Characterization and Analysis of Fish Waste as Feedstock for Biogas Production

Hortence INGABIRE, Boniface NTAMBARA, Member, IEEE, and Ezgad MAZIMPAKA

Hortence INGABIRE (corresponding author), Department of Mechanical, Production and Energy Engineering, Moi University, Eldoret 30900 KENYA (e-mail: ingahort@gmail.com).

Boniface NTAMBARA, Department of embedded and mobile systems (embedded systems), The Nelson Mandela African Institution of Science and Technology, Arusha 447 Tanzania (e-mail: bonifacen@nm-aist.ac.tz).

Ezgad MAZIMPAKA, Department of Mechanical, Production and Energy Engineering, Moi University, Eldoret 30900 KENYA (e-mail: ezgadmazimpaka@gmail.com)

Submission date: October 26, 2022

This work was supported in part by World Bank through the African Center of Excellence in Phytochemical, Textile, and Renewable Energy (ACE II PTRE).

Abstract— Fish waste (FW) is biodegradable waste that remains underutilized and causes a problem to the environment since the existing disposal techniques result in health risks and environmental pollution. FW has significant potential for producing biogas that decrease the reliance on fossil fuels because it contains easily biodegradable organic matter. The physicochemical analysis of the fish waste such as moisture content (MC) of 61.78 %, volatile solids (VS) of 93.94 %, total solids (TS) of 38.21 %, ash content (AC) of 0.52%, total organic carbon (TOC) of 54.2%, total kjeldahl nitrogen (TKN) of 9.2% and carbon to nitrogen (C/N) ratio of 5.89 % were considered and analyzed in this research. In addition, the methane potential was determined and obtained using gas detector. The results shown that the methane (CH4) content in fish waste was 50.12 % which was the potential feedstock of fish waste for biogas production. Nevertheless, the VS of fish waste was high which was good for this feedstock to be easily digested as the sign of producing biogas and demonstrates 99.9985% of performance rate. Finally, the FW had a lower C/N ratio compared to other biogas production waste. Future work needs to consider co-digestion with higher C/N ratio feedstocks.

Index Terms— Biogas production, Fish Waste Characterization, Feedstock Analysis, Discontinuous Digester, Water Hyacinth.

I. INTRODUCTION

The Feedstock or substrate refers to any organic material that is readily available and renewable that can biodegrade, including food waste, fish waste, animal waste, agricultural waste, water hyacinth, and other waste [1]. Substrates can be classified into two types: (i)Vegetation, such as floating plant waste, crop leftovers, forest, wood, and agricultural residues, etc., and (ii) Organic waste, such as organic industrial waste, fish waste, kitchen waste, food waste, municipal waste, and animal waste, etc. Fig. 1 shows the classification of feedstocks [2].

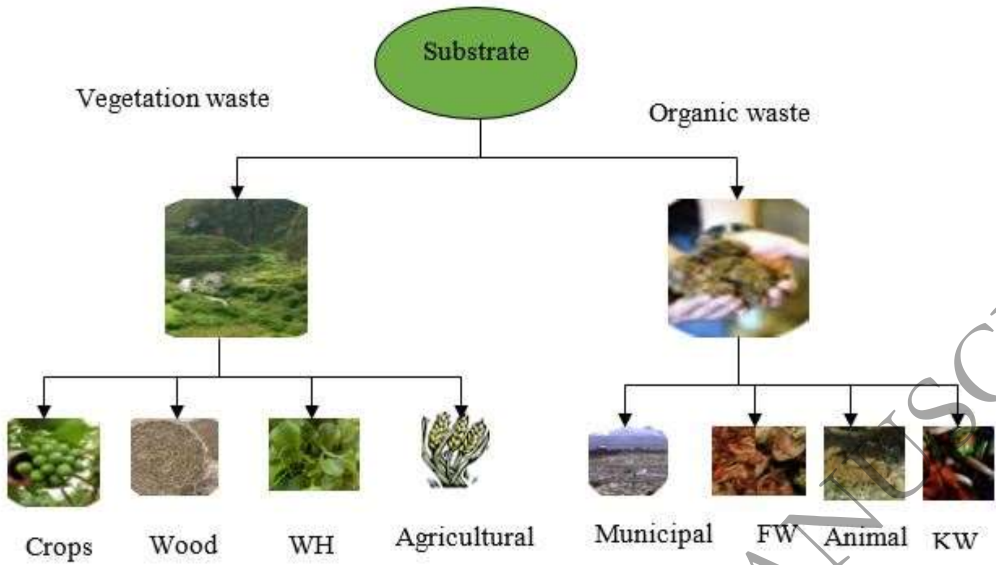

Figure 1. Classification of feedstock.

