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COMPARATIVE STUDY OF ELECTROLYSIS-ENHANCED ANAEROBIC DIGESTION OF THREE SOLUBLE SOLID WASTES FOR BIOGAS PRODUCTION

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ABSTRACT

Aim: A comparative study of biogas production from three soluble solid wastes was conducted under anaerobic conditions by subjecting each waste to both conventional and electrolyzed digesters. **Methodology and Results:** Varying weight of each of the waste was mixed thoroughly with water and fed into five digesters. Three of these digesters were electrolytically-enhanced while the other two were not. The digestion of each of the wastes was monitored for 40 days at an ambient temperature ranging from 24 to 35oC. In all the digesters, biogas production started on the day 2, and attained maximum value on day 14 to17. Biogas production ended on the day 34 and 35 in digester 1a, 1b, 2a and 2b with production ending earliest in digester 3 containing wastewater on day 19. The highest biogas was produced in digester 2b containing electrolyzed digester loaded with poultry droppings) with a cumulative volume percentage of 91.41 as compared to its conventional state with a cumulative volume percentage of 85.19 and both states of the cow dung waste with cumulative volume percentages of 77.26 and 71.64 respectively. The least production occurred in digester 3 with a cumulative volume percentage of 4.59. **Conclusion, significance and impact study:** It is therefore concluded that poultry droppings has the greatest potentials for the generation of biogas as compared to cow dung in conventional and electrolyzed state and wastewater.

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- Anaerobic Biogas Production
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- Electrolytically-enhanced
- Soluble Solid Wastes
- Cow dung waste

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1. INTRODUCTION

The continuous demand for energy worldwide as a result of fast population growth, the global depletion of fossil fuels in conjunction with the increase in their costs has prompted many countries to search for new and renewable energy sources (Xie *et al.,* 2011; Grisel *et al.,* 2013, Ajiboye *et al.,* 2018). Coal, Petroleum and other similar products have been greatly relied upon as primary and major source of energy and this has led to climatic alterations, health hazards, ecological instability and debasement of natural resources (Aragaw and Andargie, 2013). The continuous use of fossil fuels has had great negative impact on the environment. Emission of Greenhouse gas (GHG) in the atmosphere is rising, with carbon dioxide (CO2) being the main contributor. In addition, the global energy demand is increasing rapidly, with approximately 88% of the energy produced at the present time being based on fossil fuels (IEA, 2015; UNEP, 2014). Focus is now been placed on alternative and renewable energy sources such as solar energy, biogas, biodiesel, wind power, tidal energy and so on (Islam, 2012).

Recent evaluations indicate that biogas produced via anaerobic digestion (AD) provides significant advantages over other forms of bioenergy because AD is an energy-efficient and environmentally friendly technology (van Foreest, 2012; Nishio and Nakashimada, 2007). In comparison with fossil fuels, AD technology can reduce GHG emissions by utilizing locally available sources. In addition, the byproduct of this technology, called digestate, is a high-value fertilizer for crop cultivation and can replace common mineral fertilizers. Anaerobic digestion (AD) is a complex biological process in which microorganisms break down biodegradable organic matter i.e. cattle manure, kitchen waste, sewage sludge, poultry dropping, agriculture residues and other organic garbage in the absence of oxygen and thus produced biogas (Milono *et al.,* 1981, Iqbal *et al.,* 2014).

AD is a widely used method for bioconversion of wastes into fuel. It is regarded as the simplest technique due to its very limited environmental impact (Esposito *et al.,* 2012) and high energy recovery potential (Carrère, 2010). Biogas through AD has significant advantages over other forms of bioenergy production and also offers a promising substitution for fossil fuels (Ofoefule *et al.,* 2010). AD process is dependent on specific microbial consortium for degradation of biomass through four main stages namely hydrolysis, acidogenesis, acetogenesis and methanogenesis. Anaerobic digestion can be classified as liquid, semi-solid and solid or dry

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state when the total solids of substrate are less than 10%, 0-15%, or greater than 15%, respectively (Li *et al.,* 2011). The popularity of AD is increasing day by day due to its high degree of waste stabilization, less energy requirement, fewer nutrients required and methane production (Islam *et al.,* 2016).

Some studies have demonstrated increased methane production under anaerobic conditions and some under microaerobic condition (i.e. at very low dissolved oxygen concentrations) (Tartakovsky *et al.,* 2011, Jagadabhi *et al.,* 2010 and Jenicek *et al.,* 2008, 2010). This study therefore present methane production from three different soluble solid wastes placed under two conditions of electrolysis-enhanced AD and conventional AD. The methane produced from the electrolysis-enhanced AD and conventional AD reactors were evaluated and compared.

2. RESEARCH METHODOLOGY

2.1 Material

Materials used for the construction of the digesters are five (5) black plastic kegs of 50 litres capacity each (all serving as the main digester chamber), five tire tubes of 380-10 cm circumference and internal diameter (used to collect the gas produced), Flexible rubber hose (used to connect the tire tubes to the digesters), Stainless steel electrodes were inserted into the electrolyzed digesters, three 12.0 V small rechargeable battery cell, ½ inch back nuts, stop corks, ½ inch pipes, PVC gum (all used for both the inlet and outlet of the digesters), thermometer, pH meter, weighing scale and syringe (all used for various parameter's measurement).

2.2 Digester design considerations

2.2.1 Operating Volume

The operating volume of the digester is simply the volume of slurry ratio in the digester when you feed and mixed thoroughly a known and constant weight of manure with a constant volume of water into the digester (Babatola, 2008). The total volume of the slurry is usually lesser than the entire volume of the digester for optimum digestion operation.

