Valorization of Piggery Slurry Wastewater to Bioenergy

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Abstract

This work focused on the valorization of piggery industry slurry to bio energy and bio fertilizers. A sample of piggery slurry wastewater was treated using a bio catalyst, Actizyme at 0.050 g/L loading, resulting in reduction of the biological oxygen demand (BOD) by 97%, the total dissolved solids (TDS) by 89% and the total suspended solids (TSS) by 98%. The solid material from the slurry was anaerobically digested to produce biogas with 73.4% methane composition over a period of 30 days and temperature of 37 ◦C at a commercial rate of 494 kg/day. The techno economic assessment for the piggery slurry valorization indicated a return on investment of 26% and payback period of 4 years and a capital investment of USD 820 000.

Keywords:
Bio energy, biogas, bio fertilizers, BOD, economic assessment, HAZOP, piggery slurry, TDS, TDS

1. Introduction

The need for wastewater management and affordable renewable energy has attracted a lot of attention globally (Adumasu et al. 2022). This is an area of concern even in the agricultural sector in Zimbabwe and the agricultural and livestock production has been increasing for the past five years. However, it is causing considerable environmental problems, mostly air and water pollution. The Environmental Management Agency (EMA) is the statutory body responsible for the protection of the environment and has enforced laws to protect the environment but it seems as if most of the pig farms are not following them (Tshuma, 2010). Pig slurry can be used as natural fertilizer, but it is the major source of these compounds. Most pig farms result in excessive production of liquid manure which surpasses the receiving capacities of their farmland and some use inorganic fertilizer because of the odor and bacteria in the slurry (Ajeej et al. 2015). Therefore, it becomes very crucial to develop efficient methods of processing this pig slurry. There are three ways commonly used to treat piggery slurry which include bio fertilizer production, composting and biogas generation. Biogas generation has proved to be more efficient because its advantages which include improved bio-fertilizer, reduced costs for heating, reduced greenhouse gas emissions and reduced leaching of nutrients. Treating it with Acti-zyme (bio catalyst) has a potential to further increase its value.

2. Background to Pig Slurry Valorization Energy

2.1 Pig slurry characteristics

Pig slurry is a thin mixture of liquid and fine solids generated as waste during pigs' production. The characteristics of pig slurry vary because of a number of factors including age, size and diet of the pigs (Al-Rousan. and Zyadin. 2014). The solid fraction of the slurry is mainly composed of organic compounds and the liquid part is mainly nitrogen, minerals in the form of oxides of sodium, potassium and magnesium (Bhuimbar and Dandge, 2022). The composition of pig slurry in relation to its potential to generate biogas and other materials is shown in Table 1.

Table 1. Pig slurry and other bio waste potential to produce bio energy (De Baere 2006).

Biomass	Biogas yield (m^3/kg of biomass)	Methane yield (m^3/kg of volatile solids)	Methane composition
Pig slurry	0.37±0.07	0.32±0.06	65
Cattle slurry	0.24±0.05	0.21±0.04	65
Mink slurry	0.40±0.1	0.35±0.07	65
Deep bedding	0.31±0.6	0.21-0.32±	65
Chicken manure	0.40±0.04	0.35±0.07	65
Sewage sludge	0.64±0.1	0.56±0.1	70
Primary sludge	0.38±0.08	0.33±0.07	65
Biological sludge	0.17±0.03	0.15±0.03	65
House hold waste	0.43±0.09	0.35±0.07	65
Maize	0.61±0.1	0.37±.0.07	55
Grass	0.57±0.1	0.35±0.07	55

2.2 Environmental damage caused by pig slurry

The disposal of pig slurry to the environment can lead to a variety of problems. It can cause bad odor, release of animal pathogens, atmospheric methane, ammonia, nitrogen, phosphorus and other nutrients into ground and water sources (Dölle and Fritz, 2022). Organic matter in the slurry decomposes and goes through anaerobic digestion producing odors from hydrogen sulfide, ammonia and other compounds. This highly biodegradable pig slurry can also attract pests and rodents which are a threat to human health (Dolle et al., 2020). In surface waters the organic compounds can alter the taste, odor, causes oxygen depletion and eutrophication. Further exposure to highly anaerobic conditions can cause release of methane, a greenhouse gas into the atmosphere leading to climate change.

2.3 Land pollution

The pig farms generate more waste than what is required for their gardens for example Koala Park has a 10-hectare farm where they plant stock feeds for both cattle and pigs or the slurry which is not placed in the appropriate time and cannot be utilized completely by the plants so it is enriched into the soil. The organic matter gets into the surface water by rain.

2.4 Water pollution

The inefficient use and the overdose of the pig slurry gets into the surface and the sub-surface of the water there-by causing pollution. The nitrite, nitrates and nitrogen causes pollution also. The potassium, phosphorous and nitrogen which are present in pig slurry cause eutrophication.

2.5 Air pollution

The degradation of the pig slurry produces a bad odor which is irritating to humans and pollutes the atmosphere. The bad odor is a result of methane, H_2S and ammonia. The pollution starts from the livestock building, manure storing and treating place. This study then evaluated the potential for valorization of piggery slurry to a clean water, biogas and bio solids.

2.6 Methods of treating pig slurry

2.6.1 Pig slurry processed into bio fertilizer

Most of the liquid can be used to make liquid fertilizer. In places of extensive pig farming more slurry is produced that exceeds significantly the amount that can be used at the farm. Large sized storage facilities are used because the slurry is only used during specific farming seasons. Storage of the slurry is associated with emissions of biogas and ammonia into the air. The main product of liquid manure processing are bio fertilizers (Kim et al., 2011). The slurry is improved by composting it with additional low cost organic materials like saw dust to absorb the liquid fraction of the slurry.

