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Designing a Low Cost Biogas Pressurizing System in Nicaragua

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Abstract

Plug flow biodigesters are popular in developing countries due to their low cost and ability to adapt to microclimates to produce biogas for cooking. These biodigesters are primarily composed of a polyethylene bag and PVC, and, typically, cattle or hog manure is used as both the organic and microbe source for gas production. The biogas is piped to a gas stove to be used for cooking. The digesters are intended to replace traditional wood burning stoves prevalent in developing countries, which are attributed to over two million deaths per year. However, due to pressure limitations due to the plastic bag, only 30 to 45 minutes of gas is available at a time, so diet staples, such as rice and beans, cannot be cooked. A low cost, effective solution to utilize more of the biogas was developed and tested on an existing plug flow biodigester in Nicaragua using PVC and plastic water bottles, which are widely available in the country. With the new system, beans were successfully cooked in less time using less water than the traditional wood stove. It also allowed for approximately four hours of gas to be used at one time. The system is cost effective because it would only add 8% to the overall price of the biodigester if the system were installed at the same time as the biodigester was installed and 16% if it was sold as an aftermarket add-on. In the long term, this system would save money for the user because they would be able to spend more time working instead of collecting firewood.

Keywords

biogas, international, development, cooking, pressure

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Abstract. *Plug flow biodigesters are popular in developing countries due to their low cost and ability to adapt to microclimates to produce biogas for cooking. These biodigesters are primarily composed of a polyethylene bag and PVC, and, typically, cattle or hog manure is used as both the organic and microbe source for gas production. The biogas is piped to a gas stove to be used for cooking. The digesters are intended to replace traditional wood burning stoves prevalent in developing countries, which are attributed to over two million deaths per year. However, due to pressure limitations due to the plastic bag, only 30 to 45 minutes of gas is available at a time, so diet staples, such as rice and beans, cannot be cooked. A low cost, effective solution to utilize more of the biogas was developed and tested on an existing plug flow biodigester in Nicaragua using PVC and plastic water bottles, which are widely available in the country. With the new system, beans were successfully cooked in less time using less water than the traditional wood stove. It also allowed for approximately four hours of gas to be used at one time. The system is cost effective because it would only add 8% to the overall price of the biodigester if the system were installed at the same time as the biodigester was installed and 16% if it was sold as an aftermarket add-on. In the long term, this system would save money for the user because they would be able to spend more time working instead of collecting firewood.*

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Introduction

The dangers of wood burning stoves used for cooking have been demonstrated across the globe for many decades (Ezzati and Kammen, 2002). For instance, Ezzati and Kammen (2001) found that the incidence of acute respiratory infections increased with an increase of particulate matter above 10µg. Boy et al. (2002) found that mothers, who cook on an open flame or on a wood stove with a chimney, gave birth to children with lower mean birth weights than those mothers who cooked using electricity or gas. Yet, millions of people still use them every day because it is their only option for cooking food. There are still an estimated two million deaths per year that can be attributed to cooking with wood stoves, most of which are associated with cooking with wood stoves that do not have chimneys or proper ventilation (Bock and McGrath, 2011). One contributing factor to the continuing use of wood burning stoves is the low cost. Other than the lost cost of labor, many consumers are able to cut trees for fuel free of charge, which negatively impacts the environment.

One option for reducing environmental and health impacts at a low cost that has gained recent popularity is the use of biodigesters. Biodigesters are vessels composed of varying materials that are able to convert animal, human or other household wastes to biogas and fertilizer through anaerobic digestion (das Neves et al., 2009). There are several types of biodigesters that are utilized in developing countries. Examples of household-scale biodigesters include fixed dome biodigesters, floating drum digesters, and plug flow digesters (Rajendran et al., 2012). This paper will focus on the plug flow biodigester, which has become popular in Central and South America due to its low cost and easy adaptation to the microclimates of high elevations (Rajendran et al., 2012). The non-profit Emerging Opportunities for Sustainability (EOS) markets plug flow biodigesters in Nicaragua for approximately $150.

