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Design and Fabrication of a Domestic Biogas Unit for Cooking Applications

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ABSTRACT

This paper presents the design and fabrication of a domestic biogas unit by using daily organic waste for cooking. Basically, this unit consists a gas storage unit and a digester barrel. Initially, the organic wastes including kitchen wastes were deposited into the digester barrel which contains water with pH 6 once in every two days for two weeks. Then the mix started to produce biogas when the pH value reached around 6.8-7.5. After that food wastes were added slowly every day. When this step is continued further, the daily collection of biogases is 50 liters. As the digestate of this anaerobic digester is rich in nutrients this is also a good organic fertilizer for plants in the home garden. Also, this unit is designed and fabricated with easy maintenance and usage. Further, it is very much beneficial to dispose biodegradable kitchen wastes in an eco-friendly manner. In order to answer the energy demand in domestic level, it is highly essential to utilize the daily organic waste as a source of energy and produce methane as an alternative solution for cooking-energy requirement.

1. Introduction

The demand for energy is growing 6% per year in Sri Lanka and this leads to the search for alternative energy sources. Though many countries are planned to achieve carbon neutrality before 2050, Sri Lanka is forecasting to rise renewable energy capacity to reach the carbon neutrality by 2050 [1]. In this sense, Biogas is very much essential and an efficient economic way of gaining domestic renewable energy for rural communities as well as farmers [1,2]. However, the usage of bio gas is comparatively small considering with electricity from diesel generators and hydro power systems as well as petroleum products [3]. The domestic cooking in rural areas primarily uses wood as shown in Figure 1 and this leads to the serious health problems mainly for women. However, biogas is a clean fuel because it doesn't leave any dust or particulate matter during the combustion. Further, it is lighter and hence this releases less amount of carbon dioxide to the atmosphere during the burning [1,3,4].

Biogas is generated from biodegradable waste which is putrid into carbon dioxide, water, methane or simple organic molecules by the action of micro-organisms within a small time [5-9].

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Presently, the per capita solid waste generation level in Sri Lanka varies from 0.2 kg -1.7 kg per day [10,11]. On the other hand, these biodegradable wastes are the major component of municipal solid wastes and its accumulation in landfills is challenging and causes many ecological problems [12]. However, landfilling is also leading several environmental impacts owing to the release of leachate, methane and carbon dioxide and other pests. Leachate would also pollute underground water and soil along with the release of methane [4,12,13]. Further, using this solid waste as a potential source for the production of sustainable fuels complete the full cycle of this waste stream sustainably and thus, directly support and facilitate the concept of the circular economy as well [12].

Though there were several biogas units developed previously these units have several drawbacks during the construction and implementation. Particularly these units have the lack of facilities to construct in household level. Further these units were not safe and cost effective for domestic applications. However, it is very much essential to introduce sustainable biogas system to the domestic market to gain cooking gas and organic fertilizer. This particular unit presented in this paper has several advantages like easy construction, safe and cost effective in domestic level. Hence, promoting this kind of small-scale biogas units would be highly valuable.

Fig. 1. Current methods of cooking in domestic sector [1]

1.1 Process of Making Biogas and Its Composition

Bio gas is generated through anaerobic digestion which is named as a biological process which converts biodegradable wastes into methane, carbon dioxide, hydrogen sulphide and gases in less percentage with the aid of microorganisms in the absence of oxygen [6,9,14-16]. The composition of biogas is illustrated in Table 1 [6,9,14]. During the anaerobic digestion process, initially the feed stock is collected by the anaerobic digester for the pre-treatment to increase the bio gas yield. Then this feedstock is sent to the digester. Finally, the bio gas is filled in gas storage units and the byproduct is collected separately as shown in Figure 2.

Table 1
Bio Gas Composition [14,17-19]

Compound	Vol%
Methane	50-75
Carbon Dioxide	25-50
Nitrogen	<7
Oxygen	<2
Hydrogen Sulfide	<1
Ammonia	<1

