ENEG11002 Engineering Skills 2

Project 2: Engineers Without Borders Challenge

SEQ+FNQ

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Executive Summary

SEQ+FNQ have provided a design solution for the Devikulam community that will ensure sustainable development. The design solution involves the introduction of a bio-digester, which makes use of human waste in the local area, which is converted to feedstock, providing biogas (methane) as an energy source for cooking. This report will explain the science behind the bio-digester, as well as construction and detailed design so that villagers in Devikulam can implement this design independently.

The house-hold bio-digester is an innovative idea which has the potential to enhance living conditions in Devikulam, and that is our main objective. This solution is technically feasible, with consideration to skills and implementation environment. Other digesters have been considered, and this design was the most suitable for this community with respect to resources available.

The design solution can only operate efficiently if resources available, so the market we are appealing to is very small. There are 89 households in the Devikulam, there is also a school with the potential to incorporate this design. Chemical process, implementation, feasibility and construction methods are outlined in detail in this report. The village will have full knowledge of the process needed for this design solution to work.

Our goal is to provide the disadvantaged community of Devikulam with adequate health care, sustainable energy, and economic growth and we feel that our design solution will provide all of these things. In the past Indian communities have been reluctant to comply with the introduction of bio-digesters, but with proper education on benefits that the solution will provide will bring acceptance of design.

Team Reflection

The largest obstacle encountered by our EWB Challenge team was meeting the requirement to innovate. This involved developing an understanding of what constitutes innovation in this context and gaining an understanding of the community's needs and therefore what was innovative for this community. Another obstacle was the intangibility of this project. It was difficult to truly appreciate the social and environmental situation in the Devikulam community without being able to see it first-hand. Available information from the EWB site did provide some perspective, but a greater sense of interaction with the community would have helped to produce a more effective solution. The team format added another variable which made it quite difficult logistically to organise the report. This included communication challenges and not enough time allocated to initial research and design detail.

Working as a team brought different perspectives, strengths and weaknesses to most aspects of the project. The diversity of ideas, and need to articulate ideas and answer team member questions improved our overall quality of thinking. Working as a team also took the direction of the project away from the strengths of the individual and directed it towards the strengths of the group as a whole, enabling members to develop their weak areas.

Areas of this challenge that we would change include better front end research of the project and a more clear understanding and defining process of report requirements. We would also reduce the scope of the project to focus on a smaller problem within the community. Our combined effort expended in the project was adequate given the available time, however focusing on a smaller problem would reduce the amount of time required to understand and scope the problem and more time available to investigate effective solutions.

The most enjoyable aspects of this challenge have been reading and learning about the different cultures, their lifestyles and how they live day-to-day, in particular the sanitation goals and programmes in developing countries, and the socio-cultural influences that enabled and inhibited achievement of outcomes in these programmes. The challenge of learning about a particular culture and trying to adapt our solution to suit the needs of a community was also an enjoyable aspect of this project. EWB is a great example of how sustainable engineering can provide vast benefits in real-life situations and therefore is an ideal project for first year students.

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1. INTRODUCTION

1.1. Project Purpose

The Engineers Without Borders (EWB) Challenge Program calls for "innovations for the rural habitat project in the Devikulam village [in Tamil Nadu, India] to complement existing sustainable development projects" (EWB, 2011a). The purpose of this project, undertaken as part of the EWB Challenge, is to provide a design solution that addresses one or more of the Devikulam community needs identified by the Pitchandikulam Forrest Organisation and EWB (EWB, 2011a). The design solution presented in this report is a bio-digester, which makes use of human waste as the feedstock, and provides biogas (methane) as an energy source for cooking.

1.2. Report Outline

This report is structured as follows. The remainder of section one identifies the design areas, and particular community needs, that are the focus of this project, and specifies a set of criteria that guide decision making and against which the design is evaluated. The technical review is presented in two parts; the first appears in section two, which provides information about the community. The candidate concepts are presented in section three, and section four contains the second part of the technical review, the review of candidate design concepts that meet the needs identified the previous sections. Section four concludes with selection and justification of a design concept. Section five presents the details of the design specification for the selected concept, the horizontal bio-digester. Section six identifies a set of considerations for implementation of the design, and section seven focuses on community benefit - providing the evaluation against design criteria and discussion of economic, social, and long-term sustainability matters. Section eight identifies limitations, and provides recommendations, and concluding remarks.

1.3. Design Focus – Meeting Community Needs

The bio-digester design solution developed by this project addresses community needs in the Design Areas of Energy, Water and Sanitation, and Waste Management. In the area of Energy, the bio-digester contributes to the need for reliable and safe cooking technology (EWB, 2011a) by providing an alternative source of energy for cooking that is safer than the bio-mass fuel supply currently used (EWB, 2011a). In the area of Water and Sanitation, the major contribution is in the proposal that toilets be integrated with the bio-digester such that the human waste (the feedstock for the bio-digester) enters the bio-digester directly from the toilet. A reduction in open defecation may result from sanitation infrastructure being available, which may provide a secondary benefit in reducing contamination of water supply. In the area of Waste Management, the bio-digester provides potential for disposal of the organic components of household waste (in addition to human waste), and produces a valuable product, fertilizer, from the waste matter.

1.4. Design Criteria

The design criteria guide identification and evaluation of the candidate concepts, design decisions, and evaluation of and recommendations regarding, the proposed design. The three broad criteria defined for this project are discussed below, and incorporate the relevant items from the Design Brief's 'Project Statements' and 'Considerations' (EWB, 2011a).

1. Identified community needs
Criterion:
The solution addresses one or more explicitly identified community needs.

Elaboration:
The relevant identified needs (EWB, 2011a) in the selected design areas are:

1. "infrastructure ... in place in order to stop open defecation practices";
2. "infrastructure...in place in order to...ensure that human waste is disposed of properly";
3. provision of clean energy and cooking technologies that provide an alternative to burning of (solid) bio-mass sources; and
4. creating value from waste.

The review (refer section 2) confirms in particular the need to end open defecation and provide sanitation infrastructure generally throughout rural India.

2. Acceptability
Criterion:
There is consideration of, and evidence for, the cultural fit and general acceptability of the solution concept.

Elaboration:
The relevant identified considerations in the selected design areas are:

1. "cultural beliefs and practices" with regards to sanitation infrastructure (EWB, 2011a), and use of processed bio-digester effluent as fertilizer (EWB, 2011g).

The review (refer section 2) identifies influences on non-utilisation of existing sanitation infrastructure and biogas plants in many Indian communities; ways in which to overcome these influences shall be considered both in evaluation and in making design decisions.

3. Technical feasibility
Criterion: The solution is technically feasible, including in consideration of the skills available and physical characteristics of the implementation environment.

Elaboration:
Relevant considerations include:

1. technical feasibility and conditions required for success based on the technical review;
2. the availability of skilled labour, and degree of skill required, to install and maintain the solution;
3. the education level of the community members, and the knowledge required to operate the solution;
4. technical feasibility and conditions required for success, in terms of utilisation and community benefit, in the physical environment in which the solution is implemented (for example, availability of sufficient and appropriate raw materials; availability of an appropriate location for installation).

2. TECHNICAL REVIEW – COMMUNITY BACKGROUND

2.1. Current Devikulam Energy and Cooking Methods

Devikulam energy consumption and cooking methods are heavily reliant upon the burning of Bio-mass. Although electricity is supplied to all households bar two, power is used predominantly for lighting under a 'one light free' service scheme being run by the government for the Dalit caste (EWB, 2011c). The Devikulam people currently use mud stoves that vent openly into the enclosed spaces of residential properties, causing many respiratory problems often leading to death (Innovations Report). LPG is the preferred fuel for cooking however is only available in seven houses throughout the community.