The plug flow biodigester (Figure 1) is typically made from a six millimeter polyethylene bag that has a manure inlet on one end and an outlet on the other. The gas leaves the digester through a PVC pipe in the middle of the bag, which is routed to a stove top in the kitchen. There is a pressure release valve composed of a water column in a plastic bottle in the PVC between the biodigester and the kitchen. The valve inhibits the biodigester from exceeding approximately 0.15 PSI to prevent the plastic bag from exploding if the pressure becomes too high.

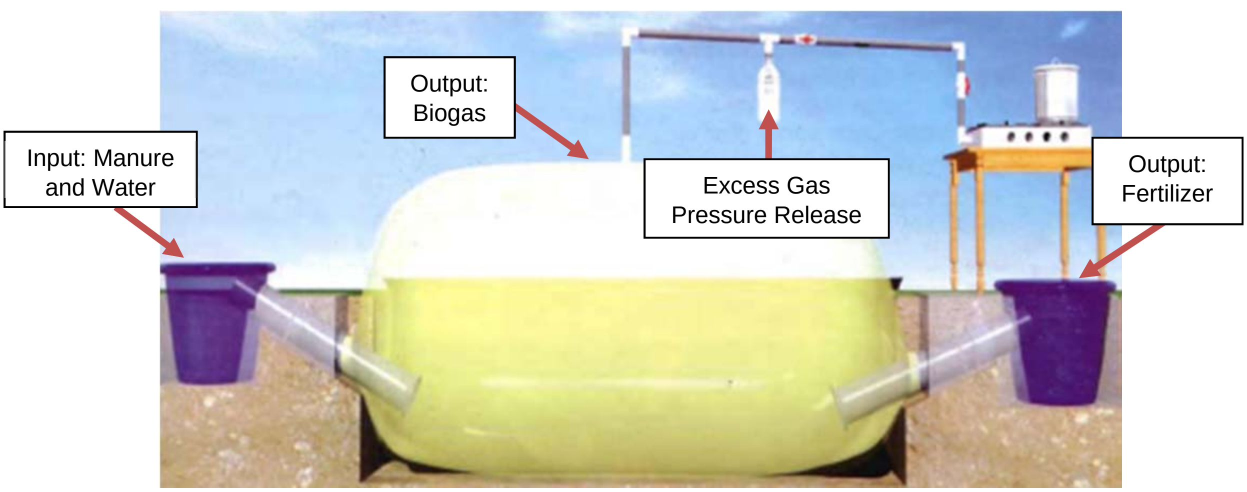

Figure 1: Functional diagram of a plug flow biodigester

One of the drawbacks of this design is the lack of pressure control. The density of biogas is similar to the density of air. Depending upon the composition, the density of biogas can range from 1.18 kg-m^{-3} to 1.21 kg-m^{-3} (Naskeo Environnement 2009). The density of air ranges from 1.16 kg-m^{-3} to 1.20 kg-m^{-3} at the typical temperatures (20-30^{o}C) found in Nicaragua (Munsen et al., 2009). Thus, biogas inside the biodigester will only escape when the pressure inside the bag is greater than atmospheric pressure. Once the pressure has equalized, the gas pressure is insufficient to sustain a flame to cook. At this point, the user must use the wood stove for the remaining of their cooking needs.

Currently there are no pressure increasing solutions used with the EOS biodigesters in Nicaragua; however other solutions have been implemented in other countries. A biodigester manual written by An et al. (1997) to be used in Vietnam utilized a three millimeter polyethylene reservoir bag placed in the kitchen with a string tied around it to increase the pressure. Storing a large amount of biogas within a house is not safe since a gas leak could potentially lead to asphyxiation. Also, there is a potential for explosion if there is an open flame near the bag. Work by Lansing et al. (2010) used additional cylindrical polyethylene bags above the digester to store extra gas in Costa Rica. However, with the biodigesters in Nicaragua, the issue is not insufficient gas volume but gas utilization. Thus, a different pressure increasing solution needed to be designed for effective biogas utilization in Nicaragua.

