OPEN ACCESS Freely available online

Journal of Petroleum & Environmental Biotechnology

Research

Design and Fabrication of Electric Jacketed Anaerobic Digester

Oluseye Omotoso Agbede, Oluwafunmilayo Abiola Aworanti*, Oladipupo Olaosebikan Ogunleye, Samuel Enahoro Agarry, Kehinde Ayoola Babatunde and Solomon Oluyemi Alagbe

Biochemical Engineering and Biotechnology Laboratory, Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomoso, Nigeria

ABSTRACT

An anaerobic bio-digester is a bioreactor used to convert organic matter to biogas through anaerobic reaction carried out by a consortium of micro-organisms. The activities of the micro-organisms and biogas yield depend on digester operating factors which include temperature, pH, agitation, total solid content, organic loading rate and concentration of substrate. Unfortunately, lack of introducing monitoring and proper control of the temperature, pH and agitation result into large hydraulic retention time and low biogas generation which consequently limits the popularization of biogas technology in rural areas. This problem can be solved by designing and fabricating an anaerobic digester which incorporates proper monitoring and control of these factors in order to achieve maximum yield of biogas and reduced retention time. Hence, a jacketed bio-digester system which incorporates a heater, an agitator and a pH probe was designed, fabricated and successfully utilized for the anaerobic co-digestion of kitchen waste and cow dung. The digester was operated at a constant volume of 12 kg, temperature of 40°C, agitation speed of 30 rpm, a total solid content of 8% and pH of 7.5 for a period of 70 days. The pH, agitation and temperature of the substrate were introduced, monitored and controlled in the reaction. The biogas yield showed a good performance of the bio-digester system. This bio-digester system can be used for laboratory experiments to train students on the conversion of biodegradable solids to biogas. It can also be used to simulate a biogas plant and generate energy for laboratory use.

Keywords: Biogas; Anaerobic bio-digester; Microorganism; Total solid content; Organic loading rate; Hydraulic retention time

INTRODUCTION

Biogas is considered as one of the cheapest and clean renewable energy resources and serves as the best alternative to fossil fuel [1-3]. Biogas can be used for generation of heat, electricity and also as a vehicle fuel. It is not only useful for power production and applications, but also helps in the management of solid waste; the digestate from the biogas process can further be used as fertilizer [4]. Thus, biogas production provides solution to the problem of environmental pollution posed by organic wastes while facilitating the conversion of the waste to resources through anaerobic digestion. Biogas also plays an important part in both circular economy and bioeconomy [5].The world is now greatly emphasizing the establishment of this technology for energy production, as several countries including Germany, Italy, China, and India are currently applying this technology in their rural areas [4].

Anaerobic digestion (or biomethanization) converts organic materials to biogas through the conversion steps of hydrolysis, acidogenesis, acetogenesis and methanogenesis, performed by a consortium of micro-organisms [6-10]. The success of the process and biogas yield depend on various factors such as temperature, pH, concentration of substrate/nutrients, agitation, pretreatment of feedstock, hydraulic retention time, total solid content, organic loading rate and the carbon to nitrogen (C/N) ratio [9,10].

It has been established that biomethanation is a complex process because of the sensitivity of the system to feedstock

***Correspondence to:** Oluwafunmilayo Abiola Aworanti, Department of Chemical Engineering, Biochemical Engineering and Biotechnology Laboratory, Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomoso, Nigeria. E-mail: E-mail: oaaworanti@lautech.edu.ng

Received: October 24, 2019, **Accepted:** April 02, 2020, **Published:** April 11, 2020

Citation: Agbede OO, Aworanti OA, Ogunleye OO, Agarry SE, Babatunde KA, et al. (2020) Design and Fabrication of Electric Jacketed Anaerobic Digester J Pet Environ Biotechnol. 11:403. doi: 10.35248/2157-7463.20.11.403

characteristics, reactor design parameters and operational conditions [11,12]. Most often, the feedstock characteristics and reactor design parameters are predetermined and fixed, thus making the operational conditions the manipulative variables for enhanced yield and quality of biogas. Also the biogas process is slow during the lag phase which consequently results in large hydraulic retention time and low gas generation. The slow process in biogas production may be due to the process parameters that are not properly introduced, monitored and controlled [13]. The basic operational conditions that affect the yield and quality of biogas are pH, temperature, agitation, total solid content and nutrient (substrate and inoculum) content [11,12]. Thus, there is the need to improve on these constraints associated with anaerobic digestion process in the biogas plant. In order to improve on these constraints the basic operational conditions need proper monitoring and control and this will only be achieved by designing and fabricating a biogas digester that will consist of a heater, an agitator and a pH monitoring system.

