The International Journal of Engineering and Science (IJES)
|| Volume || 11 || Issue || 3 || Series I || Pages || PP 14-20 || 2022 ||
ISSN (e): 2319-1813 ISSN (p): 20-24-1805

Pretreatment and Optimization Strategy for Biogas Production from Agro-based Wastes

[1]Duduyemi Oladejo*, [2]Bukola Jegede, [1]Regina J. P.,[1]Akinbomi J.G.and [1]Bakare L.O.

[1*]*Department of Chemical Engineering, Lagos State University, P.M.B 65, Lagos-Nigeria*
[2] *(ITF. gov.ng Ikeja Lagos, Nigeria)*

----------ABSTRACT----------

Biogas was produced from spoilt fruit wastes and corncobs as feedstock. Laboratory bench scale setup was employed topretreat the substrate with a view to reducing reducing the start-up time in biogas production time using Calcium Hydroxide, Calcium oxide, Amylase enzyme and Potash at different concentrationson samples of substrate labelled A-H. Application of 2g of Calcium Hydroxide to a 60g substrate was found to initiate the production and improved the quantity of gas generated as (sample B) which reached its peak of 275 mL after 8 hours on day 2. The recipe was upscaled into a pilot-scale digester to produce a higher volume of biogas which was characterized and optimized by reducing the Carbon dioxide and other impurities withadsorption through water, steel wool and Silica gel respectively. The pre-treatment of the feedstock substrate with Calcium and hydroxide and purification with silica gel produced increased yield of methane.Analysis of the biogas component revealed the high level of Methane (26.4%), lowest amounts of Oxygen (-3.4%) and Hydrogen Sulphide (-162ppm), showing that the resulting biogas was of good quality with less corrosive composites.

KEYWORDS: *Biogas, Optimization, Agro-based, Waste, Reagents, production, substrate, microbial*

Date of Submission: 03-03-2022 Date of Acceptance: 17-03-2022

I. INTRODUCTION

Agricultural produce enjoyed the diversity of species with edible and non-edible parts. The challenges of the increasing population have resulted in increased agricultural production to ease the effect of food shortage. Preservation of farm produces with high water content such as fruits and vegetables became an inevitable challenge and they constitute a menace to the environment with great losses to the farmers. The waste generated has taken its chances on globalwaste management and in the search for renewable energysources.As food production increases, about one-third of these agricultural products are discarded to unregulated dumpsites for landfilling, burning and sometimes treated for manure composting owning to post-harvest losses.

Wastes at the dumpsites degrade with time, thereby releasing methane gas into the atmosphere; Leachate from the dumpsites also results in soil and groundwater contamination. More so, the open burning of these wastes leads to the release of dioxin into the atmospherewhich may be hazardous to the environment [1]. Naturally, agricultural wastes are biodegradable and are potential feedstock for anaerobic digestion. The recovery of biogas from these wastes for energy generation will reduce challenges associated withenergy insecurity and environmental problems.

Anaerobic digestion involves the breakdown of organic wastes by micro-organisms in an airtight environment to produce biogas and the residue can be utilized as a soil amendment[2, 3]. Operational strategies for an innovative temperature and agitation had been introduced to biogas production and optimizing of mesophilic plug-flowhad been used [4,5] The biogas produced is composed of methane, carbon dioxide, smaller traces of acidic gases and impurities such as hydrogen sulfide, nitrogen, water vapour and traces of other volatile organic compounds (VOC) [6] . It has also been reported that the composition of methane solely depends on the source of the feedstock used and the decay conditions [7, 8]. Methane enrichment from biogas is significant because it improves the calorific value of the gas and achieved low emission of nitrogen oxide and other gases upon combustion. Meeting the fuel quality specifications may also enhance its injection into the natural gas grid when commercial captured [9] .

