# DESIGN OF BIOGAS SEPTIC TANKS FOR TREATING DOMESTIC SEWAGE

By

**Mawufemo Modjinou**

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## DECLARATION

I hereby declare that this submission is my own work towards the MSc in Renewable Energy Technologies and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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| Mawufemo Modjinou | PG63092-11 | ……………………………… | ………………. |
| Candidate | ID | Signature | Date |

Certified by:

| | | |
|---|---|---|
| Dr. Lawrence Darkwah | ………………………………. | ……………… |
| Supervisor | Signature | Date |

Certified by:

| | | |
|---|---|---|
| Dr. Gabriel Takyi | ………………………………. | …………….. |
| Head of Department | Signature | Date |
| Mechanical Engineering | | |

# ABSTRACT

This study is to design a novel septic tank, named Anaerobic Upflow Domestic Septic Tank (AUDST) to recover biogas as energy and treat domestic sewage. The green technology proposes alternate options to existing Domestic Septic Tanks (DST), encourages anaerobically pre-treatment to reduce bacteria, pollutants, Total Suspended Solids (TSS), Chemical oxygen demand (COD) and Biological oxygen demand (BOD) before the effluent is discharged or is removed by cesspit trucks. Studies have shown that DST in homes partially treat or just store sewage. Again, these DST have to be emptied from time to time because it lack features that will sustain anaerobic activity and usually the sludge is disposed of directly into the sea, water bodies and even into open places such as “Lavender Hills’’ without any treatment or disinfection. These practices cause severe public health and environmental problems. To tackle the challenge at household level, DST are redesigned to treat domestic sewage with less management, low operating cost, low secondary discharge of pollutants. The proposed new design concept is operated through three (3) units: such as desilting, anaerobic digestion and facultative filtration units. The anaerobic digestion stage is made up of baffle and anaerobic filter for accommodating sludge and providing a more intimate contact between anaerobic biomass and sewage which improves treatment performance. The anaerobic unit is fitted with locally woven baskets prefilled with packing materials. The aim is to strengthen the biological treatment process at this stage. The Facultative Filtration unit of the model is also packed with filtering media such as gravels (3-6mm in diameter) that is low in cost, and has a high durability to produce effluent with lower pollutants and suspended solids content to meet Ghana’s Environmental Protection Agency (EPA) standards for the discharge of domestic effluents.

**ACKNOWLEDGEMENT**

Words cannot express my gratitude first and foremost to God Almighty for helping me throughout this project. Without His grace, this work will never have been completed. My profound thanks goes to my supervisor, Dr. Lawrence Darkwah, for his support and guidance throughout the duration of this research and his immense work in editing every single page of this document. His expertise in biogas technologies improved my research skills and prepared me for future challenges.

Again, my sincere thankfulness goes to the late Prof. Brew Hammond Abeeku, Director of The Energy Centre and Chairman of the Energy Commission (EC) who encouraged me to carry out this study, may his soul rest in perfect peace.

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## ABBREVIATIONS

DST- Domestic Septic Tank

COD - Chemical oxygen demand

BOD – Biological oxygen demand

BT - Biogas Tank

BFT - Biogas Filtration Tank

EPA – Environmental Protection Agency

TDS - Total Dissolved Solids

FC - Faecal Coliforms

SS - Suspended solids

$NH_4$-N - Ammonium

TC - Total Coliforms

$NO_3$-N - Nitrate

# CHAPTER ONE

# INTRODUCTION

## 1.1. BACKGROUND

There have been several concerns from experts in the field of biogas especially in Ghana and to a great extent throughout the world about the possibility of redesigning domestic septic tanks (DST) into biogas producing system. Septic tank with anaerobic and aerobic processes that will encourage pre-treatment of sewage at household level and provide an alternate options to existing DST is inevitably going to be introduced because of high level pollution of the environment with untreated human waste in recent times.

Also, studies have shown that Domestic septic tanks (DST) in homes produce effluent that is rich in organic matter and bacteria. Sludge from 75 septage samples from Accra residents in Ghana were characterised by an average Helminthes (parasitic) eggs of 4,000 no/l and Chemical oxygen demand (COD) concentration of 6,400 mg/l, which indicates that domestic septic tanks only partially treat sewage (Kuffour *et al*, 2009). The DST in homes lack features that will induce and sustain anaerobic digestion of sewage. As a result, the DST get full quickly and have to be emptied from time to time.

Also, a survey by the Ghana Environmental Protection Agency (EPA) in 2001 revealed that less than 25% of the 46 industrial and municipal sewage treatment plants (conventional plants) available in Ghana were functional. Another, inventory conducted in 2006 indicated that only about 10 of the treatment plants are operational (Obuobie *et al*, 2006). This sharp fall in the number of sewage treatment facilities has led to recent environmental problems and sewage management that we face as country. Consequently, sludge from DST is disposed of directly into the sea and water bodies through some of these overloaded facilities untreated.

The disposal site nicknamed “Lavender Hill” continues to be a major problem to most residents living in and around Korle-Gonno in the Ablekuma South Constituency. Residents are not spared from houseflies that constantly storm their houses. In fact, “Lavender Hill” has become a major source of public concern in recent weeks as cesspit trucks from Accra Metropolis, Ga South Municipality, Kasoa in the Central Region, Madina in the La Nkwatanang Municipality, and even Nsawam travel a long distance to dislodge untreated sewage into the sea (Asare, 2013). Although the Accra Metropolitan Assembly has indicated it is going to decommission a broken down liquid waste disposal site popularly known as Lavender Garden or Hill, it still continues to receive hundreds of cesspit tankers everyday which discharge their contents directly into the sea near Accra's Light House at James Town (Edmund, 2013) as shown in figure 1 below.


Figure 1: Discharge of untreated sewage at Lavender Hill in Accra trickling into the sea
Source: Asante, 2013

Everyday, tonnes of untreated human waste and household sewage are being discharged directly into the sea and water bodies polluting the environment putting human and marine lives at risk. In fact, the reduction in the numbers of treatment plants can be attributed to the fact that the conventional methods are electricity (energy) dependent and also when the mechanical parts become faulty, the part has to be imported making it too expensive to maintain. Previous experience has shown in other countries that decentralization of septic tanks that treat sewage by anaerobic processes at household level requires less management (less sludge disposal), low operating cost and low secondary discharge of pollutants and energy is also recovered in the form of biogas. This project seeks to re-engineer domestic septic tanks into sewage treating and biogas generating tanks. The new proposed model adopts household digesters technology and equips it with a desilting, anaerobic filter and facultative filtration or contact aeration. The re-engineering which considers the EPA Discharge Guidelines of treated domestic sewage, results in comparatively lower pollutants such as SS ($\leq$ 50 mg/l), COD and $NH_3$-N. The new design needs no energy to treat sewage but rather biogas can be recovered as energy. Meanwhile for the conventional plants, 0.20-0.26 kWh of electricity is needed to treat 1 $m^3$ of sewage (Stensel *et al*, 2002). Domestic septic tanks treating and generating biogas can yield a whole range of benefits for users, the society and the environment in general. The main benefits are:

a) Sewage treatment is decentralized at household level.
b) Reduction of pathogens, worm eggs and flies for a better hygienic conditions
c) Production of energy (heat, light, electricity etc.).
d) Protection of natural resources such as forests, soil, water and air.

Another positive advantage that this project presents is the removal of additional cost and barrier faced by households in acquiring a new biogas plant. It is also envisaged that this new design will really jump start a sustainable home retrofitting in the country on a large scale.

## 1.2. PROBLEM STATEMENT AND JUSTIFICATION

DST partially treats or just store sewage and produces effluent rich in organic matter and bacteria as indicated by studies. For this reason, this project looks at continuing septic tank design and performance researches that were carried out in the past to better treat domestic sewage and generate biogas which can supply energy for domestic use. This project is relevant simply because every household is required to install or have a septic tank and will address the challenge faced with limited number sewage treatment plant that is available to the country causing dislodge of sludge from DST into lagoons or full treatment facilities pending decommission. The novel design is suitable at places where there is no centralised wastewater treatment plant and cities that do not have municipal sewage treatment system. Again, the huge one time capital investment required by conventional central treatment plant is decentralized at household level. Finally, the financial challenges faced in obtaining a new biogas system will be eliminated by simple installation of one of this novel design to perform the task of a conventional septic tank and generate biogas in addition.

## 1.3. AIMS AND OBJECTIVES

The main objective of this project is to design a novel septic tank to meet sanitation requirements and energy demands of households and institutions.

The specific objectives of the thesis are as follows:

a) propose alternate model options to existing domestic septic tanks

b) design an anaerobic digestion and filtration units for the proposed design

## 1.4. SCOPE AND LIMITATIONS

This project was carried out to provide domestic septic tank models that generate biogas and treat sewage. The performance status of DST in treating sewage was identified by research to be poor in Ghana, hence new concepts for existing DST models was considered in this project. The aspects look into were hydraulic digester design in a historic context, anaerobic treatment process, packing and filtration media, design concepts, engineering design, detail engineering and isometric drawings for illustration purposes. Field construction and other subsequent activities such as wetland design for the treatment of effluent are beyond the scope of the current study.

## 1.5. OUTLINE OF THESIS

The following is a brief summary of the overall layout of the thesis;

a) The background, problem statement, objectives, scope and limitations are outlined in Chapter 1

b) Chapter 2 reviews the literature on biogas research and development in Ghana, wastewater treatment in urban and rural areas, historic context of re-engineering domestic septic tanks, biological wastewater treatment processes, composition and pollutants of domestic sewage in Ghana.

c) The Chapter 3 looks at the design concepts, process design, preliminary design of Biogas Filtration Tank and Biogas Tank, detail and isometric drawing of Biogas Filtration Tank and Biogas Tank,

d) Chapter 4 covers the technical-economical analysis and management of the designs

e) Chapter 5 concludes the project and presents recommendations for future work.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1. RESEARCH AND DEVELOPMENT OF BIOGAS TECHNOLOGY IN GHANA

A biogas plant has been described to consist of a mixing chamber, an airtight digester with an agitator, a pond for the slurry and a gas-holder. The feedstock, which is mainly dung and poultry droppings is mixed with water in the mixing chamber and emptied into the digester where it is metabolised by micro-organisms. Biogas and digested substrate are the main output products. The latter is stored in a standard manure storage tank known as a gas storage tank. Biogas consists of approximately 60:40 mixture of methane ($CH_4$) and carbon dioxide ($CO_2$) with calorific value of 23 $MJ/m^3$, and can be used to fuel internal combustion engines to generate electricity. It can also serve as cooking and heating fuel (Akuffo *et al*, 2004).

### 2.1.1. Earlier state of biogas technology in Ghana

Ghana began exploring the technology in the late 1960s but it was not until the middle 1980s did biogas technology receive the needed attention from government. Most plants, however, collapsed shortly after construction due to immature technologies and poor technology dissemination strategies. In order to revive the technology, a cooperative agreement between Ghana and China led to the construction of a 10 $m^3$ plant at the Bank of Ghana. The Ministry of Energy demonstrated the Appolonia Household Biogas project which was producing gas for direct cooking in twenty seven (27) homes. The biogas was also used to generate 12.5 kW of electricity for the community supplied through a mini-gird. Others included a 1,000 $m^3$ digester capacity plant utilizing human waste located at Kaase a suburb of Kumasi and that at Nkawkaw Catholic Hospital (Brew Hammond, 2008).

### 2.1.2. Current state of biogas technology in Ghana

Following the low involvement of biogas projects by government, a number of private biogas companies have marketed the technology on purely business grounds, and mainly based on the ability of biogas plants to improve sanitation. Currently, the biogas technology has been used in Ghana for cooking in households, direct lighting, and small power generation.

### 2.1.3. Future of biogas technology in Ghana

Despite the relative stagnation of biogas programmes in the country, the future prospects are encouraging. Aside energy, several biogas plants in recent years has been constructed as environmental pollution abatement systems. According to the Energy Commission, studies have shown that Ghana has several opportunities to develop the technology. As a mean to removing the barriers to the development of biogas technology, the Renewable Energy (RE) Act, 2011, Act 832 was passed by the Parliament of Ghana (Otu-Danquah, 2011). Types of biogas systems that have been deployed in the country are shown in the figure below.

**A:** Floating-drum plant
**B:** Fixed-dome plant
**C:** Fixed-dome plant with separate gas holder
**D:** Balloon plant
**E:** Channel-type digester with plastic sheeting and sunshade.

