PRINT ISSN 1119-8362
Electronic ISSN 2659-1499

Full-text Available Online at
https://www.ajol.info/index.php/jasem
https://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 29 (3) 945-952 Mar. 2025

# Co-Digestion of Cow Dung, Poultry Manure, Palm Oil Mill Effluent and Water for Biogas Production: Performance Evaluation of Fixed Dome and Floating Drum Digesters

***[1]OJETOKUN, OT; [2]BADA, BS; [2]TAIWO, AM**

*[1]Institute of Food Security, Environmental Resources and Agricultural Research, Federal University of Agriculture, P.M.B 2240, Abeokuta, Nigeria*
*[2]Department of Environmental Management and Toxicology, Federal University of Agriculture, P. M. B 2240, Abeokuta, Nigeria*

**Corresponding Author Email: tosinojetokun@gmail.com*
**ORCID: https://orcid.org/orcid.org/0000-0002-7259-5600*
**Tel: +23407060533893*

*Co-Authors Email: badabs@funaab.edu.ng; taiwoam@funaab.edu.ng*

**ABSTRACT:** Biogas production from agricultural wastes has not been fully explored as a means of waste management and production of organic fertilizer. Hence, the objective of this paper was to explore the performance evaluation of fixed dome (FXD) and floating drum digester (FLD) for the production of biogas from the co-digestion of cow dung (CD), poultry manure (PM), palm oil mill effluent (POME) and water (WW) using appropriate standard procedures. Results showed that in the water/manure treatment, the FXD digester produced significantly more biogas (8.18 $dm^3$) at 33°C and pH 6.8 than other treatments. In the POME/manure treatment, the FLD digester yielded the highest biogas volume (8.05 $dm^3$) at 34°C and pH 6.4. FXD digesters were more suited for water/manure treatment, while FLD digesters were preferable for the POME/manure treatment. Analysis of digested slurry revealed N, P, and K contents of 2.54, 1.25, and 7.68 % for FXD digester, and 2.53, 1.76, and 50.14 % for FLD digester. These slurries may serve as high-quality organic manure, replacing chemical fertilizers in agriculture. The study underscores how substrate types, digester configurations, pH and temperature influence biogas production, emphasizing the sustainable potential of agricultural waste utilization.

**DOI: https://dx.doi.org/10.4314/jasem.v29i3.33**

**Cite this Article as:** OJETOKUN, O. T; BADA, B. S; TAIWO, A. M (2025). Co-digestion of Cow Dung, Poultry Manure, Palm Oil Mill Effluent and Water for Biogas Production: Performance Evaluation of Fixed Dome and Floating Drum Digesters. *J. Appl. Sci. Environ. Manage*. 29 (3) 945-952

**Dates:** Received: 13 February 2025; Revised: 17 March 2025; Accepted: 23 March 2025; Published: 31 March 2025

**Keywords:** cow dung; fixed dome digester; slurry; floating drum digester; biogas

Agricultural waste refers to by-products from cultivating and processing raw agricultural produce, including animal products like meat, dairy and poultry, as well as fruits, vegetables and crops. These wastes, also called agro-wastes, can include food processing waste, crop residues, hazardous agricultural waste and animal waste like manure and carcasses (Obi *et al.*, 2016). Improper waste management leads to pollution of the environment as a result of emission of greenhouse gases such as carbon dioxide and methane (Majd *et al.*, 2017; Akinbomi *et al.*, 2014). According to Okoro *et al*. (2018), waste management in Nigeria has become very challenging despite efforts from governments, past and present and even private sector.

Livestock production is one of the major agricultural practices and it is the biggest source of animal waste (Odejobi *et al.*, 2022). In Nigeria, approximately 6.4 million kilogram of poultry, 1.40 million kilogram of cattle and 5.20 million kilogram of piggery manures are produced daily (Itodo *et al.*, 2000), and these

**Corresponding Author Email: tosinojetokun@gmail.com*
**ORCID: https://orcid.org/orcid.org/0000-0002-7259-5600*
**Tel: +23407060533893*

wastes pose as danger to man and constitutes environmental challenges if not properly handled. The increase in farming activities in developing countries may lead to increased global agricultural waste production significantly, estimated at nearly one billion tonnes annually (Olorunnisola, 2007). Unfortunately, approximately 90 percent of these wastes end up in unengineered dumpsites or are openly burned, causing environmental pollution.

