# Conceptual Design of a System to Facilitate Production of Methane Through Anaerobic Digestion of Organic Material

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***Abstract* — There is a need to develop affordable and effective processes that make use of the anaerobic digestion process in order to produce Methane from different organic materials particularly human sewage and domestic organic waste such as food scraps. Current bio-digester designs have achieved good results, but there are some notable problems in both large-scale and small-scale systems. There is a need for further research and development in order to overcome these problems and thereby contribute to meeting the energy needs of both rural and urban communities. This work begins by identifying the factors that influence methane production during AD. This was achieved from relevant literature. The design objectives, as well as engineering constraints that are relevant to DBDs, were identified. A House of quality matrix is used to analyze the relationships between the design parameter and the engineering specifications. These factors were used as guidelines to create design concepts. The design concepts are sketched and modeled using parametric CAD software (Solidworks). From these concepts, the best design is selected using the Pugh method and a scoring matrix,1.**

***Keywords* — Anaerobic Digester, Biodigester, Organic Waste, Methane.**

## I. Introduction

The use of Methane gas as a fuel is continuing to increase. In many applications, Methane gas is replacing other fossil fuels such as coal and oil. Traditionally Methane was acquired as a by -product of drilling for oil. As the demand for natural gas increased new techniques were developed specifically to extract natural gas from underground reserves.

There is increasing scope for the use of methane gas as a fuel in developing countries. Where demand for energy is increasing while capital resources remain limited. There is a need for efficient and cost-effective facilities for the production of energy in both rural and urban areas. There is also a need for efficient, hygienic and cost-effective facilities for the disposal of organic waste in both rural and urban areas. In order to prevent the build-up of toxins and pathogens in the environment, which often leads to diseases. Both problems can be solved through anaerobic digestion process.

It has been proven that the anaerobic digestion process can be exploited as a tool for waste management and energy production. The process takes in organic material and water as influent and produces water as well as nutrient rich organic solids and natural gas. Work has been done to design mechanisms for producing Methane through anaerobic digestion, most of this work has been focused on large-scale operations aimed at producing a large amount of electric power. Such facilities have achieved good results and they pose a viable means of reducing dependency on fossil fuels for power generation.

There are many designs available for small-scale biodigesters that are meant for domestic use. These digesters are aimed at producing biogas from the organic waste that is produced by the household. The gas will then be used to supply energy for cooking, lighting, or running an electric generator. The issue with current designs is that most of them are either oversimplified or too complicated for domestic use. Most of these systems break down easily and the owners are not able to get them running properly again.

## II. Mathematical Modelling of Anaerobic Digester

Due to the increase in the use of anaerobic digesters (AD), there is a great deal of interest in analyzing the performance of Biodigesters. It is necessary for us to be able to predict or calculate values such as the Methane output, energy consumption, rates of total solids (TS) removal, etc. These predictions can be made using mathematical models. There are some general chemical equations that can be useful in this regard, there are also mathematical protocols such as the Anaerobic Digestion Model No. 1 (ADM1) that have been developed specifically to analyze the AD process

AD is a complex process that involves 4 stages of material decomposition. This process can be described in a simplified generic chemical equation (1).

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4 \quad (1)$$

A balanced chemical equation represents both the qualitative and quantitative description of a chemical reaction. Stoichiometry of anaerobic digestion is affected by alkalinity and consequently on pH as well as potential biogas (methane) production. Stoichiometry is a study of the quantities of products in relation to the quantity of reactants due to chemical reactions. Taking the structural formula of secondary sludge to be $C_5H_7O_2N$. Acid and methanogenic fermentation can be expressed as acid fermentation (2) and

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methanogenic fermentation (3).