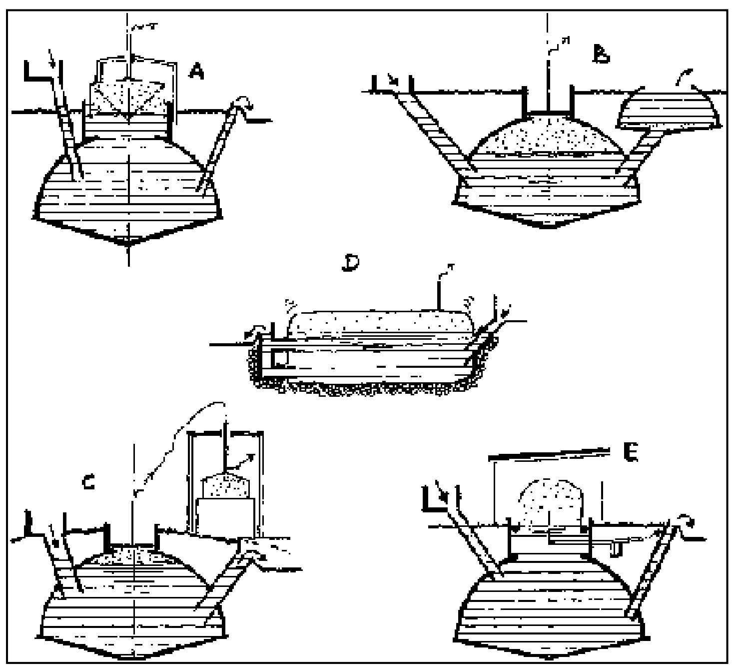



Figure 2: Variations in the Design of Simple Biogas Plants
Source: Sasse, 1988

## 2.2. WASTEWATER IN URBAN AND RURAL AREAS

Wastewater is water whose physical, chemical or biological properties have been changed as a result of the introduction of certain substances which render it unsafe for some purposes such as drinking. Wastewater can be sub-classified as in figure 3 below. It consists of stormwater runoff, industrial effluent and domestic wastewater. The stormwater is runoff precipitation that finds its way across surfaces into receiving waters. Meanwhile, industrial effluent is a type of wastewater generated by industrial processes and containing high levels of heavy metals or other chemical or organic constituents. Last but not least, is the domestic wastewater which made up of liquid waste that flows from washrooms, toilets, kitchens, and other household activities. The day to day activities of man is mainly water dependent and therefore discharge 'waste' into water. Some of the substances include body wastes (faeces and urine), hair shampoo, hair, food scraps, fat, laundry powder, fabric conditioners, toilet paper, chemicals, detergent, household cleaners, dirt, micro-organisms (germs) which can make people ill and damage the environment. It is known that much of water supplied ends up as wastewater which makes its treatment very important.

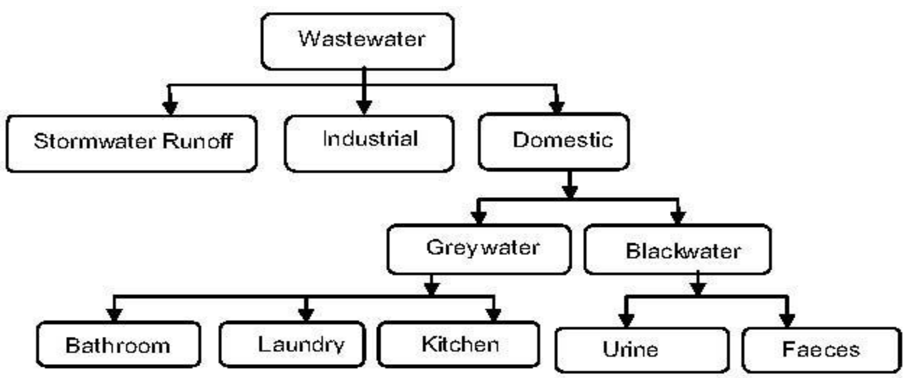



Figure 3: Types of wastewater
Soure: Intechopen, 2004

For the sake of this project, we would concentrate on the domestic wastewater which is usually constituted by *greywater (sullage)*, which is wastewater from washrooms, laundries, kitchens etc. and *blackwater*, which is generated in toilets. Blackwater might contain besides urine and faeces/excreta (together sometimes called nightsoil) also some flush water. The mixture is termed as *sewage* if it ends up in a sewerage system or *septage* if it ends up in a septic tank.

## 2.3. HISTORIC CONTEXT OF RE-ENGINEERING SEPTIC TANKS

China is one of the countries that used biogas early in the world. By the end of the 19th century, agricultural waste covered in pits were found to produce biogas through fermentation process. In 1920, Mr. Luo Guorui built a biogas digester called "Chinese Guorui Natural Gas Store" (CGNGS) in figure 4, which was the first hydraulic digester in China (Guozhong, 2010) and opened China's first biogas technical development company in Shantou City in 1929. Guorui's design is square in shape and can be adopted to form one compartment of domestic septic tank in this project along ABR and AF systems because of their ability to treat wastewater and generate biogas effectively.

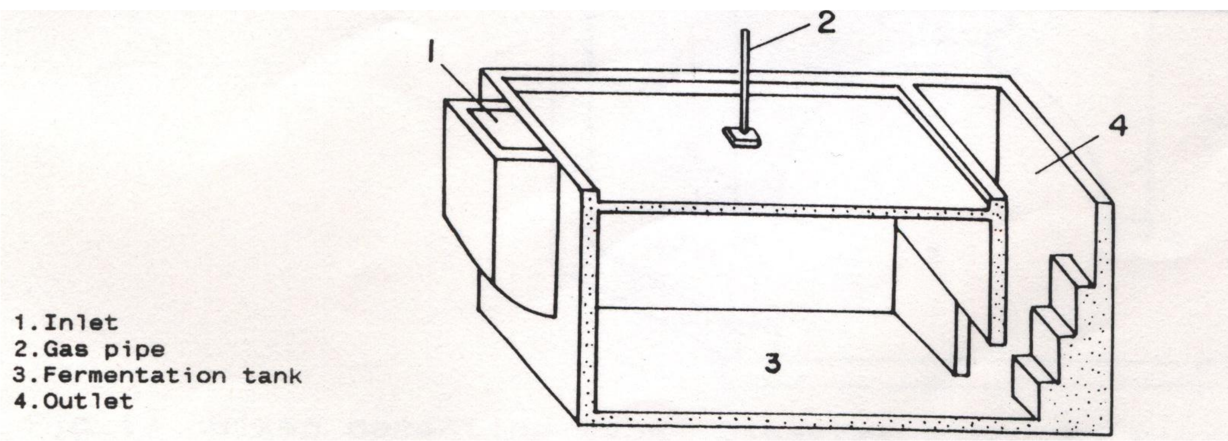
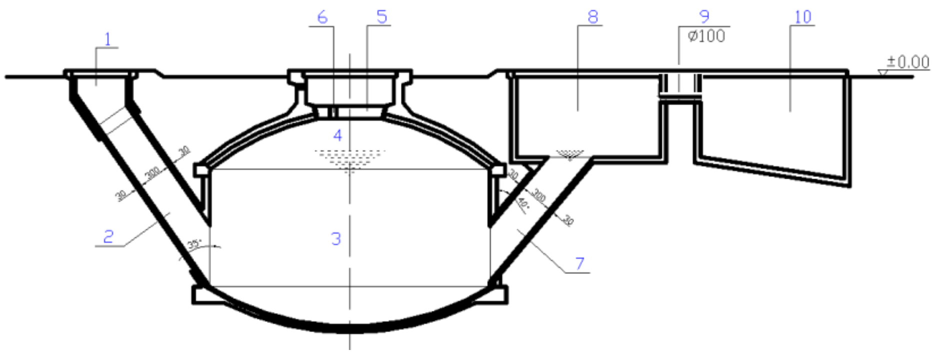



Figure 4: First Hydraulic Digester built in 1920
Source: BIOMA, 2011

Since 1980s, biogas technology has been developed very fast in China rural areas and the designs have change drastically into the fix-dome biogas hydraulic digester shown in figure 5 below. The reason being that curved shell supports more load than a flat slab. Again, curved structural components are more rigid and the stresses are smaller in them.




*1—Inlet; 2—Inlet pipe; 3—Fermentation chamber; 4—Gas chamber; 5—Movable plug; 6—Biogas guide; 7—Outlet pipe; 8—Hydraulic chamber ; 9—Overflow pipe.10—Storage tank.*

Figure 5: Hydraulic biogas digester
Source: BIOMA, 2011.

## 2.4. BIOGAS APPLIANCES

Biogas appliances are domestic appliances. The primary use of biogas was identified for cooking and lighting in homes. As research persist in the use of biogas, other appliances that operate on biogas have been introduced and modernised to a great extent as shown in figure 6 below. These include biogas water heater, biogas rice cooker, biogas generator, large burner biogas stove. It is however recommended that before the biogas can be used in these appliances, it is purified and dehydrated to avoid damage to the appliances.


Figure 6: Modernized biogas appliances
Source: Puxin, 2010

## 2.5. WASTEWATER TREATMENT PROCESSES

### 2.5.1. Primary Treatment

Primary treatment aims at the removal of coarse solid, settleable suspended solids, and part of the organic matter. Primary treatment is thus characterised by physical pollutant removal mechanisms such as sedimentation, and flotation.

### 2.5.2. Sedimentation Tanks

Septic tanks consist of either one or two compartments of settling or sedimentation tank. Most experts tend to agree that two-compartment tank will remove more solids that a single compartment (Loudon *et al.,* 2005). Figure 7 depicts a schematic cross-section of a typical double-compartment septic tank. In a double-compartment septic tank, the first compartment typically comprises 2/3 of the entire tank volume. Septic tanks are designed for gravity separation and substances denser than water settle at the bottom of the tank to form a scum layer. The organic matter retained at the bottom of the tank can undergo anaerobic decomposition and is converted into more stable compounds and gases such as carbon dioxide, methane and hydrogen sulphide. Even though the settled solids undergo continuous anaerobic digestion, there is always a net accumulation of sludge in the tank. This gradual buildup of scum and sludge layer will progressively reduce the effective volumetric capacity of the tank. To ensure continuous effective operation, the accumulated material must therefore be emptied periodically. This should take place when sludge and scum accumulation exceeds 30 percent of the tank's liquid volume.

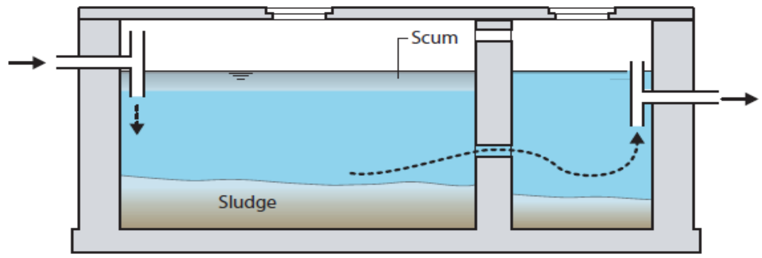



Figure 7: Sedimentation in tanks
Source: source: Morel and Diener, 2006

#### 2.5.2.1. Anaerobic Baffled Reactor (ABR)

An Anaerobic Baffled Reactor (ABR) is an improved septic tank because of the series of baffles under which the waste water is forced to flow. The increased contact time with the active biomass (sludge) results in improved treatment. The anaerobic baffled reactor (ABR) is made up of a series of upflow and downflow baffles, where the baffles are used to direct the flow of wastewater in an upflow mode through a series of sludge blanket reactors. This configuration provides a more intimate contact between anaerobic biomass and wastewater which improves treatment performance. It could be used as primary treatment as well, especially where toilet effluents are diluted with flush water. Separation of the solids retention times (SRT) from the hydraulic retention times (HRT) is the key to the successful operation of an ABR. Due to this fact, a baffled reactor is considered as the best alternative in aerobic treatment and/or primary settlement. The majority of settleable solids are removed in the sedimentation chamber at the beginning of the ABR, which typically represents 50 % of the total volume. The upflow chambers provide additional removal and digestion of organic matter: BOD may be reduced by up to 90 %, which is far superior to that of a conventional septic tank. As sludge is accumulating, desludging is required every 2 to 3 years. Critical design parameters include a hydraulic retention time (HRT) between 48 to 72 hours, up-flow velocity of the wastewater less than 0.6 m/h and the number of up-flow chambers (2 to 3). The treatment efficiency achievable is 70-95% BOD removal, which makes the effluent quality moderate but usually superior to that of a conventional septic tank. This technology is easily adaptable and can be applied at the household level or for a small neighbourhood. An ABR can be designed for a single house or a group of houses that are using a considerable amount of water for clothes washing, showering, and toilet flushing. It is mostly appropriate if water use and supply of wastewater are relatively constant.

This technology is also appropriate for areas where land may be limited since the tank is installed underground and requires a small area. It should not be installed where there is a high groundwater table as infiltration will affect the treatment efficiency and contaminate the groundwater (Bachmann *et al,* 1985). Although the removal of pathogens is not high, the ABR is contained so users do not come in contact with any of the wastewater or disease causing pathogens. Effluent and sludge must be handled with care as they contain high levels of pathogenic organisms. To prevent the release of potentially harmful gases, the tank should be vented. ABR tanks should be checked to ensure that they are watertight and the levels of the scum and sludge should be monitored to ensure that the tank is functioning well. Because of the delicate ecology, care should be taken not to discharge harsh chemicals into the ABR. The sludge should be removed annually using a vacuum truck to ensure proper functioning of the ABR.

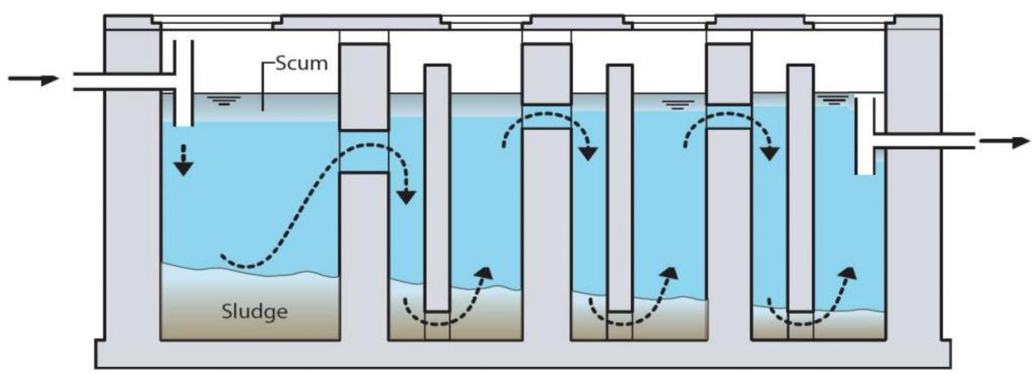



Figure 8: Anaerobic Baffled Reactor (ABR)
Source: Morel and Diener, 2006

### 2.5.2.2. Upflow Anaerobic Sludge Blanket Reactor (UASB)

The Upflow Anaerobic Sludge Blanket Reactor (UASB) is a single tank process. Wastewater enters the reactor from the bottom, and flows upward. A suspended sludge blanket filters and treats the wastewater as the wastewater flows through it. The sludge blanket is comprised of microbial granules, i.e. small agglomerations (0.5 to 2mm in diameter) of microorganisms that, because of their weight, resist being washed out in the upflow. The microorganisms in the sludge layer degrade organic compounds. As a result, gases (methane and carbon dioxide) are released. The rising bubbles mix the sludge without the assistance of any mechanical parts. Sloped walls deflect material that reaches the top of the tank downwards. The clarified effluent is extracted from the top of the tank in an area above the sloped walls. After several weeks of use, larger granules of sludge form which in turn act as filters for smaller particles as the effluent rises through the cushion of sludge. Because of the upflow regime, granule-forming organisms are preferentially accumulated as the others are washed out.