The operating volume of the digester is determined on the basis of the chosen retention

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time and the daily substrate input quantity, the operating volume as given by Ahmadu *et al.,* (2009) is expressed in Equation 1.

$$V_o = S_d \times RT\ (m^3/day \times \text{number of days}) \quad (1)$$

V_o is the operating volume of digester, S_d is the daily susbstrate input and, RT is the retention time, which is the interval of time the mixed slurry is allowed to decompose in the digester.

2.2.2 Digester Volume

Digester volume is the volume of the container that serves as the digester either ready-made or fabricated; the dimensions can be used to determine the volume of the digester in case of fabricated digester. In this case the digester volume is the volume of ready-made 50 litres containers acquired. Digester volume which also refers to the total volume should be greater than the operating volume in order to give room for the biogas produced and the rise of the slurry during fermentation. Ahmadu *et al.,* (2009) and Otun *et al.,* (2015) reported that the operating volume of the digester must not exceed 80% of the total volume of the digester to at least give 20% of the total volume for slurry rise and for biogas. The total volume V_T is thus given in equation 2.

$$V_T = V_0 \times 1.25 \quad (2)$$

2.3 Digester Components

An inlet and outlet were constructed to the bio-digesters which were made up of the 50 liters cylindrical shaped rubber containers. The mouth of the container serves as the inlet for the digester, while the sludge outlet were constructed with the cast iron tap incorporated to the bottom part of the rubber container. The digesters were in two versions-the conventional type which consist only the inlet, outlet and gas collection point and the other form with the insertion of the steel electrodes for electrolysis induction. The two constructed versions are shown in Figure 1. A three 12V small rechargeable battery cells were connected to the cathode and anode and incorporated into three of the five digesters. Stainless steel was used as the electrodes. The choice of the electrodes is due to its anti-corrosive properties and availability.

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Figure 1 a) Conventional digester and b) electrolyzed digesters

2.4 Collection and Preparation of Waste

The cow dung (CD) used was collected freshly from a mini-abbatoir behind Chicken Republic eateries located along Akure/Ilesha express road while poultry droppings (PD) were collected from the Teaching and Research Farm of the Federal University of Technology, Akure (FUTA). Wastewater (WW) used was obtained from FUTA hostel. Both solid waste samples collected (cow dung and poultry droppings) were kept in black sealed polythene bags to preserve their original moistures thereby further maintaining their freshness. Chemical analysis of the animal waste and wastewater were carried out before feeding them into the digesters. The physio-chemical analysis was conducted both in Animal Production Health Laboratory and Chemistry Laboratory of FUTA. The microbiological analysis was also done at Microbiology Laboratory of the same institution.

2.5 Experimental Procedure

20 kg of cow dung substrate was firstly weighed and mixed thoroughly with 20 litres of water in both the conventional and electrolyzed digesters labeled 1a and 1b respectively. Another mixture containing 10 kg of dried poultry droppings with 30 litres of water were fed into both the conventional and electrolyzed digesters labeled 2a and 2b. Finally, 40 litres of wastewater was weighed and fed into an electrolyzed digester labeled 3. The five digesters were subjected to manual periodic agitated to enhance complete digestion of substrate and also prevent

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formation of scum and layers that could inhibit the bacteria activities in the digesters thereby halting further gas production. Also, each of the digester was connected to gas cylinder via its outlet to trap the biogas generated.

2.6 Analysis of the Waste

The experiment was monitored for 40 days. During this period, the daily temperature was maintained between 20^{o}C and 45^{o}C for mesophilic conditions. Temperature readings were taken with thermometer attached to the digesters. Digital pH meter (Hanna Instruments) was used to measure the pH once daily. The volume of gas produced was calculated by weighing on a digital weighing balance (HR-60, 0.1 mg readability). The initial mass of the tubes was measured to be 1.2 kg then the volume of gas produced daily was determined using Equation 3.

$$Volume\ of\ biogas\ produced\ daily = \frac{Mass\ of\ biogas\ produced}{Density\ of\ biogas} \tag{3}$$

The average density of biogas used is 1.15 kg/m^3 as recorded by Peter (2009). The Physico-chemical properties of the samples, daily and cumulative biogas and methane yield, laboratory and microbial analysis were the parameters used to assess the electrolysis-induced anaerobic digestion of the soluble solid waste.

3. RESULTS AND DISCUSSION

3.1 Physicochemical and Microbiological Properties of Waste Samples

The two soluble solid wastes (CD and PD) collected were analyzed using the recommended methods of waste and manure analysis A3769 while the wastewater was also analyzed using the American Public Health Environmental Protection Agency standard methods to determine its constituents. The physicochemical and microbiological properties of the samples are shown in Tables 1 and 2.

