ASSESSING THE PERFORMANCE OF THE FILTERING UNIT OF THE BIOFIL TOILET SYSTEM

By
Isaac S-lase Kuwornu (BSc)

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ABSTRACT

This work assesses the potential of the filtration component of novel Biofil Toilet Technology in the treatment of blackwater in urban settings. Laboratory scale models of the digester were constructed using wood and pervious concrete slabs (used as filtering membranes) were also moulded in the lab. Coconut fibre and three different pervious concrete slabs were assessed for their role in removing contaminants from blackwater. The blackwater was fed through this system for a total of 25 repetitive days and after every five days, the changes in physical, biological and chemical parameters of the blackwater were measured.

The blackwater influent used was found to be of low strength with a rather high COD/BOD_5 ratio of 15:1. It also showed high variability of the chloride contents and other parameters.

A p value of 0.9563 indicated similarity between all three coarse aggregates used in moulding the filtering membranes. This was evident in their determined hydraulic conductivities and performance during feeding.

Coconut fibre (bulking material) was also found out to influence the overall treatment efficiency of the filtering unit. It accounted for significant increase in contaminant level compared to the influent raw blackwater (TSS -26%, COD – 31.7%, BOD_5 – 213%)

All three types of filtering membranes could not give any significant reduction in the level of TSS, TDS, COD, NO_3^- and PO_4^{3-}. To the contrary these parameters were about 38.8, 20.8, 80.6, 50.8 and 144.6% respectively more in the effluent from the filtering membranes.

Shredded PET (SP) filtering membrane showed significant reduction in E.Coli population in its effluent compared to the others. In general, the results suggest that none of the elements of the filtering unit is able to attenuate defined parameters to approved Ghana EPA guidelines. For cost

saving measures, either shredded PET or palm kernel shells is recommended as coarse aggregate to be used in moulding the filtering membranes among others.

This work provides a preliminary idea of using pervious concrete, made with various coarse aggregates, in blackwater treatment systems and further detailed studies are required on some key issues (e.g., loading rate, flow alternation impacts and coconut fibre stocking density) of this system.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
ACI	American Concrete Institute
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DeSaR	Decentralized Sanitation and Reuse
EcoSan	Ecological Sanitation
EAWAG	Swiss Federal Institute for Environmental Science & Technology, Duebendorf, Switzerland
FSM	Faecal Sludge Management
FS	Faecal Sludge
Ghana EPA	Ghana Environmental Protection Agency
GSS	Ghana Statistical Services
IETC	International Environmental Technology Centre
IRIN	Integrated Regional Information Networks
JMP	WHO/UNICEF Joint Monitoring Program
KVIP	Kumasi Ventilated Improved Pit latrine
MDGs	Millennium Development Goals
OSS	Onsite Sanitation Systems
ROSA	Resource Oriented Sanitation
SANDEC	Dept. of Water & Sanitation in Developing Countries at EAWAG
US EPA	United States of America Environmental Protection Agency
WHO	World Health Organization
WWTP	Wastewater treatment plant

DEFINITION OF TERMS

Biosolids**:** faecal sludge accumulated on the top of PSDBs. They are valuable organic manure that can be used as fertiliser and to improve soil structure.

Blackwater**:** the mixture of urine, faeces and flushwater along with anal cleansing water (if anal cleansing is practiced) and/or dry cleansing material (e.g. toilet paper). Blackwater has all of the pathogens of faeces and all of the nutrients of urine, but diluted in flushwater.

Bulking material: dry and fibrous materials such as sawdust, leave moulds, finely chopped straw, peat moss, rice hulls or grass clippings, mixed in the biofil digester in order to prevent odour, absorb urine, and eliminate any fly nuisance

Excreta**:** consists of urine and faeces that is not mixed with any flushing water. Excreta is small in volume, but concentrated in nutrients and pathogens. Depending on the quality of the faeces it is solid, soft or runny.

Faecal sludge**:** sludge of variable consistency collected from on-site sanitation systems such as latrines, non-sewered public toilets, septic tanks, and aqua privies. It comprises varying concentrations of settleable or settled solids and other non-faecal matter. It differs from the sewage sludge which generally refers to sludge produced in wastewater treatment plants.

Full flush system: a biofil toilet that uses as much as 7-12 liters of water per flush

Grey water**:**

Log removal**:** Pathogen removal efficiencies of a treatment unit: 1 log unit =90%;
2 log units = 99%; 3 log units = 99.9%; and so on.

Micro flush system: a biofil toilet that uses as low as 150ml of water per each flush

Onsite Sanitation: A System of sanitation where the means of storage are contained within the plot occupied by the dwelling and its immediate surroundings. It may be disposed of on site or removed manually for safe disposal.

Septage**:** sludge from septic tanks

Solid loading rate**:** total solid weight of faecal sludge applied to the system per unit surface area and time. Used as a design criterion for faecal sludge treatment facilities.

Sanitation: the safe and sound handling of human excreta. ‘‘Good’’ sanitation system as one which minimizes or removes health risks, is economically viable, and avoids negative impacts on the environment.

“Sanitation is more important than Independence” – Mahatma Ghandi

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"*Never to forget where we came from and always praise the bridges that carried us over*." - Fannie Lou Hamer

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CHAPTER ONE

1 INTRODUCTION

1.1 BACKGROUND

Sanitation, the safe disposal of human excreta (WHO, UNICEF 2010) was in 2007 voted as the most important medical milestone since 1840 by readers of British Medical Journal (BMJ). However, inadequate sanitation is still a major problem faced in developing countries and countries in transition. Diarrhoea is estimated to cause 1.5 million child deaths per year, mostly among children under five living in developing countries (WHO, 2004).This gives a clear indication of the vital role that sanitation still plays in improving public health.

The disposal of human excreta is becoming increasingly challenging with exponential increase in urban population of particularly poorer countries (USAID, 2013). Strauss (2004) highlights that approximately 2.4 billion urban dwellers rely on on-site sanitation system (OSS) installations such as pit latrines, aqua privies and septic tanks which serve about 65-100% of urban dwellers in cities of Africa, Asia and Latin America (Strauss et al., 2000).

The Ghana Statistical Service (GSS) (2008) estimates that about 51% of the population of Ghana lives in urban areas of which an estimated 85% are served by OSS (Montangero and Strauss, 2000). Due to higher population density, limited land space, improper use and operation, these systems often generate high quantities of faecal sludge which become problematic to manage especially in the absence of faecal sludge treatment facilities (Plate 1).