The gas that rises to the top is collected in a gas collection dome and can be used as energy (biogas). An upflow velocity of 0.6 to 0.9m/h must be maintained to keep the sludge blanket in suspension.

The anaerobic degradation of organic substrates occurs in this sludge blanket, where biogas is produced. The biogas produced under anaerobic conditions serves to mix the contents of the reactor as they rise to the surface. The UASB reactor has the potential to produce higher quality effluent than biogas septic tanks, and can do so in a smaller reactor volume. A UASB is not appropriate for small or rural communities without a constant water supply or electricity. A skilled operator is required to monitor and repair the reactor and the pump in case of problems. Although the technology is simple to design and build, it is not well proven for domestic wastewater, although new research is promising. The UASB reactor has the potential to produce higher quality effluent than Septic Tank, and can do so in a smaller reactor volume. Although it is a well-established process for large-scale industrial wastewater treatment processes, its application to domestic sewage is still relatively new. Typically it is used for brewery, distillery, food processing and pulp and paper waste since the process can typically remove 85% to 90% of

Chemical Oxygen Demand (COD). Where the influent is low strength, the reactor may not work properly. Temperature will also affect performance. UASB is a centralized treatment technology that must be operated and maintained by professionals. As with all wastewater processes, operators should take proper health and safety measures while working in the plant. Desludging is infrequent and only excess sludge is removed once every 2 to 3 years. A permanent operator is required to control and monitor the dosing pump (Lettinga *et al*, 1983).

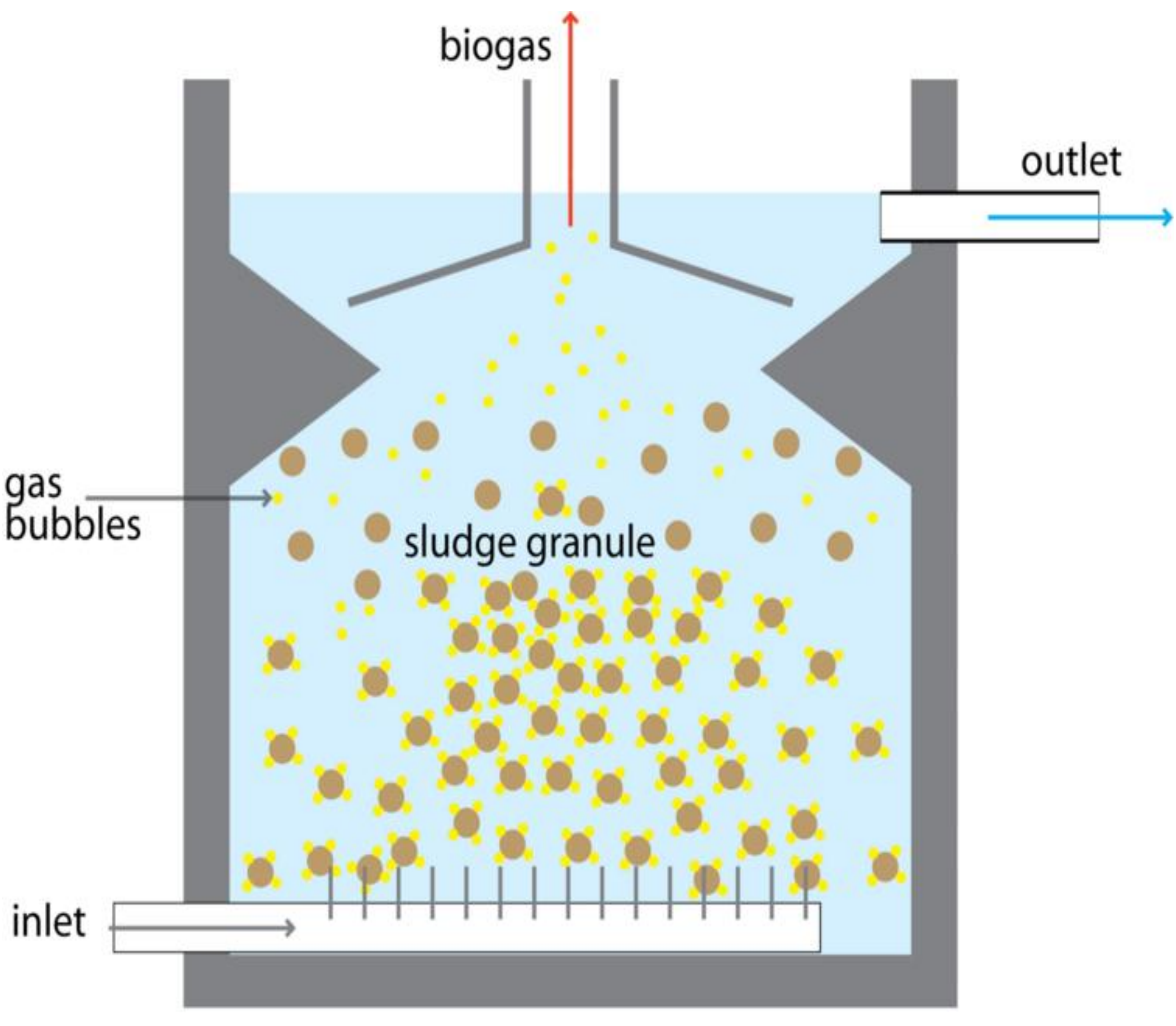



Figure 9: Upflow Anaerobic Sludge Blanket Reactor
Source: Eawag, 2014

#### 2.5.2.3. Pond System for Primary Treatment

Pond systems have been successfully used as preliminary treatment units in low and middle-income countries, though mainly for large-scale applications, as described for example in India (Mara, 1997; Mara and Pearson, 1998). Pond systems are not recommended as primary treatment unit for household greywater. Pond systems look unpleasant, emit odours and offer a perfect environment for mosquitoes if not well-operated and maintained (Ridderstolpe, 2004). The new WHO (2005) guidelines for safe use of excreta and greywater do not promote pond systems if appropriate mosquito control measures are not guaranteed. Septic or sedimentation tanks are recommended as primary treatment unit.

### 2.5.3. Secondary Treatment

The main objective of secondary treatment is the removal of organic matter and reduction of pathogen. After primary treatment, the organic matter present in greywater takes the form of (von Sperling and Chernicharo, 2005):

a) Dissolved organic matter that cannot be removed only by physical processes such as in primary treatment.

b) Suspended organic matter although largely removed in well-functioning primary treatment units, possibly contains solids that settle more slowly and thus remain in the liquid fraction.

The biological process component, where organic matter is removed by microorganisms through biochemical reactions, is of key importance in secondary treatment (von Sperling and Chernicharo, 2005). Microbial decomposition of organic matter can take place under anaerobic and aerobic conditions: Most aerobic systems used for secondary treatment of greywater are based on the principle of attached biofilms. In these systems, biological degradation of suspended and dissolved organic matter occurs as greywater passes a filter media that serves as surface for bacterial growth. The bacteria attached to the filter media decompose the suspended and dissolved organic matter in greywater. Planted and unplanted sand gravel filters are typical treatment systems taking advantage of aerobic attached biofilm processes.

#### 2.5.3.1. Anaerobic Filtration (AF)

Anaerobic filters are widely used as secondary treatment step in household greywater systems. They have been successfully used when placed after septic tank (case studies Palestine, Jordan or Sri Lanka). In Sri Lanka, several hotels and residences successfully operate greywater treatment systems based on anaerobic filters (Harindra Corea, 2001). The anaerobic filter is an attached biofilm system (fixed-film reactor) that aims at removing non-settleable and dissolved solids. It comprises a waterthight tank containing several layers of submerged media, which provide surface area for bacteria to settle. As the wastewater flows through the filter – usually from bottom to top (up-flow) – it comes into contact with the biomass on the filter and is subjected to anaerobic degradation (Figure 10 refers). The primary treatment in a septic tank is usually required to eliminate solids of larger sizes (could be faeces) before greywater is allowed pass through the anaerobic filter.

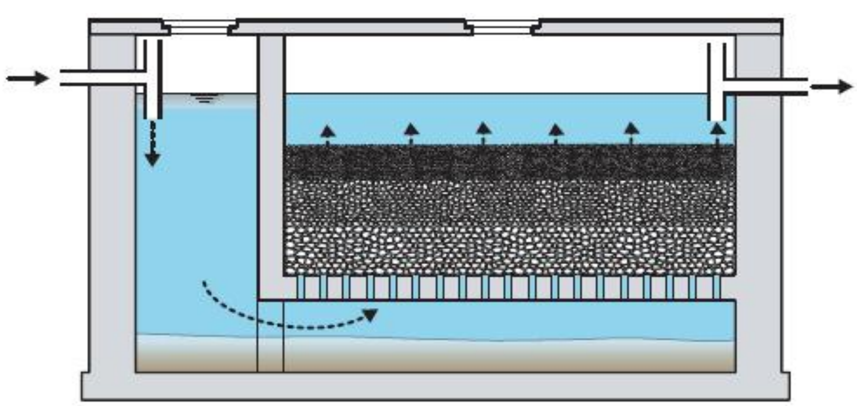


Figure 10: Schematic cross-section of an anaerobic filter
Source: Morel and Diener, 2006

#### 2.5.3.2. Pond system for secondary treatment

Literature on secondary treatment of domestic wastewater treatment with pond on household is scarce. On the other hand, pond systems for full wastewater treatment from primary to tertiary treatment have been successfully implement in both developed and developing countries. These full treatment systems comprise a series of artificial pond, each with the following very specific function: A first deep sedimentation pond for primary treatment of raw wastewater (functioning like open septic tank) is followed by two to three shallow aerobic and facultative oxidation ponds for predominantly aerobic degradation of suspended and dissolved solids (secondary treatment). Polishing ponds finally aim at retaining suspended stabilised solids, bacteria mass and pathogens (Sasse, 1998).

## 2.6. ASSESSMENT OF THE VARIOUS TREATMENT TECHNIQUES

In recent years, improved septic tanks designs have been developed to enhance removal efficiency of unsettleable and dissolved solids; a major drawback of the conventional septic tanks. The basic principle of such systems is to increase contact between the entering wastewater and the active biomass in the accumulated sludge. This can be achieved by inserting vertical baffles into septic tanks to force the wasterwater to flow under and over them as it passes from inlet to outlet. Wastewater flowing from bottom to top passes through the settled sludge and enables contact between liquid and biomass. The improved septic tank system, also known as up-flow anaerobic baffled reactor (ABR) or baffle septic tank, is relatively new. So far, it has mainly been applied in domestic wastewater and toilet wastewater (blackwater). Examples of its application comes from Vietnam, Thailand and Malaysia (Koottatep *et al.*, 2006). First positive experiences with an ABR as primary treatment of greywater were gained in Malaysia, where a three baffled reactor is operated as grease trap and sedimentation tank ahead of a trickling filter and horizontal-flow sand filter. Now, carrying out a comparative assessment of all the technologies for treating wastewater as shown in table 1 below, it was realized that ABR and Anaerobic Filtration systems outweigh other treatment that was look. As a result, they will be adopted for our design in this project.

**Table 1: Comparative assessment of all the treatment systems**

| **Treatment System** | | **Advantages** | **Disadvantages** |
|---|---|---|---|
| *Primary Treatment* | Sedimentation | • Gravity separation<br>• Anaerobic decomposition of organic matter | • Accumulation of sludge that reduce volumetric capacity of the tank<br>• Desludging frequency: Every 2-5 years |
| | Anaerobic Baffled Reactor (ABR) | • Resistant to organic and hydraulic shock loads.<br>• No electrical energy required.<br>• Greywater can be managed concurrently.<br>• Can be built and repaired with locally available materials.<br>• Long service life.<br>• No real problems with flies or odours if used correctly.<br>• High reduction of organics.<br>• Moderate capital costs, moderate operating costs depending on emptying; can be low cost depending on number of users. | • Construction and maintenance are more complex than septic tanks<br>• Costs are higher than a conventional septic tank<br>• Requires constant source of water.<br>• Effluent require secondary treatment and/or appropriate discharge.<br>• Low reduction pathogens.<br>• Requires expert design and construction.<br>• Pre-treatment is required to prevent clogging. |
| | Upflow Anaerobic Sludge Blanket Reactor (UASB) | • High reduction in organics.<br>• Can withstand high organic loading rates (up to 10kg BOD/$m^3$/d) and high hydraulic loading rates.<br>• Low production sludge (and thus, infrequent desludging required).<br>• Biogas can be used for energy (but usually requires scrubbing first). | • Difficult to maintain proper hydraulic conditions (upflow and settling rate must be balanced).<br>• Long start up time.<br>• Treatment may be unstable with variable hydraulic and organic loads.<br>• Constant source of electricity is required.<br>• Not all parts and materials may be available locally.<br>• Requires expert design and construction supervision. |

| | | | |
|---|---|---|---|
| | Pond System for Primary Treatment | • Systems is well tested and proven in low and middle-income countries used for large scale applications | • Pond systems look unpleasant Emit odours<br>• Offer a perfect environment for mosquitoes if not well-operated and maintained<br>• Not recommended by WHO (2005) guidelines for safe use of excreta and greywater.<br>• Septic or sedimentation tanks are recommended as primary treatment unit to pond |
| *Secondary Treatment* | Anaerobic Filtration | • High treatment performance (TSS, TDS); high resilience to hydraulic and organic shock loadings<br>• Long biomass retention time<br>• Low sludge yield; stabilised sludge. | • Long-term experience with greywater treatment is still lacking<br>• Limited removal of nutrients, pathogens and surfactants. |
| | Pond system for secondary treatment | • Ponds may be considered for larger scale applications<br>• Use in household management after a chain of treatment comprising primary and secondary treatment steps | • Ponds are not recommended as primary treatment of greywater for households due to mosquito breeding and bad odour. |

## 2.7 COMPOSITION AND TREATMENT OF DOMESTIC SEWAGE

Domestic wastewater is a kind of sewage containing a lot of organic matter and microbes produced by residents in their daily life. It is discharged from residential buildings, hospitals or public toilets. It contains pollutants such as organic matters consuming oxygen, infectious pathogens and viruses, nutrimental chemicals for plants and polymers. The average pollutant production of domestic sewage in Ghana falls in the ranges shown in Table 1 below. Faecal sludge refers to all sludge collected and transported from on-site sanitation systems by vacuum trucks for disposal or treatment (Strauss *et al*., 1997) and differs slightly from conventional wastewater as its quality is subject to high variations due to storage duration, temperature, technology and performance of septic tanks etc.