The compositions and characteristics of the feedstock used affect how well a biogas digester functions [3]. The feedstock compositions in terms of their carbohydrate, fat, and protein concentrations affect the bio-methane yield of the AD [4–6]. The quantity of nutrients (lipids, proteins, and carbohydrates) impacts how easily the material degrades, and consequently how much methane may be produced by the AD process [4]. Additionally, the feedstock properties such TS, MC, VS, C/N ratio, and so on can have a significant impact on the anaerobic digestion system [5]. The substrates for AD can be categorized according to several factors, including dry matter (DM) or total solids content, origin, methane yield, etc. Wet digestion (wet fermentation) uses substrates with DM contents under 20%; dry digestion (dry fermentation) uses substrates with DM contents greater than 35%. DM concentration and the amount of sugars, proteins, and lipids in the feedstock affect the types and quantities of feedstock used in AD [5, *6*]. Compared to *lingo*-cellulosic materials, substrates with high percentages of easily degradable organic matter have more potential for producing bio-methane [5]. Agriculture waste, food waste, fish waste, human waste, industrial trash, residential garbage, organic waste, water hyacinth, and other elements are all digested [7, 8]. Lignin is the main exception to the rule that most naturally occurring organic wastes can be digested [8–10]. Large amounts of fish waste are created during the processing of fish, and the majority of this waste is underutilized and ignored [1–3, 5, 6]. Before being sold, over 70 % of fish is processed. 20% to 80% of this total are by-products or waste that is not used for direct human consumption [2–5]. Around 9.1 million tons of fish waste

(FW) are thrown away each year. Consequently, fish by-products are now a global issue and pose a problem to the long-term viability of fish aquaculture [12]. The current methods of disposing of this highly polluting organic matter such as dumping/discarding onto the open ground and disposing of in sanitary landfills result in health risks/hazards, and environmental issues [5, 7, 11–13]. Accordingly, any effective development of a by-product utilization technique will lead to the energy recovery of these wasted important nutrients and eradication of the environmental pollution and health hazards or risks brought on by the incorrect disposal of the by-product processing [7, 13, 14]. When used as feedstock in biogas production, fish waste which is abundant in lipids and proteins has the benefit of producing large methane outputs [11]. Consequently, biogas technology may be a useful method for FW utilization and energy production [5, 7, 11]. The reduction of fossil fuel consumption and environmental pollution can be accomplished through the AD of this biodegradable waste [8, 9, 11, 15, 16]. When anaerobic digestion is completed, nutrients like phosphorus and nitrogen are retained in the effluent. If it meets the appropriate requirements, it can be used as a compost in farming production [8, 11, 15, 16]. This resource recovery method solves the byproduct disposal issues. A technology like that may be advantageous to fish producers everywhere in the nation and the world [13]. The biogas is mainly composed of 40–75% CH_4, 25–55 % CO_2, and small amounts of other gases [5, 7]. Some characteristics of fish waste are given in Table I [5, 7, 8, 11–13, 17, 18], indicating moisture content (MC) of 67.1-81.43%, total solid (TS) of 31.30-32.2%, volatile solid (VS) of 27.50-55.5%, total Kjeldahl nitrogen (TKN) of 5.44-10.85 %, total organic carbon (TOC) of 53-54.35%, ash content of 2.14-5.7% and C/N ratio of 3-10.1%.

TABLE I. Product Nutrition Composition of fish waste.

Characteristics	***Amount (%)***
Moisture Content (MC)	67.1-81.43
Volatile Solids (VS)	27.50-55.5
Total Solids (TS)	31.30-32.2
Total Kjeldahl nitrogen (TKN)	5.44-10.85
Ash content	2.14-5.7
Total organic carbon (TOC)	53-54.37
C/N ratio	3-10.1

The elemental composition of the feedstock extensively influences the design and operation of anaerobic digestion. The microbes' growth rate and anaerobic environment stability are both significantly impacted by the content of the organic waste supplied to a digesting system [8, 19]. The physicochemical properties of the substrate determine its biodegradability [4, 9]. A reliable method of analyzing and characterizing feedstock is required to evaluate the profitability and suitability of biogas feedstocks [20]. For maximum quantity and quality of biogas energy, knowledge of the substrate's physicochemical properties is crucial [10]. Using information found in the literature, a feedstock might be given a preliminary evaluation. If the initial evaluation suggests that the feedstock might be appropriate, a thorough laboratory investigation should come next [20]. This study provides information on the various methods used for the physicochemical characteristics (TS, VS, MC, AC, TOC, TKN, and C/N ratio) analysis of fish waste, including APHA guidelines and regular techniques, Walkley-Black method, and Kjeldahl method.