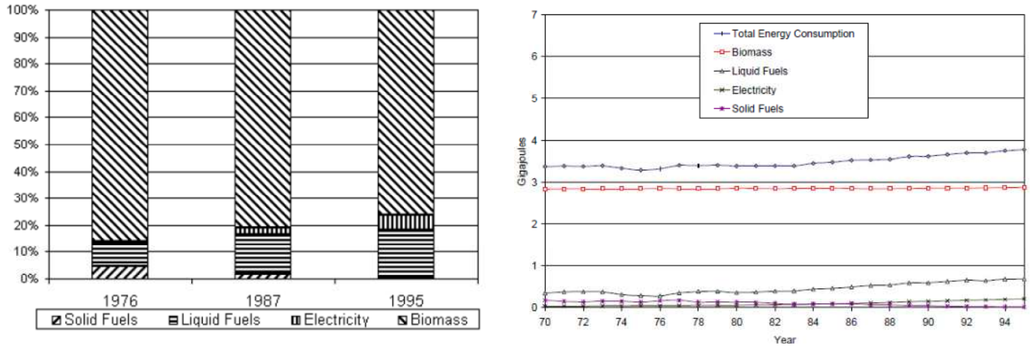

Figure 1: Indian Energy Usage
(Image Source: Dzioubinski & Chipman, 1999)

2.1.1. Electricity

Electricity is supplied to the majority of properties in Devikulam, for those of the Dalit caste (the poorer parts of the community) this is supplied for free under a 'one light free' service. In general this power source is not used for cooking as it is too expensive and inefficient; it is instead used for lights, fans, radios, and in three households to run a fridge (EWB, 2011c).

2.1.2. Bio-mass

Bio-mass, when used as an energy source is categorised as anything of biological nature from living or recently living organisms (e.g. wood and manure). In India approximately 70% of household energy consumption is provided by Bio-mass, predominantly for cooking (Dzioubinski & Chipman, 1999). In Devikulam mud-ovens are used for cooking, these are preferred over modern smokeless ovens due to the heat they can produce and the longevity of their construction. The biggest concern over the use of the mud-ovens is that they are not isolated or vented; meaning smoke is produced in large quantities often in enclosed spaces. Due to this the Indian people suffer from a large number of respiratory diseases, a figure of 1.6million deaths from smoke inhalation is recorded each year (EWB, 2011c).

2.1.3. Liquid Petroleum Gas (LPG)

LPG is the preferred fuel source as it burns clean and hot, without producing as many harmful fumes during the cooking process. Unfortunately at the moment only seven houses are set up to use LPG, and it is more expensive to obtain compared with using bio-mass.

2.1.4. Bio-digested Methane

The technique for harvesting methane from bio-mass, as featured in this report offers the opportunity to access a cheap, renewable, clean, hot burning energy for the use of the Devikulam people. The use of this gas would effectively eliminate the problems associated with respiratory problems in the Devikulam community.

2.2. Devikulam Community Water and Waste Management Systems

Almost all of the literature found on Devikilam water and waste management is from the Engineers Without Borders Challenge web pages for both Australia (EWB, 2011g) and United Kingdom (EWB, nd) challenges. The pages gives some history on the issues with the water supply, while outlining the current situation in Devikulam. The literature includes information on the water infrastructure, geographic, social and contamination issues in Devikulam. Some information was found on the Gramap web page, according to Gramap (2010) a project was completed in 2010 to replace water pipes in the village with a standard ¾" gauge system and reduce water wastage due to poor water infrastructure such as leaking taps.

Engineers Without Borders Australia (2011g) also outlines sanitation and waste water issues in Devikulam, including the practice of open defecation and the potential to transfer pathogens to both water and food supplies. The literature outlines previous solutions and there shortfalls. The document also outlines several potential solutions and some considerations for these solutions.

Further information on Devikulam community water and waste management systems, in the form of questions posted by students is available on the EWB (2011b) Challenge Participants Discussions pages. Many of these questions have been answered, giving more specific information that would assist in producing and implementing design solutions.

2.3. Devikulam Community Housing

The majority of Devikulam residents live in huts. The huts consist of cement or mud flooring, mud or brick walls and thatched or palm leaf roofs (EWB 2011d).

The baseline survey (EWB 2011e) indicates that most households are located on large blocks of land. These blocks range from ½ acre to 10 acres in size, the majority of residents have a small number of livestock, and household occupancy is generally 4-7 people (EWB 2011b).

The Devikulam residential community consists of 89 households (EWB, 2011d). The community is divided into three main residential zones and is defined by their major castes (EWB, 2009d).

2.4. Social and Cultural Aspects

2.4.1. Sanitation in India

Access to safe drinking water (from improved sources) and improved sanitation increased substantially in India in the 1990 to 2008 period (WHO, 2010), from 72% to 88% and from 18% to 31% respectively. Open defecation is common in rural India, practiced by as much as 69% of the rural (and 18%of the urban) population (WHO, 2010). The Indian government had planned to ban the practice in 2012, but target has been extended to 2017, in part due to the rate of progress in providing sanitation facilities in rural areas. The Indian government and Non-Government Organisations including Unicef and the Sulabh International Social Service Organisation have been involved in initiatives to provide improved sanitation facilities (CURE, 2010; SISSO, 2011b).

In rural areas, identified reasons for installed toilets not being used include preference for open defecation, incomplete or inadequate construction (including one toilet built in a house's front yard, with no walls), use of the buildings for other purposes including grain storage (HIP, 2006) and firewood storage (Socio-Economic Research Division, 2002).

In general, access to improved sanitation facilities can provide social benefits including better educational opportunities for girls, improved safety for women, and improved population health, and improved "quality of life of the rural people and to provide privacy and dignity to the rural women" (Socio-Economic Research Division, 2002, p180).

Much of the toilet infrastructure in India consisted of dry (that is, non-flushing) latrines, from which human waste is manually removed, a practice termed 'manual scavenging' (Directorate of Municipal Administration, 2008). Manual scavengers are ostracised by society and considered untouchables (SISSO, 2011), the occupation considered "obnoxious and inhuman (Directorate of Municipal Administration, 2008). The Indian Government's enacting of The employment of Manual Scavengers and Construction of Dry Latrines (Prohibition) Act 1993 was an impetus for a variety of programs to demolish dry latrines, construct alternative infrastructure, and provide alternative employment for manual scavengers (Directorate of Municipal Administration, 2008; SISSO, 2011a).

2.4.2. Use of Human-waste based fertilizers

The Design Brief (EWB, 2011a) advice received from EWB (2011, b) regarding the clash with local beliefs of using human-waste based fertilizer identified that potential association with manual scavenging was not expected to significantly influence attitudes toward use of human-waste based fertilizers by the Devikulam residents.

The acceptability of using human waste-based fertilizers (processed, as obtained from bio-digestion) is identified as a concern by the EWB Challenge (EWB, 2011c). The World Bank's Water and Sanitation Program undertook research on social, religious, cultural and gender-related influences on attitudes toward human-waste based fertilizers amongst rural Indonesians (WSP, 2010), specifically pertaining to use of the Eco-San toilets (which separate liquid and solid wastes). The research identified significant demand for human-waste based fertilizer, and that "more than 80% of respondents were willing to use [human waste] based fertilizer", though only 50% "were willing to process [the waste] themselves (WSP, 2010). It was also confirmed that, according to Muslim law, the fertilizer is not considered *najis* (ritually unclean), and there were not significant differences in attitudes to use between Christian and Muslim groups. Although this study did not address Hindu beliefs or caste discrimination, given the advice that it is not the association with manual scavenging that is an issue, the study supports the idea that use of human waste based fertilizers may be acceptable if appropriate information and education is provided.

2.4.3. Sanitation in Devikulam

The need for both infrastructure and education to support moving from open defecation to disposal of human waste has been identified (EWB, 2011a). The preference of residents is for a toilet to be used exclusively by members of one household, rather than shared by more than one household (EWB, 2011b). In a previous initiative, four Eco-San toilets have been trialled in Devikulam (EWB, 2011b), and in other locations within the region, composting toilets have been installed (EWB, 2011g). A potentially relevant issue with the use of Eco-San toilets is the custom of using water for cleansing, which "inhibits the use of a toilet system requiring dry storage" (WSP, 2010). Devikulam lacks reliable access to a supply of safe drinking water, however there are two operational bores, one of which provides non-drinking water for "washing, flushing, and cleaning" (EWB, 2011c).

2.4.4. Previous Indian Bio-Digester Implementations

India's National Project on Biogas Development was established "for promotion of family type biogas plants" as both a source of alternative energy and enriched organic manure for rural India (Programme Evaluation Organisation Planning Commission, 2002). An evaluation (Programme Evaluation Organisation Planning Commission, 2002) of more than twenty years of the programme identified a wide range of influences on the installation and utilisation of biogas plants. While many of these influences were technical aspects of the plants, administrative aspects of the programme, or economic factors, there were several socio-cultural influences identified.