Plate 1: Disposal of untreated septic sludge into the environment in Accra

(Source: Linda Strande, Inhabitat.com, 2013)

In addition, many of such OSSs are unable to effectively treat the excreta to meet the minimum treatment standards for discharge or application into the environment. The rippling effect of poor disposal practices such as disposal of faecal sludge into open gutters, ocean and outskirts of towns, has resulted in pollution of the environment, especially natural water bodies. The current state and practice of OSS in urban areas present a public health risk in areas where they are used. There is therefore a need for a more sustainable form of OSS.

The Biofil Toilet Technology (BTT) is a new and promising initiative of a local entrepreneur (K. Anno Engineering Ltd/BIOFILCOM) in Accra, Ghana and was launched into the sanitation market on June 24, 2008 with the Ghana Institute of Engineers (GhIE). The toilet works on the principles of vermicomposting and microbial interaction.

It is a compact onsite system combining rapid solid-liquid separation of blackwater by a porous concrete filter (PCF) and accelerated decomposition by macro-organisms (earthworms) to degrade the solids whiles the liquid undergoes bio-filtration through a sand media before final discharge via a drainfield in the subsurface soil. The technology also has a layer of bulking material made from coir as a bedding material for the activities of the earthworms and microbes. This is placed on the PCF with a mesh lining separating it from the PCF.

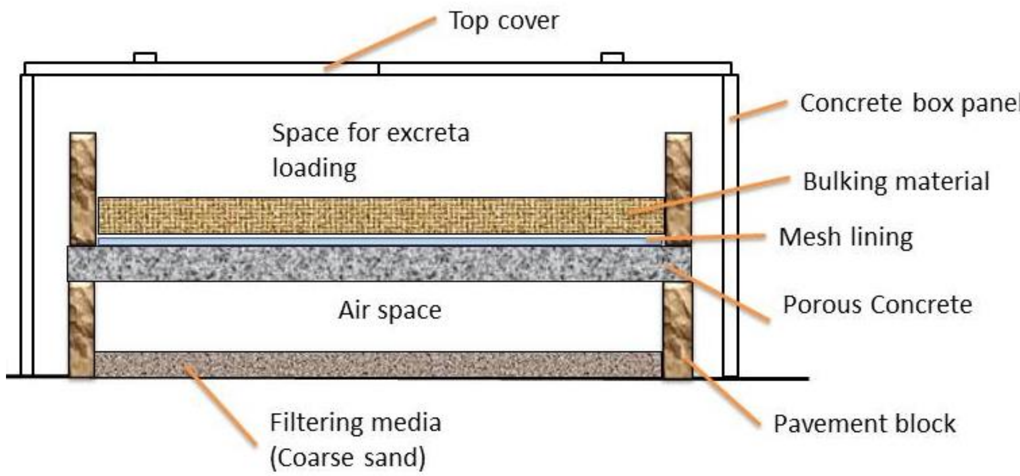

Figure 1: Schematic design of the BTTSince its development however, there has been minimum research conducted on the safety of the by-products particularly the effectiveness of the BBT filtration components for the removal of physico-chemical and bactericidal contaminants in blackwater to the acceptable limits for discharge into the environment. This study compliments initial work conducted on the effectiveness of subsurface infiltration for the treatment of BBT effluent as part of a PhD research on the BTT. It seeks to assess the filtration mechanism of the BTT components for effective removal of contaminants in blackwater and will be geared towards the optimization of the system for better performance.

1.2 PROBLEM STATEMENT

Groundwater pollution is becoming a prominent form of water contamination as a result of failure to monitor the effective treatment of wastewater by many OSSs. The use of conventional waterborne sanitation systems in the urban setting is often not suitable, thus the predominance of OSSs in such areas need to be investigated to curb the issues of groundwater contamination. Direct discharge of blackwater into pits with the intention of self-destruction of pathogens and removal of certain contaminants to acceptable limits for safe discharge cannot be over emphasized. The BTT, having filtration as one of its key treatment mechanisms for the removal of physico-chemical and bactericidal contaminants needs to be assessed to ascertain the level of its performance. In addition, the issue of clogging which is mostly associated with filtration systems needs to be assessed since it can threaten the performance of the technology.

1.3 RESEARCH QUESTIONS

The BTT acts as a biological filter and receives blackwater at the top (i.e. faeces, urine, anal cleansing material and wash water). There is solid-liquid separation of the blackwater through the bulking material, Porous Concrete Filter and the soil media before final discharge into the subsurface soil. The solid components are degraded mainly by the interaction of earthworms and microbial activities. . Micro-organisms also play a role the degradation and treatment of both liquid and solid inputs.

The bulking material and filtering membrane are key in the operation of the digester and the study will help improve the operation of the digester.

Bearing this in mind, the study will sought to answer questions such as

- What are the physical characteristics of the filtering membrane and bulking material used in the BTT?
- Does the filtering membrane and bulking material contribute significantly to contaminant and pathogen removal while performing primary solid-liquid separation?
- What other materials can be used as filtering membrane to improve performance?
- What factors contribute to the clogging of membranes leading to flooding of unit, especially with flushing toilets?

1.4 RESEARCH OBJECTIVE

1.4.1 GOAL OF RESEARCH

The goal of the study is to assess the performance of different filtering membrane and bulking materials in the digester of the Biofil Toilet Technology.

1.4.2 SPECIFIC OBJECTIVES

The specific objectives of the research are

1. To determine the physical characteristics (bulk density, porosity, hydraulic conductivity) of different filtering membranes (porous concrete, shredded PET material, coconut fibre) for solid-liquid separation in the Biofil Toilet Technology
2. To assess the performance of the different filtering membranes for bacteriological and

physico-chemical contaminant removal

3. To assess the bulking material (coconut fibre) for optimum contaminant removal in the biofil effluent.

1.5 JUSTIFICATION

In assessing the performance of the filtering unit of the biofil toilet the findings are expected to impact on the design of future biofil toilets in ways including but not limited to:

- Providing preliminary data on the filtering capacity and contaminant removal efficiency as used in the current technology
- Providing data for protocols to improve the existing technology
- Providing preliminary data on the use of alternate materials for filtration components of the technology.

In the end, future models of the toilet are expected to be optimized for filtration and contaminant removal.

1.6 SIGNIFICANCE OF STUDY

This study will provide invaluable data on the operation of the filtering membranes and bulking materials used in digesters of the Biofil Toilet Technology.