2.6.2 Composting of the pig slurry

This is an environmentally friendly and economical process of treating any organic wastes. The stabilized product from composting can be used for soil improvements, soil conditioning, enhancing plant growth and inhibiting plant pathogen growth (Mao et al., 2015). The stability can be tested by observing different physical parameters like smell, color, temperature and also chemical parameters such as carbon to nitrogen ratio and organic material content. Bio-chemical and microbiology parameters are also tested by spectroscopic analysis.

2.6.3 Biogas production

Biogas is a combustible mixture of gases that is methane (CH_4), carbon dioxide (CO_2), hydrogen sulfide (H_2S), hydrogen (H_2) and trace gases carbon monoxide (CO), nitrogen (N_2) and oxygen O_2 as shown in Table 2.

Table 2. Composition of biogas (Manyuchi et al. 2016)

Biogas component	Composition (%)
CH_4	55-70
CO_2	40-45
H_2S	1-2
H_2	1-2
CO	Trace
N_2	Trace
O_2	Trace

Biogas is generated from the decomposition of organic compounds for example animal waste, agricultural waste, industrial wastes and human waste. This process is carried out in a bio-digester. A bio-digester must be air tight to promote anaerobic conditions and temperature of approximately 37°C mesophilic and 50-55°C thermophilic. CSTR bio-digester have shown a high potential to increase biogas production.

2.6.4 Biogas from pig slurry

Treatment of pig slurry at anaerobic conditions produces biogas. Biogas was produced at thermophilic conditions which is from 35-55 ◦ C and pH of 6.5 to 8.5 in a batch fermenter with a continuous mixer for a period of 30 days (Mulinda et al, 2013). The gas was then analyzed using a gas chromatography. The gas composition was 55-60% methane gas, 25-40% carbon dioxide,0.5-2.5% nitrogen, 0.1-1.0% oxygen, 0.1-0.5% hydrogen sulfide and 0.1-0.5% carbon monoxide.

2.7 Enhanced bio-waste slurry valorization using Acti-zyme

2.7.1 Acti-zyme characteristics

Acti-zyme is a bio-catalytic additives composed primarily of bacteria, enzymes, neutralizers and nutrients required to break down and digest all organic waste. Research has shown that this biocatalyst was being used in sewage treatment plant and also it can be used in both aerobic and anaerobic environments (Manyuchi et al. 2016). If applied in abundant nutrients it multiplies by reproduction as much as 2billion colonies per gram within 48 hours.

2.7.2 Use of Acti-zyme to treat sewage wastewater

According to Tshuma (2010), Acti-zyme biocatalyst is used for vast applications such as wastewater treatment, drains cleaning and odor elimination. Acti-zyme is used to treat wastewater either aerobically or anaerobically, reducing wastewater contaminants properties such as total phosphates, total nitrogen, biological oxygen demand nitrates, ammonia and total suspended solids by over 40%. Acti-zyme also increases dissolved oxygen by over 100% (Tshuma 2010).

2.7.3 Use of Acti-zyme to produce biogas

The use of Acti-zyme as a biological catalyst under anaerobic conditions produced biogas with CH_4 composition ranging from 72-78 % with a peak being obtained for sewage loadings of 7.5 g/L and at an Acti-zyme loading of 0.050 g/L as compared to Acti-zyme free digesters which had a bio-methane composition of 53-65% (Manyuchi et al. 2016). The biogas also contained 16-20 % CO_2 and 8-12% traces amounts of H_2S, N_2 and H_2. The trace gases were in lower quantities in digesters with Acti-zyme due to the ability of Acti-zyme to hinder their production effectively improving the quality of the biogas (Manyuchi et al. 2016).

2.8 Bio-digester design

There are mainly two types of reactor stirred tank reactors for reactions in liquid and tubular or packed bed reactors for gas or liquid reactions. Stirred tank reactors include batch, semi-batch and continuous stirred tank reactors and they are ideal for biogas production due to perfect mixing meaning no gradients in temperature or concentration in the vessels (Norouzi and Dutta, 2022). Tubular reactors are usually open or packed with a catalyst and these reactors are considered ideal if there are plug flow of fluid and no radial gradients of temperature. Bio digester design considerations include material of construction, size of the reactor, the agitation and the method of supplying and removal of heat.

3. Materials and Methods

The experiments were based on: collection of a sample of organic waste from pig farms and analyze the moisture content, COD and BOD. In addition, a control experiment without Acti-zyme, performing experiments in the laboratory to decompose pig slurry to produce biogas using Acti-zyme bio-catalyst and collecting and analyzing the gas composition and testing product quality.

3.1 Measurement of slurry physicochemical characteristics

The pig slurry characteristics were measured in accordance to the APHA (2005) methodology. The pig slurry was measured for pH, total dissolved sods (TDS), total suspended solids (TSS), total nitrogen (TN), total phosphates (TP), dissolved oxygen (DO) among others. The properties were measured before and after treatment with the biocatalyst. Further, the treated slurry was compared to the EMA disposal standards.

