Global Journal of Engineering and Technology Advances, 2020, 05(02), 005–013

Global Journal of Engineering and Technology Advances

Cross Ref DOI: 10.30574/gjeta

Journal homepage: http://www.gjeta.com

(RESEARCH ARTICLE)

Automation of bio-digester stirring system using locally available materials

Kingsley Ogueri Chilakpu*

Agricultural and Bioresources Engineering Department Federal University of Technology Owerri.

Publication history: Received on 01 October 2020; revised on 08 November 2020; accepted on 12 November 2020

Article DOI: https://doi.org/10.30574/gjeta.2020.5.2.0082

Abstract

An anaerobic bio-digester with electronically controlled stirring system was fabricated and tested using locally available materials. The experiment was conducted on a laboratory scale in Federal University of Technology Owerri. Cow dung obtained from an abattoir in Owerri and household biodegradable waste randomly collected from residential homes and eateries were used as the feedstock for this work. The feedstock was pre-fermented for a period of 10 days in an airtight bag before it was mixed with water in the ratio of 1:2 to form slurry that was fed into the digester. An Arduino system controlled timer with LED display screen was designed to control the on/off signal of a 2Hp electric motor powering the stirring arms. The programmable stirring timer device was set to run the electric motor for 30minutes at an interval of four hours to allow for even distribution of nutrients and microbes in the bio-digester. A control experiment was also carried out with non-automated stirring system. . It was observed that gas production in the control experiment reached its peak in fourteen days and the period was mired by fluctuating and less volume of gas production when compared to the main experiment where the gas production increased appreciably and steadily with maximum volume recorded on the tenth and eleventh day as contained in the results obtained. Model equations were generated for the two experiments and the wide variation in values of determinant factors (R^2) in the two experiments is an indication that the automated stirring system with R^2 = 0.97 performed better than the manually timed stirred trials with R^2=0.88.

Keywords: Automation; Bio-Digester; Stirring; Anaerobic; Biodegradable.

1. Introduction

Green plants manufacture their food through the process of photosynthesis [1]. These plant foods are stored in the form of hydrocarbon compounds that could be further processed under given conditions to release the held hydrocarbon gases to meet human needs.. These natural occurring gases could be obtained through laboratory or industrial anaerobic decomposition of plants and animals materials, and are referred to as biological gases.

The major constituents of biological gas or biogas as it is commonly called include; methane (CH_4) (60-70%) and carbon dioxide (CO_2) (30-60%) and other gases (1-5%) which may include: Hydrogen (H_2), Hydrogen sulphide $(H_2$S and siloxanes [2]. Biogas is a renewable form of energy and can be produced from raw materials such as degradable home or domestic waste, plant materials, agricultural waste and other forms of biological waste through actions of some anaerobic organisms in a closed system [3].

The gases methane, hydrogen, and carbon monoxide (CO) can be combusted or oxidized with oxygen, the energy release makes biogas a source of fuel which can be used for domestic and industrial heating purposes, such as cooking or in a gas engine to convert the energy in the gas into electricity and heat [4]. Biogas can be produced basically in two ways which may include: landfill gas (LFG), which is produced by the breakdown or decomposition of biodegradable waste inside a landfill due to chemical reactions and microbes, or as digested gas, produced inside an anaerobic digester

*Corresponding author: Kingsley Ogueri Chilakpu
Agricultural and Bioresources Engineering DepartmentFederal University of Technology Owerri.

[5]. For the purpose of this work, the anaerobic digester tank approach will be considered for easy of experimental control that is globally accepted. The rate of biogas production is affected by some factors which include: Substrate temperature, pH level, type of feedstock, retention time, carbon-Nitrogen (C/N) ratio, inhibitory factors: such as presence of heavy metals, antibiotics used in livestock husbandry, substrate solid content and agitation among others. Continuous stirred tank reactors are commonly used for the production of biogas from energy crops or organic residues [6]. When using this type of biogas digester, the stirring of the substrate in the digesters is very essential for the biogas formation process. The major reasons for stirring the slurry include; even distribution of nutrients in the bio-digester, to form a suspension of liquid and solid parts, to avoid sedimentation of particles, to ensure uniform heat distribution, to prevent foam formation and to enable gas lift from the fermentation substrate at high dry matter contents [7[; [8]