As a promising OSS technology to improve sanitation in various urban and rural settlements, the Biofil Toilet Technology needs to be optimized to ensure its continued existence as a reliable technology as a low-cost sanitation option. The study will suggest appropriate filtration mechanisms and materials to enhance the efficiency of operation of the BTT, increase its acceptability and reduce the overall unit cost of production.

The study will also help determine which materials are most suitable as filtering membrane for the toilet. The outcome will also give insight into the exact role of the bulking material in the digester and its effect on solids and effluent quality.

The entire study will help optimize the operation of the digester and knowledge into materials to extend operational live of the digester and its general acceptance with production cost in mind.

1.7 SCOPE OF STUDY

The study is limited to the Biofil Toilet Technology. Three (3) types of materials used as filtering membranes and one bulking material have been assessed in the study. The study was conducted only in the Environmental Quality laboratories of the Department of Civil Engineering in Kwame Nkrumah University of Science and Technology (KNUST) with scaled down parts of the BTT with blackwater collected from homes in Ayigya (a settlement about 2km from the university). Analyses of the component materials were restricted to only physical parameters though some chemical parameters have been mentioned in literature review. Feed samples were analyzed based on physico-chemical and bacteriological parameters for wastewater discharge into natural water bodies by the Environmental Protection Agency

The performance of the entire BTT was not to be investigated in this study, and forms part of a detailed PhD study of the BTT. The study however cover detailed analysis on the influence of the bulking material and filtering membrane on solid-liquid separation, effluent quality and determination of key physical parameters required for more efficient operation of the BTT.

1.8 STRUCTURE OF THE THESIS

The thesis is written in five chapters. The first chapter introduces the dissertation and provides a background to the problem statement. Research questions, objectives, significance and scope of the study are all discussed in this chapter.

Chapter two presents review of pertinent literature related to the topic. Methodological frameworks used in collecting and analyzing data are discussed in Chapter three.

Chapter four presents the results of the study and a thorough discussion and evaluation of the findings. Chapter five concludes the dissertation and presents recommendations based on the findings of the study.

CHAPTER TWO

2 LITERATURE REVIEW

This chapter takes a critical look at different studies and efforts that have been put into maintaining public health in developing countries with emphasis on Ghana. It expounds on various ideas and concepts relating to Onsite Sanitation Systems (OSS) and Faecal Sludge Management (FSM); its handling and treatment, based on sound scientific evidence. The role of the Biofil Toilet Technology in safeguarding public health, its technological development, contaminant removal mechanism by filtration, its evolution and how they contribute to public health are also discussed in this chapter.

2.1 URBAN SANITATION IN DEVELOPING COUNTRIES

The status of urban sanitation in developing countries like Ghana is one of the most important environmental issues studied today. In order to meet the Millennium Development Goals (MDGs), WHO/UNICEF (2000, 2004) asserts that at least 400,000 persons per day will have to be provided with adequate sanitation between 2011 and 2015. This is obviously a daunting task for any government.

In 1992, WHO reported that urban growth has produced concentrations of poor people in city slums and squatter areas. Consequent to that, a major challenge for environmental health practitioners is the design and introduction of excreta disposal systems appropriate for these high-density and low-income areas.

Considering that the infrastructure development has not been commensurate to population growth, residents in areas with no sanitation services have often resorted to their own ways of sanitation; with or without the supervision of local authorities. According to Kone and Strauss (2004), one third of the world population (approx. 2.4 billion urban dwellers) rely on on-site sanitation (OSS) installations, thus unsewered family and public latrines and toilets, aqua privies and septic tanks. This situation is likely to last for decades to come, since city-wide sewered sanitation is neither affordable nor feasible for the majority of urban areas in developing countries

On-site systems will eventually reach capacity and if a long term plan for their maintenance, supported by a budget, is not in place, full toilets will become unusable and households will be effectively without basic sanitation once again. The provision of an effective and comprehensive sanitation service includes ongoing operation and maintenance of the system, either by the homeowner or by a partnership between the homeowner and the local government (DWAF, 2005).

2.2 SANITATION SYSTEMS

There are different technologies available for dealing with faecal sludge and blackwater management. Depending on the conditions, they are broadly categorized into onsite and offsite technologies. The concept of on-site is described in this section, with examples of some popular latrines and systems in use.

Onsite and decentralized sanitation are generally seen as an answer to the absence of water borne sanitation systems. The vision of onsite and decentralized systems is still unfolding and the possibilities for the future are open ended (Siegrist et al, 2013).

2.2.1 ONSITE SANITATION

On-site sanitation describes the whole set of actions related to the collection, treatment and disposal of excreta and domestic wastewater on the same premises of generation. Onsite has potential to be the most sustainable form of sanitation if managed properly. Onsite sanitation systems (OSS) aim to contain human excreta at the point of generation. It can generally be classified into two main categories: 'wet' which require water for flushing; and 'dry' which do not require any water for flushing. This type of system comprises of septic tanks Improved Pit (VIP) Latrines, traditional/simple pit latrines, pour-flush toilets, Ecosan latrines (Source: http://www.irc.nl/page/10371) and other household level technologies that do not involve sewerage.

It has emerged as a preferred mode of sanitation in cities experiencing rapid urbanization due to the high cost involved in off-site sanitation which requires conventional sewerages. Worldwide, onsite sanitation systems are being promoted widely as they can play a key role in increasing access to improved sanitation. Particularly in rural and peri-urban areas where space availability and population density are not constraining factors on its adoption and where onsite sanitation can be substantially cheaper and easier to promote than sewerage networks (IRC 2010). Table 1 gives a clear indication of the popularity of OSS in developing countries.

Table 1: Prevalence of OSS on countries or cities

City or country	% of inhabitants served by onsite sanitation systems
Ghana	85
Bamako (Mali)	98
Tanzania	>85
Manila	78
Philippines (towns)	98
Bangkok	65
Latin America	>50

Adopted from Strauss et al, 2003

Looking on conventional on-site excreta disposal systems applying the 'drop and store' principles the pit latrine in its various forms is still the dominantly used OSS in developing countries (Esrey et al., 2001).

Disadvantages of the system include possible soil and groundwater contamination with pathogens, bad odour, fly/mosquito breading, or pit collapse (Langergraber and Muellegger, 2004). It is therefore important that new sanitation technologies developed are effectively able to tackle these set backs identified.

