sludge was investigated as a waste management technique. Three 1L biodigesters were loaded with piggery slurry and anaerobic digestion took place over 35 days under mesophilic conditions of 35 ±1 ◦C. The piggery sludge properties which included pH, total solids (TS), chemical oxygen demand (COD), biogas, and biosolids compositions were measured using standard techniques. MATLAB R2013a was used for the determination of the linear models for changes in COD, TS, pH, and amount of biogas generated at a 95% confidence interval. The R^2 and the SSE were used to determine the accuracy of the derived models. As the digestion period increased the sludge's total solids content and chemical oxygen demand decreased by 80% and 90% respectively. Cumulative biogas of approximately 4 L/day was achieved with a peak at 30 days. The biogas produced had a methane composition of 65%. Accurate models with R^2 values of >0.9 can be used to determine the changes in the given parameters during biogas production. Anaerobic digestate was harnessed with an average of 4.2% nitrogen, 0.5% phosphorous, and 4.7% potassium.

Keywords:
Biogas, biosolids, resource recovery, piggery sludge, waste vaporization

1. Introduction

The piggery industry is among the major industries in Southern Africa and it generates a lot of unwanted biowaste (Kwasny et al. 2011). This piggery industry therefore poses an environmental threat if not properly managed due to the generation of greenhouse gases to the environment overall leading to climate change. The piggery industry provides waste in both liquid and solid forms and if not managed results in land, water, and air pollution (Campos et al., 2002; Gebreeyessus and Jenicek, 2016). The solid waste from the manure can be a source of raw material for biogas generation that can be used for renewable energy (methane) as well as a source for biofertilizers like any other source of biowaste (Makadi et al., 2012). The sources of waste generated in the piggery industry are shown in Figure 1.

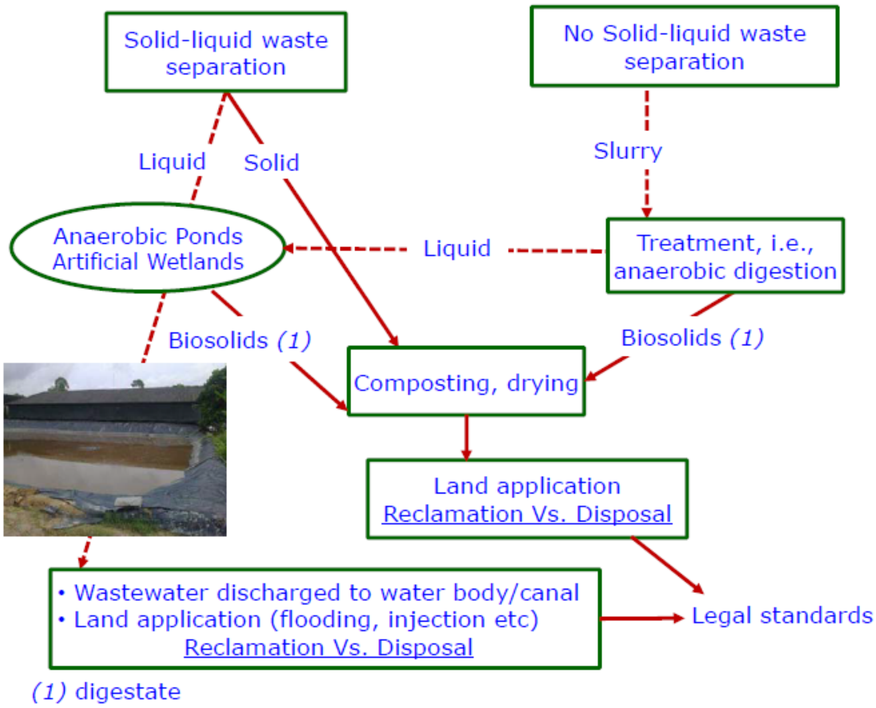

Figure 1. Waste management initiatives in the piggery industry (Gonzalez-Soria, 2012)

Biogas, the attractive option in terms of renewable energy is generated from biomass through various processes such as hydrolysis, acidogenesis, acetogenesis and methanogenesis (Kuusiku et al.2014; Masebinu et al. 2014; Alrawashdeh et al. 2017). The processes occur schematically and are described in detail below:
Step 1: Hydrolysis-At this stage there is hydrolysis of the complex organic materials to soluble products
Step 2: Acidogenesis-This step involves the generation of intermediary products such as short-chain fatty acids and involves the production of hydrogen and acetogenic micro-organisms
Step 3: Acetogenesis-This stage involves the production of hydrogen-consuming acetogenic micro-organisms.
Step 4: Methanogenesis is the methane production process and methane-forming bacteria is released.