However, to the best of the authors' knowledge there is little or no information on design and fabrication of biogas digester that has heater, agitator and pH monitor. Therefore, the objective of this study was to design and fabricate a batch jacketed biogas digester system which incorporates an agitator, a heater/boiler and pH monitor.

MATERIAL AND METHODS

Design and Fabrication

Components required: The components required for the fabrication of the bio-digester system were: jacketed digester tank, inlet valve for feeding the waste, outlet valve for the discharge of the digested slurry, gas outlet valve, gas storage system, stirrer, electrical heating coil, valves, compressor, pressure gauge, pump, thermostat, temperature controller, multimeter, inlet and outlet valves for the transfer of steam.

Materials required: The materials required were stainless steel sheet, rubber hose, elbow joint, metal sheet, clips, Polyvinyl chloride (PVC) pipes and electrical wire.

Tools required: A hack saw was used to cut the stainless steel sheet into required sizes and welding tools were used to weld them together.

Design factors: The design of anaerobic digester was based on operational factors that affect the production of biogas. The operational factors considered were the type of wastes, temperature, pH, agitation, total solid content and carbon/nitrogen. Factors such as strength, corrosion, insulation, machinability, durability, availability, affordability as well as maintenance of the digester were considered for the selection of the materials used for the fabrication. The dimensions of the various components were chosen in order to minimize the size, weight and cost of the digester and at the same time not compromising the efficient operation of the components.

Description of the jacketed bio-digester system: The anaerobic digester system consists of a jacketed digester tank, agitator, boiler, pressure gauge, temperature controller, multi-meter, pump, pH meter, gas holder, valves and supporting frame as shown in Figure 1. The jacketed digester tank was in the form of cylindrical shape of approximately 20 liters in volume; it has a height of 35 cm, a diameter of 26 cm and an annulus (i.e. the space between the digester wall and the hot water jacket) of 2.5 cm. The digester consisted of three segments of different shapes: an upper cover which has a frustum shape to accommodate the stirring shaft, the middle part made of cylindrical shape in order to have enough space to accommodate the substrates while the lower section was made of conical shape in order for the discharged slurry to flow out by gravity. It also has inlet and outlet valves of diameter 2.5 cm. It serves as the main reactor; it was made of stainless-steel sheet with a thickness of 1.6 cm, in order to prevent corrosion. The digester was inserted into a hot water jacket which serves as heating source to maintain the reaction temperature at 37-40^{o}C and a pressure gauge of 5 bar was mounted on the top of the jacketed digester to measure the pressure buildup. The hot water jacket has a diameter of 31 cm with a height of 43.3 cm and stainless steel was used for fabrication of its innermost layer because it prevents corrosion due to water and basic interaction. Fiber glass was used for the middle layer to prevent heat loss and keep the steam temperature in the annulus constant while galvanized steel was used for the fabrication of the outer layer to avoid corrosion of the hot water jacket and for easy movement of the setup. The hot water jacket also has inlet and outlet valves of diameter 1.27 cm. The stirrer comprises of a turning shaft with eight baffles powered by an electric motor of 0.0375 kW which rotates at 20 rpm. The shaft was connected to an electric motor and a round rod of 25 cm length and 13 cm diameter, and then placed in the digester in order to achieve homogenous mixing. A 3 cm diameter valve, which serves as a regulator for the discharge of slurry from the digester, was centrally fixed to the conically shaped digester bottom. The boiler is in the form of cylindrical shape with a diameter of 20 cm and height of 27.1 cm, it comprises of the electric pump, heating coil, thermocouple, inlet and outlet valves. The diameter of the cold water inlet and hot water outlet valves were 1.27 cm, the flow rate of the cold and hot water were 0.123 kg/s, while the power of the electric pump was 0.5 hp. The thermocouple was calibrated to a fixed temperature of 70^{o}C.