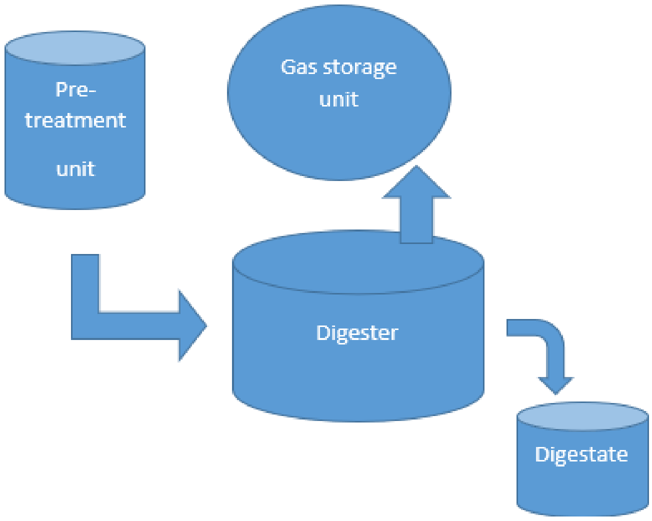
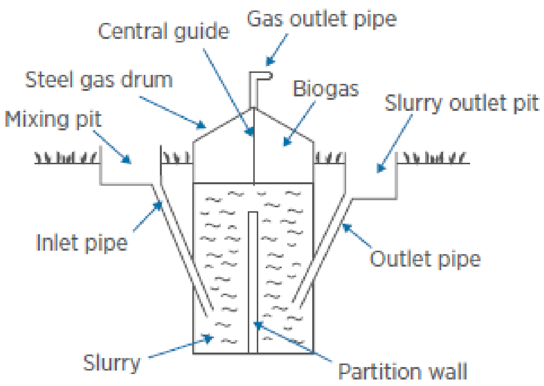


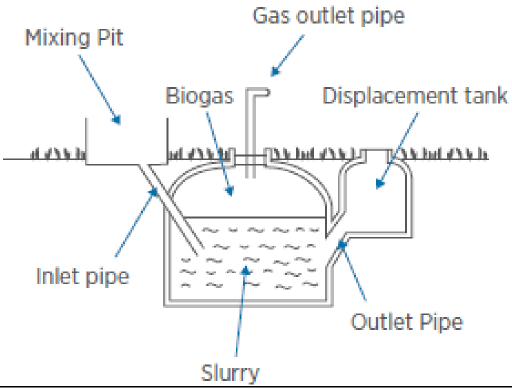
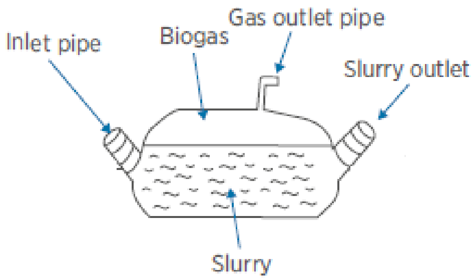
Fig. 2. Anaerobic digestion process

1.2 Available Technologies in Biogas Production and Collection

Though there are various technologies widely used in the production and collection of bio gas. Floating drum plant, Fixed dome plant and balloon/gas digester are some of the important techniques. Table 2 explains the prevailing bio gas production technologies [14,17,18].

Table 2
Prevailing bio gas production technologies [14,17-21]

Type of Technology	Description	Regional deployment
Floating Drum model 	This model consists two components named as underground digester and a moving gas-holder. Here, the gas is collected in an upright located gas drum which escalates according to the amount of gas presented [14]. In this model the drum collecting the biogas has a guide frame internally or externally. This frame keeps the drum upright and provides stability too. In this case the drum is moving up during the production of bio gas and this comes down during the consumption. The constant pressure gas is obtained in this model [14]. In this model, the volume of the gas stored would be easily identifiable through the observation of the drum position. Though this model is simple, there are some drawbacks. The steel drum is moderately expensive and maintenance is essential. Also, regular rust removing and painting is necessary. The life time of this model is also short	India

Fixed- dome Model  	It consists of an inlet compartment annexed with the digester which is enclosed by a dome shaped unit attached with the gas outlet pipe. An outlet from the digester can be fed into a compost unit to get fertilizer. This model is popular and this has lesser problems comparing with floating drum model. But Continuous flow fixed dome biogas systems are widely used in Sri Lanka animal dung and human excreta. In this model, there is a necessity to feed the input daily if there is a daily requirement [4]	Developed in China and employed in diverse developing countries like India, Nepal, Uganda and Tanzania
Balloon/Bagdigester  	This unit comprises a plastic bag connected with an inlet in order to introduce the feedstock. The slurry is extracted by the outlet. The bio gas is released through the outlet pipe on top of the bag	Developed in Latin American countries and employed in Africa and South Asian Countries

1.3 Limitations of Prevailing Technologies

According to the survey, there are about 369 biogas systems are available in Sri Lanka. Further, the survey reveals that nearly 30% of the biogas systems are functional and 70% of the household biogas systems are not in mobilization. This is happened due to the lack of knowledge, lack of credit facility, lack of extension work, high initial cost and low output, the usage of this biogas unit is declined. Therefore, developing a domestic biogas unit for cooking with very simple technology is highly motivated.

