Designing the ideal compact anaerobic digester for middle class Sri Lanka.

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E-Futures

Emily Hounslow

dtp09eph@sheffield.ac.uk

The University Of Sheffield.

Research Councils UK Energy For a Low Carbon Future

Abstract

Anaerobic digestion of food waste provides simple solutions to both waste management and the need for clean renewable energy. Individuals and not-for-profit organizations in Sri Lanka are turning to anaerobic digestion to meet their green energy and waste management needs. This experiment tested the size limits of a compact anaerobic digester run on food waste. It was found that a unit no smaller than 465litres was needed to meeting the feedstock and organic loading rate requirements for a unit that gives a 2 hour per day cooking duration for a gas cooker run off one of these units. The possibilities for reducing the size remain in reducing the retention time, and therefore future research should investigate insulating units to move them into thermophilic stages of anaerobic digestion, and also to adding hand-pumps for mixing purposes. These are suitably low cost options for improvements to the digester units. Low cost and simplicity are imperative to success of the unit design. Cultural and social obstacles may still need to be overcome before anaerobic digestion becomes widespread in Sri Lanka, but the advantages this technology shows for energy production make it an extremely attractive option to help meet energy demands.

Introduction

Anaerobic digestion of food waste has proven an inexpensive, sustainable and simple-to-operate renewable energy source in Asia. The most notably successful and well-known demonstration of this is an award-winning yet simple biodigester design by the Appropriate Rural Technology Institute (ARTI), located in Pune, India (http://www.arti-india.org/). Energy Forum, a non-profit organization that promotes sustainable resource management and use, based in Colombo, Sri Lanka (http://www.efsl.lk/), is looking for ways to encourage and general population of Sri Lanka to adopt renewable energy policies, including the increased use of biogas by the Sri Lankan population. As the development of Sri Lanka progresses, it is important to find ways for the capacity of the country to grow without an increased carbon emission level.

The success of biogas in neighbouring India has highlighted it as an attractive option for Sri Lanka. The attractions of biogas are numerous: firstly, the set up of biogas digesters is very simple and relatively inexpensive and can be done using easily obtainable materials, so it is extremely viable for people in developing countries or of poor economic status. Secondly, the sources of feedstock are waste products: the basis of the ARTI digester is that it is started with cow manure, and then run on food waste and other domestic waste products, such as fruit peelings or old flower garlands. This means that the biodigester serves a two-fold purpose of both creating biogas and managing waste, and that the feedstock is a freely available substance. Thirdly, no major changes in infrastructure have to be made for people to adopt this technology. People don't have to wait for large scale renewable energy schemes to be put in place, because this is something that can done immediately by people on an individual basis. Fourthly, biogas is versatile enough that it can be used for cooking gas, for electricity production via a generator, and in transport. Despite these advantages and the success demonstrated by ARTI's design, biogas remains a relatively new and unknown energy source to the majority of Sri Lankans, and this unfamiliarity, along with perceptions that it is an "unclean" activity, may be hindering the uptake of this technology.

Can biogas be attractive to the Sri Lankan middle classes?

Sri Lanka has a quickly expanding economy and the country, especially the big cities, are developing very quickly. Consequently, the middle class is also growing. Energy Forum recognized that the growing middle class of Sri Lanka may not want biodigesters because they are too large to fit into a modern flat or home (being made from 1000litre tanks), or because they are viewed as too "unclean", due to odours or the nature of the feedstock and culture inputs (manure and old food waste). Since the middle class of Sri Lanka is expanding and living a more modern lifestyle, Energy Forum decided to investigate the possibility of creating a small biodigester unit that would be suitable for a modern family home or an apartment. For this, the issues of size and overall design needed to be addressed.

The size of the ARTI digester's main digester holder is 1000 litres. According to ARTI, this digester can be fed with 1kg sugar a day and from this can produce two hours' cooking gas per day – enough to meet the daily cooking gas requirements of a family of 4-5. Sugar is costly and useful, but it is also possible to use food waste as a feedstock. Energy Forum wanted to know whether it was possible to reduce the size of this domestic digester, making it more compact to fit into the home. They also wanted to know if it's possible to make it more clean and attractive, so that there is the option of keeping it indoors, for those without a garden.