**Table 2: Some features of domestic sewage from urban residents**

| | Faecal sludge | | Sewage |
|---|---|---|---|
| | **High strength** | **Low strength** | |
| Source | Public toilet or bucket latrine sludge | Septage | Tropical countries |
| Characterization | Highly concentrated, stored for days or weeks only | Low concentration, usually stored for several years; more stabilized | |
| Chemical Oxygen Demand (COD) (mg/l) | 20,000 – 50,000 | <15,000 | 500 – 2,500 |
| Biological Oxygen Demand (BOD) (mg/l) | 4,000-5,000 | <1,500 | 250-1,250 |
| COD/BOD* | 5:1 -10:1 | 5:1 -10:1 | 2:1 |
| Suspended Solids (SS) (mg/l) | ≥ 30,000 | ≈7,000 | 200 – 700 |
| Total Solids (TS) (%) | ≥ 3.5 | < 3 | < 1 |
| NH4-N (mg/l) | 2,000 – 5,000 | <1,000 | 30 – 70 |
| Helminthes eggs (no/ l) | 20,000 – 60,000 | ≈ 4,000 | 300 – 2,000 |

Source: Strauss *et al.* (1997) and Mara (1978).

Faecal sludge data are more inhomogeneous for domestic wastewater and vary strongly from place to place. Only average values received from a statically sufficient number of analyses may serve as a design basis for treatment plants. One example which illustrates the variability of septage samples: the average COD concentration of 75 septage samples in Accra amounted to 6,400 mg/l with the very high standard deviation of 6,200 mg/l. Again, the COD of sludge used for dewatering on different unplanted filter beds in their dewatering experiments had high variability (COD of 50,320 mg/l has standard deviation of 28,780 mg/l) due to high variability of septage mixed with the fresh public toilet sludge (Kuffour, 2009),.

**Table 3: Faecal sludge quality in different cities**

| Parameter | Accra septage | Accra, Public toilet sludge | Bangkok septage | Manila septage | US EPA septage |
|---|---|---|---|---|---|
| $COD_{C}$, mg/l | 7,800 | 49,000 | 14,000 | 37,000 | 43,000 |
| $BOD_{5}$, mg/l | 600-1,500 | 7,600 | - | 3,800 | 5,000 |
| TS, mg/l | 11,900 | 52,000 | 16,000 | 72,000 | 38,800 |
| TVS, % | 60 | 69 | 69 | 76 | 65 |
| pH | 7.6 | 7.9 | 7.7 | 7.3 | 6.9 |
| COD/BOD | 6-12 | 6.4 | - | 9.7 | 9.0 |
| COD/TS | 0.7 | 0.9 | 0.9 | 0.5 | 1.1 |
| Helminthes eggs, No/L | 4,000 | 25,000 | - | 5,700 | - |

*All units except pH and the ratios (COD/BOD, COD/TS) are in mg/l.*
Source: Strauss *et al* (1998)

Domestic sewage from hospitals or individual patients contains many pathogens such as salmonella, *dysentery bacillus*, *comma bacillus* and *tubercle bacillus*, many viruses such as those of infectious hepatitis and poliomyelitis; many vermian ova such as those of roundworm, hookworm and schistosome and amebic protozoon.

### 2.7. 1. EPA Discharge Guideline Standard of Treated Domestic Sewage

Guideline for the quality of wastewater/effluent to be discharged into inland water bodies such as streams, lakes/dams and rivers is given by the Environmental Protection Agency (EPA) of Ghana as shown in the Table 3 below. Generally, the guideline values of developed countries are very stringent because of the advanced technology adopted for wastewater treatment and the possible enforcement by the responsible agents. However, for the case of the developing countries including Ghana, the economy makes it quite difficult to use high level technologies such as microfiltration, ultrafiltration, nanofiltration, and reverse osmosis (Hodgson, 1998) to treat its domestic and industrial wastewater thus not easy to achieve the stringent guideline values adopted by the developed countries.

**Table 4: EPA guideline values for the discharge of domestic effluents**

| Parameter | Units | EPA Guideline Value |
|---|---|---|
| pH | | 6 – 9 |
| Temperature | °C | < 3 °C above ambient |
| Colour, | TCU | 200 |
| Turbidity | NTU | 75 |
| Conductivity | uS/cm | 1500 |
| Total Suspended Solids (TSS) | mg/l | 50 |
| Total Dissolved Solids (TDS) | mg/l | 1000 |
| Total Phosphorus | mg/l | 2.0 |
| Biochemical Oxygen Demand ($BOD_5$) | mg/l | 50 |
| Chemical Oxygen Demand (COD) | mg/l | 250 |
| Nitrate | mg/l | 50 |
| Nitrite | mg/l | - |
| Ammonia as N | mg/l | 1.0 |
| Alkalinity as $CaCO_3$ | mg/l | 150 |
| Total Coliforms | MPN/100ml | 400 |
| E. Coli | MPN/100ml | 0 |

Source: (E.P.A-Ghana, 2000)

### 2.7. 2. Conventional Septic Tank

The septic tank is the most widely used onsite wastewater treatment option in the developing countries like Ghana. Currently, almost all new home being constructed in this country use septic tanks for treatment prior to disposal of home wastewater.

Septic tanks are buried, watertight receptacles designed and constructed to receive wastewater from a home, to separate solids from the liquid, to provide limited digestion of organic matter, to store solids, and to allow the clarified liquid to discharge for further treatment and disposal.

Settleable solids and partially decomposed sludge settle to the bottom of the tank and accumulate. A scum of lightweight material (including fats and greases) rises to the top. The partially clarified liquid is allowed to flow through an outlet structure just below the floating scum layer. Proper use of baffles, tees, and ells protects against scum outflow. Leakage from septic tanks is often considered and prevented. In the extreme case, the sludge layer will dry and compact, and during normal sludge empting it will be difficult to remove. Another problem is that if the tank is not waterthight, infiltration into the tank can cause overloading of the tank and subsequent treatment and disposal components.

In Ghana, septic tank (figure 11 refers) is water tight storage tank in which sewage is retained sufficiently long to permit sedimentation (Awuah, 2012) and lacks effective anaerobic treatment.

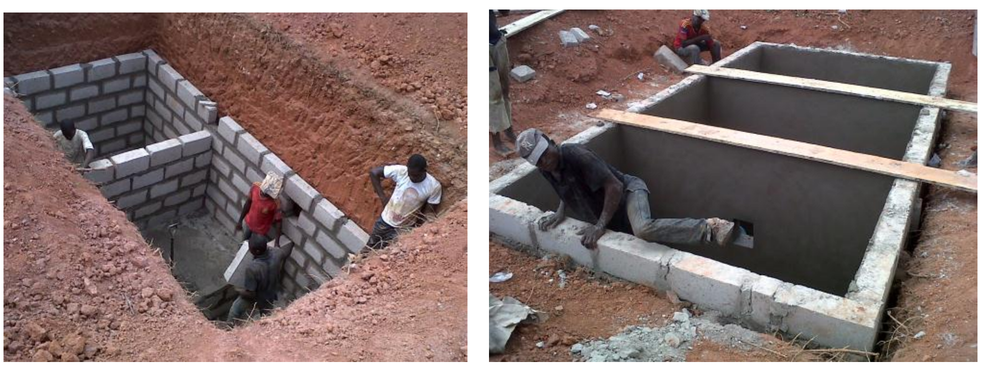


Figure 11: Typical Three-Compartment Septic tank in Ghana

In the Figure 11 shown above, the pipes are in straight lines in horizontal planes. Septic tanks can be rectangular or circular. It should have a minimum width of 750 mm, minimum depth of 1m below the water level. It should also have a minimum liquid capacity of 1000 litres. A rectangular tank is two or four times the width. Circular tanks should have a minimum diameter and depth of 1.35 m and 1 m respectively. The walls may be constructed with brick masonry to a thickness not less than 200 mm. The floor should be water tight and may be constructed with concrete of grade M15, a slope of 1 in 10 towards the sludge. Outlet should be provided to facilitate desludging. An inlet of diameter not less than diameter of incoming drain and should be T- shaped dip pipe for tanks not more than 1200 mm. The pipe should be fixed inside the tank with the top limb rising above the scum level and bottom extending about 300mm below the top water level.

The Table 5 below briefly describes the required corresponding Sizing for septic tank, seepage pit and leach line against the Number of bedrooms (Awuah, 2012).

**Table 5: Number of bedrooms and the required capacity of septic tank in volume**

| Number of Bedrooms | Required capacity of septic Tank ($m^3$) (black and grey water) | Existing capacity of Septic tanks studies in Kumasi ($m^3$) |
|---|---|---|
| 1 or 2 | 3.4 | - |
| 3 | 4.5 | 12.5 |
| 4 | 5.4 | 17.1 |
| 5 | 6.6 | 26.5 |
| 6 | 6.6 | 68.7 |

Source: Awuah, 2012

### 2.7. 3. Mathematical Relations for Designing Biogas Systems and Septic Tank

#### 2.7.3.1. Biogas Systems Design

The state of development of fixed dome digesters is quite advanced and make use of mathematical relations (see figure 12) that usually start with the determination of the size of digester and gas storage chamber. Other factors such as gas pressure, average rate of gas production, loads and forces about materials, methods of construction, cost, suitable digester feedstock and gas production rates.

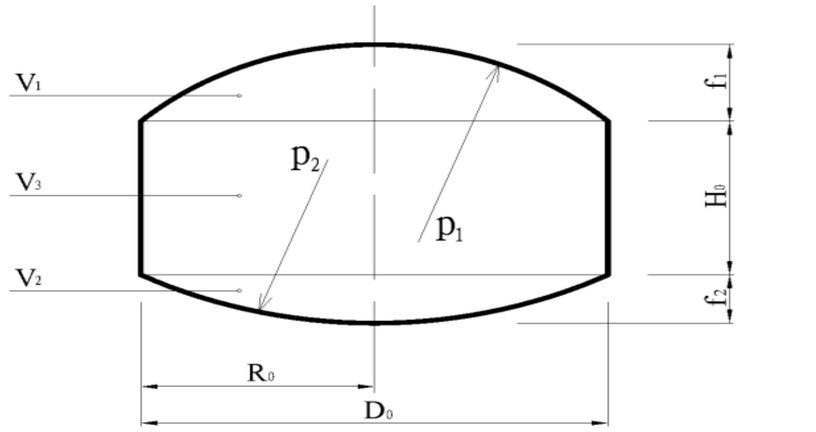



Figure 12: Schematic diagram of digester
Source: Guozhong, 2010

Formula for hydraulic biogas digester design

$D_0$ = Diameter for fermentation chamber

$R_0$ = Radius for fermentation chamber

$H_0$ = Height of hydraulic digester

$f_1$ = Upper sludge level

$f_2$ = Lower sludge level

$V_1$= Volume of gas chamber

$V_2$= Volume of bottom ball cap

$V_3$= Volume of fermentation chamber

$P_1$= inner radius of hemisphere of the gas chamber

$P_2$ = inner radius of hemisphere of the lower

Mathematical relations of parameters

$H_0 = D_0/2.5$……………………………………………………………………………*equation 1*

$f_1 = D_0/5$……………………………………………………………………………*equation 2*

$f_2 = D_0/8$……………………………………………………………………………*equation 3*

$R_0 = D_0/2$ ……………………………………………………………………………*equation 4*

$$P_1 = \frac{R_0^2}{2f_1} + \frac{f_1}{2} \quad \text{…equation 5}$$

$$P_2 = \frac{R_0^2}{2f_2} + \frac{f_2}{2} \quad \text{…equation 6}$$

From volume formulas of ball cap and cylinder, we get:

$$V_1 = \frac{\pi}{6} f_1(3R_0^2 + f_1^2) \quad \text{…equation 7}$$

$$V_2 = \frac{\pi}{6} f_2(3R_0^2 + f_2^2) \quad \text{…equation 8}$$

$$V_3 = \pi R_0^2 H_0 \quad \text{…equation 9}$$

Put $f_1$, $f_2$, $D_0$ and $H_0$ into the above formulas

$$V_1 = \frac{\pi}{6} \times \frac{D_0}{5}[3 \times (\frac{D_0}{2})^2 + (\frac{D_0}{5})^2] = 0.0827 D_0^3$$

$$V_2 = \frac{\pi}{6} \times \frac{D_0}{8}[3 \times (\frac{D_0}{2})^2 + (\frac{D_0}{8})^2] = 0.0501 D_0^3$$

$$V_3 = \pi(\frac{D_0}{2})^2 \times \frac{D_0}{2.5}] = 0.3142 D_0^3$$

*Total volume of the biogas digester (gas and fermentation chamber), V:*

Total volume of the digester then becomes,

$$V = V_1 + V_2 + V_3 \quad \text{…equation 10}$$

$$V = (0.0827+0.0501+0.3142) D_0^3$$

$$V = 0.4470 \; D_0^3 \quad \text{…equation 11}$$

If we have determined the volume of a biogas digester that will be built, its diameter and other geometric parameters is gotten as:

$$D_0 = \sqrt[3]{\frac{V}{0.447}} \quad \text{…Equation 12}$$

*Calculation for surface area, F:*

$$F = F_1 + F_2 + F_3 \quad \text{.......................} \textit{Equation 13}$$

$$= 2\pi P_1 f_1 + 2\pi P_2 f_2 + 2\pi R_0 H_0$$

$$F = 2\pi (P_1 f_1 + P_2 f_2 + R_0 H_0) \quad \text{.......................} \textit{Equation 14}$$