II. MATERIALS AND METHODS

2.1 Collection and preparation of feedstocks

The fish waste (fish intestines) used in this experiment were collected from Eldoret's fish point and blended with a blender. For physicochemical analysis, a fresh sample was used.

2.2 Fish waste (FW) Characterization

The chemical and physical analysis of organic materials was required for the operation of an AD system because it affects both bio-methane yield and system stability [21]. MC, TS, VS, and AC of FW (fish waste) were determined using APHA standard methods [32–34], while the TKN, TOC, and C/N ratio of FW were determined using the walkley-black and Kjeldahl methods [28, 29].

2.2.1 Physical analysis

The APHA 2540B and 2540E standards were used to measure the concentration of MC, VS, TS, and AC of fish waste [21–23]

(a) MC and TS determination

The MC is the amount of water content in the material while TS is the amount of dry matter content in the material. Five grams (5 g) of the fish waste sample were placed in a crucible, which was baked at 105°C for 4 hours. The crucible was cooled down for 10 minutes. The losses were then recorded until the constant weight was reached. Then, using equations (1) and (2) the percentage of MC and TS of fish waste were determined respectively using APHA 2540B [10, 13, 26, 27].

$$MC = \frac{W_2 - W_3}{W_2} * 100 \ (1)$$

$$TS = \frac{W_3 - W_1}{W_2 - W_1} * 100 \ (2)$$

(b) **Volatile solids analysis and ash determination**

To determine how many volatile organic materials were present in the sample, the VS was measured. Ash includes different nutrients in varying amounts that are necessary for microbial metabolism. Five grams (5g) of fish waste were weighed into the crucible, dried for four hours at 105 °C in an oven heater, and then burnt down at 550°C in one hour in muffle furnace. The crucible containing ashes were allowed to cool for around 20 minutes. The percentage of volatile solids (VS) and ash content (AC) of fish waste was determined using equations (3) and (4) respectively that used APHA 2540 E standard methods [10, 13, and 25, 27–31].

$$VS = \frac{W_{3*} - W_4}{W_{3*} - W_1} * 100 \ (3)$$

$$AC = \frac{W_4 - W_1}{W_{2*} - W_1} * 100 \ (4)$$

2.2.2 Chemical analysis

(a) **Total organic carbon (TOC) determination**

The Walkley-Black method was used to determine the TOC of fish waste using $H_2SO_4 + K_2Cr_2O_7$ [23, 32]. The potassium dichromate Walkley-Black technique was employed [24, 25, 33] in which 1 gram of dry sample of fish waste was placed in a conical flask of 250 mL, $K_2Cr_2O_7$ of 10 milliliters (mL) was added, and the mixture was rotated or swirled. In a fume hood, 15 mL of H_2SO_4 was added and swirled three more times. The 5 mL of phosphoric acid and 150 mL of plowed water were added after 30 minutes. With the solution of ferrous ammonium sulfate (0.5 N), the contents were adjusted until the color changed from blue to green. Equation (5) was used to compute the amount of organic carbon.

$$\%C = \frac{[(B-S)*(V*1.3*0.3)]}{W} \ (5)$$

(b) Total Kjeldahl nitrogen (TKN) determination

The Kjeldahl method was employed to determine the total nitrogen substance of fish waste [25, 32, 34], which required the digestion of the sample and volumetric measurement. 1 gram of the fish waste, K_2SO_4 of 5g, 0.5 g of $CuSO_4$ as a catalyst, and concentrated H_2SO_4 (10 mL) were all weighed into a digestion flask. The inter-mixture was heated up at a high-temperature of 420 °C in fume hood until the color of the digest turned blue, indicating that the digestion process was complete. After cooling to room temperature and being filled with distilled water, the digest was moved to a 100 ml volumetric flask. Additionally, an empty digestive tube containing acid and catalysts was produced. The diluted digest (10mL) was placed in a distilling flask and diluted or rinsed with 3mL of distilled water. A solution of 40% NaOH (15 mL) was added and the mixture was also diluted or washed with 3 mL of water (distilled). About 60 mL of distillate was produced after the distillation process. The distillate solution was titrated with HCl (0.02 N) until the color changed to orange (methyl orange). Equation (6) was utilized to compute the total nitrogen.

$$\%N = \left[\frac{(V_1 - V_2) * N * F * 100}{V*}\right] * \left[\frac{1.4}{W*}\right] \quad (6)$$

(c) Carbon to nitrogen ratio determination

To calculate the C/N ratio, divide the TOC by the TKN. The APHA 4500 B standard method was employed [26].