Different methods of upgrading and optimizing biogas focused on operating conditions, efficiency and drawback by applying life cycle assessment (LCA) to biogas upgrading [10]. Yet, researchers are still facing challenges to optimise or improve biogas yield by removing volatile organic compounds (VOC) and siloxanes often generated in raw biogas production [11, 12 and 13]

To improvethe biogas yield from agricultural wastes, pre-treatment is paramount before digestion because the lag phase of the microbial growth phase is often affected by the substrate quality. The pre-treatments might be chemical, biological, mechanical or thermal to enhance the growth rate and hence biogas production. This study is thereby focusing on the pre-treatment of the feedstock by using different chemical reagents to determine the highest biogas production under optimum condition and upgrading raw biogas via removal of impurities such as carbon dioxide which does not support combustionand bye-productlike Hydrogen Sulphide which maybe corrosiveto materials and the environment.

II. MATERIALS AND METHODS

2.1 Substrate Preparation and Characterization

Corn cobs, vegetable and fruits peels (pineapple, watermelon and cabbage peels) were sourced from Groceries in Ayetoro market, Epe, Lagos State, Nigeria. The corn cobs were obtained from farms and market dumpsites as wastes, it was dried in an oven, crushed mechanically and pulverised to smaller particlesand screened to obtain regular grain size. 10g each of pineapple, watermelon and cabbage peels were blended with 30g of dried powdered corn cob; the mixture (Agro-based wastes) was then used as the substrate for the experimental studies. The major characteristics of the substrate used during the subsequent experiment were analysed for its composition as the basal component. A recipe of 60g of the agro-waste mixture was used as the substrate for investigating the effects of the chemical additives.

2.2 Pre-treatment of Feedstock with Chemicals (Sample A-D)

Four conical flasks 250mL labelled A to D wereeach filled with 120mL distilled water and 60g agro-waste mixture as the substrate toprepare the slurry to investigate the effects of the additives. In the experiment, the conical flasks served the purpose of an anaerobic digester with the following arrangement; Sample A was set as the control without additives, 2g of Calcium Hydroxide was added to sample B, 2g of Potash was added to Sample C and 2g of granulated Amylase was added to sample D.

The corks were drilled and the measuring cylinder was connected via capillary tubes with downward delivery arrangements. All the conical flasks were airtight using bored rubber corks to prevent the escape of biogas produced to the environment and to ensure the valid result from the experiments. A water bath filled with water had the four measuring cylinders which were also filled with waterinverted in it. Gas proceeds from the set-up were harvested by downward delivery into the inverted calibrated cylinders. The level of water in each measuring cylinder was noted and subsequent gas produced by downward displacement (Archimedes Principle) are recorded every two (2) hours for five days.

The second set of experiment E-H was conducted to study the effects of increasing the Calcium Hydroxide concentration which was most yielding by administering 1g and3g of Calcium Hydroxide, while the 3g was each used for the Calcium oxide and Amylase with the same feedstock. Volumes of gas generated in each set-up were estimated. Readings were taken every two hours for five days.The assay was repeated to obtain average values of production. A pictorial view of the set-up is shown in Plate 1:

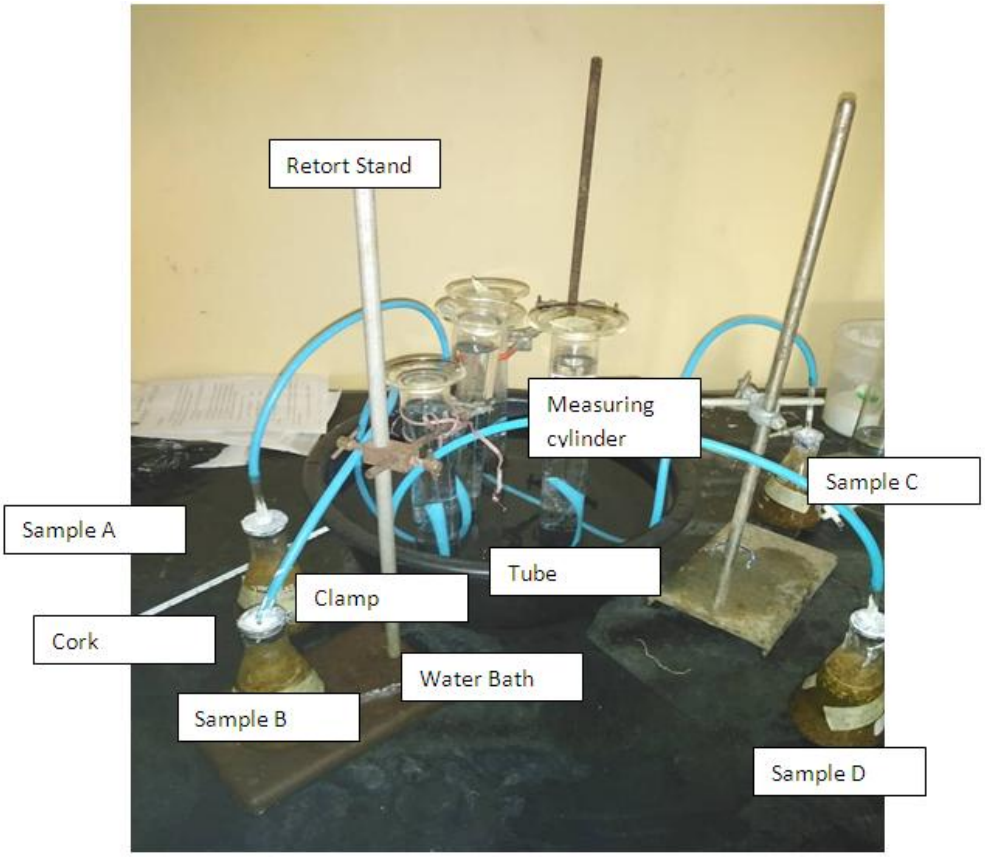

Plate (1): Laboratory bench set up for biogas production.

2.3 Description of Fabricated Anaerobic Digester

The biogas digester was made from a 30 litres capacity plastic drum fitted with an airtight lid. Other component includes PVCpipes, caps, t-connectors, gas hose, funnel, automobile tube for gas storage, airflow valve and pvc gum. The digester also consists of the following parts: the inlet chamber (feed entrance), outlet chamber (removal of exhausted waste), the gas storage and the off and on valves for control and monitoring the test point. The biodigester was carefully constructed and all the holes were sealed up with PVC gum to prevent gas leakages around the bores. All the pipes were covered with PVC caps as shown in plate 2.