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Table 1 Physico-chemical analysis of CD, PD and WW

Parameter/ Unit	CD Value	PD Value	WW Value
Moisture content (%)	11.2	9.11	92.3
Temperature (^{0}C)	37.4	36.20	28
Total solid (%)	23.0	21.02	1.05
Ph	5.53	5.11	6.6
Total volatile solid (%)	21.32	0.40	0.5
Total soluble solid (%)	0.05	0.07	0.01
Conductivity (S/cm)	62.0	63.05	52.0
Ash	1.60	1.72	1.34
Total Nitrogen gas	0.66	0.30	0.02
Total Phosphorus	0.72	1.00	1.06
Total Potassium	0.35	0.80	1.03
Total Carbon	1.01	1.02	1.07
Alkalinity	0.04	0.03	0.01
Carbon/nitrogen	0.09	0.06	0.02
Crude lipid	0.92	0.83	0.62
Protein	5.2	4.30	3.31
Hemi cellulose	6.01	8.00	16.02
Lignin	0.66	1.00	4.04
Energy	10.04	9.10	6.5
Calcium	17.03	15.00	11.03
Magnesium	17.03	0.92	0.42
Sodium (mg/l)	0.51	0.10	0.10
Zinc (mg/l)	0.03	0.01	0.02
Manganese (mg/l)	0.01	0.01	0.01
Iron (mg/l)	0.04	0.02	1.20
Copper (mg/l)	0.01	0.01	0.01
Cellulose (mg/l)	0.70	0.56	1.42

Table 2 Microbiological analysis of CD, PD and WW

Parameter/Value	CD Value	PD Value	WW Value
Total Bacterial Count (cfn/ml)	9 ×10^2 cfn	13 × 10^2 cfn	11 × 10^2 cfn
Total Coliform (mpn/100ml)	8 ×10^2 cfn	5 × 10^2 cfn	-
E. Coli (mpn/100ml)	6 ×10^2 cfn	4 × 10^2 cfn	-
Fungi	2 ×10^2 sfn	1 × 10^2 sfn	4 × 10^2 sfn

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Data obtained from the experimental setup of CD, PD and WW for each of conventional and electrolyzed digesters are presented in charts as follows. The charts show the daily volume of biogas produced, the pH and the temperatures.

3.2 Biogas Yield

Figures 2 to 4 show the plot of biogas produced from CD, PD and WW both in conventional and electrolyzed digesters against the retention period for 40 days.

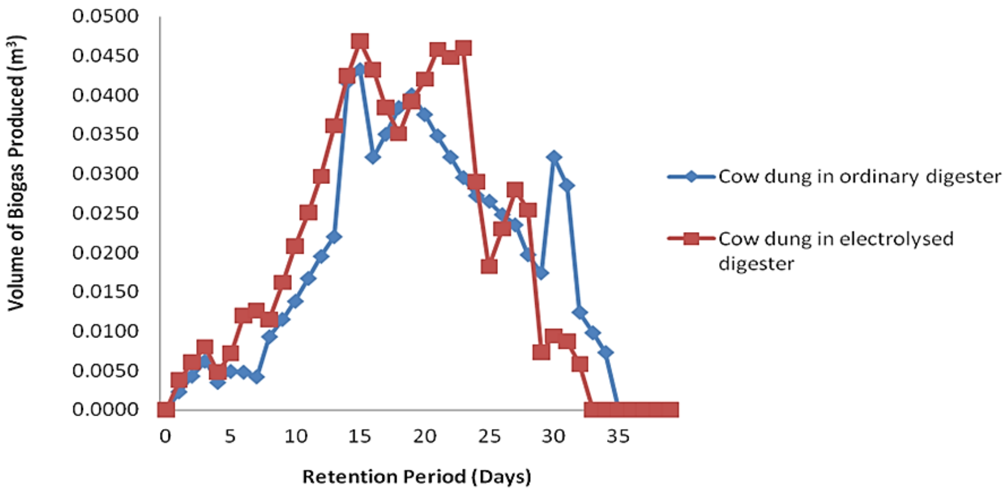

Figure 2 Volume of biogas produced versus retention period for digesters 1a and 1b

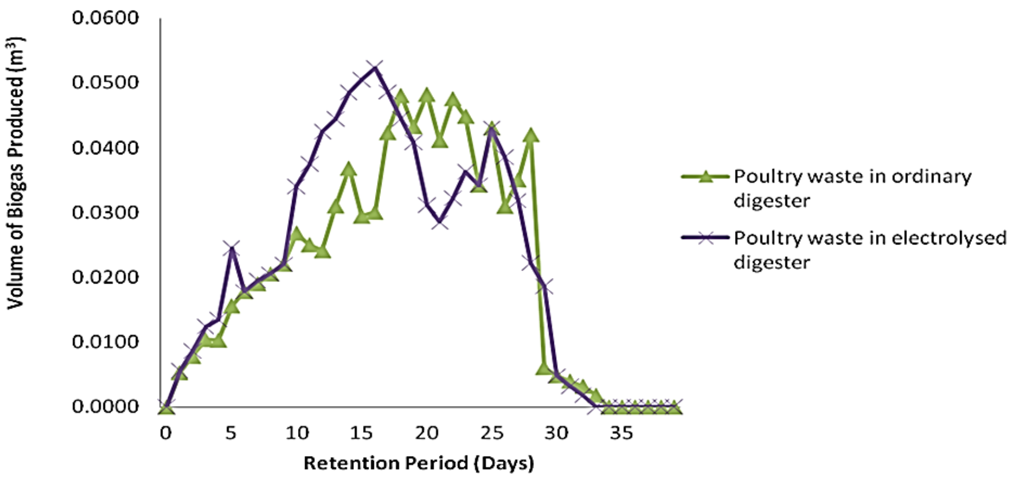

Figure 3 Volume of biogas produced versus retention period for digesters 2a and 2b