Biogas production is a sensitive process and the process conditions must be monitored continuously during the process. The various stages of biogas production are shown schematically in Figure 2. During biogas generation, gases like methane (CH_4), carbon dioxide (CO_2), hydrogen (H_2), ammonium (NH_4), ammonia (NH_3) and hydrogen sulfide (H_2S) are generated.

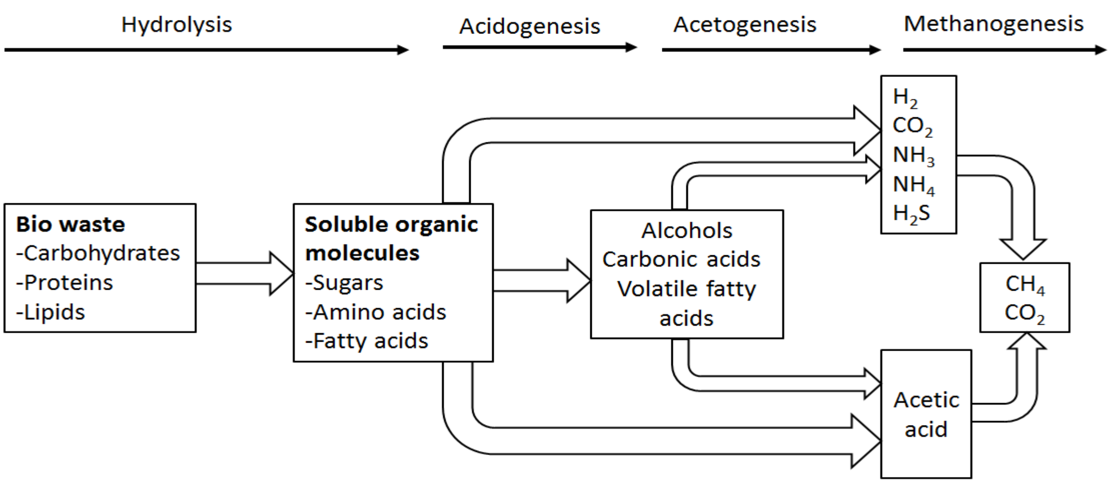

Figure 2. Biogas production processes from piggery waste

The value addition of animal waste, piggery sludge included promotes energy recovery, reduction of waste for disposal at landfill, and also reduces emissions for disposal (Pontoni et al., 2015). This study therefore looked at the potential of value-adding piggery sludge to biogas and bio solids as a waste valorisation initiative.

2. Materials and Methods

Piggery sludge was obtained from a local piggery slaughterhouse. Mesophilic conditions of 30 ±1 ◦C were employed in this study and these were maintained by the use of a water bath. Mesophilic conditions are perfect for biogas production from animal waste (Bergland et al., 2015; Toma et al. 2016). Mechanically stirred biodigesters with a capacity of 1L were used as the anaerobic digestion vessels. A retention period of 35 days was used. The composition of the gas was measured after every 5 days. A biogas 5000 gas analyzer was used for the biogas composition determination. The cumulative amount of biogas in the biodigesters was measured using the water displacement technique.