2.3 Methane content analysis

The gas sampling bags' methane content was examined and Gas chromatograph setup using a gas detector as shown in fig. 2 and biogas production setup as shown in fig. 3.

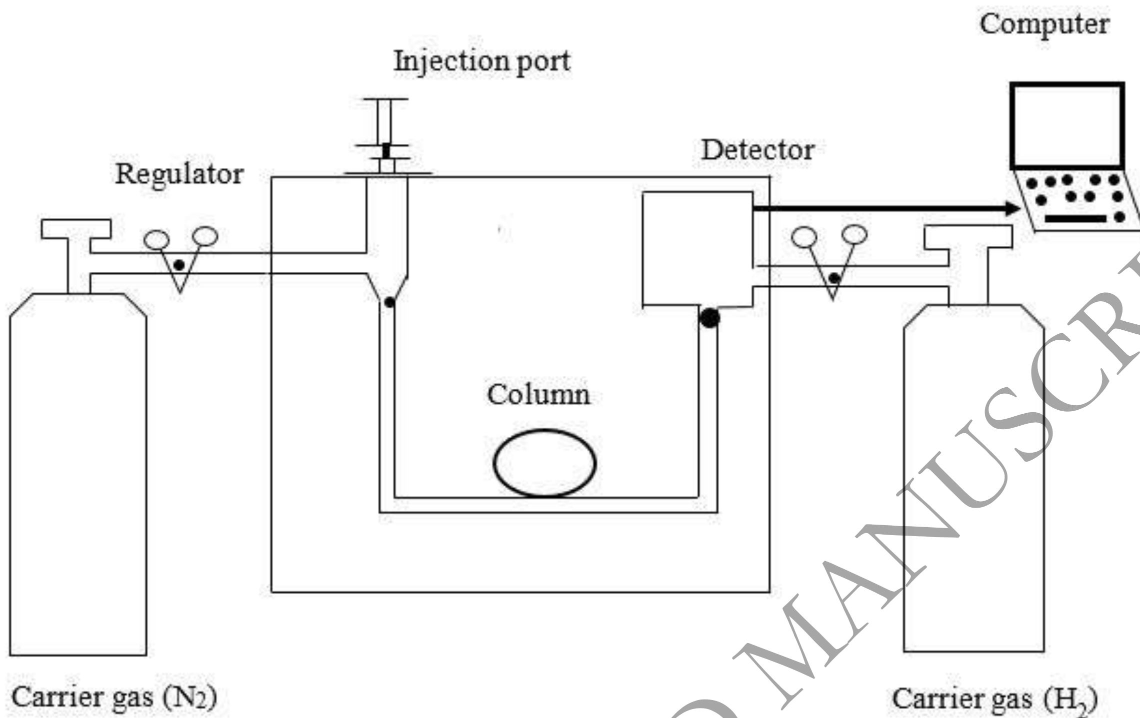

Figure 2. Gas chromatograph setup.

Figure 3. Biogas production process and setup.

III. RESULTS AND DISCUSSION

3.1 Fish waste physicochemical analysis

Initially, the fish waste was characterized by MC, TS, VS, AC, TKN, TOC, and C/N ratio. Table II summarized the results of the physicochemical analysis of fish waste.

TABLE II. Physicochemical characterization results of fish waste

Parameters	***Amount (%)***
Moisture content (MC)	***61.78***
Volatile solid (VS)	***93.94***
Total solid (TS)	***38.21***
Total Kjeldahl nitrogen (TKN)	***9.2***
Ash content (AC)	***0.52***
Total organic carbon (TOC)	***54.2***
C/N ratio	***5.89***

