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The Design and Development of Environmentally Friendly Biogas Using an Anaerobic Digestion System

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Abstract: *Environmentally friendly biogas can be synthesized using an anaerobic digestion system that is based on the purification of the biogas with some reagents (iron flakes, silica gel, and yeast catalyst). The project design considers four phases namely, the digestion (fermentation) phase, the purification phase, the conservation and the test phase. In the fermentation phase, the decomposition and reaction of micro-organisms take place whereas in the purification stage. consists of three sub-steps, involving a container rich with silica gel, iron chips, and water for the removal of moisture,* CO_2 *and* H_2S *respectively, The conservation stage (the third phase) has an air chamber (tyre tube) for gas storage while the last [hase is the test phase which consists of a Bunsen burner to test the gas stored in the tube.*

Keywords: *Green energy*, b*iogas, biogas-digester, waste, Catalyst*

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1.0 Introduction

The energy crisis is becoming an unbearable challenge for most countries especially those that are not blessed with fossil fuel. Therefore, the world has needs for the supply of environmentally friendly and sustainable renewable energy at affordable prices (Ahamed et al., 2016, Lawal *et al*., 2021, Balesa *et al*., 2021). Biogas is a biofuel produced naturally from the decomposition of organic waste (Ellacuriaga *et al*., 2021). The main objective of using anaerobic digestion of organic material to produce biogas is to produce a renewable energy carrier that can replace fossil fuels (Li, 2022). Anaerobic digestion is a process that applies microorganisms to break down biodegradable materials in the absence of oxygen (Zamri *et al*., 2021). This process is widely used for the treatment of sewage sludge, industrial and agricultural waste because it allows a reduction in volume and mass of up to 50% of the input material and because it is also considered as an energy source renewable because the methane-rich biogas can be regarded as a close substitute for fossil fuel if properly purified (Zhen *et al*., 2017). Biogas is often referred to as "swamp gas" because it is produced by the same anaerobic processes that occur during the underwater decomposition of organic material (Kumar and Gupta, 2021) Biogas comes from bacteria in the process of biodegrading organic material under anaerobic (airless) conditions (Tamošiūnas *et al*., 2022). Biogas is a colorless, flammable gas which can used animal, vegetable, human, industrial and municipal and other wastes as feedstock (Mishra et al., 2021). The major composition of biogas include methane (50-70%), carbon dioxide (20-40%), and traces of other gases such as nitrogen, hydrogen, ammonia, hydrogen sulfide, water vapor (Awe *et al*., 2017). It is smokeless, more hygienic, and more comfortable to use than most solid fuels. The production of natural biogas is a crucial part of the biogeochemical carbon cycle (Fagbenle and Olukanni, 2022). Methanogens (methane-producing bacteria) are the last link in a chain of microorganisms that break down organic material and return the degradation products to the environment (Vladei *et al.*, 2021). Biogas can help achieve the European Union's target of reducing greenhouse gas emissions by 40% (Fagbenle and Olukanni, 2022). Generally, the efficiency of the biogas plant varies depending on the type of digester, the operating conditions, and the type of material loaded into the digester (Nkuna *et al*., 2021). The major economic advantage associated with biogas production is that the required feedstocks such as cow dung, water hyacinth, poultry waste, straws, weeds, leaves, human and animal excrement, industrial solids, and household waste and liquids are readily available.

In Nigeria, apart from small scale or experimental stages production, biogas technology is relatively stagnated. The first record of biogas technology in Nigeria dates back to the 1980s when a simple biogas plant capable of producing 425 liters of biogas per day was built at Usman Danfodio University in Sokoto (Sokan-Adeaga and Ana, 2015). As the global population continues to grow rapidly, while energy consumption and consumption are also increasing, there is an urgent intervention need to closely examine all technical steps required for commercial production of biogas as an effective substitute for fossil fuel.