*Calculation for volume of hydraulic chamber (outlet chamber):*

The hydraulic chamber of the digester is volume of hydraulic chamber equals to gas production for a half day, i.e.: knowing volume of biogas digester and the gas production rate, the volume of hydraulic chamber then becomes,

$$V_h = V \times rv \times 0.5 \quad \text{.......................} \textit{Equation 15}$$

where,

$V_h$= Volume of hydraulic chamber ($m^3$)

V = Volume of biogas digester ($m^3$)

rv = Gas production rate ($m^3/m^3$/day)

*Calculation of digester volume:*

Knowing the gas production rate, the quantity of raw material, biogas consumption per person per day and number of family members, the biogas digester volume can also be calculated as:

V = ((Average biogas consumption per person x number of persons) ÷ Gas production rate) (Guozhong, 2010).

**2.7.3.2. Septic Tank Design**

The criteria for tank design are dependent on volume for settlement, volume for digestion of sludge and storage Volume.

*Settlement Volume (Vs),*

$$Vs \text{ (litres)} = Td \times Q \times n \quad \text{.......................} \textit{Equation 16}$$

where, Td = Retention time in days

Q = Flow in litres/cap/day and

n = Number of users

*Digestion Volume (Vd),*

$$Vd\ (litres) = 0.5 \times Td \times Q \times n \quad \text{......Equation 17}$$

where, Td = Retention time in days,

Q = Flow in litres/cap/day and

n = Number of users

*Storage Volume (Vst),*

$$Vst = 0.25 \times AP \times Q \times n \quad \text{......Equation 18}$$

where, AP = accumulation period in days,

Q = Flow in litres/cap/day and

n = Number of users

*The effective volume of the septic tank (V),*

The sum of settlement volume, volume for digestion of sludge and storage Volume is equivalent to the effective volume of the septic tank.

$$V = Vs + Vd + Vst \quad \text{......Equation 19}$$

### 2.7. 4. Formula for Methane Estimation from Organic Matter

Organic matters in domestic sewage mainly consist of carbohydrates, protein or lipid. Their corresponding theoretic methane yields are 0.37, 0.49 and 1.04 liter/g respectively. Therefore theoretic methane yield of certain organic matter can be calculated as follows:

$$Q_{wg} = 0.37A + 0.49B + 1.04C \quad \text{......Equation 20}$$

where, $Q_{wg}$= theoretic methane production from 1 gram of organic matter (l/g);

A= carbohydrates content in 1 gram organic matter of domestic sewage (g/g);

B= protein content in 1 gram organic matter of domestic sewage (g/g);

C= lipid content in 1 gram organic matter of domestic sewage (g/g) (BIOMA, 2011);

The potential gas production from some dung is also given in Table 6 shown below.

**Table 6: Gas Production potential of various types of dung**

| **Types of Dung** | **Gas Production per Kg Dung ($m^3$)** |
|---|---|
| Cattle (cows and buffaloes) | 0.023 - 0.040 |
| Pig | 0.040 - 0.059 |
| Poultry (Chicken) | 0.065 - 0.116 |
| Human | 0.020 - 0.028 |

Source: FAO, 1984

### 2.7. 5. Mathematical Relation for Wastewater Biogas Tank Design

Generally the flow rate is calculated based on the water consumption of residents surveyed. Firstly take the daily average water consumption as domestic sewage discharging rate per capita, then it is multiplied by n (the number people to be served by the designed system in the future) and the simultaneity coefficient k1, which is estimated as follows:

| | |
|---|---|
| $n \leq 50$ | k 1=1 |
| $200 > n > 50$ | k 1=0.95 |
| $500 > n \geq 200$ | k 1=0.90 |

Flow rate of excreta in domestic sewage for water-flush toilet can be estimated as 30 liter/capita/day, if there is no data available.

Biogas Tank volume, $V_{BT}$= (Vs) + (Vb) + (Vf) ……….……………………………….*Equation 21*

where,

Vs = Settlement unit volume,

Vb = Baffle and Anaerobic Filter unit volume and

Vf = Facultative filter unit volume.

$Vs = n \times k \times Q_{sewage} \times HRT$……………………...………..……..……………………..…………….Equation 22

where

$HRT$ = Hydraulic retention time in days

$Q_{sewage}$ = Flow in litres/cap/day

n = Number of users and

$k$ = simultaneity coefficient

$Vb = 0.5 \times k \times n \times Tdt \times Q_{sewage}$ …….…………….………..……………………….…..…..Equation 23

where,

$Tdt$ = *digestion time (days) and*

$Vf = Vb$, (Facultative filter unit volume= Anaerobic filter unit volume)

Clearly by this review, it was realised that in recent year septic tanks designs are being improved to enhance removal efficiency of unsettleable and dissolved solids which is a major drawback of the conventional septic tanks. The challenge is taken up by this project for better sewage treatment.

## 2.7 PREVIOUS WORKS ON ANAEROBIC MODIFIED SEPTIC TANKS

Many anaerobic modified septic tank systems conceptualized, constructed and tested in an attempt to addressing the weakness associated with DST in different countries. Some noticeable ones amongst others are the:

a) **Upflow SepticTank/Baffled Reactor (USBR):** The USBR is a new concept for a low-cost modified septic tank. It was constructed and tested in a small village in Egypt. In fact, a one year of continuous operation and monitoring of the USBR system was found to have very satisfactory removal results of COD, BOD and TSS. Again, it was observed that the USBR system was not affected by the imposed shock loads at the peak flow and organic periods but the results showed that the system was influenced by the drop in the temperature (Sabry, 2009)

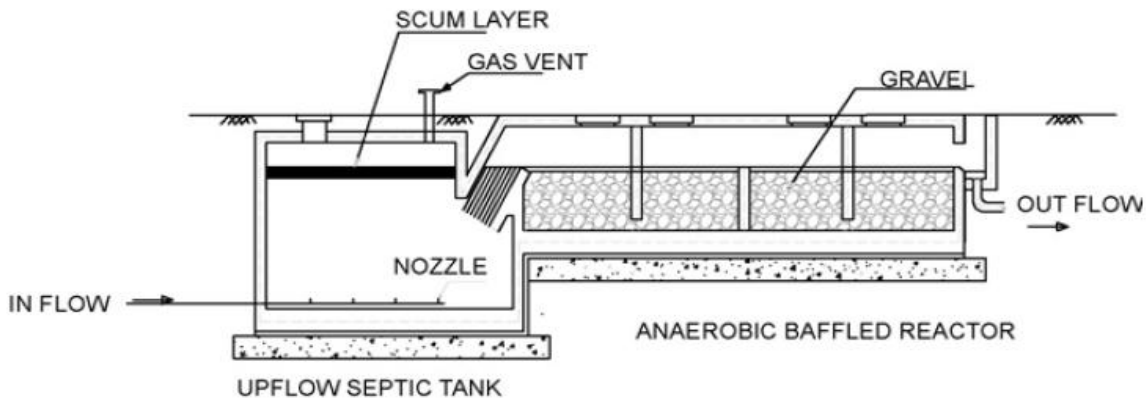



Figure 13: Cross-sectional view in the modified septic tank system.

b) Panswad and Komolmethee used full-scale septic tank/anaerobic filter unit with the tank's retention time varying from 22.5 to 90 h. They recommended a rather high retention period of not less than 48 h if the Thai effluent standards are to be met.

c) Elmitwalli *et al.* used two-step anaerobic system to treat sewage. They tested the performance of the two upflow-hybrid septic tanks which require high power input or high excavation depth due to that the two treatment steps exist in a vertical order.

d) Mendoza *et al*. studied in a lab-scale the design and performance of a novel Gradual Concentric Chambers (GCC) reactor, integrating anaerobic and aerobic processes, treating low (165mg COD/L) and medium strength (550mg COD/L) domestic wastewaters. Although the GCC reactor had reasonable performance, its operation is considered rather complicated due to using of anaerobic effluent recycling technique and aeration pump.

All the above mentioned researches were reviewed to come out with a new design concepts under this study.

## CHAPTER THREE

## DESIGN OF BIOGAS SEPTIC TANK

### 3.1. DESIGN CONCEPTS

Two types of design possibilities of the Anaerobic Upflow Domestic Septic Tank (AUDST) are considered under this research. The first possibility (Design I) is to design a rectangular septic tank that decontaminates wastewater through a filtration tank and recovers biogas. The biogas tank, Design I is made up of anaerobic baffled reactors (ABR) and Chinese Guorui Natural Gas Store (CGNGS). The ABR and CGNGS were adopted to propose Design I with the aim to introduce facilities that will induce and sustain anaerobic activities as well as baffle flow for effective treatment of wastewater. The second possibility (Design II) coupled Design I with fixed dome hydraulic digester with purpose to remove pathogens that might escape Design I, recover biogas and produce effluent that meets EPA discharge standards. The design concepts are illustrated in figure 14 below.

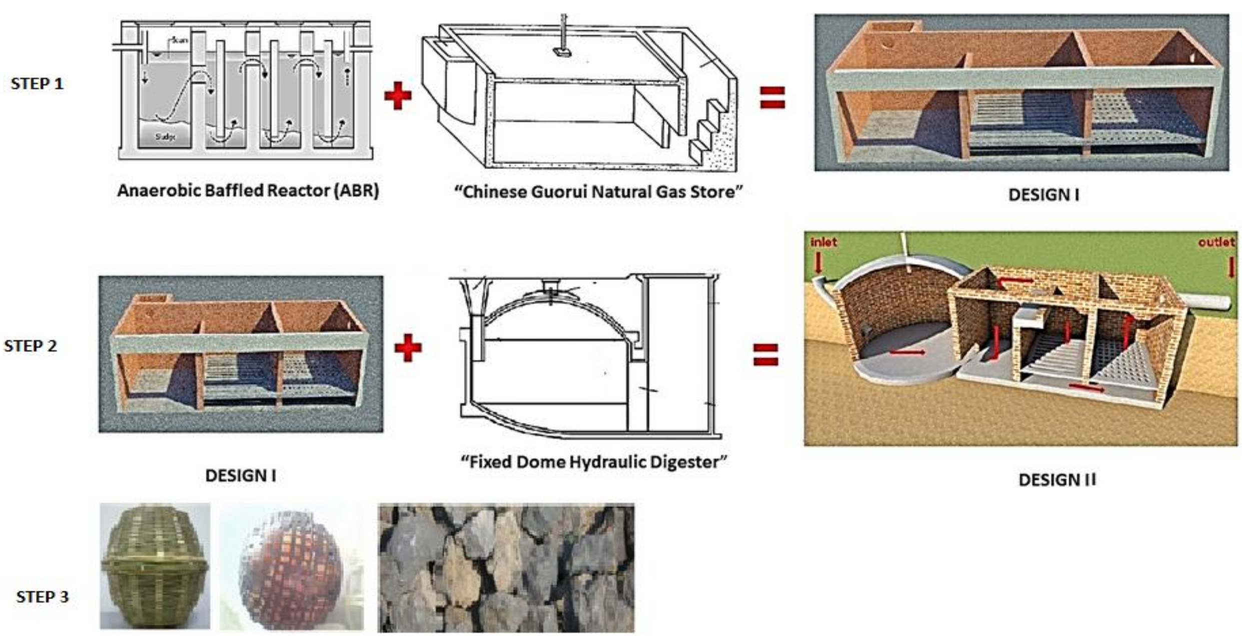



Figure 14: Design Concepts

**Step 1** – Re-engineering of Hydraulic Digester into Design I

**Step 2** – Coupling Design I to obtain Design II with an additional digester on multi-stage

**Step 3**– Add Packing and filtering media to strengthen anaerobic activities as well as decontamination of sewage.

The anaerobic unit aims at destroying pathogens. Again, the packing material used will be indigenously made baskets (figure 15 refers) intended to strengthen the biological treatment process. The last but not the least, facultative filtration unit of the model is also packed with filtering media such as uncoated and untreated gravels, 3-6mm in diameter (see figure 17), like that found in aquarium with high durability to produce effluent with lower suspended solids content to meet Ghana's Environmental Protection Agency (EPA) standards for the discharge of domestic effluents.

Figure 15: Indigenously woven basket to be used a packing material

Other available packing materials that can be used under this project is shown in figure 16 below.