Palm oil industry is among the major agro-based industries in Nigeria. The processing and production of palm oil leads to the generation of large amount of wastes in which 50 percent of it end up as wastewater commonly known as palm oil mill effluent (POME). High values of chemical oxygen demand (COD) and biochemical oxygen demand (BOD) of up to 80,000mg/l have made it an important source of environmental pollution if discharged into the surrounding without adequate treatment (Oswal *et al.*, 2002).

Animal dung consists of nitrogen (N) and phosphorus (P) in high concentrations which are potential feedstock for biogas production (Abdeshahian *et al.,* 2016). Biogas is a colorless, flammable gas produced through the anaerobic digestion of organic matter such as animal, plant, human and industrial wastes amongst others, to generate majorly methane (50-70%), carbon dioxide (20-40%) and trace gases (Maishanu *et al.*, 1990). Biogas, which is a product from the decomposition of organic materials by methanogenesis, can be the alternative source of energy for most developing nations. Methanogenesis can be carried out in different types of digesters via anaerobic digestion (Ernst *et al.,* 2000). Animal and plant wastes can be transformed into an economic and environmental benefit if harnessed correctly in a digester (Lansing *et al.,* 2010). A digester provides an optimal condition for methane producing microbes by using the wastes as nutrient source. The anaerobic digestion process leads to several benefits such as: the produced methane becomes a renewable energy source, a liquid organic fertilizer is produced, waste pollution, greenhouse gas emissions and foul odors are drastically reduced (Clemens *et al.,* 2006; Lansing *et al.,* 2010). Researches have been carried out on the use of animal manures for biogas production, e.g. Owamah *et al*. (2014) and Alfa *et al*. (2014) on poultry droppings and Anozie *et al*. (2005) on cow dung. Previous study by Sidik *et al*. (2013) have shown that POME and cow manure are excellent substrates for biogas production. Previous co-digestion studies have largely been conducted on lab-scale, un-replicated pilot digester systems which are highly specialized, expensive and difficult to maintain (Gelegenis *et al.,* 2007; Spajic *et al.,* 2009; Lansing *et al.,* 2010). These digesters are mainly inaccessible to smallholder farmers (Chara *et al.,* 2009; Lansing *et al.,* 2010).

Despite the existing knowledge on biogas production from agricultural wastes, there is insufficient exploration of specific substrate combinations and their effects on biogas production using different digester types. Hence, the objective of this paper was to explore the performance evaluation of fixed dome (FXD) and floating drum digester (FLD) for the production of biogas from the co-digestion of cow dung (CD), poultry manure (PM), palm oil mill effluent (POME)and water (WW).

## MATERIALS AND METHODS

*Construction of Fixed Dome and Floating Drum Digesters*: Two types of digesters, fixed dome and floating drum, were constructed using 25 $dm^3$ high-density polyethylene (HD-PE) containers measuring 400 x 230 mm at the base and 275 mm in height to replicate previous studies (Budiyono *et al.*, 2010). The fixed dome digester (Figure 1) was chosen for its simple construction and gas storage, while the floating drum digester (Figure 2) was selected for its easy operation and immediate gas volume recognition through the drum's position. Both digesters were equipped with airtight inlet and outlet valves secured with rubber and araldite adhesive. The outlet valves were connected to long delivery tubes, through which majority of the produced biogas flowed by pressure to the water displacement setup.

**Fig 1**: Pictorial view of a fixed dome digester

**Fig 2**: Pictorial view of floating drum digester

*Substrates and Co-substrates*: Fresh cow dung (CD), well water (WW), and palm oil mill effluent (POME) were provided by the University Teaching and Research Farm at the Federal University of Agriculture, Abeokuta, Ogun State Nigeria. Debris-free layer birds poultry manure (PM) was sourced from a commercial poultry farm at Alabata village. The WW and POME served as co-substrates to ensure proper substrate mixing.

*Experimental Setup*: Two concurrent sets of experiments were conducted using different substrate combinations. The first set involved co-digestion of CD, WW, PM, and POME in various mixtures, tested in fixed dome digesters. The second set used the same substrate combinations but was carried out in floating drum digesters. All treatments were exposed to direct sunlight for four weeks, with each condition replicated in duplicate-labelled digesters. The digesters were loaded to 70% of their capacity, resulting in a working volume of 18 $dm^3$. Biogas production was estimated using the water displacement method (based on Archimedes' principle) and measured with a calibrated cylinder. The digesters were manually agitated daily to prevent slurry settling and ensure proper homogenization. Additionally, slurry temperature, pH and biogas volume were measured weekly.

*Flammability test*: Methane which is a major component of the biogas has combustible characteristic. The presence of the methane was tested by lighting flame on a gas lighter connected to the digester.