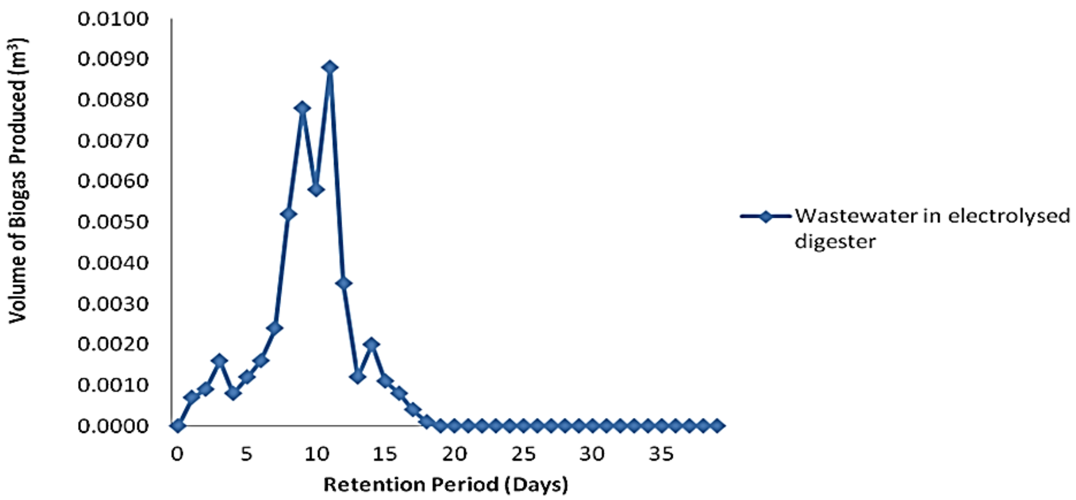

Figure 4 Volume of biogas produced versus retention period for digester 3

It was observed that, the highest biogas yield was obtained from the electrolyzed digester containing PD which peaked averagely above 500 ml between day 15 and 20. It was also observed that there was rapid rise in the biogas yield during the early period of digestion in all the digesters except in the electrolyzed digester containing wastewater which has a low biogas yield in early digestion. The biogas yield began on day 2 all through the digesters at an average value of 85 ml and increases daily to day 6, after which the yield began to fluctuate. However, on day 16, the highest biogas yield of 520 ml was recorded and from there, began to decrease for the remaining days. All through the retention period, the lowest biogas yield was recorded from the electrolyzed digester containing WW. This can be attributed to the low total solid contained in the WW. It was observed that, biogas yield from all the digesters finished before the retention period of 40 days, while others ended production at day 34 and 35, biogas yield from conventional wastewater ended earliest at day 19.

Figures 2 and 3 both show similar trend in the production rate of biogas. There was a uniform production rate in the first five days of digestion suggesting less influence of the electrolytic reactions to the substrates' solution and rapidly increasing thereafter in the electrolyzed digesters to day 25 before showing inconsistency in the production rate for the remaining days of digestion. This could be attributed to the impact of the electrolytic reactions in the electrolyzed digesters after the fifth day. Figure 4 shows a reduced rate of production all

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through the digestion period. This is as a result of the reduced amount of total solid (TS) present in the wastewater that is digestible while the highest biogas yield from poultry droppings in Figures 2 and 3 could be attributed to the available nutrients in their droppings.

Figures 5 to 7 show the pH of CD, PD, and WW both in the conventional and electrolyzed state for 40 days retention period.

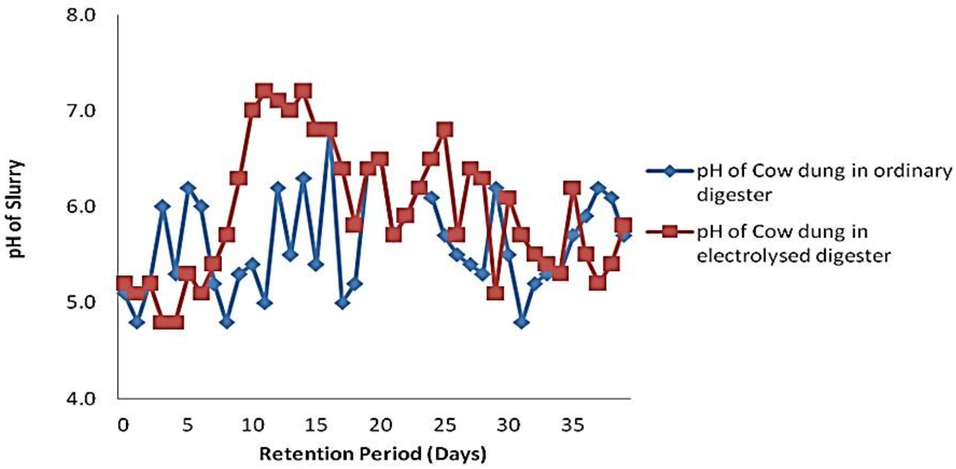

Figure 5 pH against retention period for digesters (1a and 1b)

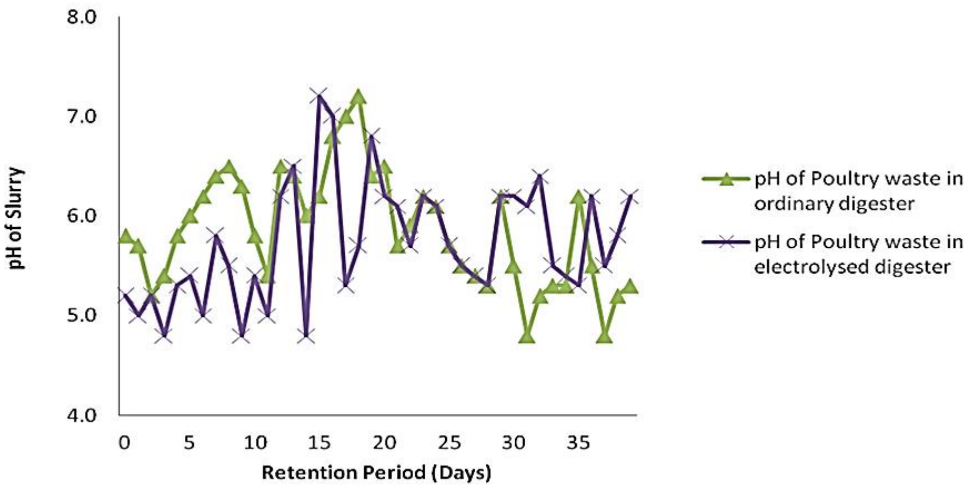

Figure 6 pH against retention period for digesters (2a and 2b)