This report gives an account of the study carried out to determine the smallest possible size for a domestic digester unit to give two hours cooking time, and the changes in digester design that were tested. Finally, the report suggests further improvements to the design. As well as being compact and being able to supply two hours' cooking gas per day, the unit also needed to be clean and free from unpleasant smells.

Using the following methodology, the parameters of the compact digester design were tested to find the smallest possible size for the compact digester. The results provided recommendations to Energy Forum on their next steps to creating the compact domestic digester unit, and to further modifications they could make to the design.

Methodology

Trials were conducted using a small biodigster unit made from metal barrels arranged as per Figure 1. This unit had been fed with cow manure to create the microbial population necessary to carry out hydrolysis, acidogenesis, acetogenesis and methongenesis. The feedstock used was food waste from the Energy Forum food bins. This waste consisted of left over rice and curry from packed lunches, and some fruit peelings of papaya and banana. The waste was mixed with appropriate volumes of water, according to the maximum Organic Loading Rate of 3-5g VS per litre per day (4gVS/L/d was used in this experiment, since it was the middle value) (Wulf *et al*., 2009), and blended in a kitchen food blender for 2 minutes. Blending was necessary both for practical feeding requirements of having the feedstock in slurry form, and to help speed up the first hydrolysis step of the anaerobic digestion process. The butterfly valve of the opening of the digester unit was then opened and the feedstock sample was poured into the unit. The gas valve was opened so that the pressure on the manometer returned to zero. The gas outlet valve and the feedstock inlet valve were then closed. Prior to the experiments, the top of the gas holder was fixed in place so that it could not expand. This was done with the intention of the gas volume remaining constant, though it was later noted that this design was flawed since effluent could be pushed out of the outflow and change the internal volume. However, the fixed lid meant that any changes in gas volume were reflected by the change in manometer reading.

A manometer was constructed using tubing connected to the top of the gas holder, and the other end open to the air. The tubing was fixed to a vertical surface in a u-shaped loop, with a board marking out distance in centimetres from a 0 midpoint. The tube was filled with water and dye until the water in both sides of the U-bend were at the zero mark. Changes in pressure within the gas holder were measured by noting the distance in cm between the water levels in the manometer.

Image 1 | Photograph of the trial digester unit and the manometer

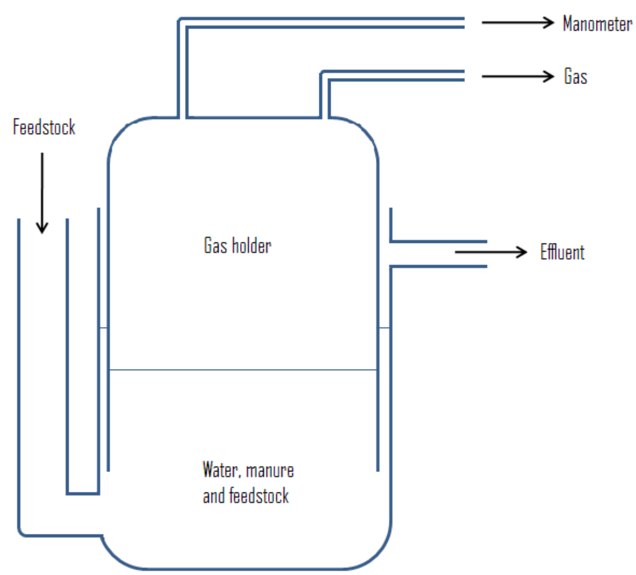

Figure 1 | Diagram of the anaerobic digester unit. The unit is constructed of 2 metal barrels with the lids cut off. The digester volume was 93Litres.

Each day, the change in gas pressure was noted, and then the gas was burned off. If the gas did not burn, it was simply released so that the pressure returned to zero. When the pressure value stopped changing, the number of days from feeding until the cease of gas production was noted. This was then recorded as the retention time of the feedstock sample entered into the digester.