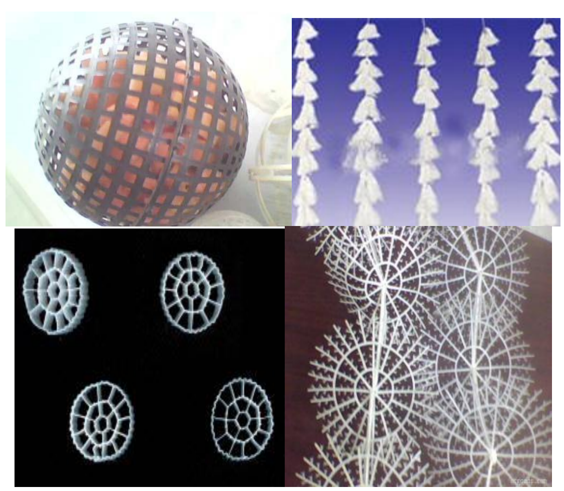


Figure 16: Plastic packing materials for strengthening anaerobic activities

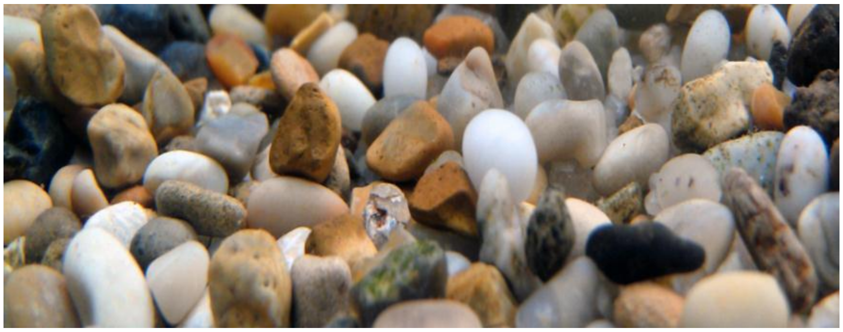


Figure 17: Gravel (3-6mm in diameter) filter materials in the Filter unit

## 3.2. PRELIMINARY DESIGN OF BIOGAS SEPTIC TANK

### 3.2.1. Flow Diagram of Proposed Designs

The schematic diagrams for the treatment and biogas generation process of sewage by the new models of septic tanks is shown in Figure 18 below. Sewage from flashed toilet with other wastewater is settled in the settlement zone provided by the desilting unit to capture the sludge (blackwater). The liquid sewage (greywater) is then baffled in an upflow mode into the aneorobic unit for an anaerobic digestion and biogas production through a series of packing media made up of locally woven basket. This configuration provides a more intimate contact to improve sewage treatment performance and biogas generation before a downflow baffling into the filtration unit made up of gravel and followed by a subsequent discharge.

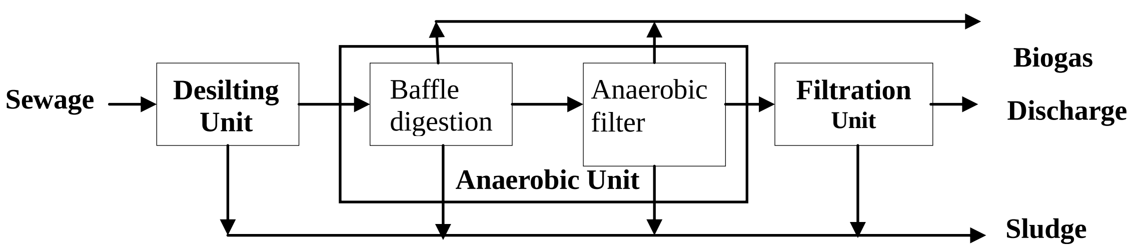



Figure 18: Flow diagram for sewage treatment from the combined discharge system

## 3.3. ENGINEERING DESIGN OF BIOGAS SEPTIC TANK

### 3.3.1. Design I

Design I is a modified rectangular septic tank that decontaminates wastewater through a filtration tank and recovers biogas.

#### 3.3.1.1. Design Parameters and Detail Design Calculation for Design I

##### *3.3.1.1.1. Design Parameters*

Design I considers 3 compartments (as in the case of a conventional septic tank), mainly settlement (desilting) unit for accommodating sewage, anaerobic digestion (baffle digestion and anaerobic filter) unit for accommodating sludge and facultative filtration unit to produce effluent with lower secondary discharge pollutants and suspended solids content.

The criteria for biogas filtration tank design are dependent on the settlement unit volume, the anaerobic filter unit volume and facultative filter unit volume.

Assumptions made in design include the followings:

a) The biogas tank (Design I) is design for a family of eight (8) people made up of father, mother and 6 children, then the number of users, n, is 8. This is needed to determine the sewage discharge rate per day, biogas generated, settlement volume and anaerobic unit.

b) Modification coefficient resulting from increase in the number of users are as follows: If the number of people n is less than or equal to 50 ($n \leq 50$), then k=1; if $200 > n > 50$ k=0.95; $500 > n \geq 200$ k=0.90 (BIOMA, 2011).

c) Average feed load per person per day 1.3 kg, and for the purpose of this design it is assumed that it is the same for all the family members.

d) Considering household of eight (8) people who use 100 litres/day each and a flush fresh sludge per person per day to be six (6) litres, the total flow rate ($Q_{sewage}$) of sewage-as well as the volume of fresh sludge ($Q_f$) can be obtained for the design.

e) Sewage hydraulic retention time (*HRT*), also known as detention time considered for the design is the average period that a given quantity of input remains in the digester to be acted upon by the methanogens for biogas generation is taken to be fifty (50) days.

f) Lastly, sludge emptying period (*SEP*) is considered to be two (2) years but maximum SEP taken as five (5) years.

#### *3.3.1.1.2. Gas production*

The potential gas production (PGP) from eight (8) people using *equation 20* and Table 6 falls in the range of 0.16 - 0.224 $m^3$ per day,

Lower PGP = 8 × 0.020 = 0.160 $m^3$

Upper PGP = 8 × 0.028 = 0.224$m^3$.

#### *3.3.1.1.3. Calculation of the Volume for Design I,* $V_{BT}$

*Using equation 19,*

$V_{BT}$ = (Vs) + (Vb) + (Vf)

where, Vs = Settlement unit volume

Vb = Baffle and anaerobic digestion volume (Anaerobic unit)

Vf = Facultative filter unit volume

Vs = n × k× $Q_{sewage}$ × HRT……………………………………………………….*Equation 24*

For 8 people, k = 1, HRT = 50 days, and $Q_{sewage}$ = 100 liters/capita/day

Vs = 8 × 1 × 0.1

Vs = 0.8 $m^3$

For a digestion time, $T_{dt}$ = 50 days and $Qf$ = 6 *liter/capita/day = 0.006 $m^3$/capita/day*

$Vb = 1/2 \times k \times n \times T_{dt} \times Q_{sewage}$ ……………………………………………….Equation 25

$= 1/2 \times 1 \times 8 \times 50 \times 0.006$

$Vb = 1.2\ m^3$

AP = accumulation period (days) = (desludging frequency (days) - digestion time (days)) (Awuah, 2012). For digestion time of 50 days and for the tank to be desuldged once every 5 years (1825 days), the accumulation Period (AP) is completed as:

$Vf = 1/4 \times k \times n \times SEP$ ……………………………………………………Equation 26

$Vf = 1/4 \times (1825-50) \times 0.001 \times 8$

$Vf = 3.55\ m^3$

Now, the effective volume of Design I (Biogas Tank), $V_{BT}$ becomes,

$V_{BT} = Vs + Vb + Vf$……………………………………………………….Equation 27

$= 0.8 + 1.2 + 3.55$

$V_{BT} = 5.55\ m^3 \approx 6\ m^3$

For the purpose of this design, rounding $V_{BT}$ to the nearest significant figure, $V_{BT}$ is 6 $m^3$.

#### *3.3.1.1.4. Constructional Brick Qualification*

The dimensions of the Design I are as follows:

Length = 2.880 m, Breath= 1.207 m and the height = 1.726 m.

Using a brick of 240 mm × 115 mm ×53 mm and weighing 3.5 kg implies that the length requires about 842 bricks (approximately 1000 bricks) to construct the 6 $m^3$ biogas tank.

#### *3.3.1.1.5. Permissible Load*

The dead loads can be calculated accurately as they are constant but the live loads cannot be calculated exactly. As a result, live loads require a greater value of safety factor than dead loads. Basic equation of total live load and dead load calculation is: Total live and dead load U

U = 1.2 D + 1.6 L…………………………………………………………………………….*Equation 28*

Where, D = dead load and

L = live load

D = density of BT × volume of BT………………………………………………………….*Equation 29*

The density of BT, $\rho$ = m /v.

where, m = mass and

v = volume of the tank

Total mass, m = self-mass of tank + mass of sewage when the tank is full.

The mass of sewage when the 6 $m^3$ biogas tank becomes full is 4,326 kg (density of sewage, 0.721 $g/cm^3$ multiplied by volume of the tank .i.e. $6 \times 10^6$ $cm^3$) and the self-mass of tank is 3,500 kg (total number of bricks multiplied by mass of brick .i.e. 1000 × 3.5 kg). So the density of the biogas digester $\rho$, becomes,

$\rho$ = (4,326 kg + 3,500 kg) ÷ 6 $m^3$ = 1304.333 kg/ $m^3$

Dead Load = (4,326 kg + 3,500 kg) × 10 $ms^{-2}$ = 78,260 N ≈ 80 KN

The live load uniformly distributed on ground is designed as 4 $KN/m^2$; and load from internal pressure of biogas is designed as 8 $KN/m^2$, which is the possible maximum pressure (BIOMA, 2011).

Live load for the design = Area × live load uniformly distributed on the tank

= (2.880 m × 1.207 m × 4 $KN/m^2$) + (2.880 m × 1.207 m × 8 $KN/m^2$)

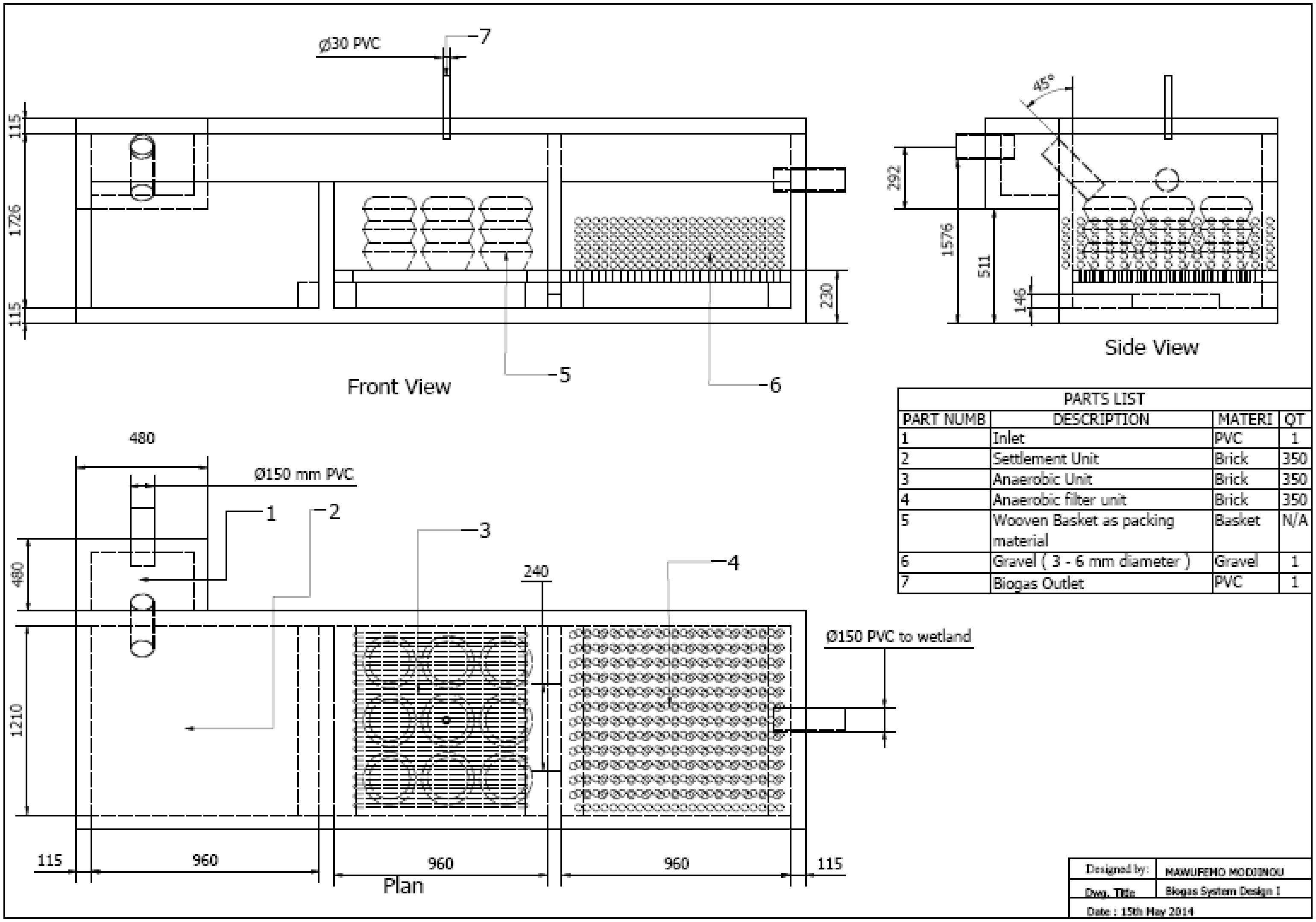
= 42 KN

Using equation 28, the total load (U) for the Design I becomes,

$$U = 1.2\ (80) + 1.6\ (42) = 163.2\ \text{KN}$$

### 3.3.1.2. Engineering Drawing of the Biogas Septic Tank (Proposed Design I)

Based on the calculations, the detail engineering and isometric drawing of proposed Design I was drawn with Autodesk Inventor 3D CAD having 3D mechanical design tool as shown in figure 19 to figure 22 below. The dimensions of the design were arrived at after the volume of the proposed design I was calculated. The 3 dimensional views of the isometric drawings was also presented to help appreciate the design and assist in further construction and test work.