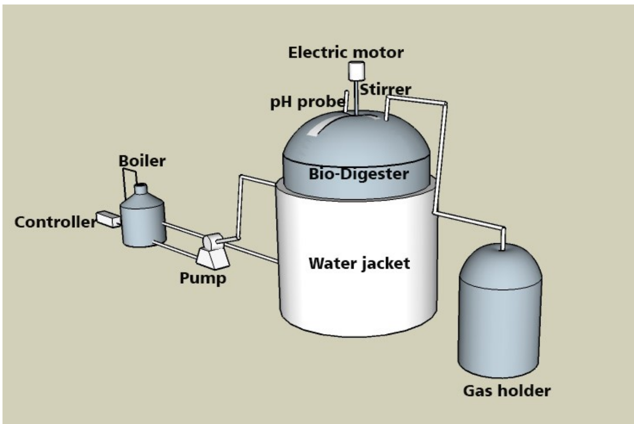

Figure 1: A 3D view of the jacketed bio-digester system showing all the associated components.

Fabrication Details and Procedure of Jacketed Bio-digester System: The procedure from Itodo, Budzianowski, Khurmi and Gupta, Rajendra, Aggarangsi and Teerasountornkul were adopted for the design of the anaerobic digester. The main components of the digester and their theoretical design are described [14-19].

Jacketed Bio-digester: The digester is the main reactor in which anaerobic digestion takes place. In this design a hot water jacket was fabricated around the main reactor to form a jacketed bio-digester. A pressure gauge, pH probe and thermocouple were fitted to the digester to measure the pressure build-up, pH and temperature, respectively. The main reactor and hot water jacket are cylindrical in shape and were fabricated using stainless steel to avoid corrosion. A steel sheet of 1.6 cm thickness, diameter of 26 cm and height of 35 cm was used to form the cylindrical vessel which was welded together with a steel electrode, the standard electrode for welding steel sheet. The main reactor was vertically inserted into the hot water jacket.

The digester lid was in a form of a frustum in which a hole was drilled and a valve of 2.5 cm was welded to serve as the substrate inlet. Another hole of 10.6 cm in diameter was drilled at the center of the digester lid, which contains the shaft connecting the electric motor to the stirrer, and bolted firmly.

A thermocouple and a pH probe were inserted into the reactor through the frustum. The hot water jacket was also folded to form a cylindrical shape of diameter 31.0 cm and a height of 43.3 cm; a space of 2.5 cm in width was created between the digester and the hot water jacket which is known as the annulus. The hot water jacket serves as heat transfer medium to the main reactor (digester), the hot water was pumped from the boiler into the annulus between the digester and hot water jacket, the hot water in the annulus region flows round the digester body in order to maintain desired uniform temperature inside the bio-digester in all weathers. The heat was transferred by means of convection into the digester; the substrate temperature was monitored by connecting the thermocouple inserted into the digester to the multimeter. A pressure gauge of 5 bar was mounted on top of the digester, this was used to observe the pressure build up in the digester.

Digester cylindrical volume: The dimensions used for the fabrication of the digester were determined using equations proposed by Itodo, Aggarangsi and Teerasountornkul, [14-16].The volume of the digester, height of the digester, area of the top cover of the frustum and the total digester volume were calculated using Equations 1-5. The orthographic view of the biodigester is shown in Figure 2.

The digester volume was determined using Equation 1:

$$VD = Sd\ (1/\text{day}) \times RT\ (\text{day}) \quad \text{equation (1)}$$

where VD is digester cylindrical volume, Sd is amount of slurry loaded into digester daily in litres/day and RT is retention time in day.

Digester cylindrical height: The height of the digester was evaluated using Equation 2:

$$VD = \pi \times r^2 \times h \quad \text{equation (2)}$$

where VD is digester cylindrical volume, r is the radius of the cylinder and h is height of the cylinder.