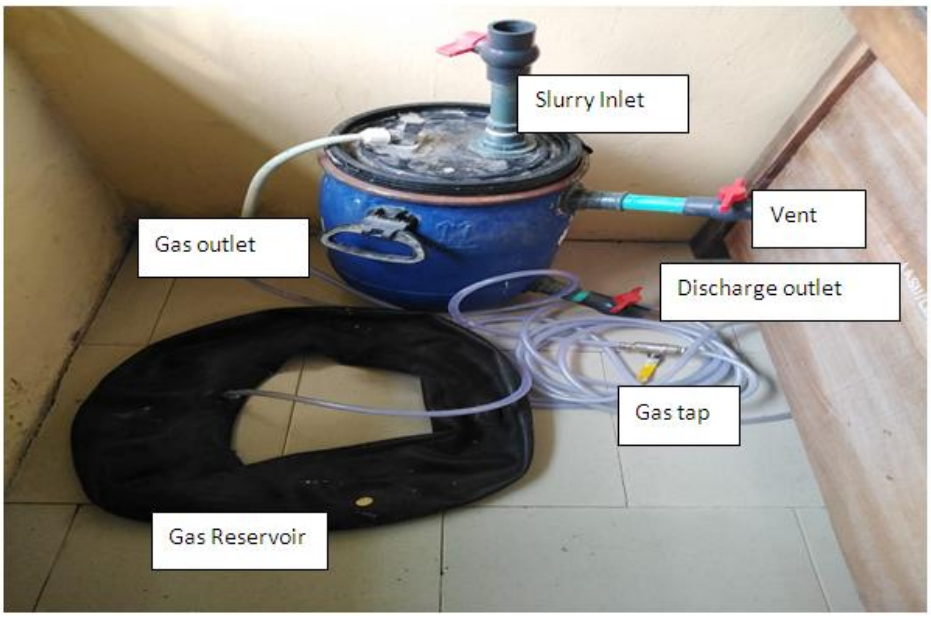

Plate 2: Batch scale set up for biogas production

2.4 Procedure for the batch biogas production

Recipe from bench scale analysis was up-scaled into the drum capacity for biogas production.120g each of pineapple peel, watermelon peel, cabbage and 360g of dried powdered corn cobs were blended in a kitchen Sonymate blender with 13.5 litres of distilled water to make the upscaled substrate in the 30 litres plastic drumwith about6.5g of calcium hydroxide added to speed up anaerobic digestion for biogas production. The biodigester was airtight to prevent leakage of gas during digestion and kept in the open to equilibrate with the environment. The biogas from the biodigester was released continuously into the storage tube for further analysis.

2.5 Purification of Bio-Gas Product

About 0.05 metric cube of biogas produced after twenty-one days from corn cobs and fruit wastes in the digester was subjected to analysis for its gaseous components. The biogas product was improved by passing the gas stream through contacting media of water, silica gel and steel wool independently. The biogas quality is determined with the Sewerin gas Analyser. A pictorial view of the biogas product upgrademethod with the adsorbers/contactor set up is shown in Plate 3:

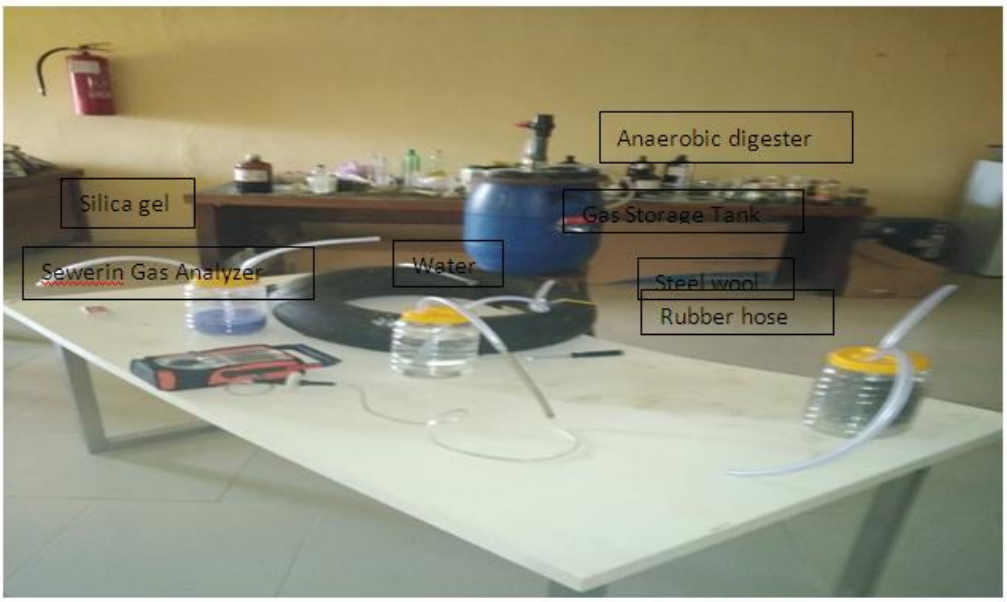

Plate (3): of Biogas Purification Set-up

III. RESULTS AND DISCUSSION

3.1 Analysis of the Substrate composition

The major characteristics of the substrate used during the subsequent experiment were analysed for its compositionto estimate the total bio-degradable composition and it is presented in Table 1:

Table 1: Characteristics of substrate used during the experiments

Parameters	Agro-based Waste
Total solids (%)	56.37
Volatile solids (%)	22.00
Moisture (%)	43.63
Crude protein (%)	6.13
Ether extract (%)	2.95
Crude fibre (%)	11.10
Protein content (%)	0.98
Total carbon (%)	12.22
C/N	12.47

3.2 Evaluations of Bio-Gas Products

Biogas produced from corn cobs and fruits wastes feedstock onbench-scale experiments wereevaluated and recorded. The effects of the chemical additives to reduce the lag phase of the microbial growth in the flasks and to initiate a quick biogas production was intended. It was observed that different trends of biogas products taken every two hours for five days period consecutively showed the effect and relevance of the respective additives considering the time taken to initiate gas productivity. The amount of gas produced and recorded for the first experiment samples A-D were in different volumes of displaced liquid which accumulated as the experiment progressed.