| PART NUMB | DESCRIPTION | MATERI | QT |
|---|---|---|---|
| 1 | Inlet | PVC | 1 |
| 2 | Settlement Unit | Brick | 350 |
| 3 | Anaerobic Unit | Brick | 350 |
| 4 | Anaerobic filter unit | Brick | 350 |
| 5 | Wooven Basket as packing material | Basket | N/A |
| 6 | Gravel ( 3 - 6 mm diameter ) | Gravel | 1 |
| 7 | Biogas Outlet | PVC | 1 |

Figure 19: Detail drawing of the proposed Biogas Septic Tank (Design I)

Figure 20: Isometric drawing of proposed Biogas Septic Tank (Design I)

Figure 21: Isometric drawing of the proposed Biogas Septic Tank (Design I)

Figure 22: Isometric drawing of the proposed Biogas Septic Tank (Design I)

#### 3.3.1.3. Operation of Proposed Design I

The proposed design is operated through three (3) units namely the desilting, anaerobic digestion and filtration units as shown in figure 23 below. The proposed design is started through inoculation with anaerobic bacteria, e.g., by adding cow dung or by allowing Septic Tank sludge to build up to initiate the process. This configuration of the proposed design provides a more intimate contact between methanogens, methane producing bacteria, and wastewater to be treated. In addition, the anaerobic unit is fitted with packing material (indigenous baskets) to serve as surface for the growth of methanogens. Due to the setup, anaerobic digestion is strengthened and sustained in the anaerobic unit. Again, wastewater from the anaerobic unit downflow into the filtration unit of the model. This unit is also packed with filtering media such as gravels (3 – 6 mm in diameter) to produce effluent that meet EPA standards and can be discharged into wetland. Biogas is generated in both the sedimentation and anaerobic unit. Both units are sealed and provide an anaerobic environment for the complete digestion of both settled and baffled wastewater.

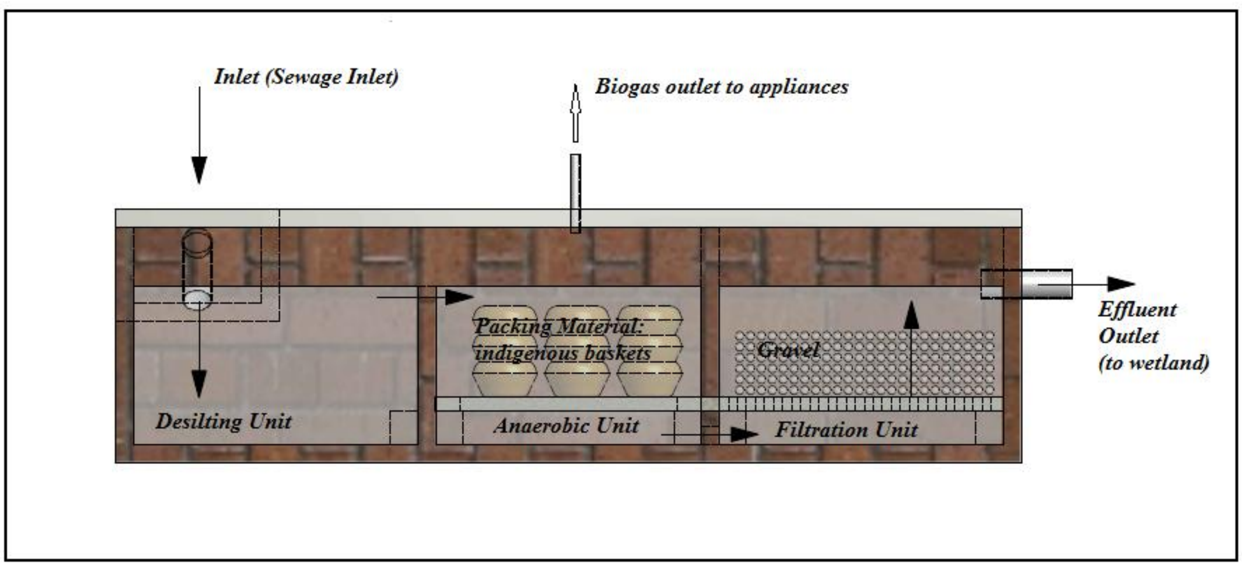



Figure 23: Operation of proposed Biogas Septic Tank (Design I)

### 3.3.2. Design II

The second design, Design II was done by coupling Design I with a hydraulic digester with the aim of removing pathogens that would not have been destroyed in Design I, recover biogas and produce effluent that meets EPA discharge limits.

#### 3.3.2.1. Detail Design Calculation for Design II

The design calculation for the Biogas System (Design II) is split into two (2) sets, the first set of calculation is to design the fermentation chamber (see figure 24) and secondly add the filtration tank design (Design I).

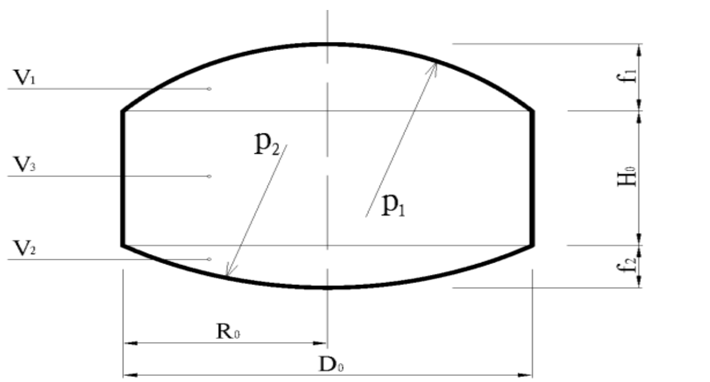



Figure 24: Schematic diagram of digester
Source: Guozhong, 2010

##### *3.3.2.1.1 Calculation of effective volume (V) of Design II*

For the construction of digester of an equivalent volume for the 8 people, a diameter of the fermentation chamber is considered $D_0 = 2.38$ m.

Using equation 1,

$H_0 = D_0/2.5$

$H_0 = 2.38/2.5 = 0.95$ m

Using equation 2,

$f_1 = D_0/5$

Upper slurry level, f1= 2.38/5 = 0.476 m

Using equation 3,

$f_2 = D_0/8$

Lower slurry level, $f_2$= 2.38/8 = 0.30m

Using equation 4,

$R_0 = D_0/2$

$R_0$ = 2.38/2 = 1.19m

Using equation 5,

$$P_1 = \frac{R_0^2}{2f_1} + \frac{f_1}{2} = 0.725\,\mathrm{D_o} \ = 1.726m$$

Using equation 6,

$$P_2 = \frac{R_0^2}{2f_2} + \frac{f_2}{2} = 1.0625\mathrm{D_0} = 2.529m$$

Substituting $H_0$, $f_1$ and $f_2$ obtained from equation 1, 2, and 3 respectively into equation 7, equation 8 and equation 9,

$$V_1 = \frac{\pi}{6} \times \frac{D_0}{5}[3 \times (\frac{D_0}{2})^2 + (\frac{D_0}{5})^2] = 0.0827D_0^3$$

$$V_2 = \frac{\pi}{6} \times \frac{D_0}{8}[3 \times (\frac{D_0}{2})^2 + (\frac{D_0}{8})^2] = 0.0501D_0^3$$

$$V_3 = \pi(\frac{D_0}{2})^2 \times \frac{D_0}{2.5}) = 0.3142D_0^3$$

Total volume of the digester:

$V_{FC} = V_1 + V_2 + V_3$

$= (0.143+0.87+0.3142) D_0^3$

$= 0.4470\ D_0^3$

$= 0.4470 \times 2.38^3$

$V_{FC} = 6.0\ m^3$

***3.3.2.1.2 Calculation for surface area:***

$F=F1+ F2+ F3 =2\pi P_1 f_1+2\pi P_2 f_2+2\pi R_0 H_0$

$=2\pi ((1.726 \times 0.476) + (2.529\times 0.3) + (1.19\times 0.95))$

$=2\pi (0.822+ 0.759+ 1.131)$

$F=17m^2$

***3.3.2.1.3 Gas production***

The potential gas production from 8 people in Table 6 falls in the range of 0.2 - 0.3 $m^3$ per day.

***3.3.2.1.4 Effective volume (V) of Design II***

Now, the effective volume (V) of the biogas tank (Design II) is calculated as

$V= V_{FC} + V_{BT}$

$V= 6.0\ m^3 + 6.0\ m^3$

$V = 12.0\ m^3$

***3.3.2.1.5 Outlet chamber:***

The outlet chamber (previously in Design I referred to as settlement volume Vs) is the same as volume of hydraulic chamber that will be accommodating the digested effluent from the hydraulic digester. Using equation 15,

$Vh = V\times rv \times 1/2$

where,

Vh= Volume of hydraulic chamber ($m^3$)

V = Volume of biogas digester ($m^3$)

rv = Gas production rate ($m^3/m^3$/day)

V = 12 $m^3$ and rv = 0.35 $m^3/m^3$/day, then

Vh= 12×0.35× 0.5 = 2.1 $m^3$

*Hence the outlet chamber is 2.1 $m^3$*

#### *3.3.2.1.6 Permissible Load*

The dead loads can be calculated accurately as they are constant but the live loads cannot be calculated exactly. As a result, live loads require a greater value of safety factor than dead loads. Using equation 28 to estimate the permissible load,

U = 1.2 D + 1.6 L,

where D = dead load and L = live load

D = density of BT × volume of BT,

where density, $\rho = m / v$.

Total mass, m = self-mass of tank + mass of sewage when the tank is full.

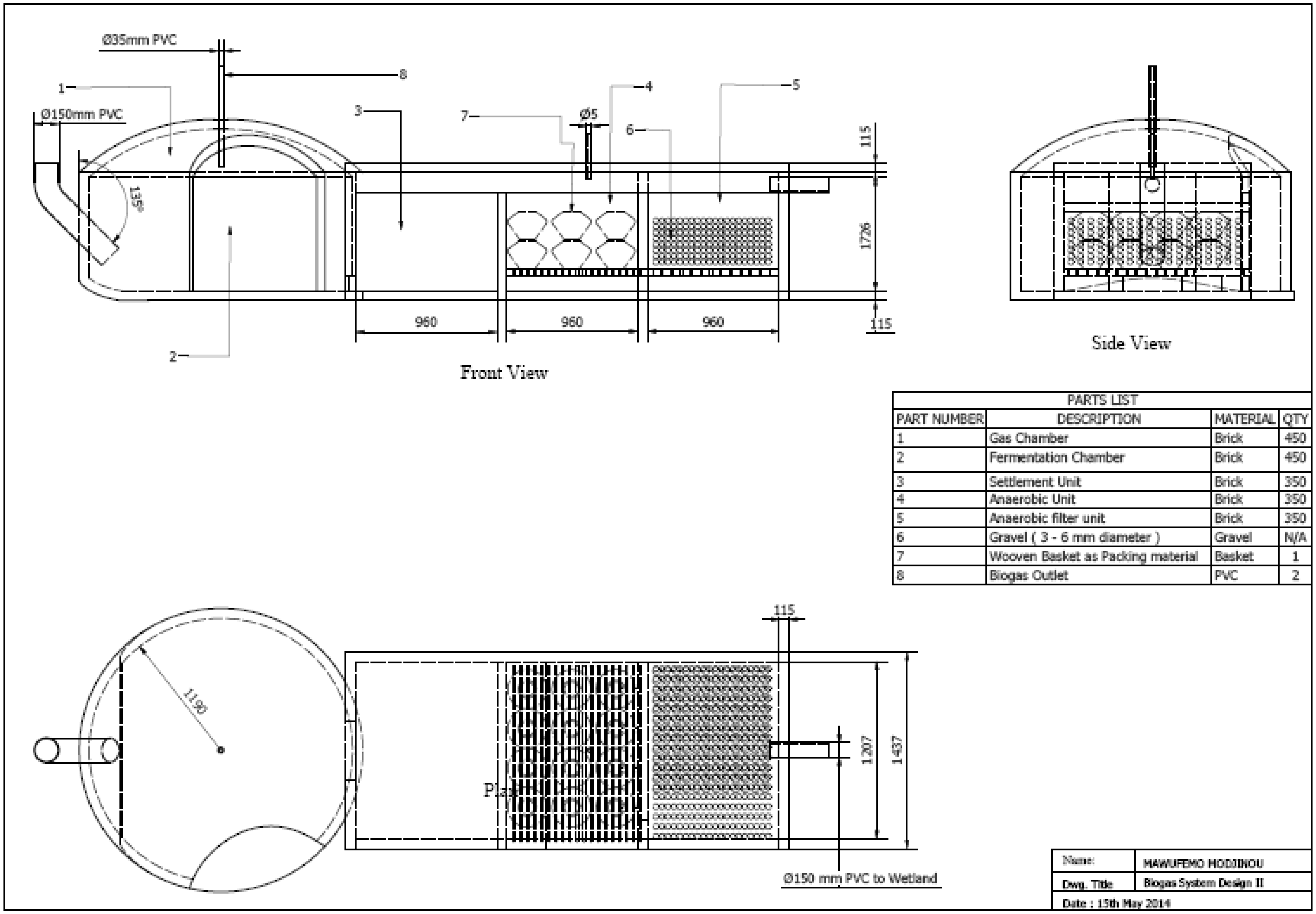
Live load = Area × life load uniformly distributed on the tank

$$= (\pi r^2 + (\text{length} \times \text{width})) \times 4\ \text{KN/m}^2 + (\pi r^2 + (\text{length} \times \text{width})) \times 8\ \text{KN/m}^2$$