*Analytical Methods*: The physicochemical parameters of the substrates and biogas slurries were evaluated using standard procedures (APHA, 2012). Parameters analyzed include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon, moisture content, ash content, crude protein, nitrogen content, carbon/nitrogen ratio, $P_2O_5$, $K_2O$ and total solids. pH and temperature were recorded with the aid of digital pH meter (Hanna HI 98129).

*Data Analysis*: For statistical analysis SAS 2002 statistical package was used.

## RESULTS AND DISCUSSION

*Physical and chemical characteristics of raw cow dung and poultry manure:* Table 1 summarizes the physicochemical characteristics of undigested cow dung (CD) and poultry manure (PM) loaded to the experimental digesters. Results showed that pH of cow dung (7.07) was neutral while that of poultry manure was in the alkaline range (8.80). The cow dung pH was quite suitable for undergoing anaerobic digestion process. This was due to the fact that the pH was within the optimum level for anaerobic digestion which ranged from 6-8 (Adebimpe *et al.,* 2020). The elevated pH of poultry manure may completely inhibit methanogenesis. Hence, co-digestion of poultry manure with cow dung would be significant to minimize the risk of digester failure due to consumption of volatile fatty acids. Neutral pH values of 7.50 and 6.83 were also obtained by Ogunwande *et al.,* (2018) and Darwin *et al.,* (2021) respectively for cow dung. Meanwhile, high pH value of 9.14 was reported by Boozhani *et al.,* (2024) in chicken manure. Poultry manure had significantly ($p<0.05$) higher pH than cow dung.

The substrate temperature obtained was 28.40 and 29.37 °C in cow dung and poultry manure respectively. This temperature was within the mesophilic range of 25-35 °C considered optimal for the support of biological reaction rates (Tchobanoglous *et al.,* 2003). The non-significant ($p>0.05$) difference observed in substrate temperature showed that there was no heat exchange through the digesters wall. A higher ash content (44.23%) was recorded for cow dung than for poultry manure (37.03%). Similar value (48%) was obtained by Udosen *et al*., (2020) for cow dung, while Boozhani *et al.,* (2024) and Udosen *et al.,* (2020) reported ash contents of 17.7% and 26.8% for poultry manure respectively. Cow dung had significantly higher ash content than poultry manure. A lower moisture content (55.78%) was recorded for cow dung than for poultry manure (62.98%). This was in agreement with the studies by Ojikutu and Osokoya, (2014) in cow dung (57.21%) while results (97.8%) and (86.50%) reported by Darwin *et al*., (2021) and Boozhani *et al.,* (2024) respectively, were higher than current studies. The higher moisture content of poultry manure is crucial to ensure desirable moisture levels during co-digestion (Karki *et al.*, 2021). Poultry manure has significantly ($p<0.05$) higher moisture content than cow dung. The C:N ratio is used as an index of the decomposition rate i.e. suitability of organic feedstock for methanogenic bacteria. Optimum carbon to nitrogen ratios in anaerobic digesters is between 20 and 30 (Ojikutu and Osokoya, 2014). A high C:N ratio is an indication of a rapid consumption of nitrogen by the methanogens and result in a lower gas production. On the other hand, a lower C:N ratio causes ammonia accumulation and pH values exceeding 8.5, which is toxic to methanogenic bacteria. Optimum C:N ratio of the feedstock materials can be achieved by mixing substrates having low and high C: N, such as cow dung and poultry manure. The C:N ratios of both substrates were below the optimal range of 20 and 30 reported for anaerobic digestion (Ojikutu and Osokoya, 2014). Significant differences ($p<0.05$) were observed in ash content, moisture content, organic matter and pH while organic carbon, C: N ratio, and temperature values were not different significantly ($p>0.05$) in both manures.