Amongst those who did not participate in any biogas scheme, socio-cultural reasons for unwillingness to join community biogas plant (CBP) schemes included family problems, social taboo, and lack of cooperation among villages. Non-contribution by members was a factor in half of the non-functional CBPs. Issues related to property ownership, changed location of residence and cattle sheds, and the presence of other cooking devices were cited as socio-economic reasons for plants becoming non-operational. Publicity and awareness was identified as an important but underfunded and activity. Income, land holding and education above primary level appear to be positively related to biogas plants remaining functional.

3. CONCEPT ENERGY AND WASTE SYSTEMS

3.1. Smokeless Stove

As stated by Engineers Without Borders Australia (2011a) a smokeless stove would reduce indoor air pollution and related health issues, while potentially conserving biomass and slowing down deforestation. It was recognised the health benefits of a smokeless stove would bring immediate quality of life benefits to Devikulam households. It was identified that if the smokeless stove was to use the current biomass fuels available in the village reduced consumption of these fuels would result in the slowing down deforestation. Reduced deforestation was not seen as a sustainable option, and further consideration was given to the problem. It was identified that a stove fuelled with biogas would have the same health benefits as a smokeless stove, while possibly eliminating deforestation for cooking purposes.

3.2. Composting Toilet

As outlined Engineers Without Borders Australia (2011g) appropriate waste water treatment is extremely important to the environment and human health. According to EWB composting toilets have been implemented, with significant benefits, including simple and safe waste disposal. Composting toilets would provide an immediate improvement in the quality of life for the people of Devikulam. There would also be medium and long term health benefits by reducing the spread of pathogen related illness. It was identified that the same benefits as a Composting toilet could be achieved by the implementation of anaerobic digesters.

3.3. Anaerobic Digestion

As identified by Engineers Without Borders Australia (2011a) biomass systems for waste water treatment. It was identified that the benefits of anaerobic digestion were threefold. Firstly the biogas produced would enable the implementation of a smokeless stove. Secondly the use of an anaerobic digester could all but eliminate the need for the burning of biomass materials such as wood, eliminating rather than reducing deforestation. Thirdly anaerobic digestion of sewage would improve the existing health and environmental problems. As identified by Engineers Without Borders Australia (2011g) the implementation of a bio-digester would require significant support because using human waste as a fertiliser clashes with local beliefs and values. This issue was noted and has been addressed in the design solution.

4. TECHNICAL REVIEW – CANDIDATE DESIGN CONCEPTS

4.1. Anaerobic Digestion - Biogas Production Process

Biogas (approximately 60% Methane CH4, 40% Carbon dioxide CO2) is produced by anaerobic digestion (United States Environmental Protection Agency, 2008). The methane produced by anaerobic digestion is a combustible fuel that can be stored and used as an energy source. Anaerobic digestion (United States Environmental Protection Agency, 2008) is the process in which organic material is broken down into similar chemical components in the absence of oxygen. Non air breathing bacteria degrade the biological material (substrate) through a series of digestive stages. Almost any organic material can be used as a feedstock for the biogas digester however there are certain conditions that must be maintained in order for the process to produce regular and efficient supply of biogas.

There are three stages in the anaerobic digestion process (Hessami, Christensen, & Gani, 1996)

1. Hydrolysis
2. Acidogenesis
3. Methanogenesis

1. Hydrolysis

In the hydrolysis stage the non-air breathing bacteria, (hydrolytic bacteria) use enzymes to breakdown and liquefy insoluble organic polymers such as carbohydrates, cellulose, proteins and fats. The Carbohydrates, proteins and lipids are then hydrolysed to sugars which continue to decompose further to form carbon dioxide, hydrogen, ammonia and organic acids. The Proteins decompose to form ammonia, carboxylic acids and carbon dioxide (Residua, 2003).

2. Acidogenesis - Acetogenesis

In the second stage Acidogenesis the organic acids formed in stage 1 are converted by acetogenic micro-organisms to acetic acid. At the end of this stage carbon dioxide and hydrogen concentrations begin to decrease. (Residua, 2003)

3. Methanogenesis

The final stage Methanogenisis produces the Methane (60%) and carbon dioxide (40%) from the organic acids and their derivatives produced in the second stage of the digestion process. The methane is a useful fuel source and methanogenic bacteria play a further role in maintaining wider breakdown processes. (Residua, 2003).

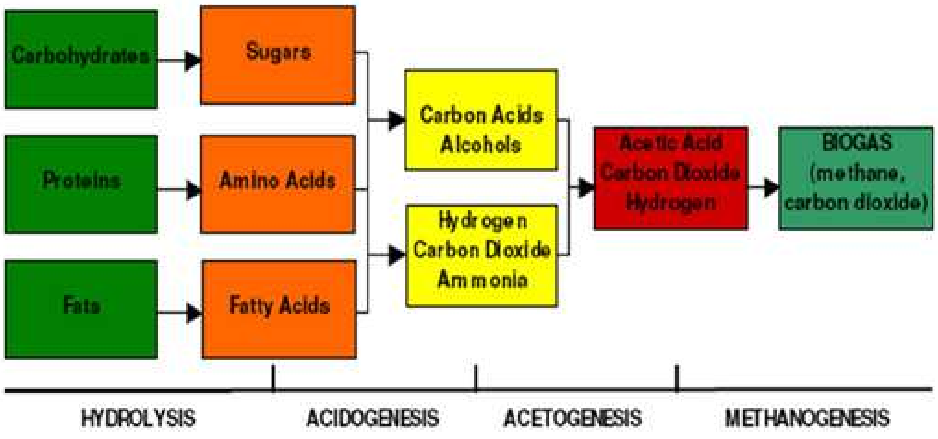

Figure 2: Anaerobic Digestion

(Image source: http://www.canadacomposting.com/Content/Images/howitworks_TheAnaerobicDigestionProcess.jpg

A simplified generic chemical equation for the overall processes outlined above is as follows:

$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$

There are two conventional operational temperature levels for anaerobic digesters, which are determined by the species of methanogens in the digesters (Song, Kwon & Woo, 2004):

- Mesophilic: which takes place optimally around 30-38 ℃ or at ambient temperatures
- Thermophilic: which takes place optimally around 49-57 ℃.

4.2. Floating Drum Digester

Floating drum digesters have been deployed across India in various commercial and Government programs. They are mostly installed in the ground and constructed of bricks or cement.

The slurry is feed into the digester via the inlet pipe (1) into the digester. The biogas is produced and stored in a floating barrel (3). A gas outlet (5) is attached to the top of the gas storage barrel to supply the desired plant. The floating barrel is weighted to increase gas supply pressure. An outlet pipe or overflow (4) is attached to remove the effluent.

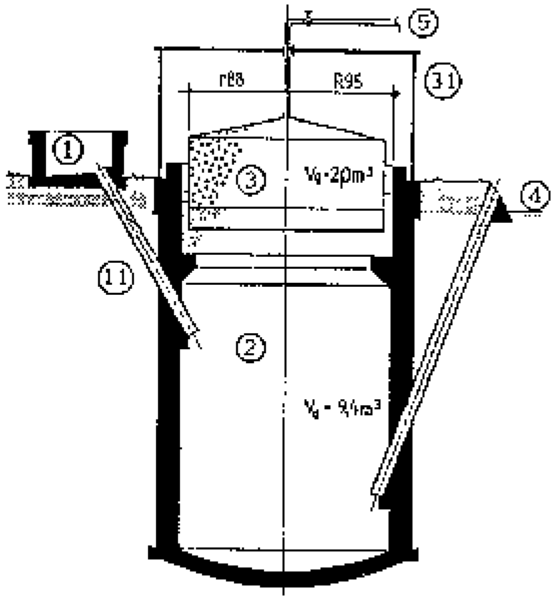

Figure 3: Floating Drum

(Image Source: Humanity Development Library 2.0
http://www.greenstone.org/greenstone3/nzdl;jsessionid=CCAD051FBDE15DA095307FB3A8E93C25?a=d&c=hdl&d=HASH01a3f321d0f133a6e59c9949.6.4.pp&sib=1&p.s=ClassifierBrowse&p.sa=&p.a=b)

Advantages

- Ground level loading and unloading of feed
- The digester has improved temperature stability because it is underground
- The level of the drum indicates the volume of gas available
- The drum automatically pressurises the gas

Disadvantages

- Relatively complex due to the structure being build on the ground
- High maintenance requirements of drum (Rust and corrosion)
- They are a permanent structure
- High cost of construction
- Relatively complicated and potentially expensive if repairs are required

4.3. Horizontal Digester

The horizontal type Biogas digester system consists of a horizontal style digester which can be constructed of various types of materials such as thin polyethylene sausage shaped bags or drum/barrels constructed individually or in series lying lengthwise to create the system.

