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Development of a Locally Sourced Miniature Facility Capable of Transforming Bio-Waste into Renewable Energy

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Abstract: The primary challenge facing the globe today is finding environmentally friendly, ecologically balanced ways to use bio-waste as a source of energy. Typically, the term “biogas” or “renewable energy” refers to a gas created when organic matter breaks down without oxygen. Thus, this study designed and developed a 200L miniature facility capable of transforming bio-waste into renewable energy using locally available materials and tested under the existing weather condition in Awka, Anambra State. The facility developed in this study was utilized to decompose cow manure anaerobically, producing 21.9L of cooking gas overall over the course of a 35-day retention period. Additionally, the water boiling test demonstrated that the purified cooking gas’ high methane gas content development of the digesting chamber using high-density polyethylene plastic (HDPE) allows a reduction in the overall cost of setting up a small-scale plant.

Keywords: Bio-waste; Renewable energy; Bio-gas; Cow dung; Anaerobic digestion.

I. Introduction

Fossil fuels are the main source of energy on the planet(Benali, Hamad, and Hamad, 2019). This kind of energy source releases a significant amount of carbon dioxide gas, one of the main greenhouse gas contributors. According to recent findings, the atmospheric carbon dioxide concentration has dramatically increased over the past century, rising from about 275 to 387 ppm with an average annual increase of 3 ppm(Igboro, 2011). This has led to an increase in global temperatures, clearly indicating that global warming will continue(Hassan, Abdullahi, and Garba, 2022).

Fossil fuels have been used as the main source of energy, causing problems with the environment, the climate, and human health. One of the main issues facing every growth is improper garbage management. This is due to the rise in commercial, agricultural, industrial, and environmental activities, which has significantly increasing waste production(Hunt et al., 2020).These wastes contribute to unsanitary environmental conditions that encourage the growth of pathogenic bacteria when they are incorrectly treated. Wastes have adverse effects on health aside from making the environment unpleasant and unsightly. These wastes can, however, be appropriately managed by being transformed into biogases, which are valuable and more environmentally beneficial forms(Castro-Amoedo et al., 2021). It is important to note that for the production of biogas, any sort of biological waste could be utilized(Shaibur, Husain, and Arpon, 2021).

The term “biogas” often refers to a gas created when organic matter breaks down in the absence of oxygen. Like solar and wind energy, it is a renewable source of energy (Sambo, 2009). It is one of the most effective and efficient options for renewable energy (Halder et al., 2016).

Additionally, the need to create alternative energy sources, such as biogas generation, has been driven by the rising cost of petroleum goods, particularly in Nigeria.Most people live in rural areas of underdeveloped nations like Nigeria, where there is little to no access to gas or electricity(Kehinde et al., 2018). As a result, they rely primarily on firewood for lighting and cooking(Sambo 2009). However, one of the main factors contributing to erosion in the southern part of the country and desertification in the arid-zone states is the sourcing of fuel wood for residential and commercial purposes(Sambo, 2009). The annual rate of deforestation is roughly 350,000 hectares, or 3.6% of the total area of forests and woodlands(Sambo, 2009). In contrast, the annual rate of regeneration is only about 10% of the annual rate of deforestation(Sambo, 2009).Biogas-based alternative energy sources can expand rural energy availability and decrease reliance on fossil fuels(Sarker et al., 2020).When properly managed, it is a cost-effective means of managing bio-waste and the most affordable way to supply both rural and urban settlements with natural gas and affordable electricity (Amakom, Nnabuchi, and Abubuko, 2015).

Installing biogas plants in these rural areas would aid in mitigating these current issues and preserving the natural environment, as agricultural residues and large amounts of solid waste are abundantand, if not properly disposed, leads to environmental and public

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health hazard. Transforming such waste into renewable energy can mitigate such effects. Therefore, this study aims to develop a locally sourced miniature facility capable of transforming bio-waste into renewable energy.

