Fabrication of Mini Bio-Gas Digester using Locally Available Material for Cooking Purposes

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ORIGINAL RESEARCH

Abstract— Energy is becoming almost unaffordable for most people, especially in Africa, where there are insufficient investments and less emphasis is given to sustainable and renewable sources of energy. This research work entails the fabrication and performance evaluation of a mini-biogas digester using locally available materials (cow dung and garbage) for domestic cooking in Nigeria. The obtained biogas was analyzed with a portable gas analyzer (PG-300) and found to have met standard cooking gas specifications for chemical composition, sulfur content, hydrogen sulfide content, and calorific value. The digester, fabricated from a 25-liter square round plastic jerry can, produced 0.39 to 0.5 m^3 of methane gas daily from cow dung and garbage mixtures, which is approximately 50–60% of the total biogas produced. This eco-friendly technology offers a sustainable alternative to fossil fuels for domestic cooking, reducing deforestation and greenhouse gas emissions.

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Keywords— Anaerobic digestion, Bio-gas digester, Biomass, Climate Change, Cow dung, Methane Gas, Nigeria, Plastic Jerry can. Renewable Energy, Sustainable Energy,

1.0 Introduction

The increasing use of fossil fuels is a cause for concern due to their perceived efficacy. However, fossil gas is ecologically unfriendly, emitting hazardous pollutants, aggravating global warming and deforestation, and increasing the risk of explosions and fires in residential areas. This emphasizes the critical need to shift to more sustainable energy sources to reduce environmental degradation and safeguard human health and safety.

Energy is required for development, and sustainable development cannot occur without it (United Nations Development Programme, 2016). Energy is sustainable if it serves the environment without endangering future generations' ability to meet their own needs. (Kutscher *et al.*, 2019). As of 2018, the energy system was responsible for 76% of global greenhouse gas emissions, while fossil fuels accounted for 85% of worldwide energy consumption (Global Historical Emissions, 2021; Mengpin et al., 2021). 790 million people live without electricity, and 2.6 billion burn fossil fuels. Paris Agreement targets need a total energy overhaul, aiming for net-zero emissions by mid-century (United Nations Development Program, 2016). An estimated 7 million people die each year from air pollution, which is mostly caused by burning biomass and fossil fuels (WHO, 2021). The shift to low-carbon energy improves people's health. There are ways to make renewable energy accessible to everyone, which will help developing nations both economically and health-wise.

The World Health Organization's recommended limits for air pollution are exceeded by an estimated 99% of the world's population (WHO, 2021). Nearly all indoor air pollution is caused by cooking with polluting fuels, including wood, coal, animal dung, or paraffin, which kills between 1.6 and 3.8 million people annually (WHO, 2018; Ritchie and Roser, 2019). It also significantly contributes to outdoor air pollution (WHO, 2016), with negative health impacts disproportionately affecting women, who are primarily responsible for cooking, and small children. Burning biomass and fossil fuels is a significant contributor to air pollution (Watts *et al.*, 2021; United Nations Development Program, 2019). Acid rain is mostly caused by emissions from burning fossil fuels in factories, power plants, and automobiles that mix with atmospheric oxygen (United States Geological Survey, 2021). The second-most common cause of death from non-infectious disorders is air pollution (WHO, 2018).

Mini-biogas digesters offer a promising alternative, converting organic waste into clean biogas for cooking. Anaerobic digestion, the breakdown of biological materials by bacteria without oxygen, produces biogas (Rohith Kumar *et al.*, 2023). Cow dung usage encourages sustainable waste management methods while also maximizing its possible uses in agriculture and the energy sector. However, there are hurdles to implementing bio digesters in rural locations (Kusmiyati *et al.*, 2023). Biogas is a volatile gas that includes trace elements, carbon dioxide, and methane. Digestate is a nutrient-rich, digested substrate that may be used as plant fertilizer (Jyothilakshmi & Prakash, 2016). Meeting existing and future energy demands sustainably is an important obstacle in the worldwide effort to prevent climate change while sustaining economic growth and raising living standards (Kessides & Toman, 2011). Energy that is both economical and dependable is necessary for