The TSS was calculated according to the Equation 1.

$$TSS\left(\frac{mg}{l}\right) = \frac{(Residue + filter)(mg) - Filter\ (mg)}{Sample\ filtered\ (mg)}\ x\ 1000\ \left(\frac{mg}{L}\right) \ldots\ldots..(1)$$

3.2 Biogas production measurement without bio catalyst

The pig slurry was dried in an oven to 75% moisture content for 5 minutes. 1000 mL volumetric flasks where used as bio-digester. Weigh 500g of the solids and then add 500g water and seal the flask with a balloon to keep it air tight and to collect the gas. Place the flask in a water bath of 37 °C for 30 days' retention time.

3.3 Biogas measurement with bio catalyst

The pig slurry was dried in an oven to 75% moisture content for 5 minutes. 1000 mL volumetric flasks where used as bio-digester. Weigh 500g of the solids then add 500g water and 35g of Acti-zyme and seal the flask with a balloon to keep it air tight and to collect the gas. Place the flask in a water bath of 37 °C for 30 days' retention time.

3.4 Measurement of amount of biogas produced

The biogas volume produced was assessed by measuring the volume of a balloon assuming a spherical shape. The flask is filled with pig slurry and Acti-zyme and the control is filled with slurry only. A tight sealed balloon is used to collect the gas produced and to exclude the air totally. The anaerobic digestion is allowed to run until no significant change in volume in volumetric flasks (the Acti-zyme free flask and Acti-zyme catalyzed flask). The amount of biogas produced was calculated after a period of 30 days by measuring the balloon diameter. The diameter of the balloon was measured using a Vernier calipers. After determining the diameter, it was then used to calculate the volume assuming a spherical shape. The composition of gas was analyzed using a Biogas 5000 analyzer.

4. Results and Analyses

Anaerobic digestion results in the decrease of the physicochemical parameters of waste water. The decrease of these parameters in Acti-zyme free digester was because of the native enzymes and bacteria present in pig slurry. The addition of Acti-zyme in treatment of waste water enhances the treatment process there-by resulting in decrease of all parameters to a range accepted by EMA. This is because of the bio-augmentation process.

4.1 Pig slurry characteristics

The pig slurry was analyzed for its potential to generate biogas based on its characteristics. The composition of the pig slurry used in this study is shown in Table 3.

Table 3. Composition of pig slurry

Component	Composition (%)
Water	73.1±14.6
Dry solids	8.1±1.6
Suspended solids	6.5±1.4
COD	9.8±2.0
Ammonia (N)	0.7±0.10
Phosphorous ($P_2 0_5$)	0.4±0.08
Potassium (K_2O)	0.7±0.10
Calcium (CaO)	0.3±0.06
Magnesium (MgO)	0.2±0.04
Chloride (CI-)	0.2±0.04
Sulphur (SO_4^{2-})	0.2±0.04

4.2 Change in physicochemical parameters of piggery wastewater during treatment

The biocatalytic treatment of wastewater with Actizyme resulted in an effluent that is clean and meets the acceptable standards from EMA as shown in Table 4.

Table 4. Changes in physicochemical parameters of the pig slurry wastewater during bio catalytic treatment

Parameters	Raw slurry	Acti-zyme free	Acti-zyme present	EMA Standards
pH	5.7±1.1	7.9±1.6	7.3±1.5	6 – 9
BOD (mg/L)	875±175	335±67	29.4±5.9	≤ 30
DO (%)	65±13	89.2±17.8	297±59.4	≥ 60
Phosphates (mg/L)	25.4±5.1	16.2±3.2	1.4±0.3	0.5 – 1.50
TKN (mg/L)	115±23	35±7.0	9.4±1.9	≤ 10
TDS (mg/L)	1525±305	475±95	165.4±33.1	500 - 1500
TSS (mg/L)	2750±550	725±145	43.5±8.7	25 -50

4.3 Influence of Acti-zyme on pH

The pH changed from acidic to neutral in both volumetric flasks. The pH in the volumetric flask with Acti-zyme was 7.3 as compared to the control which was 7.9. This is due to the contaminants removal by Acti-zyme activity and also the neutralizers present in Acti-zyme. Acti-zyme digests the bio-contaminants present in slurry and eventually neutralizing the pH.

4.4 Influence of Acti-zyme on BOD

The BOD decreased effectively during anaerobic digestion. The BOD in the volumetric flask with Acti-zyme decreased to 29.4 mg/L. The decrease was because of the bio-degradable activity of Acti-zyme in anaerobic conditions. BOD is the amount of dissolved oxygen in water needed by aerobic bacteria to break down organic matter. High BOD can lower the oxygen carrying capacity of water therefore killing aquatic life.

4.5 Influence of Acti-zyme on DO

The concentration of dissolved oxygen is inversely proportional to BOD therefore when the BOD decreases the DO increased to 297 from 65. Acti-zyme has a positive influence on the DO there-by more free oxygen available to organism and safe to dispose.

4.6 Influence of Acti-zyme on COD

COD measures the quantity of organic matter in the pig slurry. The COD in the digested slurry with Acti-zyme decreased to 80.9 as compared to 309.4 in the control because of the ability of the enzymes and bacteria present in Acti-zyme to degrade the organic matter efficiently.

4.7ce Influen of Acti-zyme on TSS and TDS

TSS is used to determine the turbidity of water. Turbidity is the cloudiness of a liquid caused by large numbers of particles suspended in solution. High amount of TSS reduces the amount of dissolved oxygen present in water. The TSS decreased efficiently in the volumetric flask with Acti-zyme than in the control because of the ability of Acti-zyme to bio degrade the solids in pig slurry. TDS refers to any minerals, salts and metals dissolved in water. This was reduced from 1525 to 475 in the control and 165.4 in the volumetric flask with Acti-zyme.