The objective of this paper is to demonstrate a safe, cost effective system to increase gas pressure for cooking with a plug flow biodigester, so this technology can more effectively replace the wood burning stoves as was intended. The solution was tested in Nicaragua where these types of biodigesters are prevalent due to implementation by a non-profit organization, Emerging Opportunities for Sustainability (EOS) International. This work was done under the assistance of local EOS technicians who had experience with the biodigesters and customers.

Methods

Overview of Current Biodigester System

By in large, the design of the system to increase gas pressure was completed in the Northern Highlands of Nicaragua in the rural township of San Isidro, Matagalpa. The biodigester had been functioning for two years. The design and installation guide used by EOS has been documented by Preston and Rodriguez (2002) and is identical except there are no 3 mil poly bags in the kitchen for pressurization. The digester was fed one-five gallon bucket of a 50:50 mixture of dairy cow manure to water three times per week.

The biodigester was capable of providing the family with about 30 to 40 minutes of biogas at a time, which is allows for preparing foods like eggs, heating milk, frying plantains, or reheating rice or beans. However, it did not provide enough gas to prepare diet staples such as rice and beans, which take about one and two hours to cook, respectively. Soup can take upwards of three hours depending upon its composition, so the biodigester was also not sufficient for this. Excess gas was also wasted by escaping through the pressure release system since it could not be fully utilized. It was estimated using size and production rates that the biodigester was capable of providing five hours of gas per day but only about 1.5 hours were actually able to be used due to pressure limitations at the outlet. Every morning, gas would escape from the water bottle pressure valve (Figure 2) because the pressure inside the bag was greater than 0.15 PSI, which indicates that the digester has a high rate of gas production.

Figure 2: Water bottle pressure valve

Design

The design was to construct a grid made of PVC which would distribute a small amount of weight evenly over the top of the biodigester bag in order to slowly force gas from it. PVC was used because it is easy to work with, relatively cheap, and locally available.

½” PVC was used to create the grid since this is already a component of the biodigester system. The length and width of the PVC grid were designed to be 0.25 m greater than the length and width of the biodigester bag, so that when the biodigester was deflated, the grid would be supported by the ground around the biodigester and not fall in the hole.

The time it took for the gas flow rate to be too low to cook food was measured without the PVC grid to be compared with the pressure increasing system. Finding an appropriate target gas flow rate was important to ensure that food is cooked in a reasonable amount of time without wasting gas. In this case, the user typically used three liters of water to cook beans, so a target gas flow rate was 2.8 L/min, which is the flow rate needed to boil three liters of water in 30 minutes. Bernoulli’s equation was used determine the weight of the system needed to achieve the 2.8 L/min target flow rate. Then, using the dimensions of the biodigester bag and Bernoulli’s Equation, it was determined that 8.5 lbs. of weight was needed to achieve the 2.8 L/min outlet target flow rate for the dimensions of the particular digester that was used for testing.

Since the constructed PVC system was less than 8.5 lbs the difference between the total weight needed for the system and the weight of the PVC was accounted for by using small plastic water bottles partially filled with water. These were attached to the center of the grid with duct tape so that the water weight was evenly distributed (Figure 3). Attaching the water bottles to the center of the grid also reduced stress on the PVC connectors, which are a potential weak point in the system.