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economic growth, education, and health care, especially for electricity (Morris *et al.,* 2015).
Achieving the majority of the United Nations 2030 Sustainable Development Goals necessitates improving energy access in the world's least developed nations and producing cleaner energy (Sarkodie, 2022), as well as providing clean cooking facilities and power to all people by 2030. Biomass is a renewable organic substance derived from plants and animals. It can be burned to provide energy and heat, or processed to create biofuels like ethanol and biodiesel, which can be used to power cars (Demirbas, 2008; Correa *et al.,* 2019). Barriers to widespread application include inadequate infrastructure, expensive installation and maintenance costs, erratic feedstock availability, and a lack of knowledge and education regarding bio digester technology (Kusmiyati *et al.,* 2023).
Existing research has shown that mini-biogas digesters are feasible for residential applications; nevertheless, issues such as material selection, digester design, and gas production efficiency persist. This work tackles these issues by providing a low-cost, portable digester made of local materials and improving the anaerobic digestion process for optimal biogas generation.

2.0 Materials and Methods

2.1 Materials

The portable biogas digester was constructed using components from the local, common market. The following resources were employed: 25 L plastic jerry can, motorcycle inner tube, ½ inch hose, glue, ¾ PVC pipe, PVC fittings (¾ elbow and end cap), GI fittings (½ gate valve, tee-joint), clips, measuring tape, pen, 20 L mixing tank, and portable gas analyzer (PG-300).

2.2 Methods

The fabrication and production were done according to the procedures of Jyothi Lakshmi and Prakash (2016). The digester fills to 80% capacity with a slurry of water and cow dung when it is charged for the first time. To create anaerobic conditions, care was taken to prevent any air from entering the digester. When the gas was filled, the gas valve that connects to the gas holder was left open, but the inlet and outlet were closed. Due to gas production, the gas holder grew throughout the first twenty days of the cycle. This 20-day period functioned as a batch reactor during the biogas production's transitional phase. Furthermore, the digester temperature, pH level, biogas, and energy production capability of the design product were assessed.

2.2.1 Digestion Chamber

The 25-liter round plastic Jerry can, which serves as the digestive chamber, has an interlocking mechanism that makes stacking them safe. Constructed using high-density polyethylene (HDPE) resin by an extrusion blow molding technique, these products are safe and prevent material from leaking or breaking. The biogas plant is made of lightweight polypropylene, which makes it both sturdy and portable. The digester tank's measurements are 295 mm x 240 mm x 447 mm. Figure 1 shows clearly that the jerry can be used as a digestion chamber. The plastic tanks were marked during the development of the mini biogas digester, marking was carried out on the plastic tanks. All necessary measurements were done, and the components were assembled. A 25-liter jerry can be used as a digester, and a motorcycle inner tube is a safe tank for the extracted gas. The fabrication was simple, as shown in the Figure 1..

Figure 1: 25-litre plastic jerry can

2.2.2 Operation of Bio-digester

A mixture of cow dung and garbage (CD and G) served as the digester feedstock, combined in a 1.5:0.5:1 ratio with water. The digester was fed daily through the inlet, and anaerobic digestion, facilitated by bacteria, converted the organic matter into biogas. The gas was collected in the motorcycle's inner tube, and pressure was monitored using the gauge. Digester temperature was maintained within the optimal range (35–40 °C) for efficient biogas production. The feeding inlet is an opening located at the top of the 25-liter jerry can. The biodegradable materials are fed directly through the feed inlet.

2.3 Production of the Clean Gas for Cooking

A group of hydrolytic and acidogenic bacteria called acidogens first break down the complex organics into a mix of volatile fatty acids (VFAs), mostly acetic, propionic, and butyric acids. Bacteria classified as acetogenic (acetogens) or methanogenic (methanogens) subsequently convert the VFAs to CO2 and CH4, respectively. The following is a representation of the anaerobic bioprocess:
Organic matter + nutrients/microbials = CO_2 + CH_4 + biomass.