4.8 Influence of Acti-zyme on phosphates

The total phosphates were reduced in both flasks. In the control it was reduced to 16.24 and in the Acti-zyme flask 1.35. In the Acti-zyme volumetric flask, the total phosphates were decreased by the uptake of nutrients from the pig slurry by Acti-zyme. The Acti-zyme utilizes the phosphates nutrients for its metabolism (Manyuchi 2016).

4.9 Influence of Acti-zyme on TKN

TKN is a measure of Total Kjeldahl Nitrogen which comprises of free ammonia, nitrogen and organically bound nitrogen. If the piggery slurry is disposed with a high nitrogen content it causes eutrophication and increase in pH in water bodies. A decrease in TKN was observed this due to use of nitrogen by bacteria in both flasks. There was a greater decrease in the Acti-zyme flasks because of the ability of the enzymes and the bacteria to digest nitrogen and use it for metabolism.

4.10 Biogas production from pig slurry

The volume of biogas increased from day one because of bio-augmentation. Acti-zyme multiplies in anaerobic conditions up to 2 billion species in 48 hours (Tshuma. 2010). The native methanogenic bacteria and Acti-zyme will both act on the pig waste therefore an enhanced bio-degradability. There was a slight change in the diameter of the balloon from day 13 to day15 this must be because of the decrease in volatile solids in the pig waste.

The volume of biogas in day 1 and 2 was zero because the number of methanogenic bacteria was still low. As the bacteria multiplied the amount of bacteria started increasing gradually. On day 15 the amount of biogas produced was still increasing showing that the rate of methanogenesis was slow as compared to that of an Acti-zyme catalyzed reaction and became stagnant after day 35 (Figure 1).

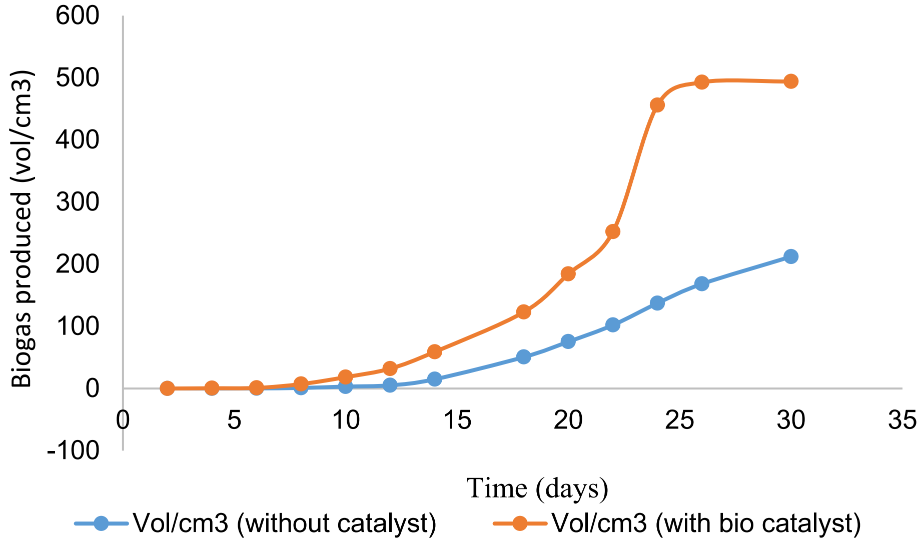


Figure 1. Biogas production from piggery slurry

4.11 Quality of biogas

The quality of biogas was analyzed using a laboratory gas analyzer. The composition of bio-methane is increased this is because of enhanced methanogenesis by both native bacteria and Acti-zyme. Acti-zyme does not contain sulfate reductase bacteria which competes with methanogenic bacteria for acetate to produce hydrogen sulfide hence increased methane and no H_2S. H_2S is present indicating the presence of sulfate reductase bacteria. Bio-methane quantity is reduced as compared to the Acti-zyme catalyzed because of the reduced population of bacteria (Table 5).

Table 5. Showing biogas composition produced from an Acti-zyme free flask

Biogas component	With catalyst (%)	Without catalyst (%)
CH_4	73.4±14.6	66.3±13.3
CO_2	25.3±5.1	30.5±6.1
CO	0.4±0.1	0.3±0.1
H_2S	0.00±0.0	1.4±0.3
Other trace gases	1.0±0.2	1.6±0.3

4.12 Quality of the bio fertilizers

The composition of the liquid and solid fertilizers obtained from the valorization of piggery slurry values shown in Table 6.

Table 6. Composition of the bio fertilizers

Component	Liquid fertilizer (%)	Solid fertilizer (%)
Nitrogen	1.5±0.3	1.8±0.4
Phosphorous	0.3±0.06	0.4±0.08
Potassium	0.2±0.04	0.1±0.02

5. Process Design

The process design covers the sequence of physical and chemical operations, operating conditions, major process specifications and the general arrangement of equipment of the process. The process design also summarises by a process flow sheet, material balance and a set of individual equipment specification.

5.1 Pre-treatment of the piggery slurry

The pre-treatment of the piggery slurry involves the removal of materials that has a potential to clog the pipes for example sticks and stones (Sosnowski et al. 2003). These can block the pipes or become trapped in moving parts and cause damages and inefficiency to the system. After removing these materials Acti-zyme catalyst is then added at a rate of 0.050g/L to the pig slurry and mixed thoroughly (Manyuchi et al.2016).