II. Materials and Method

The miniature facility was made from high-density polyethylene (HDPE) plastic. It has the following parts: the inlet chamber (feed entrance), outlet chamber A (removalof raw gas), outlet chamber B (removal of digestate), filtration chamber (A, B and C) forfiltering of hydrogen sulphide, carbon dioxide/trace of hydrogen sulphide, water vapour andthe gas storage chamber (for storing pure cooking gas). The inlet and outlet chambers wereboth incorporated into the mini plant tank, making it a single system. The reason for choosingplastic as a digester tank in this study was based on the following properties: noncorrosive, agood insulator, cost-effective, and easy to maintain. The cylindrical shape was adopted toenhance better cow dung and water mixing.. This is illustrated in Figure 1.

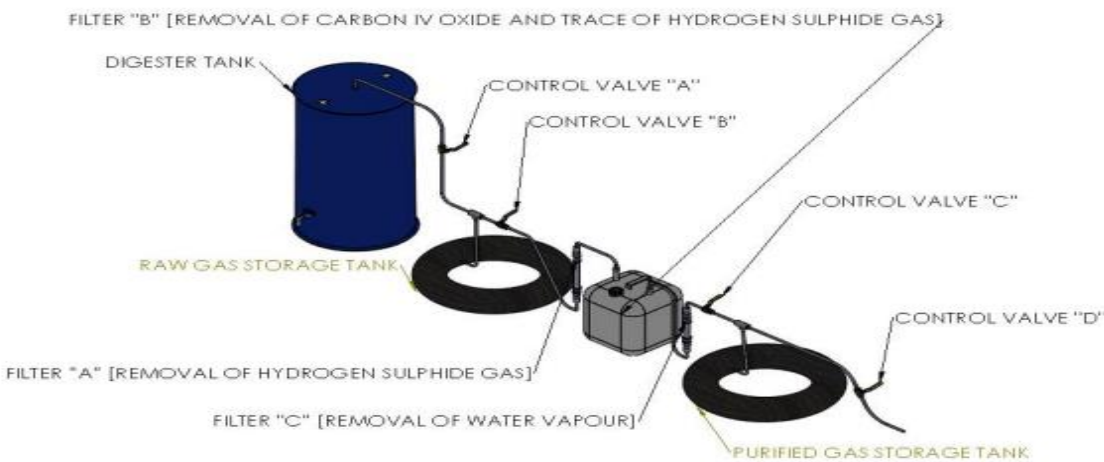

Fig 1: Bio-waste transforming facility

The following were considered during the design procedure:

i. Operating Volume: This is simply the volume of the slurry in the digester. It can be calculated using part-per-volume method as follows:

Let, B_{20} = 20 litres bucket as a part per volume tank

B_{100} = 100 litres bucket as a mixing tank,

D_{200} = 200 litres drum as a digester tank,

C_b = 150 litres calibrated bucket,

The mixing ratio of cow dung to water is 1:1

V_{130} = required operating volume of the slurry = $D_{200} \times 65\%$ of the slurry = 200 litres × 0.65 of the slurry = 130 litres of the slurry.

1. A bucket full of fresh cow dung was measured with B_{20} and poured into the B_{100},
2. The bucket full of water with another B_{20} was also measured and poured it into the B_{100}, and stirred homogeneously.
3. The mix was poured into the C_b and its volume was calibrated.
4. Steps 1 & 2 were repeated until the required operating volume of the slurry, i.e., 130 Litres of the slurry were achieved.
5. Finally, the V_{130} or 130 litres of the slurry was fed into the D_{200}.

ii. Total Volume: The total volume of the digester (VT) should be greater than the operating volume. This is to give room for the cooking gas produced and the rise of the slurry during fermentation. It can be calculated as follows;

$V_T = V_{130}/Requiredfractionoftheslurry$

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Therefore:

130 $litres of the slurry/0.65\ of the slurry$ = 200 L.

iii. Digester Dimensions: Having determined the total volume of the digester, a ratio for the dimensions can be adopted, depending on the chosen geometric shape of the digester. For a cylindrical digester, the chosen geometry for this work

$V_T = \pi r_d^2\ h_d$ (1)

Were,

V_T = Total volume of digester = 200 L or $0.2m^3$.

r_d = Radius of digester = 0.27m or 270mm.

h_d = Height of digester = $V_T r_d^2$ = $0.2m^3/\ \pi \times 0.272$ = 873mm.