2.0 Construction of Digester

The materials required for the construction of biogas digesters are readily available in the Nigerian market. The digester material should be airtight and able to withstand high temperature. The digester should be constructed to avoid leaks while consideration should be made to ensure that fluctuation weather conditions do not affects its operation. A typical assembly of a digester is shown in Fig. 1 shows the constructed biodigester

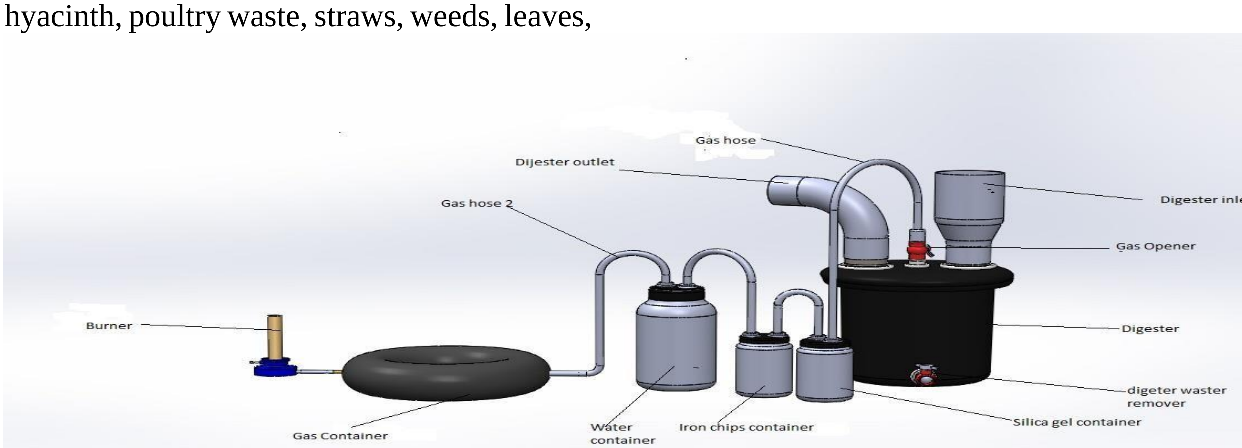

Fig. 1: Isometric view of assembled Biogas Digester showing its parts.

The digester was constructure using locally available materials such as a 25-liter bucket, PVC hose, and PVC rubber. The locally assembly digester has three holes on its rear with two of them having an average diameter of of 3 inches while that of the third was approximately equal to the diameter of a half-inch PVC pipe. The 3inch PVC pipe is cut in half, one longer than the other. And their end was tilted to an angle of 45°. The longer PVC pipe served as an inlet that passed through the hole drilled in the top directly to the digester and a funnel was used to pour the substrate (cow dung mixture) while the second PVC pipe served as the outlet which is located at half of the digestive. Also, the third hole is in the center of the top of the digester and a half-inch tube has been passed through the gas passage hole. PVC rubber can be was used to ensure a firm grip of the PVC pipe over the drilled holes and PVC rubbers were used to make the digester airtight as the clips were used to provide a firm grip of the pipe to the PVC to secure the tubes. Additional holes were drilled in the bottles containing silica gel and iron shavings and a tube was passed through them.

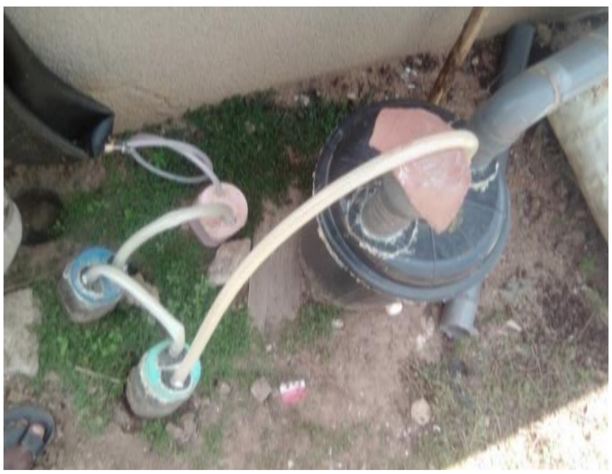

Fig. 2: Set-up for biogas purification.

Fig. 3: Set-up for catalyzed biogas

2.2 Operation of the Digester

Four liters of water (in a bucket) was used to mix 2 kg of cow manure in 2: 1 ratio. . 300 g of yeast was added as a catalyst to the reaction mixture (mixture of water and cow dung) to prevent the degradation of accelerated microorganisms in the substrate and make the reaction rapid. The substrate was cleaned in the digester after mixing, through the digester inlet, the gas passes through the gas pipe connected to the chamber that contain silica gel (moisture reduction) and to the chamber containing iron for CO_2 reduction. The partially purified gas was again passed through a water tank for the cleaning and H_2S reduction to occur before storage in in an inner tube of the tire. During the combustion test, the Bunsen burner was used to test the gas. The digester was in a clearing for 3 days with the required sunrise (30 °C). After the first 3 days, the preservation (tube) was observed, weighed with a balance, and recorded. The weighing continues every three days and upto one month to obtained sufficient quantity of biogas of was produced.