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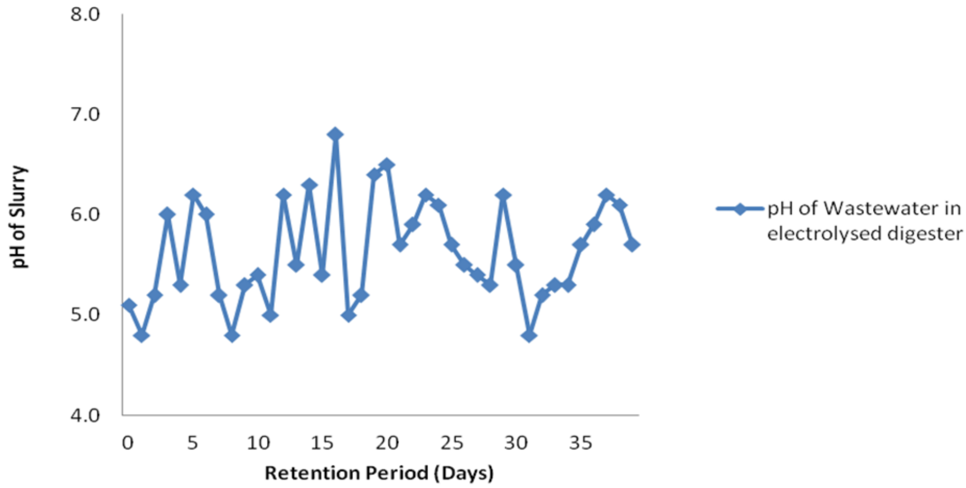

Figure 7 pH against retention period for digester 3

From the plot (Figures 5 and 6), there is a decrease in the pH in the electrolyzed digester showing state of acidity in the conversion process which indicates the first stage of anaerobic degradation with the production of acid as reported by Adu and Sangodoyin (2010). This accounted for the increase in biogas yield in the electrolyzed PD digester within this period. The pH for CD, PD and WW in both systems varies between 5.0 and 7.2. The pH fluctuated throughout the retention period; the highest pH attained was 7.2 between day 10 to day 15 by CD in both systems. There is also variation in the pH of the WW in electrolyzed digester which causes reduction in microbial activity within the system thereby resulting in low biogas yield (Figure 7).

Figures 8 to 10 show the temperature of CD, PD and WW in both conventional and electrolyzed digesters during the 40 days retention period.

The temperature varies from 24 to 33°C in conventional digester and 24 to 30°C in electrolyzed digester for CD, 27 to 32°C in conventional digester and 24 to 33°C in electrolyzed digester for PD. The temperature ranges between 24 to 32°C for WW in electrolyzed digester. All these temperatures ranges signify a transitional mesophilic thermal stage of biogas production and are in agreement with the findings of Zennaki *et al.,* (1996) and Vogeli *et al.,* (2014) who both opined that temperature inside the digester has a major effect on the biogas production process. There are different temperature ranges during which anaerobic fermentation can be carried out: psychrophilic (less than 30°C), mesophilic (30-40°C) and thermophilic (50-60°C). However, anaerobes are most active in the mesophilic stage. It was also observed from the results a higher biogas yield at 4.00 pm than at 8 am due to rise in temperature during this period of the day. Figure 7 shows a slight increase in temperature of CD in electrolyzed digester due to the increase in microbial activities within the system resulting into increase in biogas yield in the electrolyzed systems. This observation is in agreement with Pham *et al.,* (2014) which observed in their study that storing slurry in the mixing tank until its temperature peak at around 2.00 pm will increase the temperature in the digester and thus increase potential biogas production.

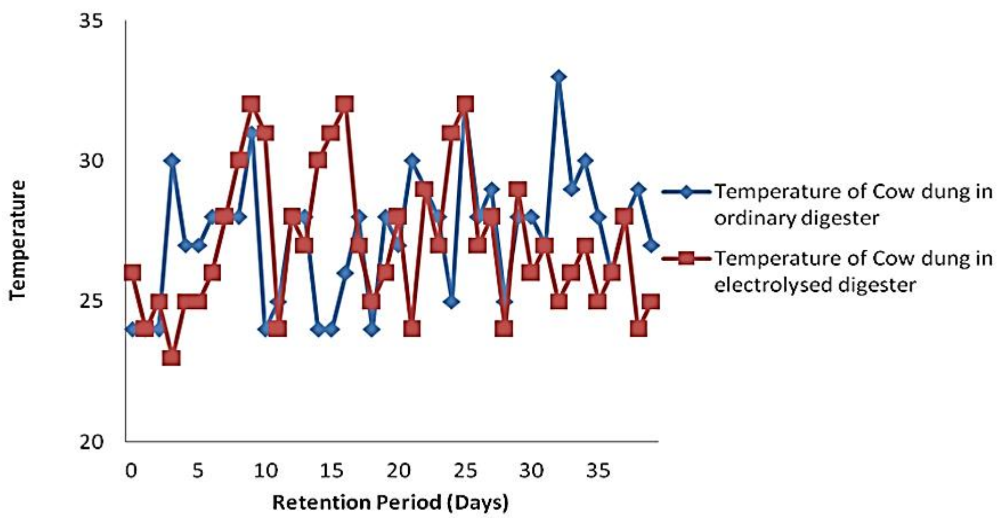

Figure 8 Temperature against retention period for digesters (1a and 1b)