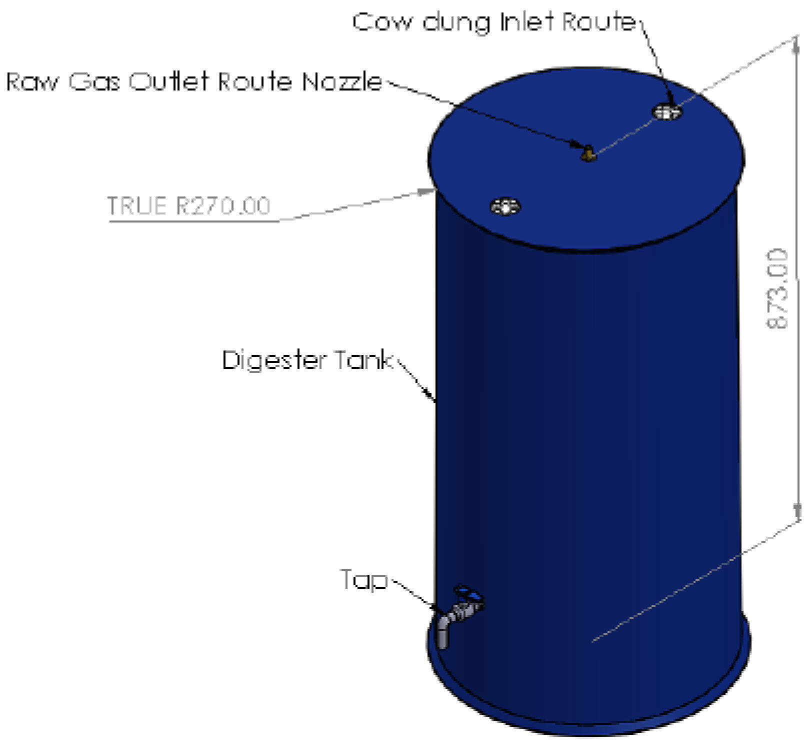

Fig 2: Digester Tank 200 L Capacity

iv. **Digester Temperature Detector (DTD):** This is simply a slurry temperature-detecting device. This digester was designed to operate within the mesospheric temperature range (***20ºC – 40ºC***).

It was designed as follows;

- DTD was purchased with a maximum temperature of 260^0C and minimum temperature of 10^0C,
- 50mL of slurry was collected from the outlet chamber with a beaker every week.
- Slurry temperature was measured and recorded with DTD.

v. **Filter 'A' Design:** This simple filter filters hydrogen sulphide H2S. The following materials and specifications were used to design it;

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Table 1: Filter 'A' Design Materials/Specifications

S/N	MATERIALS	SPECIFICATIONS
1	Thread socket	(25mmx1/2'')
2	Reducer bush	(25mmx25mm)
3	Reducer socket	(32mmx25mm)
4	PVC pipe	(215mmx25mm)
5	Nozzle	(1/2''x 10mm)
6	Steel wool	(1 strand)
7	Gum	-------

iv. Filter 'B' Design: This simple filter filters carbon dioxide, CO2 and some trace of hydrogen sulphide, H2S. The following materials and specifications were used to design it as follows:

Table 2: Filter 'B' Design Materials/Specifications

S/N	MATERIALS	SPECIFICATIONS
1	Reducer socket	(20mmx1/2'')
2	PVC pipe	(300mmx20mm), (120mmx20mm)
3	Filter tank	(20L capacity)
4	Water	(15L)
5	Sodium Bicarbonate	(30g)
6	Gum	-----
7	Tap	-----

v. **Filter 'C' Design:** This simple filter filters water vapours. The following materials and specifications were used to design it as follows:

Table 3: Filter 'C' Design Materials/Specifications

S/N	MATERIALS	SPECIFICATIONS
1	Thread socket	(25mmx1/2'')
2	Reducer bush	(25mmx25mm)
3	Reducer socket	(32mmx25mm)
4	PVC pipe	(130mmx25mm)
5	Nozzle	(1/2''x 10mm)
6	Foam	(25mmx20mm)
7	Silica gel	(30g)
8	Gum	-----