2.4 Product Analysis

The produced biogas was analyzed for its composition (methane, carbon dioxide, and other gases) using a portable gas analyzer (PG-300). This was done to ensure the gas met safety and performance standards for domestic cooking, including chemical composition, sulfur content, hydrogen sulfide content, and calorific value.

3.0 Result and Discussion

3.1 Mini Bio-gas digester Fabrication

The fabricated mini-biogas digester was simple, cost-effective, and easy to operate. The interlocking jerry cans provided stability and safety, while the readily available materials made the digester accessible to rural communities.

Figure 2: Fabricated mini bio-gas digester

3.2. Energy Detection

A gas stove was connected to the gas storage vessel and then lit. Continued combustion was observed, thus further revealing the presence of biogas constituents.

3.3 Product Analysis

The mini-biogas digester produced an average of 0.39 m^3 of biogas per day, with a methane content of 55–60%. The gas complied with standard cooking gas specifications in terms of chemical composition, sulfur content, hydrogen sulfide content, and calorific value. These results indicate that the digester can effectively generate clean biogas suitable for domestic cooking. The biogas production rate was influenced by the feedstock composition and ambient temperature. Higher organic waste content and warmer temperatures led to increased gas production.

Figure 3: Produced gas is stored in the tube.

3.4 Detailed yield calculation

A detailed calculation of the gas yield was carried out according to the reported method (Jyothilakshmi & Prakash, 2016).

Step 1: Determine the slurry's total solids (TS) content. 8.5% of the slurry, divided by 30 kg, equals 2.55.

Step II: Quantifying the Volatile Solid (VS) present in the slurry. = 0.8 TS = 0.8 × 2.55 = 2.04 for VS.

Step III: Calculating the biogas yield per kilogram of vegetable stock. About 50% of the total degradable material in the VS is present when only 0.5 × VS = 1.02 kg of VS is consumed, producing 0.4 m3 of biogas. Hence, 1 kg of VS will produce 0.4/1.02 = 3.9 m^3 of biogas will be produced from 1 kg of VS. As a result, the biogas output from cow dung slurry is 3.9 m^3/kg of volatile solids.

4.0 Conclusion

The study demonstrates the successful design, fabrication, and operation of a mini-biogas digester using locally available materials in Nigeria. The digester is a 25-liter square round plastic jerry that is constructed of high-density polyethylene (HDPE) resin using an extrusion blow molding method. It can be made with an interlocking mechanism to ensure stacking safety. Additionally, it is made to prevent broken or leaked fermented material. It produced clean biogas suitable for cooking, offering a sustainable alternative to fossil fuels and contributing to reduced deforestation and greenhouse gas emissions.

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5.0 Recommendations

- Optimize digester design for increased biogas production: This could involve exploring alternative feedstocks, temperature and moisture control mechanisms, and improved gas collection and storage systems.
- Develop community-based dissemination strategies: To ensure adoption and sustainability, research efforts should focus on creating accessible training programs, establishing local production and maintenance networks, and fostering community ownership of the technology.
- Conduct comprehensive economic and environmental life cycle analyses. Assessing the full range of costs and benefits, including long-term environmental impact and cost savings compared to traditional fuels, will strengthen the case for widespread adoption.
- Investigate potential applications beyond domestic cooking: biogas can also be used for lighting, power generation, and agricultural purposes.
- Collaborate with stakeholders: Partnering with government agencies, NGOs, and private companies can facilitate funding, distribution, and technical support for successful implementation.
- Promote policy incentives: Advocating for government policies that incentivize renewable energy solutions can further encourage the adoption and scale-up of mini-biogas digesters.

By addressing these recommendations, this research can contribute to a wider transition towards sustainable energy solutions that empower rural communities, improve health and livelihoods, and mitigate climate change.

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