5.2 Bio gas Production

The pig slurry is then piped into the bio-digester where bio-digestion process takes place (Suvi et al., 2014). The bio-digester is semi-batch and it is continuously stirred to distribute heat evenly and reduce foaming. The retention time is 3 days at a continuous agitation of 60r.p.m. to increase enzyme activity. Temperature will be maintained at 37°C to optimise enzyme activity. The bio-solids will be removed from the bottom as bio-fertilizer.

5.3 Biogas separation

Biogas is a mixture of gases which are CH_4, CO_2, H_2S, CO and other trace gases. The desired product is CH_4 therefore separation using a column is required. H_2S corrodes equipment and other gases are removed to increase the calorific value and to reduce volume occupied by the gas (Yang et al. 2015).

5.4 Bio methane storage

The bio methane from the separation unit is then channelled to the storage tank. The gas is stored at 1378.6 KPa to reduce space occupied. About 10-15% of bio methane is used in the combustion chamber to provide energy to heat our boiler.

5.5 Liquid and solid bio fertilizer production

Liquid bio fertilizer and solid bio fertilizers were also collected from the bio catalytic conversion of piggery wastewater. A summary of the overall process is shown in Figure 2.

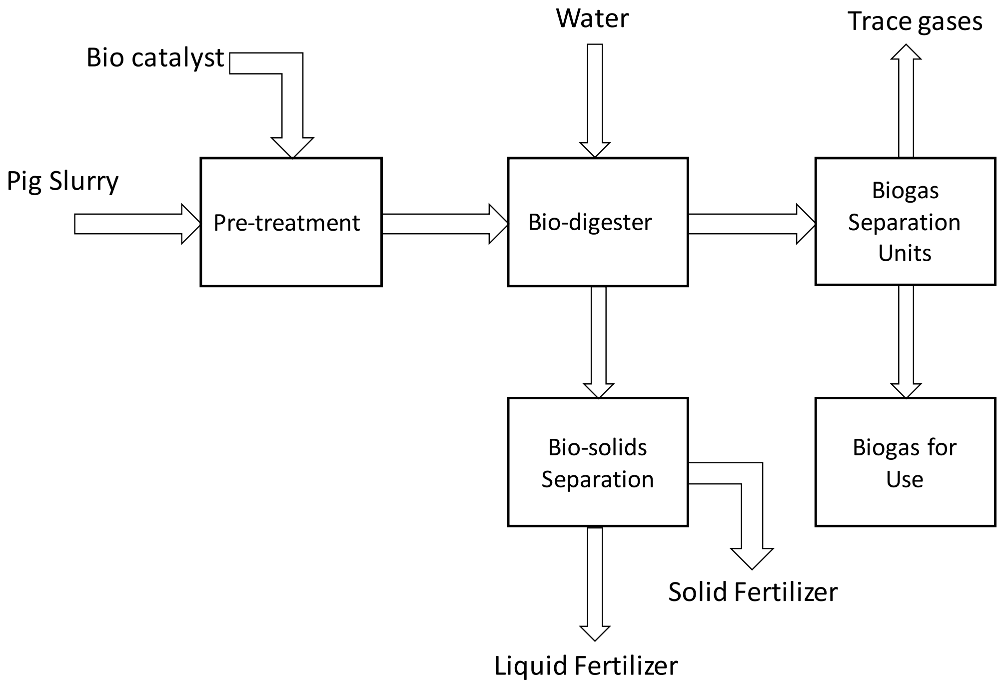


Figure 2. Process flow diagram for valorisation of piggery slurry to biogas and bio fertilizers

5.6 Mass balances and operations scaling up

A mass balance was done over the complete process to determine the quantities of raw material required to produce biogas and bio fertilizers from piggery slurry. The principle of the fundamental law of conservation of mass which states that mass can neither be created nor lost was used. The mass balance in the bio digester is represented by Equation 2.

$$Pig\ slurry + Water + Actizyme = Wet\ solids + Biogas \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

Using a basis 1 tonne/day of pig slurry is fed into the reactor, amount of biogas in accordance to Equation 2 will be 0.5 tons per day (Table 7), with a density of 1.2 kg/m^3.

Table 7. Gas composition with bio catalysis and the amount to be produced

Biogas component	**Biogas composition (%)**	**Amount produced (tones/day)**
CH_4	73.4±14.7	0.5±1.0
CO_2	25.3±5.1	0.4±0.08
CO	0.4±0.08	0.1±0.02
H_2S	0.0±0.0	0.002±0.0004
Trace gases	1.0±0.2	0.005±0.001

5.7 Energy Balances

From the principles of energy, energy can neither be created nor destroyed but changed from one form to another and for this study it's as represented by Equation 3.

$$\Lambda H + 0.5mv2 + \Lambda mgz = Q - Ws \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

Assumptions for a closed system are that: $0.5mv^2=0$, mgz=0, Ws=0 and $\Delta H=Q$. For common fuels excess air is supplied to achieve the highest possible efficiency. For natural gas, the percentage air to be fed is between 5-10%. A summary of the various biogas components and heir enthalpies is shown in Table 8.

Table 8. Biogas stoichiometric table and specific enthalpies

Substance	**Moles in (Kmol)**	**Specific enthalpy in (MJ/kg)**	**Moles out (Kmol)**	**Specific enthalpy out (MJ/kg)**
CH_4	2.27	-74.85	-	-
CO_2	-	-	2.27	31.88
O_2	-	-	0.454	21.86
N_2	-	-	18.73	20.59
H_2O	-	-	4.54	24.92

6. Bio digester Design Considerations

A number of factors are considered when designing an anaerobic bio digester including mixing time, hydraulic retention time, temperature, pH and reactor configuration.