$$C_5H_7O_2N + 3H_2O \rightarrow 2.5CH_3COOH + NH_3 \rightarrow 2.5CH_3COO^- + 1.5H^+ + NH_4^+ \quad (2)$$

$$2.5CH_3COO^- + 2.5H^+ \rightarrow 2.5CO_2 + 2.5CH_4 \quad (3)$$

The overall anaerobic digestion can be summarized as (4) or (5).

$$C_5H_7O_2N + 3H_2O + H^+ \rightarrow 2.5CO_2 + 2.5CH_4 + NH_4^+ \quad (4)$$

$$C_5H_7O_2N + 4H_2O \rightarrow HCO_3^- + 1.5CO_2 + 2.5CH_4 + NH_4^+ \quad (5)$$

Stoichiometry can be used to calculate the potential of methane generation (BMP) of a digester, bearing in mind that 1 gram of CH4 with a chemical oxygen demand (COD) content of 4 grams, will be generated from the digestion of 4 grams of organic matter expressed as COD. So the mass of produced methane can be calculated using total digested sludge production and the composition of the mass fractions of primary and secondary sludge [1].

In a review of steady state and dynamic models of the kinetics of anaerobic digestion a dynamic model developed by Hill (Auburn University, AL) was found to be sufficiently accurate and complex to form the basis for a recommended general solution for use in optimizing the gas yield from the AD process [2]. A steady state solution to Hill's simplified dynamic model was developed. (6) shows an empirical expression for the steady state digestion of animal wastes.

$$C_6H_{12}O_6 \rightarrow 0.24C_5H_7NO_2 + 2.516CH_4 + 2.279CO_2 \quad (6)$$

Hill's successfully developed a simplified dynamic model for analyzing the digestion process. The initial rates technique is able to produce accurate predictions for the steady state behavior of AD systems. Hills uses kinetic parameters which are intrinsically independent of the type of waste. This means that the modal can be applied effectively to various types of waste. The modal requires only two parameters that are specific to the type of waste that is biodegradability and acid factor. However, the modal is best used for specific substrates under mesophyllic conditions, so there is still a need for a more generalized protocol [2].

In recent time's mathematical models have become popular tools used in the design, operation and control of AD systems. In order to extend the use of mathematical models in AD, there is in need for a general modal that is applicable in a variety of situations. In 1997 the International Water Association (IWA) set up a task force to develop such a model. The Anaerobic Digestion Model No. 1 (ADM1) was created by this task force. ADM1 is a structured mathematical model that accounts for all 4 steps in the AD process. The model is expected to promote further use of mathematical models to analyze and improve AD processes. The Anaerobic Digestion Model No. 1 (ADMI) can be used to simulate the biochemical conversions in the AD process, as well as to calculate biogas production and composition. A detailed characterization of the influent is required to facilitate accurate results. Some modifications can be made to ADM1 in order create a dynamic energy balance model to calculate the net energy production of the digestion. The energy balance model demonstrated that most of the energy produced is consumed by the digester itself. This justifies a detailed calculation of the net energy production, especially since detailed knowledge of the system energy can be gained by using mathematical simulation [3].

There is currently a focus on determining accurate mathematical models for the anaerobic digestion process. Tomei et al produced a review of the various mathematical models available for describing the anaerobic digestion. Some are simple and basic others are more complex it is necessary to find a way to co relate the different models in order to create a homogenized model. As described by Batstone and co-authors, Anaerobic Digestion Model No. 1 (ADM1) was developed by the IWA Task Group for this purpose [4]. The ADM1 acts as a unified base for modeling anaerobic digestion and it uses nomenclature, units that are common in anaerobic modeling literature. Although ADM1 is capable of accurate predictions there are some issues that are yet to be solved. Regarding the kinetics of the disintegration and hydrolysis process. This is a crucial parameter in the ADM1 yet it is accepted that the method used to determine this value is inferior to other methods. Also, most of the parameters used assigned a default values and are considered to be constant based on previous research. New mathematical models are needed for the anaerobic digestion of solid waste and this is not addressed in current models. There is also a need to include data about microbial communities in the mathematical models. ADM1 assumes that all the microbial communities have similar features this limits its ability to predict performance accurately. For accurate results we must consider only one substrate at a time. Ramirez and Steyer suggested improving ADM1 by replacing the average kinetic values with a set of 10 kinetic parameters, each for a separate species of microbe. However, many assumptions still have to be made due to the complexity of the processes [5]. More data about the anaerobic process will help mathematical models to make more accurate predictions under various conditions.