2.2.1.1 TYPES OF OSS IN URBAN AREAS

In classifying the various types of OSS used in homes in Africa, Zurbru¨gg, and Tilley (2009) makes use of the classification employed by the Network for the development of Sustainable Approaches for large-scale implementation of Sanitation in Africa (NETSSAF).

Two main criteria are used for subdividing the systems; wet and dry. The terms ‘‘wet’’ and ‘‘dry’’ are used to indicate the presence of flushing water for the transport of excreta.

A dry system may nevertheless sometimes contain anal cleansing water, urine flushing water, or even greywater.

Table 2: Types of OSS used in Urban Areas

Types of OSS	Wet System	Dry System
Characteristics	• A mixed blackwater and greywater system with on-site treatment where all the waste streams are mixed and treated together. • A urine-diversion system where urine flowstream/ yellowwater is mixed with greywater flowstream. The Faecal sludge flowstream is also treated separately.	• A Dry urine- and greywater-diversion system where the urine flowstream and greywater flowstream are treated separate from the Faeces flowstream • A Dry all mixed systems. Where all flow streams are mixed and treated together.
Examples	Pour flush, septic tanks, UDFT, aqua privy, compost toilets (eg. BTT*)	Pit latrine, UDDT, VIP, arbaloo, compost toilets

*BTT –Biofil Toilet Technology

2.2.2 CURRENT MANAGEMENT PRACTICES OF SLUDGES FROM OSS

The use of OSS has resulted in collection of several hundreds of tonnes daily of faecal sludge; accumulating in septic tanks, aqua privies, family pits, bucket latrines, and public toilets; begging to be disposed off. More than ever, there is a need for innovative, low cost faecal sludge (FS) management options in the face of rising water, fertilizer and energy prices (Christoph, et. al, 2011). Unfortunately, faecal sludge in many of these cases is disposed off untreated and indiscriminately into drainage ditches, inland waters, the sea and on unused plots; a practice contributing to perpetuating the spread of gastro-intestinal infections and environmental degradation.

The choice of an FS management option depends primarily on the characteristics of the sludges generated in a particular locality and on the ended use of by products. FS characteristics vary widely within and between localities, based on the types of on-site sanitation installations in use and on the emptying practice. The fact that faecal sludge exhibit widely varying characteristics, calls for a careful selection of appropriate treatment options, especially for preliminary treatment which may encompass solids-liquid separation or biochemical stabilization if the FS is still rather fresh (Kone and Strauss, 2004).

Figure 2 shows schematically the array of theoretical options, proposed by EWAG, for FS treatment, with feasible options which can considered for use depending on the local situation prior to in-depth evaluation

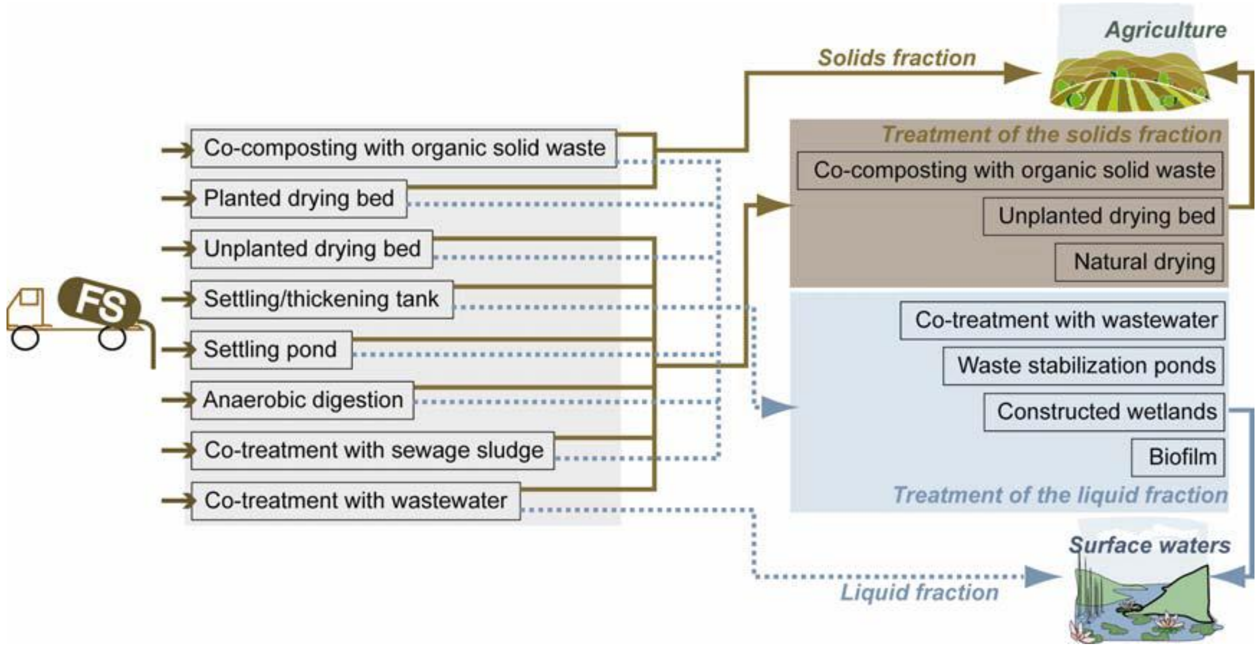

Figure 2: Overview of potential, modest-cost options for faecal sludge (Source: EWAG/SANDEC and IWMI 2003)

2.2.3 KEY CONTAMINANTS IN HUMAN EXCRETA FROM ONSITE SANITATION SYSTEMS AND THEIR REMOVAL

Excreta from OSS contains pathogens, solids, substances exerting oxygen demand, nutrients and a host of other possible pollutants which may need to be removed before the wastewater can be safely disposed (Ho, 1995).These are broadly referred to as contaminants in this dissertation. Their presence in the environment has potential to negatively impact different parts of the environment; from creation of general nuisance to the transmission of diseases. These contaminants are classified and their effects and removal discussed in this section.

2.2.3.1 Organic constituents

Organic matter is always present in human excreta. It manifests in either soluble or particulate forms and be either readily biodegradable or non-biodegradable. In which ever form they occur, their presence in the environment, especially in water bodies exert tremendous oxygen demand.

The extent of oxygen demand is measured by biochemical oxygen demand (BOD) or chemical oxygen demand (COD) for readily biodegradable organics and total organics respectively.

The organics are the main contaminants targeted among others for removal during blackwater treatment due to their oxygen demand (Gill et al., 2004).