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2.1 Gas Storage Tank Design

The gas tank volumedepends on the relative rates of gas generation and gas consumption. The motor tire tube shown in Figure 3 was selected as the gas storage tank due to the following properties:

- Chemical inertness of the tube, i.e., hydrogen sulphide present in the raw gas which when in contact with metals, causes pitting corrosion butdoes not attack tube materials.
- Expansion and contraction ability, i.e., the tube material allows expansion and contraction of the gasses without bursting.
- Low-pressure flow rate of the gas, i.e., the gas flows at self-pressure, and as a result of this self-pressure, the tube takes in the gas gradually without bursting.

Fig 3: Gas storage tank

2.2 Gas Valve Design

A 2-way ball returnable valve shown in Figure 4 was used to control the gas flow direction from the digester tank to the motor tire tube and through the filter 'A'. Again, it was used to prevent pressure drop of the gas and maintain its self-pressurewhile flowing into the gas storage tank.

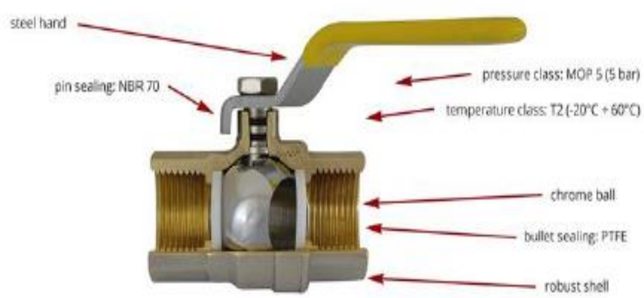

Fig 4: A 2-way ball returnable valve

A tee fitting with a female threaded connection shown in Figure 5, was used to distribute the raw gases produced into the motor tire tube and through the filter 'A'.

Fig 5: Tee fitting with female threaded connection

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Figure 6 shows the raw gas storage tank assembly incorporating tee fitting with a female threaded connection and a 2-way ball returnable valve

Fig 6: Raw gas storage tank assembly

2.3 Gas Hose Design and Digester Tank Design

Factors considered during the selection of the appropriate hose for the inlet and outlet hose are as follows:

I. Material type and size
II. Thermal expansion and temperature effect
III. Maintenance ease and installation
IV. Safety, in terms of the design factor, and adequate support.

The inlet hose and tank are cylindrical, and the bursting pressure of the inlet hose was calculated using the following equation:

$$Pb = \frac{2 \text{ x ST x MT}}{\text{Dm}} \qquad (2)$$

Where

Pb= Bursting pressure of the inlet hose in psi.

ST = Tensile strength of the pipe = P105 or 724Mpa

MT = Minimum wall thickness of the pipe = 2.5mm,

Dm = Mean diameter = 10mm.

Thus theBursting pressure of the inlet hose is 362psi.

The bursting pressure of the tank was calculated using the formula in Equation 2,

Where

Pb= Bursting pressure of the tank in psi.

ST = Tensile strength of the pipe = 22.1Mpa

MT = Minimum wall thickness of the pipe = 10mm,

Dm = Mean diameter = 540mm.

Thus the Bursting pressure of the tank is 0.82psi.

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2.4 Sample Collection and Preparation Procedure

The cow dung for the present study was collected from Garki,Amansea Junction, Awka, Anambra State. It was dissolved with water at a ratio of 1:1 (waste/water) to obtain the slurry. This was done to ensure that the percentage of the total solids was less than 10% before being fed to the facility. The facility was fed with 130 L of slurry and allowed to undergo aretention time of 7 days, 14 days, 21 days, 28 days and 35 days to evaluate the amount of cooking gas produced. The digester tank was covered with polyethylene material that could withstand harsh environmental conditions and maintain anaerobic conditions. The slurry temperatures were monitored using a Digester Temperature Detector (DTD) inserted into the slurry measured out of the outlet chamber. During the purification stage shown in Figure 7, steel wool, water and silica gel were used. The steel wool was used to react with the hydrogen sulphide, and the water was used to reduce the percentage of carbon dioxide and the silica gel was used to reduce the presence of water vapor in the purified cooking gas. The experiment took the raw cooking gas with pressure built up in the tank head and forced it through the steel wool to remove hydrogen sulphide from the cooking gas filtering unit. After steel wool removed the hydrogen sulphide, the raw cooking gas was passed into the water filtering unit for further purification.