The radius, r = ($D_0$ / 2) = (2.38 / 2) of the hydraulic digester is 1.19 m

### 3.3.2.2. Engineering Drawings of Biogas Septic Tank (Proposed Design II)

Based on the calculations, the detail engineering and isometric drawing of proposed Design I was drawn with Autodesk Inventor 3D CAD having 3D mechanical design tool as shown in figure 25 to figure 28 below.




| PARTS LIST | | | |
|---|---|---|---|
| PART NUMBER | DESCRIPTION | MATERIAL | QTY |
| 1 | Gas Chamber | Brick | 450 |
| 2 | Fermentation Chamber | Brick | 450 |
| 3 | Settlement Unit | Brick | 350 |
| 4 | Anaerobic Unit | Brick | 350 |
| 5 | Anaerobic filter unit | Brick | 350 |
| 6 | Gravel ( 3 - 6 mm diameter ) | Gravel | N/A |
| 7 | Wooven Basket as Packing material | Basket | 1 |
| 8 | Biogas Outlet | PVC | 2 |

Figure 25: Detail drawing of the proposed Biogas Septic Tank (Design II)

Figure 26: Isometric drawing of the proposed Biogas Septic Tank (Design II)

Figure 27: Isometric drawing of the proposed Biogas Septic Tank (Design II)

Figure 28: Isometric drawing of the proposed Biogas Septic Tank (Design II)

### 3.3.2. 3 Operation of proposed Design II

The biogas system (Design II) must be connected to private or public toilets with an additional access point for organic materials from kitchen or any other source. It is then operated through the hydraulic biogas reactor to initiate anaerobic activities, after which the digestate moves by gravity to the next compartment serving as a storage tank which further allows the sewage input to desilt and the remaining going through the final filtration compartment. In fact, the shape of hydraulic digester is circular simply to ensure the raw wastewater completely mix. The hydraulic retention time (digester volume divided by flow rate of sewage into the digester) in the anaeorbic digester could be modeled to 60 days because of the high pathogenic inputs from flush toilet. It should also be operated in a thermophilic temperature of at least 50°C to ensure the pathogens destruction, but can only be better achieved by siting Design II in a place with no shade. The proposed design can be efficient to co-digest blackwater from a single household if the latter is the main source of feedstock. Greywater should not be added as it will substantially reduce the HRT. At the household level, Design II can be made out with indigenous bricks with a varying size of $3m^3$ for a single family up to 100 $m^3$ for institutional or public toilet applications.

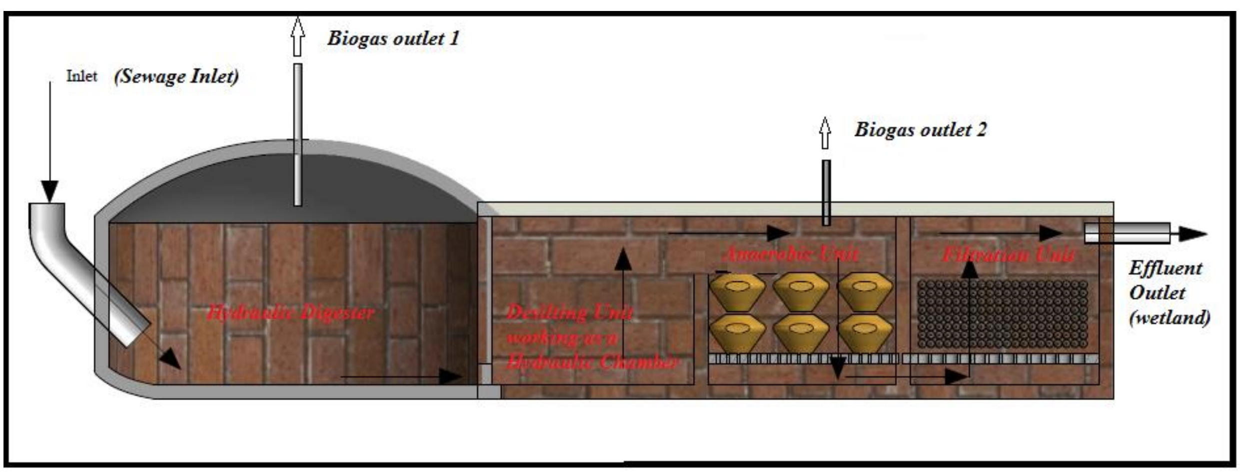



Figure 29: Operation of proposed Biogas Septic Tank (Design II)

# CHAPTER FOUR

# COST BENEFIT ANALYSIS OF PROPOSED DESIGNS

## 4.1. ECONOMIC AND TECHNICAL ANALYSIS

The techno-economic analysis of the proposed designs were carried out to enable prospective system owner to get a complete understanding of the cost involved and the technical viability of the systems

### 4.1.1 Material Estimate for Proposed Biogas Systems

The material estimate is different for the construction of the two designs proposed in this work. The material estimate for the construction of new biogas tank DESIGNS I and II are listed in Table 7 below:

**Table 7: Material estimation for construction of the designs on unit metric volume gas basis**

| Items | Design I | Design II |
|---|---|---|
| Cement (kg / $m^3$) | 200-220 | 200-220 |
| Bricks (No. / $m^3$) | 200-300 | 200-300 |
| Sand and pebbles ($m^3$) | 0.4-1.0 | 0.4-1.0 |
| Steel (kg / $m^3$) | 15-22 | 30-40 |
| Working days (person-day) | 5-10 | 20-30 |
| Unit Cost (GH₵ / $m^3$) | 400-500 | 400-500 |

(Cost in GH₵ as at May, 2014)

### 4.1.2 Cost implication for the design

Referencing Table 7 above, the proposed design II is more expensive that design I simply because Design II is bigger and consumes more construction materials than Design I. This is due to the fact that the volume of proposed design II is twice the volume of design I.

**Table 8: Cost of constructing of proposed designs I and II**

| BIOGAS PLANT PRE-SIZING | | | REFERENCE INVESTMENT COSTS (TURN-KEY, including engineering & testing) | | |
|---|---|---|---|---|---|
| | | | unit cost | unit | Total cost (GHC) |
| Design I ( construction only) | 6 | $m^3$ | 400 | GHC/$m^3$ | 2,400 |
| Biogas appliances (user preferred eg. Stove only) and connection | | | | | 1,000 |
| Annual Operational cost (Slurry removal and maintenance) | 1 | unit | 350 | GHC /unit | 350 |
| | | | | **TOTAL DESIGN I INVESTMENT** | **3,750** |
| BIOGAS PLANT PRE-SIZING | | | REFERENCE INVESTMENT COSTS (TURN-KEY, incl engineering & testing) | | |
| | | | unit cost | unit | Total cost (GHC) |
| Design II ( construction only) | 12 | m3 | 400 | GHC/$m^3$ | 4,800 |
| Biogas appliances (user preferred eg. Stove only) and connection | | | | | 1,000 |
| Operational cost (Slurry removal and maintenance) | 1 | unit | 350 | GHC /unit | 350 |
| | | | | **TOTAL DESIGN II INVESTMENT** | **6,150** |

### 4.1.3 Levelised Cost of Service (LCOS) of Designs I and II

Computing the levelised cost of service (Table 9 and Table 10 refer) provided by Design I and II over 5 years reveals that one time annual cost of the service provided by the design I and II is worth GH₵850 and GH₵1,519 respectively. Again, households that deploy Design I and Design II will start making saving in the second year after installation since the biogas systems start production. Savings are made by any household when they are using biogas produced by the proposed designs instead of Liquefied Petroleum Gas (LPG).

**Table 9: Levelised cost of service for Designs I**

| Period | CAPEX Initial Cost | OPEX Maintenance Cost | OPEX Recurrent Cost (Slurry Removal) | Total annual cost | Annual service units |
|---|---|---|---|---|---|
| year 1 | GHC 2,400 | | | GHC 2,400 | 1 |
| year 2 | GHC 0 | | GHC 100 | GHC 100 | 1 |
| year 3 | GHC 0 | GHC 250 | GHC 120 | GHC 370 | 1 |
| year 4 | GHC 0 | | GHC 144 | GHC 144 | 1 |
| year 5 | GHC 0 | GHC 300 | GHC 173 | GHC 473 | 1 |
| | | | NPV of Cost = | GHC 2,543 | |
| | | | | NPV of Service = | 2.99 |
| | Discount Rate | 20% | Levelised cost of service = | | GHC 850 |

Assumption: 58 $m^3$ of Biogas is an annual unit of service

**Table 10: Levelised cost of service for Designs II**

| Period | CAPEX Initial Cost | OPEX Maintenance Cost | OPEX Recurrent Cost (Slurry Removal) | Total annual cost | Annual service units |
|---|---|---|---|---|---|
| year 1 | GHC 4,800 | | | GHC 4,800 | 1 |
| year 2 | GHC 0 | | GHC 100 | GHC 100 | 1 |
| year 3 | GHC 0 | GHC 250 | GHC 120 | GHC 370 | 1 |
| year 4 | GHC 0 | | GHC 144 | GHC 144 | 1 |
| year 5 | GHC 0 | GHC 300 | GHC 173 | GHC 473 | 1 |
| | | | NPV of Cost = | GHC 4,543 | |
| | | | | NPV of Service = | 2.99 |
| | Discount Rate | 20% | Levelized cost of service = | | GHC 1,519 |

Assumption: 58 $m^3$ of Biogas is an annual unit of service

Based on the findings from the LCOS of the proposed designs, a technical analysis is required to justify the viability and relevance of implementing it on a pilot stage for further evaluation

#### 4.1.4 Production of Biogas and Energy Demand

Biogas produced anaerobically from the proposed designs will be able to substitute almost the complete consumption of firewood and kerosene in homes. The calorific value of biogas is about 6 $kWh/m^3$; this corresponds to about half a litre of diesel oil. This net calorific value depends on the efficiency of the burners or appliances that will be coupled with the biogas systems. Current biogas programs aim large household in order to achieve a wide dissemination, neglecting the capital cost change faced by homes. However, the proposed designs provides an alternative design options for homes that will install new septic tank to skip that cost of acquiring a separate biogas digester. The proposed systems are technically designed to treat sewage and produce biogas. More importantly, the designs will allowed to test innovative business models that could drive down CAPEX and OPEX involved. Efficiencies of the appliances and lower operation and maintenance (O&M) will make the designs inevitably achieve technical success. All components of the systems can be obtained indigenously. Other attributed technical features is tabulated in table 11 below.

**Table 11: Features of proposed designs**

| FEATURES | **DESIGN I** | **DESIGN II** |
|---|---|---|
| Capital cost | Low | High |
| Materials saving degree | Saving | Less saving |
| Difficulty of construction | Easy | Less easy |
| Pollutant removal | Lower | Higher |

## 4.2. BENEFIT OF PROPOSED BIOGAS SEPTIC TANK

### 4.2.1 Health Benefit

The main motivation for this project is sanitation. As a result, the designs work in such a way that during sewage treatment process a lot of microorganisms, that represents a health risk to both humans and marine life, are killed. By this, the hygienic standard in the environment or community would be improved. The germs such as paratyphoid, cholera and dysentery bacteria are usually killed in biogas tanks, in one to two weeks period. Hookworm and bilharzias also dies in three weeks.

### 4.2.2 Energy Benefit

Biogas is mainly composed of methane ($CH_4$), which is the same energy carrier as in natural gas. Methane can be burnt for cooking or lighting. It can also be used to power combustion engines to drive mechanical motor or generate electricity.

### 4.2.3 Economic Benefit

Biogas plants could generate economic activities such as fish culture, piggery and small cottage industry once installed. It is recognized that the use of slurry for fertilizer also plays an important role in the economics of biogas plants.

### 4.2.4 Agricultural Benefit

The liquid slurry from biogas plants that are feed with cow dung or animal waste, can be easily used as organic fertilizers to improve the growth of the crops.

## 4.3. MANAGEMENT OF BIOGAS SEPTIC TANK

To guarantee normal performance of the biogas tanks, it a better option to assign the itinerant management to a technician. However, owners can also undertake the following maintenance procedures as follows:

a) During the period of high flow rate, remove the cover of Desilting tank to observe if any sediment or scum clogs the inlet. If it is clogged, please remove them all;

b) If no clog at inlet, then remove the cover of facultative filter to observe its effluent. If the influent rate is higher than that of effluent, it means that the device is clogged somewhere inside, then open the check well and dredge it;

c) Control the live load to assure safety of the structure of tanks. When the ground above the tanks is over loaded, wood or steel plate should be laid on the ground to increase the area. They can transfer live load and reasonably distribute the force to prevent the structure of the tanks from being destroyed;

d) Regularly check the junctions and valves to prevent leakage; if there is a leakage, make sure you seal it with the appropriate material.

e) Prevent leakage of biogas around the covers and gas distribution pipes.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

## 5.1. CONCLUSION

Evidently, domestic septic tank can be redesigned to treat sewage and recover biogas as energy. Alternate models have been designed and proposed for adoption against the existing domestic septic tanks for treating domestic sewage for both energy recovery and meeting the environmental requirements for such exuding effluent.

## 5.2. RECOMMENDATIONS

Financial analysis of the alternative models proposed in this work can be undertaken towards feasibility studies for such systems. It is therefore that a prototypes be built for pilot studies and evaluation.

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