The control sample began producing biogas at about the 8th hour of the first day and continued to increase until it reached it peaked at 163 mL, which it maintained until the second day, then it declinedto 125 mL. Afterwards, increase in the amount of gas produced increased again as the increased. Biogas production with sample B started slowly on the first day from 80mL at 8hrs and kept increasing until it reached its highest peak of 275mL at the 8 hours of the second day. The volume of water displaced was sustained for 30hrs, implying no biogas was produced after it reached the peak of 275mL, the water inside the vessel was used up during the digestion process. Therefore, it could be acknowledged that the irregular gas evolution from the process was due to possible initial reactions between the substrate and the additives. Sample C had water displacement from 20 mL at the 18th hour of the third day to 135 mL at the 10th hour of the fourth day it reached its highest peak level of 228 mL till the fifth day. The organic acids which may result from the fermentation process could also have affected the microbial growth behaviours. The rate of biogas production observed in sample D follows the same pattern as sample A but for the delay or lag phase of the profile. The deduction from this exercise is that the volume of gas produced depend on the enrichment of the media with additives and their effect on the microbial strains.

The patterns of biogas production for group two experiment samples E-H also had a similar production pattern but with a different yield which increased as the concentrations of the $Ca(OH)_2$additives increased from 1g to 2g to 3g dosage. The cumulative biogas volume was also evaluated to show increased biogas generated.

The production levels of the biogas werefluctuating as recorded duringthe digestion process in all the experiments. However, a similar pattern was observed in each recipe. This explains the increasing growth rate of the microbes from a start-up until asustainedvolume of about150 cm^3after 14 days, The cumulative growth rate of the process is plotted as shown in Figure 1. The declining growth phase depicts the exhaustion of the substrate where all the nutrients have either been used up or the media was no longer supporting, leading to the death of the microorganism. This trend followed the submission that under an anaerobic condition, organic materials are converted into gases (biogas) through microbiological reactions[14, 15] .This implied that the growth phase and exponential phase of the microorganism occurred during the first three days of the experiment while the declining growth phase started on day 4 as a result of the exhaust of nutrients in the medium.

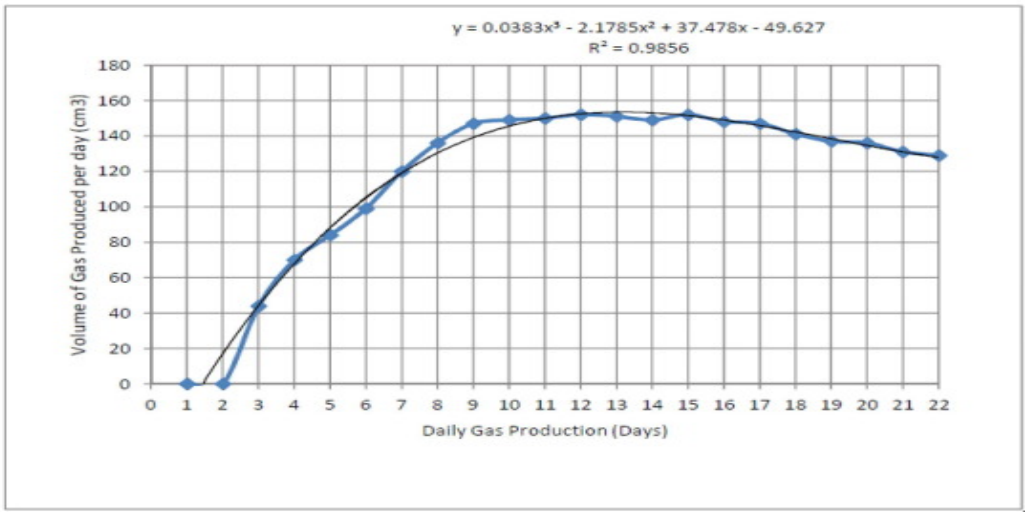

Fig 1: Signoid curve for daily gas production from corncob and fruits feedstock.