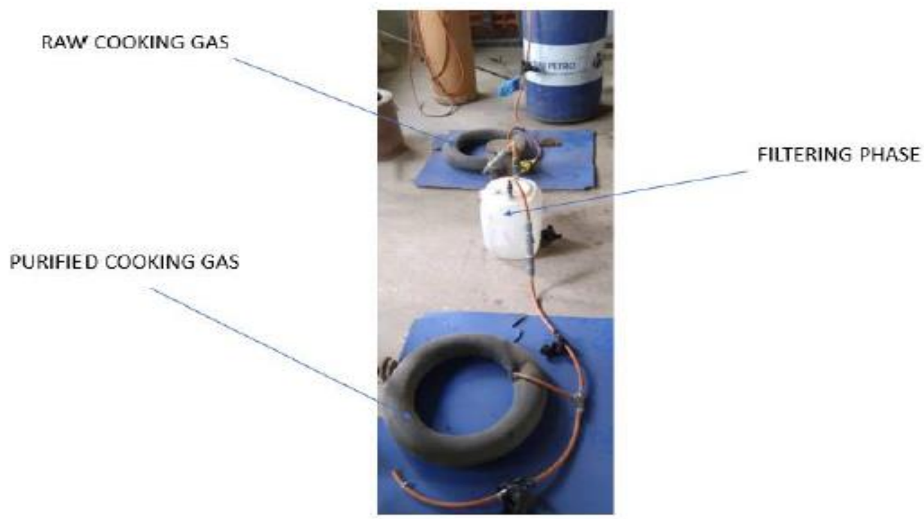

Fig 7: Cooking Gas Filtering and Purification System

The liquid leaving the filtering unit will thus contain an increased concentration of carbon dioxide, while the gas leaving the filtering unit will have an increased methane concentration. The purified cooking gas collected at the top of the filter unit contains some amount of water vapours. Since water vapor is the leading causes of corrosion, silica gel was used in this experimental set-up to absorb it.

III. Results and Discussion

Details of the results obtained during the experiments are tabulated below. Volumes of cooking gas produced, the temperature of the environment, and the temperature of the slurry at a retention time of 7, 14, 21, 28, and 35 days are presented in Tables 4 and 5. The values of heating efficiency before and after filtering of impurities from the produced gas are also presentedin Table 6.

Table 4: Cooking gas produced against retention time

Retention time (day)	Cooking gas produced (L)
7	1.8
14	2.5
21	3.4
28	4.2
35	10.7

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Table 5: Temperature of environment and slurry against retention time

Retention (day)	Environment Temperature ^{O}c	Slurry Temperature ^{O}c
0	20	20
7	25	30
14	26.5	32
21	28	34
28	24	29.5
35	30	38

Table 6: Time for boiling 200ml of water

Days	Heating efficiency before filtering (mins)	Heating efficiency after filtering (mins)
7	0	0
14	35	31.5
21	20.33	16.53
28	8.20	12.50
35	6.31	2.46

The designed and constructed 200 Lfacility was installed at the Faculty of Engineering foundry shop, NnamdiAzikiwe University, Awka. Cooking gas yield was made possible by the action of anaerobic bacteria in the presence of moisture and the absence of oxygen. The mini plant's cooking gas performance over the 35 day' retention period and is presented in Figure 7. The facility was fed with cow dung at a mixing ratio 1:1 for slurry and water. Figure 7 shows that cooking gas production was initiated from day 7 with agradual increase in the volume of gas produced. The production of higher amount of cooking gas from day 7 to day 35 further proved that the three stages of anaerobic digestion were occurring simultaneously within the mini plant.