The temperature and pH were measured using a Hanna 98194 multiparameter sensor. The pH adjustment was done using 10M sodium hydroxide (NaOH). The total amount of solids (TS) was measured using a PCE MB Thermo balance through centrifugation at 5000 rpm and then membrane filtration with a 0.45 micrometer (μm). The volatile solids (VS) were measured using the gravimetric method in accordance to the EPA standard method N 1684. The moisture content of the piggery sludge was measured using the ASTM Standard D 44442-07. The chemical oxygen demand (COD) of the piggery sludge was measured using a Hach DR3900 Laboratory VIS spectrometry. Moisture content was measured using a MoistureTech IR 3000 sensor. The total nitrogen composition in the bio-solids was measured using the KJeldhal method. The total phosphate was measured using the Hach DR3900 Laboratory VIS spectrometry whilst the total potassium was measured using the Perkins Elmer 3110 AAS**.** All experiments done in this study were done in triplicates. MATLAB R2013a was used for determining the linear models for changes in pH, TS, COD, biogas and methane generation at 95% confidence interval.

3. Results and Discussion

3.1 Feedstock properties

The piggery sludge had a high composition of total solids (TSS) with an average of 60% as well as high COD averaging between 32%. These properties are indicated in Table 1 and are critical for the anaerobic digestion of piggery sludge to biogas and biosolids.

Table 1. Piggery sludge feedstock properties

Parameter	Content (%)
Organic matter (OM)	39.3-40.9
Volatile solids (VS)	26.5-29.6
Total solids (TS)	58.6-65.7
pH	6.5-7.4
Moisture content (MC	63.1-70.6
Chemical oxygen demand (COD)	29.8-35.2

3.2 Biogas and biosolids generation process

The biogas and bio-solids generation process from piggery sludge is indicated in Figure 3. The piggery sludge is fed into a bio-digester where the biogas generation process is allowed to take place. The biogas generated has the potential to generate electricity and thermal energy whilst the biosolids can be used as a source of biofertilizers (Figure 3).

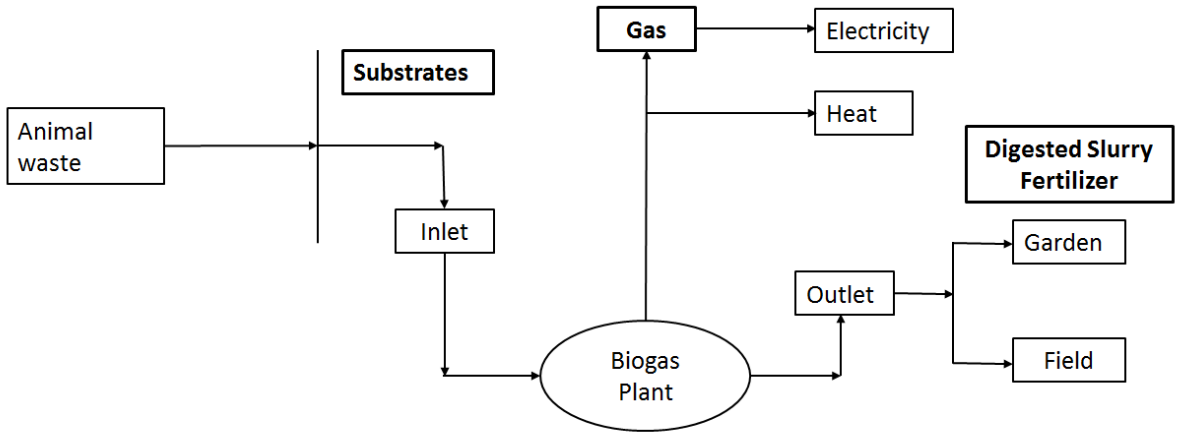

Figure 3. Biogas from piggery sludge production process

3.3 Effect on process factors

3.3. 1 pH changes

As the anaerobic digestion process of the piggery sludge occurred, the pH changed to neutral in all the reactors. The methanogenesis process is very sensitive to pH and these must be closely monitored to maintain almost neutral conditions (Hamawand and Baille, 2015; Pontoni et al., 2015). The biogas production was optional for pH around 7 (Keramiti and Beiki, 2017). The pH trend during the piggery sludge bioconversion is given in Figure 4.

