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# Innovative Designs in Household Biogas Digester in Built Neighbourhoods

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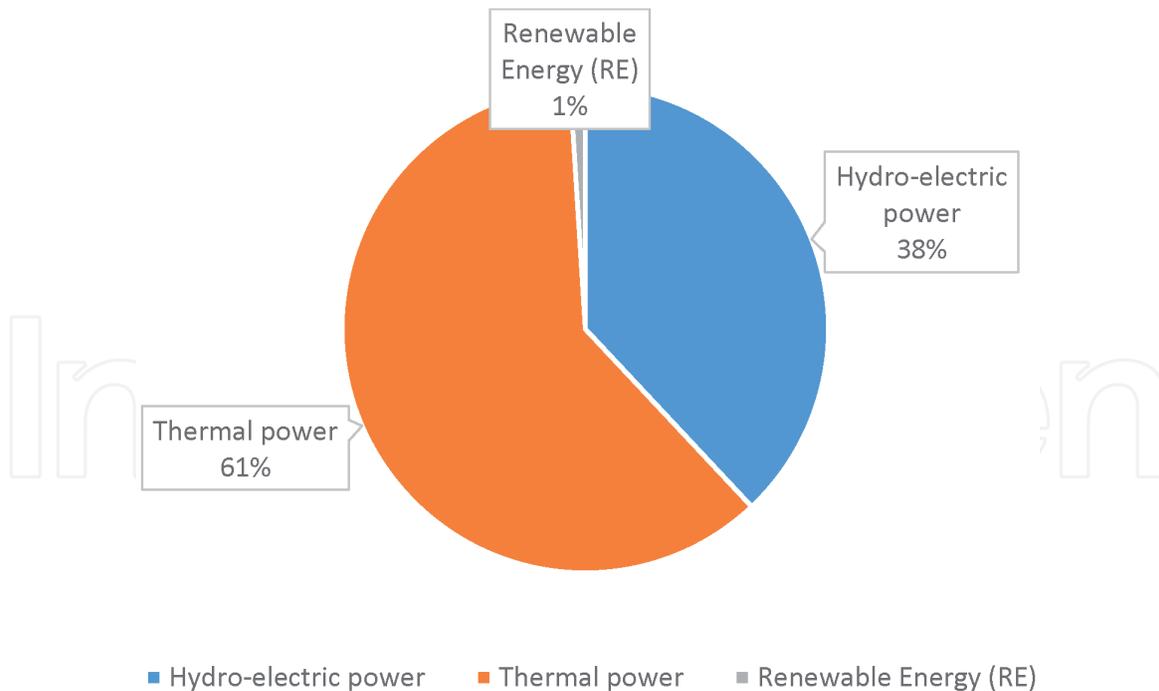
## Abstract

Most household biogas digesters operate on continuous automatic stirring modes. Often, these digesters rely on electrical energy for their continuous operations which are often mesophilic. Rarely do manually-stirred discontinuous household biogas digesters operating on hyper-thermophilic conditions exist. This work seeks to highlight some innovative designs in a household biogas digester piloted in Terterkessim slum in the K.E.E.A. Municipality of the Central Region, Ghana. A pyramidal dome-shape biogas digester was constructed on an abandoned septic tank using blocks and concrete. The digester has a rectangular sub-surface base and a pyramidal gas holder above the surface of the soil. The digester has a two-blade manual stirrer, a ball bearing affixed at the bottom and a handle to manually mix the content of the digester. In order to heat the content of the digester to a hyper-thermophilic condition for hygienising the digestate, a solar-photovoltaic was installed on the roof of a toilet connected to the household biogas digester.