6.1 Hydraulic retention time

The hydraulic retention time is represented by θ (days) and it is the average amount of time the raw materials stays within the bio reactor. The hydraulic retention time is represented by Equation 4. The volume of the reactor is represented by Equation 4, and the volume of the reactor was 250 m^3.

$$Hydraulic\ retention\ time = \frac{Volume\ of\ reactor\ (m3)}{Volumetric\ flow\ rate\ (\frac{m3}{day})} \dots\dots\dots\dots\dots\dots\dots\dots (4)$$

Where: V is the volume, Q is the influent flow rate and Ɵ is the hydraulic retention time

6.2 Mixing

Mixing is also important in the design of an anaerobic bio digester. Mixing increases, the rate kinetics of anaerobic digestion and accelerates the biological conversion process of the piggery slurry. Mixing also allows uniform heating of the reactor.

6.3 pH
Another important parameter is the pH. It should be maintained between 6.5 and 7.5 or neutral if the pH decreases the solution becomes acidic and corrosive to the reactor material. It also causes decrease in biogas production.

6.4 Temperature
The bacterial growth during the piggery slurry digestion is assisted by a complex set of enzymatic chemical reactions and the reaction rate of all chemical reactions depends on temperature. bacterial growth rates double for each 10 °C rise in temperature over a temperature range, which varies by bacterial species. High temperatures denature enzymes, killing the microorganism. Acti-zyme is at optimum at 37°C.

6.5 Biomass size and amount
The biomass particle size of bio waste affects the anaerobic digestion and bio digester size. The large particle slows the bio-reactions hence there is a need to reduce the size of the biomass. Biomass size reduction increases, the surface area to volume ratio for enzyme and microbiological activity. The amount of solids and size also determines the design of the impeller. Particle size reduction is achieved through grinding or shredding.

6.6 Concrete as a Choice of material
Most bio digesters are made from concrete mainly because it has anti-corrosion characteristics than steel and also is a better insulator than glass. The safety factor for concrete is 1.5. A summary of the bio digester reactor design specifications is shown in Table 9.

Table 9. Summary of reactor design

Parameter	Value
Volume	250m^3
Diameter	2.44m
Height	10.0m
Wall thickness	3.60m
Pressure	1atm
Temperature	37°C
Retention time	30 days
Material of construction	Concrete

7.Hazard and Operability Analysis

A Hazard and Operability Analysis (HAZOP) was conducted so as to examine and analyze each step or unit operation and explore all of the possible ways that failures and hazards can occur.

7.1 Safety of biogas plants

The operation of a biogas plant is related to a number of important safety factors, potential risks and hazards for the environment. Taking proper precautions and safety measures can avoid and minimize any risks. In this HAZOP study, the following major factors were considered: fire prevention, explosion prevention, mechanical dangers, electrical safety, thermal safety, lightning protection, hygienic safety, explosion prevention, avoidance of air polluting emissions, prevention of ground and surface water leakages.

7.2 Fire and explosion prevention

Biogas combined with air can form an explosive gas mixture. The risk of fire and explosion is high close to bio digesters and gas reservoirs. Therefore, specific safety measures must be certain during operation of biogas plants. Table 10 compares biogas and its main components with other gases, in respect to explosion liability. Table 11 gives the symptoms that one can have due to exposure to biogas and Table 12 gives the key monitoring parameters for biogas production.

Table 10. Biogas properties and stability

Component	Methane	Carbon dioxide	Hydrogen sulfide
Color	Colorless	Colorless	Colorless
Odor	No noticeable smell	No noticeable smell	Rotten eggs
Critical temperature	-82 °C	31 °C	100 °C
Relative density to air	0.6	1.5	1.2
Stability and reactivity	Explosive and reacts violently with oxidants	Stable under normal conditions	Can form explosive mixture with air and also forms corrosive liquid when mixed with water

Table 11. Symptoms of exposure to biogas

Gas	Minimum Identifiable Odor (ppm)	Toxic Limit Value (ppm)	Physiological effects	Symptoms of over exposure
CH_4	-	-	Asphyxiation	Dizziness/headache

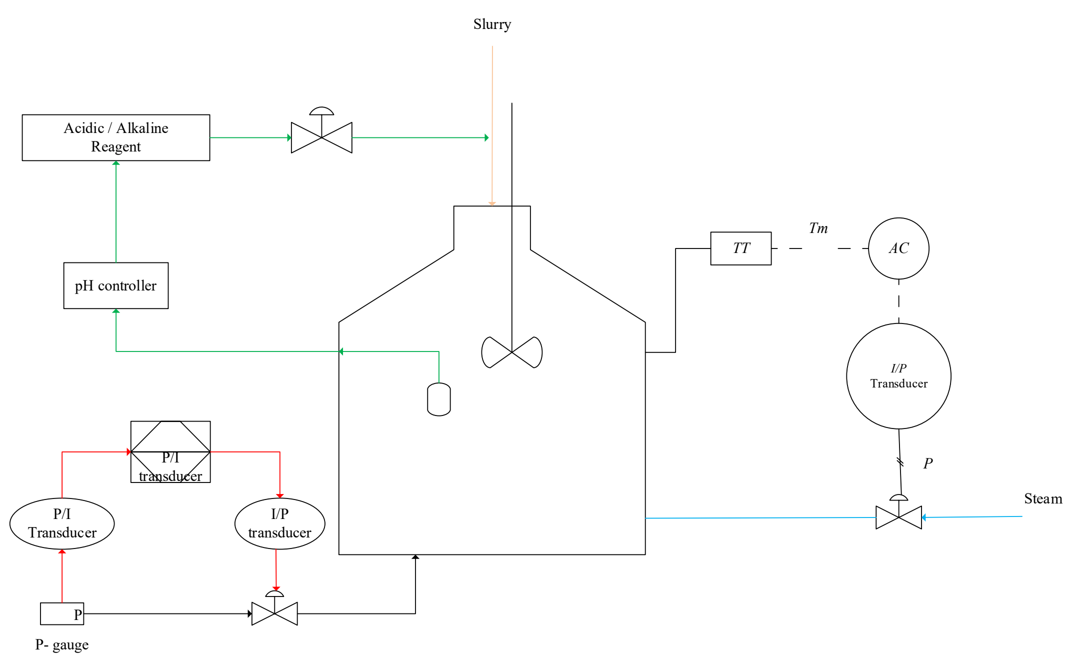
CO_2	-	5000	Asphyxiation	Restlessness
H_2S	0.7	10	poison	Eye irritations and convulsions