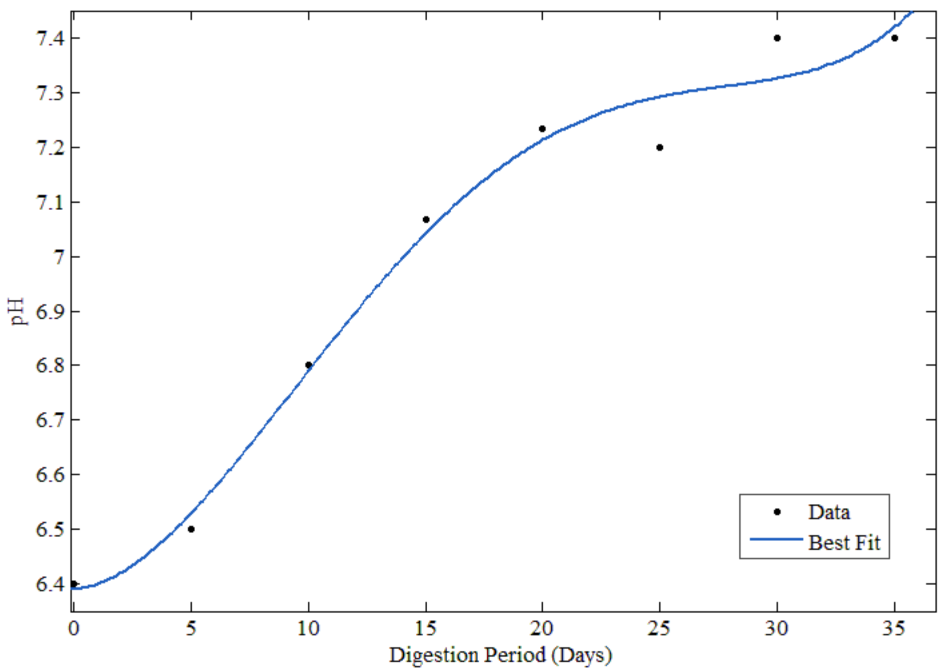

Figure 4. pH changes during biogas production

The linear model that describes the pH changes during the anaerobic digestion process is given by Equation 1. The linear polynomial model had an R^2 value of 0.98 with an SSE of 0.0165 indicating the good fit of the model.

$$f\ (x) = p_1 x^4 + p_2 x^3 + p_3 x^2 + p_4 x + p_5 \dots\dots\dots\dots\dots\dots\dots.. (1)$$

Where the coefficients at 95% confidence interval are:

p_1 = 3.94e-06 (-4.94e-06, 1.28e-05)

p_2 = -0.00029 (-0.0009179, 0.0003341)

p_3 = 0.0061 (-0.0079, 0.020)

p_4 = 0.0041 (-0.10, 0.11)

p_5 = 6.39 (6.16, 6.62)

3.3.2 TSS changes

The total solids (TSS) indicate the total amount of solids that are available for bio conversion into biogas (Nagy and Wopera, 2012; Toma et al., 2016). As the anaerobic digestion progressed, the number of solids in the sludge significantly decreased by more than 80%, indication the increase in the biogas production rate with time. The TS changes are represented in Figure 5.