Heterotrophic micro-organisms are generally responsible for the breakdown of these organics. Brady and Weil (2002) found that the presence of large surface area, during filtration or percolation of wastewater through a media provide high potential for biofilm development which is of great importance in the breakdown of organics in the wastewater.

2.2.3.2 Inorganic constituents and nutrients

Key inorganic contaminants found in excreta are indicated in Table 2.4.1.2. The EPA of Ghana also recognizes nitrogen, phosphorous and sulphide compounds as the main inorganic contaminants that should be treated prior to discharge into surface waters. These nutrients occur in many forms depending on the prevailing conditions.

(i) Nitrogen

Two forms of nitrogen are of importance in the pollution of water sources; Ammonia (NH_3) and Nitrate (NO_3). The toxicity of nitrate to humans is mainly attributable to its reduction to nitrite in the blood stream. The major biological effect of nitrite in humans is its involvement in the oxidation of normal haemoglobin (Hb) to methaemoglobin (metHb), which is unable to transport oxygen to the tissues. The reduced oxygen transport becomes clinically manifest when metHb concentrations reach 10% of normal Hb concentrations and above; the condition, called methaemoglobinaemia (WHO, 2011 and Walton, 1951).

Nitrates in water actively promote eutrophication (Harman et al., 1996) as it is one of the key nutrients for growth of autotrophic organisms. The transformation, retention, loss, or movement of nitrogen in OSS is governed by the mechanisms of mineralization, nitrification, denitrification, adsorption, biological uptake, and volatilization (Bicki et al, 1984).

(ii) Phosphate

Phosphorus is one of the key elements necessary for growth of plants and animals.

It is present in onsite sanitation systems as orthophosphate, dehydrated orthophosphate and organic phosphorous (Siegrist et al., 2000). The increasing phosphate concentrations in surface waters is also responsible for eutrophication,

Most of the influent phosphorus in the organic and phosphate forms are converted to soluble orthophosphate by the anaerobic process occurring in septic tanks and bottom of pit laterines. When effluent is discharged into drain fields, phosphorus is retained or immobilized in the soil systems by the mechanisms of adsorption, chemisorption, precipitation, and biological uptake and reductions in total phosphorus content of effluent in soil range from 85 to 95% or more (Bicki et al, 1984).

Studies by Bicki et al (1984) and Rose (1999) found out that phosphorus concentration in ground water is found to decrease with distance from OSS because phosphorus is capable of undergoing sorption and .precipitation within ground water.

(iii) Sulphides

Soluble sulfides are hydrolysed in water to form hydrogen sulfide. In water, hydrogen sulfide dissociates into its constituent ion species. The relative concentrations of these species are a function of the pH of the water (WHO, 2003). The presence of hydrogen sulphide imparts rotten egg smell and bitter taste to the water. WHO recommends that hydrogen sulphide should not e perceptible in taste and smell of the water body.

2.2.3.3 Pathogens

Pathogens commonly found from onsite sanitation facilities include enteric bacteria, viruses, protozoa and helminths, which occur at highly variable and episodically released levels (Cliver, 2000). Most of these pathogens are readily transported by water even to lower depths in the system (Abu-Ashour et al., 1994).

Bicki et al (1984) again found out that, these pathogens are removed or otherwise inactivated from effluent (of OSS) in soil by the mechanisms of filtration, adsorption, and natural die-off. The biological clogging mat or crust that commonly forms within the first few inches of the soil below an absorption trench or bed has been found to be an effective barrier to bacterial transport.

Considering the significant dependence of several communities on surface water sources (WHO/UNICEF JMP, 2012), the occurrence of these pathogens needs to be closely monitored in any treatment scheme. Protozoa and helmith eggs persist for longer periods outside their host and tend to be the most problematic in onsite sanitation systems (Gray, 1994).

2.3 OSS BEST PRACTICES

The magnitude of the global sanitation problem desperately requires creative new approaches to find the appropriate technology and the best way of implementing, operating and financing. This gave impetus to various models and concepts of sanitation aimed at maintaining a sanitary environment and promoting water, nutrient and energy recovery and reuse. A key underlining principle of all these concepts is the realization that sewage can no longer be classified as waste but as a resource. Prominent among these models and concepts are Resource Oriented Sanitation (ROSA), Decentralized Sanitation and Reuse (DESAR), and Ecological Sanitation (EcoSan).

DeSaR is more concerned with the use of liquid effluents (greywater and blackwater) to produce fertilizer and electrical energy using advanced wastewater treatment systems.

When properly designed and operated, Ecosan systems provide a sanitised, economic, and closed-cycle to convert urine and faecal matter into valuable nutrients to be returned to the land or use as biofuel. The Ecosan is used predominantly in areas with no access to sewerage or with scarce water supply. The EcoSan approach is resource minded and represents a holistic concept towards ecologically and economically sound sanitation. The technologies involved are picked from the whole range of available conventional, modern and traditional technical options, combining them to EcoSan systems. (Langergraber and Muellegger, 2005)

Resource-oriented sanitation concepts are a way towards a more ecological sound sanitation. The concepts are based on source separation and reuse. ROSA focuses on collecting and treating the different wastewater flows (faecal sludge and urine) separately to optimise the potential for reuse (Esrey et al., 1998). Dry toilet systems are best preferred for this system. Hygienic hazards are well known and guidelines for the treatment and safe use of urine and faeces are available. There are many technological options so that most social and economic conditions can be met. It avoids the disadvantages of conventional wastewater systems. Human excreta and water from households are recognised as a resource (not as a waste), which should be made available for re-use. The applied technologies may range from natural wastewater treatment techniques to compost toilets, simple household installations to complex, mainly decentralized systems (Otterpohl, 2004).

Compost toilets emerge as a hybrid of these concepts of FSM and sanitation practice of which the Biofil Toilet Technology is inclusive. The Biofil Toilet Technology treats both liquid (by filtration) and solid (using mainly macro-organism composting) for the production of organic fertilizer and polishing of wastewater for non-consumptive uses.

2.4 CHALLENGES IN OSS

Though designed to manage excreta onsite, most OSS are unable to meet this criteria. A major concern with the design and usage of OSS is the potential of polluting the groundwater and surrounding environments. This is because faecal matter accumulates in one place and contaminants may leach into the subsurface environment. The liquid part of

the waste in an OSS that infiltrates into the soil, when high and exceed natural attenuation potential in the sub-surface, lead to direct contamination of groundwater supplies (Lawrence et al, 2001). Groundwater contamination is known to have occurred in areas where there have been high densities of OSS. Problems with OSS are worsened when communities that rely on subsurface disposal systems (for effluent from OSS) also depend on private wells for drinking water. Several studies carried out in India (Pujari et al, 2012) show groundwater pollution from septic tank effluent in different soil media.