## III. Design Methods

Considering that our aim is to design a prototype domestic biodigester (DBD) it is necessary to define what a biodigester is. It is also important to determine the parameters that are relevant to the performance of a biodigester. Design parameters represent the engineering specifications that apply to a product. These factors denote the essential characteristics of the product that allow it to function as it is intended to. A biodigester also called a bioreactor is an apparatus that is designed to facilitate the process of anaerobic digestion (AD), and to capture the gas that is produced in the process. In principal a biodigester is simple to construct and there are many possible designs for a bioreactor. However, every functional biodigester must consist of an enclosed container to hold the substrate and the gas under anaerobic conditions. A biodigester must also have three pipes attached to the substrate container, one for adding influent, one for extracting gas, and one for extracting effluent.

TABLE I: DESIGN PARAMETERS AND ENGINEERING SPECIFICATIONS

| Parameter / Factors | Desired qualities | Engineering Specifications |
|---|---|---|
| Temperature | Mesophilic bacteria 20ºC – 45ºC<br>Thermophilic bacteria 50ºC – 65ºC | Bio reactor color |
| Organic loading rate (OLR) | Adequate loading for domestic cooking needs | Bio reactor Volume |
| Retention time (HRT) | Minimal Hydraulic retention time | Bio reactor Volume |
| pH balance | 6.4 – 7.2 | pH monitor |
| Feasibility | Minimal effort to manufacture | Minimum # of processes |
| Durability | Maximum reliability | Material selection |
| Ergonomics | Comfortable for users | Bio reactor dimensions |
| Cost | Minimal cost of production | Minimum # of components |

There are several factors that affect the production of Methane through the AD process. It is necessary to consider these factors and account for them when designing an anaerobic digester. These factors are listed below.

a. Total solids (TS) content; The amount percentage of solid material (TS) in comparison to water in an AD system has significant effects on biodigester performance.
b. Temperature; Temperature is a major factor that influences AD. This is because temperature affects the activity of the micro-organisms involved in the process. Mesophilic bacteria generally function best between 20 ºC and 45 ºC, while Thermophilic bacteria prefer temperatures between 50 ºC and 65 ºC.
c. Retention time (HRT); The Hydraulic Retention Time (HRT) this value shows how much time it takes for an amount of water to pass through the system. AD typically has high values for HRT. Mesophilic bacteria's HRT is between 15–30 days, compared to Thermophilic bacteria which have HRT between 12–14 days.
d. Acid / Alkaline balance pH; The ideal pH level is different for different stages of the AD process. In order to function well pH levels must remain between 6.4 and 7.2, pH levels below or above this range are toxic to the bacterial communities.
e. Carbon to Nitrogen ratio (C:N); High Nitrogen levels are associated with low methane yields because the methogens are rapidly consuming nitrogen instead of Carbons. High Carbon levels lead to the accumulation of ammonia which raises the pH levels in the substrate. pH levels above 8.4 are toxic to bacterial communities.
f. Mixing; It is important for there to be contact between the micro-organisms and fresh substrate. This can be achieved through mixing or stirring the substrate.
g. Organic loading rate (OLR); ORL measures the biological conversion capacity of a digester. OLR can be defined in kg as chemical oxygen demand (COD), or in $m^3$ as volatile solids (VS). OLR is an important factor to consider because excessive feeding of biodigesters causes the accumulation of fatty acids and reduces biogas production.