Volume of frustum top cover: The frustum volume of the digester was obtained from the following relationship below:

$$VFT = 1/3 \times \pi \times t \times (R^2 + r^2 + R \times r) \quad \text{equation (3)}$$

Where VFT is the frustum volume, R is the radius of bigger circle, r is the radius of small circle and t is the height of frustum.

Volume of conically-shaped bottom: The cone shape bottom of the digester was estimated from the relationship below:

$$VCB = 1/3 \times \pi \times r^2 \times h \quad \text{equation (4)}$$

where VCB is the volume of the cone shape bottom cover, h is the height of cone determined to be and r is radius of the cone.

Design of total digester volume: The total digester volume was obtained by summing volumes of the individual shapes (frustum top cover, middle cylinder and cone shape bottom cover):

$$TDV = VD\ (A) + VFT\ (B) + VCB\ (C) \quad \text{equation (5)}$$

TDV is the total digester volume, VD is the digester cylindrical volume, VFT is the volume of Frustum top cover and VCB is the volume of cone shape bottom.

Power required to mix the digester content: The power required for the agitation of digester content was determined using the equation proposed by Dave and John (2006):

$$PD = 0.185 \times \%\ Ts \times \text{liquid capacity}\ (VD+VCB) \quad \text{equation (6)}$$

where PD is power required to mix the digester content, VD is digester cylindrical volume, VCB is volume of the

cone shape bottom cover of the digester and TS is % total solid content determined.

Torque of stirrer shaft: The twisting moment (T) was obtained by the equation reported by Khummi and Gupta [17]:

where T is the torque of the stirrer shaft, P is the power transmitted by the shaft obtained from electric motor and N is the speed of shaft in rpm.

Stirrer shaft diameter: The stirrer shaft diameter as given by Rajendra [18] is:

$$d = (16T/(\pi\tau)) \quad \text{equation (7)}$$

where d is the stirrer shaft diameter, T is the torque of the stirrer shaft and τ is the shear stress of the shaft materials.

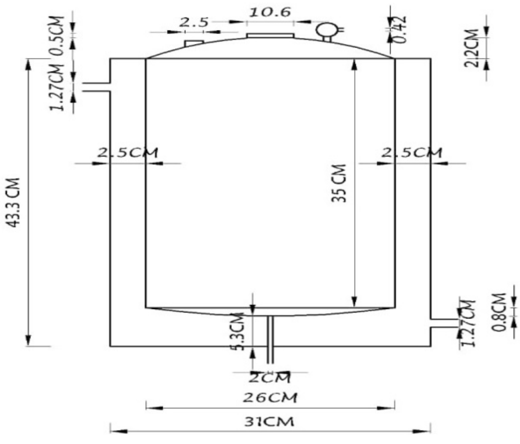

Figure 2: Orthographic view of the bio-digester showing the dimensions of different parts of the digester.

Boiler and pump: The boiler serves as a heating source which supplies hot water to the hot water jacket. It is a cylindrical vessel made of stainless sheet of height 27.1 cm and diameter 20 cm. The sheet was folded into a cylinder and welded using steel electrode. An electric steel heater with maximum operating temperature of 100°C was fitted into the boiler and was positioned 2 cm above the bottom of the boiler. Stainless steel was used for the fabrication to avoid corrosion. Hot water outlet and cold water inlet holes were also drilled into the boiler and a valve of 1.27 cm was welded to each hole in order to maintain a constant flow rate. To maintain constant flow of hot water through the annulus, a pump of 0.5 hp was used to convey the steam from the boiler outlet pipe to the hot water jacket inlet pipe and a gravity flow of cold water occurs from the hot water jacket outlet pipe back to the boiler inlet. The orthographic view of the boiler and pump are shown in Figure 3 and Figure 4, respectively.