According to analyses in the Lemwig (Denmark) biogas plant, major reasons for decrease in gas yield and frothing was both the composition of the substrate used and improper mixing attributes [9]; [10]. Bartfai,et,al. 2015 [11] reported that adequate carbon-nitrogen ratio is important since nitrogen is required to build proteins, if there is nitrogen deficiency, the amount of carbon processed decreases, and if there's too much, there will be too much ammonia, which inhibits methane generation. The required carbon-nitrogen balance can be achieved via properly mixing of the base materials

Although Limited information is available on the optimal choice of agitators, their mixing intervals and the time required for optimal homogenization. Studies on electric energy consumption at the research biogas plant of Hohenheim University have shown that mixing consumes up to 51% of total electric energy consumption for the biogas production process of electric energy for agitation in the first fermentation stage [12] Kissel et al.[13] in 2008 reported that survey of ten pilot biogas plants reveal that, the electric energy consumption for agitation accounted for over 25% to 58% (in the first fermentation stage) of total electric energy consumption This high electric energy demand is causing high costs and moreover lowering the CO_2 balance of this bio-energy source. By the end of 2012, approximately 7589 biogas plants with an installed electrical capacity of 3179 MW have been in operation in Germany. Taking into account that approximately 8% of the produced electricity is used for biogas plant operation and 50% of this energy is used for agitation, calculations show that 1 billion kW h/a are used for agitation in German biogas stations. At an energy price of around 0.2 €/kW h, approximately 200 million €/ann are spent on agitation [12] .This calculation clearly shows the impact on the profitability of biogas plant operation.

To ensure optimal gas production and economic viability of biogas plants, there is need to automate the base materials (substrate) stirring process. This work presents an automated bio-digester stirring system using locally available materials. The digester comprises of a plastic tank (because of the corrosive nature of substrates), agitator/stirrer, gas storage tank and the electrical components which controls the electric motor powering the stirrers. Provisions for feedstock inlet, thermometer, slurry and gas outlet were made on the plastic tank while the gas collection tank houses the pressure gauge and stop valves. The electric motor is connected to the agitator by means of a toothed driving belt (to minimize slip).

2. Material and methods

2.1. Materials

Evacuation of domestic waste can be quite challenging in some homes and public eateries. In the quest of turning waste to wealth, the choice of using domestic wastes as feedstock in this work was made. Other key materials include; 30liters plastic tank, 25mm diameter galvanized stirring shaft,

6 pieces of 152.4mm long and 8mm thick galvanized metal bars for stirring arms, 6 liters galvanized cylinder for gas collection, rubber hoses for conveying produced gas, lock valves, mercury bulb thermometer, pressure gauge and cow dung to introduce the required process bacteria. The entire set-up was mounted on a mild steel frame with rollers for easy of movement while a Bunsen burner was used to test flammability of the produced gas.

2.2. Method

The workshop processes of arc welding, cold welding, manual cutting of materials and filling with an angle grinder were employed were necessary in the workshop fabricating of the bio digester and accessories. To create adequate space for the gases to be generated from the experiment, two-third of the digester total volume (V_1) was used as the operating volume of the digester tank (V_a) which is also the maximum volume of the feedstock. This is in agreement with the work of Kossmann and Ponitz (2011) [2], which states that;

Operating volume, $V_a = \frac{2}{3}V_1$(liters)

Torsional moment was calculated using:

$P = 0.105N_{rpm}T$

Where;

P = power of electric motor

N_{rpm} = Shaft speed

T = Torsional moment (Nm)

The shaft speed was determined using $N_1D_1 = N_2D_2$ as proposed by Khurmi and Gupta (2005) [14].According to the work of Chilakpu et al., 2014 [1], the theoretical mixing force (F) was determined using equation; $F = mrw^2 = mr(2\pi n)^2$

Where;

m= mass of slurry

r= radius of digester tank

n= rotational speed of shaft

An Arduino system controlled timer with LED display screen was designed to control the on/off signal of the electric motor powering the stirring arms. A simple algorithm flow chart is as presented in fig,1