3.3 Qualitative Analysis of the Generated Gas.

Gas generated in each of the experiments did not inform whether the volume generated was purely bio-alkanes as the required biogas or a mixture with other gases. Continuous production of gas from the respective set-up A-H was allowed to attainmaximum yieldsrecorded 10th hour of the third day.

Analysis of the gaseous products revealed that the set-up of B and C in experiment 1, and E and H in experiment 2 contain methane gasses while the other samples had none. Sample B had the highest percentage

composition of methane (87 %), while samples C, E and H had 75 %, 72% and 55% methane composition respectively, This implied, as the concentration of $Ca(OH)_2$ is increased more gas was enhanced even at a reduced lag phase in the order 1g < 2g< 3g of $Ca(OH)_2$hence making sample B the most preferred as presented in Table 2:

Table 2: Composition analysis of gases produced during the

	Methane (%)	Carbon-dioxide (%)	Oxygen (%)	Hydrogen Sulphide (ppm)
Experiment 1				
Sample A	--			
Sample B	87	6	7	-224
Sample C	75	22	3	-84
Sample D	--			
Experiment 2				
Sample E	75	23	2	-82
Sample F	75	22	3	-224
Sample G	--			
Sample H	55	12	3	-224

Where A: control, B: 2g $Ca(OH)_2$, C: 2g Potash, D: 2g AmylaseE: 3g $Ca(OH)_2$, F:3g CaO, G: 3g Amylase, H:1g $Ca(OH)_2$.

The controlled set-up 'A' without any additives experienced a delay in gas production until five daysafter. It was an indication of an extended lag phase during which adaptation of the microbes and subsequent growth took a longer time. Introduction of granulated Amylase enzyme into the media was to enhances the digestion of the carbohydrate in the substrate and prompt conversion of product to gas by the microbes. However, its application was not helpful even when the quantity was increased to 3g. presumably due to inhibition or competition for substrate, or out right digestion of the available carbohydrate which could make the media unsuitable for the microbes to thrive and produce gaseous products from the substrate.

The concept of removing impurities and other undesired gases associated with biogas products was advanced by passing the gas stream through selected adsorbers described in plate 3. The gas analysisrecorded the respective compositions of the gas streams after due contact through the steel wool, Water and silica gel to know the extent of improvement on the biogas quality that was produced from the pilot-scale chamber demonstrated in plate 3. The results from the product analysis as presented in Table 3:

Table 3: Effect of Adsorbers on the biogas qualities

S/n	Raw Biogas	Steel Wool	Water	Silica Gel
methane (CH_4)	30	3.1	18.7	26.4
Carbon dioxide	28	3.0	26.0	24.0
Oxygen	8.6	7.9	-2.0	-3.4
Hydrogen Sulphide (ppm)	-224	-118	-159	-162

The results of the gas analyser gave the level of purity associated with the respective adsorbers. From the result in Table 3, Silica Gel proved to be the best reagent as its purified biogas had the highest amount of Methane (26.4%) and the least amounts of Oxygen (-3.4%) and Hydrogen Sulphide (-162ppm) which signifies high purity of the produced biogas. Another part of the gaseous composition which could not be measured in this case is Nitrogen.

Steel wool had a devastating effect on the methane gas obtained from the contactor device. The value of methane recorded was the least but the Hydrogen Sulphide was higher thus suggesting possible reactions or conversion of the initial composition into another gas product using the steel wool not accounted for. Higher methane was however recorded with silica gel followed by the water contactor. Silica gel proved to have removed a higher quantity of Carbon dioxide which is desired as it does not support combustion. Therefore, biogas purified by passing the stream through Silica gel has a higher methane value. The level of purity may however depend on the mode of contact and the contact time.