One end of the Digester can be slightly elevated to increase the flow of slurry and effluent material in and out of the digester.

The Feedstock is feed through the inlet pipe (1) to the main digester (2). The Biogas is collected in the top section of the digester (3). A gas outlet pipe is connected to the top section of the digester to supply gas to the desired plant (5). The effluent material is removed via the outlet pipe (4).

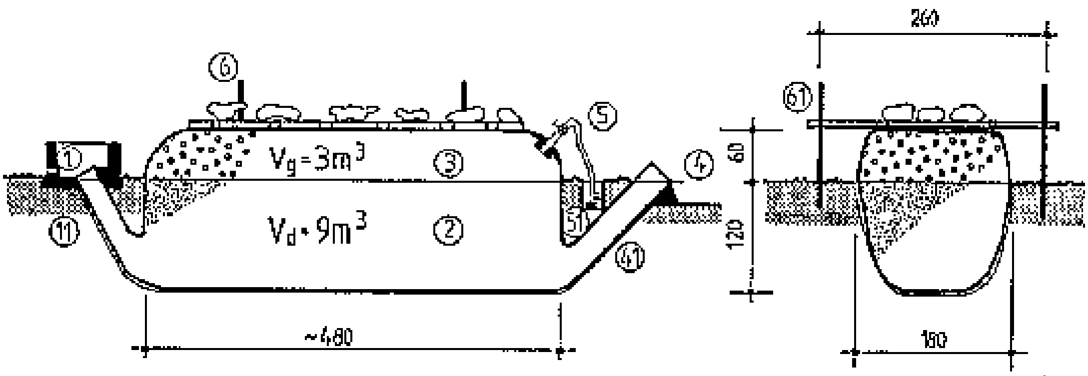

Figure 3: Horizontal Digester

(Image source - Humanity Development Library 2.0
http://www.greenstone.org/greenstone3/nzdl;jsessionid=CCAD051FBDE15DA095307FB3A8E93C25?a=d&c=hdl&d=HASH01a3f321d0f133a6e59c9949.6.4.pp&sib=1&p.s=ClassifierBrowse&p.sa=&p.a=b

Advantages

- Ground level loading
- The digester has improved temperature stability because it is semi underground
- Continuous batch feeder
- Relative low cost construction
- Can be constructed of other materials barrels etc

Disadvantages

- Polyethylene degrades relatively quickly
- Lower gas pressure
- Closed system

4.4. Fixed Dome Digester

The Fixed dome digester consists of a dome shaped digester with a fixed immovable gas storage area at the top of the digester. The system is a closed unit constructed of masonry. It is lined with paraffin or bitumen to make it airtight for the gas storage. The digester is buried underneath ground and is suitable for colder climate.

The slurry is added to the inlet (1) where it feeds into the main digester (2). The gas is produced and stored at the top of the unit (3). A gas feed line is connected to top of the digester (5) to supply the desired plant. The pressure created by the production of biogas pushes the processed slurry out of the overflow (4).

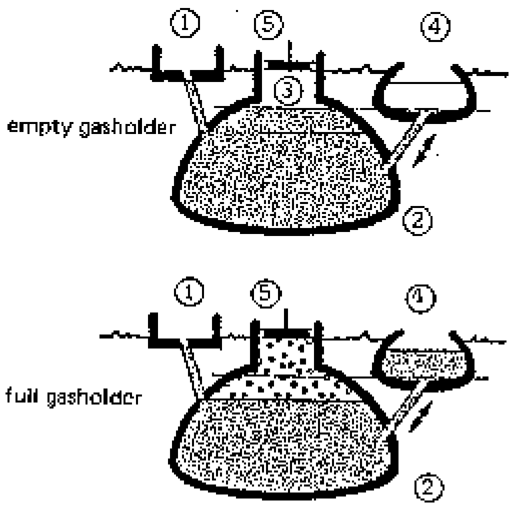

Figure 4: Fixed Dome Digester

(Image source - Humanity Development Library 2.0 http://www.greenstone.org/greenstone3/nzdl;jsessionid=CCAD051FBDE15DA095307FB3A8E93C25?a=d&c=hdl&d=HASH01a3f321d0f133a6e59c9949.6.4.pp&sib=1&p.s=ClassifierBrowse&p.sa=&p.a=b)

Advantages

- Ground level loading
- The digester has improved temperature stability because it is buried beneath the ground
- Continuous batch flow and displacement well for effluent
- Airtight seal
- Gas pressure increases with production and pushes effluent into displacement well
- Low initial cost
- Long life system

Disadvantages

- Fixed unit and must be constructed where it is to be used
- Closed system difficult to maintain when necessary
- Difficult construction method
- Requires the use of a sealant.
- Cracking often causes irreparable leaks.
- Unreliable gas pressure

4.5. Design Concept Feasibility Analysis

The Final design choice is aimed and finding a feasible and safer energy solution for cooking in the Devikulam community household. The design using biomass as a fuel source needs to move away from the current technologies being used in the community. As out lined by EWB (2011c), 70% of India's population currently cook on biomass stoves that are inefficient and impact health. The overall design choice is a single household digester using either Horizontal HDPE Barrels or Polyethylene horizontal sausage shaped bags servicing each individual house as a separate unit. The system would incorporate a simple delivery method of human household waste and provide an automated effluent disposal method to avoid manual handling of processed product.

4.5.1. Rationale

The bio-digester provides biogas to a burner which essentially is a smokeless stove technology. When implemented in the household it has a clear advantage over current biomass-burning technologies due to the removal of harmful smoke from the current method of cooking. The implementation of a bio-digester as a solution allows for the design to address other concerns in the community such as the phasing out of open defecation and the disposal of human waste. The bio-digester also provides a renewable and reliable energy system for the households in the community. The process of anaerobic digestion can remove up to 90% of harmful pathogens from human waste. The reduction in harmful pathogens allows for healthier and safer community lifestyles.

4.5.2. Digester size

The size of the digester had to take into account the needs of the Devikulam community to successfully address the main focus of the current issue of harmful and inefficient cooking methods within each household. Other considerations needed to be met such as - process for adding feedstock, maintaining the system and community acceptance.

Considerations were made with several different scaled systems but overall the most feasible solution was to produce a single household digester that would also provide solutions to open defecation and waste management of the individual household.

The Analysis of Community, Multiple house and single house digesters and there advantages and disadvantages is detailed below.

4.5.2.1. Community Digester

Although large scale community based systems could be used to fuel the entire village during the need for alternate energy, it would raise questions of the social impact as well as issues of responsibility. With Castes already an issue in Devikulam a large scale community bio-digester could possibly continue to encourage the segregation within the community.

An Indian Government report (Programme Evaluation Organisation Planning Commission, 2002) also indicated community projects had a high rate of failure. The main reasons for failure are: larger number of members, non-contribution of monthly maintenance charges as well as dung, non-availability of labour to operate the plant and complaints about non availability of gas, unsuitable timing of operation, non-cooperation of members for repair/ maintenance (Programme Evaluation Organisation Planning Commission, 2002).

Advantages

- Large system can implement proper maintenance schedule
- One system to supply energy needs to the community

Disadvantages

- More complex system
- would need to regulate pressure through gas feeder lines
- Large infrastructure
- Difficult to regulate the cost of production and use without a meter

4.5.2.2. Multiple household System

A system that would supply biogas to several households would appear on the surface to have significant advantages however when looking at the system as a whole it was identified that it could pose conflicting issues of responsibilities between the occupants. In this system a great emphasis on people and processes would need to be instilled to the cluster of operators to ensure effective operation. It could impose a negative social impact on individual households. For accessibility the location would need to become common ground. The Devikulam community live on relatively large blocks of land and the safe infrastructure and delivery of biogas supply would be costly and may have issues such as gas pressure.