*A. Required Parameters and Specifications*

Total solids (TS) content and Carbon to Nitrogen ratio (C:N) are both very influential in the AD process. However, these factors cannot be addressed through bio-digester design. These two factors are more relevant to pre-processing of feedstocks rather than the digester itself. This work will not address mixing due to the high energy input required to operate the mixer. For this reason, the focus shall be on the remaining factors listed above as well as four additional factors which are Cost, Feasibility, Durability and Ergonomics. The relationship between these eight parameters and the relevant engineering specifications that satisfy these parameters is discussed below.

a. Temperature: The desired temperature range depends on the type of bacteria that is dominant in the system. Mesophilic bacteria generally prefer 20 ºC and 45 ºC, while Thermophilic bacteria prefer temperatures between 50 ºC and 65 ºC. The temperature inside the DBD can be affected by the color and texture of the outer surface of the DBD. Temperature can be raised by painting the surface with matte black paint. Which will allow the surface to absorb heat from the atmosphere. Similarly, the temperature can be lowered by painting the same surface with white gloss paint. This will cause the surface to reflect more heat and keep the interior of the DBD cooler.
b. Organic loading rate (OLR): The desired rate of organic loading depends on the volume of the biogas reactor. The Appropriate rural technology institute of India (ARTI) biogas concept is designed to use a 1 $m^3$ reactor volume to process 1–2 kg (ODS) of Food Waste (FW) over 24 hours [6]. The appropriate volume for the design concepts will be based on this ratio.
c. Hydraulic retention time (HRT): It is desirable to have the lowest possible HRT in order to free up the water for other uses. The best way to minimize HRT is to ensure that the bioreactor is operating at maximum efficiency. This can be done by attaining the correct balance between biogas output, influent volume, and reactor volume.
d. pH balance: The desired pH levels are between 6.4 and 7.2. In order to ensure that the level remains within this range, it is necessary to incorporate a pH monitoring system into the DBD design. pH monitoring will allow the DBD operator to take necessary action in order to restore the desired levels.
e. Feasibility: This relates to how easily the design can be fabricated. It is best to minimize the amount of effort required to make the product. This can be done by minimizing the number of manufacturing processes involved in the fabrication. The fewer the processes the easier it will be to produce the product.

f. Durability: This relates to how reliable the product will be. It is desirable for the product to be able to continue to function reliably under harsh conditions for a long time. This can be addressed through material selection. I have chosen to use HDPE plastic for the bioreactor and the gas holder due to the material's high levels of strength. PVC has also been proven to be robust reliable material. PVC was chosen for the pipes and connecting components.

g. Ergonomics: This relates to how way it is for the operator to use the product. It is desirable for the product to be highly user-friendly. This can be achieved by ensuring that the DBD design is ergonomic. This means that the dimensions of the DBD must be selected with reference to the size of the human body. So that users do not have to bend or stretch or strain excessively in order to operate the DBD.

h. Cost: This relates to the financial cost of making the prototype. It is desirable for the cost of the product to be as low as possible. It is noted that material costs generally constitute the majority of total manufacturing costs. In light of this, we can see that the cost of the product can be reduced by minimizing the number of components in the product. It is also best to use as many standard stock components as possible. Since custom components invariably cost more than d standard parts. Fewer custom parts will make the product cheaper to produce.

## B. *House of Quality*

A House of quality (HOQ) matrix will be used to analyze the relationships between the design parameter and the engineering specifications. Several relationships can be analyzed in Table II, these include; correlations between different design factors and engineering specifications, correlations between individual engineering specifications, and comparisons between similar products and the proposed prototype. A scale of 1 to 5 is used to rate the parameters/factors based on the data gained from the literature review. A scale of 3, 6, and 9 is then used to rate the relationship between each factor and the list of engineering specifications. 9 is indicated where there is a strong relationship, 6 where there is a moderate relation and 3 is assigned when there is a weak relationship.