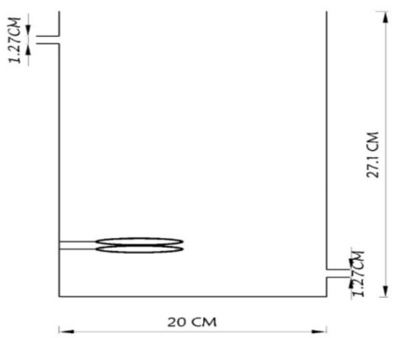

Figure 3: Orthographic view of the boiler showing the dimensions of different parts.

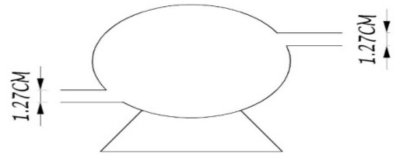

Figure 4: Orthographic view of the pump showing the diameter of the inlet and outlet pipes.

Agitator: The stirrer consists of a rod fabricated from stainless steel of height of 31 cm and diameter of 0.8 cm. A shaft connects the upper part of the rod to an electric motor, mounted on the digester lid, which rotates the stirrer at 20 rpm. A stirring paddle which consists of eight baffles, each of 8 cm length and horizontally positioned, was formed at the lower part of the stirrer rod by welding the baffles together using a steel electrode.

Figure 5: Orthographic view of the stirrer placed inside the digester.

Operational set-up

The experimental rig consists of a digester tank, substrate mixer with electric motor, feed inlet and outlet, hot water jacket, boiler, pressure gauge, multi-meter, pump, pH meter, gas holder, valves, thermocouple and supporting frame. The digester tank is a cylindrical container of approximately 20 liters in volume which serves as the main bio-reactor, the digester was inserted into a hot water jacket. Bio -digester was fitted with inlet and outlet valves on the cover with two flexible pipe connected to the valves. The inlet valve was used for introducing the feed into the digester while the outlet valve was connected to a storage tank and the outlet valve of the storage tank was connected to a compressor for compressing the biogas into a gas cylinder. The inlet and outlet valves for feeding of slurry and collection of gas had an open and closed valve. The boiler and hot water jacket has inlet and outlet valves drilled at the bottom of the boiler and hot water jacket and they are located at opposite side of the boiler and the hot water jacket. Two flexible pipes were connected to the valves. The outlet flexible pipe from the boiler was connected to the hot water jacket inlet valve and this valve serves as loop for transferring hot water coming from the boiler into the hot water jacket. While the outlet flexible pipe from the hot water jacket was connected to the boiler inlet valve in order for the cold water coming from the hot water jacket to flow back into the boiler. A pump was connected to the boiler, which aid the flow of the hot water through the loop of the pipe into the hot water jacket. In order to provide necessary heat to maintain the feedstock at the required temperature, hot water at 100ºC from the boiler was pumped continuously into the space between the digester and the hot water jacket called annulus thus the heat was transferred into the digester by convection, this occurs as result of either forced or natural movement of a hot fluid. The hot water in the boiler was achieved by conduction process, in which heat was transferred from the boiling ring to the water. A thermocouple connected to a multimeter was inserted into the bio-digester to measure the temperature inside the digester. An inlet valve was created at the top of the digester to allow charging of acid or base to the substrate which cater for variability of pH in the substrate concentration. Attached to it is a pH meter which measures the degree of acidity or alkalinity of the slurry during biodegradation. The shaft of a stirring system coupled with a motor was inserted at the center of the bio-digester with a speed range of 10 to 50 rpm and about 10 cm below the liquid surface level to mix the feed stocks. The propeller consists of flat stirring paddles and four vertical baffles for efficient agitation. The mixing of the substrate inside of the digester is achieved by a stirrer which converts rotary motion into circular motion turning the substrate. A process flow diagram of theexperimental set up is shown in Figure 6.

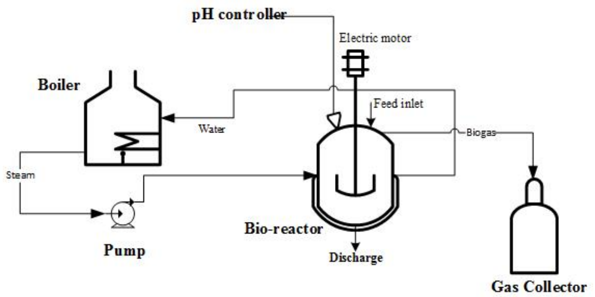

Figure 6: Process flow diagram of experimental setup for biogas production from waste.