**Table 1**: Physicochemical properties of undigested cow dung and poultry manure

| | | N | Mean | Std. Deviation | Minimum | Maximum | F | Sig. | |
|---|---|---|---|---|---|---|---|---|---|
| % Ash | CD | 3 | 44.23 | 1.43 | 42.80 | 45.65 | 72.843 | .001 | Sig. |
| | PM | 3 | 37.03 | 0.32 | 36.71 | 37.35 | | | |
| % M. C | CD | 3 | 55.78 | 1.43 | 54.35 | 57.20 | 72.800 | .001 | Sig. |
| | PM | 3 | 62.98 | 0.33 | 62.65 | 63.30 | | | |
| % O. M | CD | 3 | 32.43 | 0.83 | 31.60 | 33.26 | 72.300 | .001 | Sig. |
| | PM | 3 | 36.61 | 0.19 | 36.42 | 36.80 | | | |
| % O. C | CD | 3 | 29.09 | 10.05 | 19.04 | 39.13 | 1.965 | .234 | Not Sig. |
| | PM | 3 | 20.86 | 1.59 | 19.27 | 22.44 | | | |
| C: N Ratio | CD | 3 | 7.85 | 2.54 | 5.31 | 10.38 | 4.322 | .106 | Not Sig. |
| | PM | 3 | 11.03 | 0.78 | 10.25 | 11.81 | | | |
| Temp. (℃) | CD | 3 | 28.40 | 0.30 | 28.10 | 28.70 | 1.646 | .269 | Not Sig. |
| | PM | 3 | 29.37 | 1.27 | 27.90 | 30.10 | | | |
| pH | CD | 3 | 7.07 | 0.06 | 7.00 | 7.10 | 208.000 | .000 | Sig. |
| | PM | 3 | 8.80 | 0.20 | 8.60 | 9.00 | | | |

Sig.-significant

**Table 2**: Effect of co-substrate and digester types on biogas parameters

| | | | N | Mean | SD | Min | Max | t-test | Sig. | |
|---|---|---|---|---|---|---|---|---|---|---|
| Water | Temp (℃) | Floating | 40 | 31.42 | 2.59 | 27.80 | 35.60 | 9.004 | .004 | Sig. |
| | | Fixed | 40 | 32.89 | 1.73 | 28.20 | 36.00 | | | |
| | pH | Floating | 40 | 6.71 | 0.73 | 5.30 | 8.20 | .473 | .494 | Not Sig. |
| | | Fixed | 40 | 6.81 | 0.51 | 5.90 | 7.90 | | | |
| | Gas ($dm^3$) | Floating | 40 | 5.63 | 2.86 | 1.80 | 18.00 | 7.316 | .008 | Sig. |
| | | Fixed | 40 | 8.18 | 5.22 | 0.25 | 20.00 | | | |
| POME | Temp (℃) | Floating | 40 | 33.57 | 2.56 | 28.80 | 36.70 | 11.127 | .001 | Sig. |
| | | Fixed | 40 | 31.73 | 2.35 | 27.60 | 35.40 | | | |
| | pH | Floating | 40 | 6.37 | 0.75 | 5.30 | 8.60 | 2.641 | .108 | Not Sig. |
| | | Fixed | 40 | 6.09 | 0.75 | 4.80 | 8.10 | | | |
| | Gas ($dm^3$) | Floating | 40 | 8.05 | 5.61 | 0.00 | 24.00 | 3.047 | .085 | Not Sig. |
| | | Fixed | 40 | 6.08 | 4.42 | 0.50 | 18.00 | | | |

Sig.-significant

*Effect of co-substrate and digester type on biogas parameters:* The effects of co-substrate and digester types on biogas parameters was presented in Table 2. In the water/manure treatment, fixed dome digesters substrates exhibited significantly higher temperature values (32.89°C) and biogas volume (59%) than floating drum digesters, whereas, in POME/manure treatments, the table also demonstrates a significant difference ($p<0.05$) in the mean temperature (33.57°C) under floating drum conditions, which is consistently higher than under fixed dome conditions. Also, there was no significant difference between the gas volume produced by the digesters under floating drum and fixed dome conditions, though floating drum digester exhibited a slightly higher value (57%). This means that, depending on digester availability, either fixed dome or floating drum digesters are appropriate for biogas production while co-digesting cow dung, poultry manure and POME. It also implies that fixed dome digester is best suited for co-digestion of cow dung and poultry manure with water while floating drum digester is most suitable for mixing POME with cow dung and poultry manure towards achieving maximum biogas production. The pH readings for both water/manure and POME/manure treatments were close to neutral and were not significantly different. This implies that the pH level of both mixtures remains unaffected by digester type, whether floating drum or fixed dome.

*Effect of co-substrate only on biogas production:* Figures 3-5 summarizes the sole influence of co-substrate on biogas production. The co-substrate temperatures were similar (32-33$^{O}$C), indicating mesophilic thermal range operation. There was no significant temperature difference ($p > 0.05$) between water-added and POME-mixed substrates, though POME-added substrate exhibited a slightly higher value. The pH of water-added manure was significantly higher ($p<0.05$) than that of POME-mixed manure, while gas volume from both water and POME-added substrates did not significantly differ.