The fish waste had a VS of 93.94 %. The range of biodegradability for the substrate to produce high bio-methane yield was 70-95% [9, 25, 35]. This shows that fish waste is biodegradable which makes it a potential substrate for the production of biogas. In addition, the organic waste with high VS content, has a high potential of being used as a source of biogas energy where the MC of fish waste was 61.78%. The substrate that includes MC between 60–80% was suitable for the AD process. Therefore, fish waste is amenable to AD. The biogas production results obtained in this research were compared to previous biogas waste production done by [11–13], where the MC of fish waste varies between 57.15-73%. High MC in the substrate facilitates the AD process [39]. Consequently, fish waste is a good feedstock for biogas production as it has the good TS of fish waste of 38.21%. According to [40, 41], the 7–9% TS is preferable. This shows that the TS of fish waste is out of range. However, the results for fish waste are in line with the results reported by [11, 17] where the TS in fish waste is 31.30 % and 32.2 % respectively. TS measures the overall volume of material that remains after all the moisture has evaporated [42]. Less than 10% of TS in AD systems are low or wet solids, 15-20% are medium solids, and 22–40% are high or dry solids processes [26, 41, 42]. A dry AD system makes the digester's solution more compact, which offers high loading rates, consequently more biogas than a wet AD system because the high loading rate and compactness of by-products increase the level of material digestion [42, 43]. Dry AD is advantageous: (i) requires less water, (ii) having less water in the residue results in a smaller reactor capacity, and (iii) produces a larger volumetric bio-methane yield [43, 44]. The ash content (AC) was 0.52%. The TOC and TKN for fish were 54.2% and 9.2% respectively. The C/N ratio of fish waste was 5.89:1. According to [26, 45], the optimal C/N ratio for AD is between 20-30%. Therefore, the C/N ratio (5.89) of FW was out of range for biogas generation. However, the results above are within the range of [6, 8, 11, 18] where the carbon to nitrogen ratio of FW is between 3-5%. The C/N ratio depends on the type of feedstocks. A low C/N ratio can quickly lead to ammonia toxicity and high pH levels, which are poisonous for methanogenic bacteria while a high C/N ratio causes poor buffering capacity, hence lower biogas generation [18, 26, 45–50]. The organic waste with low C/N ratio can be combined with high C/N ratio organic waste to reduce the concentration of inhibitory substances and achieve the digester's ideal C/N ratio [14, 18, 26, 45, 48, 51].

3.2 Methane gas content in fish waste

It was important and necessary to examine the content of the biogas in a feedstock in terms of CH4 (methane) and CO2 (Carbon dioxide). The biogas is mainly consisted of 40–75% of CH_4, 25–55 % of CO_2, and small amounts of other gases [5, 7]. The methane content in fish waste was 50.12 %, as shown in Table III. The removal of CO_2 is crucial because is hazardous to humans and corrodes motors and pipes [52, 53].

TABLE III. Content of CH4, CO2, O2, H2S, and other gases in fish waste

Compositions	***Unit***	***Amount***
CH_4	%	***50.12***
CO_2	%	***39.72***
O_2	%	***0.34***
H_2S	ppm	***235***
Others	%	***8.92***

IV. CONCLUSION AND RECOMMENDATION

The fish waste was examined for its initial MC, TS, VS, AC, TOC, carbon to nitrogen ratio, and TKN. The FW physicochemical analysis results include: MC of 61.78 %, VS of 93.94 %, TS of 38.21 %, AC of 0.52%, TOC of 54.2%, TKN of 9.2% and C/N ratio of 5.89 %. The methane (CH4) content in fish waste was 50.12 %. The results indicated that fish waste is a potential feedstock for biogas production. FW had a lower C/N ratio, further study needs to consider co-digestion with higher C/N ratio feedstocks. Nevertheless, the VS of fish waste was high which was good for this feedstock to be easily digested as the sign of producing biogas.

Data Availability

The research covers all of the needed data. More data is available upon request from the main author.

Conflict of interest

No conflicting of interests.

ACKNOWLEDGMENT

The authors would like to thank Moi University for allowing them to use their laboratory facilities during this research. The research was funded by the World Bank through the African Center of Excellence in Phytochemical, Textile, and Renewable Energy (ACE II PTRE).

REFERENCES

[1] B. Girisuta, *Levulinic Acid from Lignocellulosic Biomass Buana Girisuta*, no. May. 2014.

[2] V. R. Akula, "Wetland biomass - suitable for biogas production?" 2013.

[3] T. O. Araoye, C. Mgbachi, and G. A. Ajenikoko, "Development of a Simplex Optimization Technique for Biogas Generation," no. November 2018.

[4] S. Aslanzadeh, "Pretreatment of cellulosic waste and high-rate biogas production," University of Borås, 2014.

[5] A. Pina, P. Ferrão, J. Fournier, B. Lacarrière, O. Le Corre, and A. I. Andri, "Approach for modeling anaerobic digestion processes of fish waste," *Energy Procedia*, vol. 147, pp. 390–396, 2018.