Experimental Procedure

The fabricated bio-digester of capacity 20 liters was loaded with prepared slurry (water, dried kitchen wastes and cow dung). The working capacity of the bio-digesters was kept at 12 liters. The digester was operated at a constant volume of slurry of 12 liters, temperature of 40ºC, agitation speed of 30 rpm, a total solid content of 8% and pH of 7.5. In order to achieve anaerobic conditions, all the valves were airtight. Biogas produced was compressed into a gas cylinder. The process was carried out for 70 days. The pH and temperature of the reaction were also monitored and recorded.

RESULTS AND DISCUSSION

Fabricated Bio-digester System

An image of the bio-digester system fabricated according to the design discussed in section 2 is shown in Figure 7. This system was successfully utilised for the anaerobic co-digestion of kitchen waste and cow dung. Jyothilakshmi, et al. [21] designed and fabricated a small scale anaerobic bio-digester for domestic biodegradable solid waste with energy recovery. The results obtained show that the fabricated anaerobic digester was able to convert the solid waste to biogas. Abubakar, et al. [22] designed and fabricated a total mixed anaerobic digester. The total mixed anaerobic digester fabricated was tested by loading mixed sample of substrate into the digester tank, mixing of the substrates inside the digester was achieved by a worm gear powered by human efforts while the operating temperature was at ambient temperature. Preliminary flammability test was conducted on the biogas produced and it was found to be flammable. This result indicates that total mixed anaerobic digester fabricated can be used for biodegradation of organic material in the absence of oxygen. Michael [23] reported that a total mixed digester with agitator can be used to convert waste into biogas. To achieve reasonable conversion of solids to gas, a completely mixed reactor is required. Rajesh and Sounak [24] reported that total mixed digester is widely used in the industries to convert waste into gas.

Figure 7: Image of the fabricated jacketed batch bio-digester system showing all components.

Biogas Yield

The yield of biogas generated from the fabricated bio-digester is shown in Figure 8, where cumulative biogas yield was plotted against time in days. It was observed from the result, that 20 dm3/g of biogas was produced during the first week; it increased to 60 dm3/g until it reached its stationary phase at week 6 and then declined at week 9. Similar observation was reported by Jyothilakshmi, et al. [21] who produced 0.18 m3 of biogas from 20 kg of cow dung using fabricated biogas digester reactor in 20 days. The analysis of biogas produced is shown in Figure 9 and it was observed that biomethane (CH4) has the highest percentage shown in Figure 8.

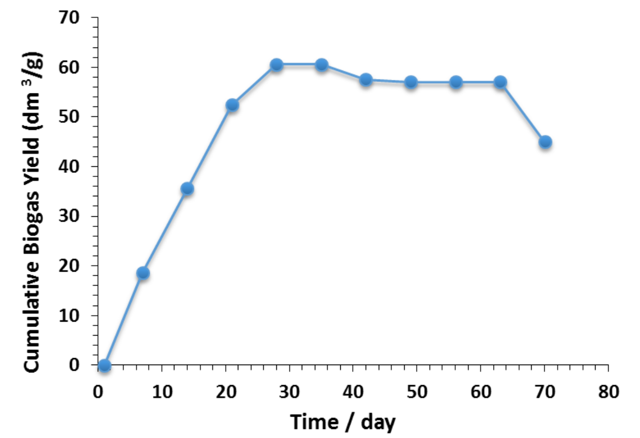

Figure 8: Plot of cumulative biogas yield versus time obtained from the experiment.