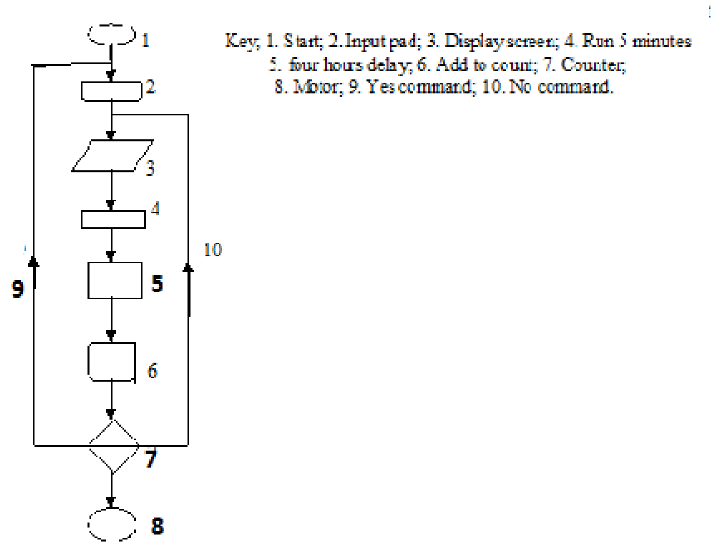

Figure 1 Algorithm flow chart of electric motor timer switch

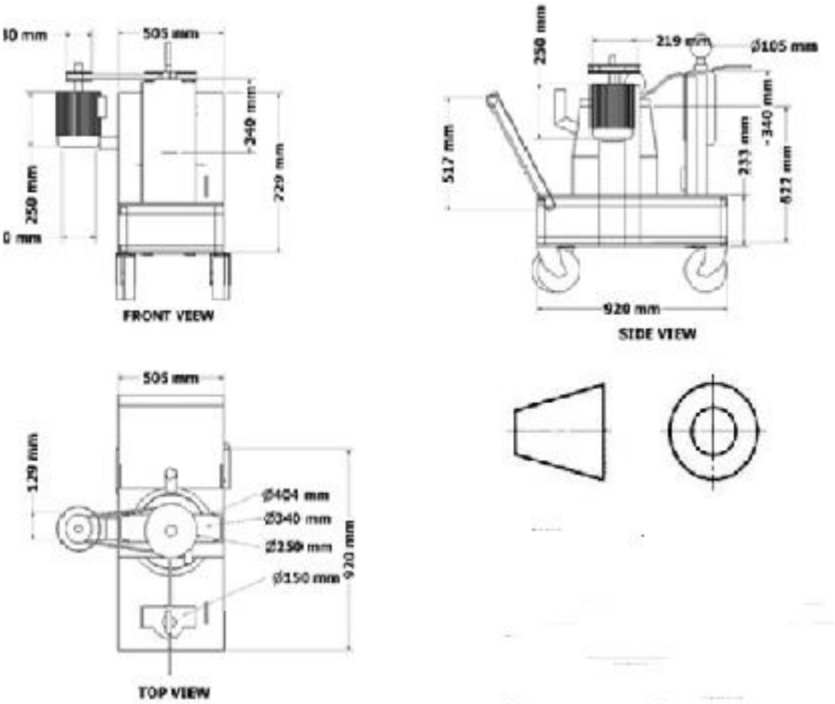

Figure 2 Orthographic views of the Machine

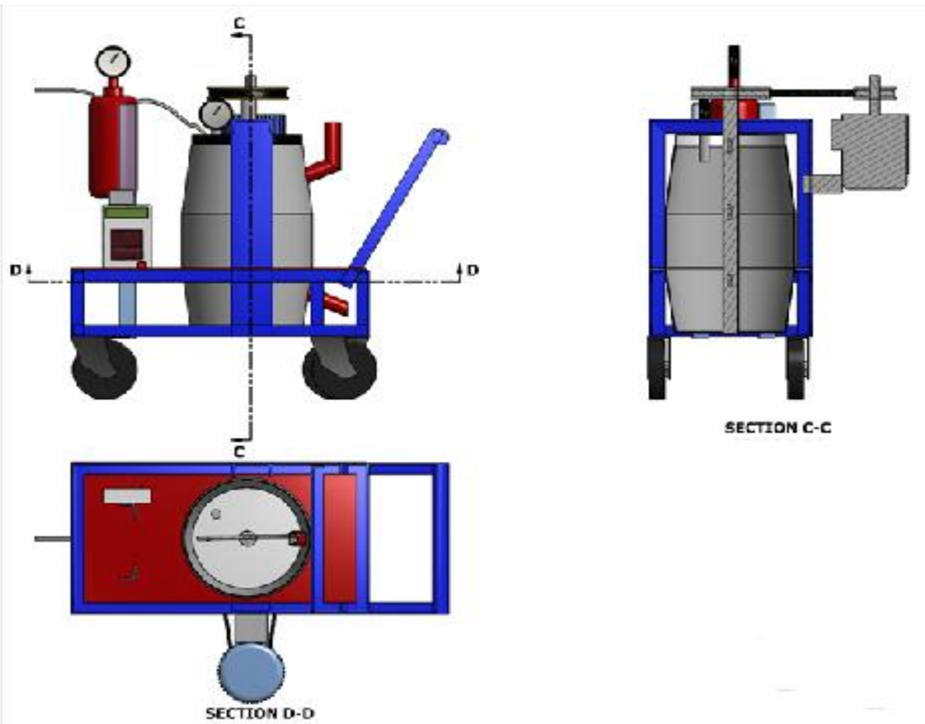

Figure 3 Sectional View of the Digester Setup

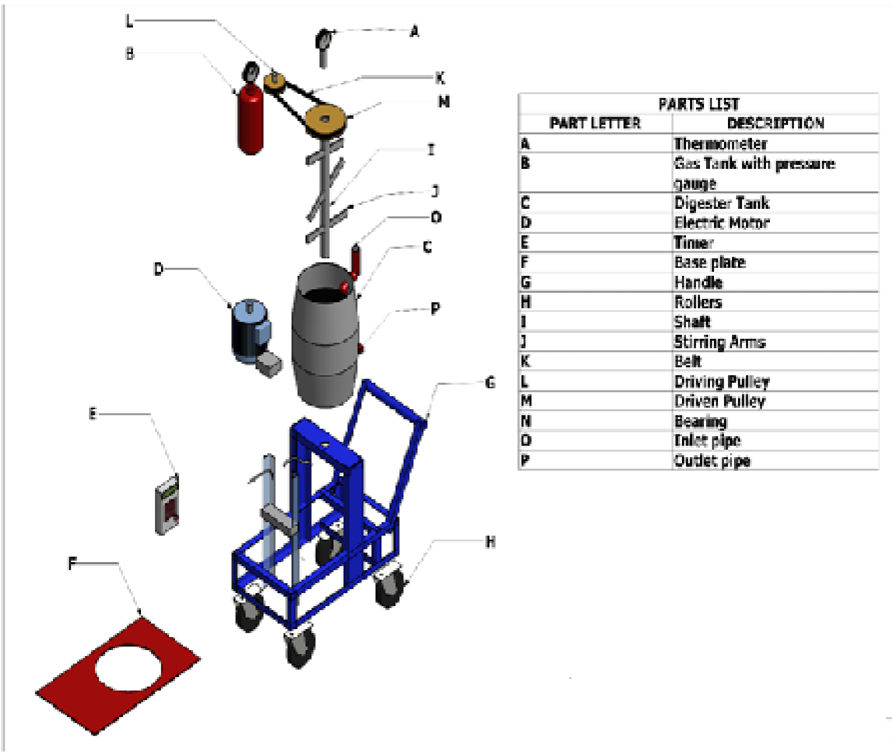

Figure 4 Exploded View of the Auto- stirring Digester System

Plate 1 Fabricated Machine.

2.2.1. Experimental Procedure

Cow dung obtained from an abattoir in Owerri and household biodegradable waste randomly collected from residential homes and eateries were used as the feedstock for this work. The feedstock was pre-fermented for a period of 10 days in an airtight bag before being fed into the digester. Before loading the bio-digester, the empty tank was pressure tested to ensure air-tightness of the system, then the inlet and outlet ball valves were opened to allow the trapped air in the system to escape in order to prevent negative pressure build up in the digester. 45kg of the pre-fermented waste mixed with water to form slurry in the ratio 1:2 by volume were introduced into the digester tank through the inlet pipe. The slurry occupied two-third of the digester space which is the operating volume of the digester. The slurry in the digester was allowed to ferment for a period of 21 days under mesospheric condition (temperature range of 21℃-37℃). This is in line with the work of Kougias, et,al., 2014 [15]. The required temperature range was achieved by controlling the temperature of the room housing the experiment through the use of the shutters and high wattage bulbs in the room. While lime was used when necessary to stabilize the pH range of 4.5 to 6.3 required in the experiment. The programmable stirring timer device was set to run the electric motor for 30minutes at an interval of four hours to allow for even distribution of nutrients and microbes in the bio-digester. This is in agreement with the work of Hopfner-Sixt and Amon (2007) [16]. The stirring also got rid of the formation of scum on the surface of the slurry. The system was checked for gas production through the pressure gauge with the corresponding temperature as recorded on the thermometer. A control experiment similar to the main work was also conducted as a check only that this time the stirring mechanism was manually controlled.