**Keywords:** Solar photovoltaic, manual stirrer, hyper-thermophilic, household, biogas digester

## 1. Introduction

In Sub-Saharan Africa and especially Ghana, the use of renewable energy such as biogas is highly under-developed [1] thus accounting for the country's over-reliance on natural gas and other fossil-based fuels for electrical power generation [1]. It is, therefore, very crucial for Ghana to expand the production of renewable energy such as biogas from food wastes, black water (BW) (waste water comprising human faeces, urine and flush water) for both industrial and household consumption. Consequently, coming up with an innovative and good technological design for household biogas production is very imperative. The choice of the type of reactor and the innovative designs that can be made for efficient technological processes of a household biogas digester in a built is crucial. This is because of the financial repercussions for the citizens (for example, affordability) and its technical complexity for operation and maintenance. In addition, the efficiency and the applicability to the populace especially, in a developing country like Ghana are some of the reasons the choice of a particular innovative design cannot be overlooked. In Ghana, different energy mix is used for various applications such as domestic/residential, non-residential and other industrial facilities (**Figure 1**) [2]. The greatest



**Figure 1.**

Percentage contribution of different energy sources used in Ghana. NB: Renewable energy (RE) in Ghana comprises solar energy, energy from biogas, wind energy and biomass energy.

percentage of the energy generation in Ghana is from thermal energy source (61%), followed by hydro-electric power (38%) and 1% making up renewable energy sources such as biogas, solar energy, wind energy and biomass [2].

Different treatment technologies such as Membrane Bioreactor (MBR), Anaerobic Membrane Bioreactors (AMBRs), advanced fluidized bed (AFB) reactors, EGSB and IC® [3] and UASB reactor [4], continuous stirred tank reactor (CSTR) [5] fixed-dome biogas digester (Deenbandhu type) [6, 7] have already been used for biogas production using different substrates and treatment parameters. However, most of these digesters, even though may be modern, did not incorporate other innovative designs that will make them affordable, less technically complex, efficient and easily applicable. This work seeks to address some of these innovative technological missing gaps for easy adoption and implementation, especially, by households in tropical developing countries.

However, single-stage systems are considered to be simple, easy to design and less expensive to be constructed and operated making them common in the anaerobic treatment technology applications [8, 9] Considering small scale anaerobic treatment systems, single-stage reactors have been often used compared to large scale reactors (with a capacity of more than 50 000 tons/year) that use multi-stage systems [7]. According to [7], a fixed-dome (Deenbandhu type) is a closed-dome shaped digester which has an immovable rigid gas-holder. It has an influent inlet and a displacement pit called the compensation tank where the effluent and the digestate exit the reactor. The gas holder is designed to be on top of the digestate in the reactor. With a closed gas valve, higher production of biogas could cause a displacement of the digestate into the compensation tank [6, 7].

The choice of a fixed-dome biogas digester plant for the pilot-scale study in this research for the treatment of household BW in Terterkessim slum in Elmina - Ghana, is based on the following reasons: the user interface is directly connected to the biogas digester [6], the digester can work with or without urine, the reactor can be built underground protecting it from temperature variations [7] and also implies little space is required (making it feasible in a densely

populated area like a slum) [6]. Other advantages include: the reactor functions on a wide range of organic input such as animal manure, kitchen waste and BW. Thus, co-digestion would be done to enhance biogas production. It also supports pour flush toilet system (less water used – concentrated BW, higher biogas production), surrounding soil help to counter the in-built pressure in the reactor, moderately not expensive (the use of local materials and labour), has a life span of between 15 to 20 years as there is no corrosion [7].

## 2. Location for the construction of household biogas digester

The household biogas digester was constructed in Terterkessim slum in Elmina, a coastal town and the administrative capital of the Komenda Edina Eguafu Abirem (K.E.E.A.) Municipality of the Central Region of Ghana [10]. Elmina is bordered to the South by the Gulf of Guinea, West by Bantoma, East by Abakam and North by Bronyibima townships [10]. Elmina lies within latitudes  $5^{\circ} 05'$  North and  $5^{\circ} 60'$  North and longitudes  $1^{\circ} 20'$  West and  $1^{\circ} 22'$  West (**Figure 2**). The town is one of the biggest fishing hubs of Ghana and thus, the major occupation in the town is fishing. The presence of Brenya lagoon, which stretches and overflows (during high tides) to Terterkessim slum, has also made some of the inhabitants to be involved in salt production at commercial quantities. Temperatures are generally high with average being  $27^{\circ}\text{C}$  and annual rainfall ranging between 750 mm to 1000 mm. The vegetation are mostly shrubs and grasses [10]. The town has a total population of approximately 34000, of which about 7600 of the Inhabitants live in Terterkessim slum where the household biogas digester was constructed (Personal Communication with Mr. Dampsey- K.E.E.A. Municipal Environmental Health Officer, 2016).