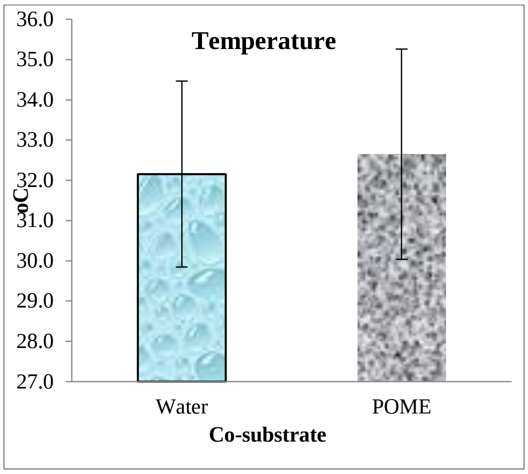

**Fig. 3**: Effects of co-substrate only on temperature

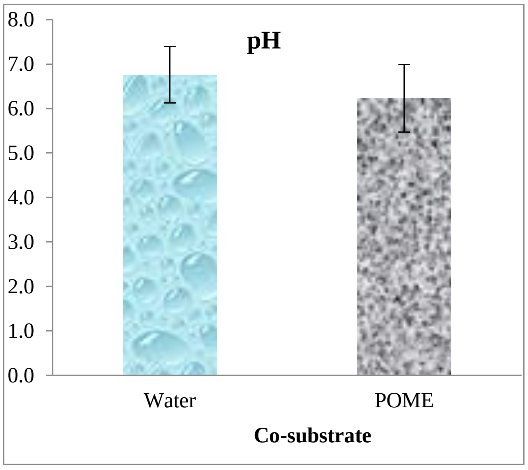

**Fig. 4**: Effects of co-substrate only on pH

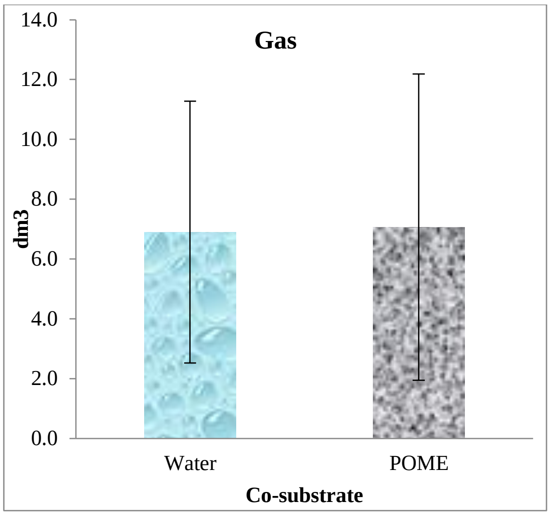

**Fig. 5:** Effects of co-substrate only on biogas volume

*Temporal biogas parameter variations using water and POME as co-substrates:* Figures 6-8 presents temporal biogas parameter variations for both water and POME-added substrates over a period of four weeks. POME/manure treatment consistently increased in temperature during the retention period. However, in water/manure treatment, temperature increased up to the second week, slightly decreased by the third week, and then increased again by the fourth week. Throughout the anaerobic digestion period, both digesters maintained mesophilic temperatures.

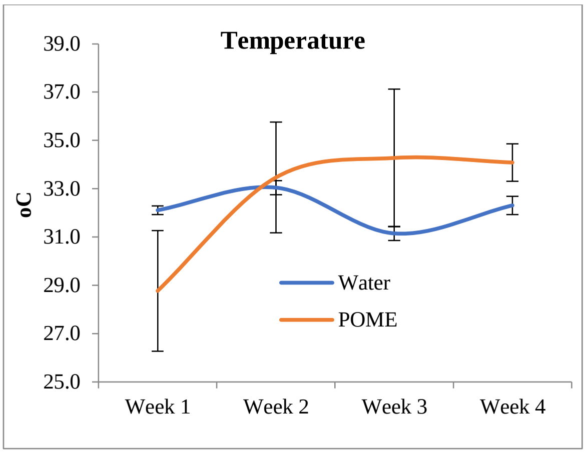

**Fig. 6:** Temporal variations of temperature using water and POME as co-substrates

The pH of the water-manure mixture remained stable over time, while the POME-manure mixture exhibited a decline until the second week before stabilizing by the fourth week. In water-manure treatments, biogas production peaked during the first week, declined until the third week, and increased again by the end of the retention time. Conversely, biogas production in the POME-manure mixture peaked in the second week, decreased in the third week, and increased again by the end of the experiment.