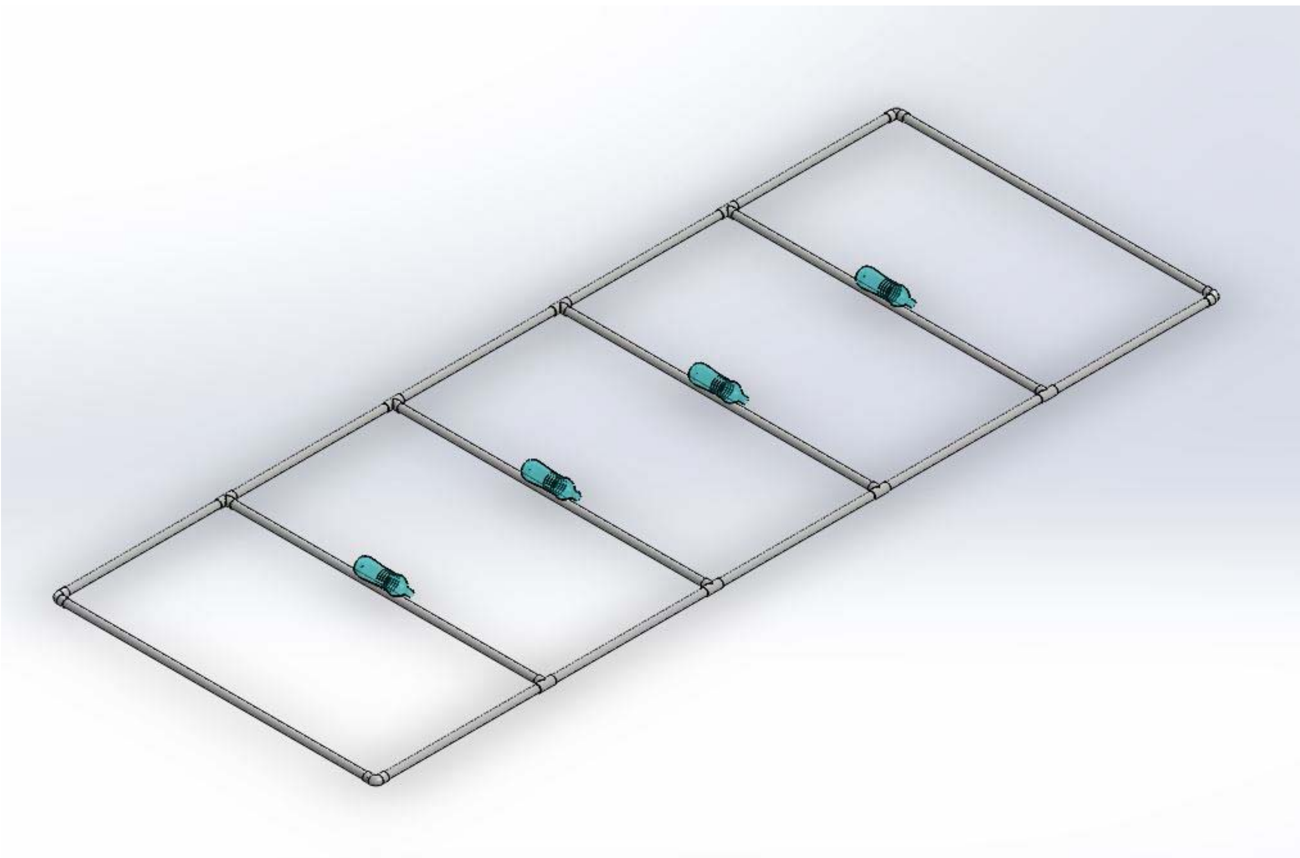

Figure 3: PVC grid with added water weight

With this amount of weight put on the biodigester, a theoretical four hours of constant cooking time was calculated using the target flow rate and volume of gas in the digester bag, assuming that the digester bag is completely full when cooking begins. In practice, the gas may last more or less than four hours depending on user factors, such as whether or not the biodigester was full of biogas at the start of cooking, time that system is lowered onto digester, and size of the digester.

Since there was sufficient gas pressure and flow when the biodigester was full of gas, it was determined that the PVC grid should be tied above the biodigester and lowered after approximately 30 minutes of cooking. This time frame can also be thought of as the time to take the water to start to boil. Then, after the food was cooked, the system could be raised again to allow the biodigester bag to reflate with gas. Although it would not harm the biodigester to lower the PVC grid in the beginning of cooking, it would lower the stove’s fuel efficiency due to an unneeded increase in gas flow rate.

Results

System Testing

After the pressurizing system was implemented, it was tested by the biodigester owner. She was asked to cook one pound of dry beans using both her wood stove and her biodigester with the pressurizing system in order to compare the time to cook beans on both and also to prove that the new system was successful in meeting its goal of cooking beans.

When the user tested the system, took 120 minutes to cook 1 lb. of dry beans using the wood burning stove using 3.5 L of water. When the same test was conducted using the biodigester with the PVC grid lowered after 35 minutes when the water and beans started to boil, the beans took a total of 105 minutes to cook. After the cooking was complete, there was 1.25 L excess water left in the beans, which indicates that less water is needed when cooking with the biodigester than the wood stove.