The construction of a household biogas digester connected to a household toilet facility was imperative to help curb the issue of open defecation in the slum due to



**Figure 2.** Map of Ghana showing the district map of the study area, Elmina. Source of the map: Adade, F. (2016). GIS, Department of Fisheries and Aquatic Sciences (DFAS), University of Cape Coast, Cape Coast-Ghana.

lack of public toilets in the community. In addition, the only available toilet facility in the community was in a very bad state. Furthermore, most individual households in the Terterkessim slum do not have household toilet facilities, thus giving the residents the impetus to defecate in the open gutters, lagoon and even in and around the salt ponds. Thus the construction of a household toilet facility connected to a biogas digester with innovative designs for both biogas production and disinfection of digestate was imperative for the Terterkessim urban slum in Elmina.

## **2.1 Innovative designs for household biogas digesters**

The household biogas digester was constructed on an abandoned septic tank thus, it received a lot of modifications to enhance its functionality and efficiency. The innovative designs introduced in the household biogas digester constructed included construction of pyramidal-dome-shape biogas digester, introduction of pour-flush water closet (WC) toilet seats and introduction of manual stirrer in the digester. Other innovative modifications in the household biogas digester built in Terterkessim slum included, adoption of solar photovoltaic to heat the digester to a hyper-thermophilic condition and co-digestion of BW and kitchen food wastes will be highlighted.

## **2.2 Construction of pyramidal-shape biogas digester**

A single-stage household biogas digester was constructed with 6-inch-blocks (moulded sand, cement and water), reinforced with concrete material and plastered with mortar. The concrete material was made of 10 head pans of quarry sand, 10 head pans of 0.5-inch stones (igneous type), 2 bags of rapid strength Portland cement and 10 L of tap water. Additional mortar and water-proof cements like FEB TANK (UK) were used to stop all water leakages into the reactor chambers. The mixture of the mortar was 1 bag of Portland cement (50 kg), 6 head pans of quarry dust, 1 head pan of eroded sand and 2 kg of waterproof FEB TANK cement. About 10 L of water was added and homogenised into a thick paste of mortar for the reinforcement of the weak walls and floor based on the specifications by the manufacturer of the FEB TANK waterproof cement.

The reactor was a modified form of a circular fixed-dome biogas digester with the circular dome modified into a pyramidal-shape roof for biogas storage. The pyramidal shape roof was done instead of the circular dome because the base of the reactor was rectangular, consequently, a pyramidal shape roof on the rectangular base would ensure airtightness. This was because the rectangular base had corners which a circular dome shape could not perfectly fit on without leakages. Ten pieces of 14-ft Wawa wood of dimensions 2-in by 4-in as well as 15 pieces of 14-ft Wawa wood of dimensions 2-in by 2-in were used for the construction of the gable of the pyramidal dome shape of the biogas digester fastened with 3-in concrete nails. The skeletal structure of the pyramidal-shape roof of the biogas digester was covered with 5 pieces of ¼-plywood. A black thick polythene bag was used to cover the plywood before the concrete layer was formed on the reactor (**Figure 3**). The 6-in (15.24 cm) concrete layer for the roof of the SSHTABD was made of 15 pieces of 0.6-in (1.5 cm) diameter iron rods, 1.5-in (3.8 cm) diameter stones (igneous type) and sand (both coarse and fine). A manual stirrer with four (4) galvanised metal blades of dimensions 15 cm by 30 cm each was affixed into the household biogas digester (**Figure 4**). The rotating metal rod of the stirrer was welded into two ball bearings (one affixed to the bottom of the concrete and the other at the top of the metal rod just beneath the pyramidal shape) to enhance easy rotational movement when manually stirred.