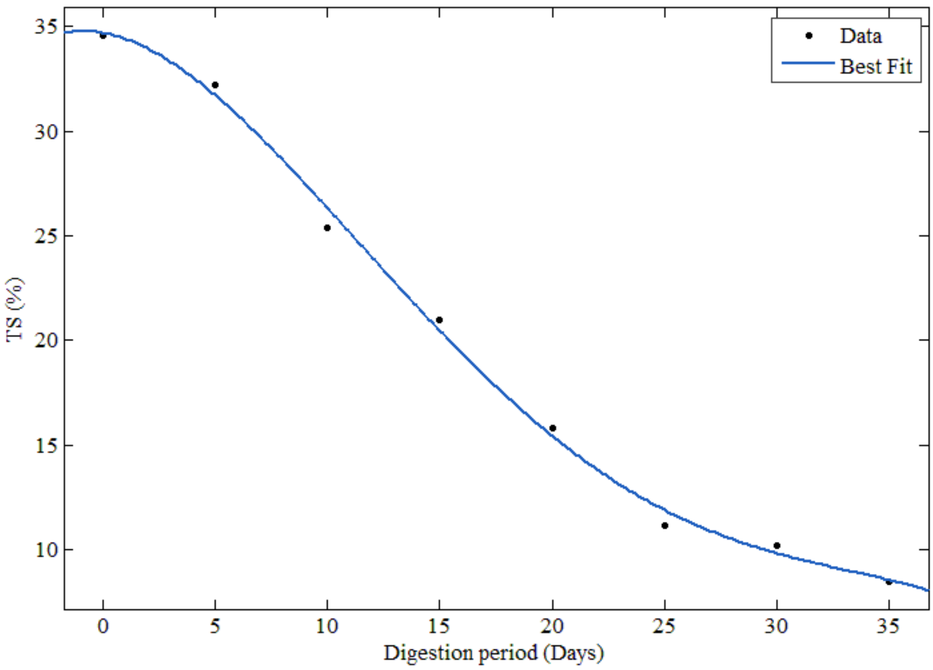

Figure 5. TS changes during biogas production from piggery sludge

The linear 4th-order polynomial model that described the change in TS is given in Equation 2.

$$f(x) = p_1 x^4 + p_2 x^3 + p_3 x^2 + p_4 x + p_5 \dots\dots\dots\dots\dots\dots\dots..(2)$$

Where the coefficients at 95% confidence interval are:

p_1 = -4.38e-05 (-0.00015, 5.92e-05)

p_2 = 0.0039 (-0.0033, 0.011)

p_3 = -0.099 (-0.26, 0.064)

p_4 = -0.18 (-1.45, 1.07)

p_5 = 34.68 (31.97, 37.38)

The linear polynomial model had an R^2 value of 0.99 with an SSE of 2.22 indicating a good fit of the predicted polynomial model.

3.3.4 COD changes

The chemical oxygen demand (COD) decreased with an increase in the digestion period of the piggery sludge (Figure 6). During biogas production, the COD was converted by the micro-organisms (Sumardiono et al., 2013). COD decreases of more than 90% were observed during the anaerobic digestion of piggery sludge to biogas thus indicating the high biodegradability of the piggery slurry.

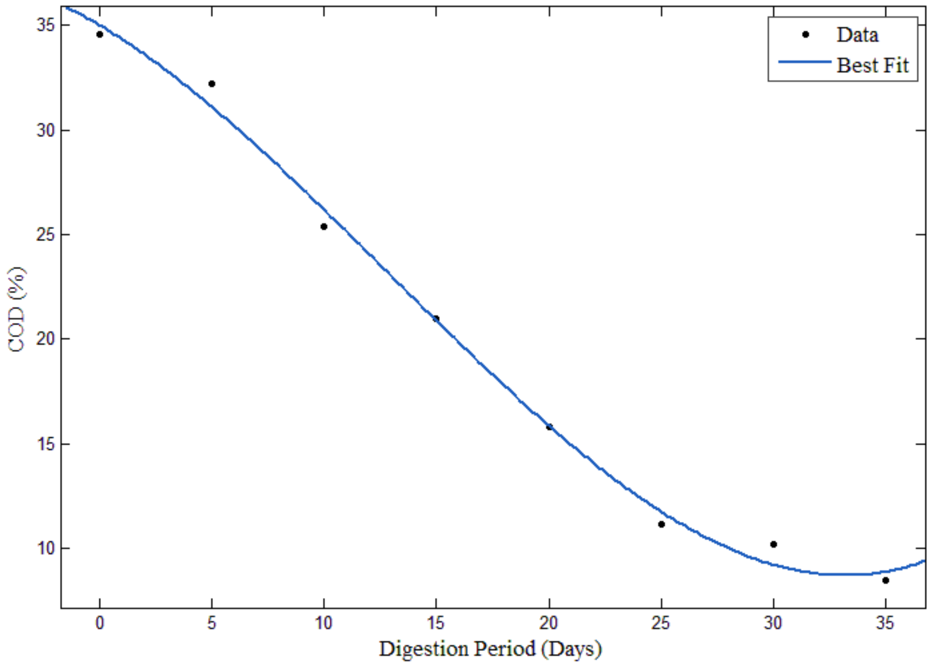

Figure 6. COD changes during biogas production from piggery sludge

The COD changes during biogas production are represented by the linear polymeric model order 3 in Equation 3. The linear polynomial model had an R^2 value of 0.99 with an SSE of 3.58.