1.4 Factors Effecting Bio Gas Production

While designing small scale Anaerobic digester for domestic environment for treatment of organic waste, it is highly recommended to consider the factors like characteristics of waste, environmental, social, technical and economic conditions. Since the temperature, Ph value, retention time and composition of food waste are some of the most important factors they are described clearly with their operating conditions.

1.4.1 Temperature

Operating temperature is highly considerable feature when deciding the performance of the anaerobic digesters because it is an essential element for the existence of microorganisms. In addition to this the bacteria have two optimal temperature ranges, called mesophilic and thermophilic. The operating temperatures of mesophilic and thermophilic digesters are 25 - 40 °C and 50-65°C respectively. Thermophilic digesters permit higher rate of loading and produce higher amount methane. Due to the higher temperature, the retention time is less because of the reaction of degradation is very fast. Nevertheless, the thermophilic bacteria are highly sensitive to contaminants and environmental changes. Due to the additional energy requirement for self-heating, it is not that much suitable for commercial requirements [1,9,19-23].

1.4.2 pH Value

Though the micro -organisms need alkaline environment the recommended pH value is 7.0-8.0. The ratio of acidity and alkalinity and the carbon dioxide content decides the pH inside biogas digester. The concentration of volatile acid measured by acetic acid should be below 2000 ppm for the normal fermentation [25]. However, higher the concentration significantly inhibits the methanogenic action of micro-organisms [9,19-21].

1.4.3 Retention Time

The retention time in the anaerobic digesters is determined by the average time needed for decomposition of the organic material, measured by the chemical oxygen demand (COD) and the biological oxygen demand (BOD) of the influent and the effluent material [23]. In this sense, the substrate should be kept for a longer to reach the appropriate conditions of reaction [24]. However, the reaction rate declines with longer retention time. Basically, the required time depends on the type of feeding, environmental conditions and the use of the digested material [23]. However, the optimal retention time for complete biological conversion is, 12–24 days for thermophilic and 15–30 days mesophilic digester [19-26].

1.4.4 Composition of Food Waste

The exact requirement of the composition of food waste is a vital during the design of biogas unit to reach the efficient biomethanization. Because the biomethanization depends upon four main components like proteins, lipids, carbohydrates, and cellulose [24]. The maximum methane yields accompanying reactor having surplus of lipids but necessitates higher retention time. Further, the methanization is fast in the system containing excess of protein followed by cellulose and carbohydrates [24]. The component composition assessment of food waste from different origin with respect to the percentage of dry weight, the house-hold waste contains 60.7% carbohydrates, 14.4% proteins and 14.04% lipids [19-26].

2. Materials and Methods
2.1 Design of Model

Since this anaerobic bio gas unit is to be used for cooking in domestic level it is vital to design the parameters in an effective and efficient manner. As an initial step, the digester volume, height and width are designed by considering the maximum daily charge. Then the gas storage unit is designed by considering all essential factors. After that the inlet tube to digester is also designed. According to the conceptual designs, the optimal design parameters are proposed. Table 3 given below illustrates the design parameters and Figure 3 shows the proposed model of this biogas unit. In order to fabricate this unit in a cost-effective manner, the 55 gallons capacity of blue tight head High Density Poly Ethylene (HDPE) plastic drum with the wall thickness of 2.2 mm is chosen for the digester. On the other hand, the cylindrical gas storage unit is fabricated by using 1.5 mm thickness of sheet metal. The 35 mm diameter hollow steel pipe with the fins at the bottom end is attached to the gas storage unit to move up and down along the central shaft. Here, the fins are allowing to use the gas storage unit as a stirrer for the digester.