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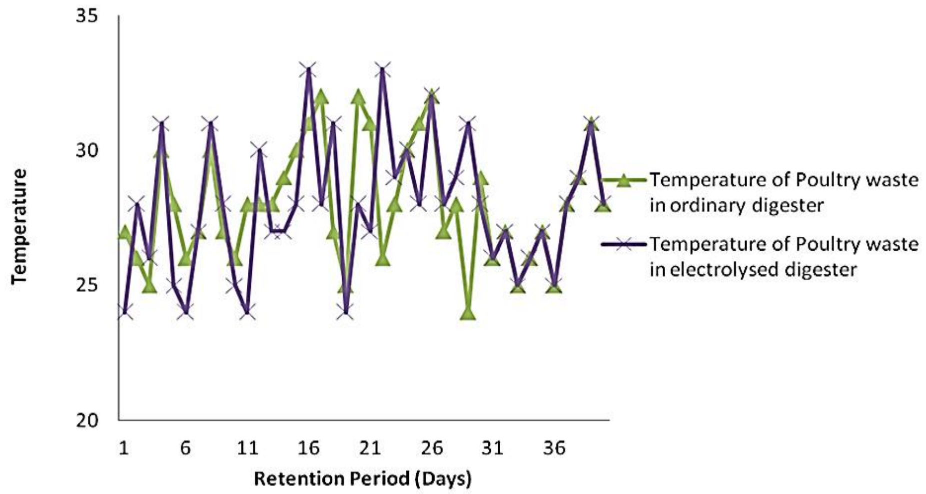

Figure 9 Temperature against retention period for digesters (2a and 2b)

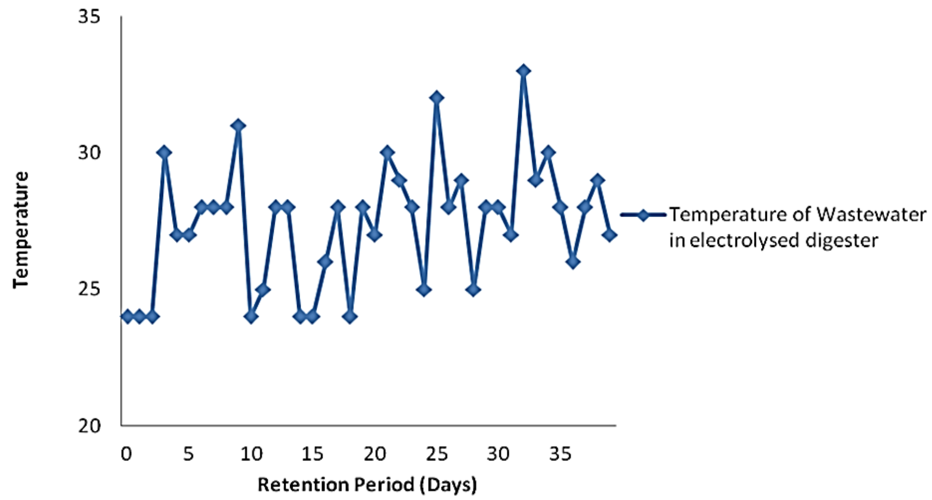

Figure 10 Temperature against retention period for digester 3

Figure 11 shows the cumulative biogas produced from CD and PD in both conventional digester and electrolyzed digester and wastewater in an electrolyzed digester within the retention period of 40 days.

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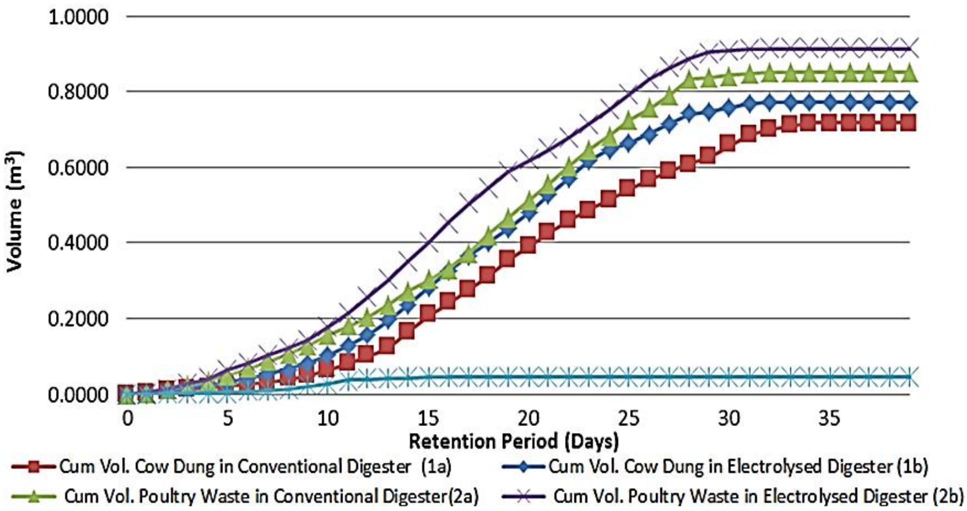

Figure 11 Cumulative volume of biogas against retention period

At the end of 40 days retention period, the cumulative volume of 7,164, 7,726, 8,519, 9,141 and 459 ml biogas was produced from the five digesters respectively. The plot shows that the highest cumulative biogas was produced in digester with PD in electrolyzed digester while the lowest biogas production was from wastewater in electrolyzed digester. Ojolo *et al.,* (2007) and Alfa *et al.,* (2014) both obtained similar results for the average biogas production from poultry droppings, cow dung and kitchen waste. They reported that poultry droppings produced more biogas because it contains more nutrient and nitrogen compared with plant and other animal waste.