The H.O.Q will determine the engineering priorities for the design concepts. A ranking will be given to each engineering specification based on how relevant it is to the design parameters. Top priority will be given to the highest scoring engineering specifications.

TABLE II: HOUSE OF QUALITY MATRIX

Key;
O = Strong synergy
Δ = Weak synergy
□ = Weak conflict
◊ = Strong conflict

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | Δ | | | | | |
| □ | Δ | O | □ | | | |
| | | | Δ | O | | |
| □ | | | | | | |
| □ | O | Δ | □ | | □ | Δ |

| Direction of movement | | + | = | = | + | = | + | + | = | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Units | | | $m^3$ | m | | | $j/m^2$ | | | | | | | |
| 9=strong connection<br>3=moderate connection<br>1=weak connection | Customer importance | Reactor color | Reactor volume | Reactor dimensions | pH monitor | Min. No. of processes | Material strength | Reactor design | Min. No. of components | ART1 concept | Proposed product | Competitor ratio | Improvement ratio | Relative weight |
| Temperature | 4 | 9 | – | – | – | – | – | – | – | 1 | 4 | 4.00 | 16 | 0.29 |
| Organic loading rate (OLR) | 4 | – | 9 | 9 | 3 | – | – | – | – | 3 | 3 | 1.00 | 4 | 0.07 |
| Hydraulic retention time (HRT) | 4 | – | 9 | 9 | – | – | – | – | – | 3 | 3 | 1.00 | 4 | 0.07 |
| pH levels | 4 | – | – | – | 9 | – | – | 3 | – | 1 | 4 | 4.00 | 16 | 0.29 |
| Manufacturability | 4 | 3 | 1 | 3 | 3 | 9 | 1 | – | 3 | 5 | 5 | 1.00 | 4 | 0.07 |
| Durability | 3 | – | – | – | – | – | – | – | – | 3 | 4 | 1.33 | 3.99 | 0.07 |
| Ergonomics | 3 | – | 1 | – | – | – | – | 9 | – | 2 | 3 | 1.50 | 4.50 | 0.08 |
| Cost | 3 | 1 | 1 | 1 | 1 | 9 | – | 3 | 9 | 4 | 4 | 1.00 | 3 | 0.05 |
| Abs. important | | – | – | – | – | – | – | – | – | | | | 55.49 | 0.99 |
| Rel. important | | – | – | – | – | – | – | – | – | | | | | |
| Rank order | | 6 | 2 | 1 | 4 | 3 | 8 | 5 | 7 | | | | | |

Table III shows the list of parameters in order of priority based on the HOQ. It is noted that Reactor Dimensions and Reactor volume score higher than the other parameters. This is because the two factors are very similar, they have high synergy which increases their individual relevance. Reactor Volume simply measures the capacity of the biodigester. While Reactor dimensions relate to the ratio of height and base area. It is important to consider the intended Biogas output when designing a bioreactor. So as to match the reactor volume to the intended biogas output.

TABLE III: DESIGN PRIORITIES

| Parameter | Priority |
|---|---|
| Reactor dimensions | 1 |
| Reactor volume | 2 |
| Min # of processes | 3 |
| pH Monitor | 4 |
| Reactor design | 5 |
| Reactor color | 6 |
| Min # of components | 7 |
| Strength of materials | 8 |

### C. *Conceptual Design*

The design concepts will be sketched and modelled using parametric CAD software (Solidworks). From these concepts the best design will be selected using Pugh method and a scoring matrix. A brief discussion about each concept is given below. The conceptual design characteristics is also presented in Table IV.