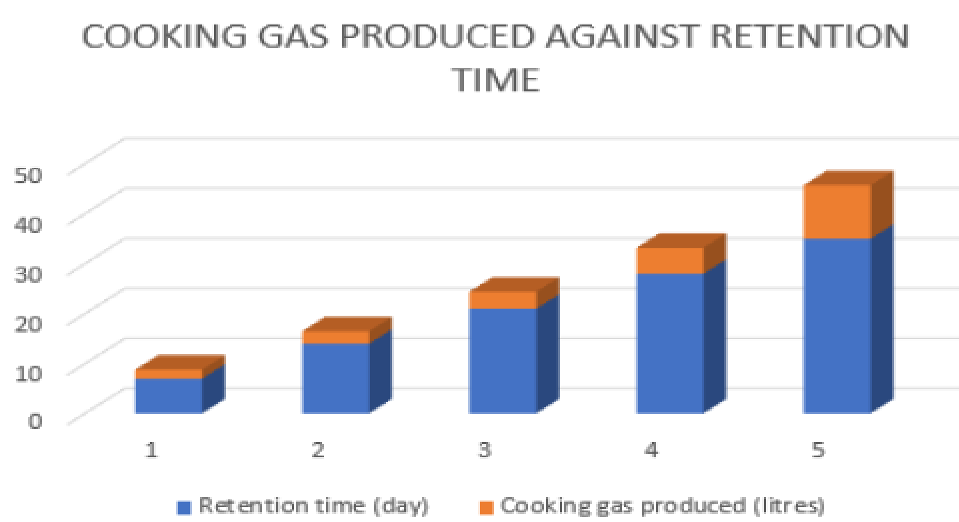

Fig 7: Cooking Gas produced as against Retention Time

The effect of environmental temperature was noticed in the digestion of the cow dung slurry. In Figure 8, it was observed that temperature affects the digestion of the slurry. This was observed from day 7 to day 21and day 28 to day 35, where there was an increase in temperature. As a result of the variation in temperature of the environment, the digestion of the slurry was quickening, which led to a higher yield of cooking gas. From day 21 to day 28, the temperature of the environment reduces which also lowers

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the slurry temperature and yieldslittle increase in the amount of cooking gas produced. Thus showing that the mini plant operated within the mesophilic temperature range.

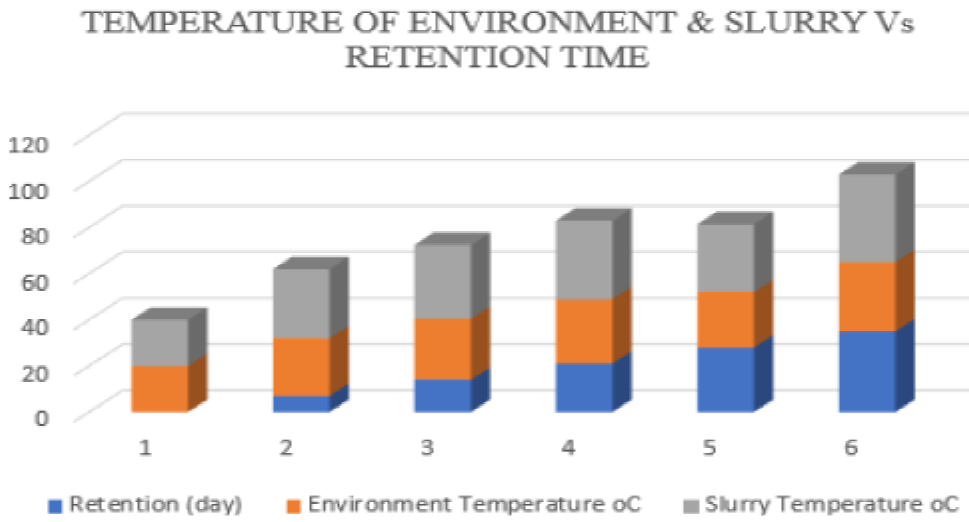

Fig 8: Effect of Environmental Temperature

IV. Conclusion

The study designed and developed a 200 L miniature facility capable of transforming bio-waste into renewable energy using locally available materials and tested under the existing weather conditions in Awka, Anambra State. The facility developed in this study was utilized to decompose cow manure anaerobically, producing 21.9 L of cooking gas overall over the course of a 35-day retention period. Additionally, it was discovered that the environment's temperature was mesophilic and strictly related to the slurry's temperature. Additionally, the water boiling test demonstrated that the purified cooking gas' high methane gas content development of the digesting chamber using high-density polyethylene plastic (HDPE) allows a reduction in the overall cost of setting up a small-scale plant.