Table 3
Design parameters of the Biogas unit

Design parameters	Value
Daily production of bio gas V_o/(m^3/day)	8.746 X 10^{-3}
Retention time/(days)	15
Digester Volume V_d/(m^3)	0.1312
Diameter of the digester tank/(m)	0.5
Height of the digester tank/(m)	0.668
Volume of the gas holder V_g/(m^3)	0.765
Hydrostatic pressure on the walls of the digester P_h/(Kg/m^2)	229.8
Biogas inlet tube diameter/(mm)	110

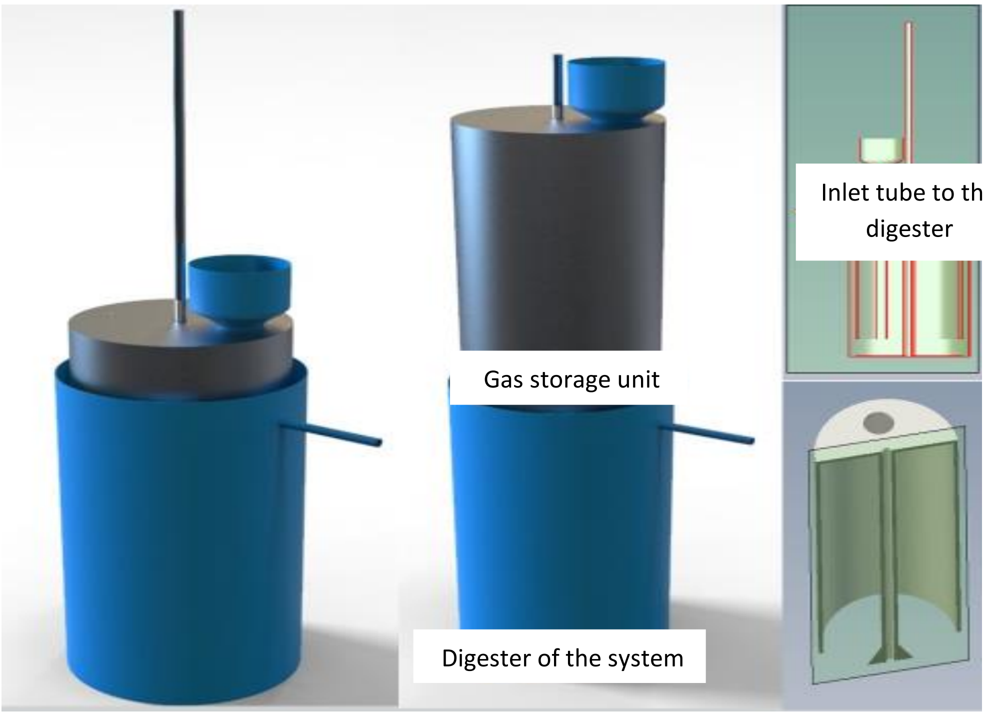


Fig. 3. Proposed model of the biogas unit

2.2 Implementation of the Model

As per the design parameters described, initially each and every sub component were implemented. Then these subcomponents were assembled to reach the entire system as illustrated in Figure 4.

Fig. 4. Implemented biogas system

3. Results and Discussion

In order to test and validate this fabricated unit initially water with pH 6.0 was added until ¾ of the digester. Then 2Kg of organic waste including cow dung and kitchen waste was mixed with 10 liters of water once in every two days, for two weeks. The Ph value of the effluent was tested frequently. When the pH value reached around 6.8-7.5, then the mix will start to produce biogas. After that food waste was added slowly every day. Then there are about 50 liters of biogas per day was collected. As per the interview with domestic users, this amount of biogas would be very much useful to save around 200 Sri Lankan rupees per day from other energy sources. On the other hand, the energy calculation reveals that, 1 m^3 of bio gas contains 1.83 KWh.

As per the test results and energy calculation, it is highly essential to improve the quality of the methane gas. Further research studies have to be carried out on microbiological actions on four processes of bio gas production and to analyze the feasibility of two stage bio gas production and its efficiency. Statistical research studies are highly recommended to analyze the BOD values of Sri Lankan waste content. In addition to this, it is necessary to regulate design standards for pits to be used in various waste categories like poultry, domestic and industrial wastes. Further, necessary steps have to be taken to analyze the feasibility for the construction and distribution of large-scale biogas plants.

4. Conclusion and Future Directions

Though the bio gas generation by biodegradable waste is a very old technique this would be a major energy source all around the world. But in the Sri Lankan context anaerobic digestion of kitchen waste in small scale digester tanks is feasible alternative to the other means of bio gas generation. Hence the proposed model is highly recommended due to the special characteristics like lower operating cost as well as fabrication cost and user-friendly etc. In addition to this organic fertilizer will also be produced as byproduct. Further, future improvements are highly essential to develop special stoves for methane and filling in a container in a safe way to promote in Sri Lankan domestic market.

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