Table 12. Monitoring parameters of biogas production

Study node	**Process parameters**	**Deviations**	**Possible causes**	**Possible consequences**	**Action required**
Mixing	Level	High	Inlet control valve failure	Low purity	Install level sensor
Mixing	Flow	No	Control valve Failure and pipe blockage	Empty or almost empty reactor	Repair control valve and pipe
Mixing	Flow	More	Control valve Fully opened	Liquid overflow	Fit high flow alarm
Heating	Flow	No	Heating water Service flow	Loss of heating enzyme activity decreased	Check if water is flowing from the boiler
Heating	Flow	No	Controller fails and valves closes	Loss of heating	Place controller on critical instrumentation list
Heating	Flow	High	Valve fully opens	Reactor heated above temperature required enzyme denatured	Place controller on critical instrumentation list

Heating	Flow	Reverse	Back flow due to high back pressure	Loss of heating enzyme activity decreased	Install check valve
Heating	Flow	Later on	Operator error	Temperature rises	Interlocking between heat flow and reactor feed
Heating	Temperature	High	Low-steam water supply temperature	Enzyme denatured	Install cooling water high temperature
Stirring	Agitation	No	Stirrer	Motor malfunction	Interlock with feed line
Stirring	Agitation	More	Stirrer motor control fails resulting in high motor speed	none	none

A summary of the process control over the bio digester is shown in Figure 2.



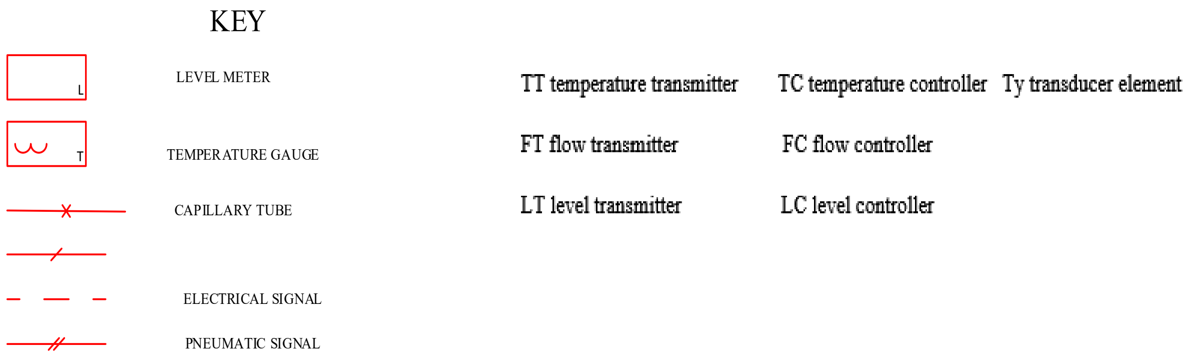


Figure *3*. Process control of the bio-digester control system

8. Economic Analyses

8.1 Fixed Capital Cost

The fixed capital cost is the total cost required to purchase and set up all capital equipment and premises making the plant ready for start-up.

8.2 Manufacturing capital investment

The manufacturing capital investment include: equipment, facilities, piping and site preparation related to the process operation. Non-manufacturing capital investment such warehouse, office furniture, utility generation waste disposal is all depreciable except for land.

8.3 Working capital cost

The working capital cost is the additional equipment required over and above the fixed capital to start up until income is earned. It consists of the following: raw materials and supplies for plant start up, finished and semi-finished products, accounts payable, accounts receivable, taxes payable and any additional cash required to operate the process. The capital cost of the plant was obtained using a method in L.A.W Anaerobic Digestion Design Cost of digestion plant C_2 = Cost of digestion plant as represented by Equation 4.

$$C2 = \left(\frac{S2}{S1}\right) n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (4)$$

Where: C_1 is the capital cost of the plant with capacity S_1, C_2 is the capital cost of the plant with capacity, S_2 and N is an index taken as 0.6. Using a basis of the L.A.W.P.C.A anaerobic digestion and energy recovery project, which had the capacity of 5800m^3 waste/day and a cost of 11 350 000 the 250 m^3 digestion plant is computed as represented by Equation 4. Cost for the biogas production process (C_2), where: C_1 is USD 5 350 000, S_1 is 5 800m^3 waste/day, S_2 is 250 m^3 waste/day. Therefore, C_2 is equal to USD 820 000 and the Capital Investment is USD 820 000.

8.4 Estimation of fixed capital investment

The manufacturing fixed-capital investment represents the capital necessary for the installed process equipment with all auxiliaries that are needed for complete process operation. Fixed capital investment can be broken down into direct costs and indirect costs.