The percentage cumulative volume of biogas produced for each digester was also determined (Figure 12) with the electrolyzed PD accounting for cumulative production of 91.41%. There is also an increase in production accounting for around 6% in volume between the conventional waste solution and its electrolyzed state.

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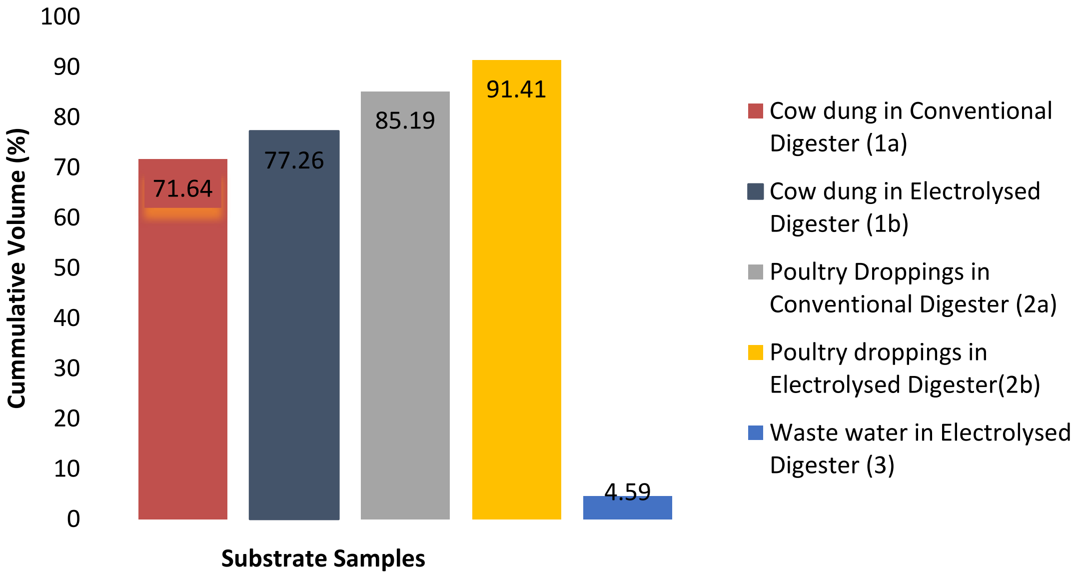

Figure 12 Cumulative volume of biogas (%)

4. CONCLUSION

The results of this study have shown that generation of biogas can be enhanced when the digestion of solid substrates is induced by means of electrolysis. The outcome of this study shows that electrolysis can be applied to solid waste to enhance the production of biogas. Poultry droppings have great potentials for the generation of biogas as compared to cow dung both in an ordinary and electrolyzed solution. The usage of cow dung and poultry waste in anaerobic digestion and inclusion of electrolysis account for 7% increase in volume of the biogas produced. The outcome of this research has also given clear indications that biogas production in wastewater is comparatively low to soluble solid waste.

REFERENCES

Adu, J. T., and Sangodoyin A. Y. 2010. Development of Appropriate Technology for Biogas Production from Water Hyacinth for Domestic Use in Nigeria. *Journal of Engineering Research.* 15(3): 29-38.

Ahmadu, T. O., Folayan, C. O., and Yawas, D. S. 2009. Comparative Performance of Cow and Chicken droppings for Biogas Production. *Nigeria Journal of Engineering*. 16(1): 154-164.

p-ISSN 2579-9150; e-ISSN 2579-9207, Volume 4, Number 1, page 11-28, October 2020
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Ajiboye, A. V., Lasisi, K. H., and Babatola, J. O. 2018. Evaluation of the Effect of Sodium Hydroxide Solution on Biogas Yield of Anaerobic Digestion of Poultry Waste and the Digestate. *Int. J. Energ Water Res*. 2(1-4): 23-31. Doi: 10.1007/s42108-018-0003-2.

Alfa, I. M., Dahunsi, S. O., Iorhemen, O. T., Okafor, C. C., and Ajayi, S. A. 2014. Comparative Evaluation of Biogas Production from Poultry Droppings, Cow Dung and Lemon Grass. *Bioresource Technology.* 157: 270-277.

Aragaw, T., and Andargie, M. 2013. Co-Digestion of Cattle Manure with Organic Kitchen Waste to Increase Biogas Production using Rumen Fluid as Inoculums. *International Journal of Physical Science*. 8: 443-450.

Babatola, J. O. 2008. Comparative Study of Biogas Yield Pattern in Some Animal and Household Wastes. *International Multidisciplinary Journal of African Research Review.* 2(4): 54-68.

Carrere. 2010. Pretreatment Methods to Improve Sludge Anaerobic Degradability: A Review. *Journal of Hazardous Materials*. 183(1): 1-15.

Grisel, C., Laura P., Umapada P., Fortino B., and Minerva, R. 2013. Generation of Biogas from Coffee-Pulp and Cow-Dung Co-Digestion: Infrared Studies of Postcombustion Emissions. *Energy Conversion and Management*. 74: 471-481.

International Energy Agency. World Energy Outlook Special Report (2015): Energy and Climate Change. Final report. Paris: OECD/IEA, 2015.