Advantages

- Multiple houses supplied by 1 system
- Shared responsibility
- Shared implementation costs

Disadvantages

- Raises questions of who will feed the digester and maintain it
- Possible issues- who will contribute to implementation
- Lower gas pressure
- Long gas feeder lines to each household
- Very little opportunity to provide sanitation solutions

4.5.2.3. Single household System

A less complex design that could possibly implement the use of direct house hold waste and address sanitation issues in the community is seen as advantageous. The responsibility of feeding and maintaining the system is up to the beneficiary of the system. Smaller scale plant is easier to implement and maintain. Pressure would be greater as only supplying a single household. Another advantage would be a single household digester would avoid the need to handle or transport human waste, and therefore avoiding the sensitive issues of manual scavenging and caste discrimination.

The single household size digester meets all the needs of our outlined design criteria.

Advantages

- Small system

- Each household responsible for their own system – feedstock and maintenance
- Smaller amounts of organic material required in each household
- Sanitation issues can be addressed as a fuel source with a household delivery system

Disadvantages

- Must be feed daily
- Everyone in the community needs to be trained to operate and maintain the plant
- Understanding of Ph testing and gas production by each household
- If the digester is not maintained of feed effectively it will not operate efficiently

4.5.3. Anaerobic Digester Design Type

The most effective and efficient system for the individual household was also selected with multiple considerations such as cost, simplicity, maintenance and operational difficulty. The Horizontal style digester met the design considerations in the most feasible way. The analysis, advantages and disadvantages of the floating barrel, vertical and horizontal design digesters are detailed below.

4.5.3.1. Floating barrel digester

The floating barrel digester design has some clear advantages such as low level loading of the organic material and temperature stability. There is also the ability to increase the gas pressure by weighting the floating barrel to force the gas through the line at the desired rate. These units are however difficult to maintain, become a permanent structure are generally expensive and complicated to construct.

Advantages

- Ground level loading and unloading of feed
- The digester has improved temperature stability because it is underground
- The level of the drum indicates the volume of gas available
- The drum automatically pressurises the gas

Disadvantages

- Relatively complex due to the structure being build on the ground
- High maintenance requirements of drum (Rust and corrosion)
- They are a permanent structure
- High cost of construction
- Relatively complicated and potentially expensive if repairs are required

4.5.3.2. Horizontal Digester

The Horizontal digester shows great potential in meeting the cooking needs of the each Devikulam community household and has a beneficial advantage of addressing sanitary and waste management with the integration with a toilet delivery system. The low cost and general low maintenance systems are also an advantage to the household and would remove the need to defecate in public and help to improve social acceptance. It is customisable and can be removed easily as it is not a permanent structure. The option to increase capacity is advantageous to households as it can be tailored to suit their needs. To mitigate the degradation and relatively short lifespan of the horizontal style bio-digester (polyethylene bag) it is proposed that the material will be a more robust plastic material such as barrels.

Advantages

- Can be constructed of cheap polyethylene material or rigid plastic barrels (generally lower associated cost)
- Simple continuous flow digester
- Low maintenance
- Possibility of expanding the system
- Can be partially buried
- Can be built relatively close to the household providing a direct feed that will also provide sanitary and waste management advantages
- An auto feed system would also decrease the occurrence of open defecation within the community by implementation of house hold toilets as a delivery method for feedstock

Disadvantages

- Polyethylene degrades relatively quickly
- Lower gas pressure
- Household feed and maintained and would need community training
- Understanding of Ph testing and gas production by each household

4.5.3.3. Vertical Digester

The vertical digester is a feasible solution but has very few distinguishable advantages over the horizontal continuous feed anaerobic bio-digester.

Advantages

- Compact design
- Continuous or batch feed designs
- Can be constructed above ground or partially below ground
- Customisable to suit individual household needs

Disadvantages

- In the vertical digester organic waste often escapes being "eaten" by the bacteria (Anon, n.d.)
- Given equal size and other factors, horizontal digesters will produce more biogas than vertical digesters (Fry, 1973)
- Vertical digesters are labour intensive and need regular cleaning and maintenance

5. DESIGN SOLUTION

5.1. Design Requirements and Considerations

The literature review conducted on bio-digesters identified many reasons behind past failures of bio-digester projects in India. This provided good insight into the considerations required to optimise the success of the project.

5.1.1. Effluent and Social Issues

According to Engineers Without Borders Australia (2011g) that the implementation of bio-digesters would require significant support as the idea of using human waste as a fertiliser clashes with local beliefs and values. Consideration was given to this issue and it was decided that the effluent would be drained away via a pipe system to soak into the ground much the same way as a septic system does.

5.1.2. Feed-stocks

The primary purpose of the digester is to address sanitation and energy issues. The digester is designed for sewage and kitchen waste as the primary feed-stocks, as these are common to all households.

5.1.3. Material Selection

Digester components made of steel such as floating drums have a limited life expectancy due to corrosion of the steel. Painting of steel surfaces would extend the life of the materials, but this requires ongoing maintenance. Given that the failure of Biodigester was frequently due to a lack of maintenance, materials that do not require maintenance would be more suitable.

Polypropylene bags are a common material used to construct horizontal digesters. While this could be a suitable design and has many benefits it was not selected as research showed they have a limited life expectancy of around 10 plus years. In a report by Jenangi (n.d.), gas escaped the digester because of holes caused by animals.

The material chosen to form the chambers of the digester is High Density UV stabilised Polyethylene drums which have a relatively long life expectancy, especially if protected from direct UV exposure. Another advantage of HDPE according to Gabriel (n.d.) is that non-stick surface of HDPE resists scaling, which is identified by The University of Adelaide (2011) as an issue with anaerobic digestion.

5.1.4. Construction and expansion

HDPE drums are used to form the mixing and digestion chambers of the digester. The drums are modified to form any part of the digester. The use of drums allows the expansion and customisation of systems.

5.1.5. User Friendly Features

Both the latrine and kitchen waste pipes have been positioned to stop slurry splashing back when adding material to the mixing chamber (See figure 6).

5.1.6. Biogas Purification and Storage

According to The University of Adelaide (2011) biogas produced by anaerobic digestion contains around 50-60% methane. Some of the other gases that are typically contained in the biogas mixture are Carbon Dioxide, Nitrogen, Hydrogen and Hydrogen Sulphide. The biogas produced by the digester is passed through a simple water scrubber to remove some of the other gases contained in the biogas mixture.

The scrubber is integrated with a floating drum style gas holder to store the gas produced.

5.1.7. Safety

Some methane from the mixing chamber may rise into the enclosure housing the latrine. To avoid potential methane build up in the enclosure, significant voids will need to be left between the bottom of the walls and the floor, and the top of the walls and the roof. It will also need to be advised that ignition sources such as a gas lamps, candles or cigarettes must not be taken into the latrine enclosure. Biogas systems are usually fitted with a device to limit the pressure of the gas in the system, this function is performed by the gas holder.

5.2. Design Solution

The design solution is based on a horizontal digester. The design selected consists of a mixing chamber fed from a latrine and a kitchen waste inlet. The feed from the mixing chamber passes into the digestion chamber where the biogas from the digestion is piped off the top of the digestion chamber and the digester matter leaves the chamber as effluent. The gas from the digestion chamber is piped to a combination scrubber/gas holder, before being piped to the household for use (see figure 5).