[6] R. J. Teodorita Al Seadi, Dominik Rutz, Heinz Prassl, Michael Köttner, Tobias Finsterwalder, Silke Volk, *biogas handbook*. 2010.

[7] A. Oke, "The utilization of fish and fish farm wastes in biogas production: 'A Review,'" no. October 2016.

[8] U. Marchaim, *Biogas processes for sustainable development*. 2007.

[9] T. Nadu and T. Nadu, "Operational Conditions of Anaerobic Digestion and their Optimization for Enhanced Biogas Production – A," vol. 7, no. 7, pp. 49–54, 2017.

[10] E. P. Makhura, E. Muzenda, and T. Lekgoba, "Effect of co-digestion of food waste and cow dung on biogas yield," vol. 01005, 2020.

[11] G. K. Kafle and S. H. Kim, "Evaluation of the Biogas Productivity Potential of Fish Waste: A Lab Scale Batch Study," vol. 37, no. 5, pp. 302–313, 2012.

[12] A. Kandyliari *et al.*, "Nutrient Composition and Fatty Acid and Protein Profiles of Selected Fish By-Products," pp. 1–14, 2020.

[13] S. Maghaydah, "Utilization of fish processing by-products for the nutritional formulation of fish feed," 2003.

[14] H. I. Owamah, "Optimization of Biogas Production through Selection of Appropriate Inoculum-to-Substrate (I/S) Ratio," pp. 17–24, 2010.

[15] E. A. Tsavkelova and A. I. Netrusov, "Biogas Production from Cellulose Containing Substrates: A Review," vol. 48, no. 5, pp. 421–433, 2012.

[16] G. B. Adebayo and O. S. Odedele, "Production and Characterization of Biogas from Domestic Waste by Anaerobic Digestion," vol. 15, no. 1, pp. 1–9, 2020.

[17] Y. Nalinga and I. Legonda, "Experimental investigation on biogas production from anaerobic co-digestion of water hyacinth and fish waste," *IJIRTS*, p. 8, 2016.

[18] O. Ojikutuabimbola and O. O. O, "Evaluation of biogas Production from food waste," no. January 2014, 2016.

[19] C. Phun *et al.*, "The characterization and treatment of food waste for improvement of biogas production during anaerobic digestion – a review," *J. Clean. Prod. 16*, 2017.

[20] B. Drosg and R. Braun, *Analysis and characterization of biogas feedstocks*. Woodhead publishing Limited, 2013.

[21] B. Kubaská, M., Sedláˇcek, S., Bodík, I., Kissová, "Slovak Society of Chemical Engineering Institute of Chemical and Environmental Engineering Slovak University of

Technology in Bratislava Food Waste as Biodegradable Substrates for Biogas Production," pp. 1413–1418, 2010.

[22] APHA, "APHA Method 2320: Standard Methods for Examination of the Water and Wastewater," *Phys. Aggreg. Prop.*, no. 2540, pp. 1–7, 2000.

[23] C. Shen, "Pilot-scale Study on Anaerobic Digestion Applied to a Saline Industrial Waste Activated Sludge," 2008.

[24] X. Cheng and C. Zhong, "Effects of Feed to Inoculum Ratio, Co-digestion, and Pretreatment on Biogas Production from Anaerobic Digestion of Cotton Stalk," 2014.

[25] N. Bakr and S. M. El-ashry, "Communications in Soil Science and Plant Analysis Organic matter determination in arid region soils: loss-on-ignition versus wet oxidation," *Commun. Soil Sci. Plant Anal.*, vol. 00, no. 00, pp. 1–15, 2018.

[26] Maurice Twizerimana; Milton Marimi; Xumay Bura; Eric Oyondi Nganyi, "Biogas Production from Co-digestion of Cotton Yarn Waste and Human Urine," *J. Energy Res. Rev.*, vol. 1, no. 6, pp. 1–10, 2021.

[27] M. O. Jnr, "Biogas production from kitchen waste generated on KNUST Campus," no. August 2011.

[28] E. Hasanzadeh, S. Mirmohamadsadeghi, and K. Karimi, "Enhancing energy production from waste textile by hydrolysis of synthetic parts," *Fuel*, vol. 218, no. September 2017, pp. 41–48, 2018.

[29] B. P. Ismail, "Ash Content Determination," *Springer International, New York*, pp. 117–119, 2017.

[30] E. K. Orhorhoro, P. O. Ebunilo, and G. E. Sadjere, "Experimental Determination of Effect of Total Solid (TS) and Volatile Solid (VS) on Biogas Yield," vol. 3, no. 6, pp. 131–135, 2017.