$$f\,(x) = p_1 x^3 + p_2 x^2 + p_3 + p_4 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

Where the model coefficients at 95% confidence interval were:

p_1 = 0.00086 (-3.44e-06, 0.0017)
p_2 =-0.033 (-0.079, 0.013)
p_3 = -0.64 (-1.30, 0.025)
p_4 = 35.01 (32.52, 37.49)

3.4 Biogas production

The biogas production rate increased with increase in the digestion period (Figure 7).Before 15 days, the biogas production was minimal and then a peak was an achieved at 30 days. As the digestion time increased, the methanogens which are good in biogas production were produced leading in increased amount of biogas produced. The same trends in biogas production have been observed from literature (Campos et al., 2002; Toma et al; 2016).

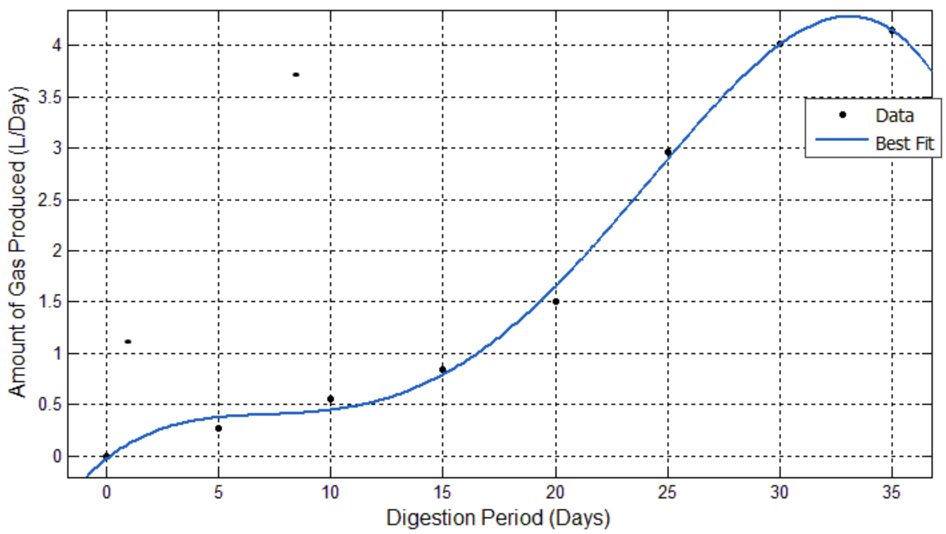

Figure 7. Cumulative biogas production from piggery sludge

The biogas production rate from the valorisation of piggery sludge was a linear polymeric order 4 as represented by Equation 4. The linear polynomial model had an R^2 value of 0.99 with an SSE of 0.05.

$$f\ (x) = p_1 x^4 + p_2 x^3 + p_3 x^2 + p_4 x + p_5 \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4)$$

Where the biogas model coefficients at 95% confidence interval were:

p_1 = -2.45e-05 (-4.06e-05, -8.39e-06)
p_2 = 0.0015 (0.00040, 0.0027)
p_3 = -0.026 (-0.051, 0.00019)

p_4 = 0.17 (-0.026, 0.37)

p_5 = -0.027 (-0.45, 0.40)

As the digestion period of the piggery sludge increased, the amount of methane produced also increased (Figure 8). Methane compositions were as high as 65% showing an indication of the potential of the piggery sludge biogas to be used as a source of fuel.