**Figure 3.**  
*Construction of a pyramidal-shape biogas digester insulated with black polythene bag.*



**Figure 4.**  
*Manual stirrer in the biogas digester.*

### **2.3 Pour-flush water closet toilet**

Two pour-flush water closet (WC) toilet seats were installed in each of the toilet unit connected to a household biogas digester (**Figure 5**). Polyvinyl chloride (PVC) pipes of diameter 4-inches were connected to the toilet seats and into the main chamber of the digester. Adjoining pipes from the WC into the digester were



**Figure 5.**  
*A 3-litre pour-flush toilet seat connected to the biogas digester.*

connected using 4-inch Tee, 4-inch 45° and 4-inch 90° pipes. The influent pipe was inserted into the reactor to a depth of 450 mm above the floor of the reactor. This was done to ensure that the influent fully covered the pipe to avoid any biogas leakage through the influent pipe. An inlet pipe with a cover was also connected to the influent pipe carrying faecal materials to enhance co-digestion processes (**Figure 6**).

#### 2.4 Manual stirrer

Most biogas digesters that operate in a continuous mode and use stirrers that rely on electrical energy for stirring the digesters. In this design, a manual stirrer was introduced into the household biogas digester for discontinuous stirring by the users in the household. The users were educated and trained to manually stir the digester anytime they visited the toilet. In this way, it was ensured that the old and new feedstock would easily mix to enhance faster digestion. The manual stirrer with four (4) galvanised metal blades of dimensions 15 cm by 30 cm each was affixed into the household biogas digester. The rotating metal rod of the stirrer was welded into two ball bearings (one affixed to the bottom of the concrete floor of the digester and the other at the top of the metal rod just beneath the pyramidal shape) to enhance easy rotational movement when manually stirred (**Figure 4**).

#### 2.5 Installation of solar-photovoltaic for heating the digester

A high quality 50 W offgridtec® autarkic mono photovoltaic panel of dimensions 60.5 cm x 47.5 cm (0.3 m<sup>2</sup>) was installed on the roof of the toilet connected to the SSHTABD for heating. The photovoltaic panel was offgrid with model number 3-01-001260 and had a voltage of 22.3 V (made by offgridtec® AGM GmbH, CMK ENERGY, Germany). The photovoltaic panel was connected to a solar charge controller (Stecca PR1010 756.477 by Solar Electronics, PV offGrid, PV Autarke



**Figure 6.**  
*Pipe connections from the pour-flush toilet into the innovative household biogas digester.*

systeme, made in EU) via solar cables. The charge controller was connected to a 12 V/30 A/20 Hours offgridtec AGM gel battery series (by offgridtec AGM GmbH, Germany). The battery had a constant voltage charge and voltage regulation with cycle use of 14.5–14.9 V at 25°C and standby use of 13.6–13.8 V at 25°C. The battery was connected to an NP series pure sine wave inverter (Model number NP 300, made by Solartronics, Leipzig-Germany) which had a maximum peak power of 600 W and an average current of 300–400 W. It also had an input voltage of 12 V and an output voltage of 230 V - 50 Hz and efficiency of 84–94% (**Figure 7**).

## **2.6 Installation of galvanised copper pipes into kitchen**

Galvanised copper pipes were used to connect the SSHTABD to the kitchen of the household where potential biogas to be produced was to be used. The copper pipes had diameter of 2 cm. Stop corks or valves were installed at adjoining points to regulate the flow of biogas into a biogas bag to monitor the daily biogas production. The copper pipe was laid into the walls of the restroom to the kitchen at an angle of 45° in order to ensure that all water vapour that could form during the operation of the SSHTABD would trickle down by gravity into a collection tube to be discharged (without losing biogas from the reactor) (**Figure 8**).