8.5 Direct cost

Direct costs refer to materials and labor involved in actual installation of a piggery slurry based biogas plant and that is 70-85% of fixed capital investment. The total cost of equipment was 688 000 USD (Table 13).

Table 13. Cost of equipment

Cost description	Range (%)	Chosen	Cost USD (000)
Purchased Equipment cost PEC	(15-40) of CI	35	287
Construction and Installation	(25-55) of PEC	45	129.15
Instrumentation and Controls	(6-30) of PEC	25	71.75
Electricals	(10-15) of PEC	10	28.7
Buildings	(10-20) of PEC	15	43.05
Yard Improvements	(10-20) of PEC	10	28.7
Piping	(15-25) of PEC	25	71.75
Water source	(10-15) of PEC	10	28.7
Total direct costs			688.8

8.6 Indirect costs

These are expenses that are not directly involved with material and labor of actual installation of piggery slurry based biogas plant and are 15- 30% of fixed capital investment. The total indirect costs were USD 130 872.00 (Table 14).

Table 14. Indirect costs

Component	Range (%)	Chosen	Cost USD (thousand)
Engineering and Supervision	(5-30)DC	8	55.104

Contingency	(2-8)DC	5	34.44
Contractors' fee	(5-15)DC	6	41.328
Total			130.872

It was assumed that working capital is 15% and the total capital investment was USD 820 000 (Table 15).

Table 15. Total capital investment

Type of investment	Assumed % total	Amount
Fixed capital	85	697000
Working capital	15	123000
Total	100	820000

8.7 Cost factors estimation

The cost factors provide approximate percentages of all costs involved in the complete operation of plants chemical processing plants. The total production cost is calculated in Table 16. Since the main raw material (manure) is a waste, its cost has been assumed to be minimal.

Table 16. Cost estimation

Direct production	%TPC	Cost (USD Thousands)
Raw materials	5	3.446
Operating labor	18	12.41
Utilities	50	34.46
Maintenance and repairs	15	10.338
Patents and royalties	4	2.756
Direct supervisory	12	8.27
Total		68.92

8.8 Fixed charges

The total fixed charges were USD 20 000 (Table 17).

Table 17. Fixed charges

Fixed charges	Chosen %	Cost (USD thousands)
Depreciation	20	8
Local taxes	10	3
Insurance	15	4.5
Rent	15	4.5
Total		20

The total manufacturing costs is the sum of the direct production cost and the fixed charges which equals USD 88 920 (Table 18). One of the most important factors for determining feasibility is the production price per kilogram. This is calculated in Table 18.

Table 18. Analyses for selling price of biogas.

Item	Value
Daily production	494 kg
Annual production days (300 days)	148 200 kg
Total cost of production	USD 88 920
Price	0.60 USD/kg

Assuming a profit margin of 70%, this translates to a selling price of USD1.30/kg. This is a competitive price in comparison with LPG which sells for USD1.50/kg. Table 19 shows the profitability analysis summary for the valorization of pig slurry to biogas.

Table 19. Profitability analysis for piggery slurry valorization to biogas

Item	Formulae	Value
Total gross annual profit	(Selling price-Cost price) * Capacity	USD 238 000
Income tax	25% Income	USD 35 700
Net profit		USD 202 300
Payback period	(Total capital investment/Profit) * 100	4.1%
Return on investment	(Profit/Total capital investment) * 100	24.7%

According to the breakeven analysis (Figure 2), the breakeven sales is USD 546 665 and the breakeven in units for biogas is 420 512 kg.

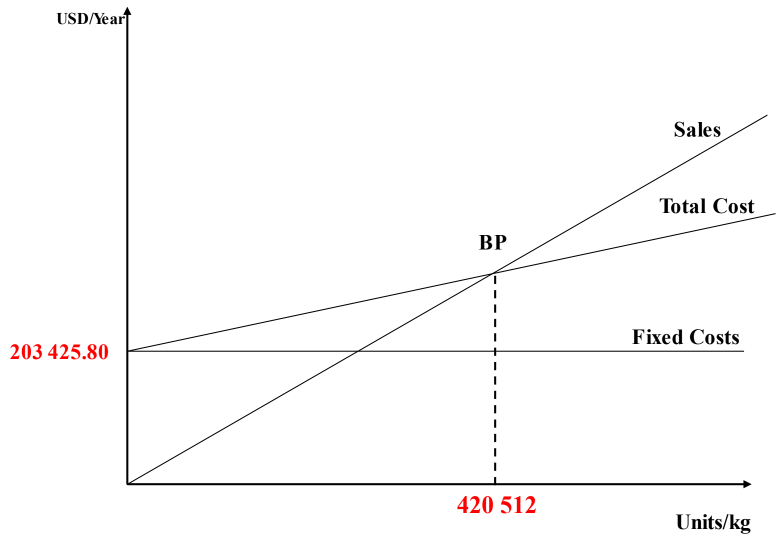


Figure *4*. Break even chart for valorization of pig slurry to biogas

9. Conclusion

Biogas and bio-fertilizer can be co-generated from bio-catalyzed anaerobic digestion of pig slurry. Bio catalytic treatment of piggery catalyst can efficiently convert waste into valuable products that is clean water, bio fertilizers and biogas. The treated effluent met the set standards for effluent water disposal and biogas was produced with a bio-methane composition of about 73.4%. The bio catalytic bio digestion of pig slurry using proves to be an attractive way of producing clean and renewable energy for use as well as bio fertilizers.

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