Iqbal, S. A., Rahaman, S., Rahman, M. and Yousuf, A. 2014. Anaerobic digestion of kitchen waste to produce biogas. *10th International Conference on Mechanical Engineering, ICME 2013*. *Procedia Engineering.* 90: 657-662.

Islam, A., Hossain, S. and Iqbal, S. A. 2016. Upgraded Method of Biogas Production from Kitchen Waste, Cow dung and Chicken Manure in Anaerobic Co-digestion Process. *International Conference on Mechanical, Industrial and Energy Engineering* 26-27 December 2016, Khulna, Bangladesh.

Islam, M. N. Energy Resources and Governance Issues: Bangladesh Perspective, Lecture delivered at policy planning and management Course (PPMC), Organized by Bangladesh Public Administration Training Center (BPATC), Savar-1243, Bangladesh, 2012.

Jagadabhi, P.S., Kaparaju, P., Rintala, J., 2010. Effect of Micro-aeration and Leachate Replacement on COD Solubilization and VFA Production during Mono-digestion of Grass-silage in One-stage Leach-sed Reactors. *Bioresoure Technology.* 101: 2818-2824.

Jenicek, P., Keclik, F., Maca, J., Bindzar, J., 2008. Use of Microaerobic Conditions for the Improvement of Anaerobic Digestion of Solid Wastes. *Water Science and Technology*. 58(7): 1491-1496.

p-ISSN 2579-9150; e-ISSN 2579-9207, Volume 4, Number 1, page 11-28, October 2020
Accredited SINTA 2 by Ministry of Research, Technology, and Higher Education of The Republic of Indonesia No. 23/E/KPT/2019 on August 8th, 2019 from October 1st, 2018 to September 30th, 2023

Jenicek, P., Koubova, J., Bindzar, J., Zabranska, J., 2010. Advantages of Anaerobic Digestion of Sludge in Microaerobic Conditions. *Water Science and Technology.* 62(2): 427-434.

Li, Y., Park, S.Y. and Zhu, J. 2011. Solid-State Anaerobic Digestion for Methane Production from Organic Waste. Renewable Sustainable Energy Rev. 15(1): 821-826.

Milono, P. Lindajati, T. Aman, S. 1981. Biogas Production from Agricultural Organic Residues, *The First ASEAN Seminar Workshop on Biogas Technology*. Working Group on Food Waste Materials, p. 52-65.

Nishio N, Nakashimada Y. 2007. Recent Development of Anaerobic Digestion Processes for Energy Recovery from Wastes. *J. Biosci. Bioeng.* 103(2): 105-124.

Ofoefule, A. U., Uzodinma, E. O. and Anyanwu, C. N. 2010. Studies on the Effect of Anaerobic Digestion on the Microbial Flora of Animal Wastes: Digestion and Modeling of Process Parameters. *Trends in Applied Sciences Research.* 5(1): 39-47.

Ojolo, S. J, Oke, S. A, Animasahun, O. K., and Adesuyi, B. K. 2007. Utilization of Poultry, Cow and Kitchen Wastes for Biogas Production: A Comparative Analysis. *Iranian Journal Environment Health, Science and Engineering*. 4: 223-228.

Otun, T.F, Ojo, O.M, Ajibade, F.O. and Babatola, J.O. 2015. Evaluation of Biogas Production from the Digestion and Codigestion of Animal Waste, Food Waste and Fruit Waste. *International Journal of Energy and Environmental Research*. 3(3): 12-24.

Peter, J. J. Plan Energi and Researcher for a Day. Faculty of Agricultural Sciences, Aarhus University, 2nd edition, 2009.

Pham, C.H., C.C. Vu, S.G. Sommer and S. Bruun. 2014. Factors Affecting Process Temperature and Biogas Production in Small-scale Rural Biogas Digesters in Winter in Nothern Vietnam. *Asian-Australasian Journal of Animal Sciences*. 27(7): 1050-1056.

Tartakovsky, B., Mehta, P., Bourque, J. S. and Guiot, S. R. 2011. Electrolysis-enhanced Anaerobic Digestion of Wastewater. *Bioresources Technology.* 102(2011): 5685-5691.

United Nations Environment Programme. The emissions gap report (2014): A UNEP synthesis report. Final Report. Nairobi, UNEP, 2014.

van Foreest F. Perspectives for biogas in Europe. Oxford: Oxford Institute for Energy Studies. Renewable Energy: Power for a Sustainable Future. (2nd ed.). Oxford: Oxford University Press, 2012.

Vögeli Y., Lohri C. R., Gallardo A., Diener S., Zurbrügg C. 2014. Anaerobic Digestion of Biowaste in Developing Countries: Practical Information and Case Studies. Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland.

p-ISSN 2579-9150; e-ISSN 2579-9207, Volume 4, Number 1, page 11-28, October 2020
Accredited SINTA 2 by Ministry of Research, Technology, and Higher Education of The Republic of Indonesia No. 23/E/KPT/2019 on August 8th, 2019 from October 1st, 2018 to September 30th, 2023

Xie, S., Lawlow, P.G., Frost, J. P., Hu, Z., Zhan, X. 2011. Effect of Pig Manure to Grass Silage ratio on Methane Production in Batch Anaerobic Co-digestion of Pig Manure and Grass Silage. *Bioresource Technology.* 102: 5728-5733.

Zennaki, B. Z., Zaid, A., Bentaya, K. 1998. Anaerobic Digestion of Cattle Manure Mixed with the Aquatic Used Pistia Stratiotes. *Cahiers Agric.* 7(4): 319-321.