In order to minimize production costs, the concept of elephant 1 as shown in Fig. 2 is designed around pre-existing standard components. The bioreactor and gas holder will be made from High-density polyethylene (HDPE). This is a cheap and robust material that can function reliably for a long time under the operating conditions of a DBD. In terms of Ergonomics standard plumbing supplies are typically designed to be user-friendly. For example, the height of standard drums is such that the drums can be opened and closed easily. However, using stock parts has a disadvantage in that the volume of the reactor will depend on the availability of the right size drum, rather than ideal design specifications. This design will also facilitate easy pH monitoring by allowing a pH strip to be dipped into the center of the main substrate volume through the feed pipe which is centrally located. This will give better results than pH strips that are dipped into a feed pipe that is outside of the digester.

An attempt to improve upon the ARTI biodigester concept, by reducing the amount of Biogas that is lost to the atmosphere is presented in Fig. 3. A custom bioreactor and gas holder have been designed for this purpose. The design aims at minimizing the gap between the bioreactor and the gas holder while also minimizing friction between the two bodies. The bioreactor and gas holder will be made from High-density polyethylene (HDPE). In terms of Ergonomics the dimensions of the reactor and gas holder are designed to be user-friendly. Standard plumbing supplies will be used for the remainder of the components. These are also typically designed to be user-friendly. Using custom components for the reactor and gas holder has the disadvantage of making the design more difficult to fabricate as well pushing up the cost of the project. This design will facilitate pH monitoring by allowing a pH strip to be dipped into the external feed pipe at the side of the reactor.

Fig. 4 is a pre-fabricated Biodigester design that can be broken down into small interconnecting components for easy transportation. The design is inspired by classic wine barrels. The reactor will consist of two round HDPE discs that make up the base and the top of the reactor. A number of curved strips will be placed around the discs until the volume is closed. Then the strips will be fastened to the discs via grooves that are cut into the strips and two metal belts that will be tightened around the strips. In terms of Ergonomics the dimensions of the reactor are user-friendly. Standard plumbing supplies will be used for the remainder or the components. These are also typically designed to be user-friendly. This design does not feature a gas holder. It is intended to be used in conjunction with a Biogas scrubber as well as a compressor and a high-pressure storage tank. Using custom components for the reactor and gas holder has the disadvantage of making the design more difficult to fabricate as well as pushing up the cost of the project. This design will facilitate pH monitoring by allowing a pH strip to be dipped into the external feed pipe at the side of the reactor. The table below shows a brief description of how the design will meet the product requirements.

TABLE IV: DESIGN CHARACTERISTICS

| Parameter | Solution | | |
|---|---|---|---|
| | Elephant 1 | Elephant 2 | Elephant 3 |
| Reactor dimensions | Dependent on availability of existing products | Can be determined by optimal reactor volume | Can be determined by optimal reactor volume |
| Reactor volume | Dependent on availability of existing products | Can be determined by required biogas output | Can be determined by required biogas output |
| Minimum number of processes | No custom component required. Simple assembly procedure | Custom component required. Simple assembly procedure | Custom component required |
| pH Monitor | pH strips can be dipped into the center of the substrate | pH strips can only be dipped in to the external feed pipe | pH trips can only be dipped in to the external feed pipe |
| Reactor design | Ergonomic placement of pipes and valves | Ergonomic placement of pipes and valves | Ergonomic placement of pipes and valves |
| Reactor color | Can be easily painted matte black of gloss white | Can be easily painted matte black of gloss white | Can be easily painted matte black of gloss white |
| Minimum number of components | Design is streamlined no unnecessary components | Design is streamlined no unnecessary components | High number of parts. Requires auxiliary equipment |
| Strength of materials | HDPE plastic | HDPE plastic | HDPE plastic |

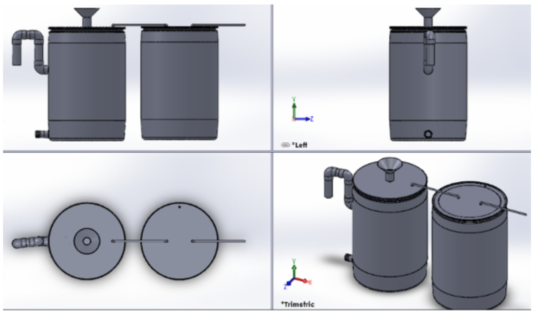

Fig. 2. Elephant 1.