IV. CONCLUSION

The study showed that agro-based waste which abound in our immediate environment as wastes and which had constituted environmental hazards is a very good feedstock for biogas production. Chemical additives could be enhanced for timely production of biogas thereby reducing the lag phase of the microbial growth or as boosters to earlier and higher yields. As a result of the pre-treatment of the feedstock, it was deduced that calcium hydroxide is effective in the pretreatment of feedstock while silica gel was observed to be the better adsorber as it produced the highest proportion of Methane.

REFERENCES

[1]. Strange, K. 2002. Overview of waste management options: their efficacy and acceptability. *Issues in Environmental Science and Technology*, **18**, 1-52.

[2]. Foereid, B., Szocs, J., Patinvoh, R. J., & Horváth, I. S. (2021). Effect of anaerobic digestion of manure before application to soil–benefits for nitrogen utilisation?. *International journal of recycling organic waste in agriculture*, *10*(1), 89-99.

[3]. Erick, L. and Martín, M. (2016) Optimal production of power in a combined cycle from manure-based biogas. Energy Convers Manage,114, 89–99

[4]. Veluchamy, K., Brandon, H., Gilroyedb, A. and Kalamdhad, S. (2019) Full-Length Article Process performance and biogas production optimizing of mesophilic plug-flow anaerobic digestion of corn silage, *Agricultural Renewable Energy and Sustainability*,253,1097- 1103.

[5]. Senem, O., Nsair, A., and Kuchta, K. (2019) Innovative operational strategies forbiogas plant including temperature and stirring management. Waste Manage Res., 37, 237–246

[6]. Sarker S, Nordgård ASR, Lamb JJ, Lien KM (2020). Biogas and hydrogen. In: Hydrogen, Biomass and Bioenergy: Integration Pathways for Renewable Energy Applications. Academic Press; *(18)(PDF) Analysis and Pre-Treatment of Feedstocks*. Available from:https://www.researchgate.net/publication/342068215_Analysis_and_Pre-Treatment_of_Feedstocks [accessed Feb 22 2022].

[7]. Seman, S.Z.A., Idris, I., Abdullah, A., Shamsudin, I.K., Othman, M.R. (2019) Optimizing purity and recovery of biogas methane enrichment process in a closed landfill. Renewable Energy. 131, 1117- 1127

[8]. Matsui, T. and Koike, Y. (2010))

[9]. Eusoff, N.F and Solar, V. (2019) Focus on RE Business, Expects 10MW Biogas Energy to Contribute in Late 2019. *Energy*,3,4-9

[10]. Ariunbaatar J, Panico A, Frunzo L, Esposito G, Lensc PNL, and Pirozzi F. (2014) Enhanced anaerobic digestion of food waste by thermal and ozonation pretreatment methods. J Environ Manage. 146:142–149.

[11]. Ryckebosch, E., Drouillon, M. ,and Vervaeren, H.,(2011) Techniques for transformation of biogas to biomethane. *Biomass Bioenerg*. 2011;35, 1633–1643

[12]. Khan, I.U., Othman, M., Hafiz, D., Hashim. H., Matsuura, T., Ismail. A.F., Rezaei-DashtArzhandi M., and Azelee, I.W. (2017) Biogas as a renewable energy fuel–a review of biogas upgrading, utilisation and storage. *Energy Convers Manage*,150:277–94.

[13]. Starr, K., Gabarrell, X., Villalba, G., Talens, L. and Lombardi, L.(2012) Life cycle assessment of biogas upgrading technologies. *Waste Manage*, 32, 991–999.

[14]. Panoutsou, I., Eleftheriadis, C., Nikolaou, J, A. (2009) Biomass supply in EU 2010 to 2030. *Energy Policy*,12.5675–86.

[15]. The World Bank. Understanding Poverty – Climate-Smart Agriculture. Accessed 9/2/2022; Available from: https://www.worldbank.org/en/topic/climate-smart-agriculture

Duduyemi Oladejo, et. al. "Pretreatment and Optimization Strategy for Biogas Production from Agro-based Wastes." *The International Journal of Engineering and Science (IJES)*, 11(3), (2022): pp. 14-20.