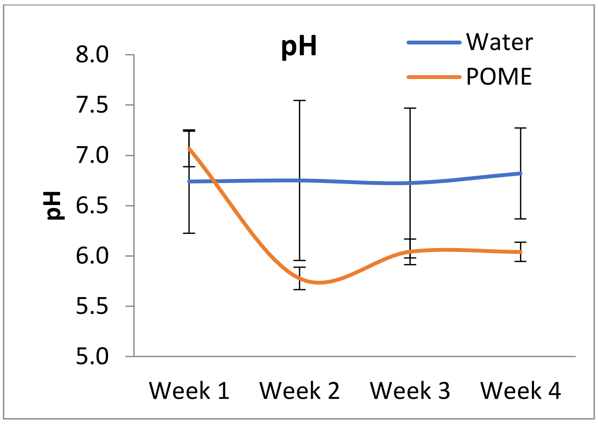

**Fig. 7:** Temporal variations of pH using water and POME as co-substrates

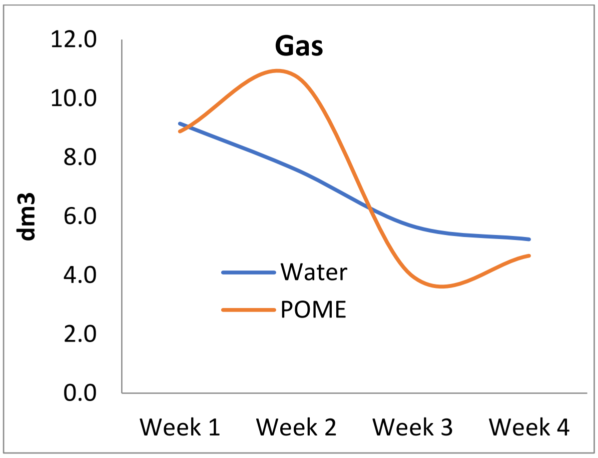

**Fig. 8:** Temporal variation of biogas volume using Water and POME as co-substrates

*Test for Methane in the Biogas Produced:* Biogas was tested and was confirmed to be combustible (Figure 9). An orange-colored flame glowed and this lasted for several minutes. Presence of impurities in the biogas was responsible for the flame color.

*Manure Contents in Digested Slurry:* Table 3 displays the manure contents (N, P, K) in the digested slurry obtained from both digesters. Biogas slurry has been shown to contain a significant concentration of macro and micronutrients in forms that are easily accessible, which are essential for the growth and development of plants (Kumar *et al.*, 2015; Cao *et al.*, 2016).

**Fig. 9:** Testing the flammability of produced biogas

The fixed dome digester exhibited a maximum nitrogen content of 2.54%, while the floating drum digester had a nearly identical nitrogen content of 2.53%. Phosphorus content in the digested slurry was highest at 1.76% in the floating drum slurry, compared to 1.25% in the fixed dome slurry. Additionally, the potassium content in the slurry from both digesters was 7.68% in fixed dome and 50.41% in floating drum digesters. The N, P, K contents obtained in this study were higher than that reported by Liang *et al.*, (2021) for animal wastes fermentation residues; Marchioro *et al.*, (2018) in solid state anaerobic digestion of poultry litters and Ayedun *et al.*, (2023) from poultry waste modified with sawdust. This can be traced back to the different substrate types used. Nitrogen content in both digester slurries were below the WHO, (2006) limit while phosphorus and potassium concentrations recorded in fixed dome digesters falls within the WHO, (2006) standard. Meanwhile, potassium contents in floating drum digesters slurries were higher than values reported by WHO. These digested slurries are considered high-quality organic manure which may be suitable for replacing chemical fertilizers in agricultural crop production systems, maintaining soil health, and promoting organic farming.

**Table 3:** Nitrogen, phosphorus and potassium contents in digested slurry

| Parameter | FXD digester slurry | FLD digester slurry | WHO Limit (2006) |
|---|---|---|---|
| Nitrogen (N), % | 2.54±0.06 | 2.53±0.10 | 10-30 |
| Phosphorus (P), % | 1.25 ±0.09 | 1.76±0.08 | 1-10 |
| Potassium (K), % | 7.68 ±0.68 | 50.41±43.04 | 1-10 |

*Conclusion:* In biogas production, co-digestion of cow dung and poultry manure with water outperformed co-digestion of cow dung and poultry manure with POME in fixed dome digesters. Both well water and POME are well suited as co-substrates during biogas production. For small holder farmers and rural dwellers with access to water, co-digestion of cow dung and poultry manure using fixed dome digester is recommended while those with access to POME may co-digest cow dung and poultry manure in floating drum digester for maximum biogas production. The N, P and K contents of the biogas slurry were mostly within the WHO recommended limit for wastewater.