For OSS that rely on subsurface polishing of effluents, like the septic tanks and pit latrines, another common failure of a system is when the capacity of the soil to absorb effluent is exceeded. When this happens the wastewater from the drain lines makes its way to the surface. Water runoff from rain may wash the contaminants into surface waters or into inadequately sealed wells downstream. A significant failure also is when pollutants from the drain field move too quickly through the soil and potentially into the groundwater.

Currently no treatment of pit latrine content is done on-site in rural and remote areas and when the pit is full, it is closed and a new pit is installed (Koné and Strauss, 2004). The absence of any treatment in the pits means that these pits, from start of use, constantly release high concentrations of contaminants into the soil (depending on the soil conditions).

To remedy these problems with OSS, special attention must be directed to adequate treatment of excreta within the system prior to any effluent discharge.

2.5 HUMAN EXCRETA CHARACTERIZATION

In this section of the dissertation, the chemical, physical and biological characteristics of fresh faeces and urine from literature are examined from different perspectives and what influences these characteristics; these two being the major contributors to blackwater and key to the provision of improved sanitation.

Technology development for collection, transport, treatment and disposal of blackwater requires in depth knowledge of its properties. Knowledge of the characteristics of the components of faecal matter and urine can lead to better design in sludge processing technologies for sustainable and feasible downstream processing. The amount of urine and faeces an individual excretes varies widely, even locally, depending on water consumption, climate, diet, and occupation (Thye et al. 2011, Still and Foxcon, 2012[2]).

2.5.1 FAECAL MATTER

A study by Woolley et al (2013) and Foxcon et al (2008) identified that the composition of faecal matter can vary significantly between different people and from different faecal samples from the same person. This physico-chemical variation of the faeces is attributed to variations with age, health, diet, lifestyle, climate and geographical region of the individuals. Due to these variations, faeces production varies widely between 70-520 g/c/d (wet weight) (Chaggu EJ, 2004, WRC (2011) and Weaver (1988)).

Normal human stool is estimated to consist of roughly 70-80% water and around 20-30% solid matter. Water content varies in excreta depending on its position in the digestive tract. Excreta normally contain 75% water. When measured directly from the transverse colon, it contains 82-83% water; from the left colon 84-85% water; and from the ileo caecum, 90-95% (Jensen et al, 1976). The water content of faecal matter thus does not depend on dietary intake but on digestive function. The majority (84%) of the solid matter in faeces is organic in nature, and is mainly composed of bacteria (≈55%) and residual dietary fibre (17%).

Other studies carried to characterise faeces and to describe their biodegradability showed that in terms of chemical oxygen demand (COD), 80% of fresh human excreta are made up of slowly biodegradable organic matter and the other 20% is biologically inert material (Stephen and Cummings, 1980). Readily biodegradable organic matter is generally not regarded as a component of faeces as they are expected to be absorbed during the digestion process.

If users are infested with faecal pathogens, part of their pathogen load will be excreted along with faeces. The material used by the household for anal cleansing will also constitute part of the faecal sludge. If the toilet is of a pour-flush or low-flush design, flushing water will also comprise part of the sludge (Still and Foxcon, 2012).

Excreta are a rich source of organic matter and of inorganic plant nutrients such as nitrogen, phosphorus and potassium. Each day, humans excrete in the order of 30 g of carbon in 90g of organic matter, 10-12g of nitrogen, 2g of phosphorus and 3g of potassium. Most of the organic matter is contained in the faeces, while most of the nitrogen (70- 80 %) and potassium are contained in urine. Phosphorus is equally distributed between urine and faeces (EWAG/SANDEC and IWMI, 2003).

About 25-50 kg of wet faeces is produced per person per year, which contains up to 0.55 kg-N, 0.18 kg-P, and 0.37 kg-K. Elements that are contained in the diet in relatively large amounts, such as aluminium, tin, zirconium, strontium and vanadium, remain practically unabsorbed and more than 99% are excreted in faeces (Chaggu E.J., 2004). Other characteristics are summarized in table 5.

Table 3: Quantity, Composition and Characteristics of Human Faeces and Urine

Parameter	Units	Faeces	Urine
Quantity (wet)	g/person/day	70-520	1000-1500
Quantity (Dry solids)	g/person/day	30-70	50-70
Moisture content	%	66-85	93-99.5
Organic matter	%	88-97	65-85
Nitrogen (N) (%)	%	5.0-7.0	15-19
Phosphorus (as P_2O_5)	%	3.0-5.4	2.5-5.0
PO4-P	%	-	0.20
Total Phosphorus	g	0.69-2.5	1.08-2.2
Potassium	g	0.80-2.1	2.5-3.7
CODtotal	g/l	46.23-78.31	12.79-
TS	%	33	-
pH		-	7.08-9

Adapted from Chaggu E.J., 2004

2.5.2 URINE

Urine contains few disease-producing organisms, while faeces may contain many. It is a dilute aqueous solution of metabolic wastes such as urea, salts, and organic compounds. In total the dissolved material amounts to about 5% by weight. Subsequent to elimination from the body, urine can acquire strong odours due to bacterial action. Most noticeably, ammonia is produced by breakdown of urea. Some diseases alter the quantity and composition of the urine, such as sugar as a consequence of diabetes (Torondel, 2010).

Chaggu (2004) estimates that an adult produces 400-500 litres of urine/year and contains 4.0 kg-N, 0.4 kg-P and 0.9 kg-K. Urine is the fraction that contains the major part of nutrients in domestic wastewater or black water, approximately 80% of the nitrogen, 55% of phosphorus and 60% of the potassium (Jonsson et al., 2000). Due to its relatively high nutrient content, human urine is a quick-acting fertilizer that can replace mineral fertilizer especially in cereal crop production (Chaggu, 2004).

A more detailed composition of urine is also described in Table 5.

2.5.3 EXCRETA GENERATION RATES

An individual produces between 0.12-0.40 litres of faeces and 0.6-1.5 litres of urine per day (Buckley et al., 2008). Averaged over a year, this amounts to 110 litres of faeces and 440 litres of urine per person per year: a total volume of 550 litres of excreta per person per year (Still and Foxcon, 2012). The values for urine fall within the estimate of 400-500 litres per capita per year as determined by Chaggu in 2004.