[31] K. Rajendran and G. Balasubramanian, "High-rate biogas production from waste textiles," University of Borås, 2011.

[32] M. N. A. El-din and M. A. Badawi, "Biogas Production from Crop Residues and Aquatic Weeds," vol. 3, pp. 33–45, 1989.

[33] H. Myovela, "Anaerobic digestion of spineless cacti (Opuntia ficus-indica (L. Mill) Biomass in Tanzania: The effects of aerobic pre-treatment," Pan African University Institute of Science, Technology and Innovation, 2018.

[34] E. Elbeshbishy, A. Nakevski, H. Hafez, M. Ray, and G. Nakhla, "Simulation of the Impact of SRT on Anaerobic Digestibility of Ultrasonicated Hog Manure," pp. 974–988, 2010.

[35] A. State, I. Akpaden, and M. E. L. G. A, "Optimization investigation of biogas potential diversifolia as an alternative energy source," vol. 3, no. 3, pp. 46–55, 2016.

[36] F. A. Alfarjani, "Design and Optimization of Process Parameters in Bio-Gas Production Systems," 2012.

[37] R. Le *et al.*, "Influence of substrate concentration and moisture content on the specific methanogenic activity of dry mesophilic municipal solid waste digestate spiked with propionate," *Bioresour. Technol.*, vol. 102, no. 2, pp. 822–827, 2011.

[38] A. Khalid, M. Arshad, M. Anjum, T. Mahmood, and L. Dawson, "Anaerobic digestion of solid organic waste," *Waste Manag.*, vol. 31, no. 8, pp. 1737–1744, 2013.

[39] L. Deressa, S. Libsu, R. B. Chavan, D. Manaye, and A. Dabassa, "Production of Biogas from Fruit and Vegetable Wastes Mixed with Different Wastes," vol. 3, no. 3, pp. 65–71, 2015.

[40] A. M. and S. T. Muhammad Rashed, "Enhancement of Production and Upgradation of Biogas Using Different Techniques- A Review," 2015.

[41] V. R. Yadvika, Santosh, T.R. Sreekrishnan, Sangeeta Kohli, "Enhancement of biogas production from solid substrates using different techniques," *Sci. direct*, p. 10, 2004.

[42] N. I. Madondo, "Optimization of anaerobic co-digestion of sewage sludge using biochemical substrates," 2017.

[43] L. Sun, *Biogas Production from Lignocellulosic Materials*. 2015.

[44] A. T. Jansson, R. J. Patinvoh, and S. Iiona, "Dry Anaerobic Digestion of Food and Paper Industry Wastes at Different Solid Contents," pp. 1–10, 2019.

[45] A. Rabii, S. Aldin, Y. Dahman, and E. Elbeshbishy, "A Review on Anaerobic Co-Digestion with a Focus on the Microbial Populations and the Effect of Multi-Stage Digester

Configuration," *Energies*, vol. 12, no. 1106, pp. 1–25, 2019.

[46] N. V Stojkovi, B. B. Milutinovi, and M. P. Ivanovi, "The organic waste fractions ratio optimization in the anaerobic co-digestion process for the increase of biogas yield," vol. 22, pp. 1525–1534, 2018.

[47] F. T. Y. Avs, "Effects of co-substrate on biogas production from cattle manure: a review," pp. 2303–2312, 2016.

[48] X. Hhaygwawu, "Biogas production from cow dung and grass in anaerobic co-digestion for semi-arid areas," 2016.

[49] J. Katima, "Production of biogas from water hyacinth: Effect of substrate concentration, particle size and incubation period." 2001.

[50] J. C. Akunna, *Anaerobic wastewater treatment, and biogas plants*. 2019.

[51] T. Abbasi. S.M. Tauseef. S.A. Abbasi, *Biogas energy*. 2012.

[52] O. Almoustapha and S. Kenfack, "Biogas production using water hyacinths to meet collective energy needs in a Sahelian country," vol. 1, no. April 2019.

[53] U. C. Okonkwo, E. Onokpite, and A. O. Onokwai, "Comparative study of the optimal ratio of biogas production from various organic wastes and weeds for digester / restarted digester," *J. king saud Univ. -Engineering Sci.*, no. February 2016.

ABBREVIATIONS

***W1**:* The crucible's weight

***W2**:* The crucible and wet sample weight

***W3**:* The crucible and dry sample weight at 105 °C.

%C: The percentage of total organic carbon,

S: The material sample reading (mL).

B: The blank reading (mL).

W: The weight of the fish waste sample (g).