## REFERENCES

Abdeshahian, P; Lim, JS; Ho, WS; Hashim, H; Lee, CT (2016). Potential of biogas production from farm animal waste in Malaysia. *Renew. Sust. Ene. Rev*. 60:714-723 https://doi.org/10.1016/j.rser.2016.01.117

Adebimpe, OA; Edem, IE; Ayodele, OL (2020). Investigation of the effects of starting pH, mass and retention time on biogas production using poultry droppings as feedstock. *Nig. J. Tech.* 39(1): 203-211 http://dx.doi.org/10.4314/njt.v39i1.35

Akinbomi, J; Brandberg, T; Sanni, S; Taherzadeh, M (2014). Development and dissemination strategies for accelerating biogas in Nigeria. *Biores.* 9(3):5707–5737

Alfa, I; Dahunsi, S; Iorhemen, O; Okafor, CC; Ajayi, SA (2014). Comparative Evaluation of Biogas production from Poultry droppings, Cow dung and Lemon grass. *Bioresour. Technol*. 157:270-277. https://doi.org/10.1016/j.biortech.2014.01.108

Anozie, A; Layokun, S; Okeke, C (2005). An evaluation of a batch pilot-scale digester for gas production from agricultural wastes. *Ene. Resour*. 27:1301-1311.

APHA (2012). Standard Methods for the examination of Water and Waste water, 20th Ed., America Public Health Association, Water Works Association/Water environment Federation, Washington DC, USA.

Ayedun, H; Adeyemo, AI; Ayadi, PO (2023). Biogas Production from poultry waste modified with sawdust. *Sci. Worl. J.* 18(2): 254-258. https://dx.doi.org/10.4314/swj.v18i2.12

Boozhani, KS; Reza, Y; Ahmad, J; Kamran, K; Seyed Hadi, E (2024). The effect of raw material (cow and chicken manure) and reactor type for improving and maximizing biogas production. *Env. Sci. Poll. Res*. 31. 1-11. 10.1007/s11356-024-34224-7.

Budiyono, B; Nyoman, W; Seno, J; Sunarso, S (2010). The Kinetic of Biogas Production Rate from Cattle Manure in Batch Mode. *Int. J. Che. Bio. Eng*. 3(1): 39-44.

Cao, W; Cao, C; Guo, L; Jin, H; Dargusch, M; Bernhardt, D; Yao, X (2016). Hydrogen production from supercritical water gasification of chicken manure. *Int. J. Hyd. Ene.* 41(48): 22722-22731. https://doi.org/10.1016/j.ijhydene.2016.09.031

Chara, J; Pedraza, G; Conde, N (1999). The productive water decontamination system: A tool for protecting water resources in the tropics. *Livest. Res. Rur. Dev*. 11:4

Clemens, J; Trimborn, M; Weiland, P; Amon, B (2006). Mitigation of greenhouse gas emissions by anaerobic digestion of cattle slurry. *Agric. Ecosys. Environ*. 112:171-177.

Darwin, AE; Diana, N; Mardhotillah, A; Pratama, A (2021). Anaerobic co-digestion of cow manure and Palm oil Mill Effluent (POME): Assessment of methane production and biodegradation efficiency. *Int. J. Des. Nat. Ecodyn*. 16(6): 671-676.

Ernst, M; Rodecker, J; Luvaga, E; Alexander, T; Miranowski, J (2000). Viability of methane production by anaerobic digestion on Iowa swine farms, Swine Research Report, ASL-R1693, Dept. of Economics, Iowa State, University.

Gelegenis, J; Georgakakis, D; Angelidaki, I; Christopoulou, N; Goumenaki, M (2007). Optimization of biogas production from olive oil mill wastewater, by co-digesting with diluted poultry manure. *Appl. Ene*. 84:646-63.

Itodo, IN; Awulu, JO; Philip, T (2000). A comparative analysis of biogas yield from poultry, cattle, and piggery wastes. *Afr. J. Environ. Stud*. 2(1):152-154.

Karki, R; Chuenchart, W; Surendra, KC; Shrestha, S; Raskin, L; Sung, S; Hashimoto, A; Khanal, SK

(2021) "Anaerobic co-digestion: current status and perspectives", *Biores.Tech*. DOI: https://doi.org/10.1016/J.BIORTECH.2021.125001, 330, 125001, 2021.