Retention times were then used in conjunction with the organic loading rate (OLR) and the required substrate quantities for two hours' cooking time, as calculated from ARTI's tested figures, to calculate the minimum bioreactor size needed for the biodigester unit.

Trials were conducted for different quantities of food waste and other substrates. The first trial was 1kg food waste only, with the subsequent trials being experimental combinations of food waste and either gliricidia or paper, with different water additions. The details of the feedstock compositions are detailed in Table 1, named S1-S4. S2 was based on the assumption that 134g dry gliricidia is the equivalent of 500g wet weight, therefore trying to represent a 1:1 ratio of food waste to fresh gliricidia. S3 used 9:1 food waste to paper ratio, and required a high water input because the OLR for paper is very high. Although the OLR for gliricidia is higher than that of food waste, S4 was also carried out to investigate the effect of replacing 30% of the food waste input with gliricidia but without increasing the water input. This was partially to see if digestion would be inhibited by an insufficient OLR. Wet food waste is 4.1% volatile solids (VS) (Dae-Kim *et al*., 2008). Therefore for every 1kg wet food waste fed in to the digester, 10.25L water would also need to be fed into the digester. Gliricidia is 22.4% VS (Gunaseelan, 1988). Therefore for every 1kg Gliricidia fed in to the digester, 56L water would also need to be fed into the digester. Paper is 87.4% VS (average calculated from Owens & Chynoweth, 1993). Therefore for every 1kg paper fed in to the digester, 281.75L water would also need to be fed into the digester.

Results

Sample name	Water (Litres)	Food waste (g)	Gliricidia (dry) (g)	Paper (g)	Retention time
S1	10.25	1000	-	-	7 days
S2	12.6	500	134	-	9 days
S3	31.1	900	-	100	6 days
S4	10.25	700	300	-	9 days

Table 1 | Feedstock composition samples and their resultant retention times

Figure 2 graphically displays the manometer reading outputs per day. These could not be used as to calculate the volume of gas produced, since the volume of gas inside the tank was not known. They were, instead, used as an indicator of comparatively how high a pressure the gas was producing, and therefore indicating which substrates were producing the biggest pressure change due to large gas production, and also to measure the retention time, as the gas pressure stopped changing once gas stopped being produced at the end of the digestion process.

Figure 2 shows that food waste with paper (S3) digests the most quickly, with a 6 day retention time. One of the food waste and gliricidia trials (S4) also shows very good results with high pressure generation and the majority of the material being digested in the first 6 days, and taking 9 days for a complete digestion. The other gliricidia and food waste trial (S2) has a 9 day retention time, fluctuates over time in gas production, and also appears to give a lower gas output overall (suggested by the lack of pressure generated). This is the trial in which the gliricidia was measured out as an equivalent of 500g wet gliricidia, and therefore only 134g dry leaf weight was put into this trial. This explains why the gas pressure (proportional to gas production) is generally lower than the other gliricidia trial in which the dry weight was used. The paper and food waste trial shows fast digestion, but with gas production showing a smaller effect on pressure than in the other trials – this suggests that less gas is being produced and that therefore paper is not an ideal feedstock to use.

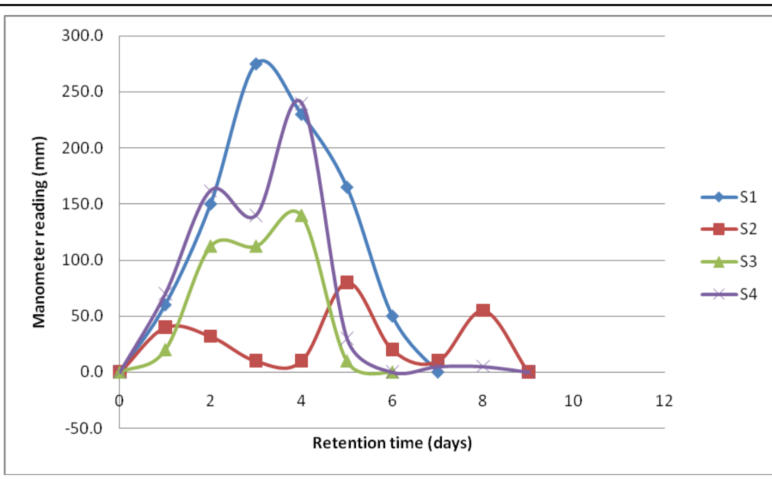

Figure 2 | Graphical display of manometer readings over time from the gas production of digestion of samples S1-S4.