3. Results

The average values of results obtained from the experiments were presented in graphical form in

fig. 5; fig. 6; fig 7 (control experiment) and fig. 8 (Comparing graphs of average pressure against retention period for both the main and control experiments) for easy understanding.

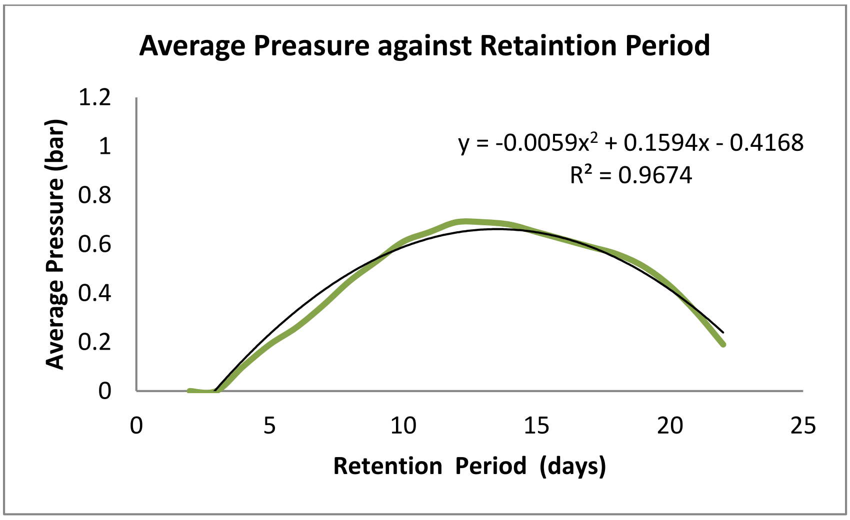

Figure 5 Average pressure against retention period

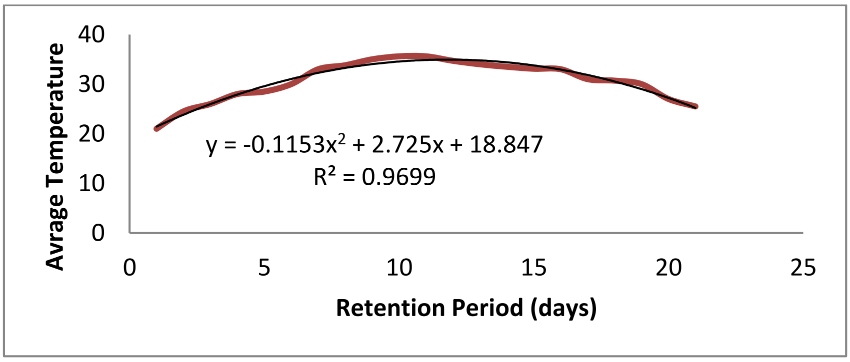

Figure 6 Average temperature against retention period

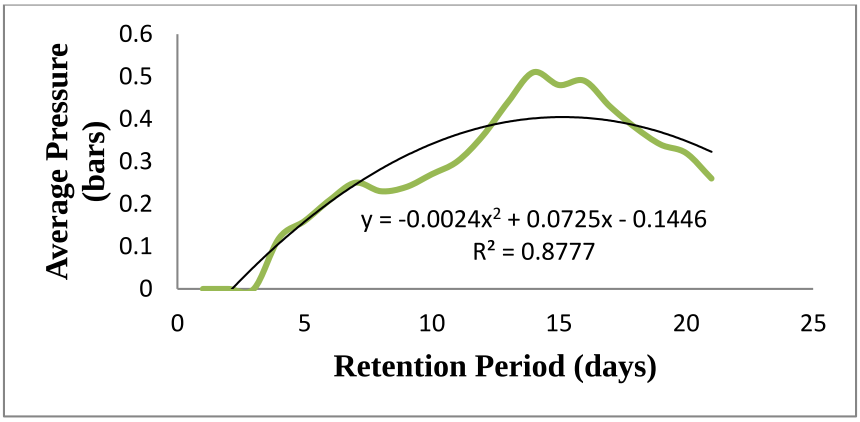

Figure 7 Average pressure against retention period for manually timed control experiment.