Lawrence T. Weaver (1988) reported that in the western world (developing countries) excreta output ranged fron 50g to 300g per day with an average wet weight of 140g. Wenzl et al (1995) estimated that stool weight per person varied from 39 to 235 g/day. Torondel (2010) also estimated that a typical adult excretes an average of 0.4 kg of faeces per day, which comprises 0.1 kg of dry mass if the moisture content, which comprises 70-80%, is removed.

Table 4: Quantity of wet faeces excreted by adults (in grams per person per day).

Country	Quantity
China(men)	209
India	255 - 311
Peru (rural area)	325
Uganda (village)	470
Malaysia (rural)	477
Kenya	520

Adapted from Torondel (2010)

Wide variations in the determination of urine and faeces generation rates indicate the difficulty in measuring them and wide individual variation. The amounts excreted daily by individuals vary considerably depending on water consumption, climate, diet and occupation. The only way to obtain an accurate determination of the amount at a particular location is direct measurement.

Even in reasonably homogeneous groups there often wide variation in the amount of excreta produced per person. Generally, active adults eating a high-fibre diet and living in a rural area produce more faeces than children or elderly people living in urban areas eating a low-fibre diet. The amount of urine is also greatly dependent on the local temperature and humidity.

In the absence of local information the following figures are suggested as reasonable averages (Franceys et al., 1992):

- High-protein diet in a temperate climate: faeces 120 g, urine 1.2 litre/person/day.
- Vegetarian diet in a tropical climate: faeces 400 g, urine 1.liter/person/day.

For the purposes of this study, an average faeces production per capita of 400g is assumed.

2.6 FILTRATION AND WASTEWATER/BLACKWATER

2.6.1 Solid –liquid Separation

The separation of solids and liquids, which make up FS, is the process-of-choice in FS treatment unless it is decided to co-treat FS in an existing or planned WWTP and if the FS loads are small compared to the flow of wastewater. Solids-liquid separation may be achieved through sedimentation and thickening in ponds and tanks or filtration and drying in sludge drying beds. Resulting from this are solids and liquid fraction. The separated solids will in most cases require further storage, dewatering, drying, or composting resulting in biosolids usable as a soil conditioner-cum-fertilizer.

The liquid fraction will normally have to undergo polishing treatment to satisfy criteria for discharge into surface waters and/or to avoid groundwater pollution, where effluents are allowed to infiltrate (Kone and Strauss, 2004).

Some well known methods of solid-liquid separation of FS include: Settling ponds, settling/thickening tanks, unplanted drying beds, constructed wetlands (Kone and Strauss, 2004) and more recently, filtration (as used on the Biofil Toilet Technology).

2.6.2 FILTRATION

Filtration is widely used for removing particles from water. Filtration can be defined as any process for the removal of solid particles from a suspension by passage of the suspension through a porous medium (Howe et al, 2012).

Filtration has different significance in different applications. Generally however, it serves the purpose of removing various contaminants from the liquid phase as practised in drinking water treatment. The contaminants in this case range from physical, pathogenic/biological as well as chemical contaminants.

Although filtration has the potential of removing pathogenic organisms from water, Peavy et al (1985) advice that it should not be relied upon for complete public health protection. In onsite sanitation systems, filtration systems serve as biological filters where purification occurs by processes of physical filtration, chemical reaction and biological transformation (Stevik et al, 2004).

Riahi et al (2009) identify filtration as one of the attractive and effective processes to improve effluent quality in wastewater treatment. Application of filtration has resulted in significant removal of organics, nutrients, and particulates and in some cases metal contaminants.

2.6.2.1 Contaminant Removal Mechanisms during Filtration

There are several contaminant removal mechanisms associated with filtration. However, in the context of sanitation, the most relevant mechanisms responsible for removing the bulk of contaminants and the immobilization of pathogens in wastewater are straining and adsorption (Stevik et al, 2004).

A Straining

When particles are larger than the void spaces in the filter, they are removed by straining. When particles are smaller than the voids, they can be removed only if they contact and stick to the grains of the media (Howe t al 2012, Crittenden et al, 2012).

This removal mechanism involves the physical blocking of the movement of through pores smaller than a contaminant. The straining effect is influenced by the pore size of the porous media, contaminant size and shape, hydraulic load on the media, and level of clogging within the filter (Stevik et al, 2004). Straining causes a cake to form at the surface of the filter bed as well as within the pores, which can improve particle removal but also increases head loss through the filter (Howe t al 2012, Crittenden et al, 2012). Development of biofil within the pores of the filter reduces the pore size within the filters. This also enhances the effect of straining to remove the contaminants together with other minor mechanisms such as adhesion and flocculation (Metcalf and Eddy, 2004).

A study by Logan et al (2001) into Cryptosporidium oocyst removal suggests that the larger surface area associated with finer aggregates as opposed to coarser aggregates together with the accompanying increased residence time were more important factors during straining than pore size per se.

B Adsorption

Stevik et al (2004) reported that adsorption has been observed as an important mechanism influencing bacterial transport in porous media. Once a particle is brought in contact with surface of the filtering medium or other particles, either physical or chemical adsorption or both will act to hold it there (Metcalf and Eddy, 2004).

Adsorption is affected by nature of the porous media, temperature, water flow velocity, ionic strength and species in wastewater, pH, and structure or nature of the contaminants.

More importantly, with the passage of time, as material accumulates within the interstices of the medium, the efficiency of the filtration process is hindered and a maintenance operation will have to be carried out. Often by backwashing (Metcalf and Eddy, 2004). It can be deduced from Nam et al (2000) that increases in treatment efficiency can be achieved with decreasing particle size which, indicates the importance of straining and adsorption. Higher removals tend to be due to smaller interstices between smaller particle sizes, as well as the larger surface area available of the smaller particles, which allows more adsorption to take place In the same way, having a particles that are too fine will lead to rapid clogging.

2.6.2.2 Chemical Transformations during filtration

The nitrogen content of human excreta and domestic wastewater on an average is about 60-75% ammonium and 25 to 40% organic nitrogen (Eawag/Sandec, 2008, Henze et al., 2008). During mineralization, organic nitrogen containing amine groups, are broken down by micro-organisms, a process called into simple amino compounds which are then hydrolysed releasing nitrogen in the form of ammonium (NH_4^+). The reduction in ammonium concentration in the wastewater as it percolates through the unsaturated filtering membrane is accompanied by an increase in nitrate (NO_3-) concentration brought about by the process of nitrification (Brady and Weil, 2002).