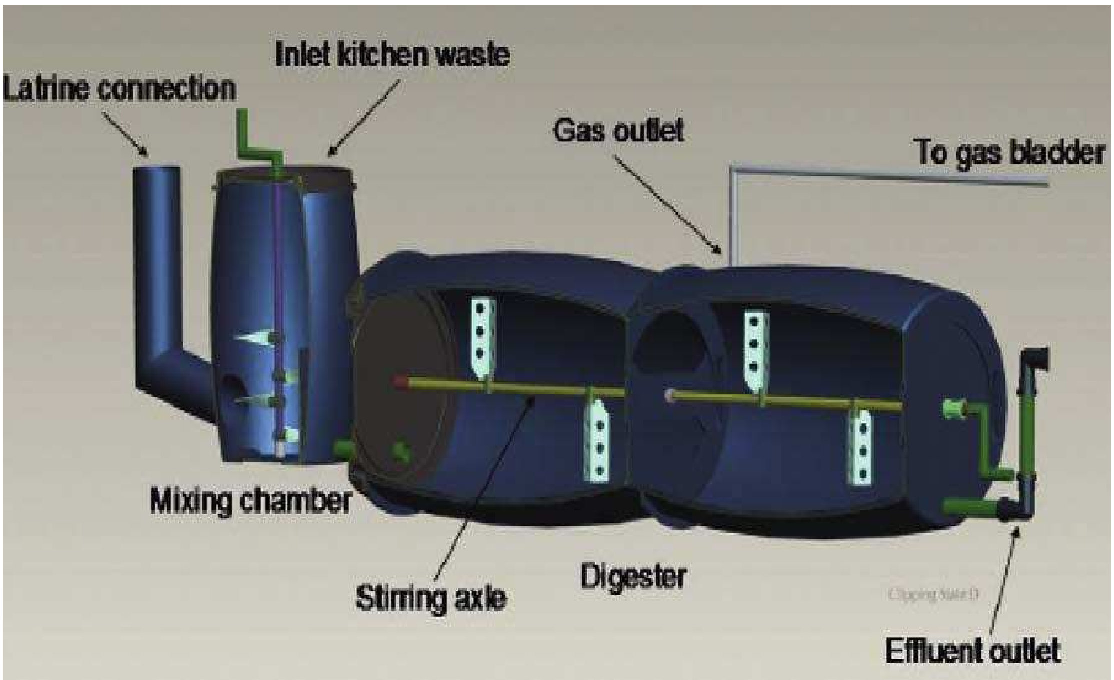

Figure 5: Horizontal Digester Design

(Image Source: Martinssonb, Mboyaa, Odhiamboa, Onyangoa & Sorenb, 2009)

5.3. Design Specifications

5.3.1. Digester

The design selected is constructed using either 200, 220, 235 or 250 litre HDPE drums to form the main chambers of the digester. All sizes are suitable for the mixer and digester, but only drums of the same size can be directly coupled. The digester features a vertical mixing chamber with two inlets one from a latrine and the other for the addition of other feed stocks such as kitchen waste. The latrine pipe is 160mm HDPE and positioned to eliminate slurry splashing as new material is added. The kitchen waste inlet is also positioned to eliminate slurry splashing back when adding material. The mixing chamber incorporates a vertical agitator to blend the feed stocks. A 90mm HDPE pipe connects the mixing chamber to the main digestion chamber which consists of a large horizontal chamber with a horizontal agitator. The digested effluent leaves the main digestion chamber via a 90mm pipe which is attached to the bottom of the main chamber. The pipe raises up from the base of the digestion chamber to a height suitable to maintain an appropriate slurry level in the digester. The biogas exits the top of the digestion chamber and is passed through a combination scrubber and gas holder.

5.3.2. Agitators

The agitator shafts are made from 25 or 32mm HPDE pipe, preferably of the thickest wall available. The paddles are made from left over plastic that has been cut out of the drums during the construction. The paddles are fixed to the agitator shafts by slots cut in opposite sides of the shaft the same as the thickness of the paddles. The paddles inserted into the shaft so they protrude from the opposite side of the shaft and fixed in place by plastic adhesive.

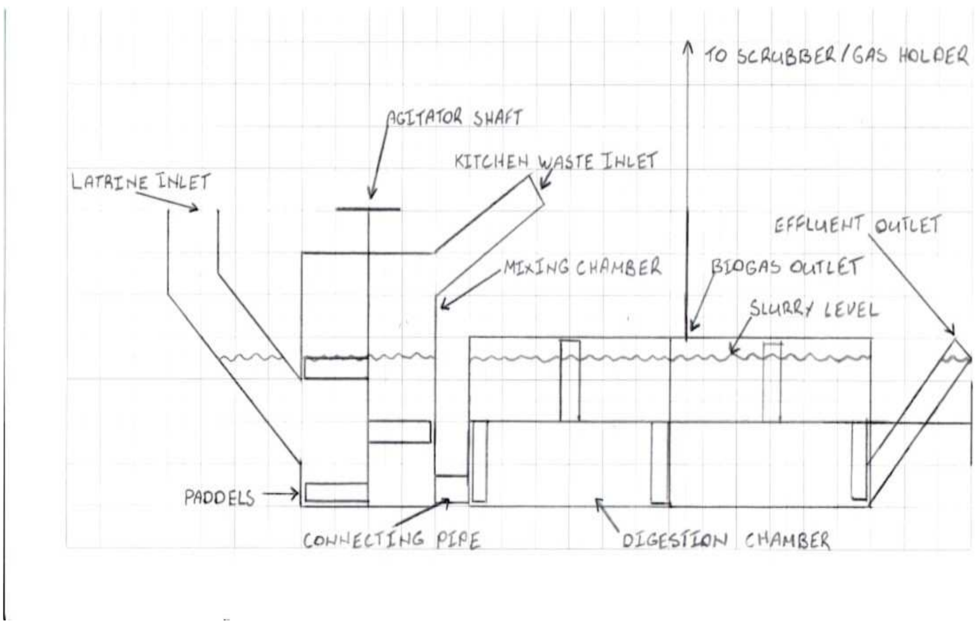

Figure 6: Horizontal Digester Design Sketch

5.3.3. Water Scrubber/Gas Holder

The combination scrubber and gas holder is constructed using two HDPE drums of varying size, both with the tops removed and one fitted inside the other. For more storage capacity multiple gas holders may be used. An inlet pipe and outlet are installed in the floating drum to enable the entry and discharge of gas into the scrubber/gas holder. The inlet pipe should be as long as the floating drum is deep, to ensure the gas passes through as much water as possible. The outlet should be as close to the top of the floating drum as possible to enable all the gas to leave the digester. The gas holder also acts as an overpressure safety device. Once the floating drum has lifted to the height of the water, the gas will begin to escape from around the base of the floating drum.

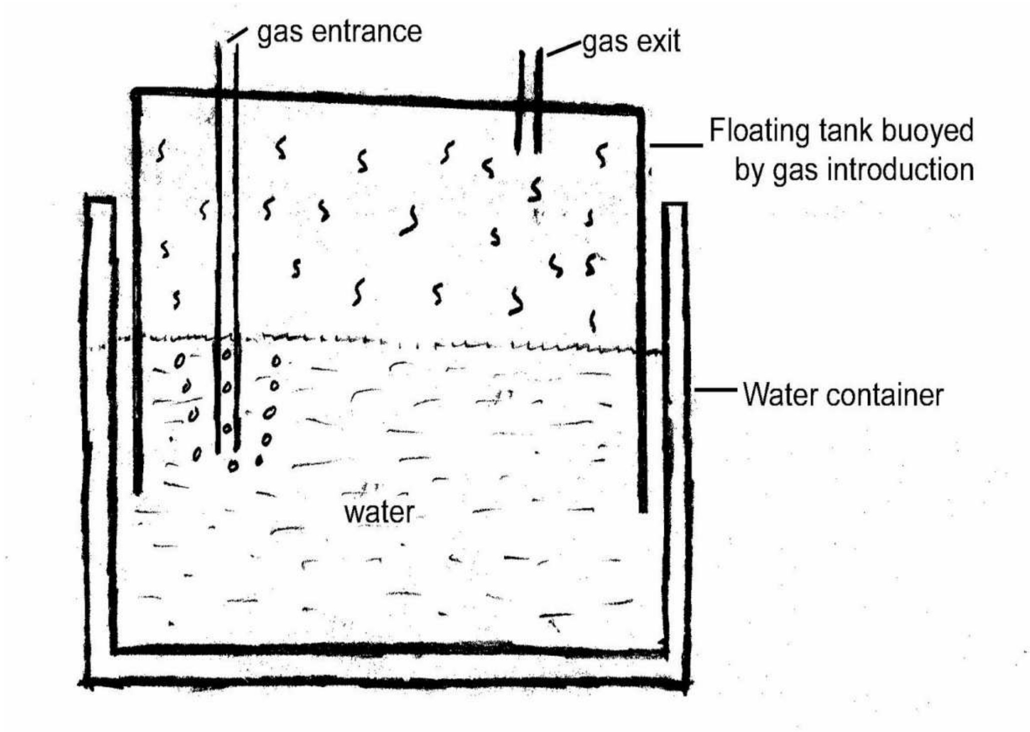

Figure 7: Water Scrubber / Gas Holder
Image source: Source: Forst (2002).

5.4. Materials

The number of drums will depend on the amount of material available but 200, 220, 235 or 250 litre HDPE drums are suitable. One drum per digester will need to be a different size for the scrubber/gas holder.