V. Recommendation

Future research should consider, whether adding alkaline materials like limestone, sodium hydroxide, and potassium hydroxide to the water used to mix cow dung could raise the pH level to the ideal range for anaerobic digestion.

References

1. Amakom, C., Nnabuchi, M, N. & Abubuko, F. 2015. "Comparative Analysis on the Biogas Yield for Chicken Droppings and Cow Dung." In Renewable Energy and Sustianable Environment - 2015 RAESON Annual Conference Proceedings.
2. Benali, Moutaz, Tarek Hamad, and Yousif Hamad. 2019. "Experimental Study of Biogas Production from Cow Dung as an Alternative for Fossil Fuels." Journal of Sustainable Bioenergy Systems 09 (03): 91–97. https://doi.org/10.4236/jsbs.2019.93007.
3. Castro-Amoedo, Rafael, Nicolas Morisod, Julia Granacher, and François Maréchal. 2021. "The Role of Biowaste: A Multi-Objective Optimization Platform for Combined Heat, Power and Fuel." Frontiers in Energy Research 9 (September): 1–17. https://doi.org/10.3389/fenrg.2021.718310.
4. Halder, P. K., N. Paul, M. U.H. Joardder, M. Z.H. Khan, and M. Sarker. 2016. "Feasibility Analysis of Implementing Anaerobic Digestion as a Potential Energy Source in Bangladesh." Renewable and Sustainable Energy Reviews 65: 124–34. https://doi.org/10.1016/j.rser.2016.06.094.
5. Hassan, Ismail, Musa Abdullahi, and Lawal Garba. 2022. "Biogas Production from Cow Dung Using Laboratory Scale Digester as Potential Tool for Abattoir Waste Management." Gadau Journal of Pure and Allied Sciences 1 (1): 40–47. https://doi.org/10.54117/gjpas.v1i1.13.
6. Hunt, Natalie D., Matt Liebman, Sumil K. Thakrar, and Jason D. Hill. 2020. "Fossil Energy Use, Climate Change Impacts, and Air Quality-Related Human Health Damages of Conventional and Diversified Cropping Systems in Iowa, USA." Environmental Science and Technology 54 (18): 11002–14. https://doi.org/10.1021/acs.est.9b06929.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue IX, September 2023

7. Igboro, S. B. 2011. “Production of Biogas and Compost from Cow Dung in Zaria, Nigeria.” Ahmadu Bello University, Zaria, Nigeria.
8. Kehinde, O., K. O. Babaremu, K. V. Akpanyung, E. Remilekun, S. T. Oyedele, and J. Oluwafemi. 2018. “Renewable Energy in Nigeria - A Review.” International Journal of Mechanical Engineering and Technology 9 (10): 1085–94.
9. Sambo, By Abubakar S. 2009. “Strategic Developments In Renewable Energy In Nigeria.”
10. Sarker, Swati Anindita, Shouyang Wang, K. M.Mehedi Adnan, and M. Nahid Sattar. 2020. “Economic Feasibility and Determinants of Biogas Technology Adoption: Evidence from Bangladesh.” Renewable and Sustainable Energy Reviews 123 (February): 109766. https://doi.org/10.1016/j.rser.2020.109766.
11. Shaibur, Molla Rahman, Humaira Husain, and Samsul Huda Arpon. 2021. “Utilization of Cow Dung Residues of Biogas Plant for Sustainable Development of a Rural Community.” Current Research in Environmental Sustainability 3: 100026. https://doi.org/10.1016/j.crsust.2021.100026.