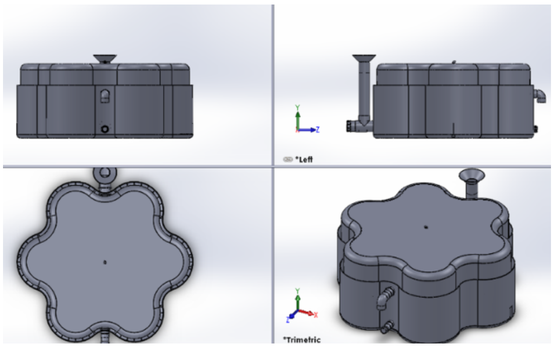

Fig. 3. Elephant 2.

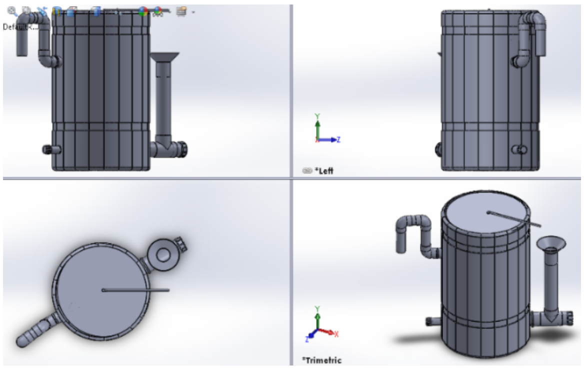

Fig. 4. Elephant 3.

## IV. Concept Evaluation

After completing the conceptual designs, it is necessary to select the best design. It is best to make this selection through a process of systematic design evaluation. There are several techniques that can be used for this purpose. Among them, I have chosen the Scoring matrix and the Pugh method for this project. I will use two different techniques in order to verify my selection of the best design. If the evaluation has been done correctly, it is expected that the two separate evaluation methods will produce the same results. A brief description of how each method works is discussed below as well as Table IV and Table V showing the process of evaluation.

### *A. Scoring Matrix*

The Scoring matrix is a simple evaluation procedure. The criteria used to compare the concepts are given by the engineering specifications. A percentage weight is given to each criterion based on its importance to the final product. Each concept is then scored on how well it meets each criterion. The weight of the criterion is divided by 100 and multiplied by the corresponding score. This operation gives a value that represents the weighted rating of the concept with regard to a criterion. The weighted ratings are then added up to give the total score for the concept. The best design is taken to be the concept that has the highest total score. Table V shows the summary of each concept for the scoring matrix

### *B. Pugh Method*

During this evaluation the Elephant 2 concept was chosen as the Datum, meaning that the other two concepts were compared against the Elephant 2 in terms of how well the designs meet the engineering specifications. Elephant 2 was selected as the datum because it is directly based on an existing DBD design (Arti biogas digester concept) which has been proven to be reliable. For parameters where another concept is superior, it is assigned a "+" for that criterion. In cases where another concept is equal to Elephant 2 such as material strength which is similar in all the designs since they are made from the same material, a "0" is assigned to that criterion, a "-" is assigned in cases where the other concept is inferior to the Datum. When all criteria have been considered for both of the other concepts the "+s, 0s, and –s" are added up. The concept that scores the highest net score is taken as the best design. This evaluation found that Elephant 1 performed better than the others in terms of Manufacturability, cost, and pH monitoring. Elephant 1 is the best design because the concept had a positive net score that is higher than the other concepts. A summary of this evaluation is presented in Table VI.

Having performed the evaluations we can see that the Scoring matrix and the Pugh method both reported Elephant 1 as the best design. Therefore, I can be confident design team is confident that Elephant 1 is the best design since two separate evaluation methods reported the same result.