3.0 Results and Discussion

Table 1 displays the obtained data received directly from the experiment, the calculation formula, and the findings produced after the computations.

where, B is the volume of biomass (m^3/day) , W is the volume of water (m^3/day), V_T is the total volume of digester (m^3), V_0 is the operating volume (m^3), V_T is the total volume of the digester, r_d is the cylindrical radius of digester (m), h_d is the height of the digester (m), V_c is the volume of the gas collecting chamber, V_{gs} is the volume of gas storage chamber, Vs is the volume of sludge, V_H is the volume of the hydraulic chamber, V_f is the volume of fermentation chamber and G_h is the gas produced in an hour (m^3/hr)

Table 1: Results obtained and formula used for the calculation of the respective parameters .

Initial Data	Calculation	Results
ρ_{cd} **= 650kg/m^3**	**Operating volume of digester**	B = 0.0077
m_{cd} **= 5kg**	$V_o = S_d * RT$	W = 0.0154
	$S_d = B + W$	
W = 2B (2:1)	B = mcd/Pcd	
	B = 5/650	$S_d = 0.023m^3$
	S_d = 0.0077 + 0.0154 = 0.0231m^2	
S_d **= 2:1**	$V_0 = S_d * RT$ = 0.023 *1 = 0.023	
		$V_0 = 0.023m^3$
	Digester working dimensions	$V_T = 0.0288m^3$
	$V_o = 0.023m^3$	r_d=235mm
RT = 1day	$V_o = 0.8V_T$	
	V_T = Vo/0.8 = 0.0288m^3	
h_d **= 3rd**	VT = πrd^2hd	
	rd = $^4\sqrt{VT/\pi(3)}$ = 0.2351m	
	$h_d = 3r_d^2$ = 3*0.2351 = 0.7053	
	Hourly gas production of the digester	h_d =705mm
m_{cd} **= 5kg**	G_h = m_{cd} * 0.03/45*24 = 5*0.03/45*24	G_h = 0.000138m^3/hr
	G_h = 0.000138m^3/hr.	

Two biogas set-ups were employed under the following conditions:

(i) When purification was done on the gas collected.

(ii) When catalyst (yeast catalyst) was applied to hasten the period for gas production.

Equation for the removal of hydrogen sukphide from the produced gas is given as

$$Fe_2O_3 + 3H_2O \rightarrow Fe_2S_3 + 3H_2O$$

The equation shows that the product of the reaction of iron oxide and H_2S produces iron oxide and water. The pink color of the silica gel was observed to change to white, which indicated that moisture was adsorbed. , Water vapor is the main risk factor for corrosion when it reacts with H_2S, producing acidic H_2S. The color of the silica gel changed from pink to white after absorbing the water vapor from the raw biogas. A decrease in moisture content was noted as the amount of silica gel increased. In the second setup, we determined the rate of gas production when 0.2 kg of yeast catalyst was used and the results obtained indicated that the weight of the pipe increase from 3.29 N to 3.43 N which gives a difference of 0.14 N (mass = 0.014 kg) and a volume of 0.012m^3.

Figure 4: Image of the Tube after 7 days

4.0 Conclusion

The digester has been successfully designed and built and the construction is done with materials available locally in the workshop. The tested digested produces reasonable quantity of biogas and was effective in the removal of mixture, hydrogen sulphide while the study has strong potential to serves as a good organic fertilizer. The material used for the digester must be airtight. For the construction of the digester, fabricated metal should preferably be used to avoid losses. The use of highly adhesive material for the joints to make them airtight and to provide a drainage system at the bottom of the digester for easy disposal of sludge.

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This work was carried out in collaboration among all authors. Authors K. A Bala, Ogunlana Yusuf Olayinka initiated the work and sourced all the relevant journals for the review. Maryam Aliyu and K. A Bala performed all the analysis of the work. All authors took part in the compilation of results, proof reading and effecting all corrections. All authors read and approved the final manuscript.