- 1.2 meters of 160mm HDPE pipe
- 3 meters of 90mm HDPE pipe
- 90mm pipe lid for kitchen waste inlet
- 25 or 32mm HDPE pipe for the stirrer length as required by digester size
- Two 25 or 32mm HDPE tee pieces for agitator handles
- 3M Scotch-Weld DP-8005 or 8010 plastic adhesive

5.5. Household Methane Requirements

Estimates indicate once the digester has been initially filled, around 16.6kg of human solids waste per day, would produce 200 litres of biogas. It was identified by The University of Adelaide (2011) that 200 litres of biogas would be sufficient to produce three cooked meals per day. The addition of organic materials with a higher volatile solids content, such as cow manure or food scraps would increase the biogas production or compensate for a reduced quantity of human waste.

5.6. Feedstocks

According to the United States Environmental Protection Agency (n.d.), organic materials are suitable for anaerobic digestion. According to Forst (2002), fibrous material digests at a much slower rate and digests much less completely. Because of this fibrous materials such as wood or paper are not suitable for this digester. The digester design covered in this project is suited to many of the bio-degradable substances that would be available of in Devikulam. The digester is intended for two feed stocks in particular human waste and food scraps or kitchen waste. The use of other feed stocks such as animal manure is encouraged, but it is understood this is not available to all households.

5.7. Feedstock Yield

While there are large variations in biogas production due to digester performance and feed stock composition, the expected yield from digester feed stocks can be estimated. According to The University of Adelaide. (2011) “one kilogram of” Volatile Solids” (the biologically degradable portion of wastes) produces 0.5 cubic metres of methane.” As this is a simple digester around half of the volatile solids introduced to the digester can be expected to break down and produce methane. Due to this inefficiency around 0.5kg of volatile solids would be required to produce the 120 litres of methane that would be needed for three cooked meals per day.

Manure production in kilograms per 1000kg live weight

Source	Human	Cow	Goat	Hen
kg	-	86	41	64
% VS	3%	10%	-	12%

Table 1: Manure production
Source: The University of Adelaide (2011)

The percentage of volatile solids in biodegradable matter will determine the biogas yield of that matter. According to The University of Adelaide. (2011). human waste (solids) contains around 3% volatile solids, this equates to a methane production ratio of around 7.2m^3/ton. At this ratio around 16.7 Kg of human waste would be required to supply the 120 litres of methane. Food waste generally has a much higher percentage of volatile solids than human waste producing 376m^3/ton according to (United States Environmental Protection Agency. n.d.).

5.7.1. Example Calculation

1 kilogram of volatile solids will produce 250 litres of methane. If human waste solids contain 3% VS we can calculate how many kilograms are required to produce 250 litres of methane. 1kg/0.03%VS = 33.333 therefore 33.333kg of human waste is required to produce 250 litres of methane.

5.8. Digester Sizing

The digester can be used for one or more households depending on the volume of matter available and should be sized accordingly. One of the factors that led to the failure of digesters in past implementations was being over sized relative to the volume of feed available (Programme Evaluation Organisation Planning Commission, 2002; Walekhwa, Mugisha, & Drake, 2009)

To calculate the digester size the volume of materials fed into the digester needs to be estimated. For example if 1kg of dry solids waste was to be added per day then around 15 litres of water would be required.

Approximate Materials Mixing Ratio

Material Type	Mass	Water Required
Wet Solids	5kg	15L
Dry Solids	1kg	15L

Table 2: Mixing Ratios
Source: The University of Adelaide (2011)

Digester capacity is also based on achieving a pre-determined retention time, that ensures pathogens are reduced to an acceptable level. The University of Adelaide. (2011) gives both minimum and recommended retention times. To decide between the minimum or recommended retention time, both cost and final use of digester effluent should be considered. The length of time that the matter is required to be in the digester to achieve the pathogen reduction is reduced by an increase in ambient temperature. According to Travel Marg (n.d.) the average winter/summer temperatures are apparently 23.9/31.5 degrees Celsius and the minimum winter temperature is 20 degrees and maximum summer temperature is 35 degrees Celsius.

Digester Retention Time Guide

Temperature in Degrees Celsius	Minimum Retention Time (days)	Recomended Retention Time (days)
10	60	120
20	22	44
30	9	18

Table 3: Digester Retention Time
Source: The University of Adelaide (2011)

Digester Sizing Example

Volume of Material Per Day (litres)	Multiplied by Retention Time (days)	Digester Size (litres)
60L	22	1320 L

Table 4: Digester Sizing
Source: The University of Adelaide (2011)

5.9. Effluent Management

Once up and running the digester will produce a similar amount of effluent, to the volume of material added to the digester. The effluent can be collected in a container and used as fertiliser or channelled away from the digester and adsorbed into the ground similar to a septic tank.

According to Engineers Without Borders Australia (2011g) “using human waste as a fertiliser clashes with local beliefs and values.”

Figure 8: Outdoor Latrine/Digester Combination
(Image Source: Martinssonb, Mboyaa, Odhiamboa, Onyangoa & Sorenb, 2009)

6. IMPLEMENTATION

6.1. Construction

It was identified by EWB that some villagers have the skills to build buildings. From this it is assumed that the skills to build the digester can be explained and the digester constructed.

6.2. Operation

Feed added to the digester must be diluted with water as per section 5.8. The size of the solids fed in through the kitchen waste inlet should be as small as possible to reduce the chance of blockages.

The feed enters the mixing chamber where the slurry is mixed by a hand operated agitator. As new feed is added and the slurry level in the mixing chamber becomes higher than the effluent discharge pipe, the head pressure present pushes the slurry into the digestion chamber. The same forces that push the slurry from the mixing chamber into the digestion chamber also move the slurry through the digestion chamber. Although digestion begins in the mixing chamber, most of the anaerobic digestion takes place in the digestion chamber where the methane is released and makes its way to the top of the chamber. According to The University of Adelaide. (2011) if correctly designed once the slurry reaches the effluent pipe around half of the volatile solids present in the feed stocks have been digested and most of the pathogens have died off.

6.3. Location

The location of the digester will depend on whether it is for a single household or group of households. This is subject to resource availability. Digester also suitable for introduction into school, but there are implications associated with school children that will use the digester, which introduce potential problems such as limited maintenance, lack of understanding and actual logistics of setup.

6.4. Maintenance

The digester is designed to be low maintenance. If the mixture of water and solids are correctly maintained, scum build up is limited, reducing the chance of blockages. The stirring paddles are positioned where blockages are most likely to occur and are designed to reduce the chance of blockages. The combination scrubber/gas holder will require the water to be topped up to maintain a suitable water level and changed periodically as the water becomes saturated with contaminates. The gas pipe between the digester and the scrubber is the most likely to suffer from contaminate build up and require flushing with water, which is a potential issue with all of the gas pipes.

6.5. Community training and support

According to Engineers Without Borders Australia (2011c) some of the people in Devikulam have the skills to construct buildings. These skills would be sufficient to construct this digester though, support from someone with at least a high school education and good handyman skills would also be required. The Pitchandikulam community outreach program, EWB or another volunteer organisation could arrange this. The people of Devikulam will need to be trained in the following:

- Appropriate feed stocks and requirement for mixing with water
- The benefits of using digester effluent as fertiliser
- Construction of the digester, gas holder and biogas distribution
- Operation of the digester
- Maintenance of the system

Once the systems are constructed and operational, support could be provided as required through Pitchandikulam and their community outreach program. Another option according to the Programme Evaluation Organisation Planning Commission (2002) is the Rural Development & Panchayat Raj Department, who manage the National Project on Biogas Development in Tamil Nadu.

7. COMMUNITY DESIGN SOLUTION – HOUSEHOLD HORIZONTAL BIO-DIGESTER SYSTEM ANALYSIS

7.1. Design Criteria Evaluation

A summary of the evidence that the proposed solution meets the design criteria specified for this project (refer section 1.3) is presented in this section.

Criterion 1 The solution addresses one or more explicitly identified community needs.

The bio-digester is part of a system for the disposal of human waste, that encompasses a latrine, the bio-digester, and the supply of gas to as an energy source for cooking. It meets the identified needs (EWB, 2011a) of providing infrastructure to stop open defecation (the latrine itself), ensuring that human waste is disposed of properly (the bio-digester processes the waste such that pathogens are rendered harmless), and providing a clean energy source for cooking. The design solution provides for the creation of value from waste in two ways – the biogas reduces the need for kerosene and LPG, and the bio-digester effluent is suitable for use as a fertilizer.