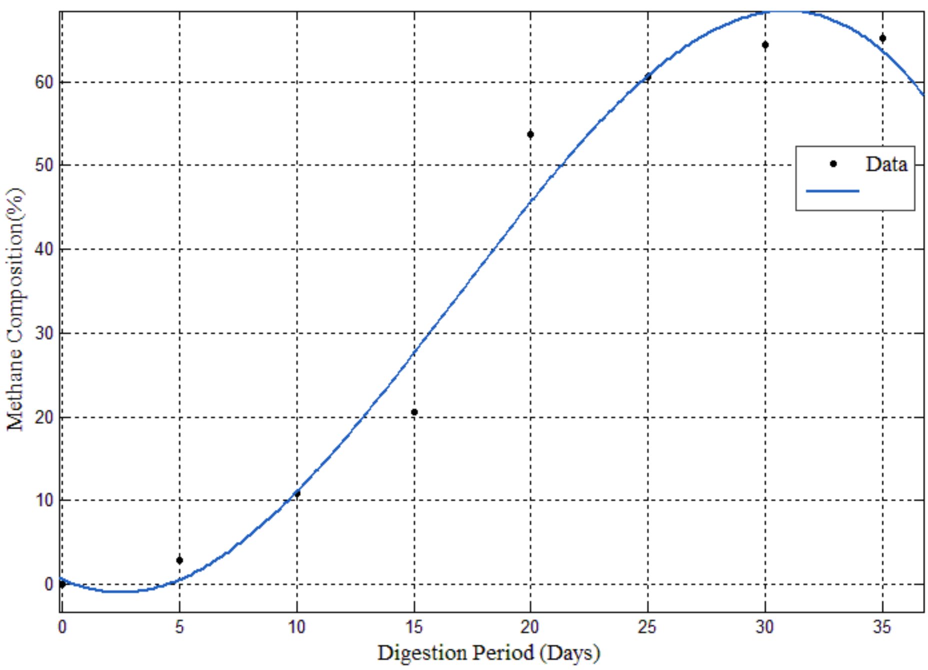

Figure 8. Composition of methane from piggery sludge

The methane production rate from the valorisation of piggery sludge was a linear polymeric order 3 as represented by Equation 5. The linear polynomial model had an R^2 value of 0.98 with an SSE of 5.86.

$$f(x) = p_1 x^3 + p_2 x^2 + p_3 x + p_4 \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5)$$

Where the bio methane model coefficients at 95% confidence interval were:

p_1 = -0.006051 (-0.01139, -0.0007084)

p_2 = 0.3028 (0.0179, 0.5877)

p_3 = -1.385 (-5.488, 2.718)
p_4 = 0.6621 (-14.73, 16.05)
The biogas also contained carbon dioxide, nitrogen and oxygen. The composition of the biogas is given in Table 2 with the methane composition ranging from 55-65%. The biogas composition obtained is in similar range as reported in animal wastes (Makadi et al. 2012).

Table 2. Piggery sludge biogas composition

Biogas component	**Composition (%)**
Methane (%wt.)	55-65
Carbon dioxide (%wt.)	35-40
Nitrogen (%wt.)	<2
Oxygen (%wt.)	<1
Hydrogen sulphide (%wt.)	600 ppm
Ammonia (%wt.)	100 ppm

3.5 Bio solids Generation

Bio solids were recovered in the form of the anaerobic digestate and can be a source of bio fertilizers for application in agriculture (Kuusik *et al*., 2014). These bio solids contained nitrogen, phosphorous and potassium (NPK) with composition an average composition of 4.1%, 0.55% and 4.6% respectively. The composition of the anaerobic digestate is given in Table 3.

Table 3. Properties of the anaerobic digestate from piggery sludge

Parameter	**Value**
pH	6.9-7.1
Moisture content (MC)	10.1-10.8
Total nitrogen (TN)	3.7-4.5

Total phosphate (TP)	0.4-0.7
Total potassium (TK)	4.2-4.9

4. Conclusion

The piggery sludge generated as waste can be managed through conversion to biogas and biosolids using anaerobic digestion. A rich biogas, which is a renewable energy source, was produced with methane content as high as 65%. Polynomial models generated from the valorization process can be used for determining the amount of biogas and biomethane generated. The anaerobic digestion produced during the process can be used as biosolids for application in agriculture due to their high composition of NPK.

Acknowledgments

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