**Figure 7.**  
*Components of solar-photovoltaic system installed on the biogas digester.*



**Figure 8.**  
*Installation of galvanised copper pipes for tapping biogas into kitchen.*

## 2.7 Detailed description and performance of innovative household biogas digester

The single-stage innovative household biogas digester constructed in Terterkessim slum composed of 3 chambers which were originally designed for a septic tank system. The septic tanks were connected to a two-unit toilet meant for that household. The first chamber was the biggest and was converted into the main single-stage household biogas digester in which the AD process occurred. It had a total volume of  $8.64 \text{ m}^3$ . Adjoining the main reactor was a compensation tank which had a tunnel from the main digestion chamber. The compensation tank was about  $3.17 \text{ m}^3$ . Within the compensation chamber were steps designed to help with settling of particles as well as directing clear effluent to be discharged into the next chamber, the effluent collection and storage tank. The effluent collection and storage tank had a total volume of  $4.52 \text{ m}^3$ . It had an effluent discharge pipe for overflow into a collection container for agricultural usage. An average COD removal of 97.6% was recorded for the digester. The operational parameters for the innovative household biogas digester were a mean temperature of  $37^\circ\text{C}$ , average daily flow rate of 182.1 L/d and mean HRT of 51.3 days. The mean daily volumetric loading rate and mean daily organic loading rates of  $0.97 \text{ kgCOD}/(\text{m}^3\cdot\text{d})$  and  $0.06 \text{ kgVS}/(\text{m}^3\cdot\text{d})$ , respectively, were also recorded for the digester. These operational values for the biogas digester gave an implication the digester had more potential of receiving more organic load for treatment daily. The digester could produce about  $2.52 \text{ Nm}^3\text{CH}_4/(\text{kgCOD}\cdot\text{d})$  which could be burnt for at least 8 hours for purposes such as cooking and heating in the households in the slum. This high value was recorded because of the simultaneous conversion of food waste and human faeces into biogas.

### **3. Conclusions**

Manually-stirred discontinuous household biogas digesters which also operate on hyper-thermophilic conditions for anaerobic digestion processes rarely exist. In this study, the objective was to highlight some innovative designs in a household biogas digester piloted in a slum called Terterkessim in the K.E.E.A. Municipality of the Central Region of Ghana. A 2-seater toilet compartment was constructed on a pilot manually-stirred, fixed pyramidal-dome-shaped single-stage household biogas digester for a compound house of 32 persons in the Terterkessim slum. The pyramidal dome-shape biogas digester was constructed on an abandoned septic tank meant to contain faeces from the toilets. Blocks and concrete were used for the construction. The digester has a rectangular sub-surface base and a pyramidal gas holder above the surface of the soil. It also has a two-blade manual stirrer, a ball bearing affixed at the bottom and a handle to manually mix the content of the digester. A solar-photovoltaic was installed on the roof of the toilet connected to the digester to heat the content to a hyper-thermophilic condition for hygienising the digestate.

The innovative household biogas digester has a potential to produce about 2.52 Nm<sup>3</sup>CH<sub>4</sub>/(kgCOD.d) which could be burnt for at least 8 hours for purposes such as cooking and heating in the household. With average daily flow rate of 182.1 L/d and mean HRT of 51.3 days, 97% of the influent was removed. Consequently, this innovative household biogas digester can be employed in already existing residential facilities or new residences for wastewater treatment at the household level and energy recovery from the waste.

### **Acknowledgements**

We wish to acknowledge the contributions of all laboratory and technical staff of the School of Agriculture laboratory in the University of Cape Coast Technology Village for their immense contributions during the laboratory analyses.

### **Conflict of interest**

“The authors declare no conflict of interest.”

### **Notes/thanks/other declarations**

We declare that the information provided in this Book Chapter form part of the data and work obtained by the corresponding author of this scholarly work and needs no copy right declaration. In addition, the authors wish to declare that the research was not funded by any organisation.

We wish to thank all labourers and artisans who supported with the construction of the household biogas digester.

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