The combustibility of the gas was also tested. For the food waste and first gliricidia trial (S1 and S2), the gas was combustible on around the second or third day of production. For the second gliricidia trial and so far for the paper trial, the gas has failed to combust (S3 and S4). This could be due to a high proportion of carbon dioxide being produced. However, it is also possible that the pressure regulator on the gas cooker, which had been malfunctioning at some points during the experiment, was preventing the gas from combusting when lighting was attempted.

The results from these trials allow the minimum required digester size to be calculated, and therefore fundamental to the challenge of creating a compact digester unit. The size of the unit will be calculated by:

Daily volume of water and feedstock required to meet the organic loading rate without over-feeding * the quantity of feedstock required * the retention time in days

According to ARTI literature ("ARTI's Energy Technologies" document), 1kg dry food waste will produce 1kg biogas. Assuming their stated figures that this 1kg biogas comprises 250g methane and 750g carbon dioxide, it was calculated that 1kg dry food waste would produce 0.78m^3 biogas. If the desired amount of gas is 1m^3, 1.28kg dry food waste is needed. If food waste has a moisture content of 80%, 6.4kg wet food waste will be needed to get 1m^3 biogas.

For a unit run only on food waste, this is calculated by:

=10.35 (litres) per day * (6.4 kg) * 7 days =66.24* 7= 463.68 litres. Therefore a 465 litre tank is needed as the minimum unit size for a digester meeting the requirements of 2 hours cooking time, run only on food waste.

These figures represent the minimum volume requirements. They indicate that even though comparatively little feedstock is fed in, the importance of water for the organic loading rate is paramount. Without this the system is much more likely to stall. The system might show smaller retention times if a bigger tank was used, as to some extent the speed is determined by the number of microorganisms (larger tanks hold more and therefore a larger tank can digest the feedstock faster), but this would defeat the object of using a small tank for a compact system. The optimum tank size will primarily be determined by the OLR.

According to our calculations, based on ARTI's figures of how much food needs to be put in the reach a daily requirement for a family's cooking needs, a total of 66.24 litres volume will be required to be added to the digester for every daily feedstock dose. Because the retention time here is 7 days for food, it would be possible to use a 465litre tank as a bioreactor. This would not take into account gas storage, which would make the unit bigger, therefore to keep to these parameters, a separate gas storage system such as a bag, would need to be used. These size parameters also do not allow any buffer time for if the retention time increases for any reason. With a biological system, thin margins of error may cause problems, and bigger units will have less risk of stalling. If other feedstocks with longer retention times are used, the unit will have to be larger. Since the food waste alone may not be feasible for supplying enough gas to meet cooking needs, adding feedstocks that take longer to break down, such as gliricidia or paper, will again cause an increase in the digester size. For example both gliricidia trials show a 9 day retention time, so a 590L (or 600L to round up) tank would be required for using combinations of gliricidia and food waste. And this figure assumes a water input which is the same as food waste alone, which would not be the case since gliricidia has a higher VS content and therefore would need more water. However, one trial (S4) that was experimentally carried out using this same water input showed good results, with a high pressure being generated and fast reaction time, so it may be possible to work within the 1kg feedstock to 10.25L water ratio even with high VS gliricidia, but overloading would remain a risk. Another factor is that the gas output from gliricidia is unknown, and may also alter the size of tank required for a gliricidia feedstock.