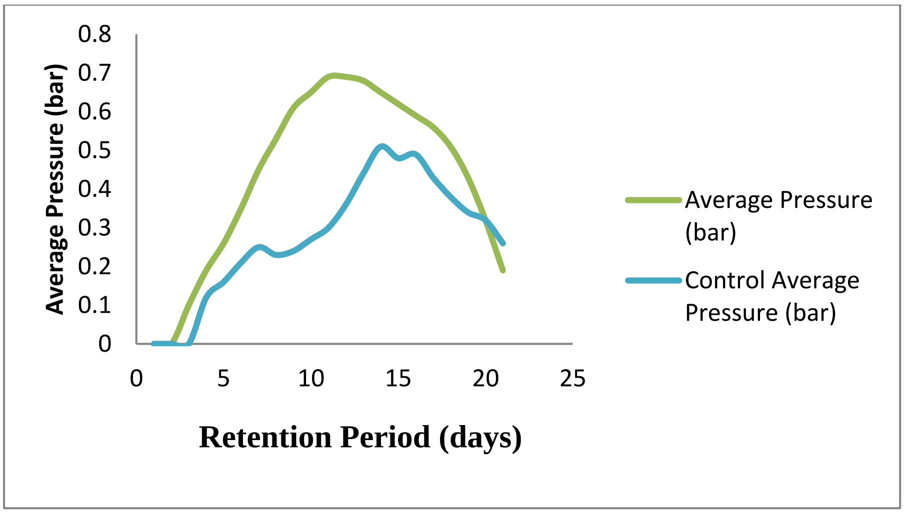

Figure 8 Comparing graphs of average pressure against retention period for both the main and control experiments

4. Discussion

The data obtained from the experiment indicated an insignificant volume of gas production on the first and second day, this may account for the necessary time lag to allow for proper fermentation of the feedstock. However from the third day, the gas production increased appreciably and steadily with maximum volume recorded on the tenth and eleventh day before a steady decline of gas production was recorded. This could be as a result of decline in microbial activities which also recorded a decline in reaction temperature. The appreciable and steady increase in biogas production recorded in the main experiment could be linked to the automation of the stirring system which ensured even distribution of nutrients, microbes and generated heat within the anaerobic tank. This is in agreement with the works of Loum and Fogarassy (2015) [9] and Boroczet,al.,(2015) [10].

Except for the stirring method, all other conditions were maintained for both the main and control experiments. The results obtained from the control experiment where the stirring mechanism was manually switched on and off at the designed intervals (fig. 7) showed that there was a delay of 3days before production of notable volume of gas commenced as opposed to the two days observed in the automated stirred experiment. This could be as a result of uneven distribution of nutrients and microorganisms in the bio-digester occasioned by inconsistent stirring timing. It was also observed that gas production in the control experiment reached its peak in fourteen days and the period was mired by fluctuating and less volume of gas production when compared to the main experiment. This could be as a result of human errors which occurred in timing stirring process or time lapse while the operator was asleep at night.

In fig. 5 a plot of average pressure against retention period in the main experiment presented a second order polynomial model equation of; $y = -0.005x^2 + 0.159x - 0.416$ with a determinant factor of $R^2 = 0.97$. A plot of average temperature against retention period as shown in fig.6 presented a second order polynomial model equation of; $y = -0.115x^2 + 2.725x$

+ 18.84 with also a determinant factor of R^2 = 0.97. The determinant values of 97% obtained in this work are indication of high percentages of conformity of the experimental data to expected results. Furthermore, the model equations so obtained can be used in predicting the volume of gas production and likely reaction temperature given the retention days without repeating the entire experiments. On the other hand, fig. 7 and fig. 8 presented plots of average pressure against retention period for manually timed control experiment and comparison of average pressure against retention period for both the main and control experiments respectively. A second order polynomial model equation of $y = -0.002x^2 + 0.072x - 0.144$ was obtained with a lower determinant factor of R^2=0.88.

5. Conclusion

The wide variation in values of determinant factors in the two experiments is an indication that the automated stirring system (R^2 = 0.97) performed better than the manually timed stirred trials (R^2=0.88). This is in agreement with the work of Bartfaiet,al (2015) [11]. The need for proper stirring of feedstock in anaerobic digesters cannot be over emphasized. The result of this work has highlighted the need for automation of the agitating system in order to derive maximum biogas production from biological base feedstock.