V: The volume of 1N $K_2Cr_2O_7$ (mL).

W2*: The wet material sample and crucible weight

W3*: The dry material sample and crucible weight at 105 °C

W4: The crucible and material sample weight after ignition at 550 °C.

%N: The percentage of Total Kjeldahl nitrogen.

V_1**:** Sample volume (mL)

N: The standard Normality (HCl).

V_2*:* Volume of the blank (mL).

V**:*** The distillation volume

F: Factor of standard (HCl)

W*: Sample weight (g).

BIOGRAPHIES

Hortence INGABIRE received her BSc in Electrical Engineering at National University of Rwanda, MSc in Energy Studies at Moi University. Her area of interest includes but not limited to Analyze energy systems, energy loss reduction, energy low emission development, country energy security strategies, streamline energy project development and investment processes, improvement of climate mitigation and resilience by providing technical assistance to Kenya power, diversification of energy resources, Minimize unnecessary energy consumption, development of renewable energy technologies, analyzing of the trends and major factors in the energy trading market , energy trades methodologies and practices , and identification of quality major stakeholders in the energy sectors, develop of energy policies and standards, advise on heating systems energy efficiency.

 **Boniface NTAMBARA** was born in Rwanda in 1990. He received the BSc (Eng.) degree in Electrical Power Engineering from the University of Rwanda/College of Science and Technology, Rwanda in 2015, MSc in Industrial Engineering at Moi University, Kenya in 2022, MSc in Embedded and Mobile Systems (Embedded System Option) at Nelson Mandela African Institution of Science and Technology, Tanzania. His current research interests include Industrial Automation, PLC and SCADA Systems, Intelligent Systems, Aerial Robotics, Drone Technology, Sensor Systems and Embedded Computing, Power and Energy Automation, Industrial Power Systems, Aeronautical and Aerospace Engineering and HMI and Cyber Physical Systems, Industrial Instrumentation and control, Industrial total quality management, Drone technology with Military applications and Defense Technology, Electric Power System Applications of Optimization ,Electrical Power Equipment Maintenance and Testing, Electric Systems, Dynamics, and Stability with Artificial Intelligence Applications, Transformer Engineering: Design and Practice, Vehicular Electric Power Systems: Land, Sea, Air, and Space Vehicles, Power System State Estimation: Theory and Implementation, Protection Devices and Systems for High Voltage Applications, Power System Analysis: Short Circuit Load Flow and Harmonics, Control and Automation of Electric Power Distribution Systems, Protective Relaying for Power Generation Systems, Understanding Electric Utilities and De-regulation, Renewable Energy Utilities and its uses, and energy policy and economics, Power Engineering, Energy Engineering, Micro Grid, Smart Grid, Small wind turbines(Off Grid systems), High Voltage Direct Current Technology(HVDC), Wind Power Plant with Double Feed Induction Generator(GFIG), Hydropower with pumping and classical power generation, Power Transmission and Protection Technology, Industrial Photovoltaic systems, Microgrid Power system with synchronization, Smart Grid SCADA Monitoring and Remote control, Smart Grid distribution and double Bus Bars FRT(Fault ride through, dynamic grid fault simulation), Manufacturing and Automation Engineering with mechatronics systems. MSc (Eng.) Boniface is an active member of Institute of Electrical and Electronics Engineers (IEEE). Currently, Boniface

is a Reviewer at Springer Nature: International Journal of Intelligent Systems and Robotics Applications (JIRA), Reviewer of IEEE Southern Power Electronics Conference (IEEE SPEC 2022).

Ezgad MAZIMPAKA received the B.S. degree in electrical power engineering from University of Rwanda in 2015, MSc in Energy Studies from Moi University/Kenya, in 2021. His fields are Electric Power System Applications of Optimization, Electrical Power Equipment Maintenance and Testing, Electric Systems, Dynamics, and Stability with Artificial Intelligence Applications, Transformer Engineering: Design and Practice, Vehicular Electric Power Systems: Land, Sea, Air, and Space Vehicles, Power System State Estimation: Theory and Implementation, Protection Devices and Systems for High Voltage Applications, Power System Analysis: Short Circuit Load Flow and Harmonics, Control and Automation of Electric Power Distribution Systems, Protective Relaying for Power Generation Systems, Understanding Electric Utilities and De-regulation, Renewable Energy Utilities and its uses. Currently, Eng. Ezgad Mazimpaka is electrical maintenance engineer at Burera District/Rwanda and he is a certified member of Institute of Engineers Rwanda (IER).