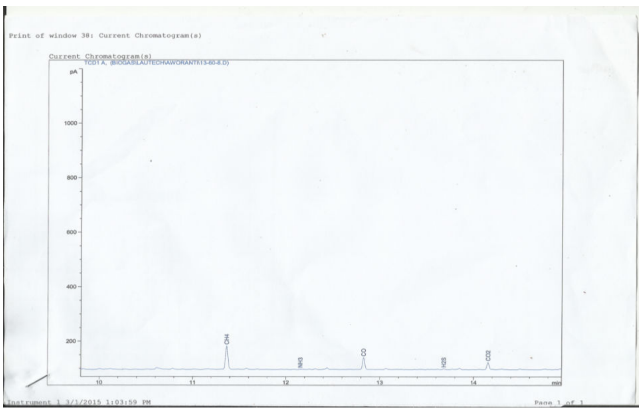

Figure 9: Chromatogram of biogas produced.

pH and Temperature

The initial pH of the substrate loaded into the digester was 7.5. The pH was monitored and controlled throughout the digestion period. It was observed that pH value obtained at every 24 hours from the slurry using a pH probe varied between 6.0-6.8. Similar observation was reported by Natcha et al, Ogunleye et al. [25, 9] reported that anaerobic bacteria require a neutral environment and thus a pH range of 7.5-8.0 is needed for optimum biogas production. The pH was controlled and reverted back to the required neutral pH of 7.5 by adding prepared sodium hydroxide solution into the slurry in the digester. Temperature is a very important parameter to be considered in the design of biogas digester. It was observed during the process of monitoring the slurry temperature by multimeter that the slurry temperature by multimeter that the slurry temperature increased from the initial slurry temperature value of 30oC to 40oC. The increase in the slurry temperature was achieved by hot water jacketed reactor and this increased slurry temperature was maintained throughout the digestion period. The declined in the process shows that the micro-organisms present in the digester were no more active and also there was no nutrient in the substrates for the microorganism to feed on.

The cumulative biogas production/the quantity of biogas produced can be improved by the following methods; introduction of operating parameters such as temperature, pH, total solid content, and carbon-nitrogen ratio into the design process, recirculating the digested slurry back into the reactor, use of additives such as biological and chemical additives with the main substrates [26]. Sharma [27] reported that addition of 1% onion storage waste to cattle dung in a 400-L floating drum biogas reactor will give an increment of 40-80% of biogas production. Ogunleye, et al. [9] reported that addition of biological additives (pineapple fruit waste and chicken rumen) to animal waste (cattle, pig and poultry) increased the biogas yield to 70%. The biogas yield shows the good performance of the fabricated bio-digester.

CONCLUSION

A jacketed bio-digester system which incorporates a heater, an agitator and a pH probe was designed, fabricated and successfully utilized for the anaerobic co-digestion of kitchen waste and cow dung. This bio-digester system can be used for laboratory experiments to train students on biogas process. It can also generate energy that can be used in the laboratory. In addition, this system can be used to simulate a biogas plant. It can be concluded from the result of the biogas yield obtained from the anaerobic digestion of cow dung co-digested with kitchen waste that jacketed biodigester fabricated can be used for anaerobic digestion of organic waste to form biogas. The slurry temperature can also be increased and maintained to desire temperature by the help of hot water jacketed reactor. Additionally, the pH and temperature of the slurry, controlled and maintained at specific value positively affected the reaction by increasing the biogas production potential and rate, which subsequently increased the biogas yield.

REFERENCES

1. Momoh OLY, Nwaogazie LI. Effect of waste paper on biogas production from co-digestion of cow dung and water hyacinth in batch reactors. J App Sci Environ Manage. 2008;12: 95-98.
2. Chanchal M, Biswas GK. A Comparative study on production of bio gas using green and dried vegetable wastes by anaerobic batch digestion process. Int J Eng Sci. 2012;1:1-6.
3. Umar HS, Firdausi BR, Sharifah, RWA, Fadimtu M. Biogas production through Co-digestion of palm oil mill effluent with cow manure. Nig J Basic appl. 2013;1:79-84.
4. Farooq M, Chaudhry LA, Hussain S, Ramzan N, Ahmed M. Biogas up gradation for power generation applications in Pakistan. J Inf Technol Manag. 2012;8: 107-118.
5. Lindkvist E, Johansson MT, Rosenqvist J. Methodology for analysing energy demand in biogas production plants-A comparative study of two biogas plants. Ener J. 2017;10: 1-20.