TABLE V: Scoring Matrix

| Criteria | Weight % | Elephant 1 | | Elephant 2 | | Elephant 3 | |
|---|---|---|---|---|---|---|---|
| | | Score (1-5) | Rating | Score (1-5) | Rating | Score (1-5) | Rating |
| Temperature | 14 | 3 | 0.42 | 3 | 0.42 | 3 | 0.42 |
| Organic loading rate (OLR) | 14 | 3 | 0.42 | 3 | 0.42 | 4 | 0.56 |
| Hydraulic retention (HRT) | 14 | 3 | 0.42 | 3 | 0.42 | 3 | 0.42 |
| pH levels | 14 | 4 | 0.56 | 2 | 0.28 | 2 | 0.28 |
| Manufacturability | 14 | 5 | 0.70 | 3 | 0.42 | 2 | 0.28 |
| Durability | 10 | 4 | 0.40 | 4 | 0.40 | 4 | 0.40 |
| Ergonomics | 10 | 4 | 0.40 | 4 | 0.40 | 4 | 0.40 |
| Cost | 10 | 5 | 0.50 | 3 | 0.30 | 2 | 0.20 |
| Total score | | 3.82 | | 3.16 | | 2.96 | |
| Rank | | 1 | | 2 | | 3 | |

TABLE VI: PUGH METHOD

| Criteria | Concepts | | |
|---|---|---|---|
| | Elephant 1 | Elephant 2 | Elephant 3 |
| Temperature | = | DATUM | = |
| Organic loading rate (OLR) | = | | + |
| Hydraulic retention (HRT) | = | | = |
| pH levels | + | | = |
| Manufacturability | + | | - |
| Durability | = | | = |
| Ergonomics | = | | = |
| Cost | + | | - |
| ∑ + | 3 | | 1 |
| ∑ = | 5 | | 5 |
| ∑ - | 0 | | 2 |
| Net score | 3 | | -1 |
| Ranking | 1 | | 2 |

## V. CONCLUSION

It is possible to exploit the process of microbial metabolism to release energy from the decomposition of organic waste materials. During the process of Anaerobic digestion, microorganisms produce Water as well as carbon dioxide and Methane. Methane can be stored and used for cooking or other purposes such as running a generator. By operating a Biodigester, it is possible to provide two essential services within the rural and urban environment, the disposal of organic waste and the production of energy.

Current biodigester designs have achieved good results, but there are some notable problems in both large-scale and small-scale systems. There is a need for further research and development in order to overcome these problems and thereby contribute to meeting the energy needs of both rural and urban communities.

## REFERENCES

[1] van Haandel A, van der Lubbe J. *Handbook biological waste water treatment-design and optimisation of activated sludge systems*. 2007: Webshop Wastewater Handbook.

[2] Husain A. Mathematical models of the kinetics of anaerobic digestion—a selected review. *Biomass and Bioenergy*, 1998; 14(5-6): 561-571.

[3] Lübken M, Wichern M, Schlattmann M, Gronauer A, Horn H. Modelling the energy balance of an anaerobic digester fed with cattle manure and renewable energy crops. *Water research*, 2007; 41(18): 4085-4096.

[4] Batstone DJ, Keller J, Steyer J. A review of ADM1 extensions, applications, and analysis: 2002–2005. *Water science and technology,* 2006; 54(4): 1-10.

[5] Ramirez I, Volcke EIP, Rajinikanth R, Steyer JP. Modeling microbial diversity in anaerobic digestion through an extended ADM1 model. *Water research*, 2009; 43(11): 2787-2800.

[6] Voegeli Y, Lohri CR, Kassenga G, Urs B, Zurbrügg, C. Technical and biological performance of the Arti compact biogas plant for kitchen waste-case study from Tanzania. in *Proceedings Sardinia.* 2009.