Gas Utilization

There was also gas leftover after cooking the beans with the biodigester. On the day that the test was conducted, the family used the biodigester to cook both breakfast and lunch, as usual. Then, after lunch the beans were cooked. They finished cooking around 2:00pm. The PVC grid was lifted off the biodigester to allow it to reflate. Around 5:00pm the grid was lowered again in order to cook dinner since the biodigester was not yet totally inflated. After dinner, the grid was raised again to allow the biodigester time to reflate. By 7:00am the next day, when the family was ready to cook breakfast, the bag was full again with some gas escaping through the pressure valve, indicating that the rate of gas production was sufficient to provide gas for this family's entire cooking needs. Previously, the biodigester was only able to provide enough gas to deliver 30 to 40 minutes of continuous cooking time three times per day. It was shown that two hours of continuous extra cooking time can be gained per day using this system.

System Cost

The total cost of the system when implemented in Nicaragua depends on whether or not it is installed at the same time as the biodigester. As shown in the tables below, the system ideally would be installed at the same time as the biodigester (Table 1). If installed as an aftermarket add-on, it would be twice as expensive (Table 2) compared to the cost of time and transportation for a technician to return to the site of the biodigester. However, if it was installed at the same time as the biodigester, the cost of the technician and transportation are already included in the price of the biodigester, so the cost of the pressurizing system is only the cost of the parts.

Table 1: Cost of the system if installed at the same as the biodigester

Part	Cost, $	Quantity	Total, $
1/2" PVC elbow	$ 0.21	4	$ 0.83
1/2" PVC T	$ 0.21	8	$ 1.67
1/2" PVC Pipe, 10ft	$ 3.13	2	$ 6.25
PVC glue	$ 3.13	0.25	$ 0.78
Twine	$ 1.04	1	$ 1.04
Duct Tape	$ 4.17	0.25	$ 1.04
Total			**$ 11.61**

Table 2: Cost of the system as an aftermarket add-on

Item	Cost, $	Quantity	Total, $
PVC grid	$ 11.61	1	$ 11.61
Technician	$ 10.83	1	$ 10.83
Transportation	$ 2.00	1	$ 2.00
Total			**$ 24.45**

If the system cost is the higher price of $25, then the overall price of the biodigester would increase 16%. If the system was installed at the same time as the biodigester, it would increase the price by approximately 8%. Another way to look at this is in terms of income. The typical rural worker makes approximately $5 per day. In these terms, the worker would work for five days to pay for the system as an aftermarket add-on and only two days to have it built at the time of the biodigester installation. One final way to look at this is in terms of the cost of firewood collection. Typically, a worker would have to spend a full week (seven days) every year in the countryside cutting wood to stockpile firewood for a year. With the new PVC system, they would use their wood stove substantially less, which means less wages lost cutting wood for the family. Potentially, in one year the family could pay off the system.

Conclusion and Recommendations

Overall, this system will allow the consumer to utilize their biodigester in the way that it was intended, which is to replace their wood burning stove. While this system worked well in Nicaragua, design changes may need for implementation in other countries due to cost and availability of certain materials. Consideration of weight, cost, durability, and likelihood of harming the biodigester bag should all be taken into account when choosing other materials.

Although the biodigester is now capable of providing four hours of biogas at one time to the user, further testing could be done to see if a lower flow rate would be sufficient to sustain boiling. A lower gas flow rate would mean a longer period of gas flow. In Nicaragua, beans and soup take the longest to cook. Beans typically take two hours while soup can take even longer so providing 3.5 more hours of gas at one time is a step in the right direction.

In the past, it was not practical to build larger digesters since more gas volume did not necessarily result in more gas available for cooking. With the PVC grid system, larger digesters could be built as long as the PVC weight and size are adjusted to the size of the digester bag. Larger digesters could be used for larger families, communities, or businesses. Thus the PVC grid system allows digester to be sized based on the gas needs of the user.

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