6. Cassidy DP, Hirl PJ, Belia E. Methane production for ethanol coproduction in anaerobic SBRS. Water Sci Technol. 2008;58: 789-793.
7. Xiao W, Yao W, Zhu J, Miller C. Biogas and CH4 productivity by co-digesting swine manure with three crop residues as an external carbon source. Bioresour Technol. 2010;101: 4042-4047.
8. Tiehm KN, Zellhorn M, Neis U. Ultrasonic waste activated sludge disintegration for improving anaerobic stabilization. Water Res. 2001;35: 2003-2009.
9. Ogunleye OO, Aworanti OA, Agarry SE, Aremu MO. Enhancement of animal waste biomethanation using fruit waste as co-substrate and chicken rumen as inoculums. Energy Sources, Part A: Recov. Utiliz Environ Effect. 2016;38:1653-1660.
10. Sreenivas R, Retter RA, Hobbs PJ. Effect of biomass hydrolysis on biogas production. Process Biochem.2010;28: 119-123.
11. Krishna RH. Role of factors influencing on anaerobic process for production of bio hydrogen: future fuel. Int J Adv Chem. 2013;1:31-38.
12. Phetyima N, Wanthonga T, Kannikaa P and Supngama A. Biogas production from vegetable waste by using dog and cattle manure. Energy Procedia. 2015;79: 436-441.
13. Mallick J, Narayana KL, Khuntia S, Singh D, Barik R. Biogas generation from leafy biomass and vegetable wastes by application of ultrasound. Inst Miner Mater.2000;35: 2003–2009.
14. Itodo IN. Agricultural Energy Technology: Agricultural Engineering Department, Federal University of Agriculture Makurdi (1st Ed.). Makurdi, Benue State, Nigeria: Aboki Publishers, 2007.
15. Budzianowski WM. Sustainable biogas energy in Poland: Prospects and challenges. Renew Sust Energ Rev 2012;16: 342-349.
16. Abubakar MS, Bello SA. Design and fabrication of an anaerobic digester. Arid Zone J Eng Tech and Env.2017;13: 77-85.
17. Khurmi RS, Gupta JK. A textbook of machine design(14th Ed.). New Delhi India, Eurasia Publishing House Ltd, 2005.
18. Rajendra K. A textbook on machine design(1st Ed.). New Delhi, Laxmi Publications Ltd,1999.
19. Aggarangsi P, Teerasountornkul T. Practical design and efficiency of large scale biogas digesters for swine farms in Thailand. J Sus Energ Env. 2011:51-55.
20. Dave R, John B. Anaerobic digestion of animal waste: Factors to Consider. UK: ATTRA, Ltd, 2006.
21. Jyothilakshmi R, Prakash SV. Design, Fabrication and Experimentation of a Small Scale Anaerobic Biodigester for Domestic Biodegradable Solid Waste with Energy Recovery and Sizing Calculations. International Conference on Solid Waste Management. 2006;35: 749-755.
22. Abubakar BSUI, Ismail N. Anaerobic digestion of cow dung for biogas production. ARPN J Eng App Sci. 2012;7: 169-172.
23. Michael RT. History and future of domestic biogas plants in the developing world, Energy for Sustainable Development. 2011;15: 347–354
24. Rajesh G, Sounak B. A review study on anaerobic digesters with an insight to biogas production. Int J Eng Sci Inven. 2013;2: 8-17
25. Phetyim N, Wanthong T, Kannika P, Supngam A. Biogas Production from Vegetable Waste by using Dog and Cattle Manure. International Conference on Alternative Energy in Developing Countries and Emerging Economies. 2015;79: 436-441.
26. Yadvika S, Sreekrishnan TR, Sangeeta K, Vineet R. Enhancement of biogas production from solid substrates using different techniques– Bioresource Technology. 2004;95: 1-10.
27. Sharma DK. Studies on availability and utilization of onion storage waste in a rural habitat. Ph. D. thesis, Centre for Rural Development and Technology, Indian Institute of Technology, Delhi, India, 2002.