Kumar, S; Malav, LC; Malav, MK; Khan, SA (2015). Biogas slurry: source of nutrients for eco-friendly agriculture. *Int. J. Ext. Res*. Vol. 2: 42-46.

Lansing, S; Martin, JF; Botero, RB; Silva, TN; Silva, ED (2010). Wastewater transformations and fertilizer value when co-digesting differing ratios of swine manure and used cooking grease in low-cost digesters. *Biom. Bioene*. 34:1711-1720.

Liang, S. J. Sun, J. Mahmood, A. Basir, A. Ashraf, I. and Yang, S. (2021). Potential of Rapid Anaerobic Fermentation on Animal Slurry for Biogas Production and Storage of Biogas *Pol. J. Env. Stud.* 30, 247 – 256.

Maishanu, SM; Musa, M; Sambo, AS (1990). Biogas Technology: The output of the Sokoto Energy Research Centre. *Nig. J. Solar Ene*. 9:183-194.

Majd, S; Abdoli, M; Karbassi, A; Pourzamani, H; Rezaee, M (2017). Effect of physical and chemical operating parameters on anaerobic digestion of manure and biogas production: A Review. *J. Enviro. Hlth. Sus. Dev*. 2(1):235–247.

Marchioro, V; Steinmetz, RL; Amaral, AC; Gaspareto, TC; Treichel, H; Kunz, A (2018). Poultry litter solid-state anaerobic digestion: Effect of digestate recirculation intervals and substrate/inoculum ratios on process efficiency. *Front. Sus. Food Sys.* 2:46- 53 doi: 10.3389/fsufs.2018.0004

Obi, FO; Ugwuishiwu, BO; Nwakaire, JN (2016). Agricultural Waste Concept, Generation, Utilization and Management. *Nig. J. Tech*. 35(4): 957-964. http://dx.doi.org/10.4314/njt.v35i4.34

Odejobi, OJ; Ajala, OO; Osuolale, FN (2022). Review on potential of using agricultural, municipal solid and industrial wastes as substrates for biogas production in Nigeria. *Biom. Conv. Bioref.* 14:1-13 DOI: 10.1007/s13399-022-02613-y

Ogunwande, GA; Adanikin, BA; Adesanwo, OO (2018). Comparative evaluation and kinetics of biogas yield from duckweed (Lemna minor) co-digested with water hyacinth (Eichhornia crassipes). *Ife J. Sci.* 20(3): 649-661

Ojikutu, AO; Osokoya, OO (2014). Evaluation of biogas Production from food waste. *The Int. J. Eng. Sci.* 3(1): 1-7.

Okoro, E; Igwilo, K; Sanni, E; Orodu, K (2018) A review on waste to biogas sources and its potential in Nigeria. *Int. J. Eng. Tech*. 7(4):5960–5966. https://doi.org/10.14419/ijet.v7i4.24458

Olorunnisola, A (2007). Production of Fuel Briquette from Waste Paper and Coconut Husk admixtures. *Agric. Eng. Int. CIGR J.* 11:50 - 55.

Oswal, N; Sarma, PM; Zinjarde, SS; Pant, A (2002). Palm oil mill effluent treatment by a tropical marine yeast. *Biores. Tech*. 85:35-37.

Owamah, H; Alfa, M; Dahunsi, S (2014). Optimization of biogas from chicken droppings with *Cymbopogon citratus Renew. Ene*. 68:366-371.

SAS. (2002). *Statistical Analysis Software Guide for Personal Computers*. Cary, NC, USA: Release 9.1. SAS Institute Inc.

Sidik, UH; Razali, FB; Alwi, SRW; Maigari, F (2013). Biogas Production through co-digestion of palm oil mill effluent with cow manure. *Nig. J. Bas. Appl. Sci*. 21(1):79-84. https://doi.org/10.4314/njbas.v21i1.12

Spajic, R; Burns, RT; Moody, L; Kralik, D; Poznic, V; Bishop, G (2009). Anaerobic digestion of swine manure with different types of food industry wastes. *ASABE* doi:10.13031/2013.27301

Tchobanoglous, G; Burton, FL; Stensel, HD (2003). Wastewater engineering: Treatment and reuse (4th edition). Metcalf and Eddy, Inc., Boston: McGraw-Hill.

Udosen, IE; Samuel, E; Nasai, J; Shehu, AI (2020). Production of biogas using cow dung and poultry droppings. *Afr. Sch. J. Agric. Agric. Tech.* 18(1):1-14

WHO (2006) Guidelines for the Safe Use of Wastewater, Excreta and Grey Water. World Health Organization Press, Geneva, Switzerland.