Criterion 2 There is consideration of, and evidence for, the cultural fit and general acceptability of the solution concept.

The evidence of consideration of and design for cultural fit and acceptability is of two types. Firstly, the report presents details of influences on non-utilisation of bio-digesters and sanitation infrastructure in previous implementations, and of the motivations for use of these. Secondly, these influences are taken into consideration in the design itself (refer section 5.1), for example:

- the bio-digester design provides an option for effluent can be drained away, rather than necessarily being handled and used as fertilizer;
- the use of human waste as a feedstock overcomes the issue of lack of livestock for supplying the bio-digester;
- the choice of materials is guided by the need for the bio-digester to be low maintenance, as maintenance issues had been identified a strong influence on non-utilisation.

Criterion 3 The solution is technically feasible, including in consideration of the skills available and physical characteristics of the implementation environment.

The proposed design solution is based on mature, proven technologies with demonstrated technical feasibility (refer sections 4.3, 4.5. 5). The design concept chosen for development is the least technically-complex of the candidate concepts (refer sections 4.2 to 4.4), and is suitable to the target physical environment. The proposed solution requires minimal maintenance.

It is therefore considered that the proposed design solution meets the specified design criteria.

7.2. Environmental Impact

The EWB Challenge identifies biomass systems for waste water treatment. It was identified that the benefits of anaerobic digestion were threefold.

Firstly the biogas produced would enable the implementation of a smokeless stove.

As stated by EWB Challenge, a smokeless stove would reduce indoor air pollution and related health issues, while potentially conserving biomass and slowing down deforestation. It was recognised the health benefits of a smokeless stove would bring immediate quality of life benefits to Devikulam households. It was identified that if the smokeless stove was to use the current biomass fuels available in the village reduced consumption of these fuels would result in the slowing down deforestation. Reduced deforestation was not seen as a sustainable option, and further consideration was given to the problem. It was identified that a stove fuelled with biogas would have the same health benefits as a smokeless stove, while possibly eliminating deforestation for cooking purposes.

Secondly the use of an anaerobic digester could all but eliminate the need for the burning of biomass materials such as wood, eliminating rather than reducing deforestation.

Thirdly anaerobic digestion of sewage would improve the existing health and environmental problems, specifically open defecation. It was noted by EWB that the implementation of a bio-digester would require significant support because using human waste as a fertiliser clashes with local beliefs and values. This issue was noted and has been addressed in the design solution.

As mentioned earlier, the digester uses high density polyethylene barrels that have a lifetime of approximately 50 years. Since polyethylene is not biodegradable, the barrels must be recycled, unless a better disposal solution is found in the meantime.

7.3. Economic Considerations

It was found during the Indian Government Bio Gas investigation, users of the digesters found the process of running the digester tedious, and would use any alternate fuel sources possible, such as LPG and wood (Programme Evaluation Organisation Planning Commission, 2002). Since the inhabitants of Devikulam currently use wood as their primary cooking fuel source, it is reasonable to expect that they will use it in preference to the bio gas, if the process is difficult or time consuming. Since it is difficult to compromise the human interaction with the digester, which involves emptying food waste into the top, it is suggested that use of the bio-digester would be most accepted within the community if it were based on fiscal incentive rather than health or sustainability reasons.

The Indian government investigation found that the enriched slurry produced as waste reduced the cost of chemical fertilizers for 90% of users (Programme Evaluation Organisation Planning Commission, 2002). Since the Devikulam village is surrounded by farmlands, it is suggested that an arrangement between local farmers and Devikulam villagers could be made to provide farmers with cheap, sustainable fertilizer, and the villagers with their fiscal incentive for using the bio-digesters.

7.4. Design Solution Social Benefits and Impacts

The purpose of this project is to provide health and waste management solutions to existing problems in Devikulam community. Implementation of this bio-digester is expected to eliminate respiratory problems caused by smoke from biomass fuelled stoves, and the unsustainable waste management solutions in place for human and food wastes.

During the study investigating the success of bio gas plants in India, it was found that sanitary bio plants (using human waste as a fuel source) have low rates of acceptability due to socio-psychological inhibitions (Programme Evaluation Organisation Planning Commission, 2002). The majority of bio plants were owned and used by well off, or higher class farmers. Since the majority of inhabitants of the Devikulam village are of the Dalit caste, who are often employed to clean latrines and sewers, it is expected that this will be less of a problem in this project. Nonetheless, it is recommended that the delivery of toilet waste to bio-digesters be as automated as possible, incorporating the toilet into the bio-digester .

Despite two government maintenance and repair schemes, only 11% of bio gas plants reported faulty were actually repaired. In the government scheme Rural Energy Technicians (RET) were trained in the repairs and maintenance of the bio gas plants, being paid between 6 and 10 AUD per plant repaired. Most RET's left within a year due to under payment (Programme Evaluation Organisation Planning Commission, 2002).

For the Devikulam situation it is recommended a village member be trained in repairs and everyday maintenance of bio-digesters and be paid a percentage of income generated from each bio-digester, to provide incentive of ensuring bio-digesters are running at optimum capability. This will also protect, the digesters from users inadvertently using inappropriate material as fuel.

As discussed in section 7.3 slurry produced from the bio-digesters may provide economic benefits in addition to health and waste management benefits.

7.5. Sustainability and Design Lifetime

The anaerobic digestion process proposed is potentially a sustainable process if the effluent is used as fertiliser. According to Budzianowski (2011) Biogas is a renewable and sustainable energy carrier when generated via anaerobic digestion of biomass.

The design lifetime of the digester is limited by wearing of the digestion chamber due to the rotation of the stirring shaft. This is expected to be minimal and could be repaired or designed out. The only other limiting factor of the design lifetime is the digester materials. Reliable figures on the life expectancy of HDPE were not found. It is established that the life expectancy of HDPE depends on the composition of the plastic and the level of exposure to sunlight.

If the digester is discarded the materials can be recycled. According to All Recycling Facts.com (n.d.) “HDPE plastic can be recycled into bottles for holding household chemicals such as detergent, shampoo, conditioner and even motor oil. Recycled HDPE plastic can also be made into pipes, buckets and bins, pens, flower pots, film and sheets, benches, and even dog houses.”

8. Limitations, Conclusion, and Recommendations

8.1. Limitations

The key limitations of this report are the elements of design excluded from scope, and limitations on available sources of information in preparing the report.

Necessary for the complete bio-digester system, but excluded from the scope of this design specification are:

- The biogas system from the scrubber/gas holder to the point of supply, and the supply of suitable cooking equipment;
- Design of the latrine; and
- A sealing arrangement for the agitator shafts

Limitations regarding information sources include:

- The materials have not been priced. Contact was made with Indian goods trading companies but requested costings were never provided.
- Detailed figures on the actual supply of feedstock were not available - to address this information on required /recommended volumes of feedstock is provided, and it is recommended that this be considered in making a final decision on digester size.

Additionally, it is noted that further information regarding implementation, and including information and education materials, are required, but are not within the scope of this report.

8.2. Conclusion

Based on evaluation of suitability of the proposed design with respect to the design criteria (refer section 7.1) and the potential benefits of the proposed design (refer sections 4.4 and 7), it is concluded that the proposed design is capable of making a valuable contribution to addressing sanitation and cooking needs within the Devikulam community.

8.3. Recommendations

Acknowledging the limitations identified in 8.1, it is recommended that the following activities be undertaken.

1. Develop the latrine design.

   Recommendations concerning the latrine design are that the digester will need to be installed below ground level or the latrine raised above ground level or buckets need to be used as latrines and the contents poured into the digester. It has been identified that the villagers would squat and wash with water. Unlike the eco-san toilets, the bio-digester is suited for washing with water. Efforts should be directed at overcoming reasons for non-use of latrines, including by providing education/information on benefits, appropriate location and structure.

2. Develop the system of supply of gas to point of use, and approach for providing suitable appliances

3. Obtain additional details of feedstock availability and make decisions on optimal digester size.

4. Undertake detailed costings, and further investigate the availability of financial assistance. The capital costs are potentially the most significant influence on feasibility.

5. Develop information and educational materials.

Finally, direct involvement of community members, particularly in decisions about latrine design and location, is highly recommended as a strategy for reducing the likelihood of non-utilisation as has been experienced in past sanitation and biogas implementation programs.

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