Compliance with ethical standards

Acknowledgments

The intellectual and moral contributions of Engr. Prof G.I Nwandikom and Mr Chijioke Nkwocha among others towards the success of this work are deeply appreciated.

Disclosure of conflict of interest

No conflict of interest.

References

[1] Chilakpu, K. O., Nwandikom, G. I., Asoegwu, S. N., & Egwuonwu, C. C. Effects of Multiple Stirring Arms In Optimizing Biodiesel Yield In A Batch Reactor. *Research Journal In Engineering and Ap*. 2014; *5*(4);262-264.

[2] Kossmann, W., & Ponitz, U. Biogas Digester: Biogas Basics*.* GIZ. 2011.

[3] NNFCC. Renewable Fuels and Energy Factsheet: Anaerobic Digestion, 2011 Retrieved June 20, 2018, from National Non-food Crops Centre: https://www.nnfcc.co.uk/publications/nnfcc-renewable-fuels-and-energy-factsheet-anaerobic-digestion.

[4] ClarkeEnergy. Biogas and Engines: Biogas Composition*.* 2011.Retrieved June 20, 2018, from Clarke Energy: www.clarke-energy.com/biogas/

[5] Wikipedia, 2018, Retrieved June 20th 2018. https://en.wikipedia.org/wiki/Biogas#cite_note-3.

[6] Gemmeke, B.; Rieger, C.; Weidland, P.; Schröder, J. Biogas-MessprogrammBiogasanlagenimVergleich(in German); FachagenturNachwachsendeRohstoffe: Guelzow-Pruezen, Germany, Abstract, 2009; pp. 1–168.

[7] Abdel-Hadi, M.A.; Abd El-Azeem, S.A.M. Effect of heating, mixing and digester type on biogas production from buffalo dung. Misr J. Agric. Eng. 2008;Pp.1454–1477.

[8] Vesvikar, M.S.; Al-Dahhan, M. Flow pattern visualization in a mimic anaerobic digester using CFD.Biotechnol. Bioeng. 2005;pp. 719–732.

[9] Loum A., Fogarassy C. The effects of climate change on cereals yield of production and food security in Gambia. Applied Studies in Agribusiness and Commerce, 2015; –Abstract Vol. 9. No. 4:pp. 83-92. http://Dx.Doi.Org/10.19041/Abstract/2015/4/11

[10] Borocz M., Horvath B., Herczeg B., Kovacs A. Greener cement sector and potential climate strategy development between 2015-2030 (Hungarian case study). Applied Studies in Agribusiness and Commerce – Abstract, 2015; Vol. 9. No. 4:pp.65-74. http://dx.doi.org/10.19041/Abstract/2015/4/9

[11] Bártfai, Z; Tóth, L; Oldal, I; Szabó, I; Beke, J and Schrempf, N. Modelling the Stirring Process of Biogas Plants Using Mixed Materials. Periodical of TheComittee of Agricultural and Biosystem Engineering of the Hungarian Academy of Sciences and SzentIstván University, 2015.

[12] Naegele, H.-J.; Lemmer, A.; Oechsner, H.; Jungbluth, T. Electric energy consumption of the full scale research biogas plant “UntererLindenhof”: Results of long term and full detail measurements. Energies, .2012;Vol. 5: pp.5198–5214.

[13] Kissel, R.; Effenberger, M. Empfehlungenfür die Auswahl von RührwerkenfürGärbehälter(in German); Biogas Forum Bayern: Freising, Germany, Abstract, 2008; pp. 1–16.

[14] Khurmi, R. S., & Gupta, J. K. *A Textbook of Machine Design (S.I. Units)* (First Multicolor Edition ed.). Ram Nagar, New Delhi: Eurasia Publishing House (Pvt.) Ltd, 2005.

[15] Kougias P. G., Boe K., Thong S. O, Kristensen L. A. and Angelidaki I. Anaerobic digestion foaming in full-scale biogas plants: a survey on causes and solutions, ISWA publishing,2014.

[16] Hopfner-Sixt, K.; Amon, T. Monitoring of Agricultural Biogas Plants in Austria—Mixing Technology and Specific Values of Essential Process Parameters. In Proceedings of the 15th European Biomass Conference and Exhibition, Berlin, Germany,2007; pp. 1718–1728.