It does appear that it will be possible to reduce the size of the domestic unit from the one made by ARTI, and possibly even halve the size of the unit without losing biogas output. Therefore based on these trials, we recommend a biogas unit of minimum liquid holding capacity 600Litres in order to hold enough food waste, water and gliricidia to successfully meet the desired 2 hours cooking gas per day. This does not take into account storage of generated gas, which will push liquid down and out of the digester outflow pipe if the capacity is not big enough, or the fitting of a second barrel on top as a floating gas holder, which is likely to take up some significant space. This 600litre measurement works if the gas is piped off into a gas storage bag, although it may potentially also work with the ARTI design, depending on how much space the upper barrel takes up.

Discussion

The results from this experiment show that it is possible to reduce the biodigester reactor size from 1000litres to 465litres (or, to round up, 500 litres), based on the calculated minimum requirements found in this experiment. Ideally the digester would be as small as possible, to minimize the space it takes up in the home or garden. However, with the demands of a middle class family, the digester would have to produce 1m^3 methane cooking gas daily to meet requirements, and therefore a unit size smaller than 465litres is not possible without risking problems to do with overfeeding.

During the course of these experimental trials, the key aspects of problems that can occur with anaerobic digesters were highlighted. The main one was the problem of overfeeding. The digester, prior to feeding with the food waste, was overfed with sugar. This led to the entire system and becoming acidic, with pH readings of between 3 and 5, and stalling as a result. When this happened, feeing was ceased until the system returned to a neutral pH reading. The pH of the system was measured daily during the course of the experiment. During the trials detailed in this study, the pH remained at 6.5 or 7. Two systems were originally constructed at the start of the experiment, but one remained too acidic to carry out retention time trials on. This emphasizes the importance of not overfeeding the system and for adhering to the limits of the organic loading rate.

The second system had a hand-pump attached and was intended to be used for trials looking at reducing the retention time. The next stage in this investigation would to test whether the retention time could be even further reduced by using insulation and a mixing hand-pump. These may allow the unit to be made even smaller.

Issues that remain with this concept are twofold: one aspect is availability of feedstock, and one is the cultural and social aspects that will prevent people from taking this technology up. Firstly the issues of feedstock will be addressed. Dr Karve of ARTI in India states that 1kg of dry food waste, or sugar, is enough to produce 1kg gas. Though this doesn't sound like much, in reality food waste is always wet, and therefore you would need a daily supply of 6.4kg (based on 80% moisture content) food waste to meet this energy demand. No family household will produce this much waste. From personal communication with Sri Lankan families, the average waste quantity is 1kg. The feedstock would therefore be required to be supplemented with either extra food waste gathered from other sources (neighbours or from the streets) or by another source, such as garden waste, market waste, or gliricidia. A middle class family would find it socially unacceptable to gather food waste from their neighbours or from the streets. The options that remain then are to used garden waste which will increase the digester size through higher OLRs and higher retention times, or to accept that based on the waste outputs of the average family, 2 hours cooking gas per day will not be produced. Instead, 20 minutes gas will be produced per day, enough to, for example, heat the water for tea for the day.

The second issue is that these units contain "dirty" substances of manure and food waste. Because of this, it is not possible to have a digester based on this design within the home; it must be kept outside. However, the issue of odour and cleanliness may discourage people from taking up the technology at all, if they still have the cheap easy option of conventional LPG cooking gas. This is an issue that will only be resolved when people see demonstrations of the benefits outweighing these minor negative aspects. Finally, and most importantly, the system must be simple and it must be convenient. If it requires a lot of cost, care, or additional input, people will not choose to use it when LPG gas is easily obtainable. Maintaining the simplicity of ARTI's design is, therefore, paramount to success.

Conclusions

The size of the compact domestic biogas unit is mainly determined by the OLR of the feedstock, and therefore at least 465litres volume is required to meet 2 hours cooking requirements. Methods of speeding up the retention time, such as use of insulation to take the bioreactor into the thermophilic zone, and hand pump attachments to gently mix the contents of the digester, should be the next stage of investigation and may help reduce size requirements, but organic loading rate principles remain the biggest factor in determining digester size and avoiding overfeeding.

Acknowledgements

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