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O \qquad (1)$$

When the nitrified wastewater infiltrates down and encounters an anaerobic pocket, or zone of reduced oxygen concentration. In the presence of appropriate bacteria and a supply of readily available carbon source in the form of organic substrate, it further undergoes denitrification which reduces the nitrate to other nitrogen forms (NO, NO_2) and ultimately gaseous nitrogen

(N_2). In the case of filtration through pervious concrete, denitrification is not expected to play any significant role especially considering the fact that the filtration process occurs in a completely aerobic environment. Concentration of Nitrite (NO_2) in the effluent would therefore be significantly lower

Phosphorous removal from wastewater normally occurs by two processes of adsorption and precipitation. Lance (1984) realised that adsorption occurs more readily compared to the precipitation process which is a much slower process and leads to the regeneration of additional adsorptive surfaces.

For filtration through pervious concrete, the depth of the media, pore sizes and hydraulic loading rate play critical roles in these processes. Temperature, oxygen and pH are key in the determination of how these processes occur (Henze et al., 2008).

2.7 FILTRATION IN SANITATION

In the field of onsite sanitation, filtration is not explicitly mentioned as a method of treatment or purification as is done for drinking water. Several technologies utilize principles of filtration in wastewater or faecal sludge treatment.

Wetlands, Soil Aquifer Treatment (SAT), Compost toilets, and sludge drying beds are a few of the technologies where filtration is used, as a stand alone treatment method or as part of a more complex treatment process.

Investigations by EAWAG (2003) proved that solid-liquid separation (an aspect of filtration) is an important first step in effectively treating faecal sludge especially on site.

Compost toilets, including the Biofil Toilet Technology, actively utilize this concept of solid-liquid separation in treating faecal sludge on site.

The absence of evidence on the application of biological filters to treat VIP effluent on-site led Coetzee et al (2011) to propose of a new modified VIP system, where the faecal sludge in the pit will be allowed to leach into a biological Filter.

The proposed filter is packed with stones. A vent pipe is fitted with an extraction fan to induce a draft through the filter. Thus, all the liquid that seeps from the top part of the pit will be treated in the biological filter. With 92 % nitrogen removal, their results suggested that it was possible to remove nitrogen effectively using a biological filter beneath a modified ventilated improved pit latrine.

Bear Valley Ventures, a UK firm, has also come up with Project Tiger. The aim of this project is to transform the sanitation experience for people currently using basic pit latrines. This is being done by the design and scaling up of a biofilter toilet system. The Project Tiger system will be an onsite treatment plant, treating both liquid and solid elements of waste so they're safe to discharge into the environment.

Their biofilters are pre-fabricated units typically consisting of an active layer near the surface, where tiger worms (hence Project Tiger) and other organisms digest the excreta as it enters the system. Beneath this is a filtration bed where the liquid waste is further treated by aerobic bacteria, resulting in a highly treated effluent which can be safely discharged into the environment. Compost is generated at the top of the system, making it easier to empty, and the treated liquid is discharged into the soil. The unit can be linked to flush or pour-flush toilets, so there's the immediate benefit of waste being removed from sight, compared with a latrine.

The use of filtration in most onsite treatment facilities is restricted to solid-liquid separation and as a polishing step after a more rigorous treatment process. Indeed, there is scarce literature available indicating how filtration or solid-liquid separation is able to or aids in the removal of contaminants in onsite sanitation systems apart from granular porous media.

2.8 PERVIOUS CONCRETE

2.8.1 Description and constituent materials

The American Concrete Institute (ACI) 522 committee defines pervious concrete as a zero-slump, opengraded material consisting of portland cement, coarse aggregate, water, little or no fine aggregate, with or without admixtures.

It is also referred to as porous concrete, permeable concrete, and no fines concrete. It is characterized by its high porosity that allows water to pass directly through compared to conventional concrete due to its interconnected pore structure.

The materials typically used include coarse aggregate, cementitious materials, and optional additives. The Coarse aggregate grading used in pervious concrete is typically gap-graded or single-sized coarse aggregates or narrowly-graded between 3/4 and 3/8 inch (19 mm to 9.5 mm). The cementitious material is often Portland cement with a water cement ratio between 0.3 and 0.4 (Tong, 2011, BS 1881 part 113 (1983)).

3 types of coarse aggregates are used to make 3 variants of pervious concrete in this research and their contaminant removals assessed. Palm kernel shells, shredded PET (Polyethylene terephthalate) bottle, and granite chippings.

2.8.2 CHARACTERISTICS OF SELECTED COARSE AGGREGATES

Osei and Jackson (2012) suggest the possibility of depletion of conventional aggregates used in construction in the near future. Rising cost of concrete products and need to reduce environmental stresses and make concrete products more sustainable has led to the use of alternative materials in the manufacture of concrete products.

Challenges faced globally with solid waste management has led to the promotion of reuse and recycling of materials and concrete has not been left out of this revolution.

These wastes generally have very little commercial value and their availability locally means that the cost involved in procuring them is minimal (Chandra and Bentsson, 2002).

Their use as replacement materials would not only contribute to construction cost reduction and drive infrastructural development, but also contribute to reduce stress in the environment. Zemke and Woods (2009) proffer that such replacement materials should be cheap and readily available. The use of these materials should also not lead to a loss of performance as this is very crucial to the growth of developing countries.

A GRANITE CHIPPINGS

Granite is an igneous rock which is widely used as construction aggregate in different forms. Granites are light coloured plutonic igneous rocks. They are generally distinguished on the basis of relative abundance of some accessory minerals and special textural features (**Williams et al, 2008).** Granite aggregates are produced by crushing quarry rocks, boulders, cobbles, or large-sized gravel.

B SHREDDED PET BOTTLES

PET is one of the most common consumer plastic in use currently and is mostly produced from synthetic fibres. Based on how it is processed, PET can be semi-rigid to rigid, and it is very lightweight. It is designed to be chemically inert in most of its application; packaging of consumable products.

Polyethylene Terephthalate (PET, PETE or polyester) as plastic is non biodegradable and its disposal has been a problem. Its management involves processes of either recycling or reuse (Ramadevi and Manju, 2012).

Chowdhury et al (2013) report of a study done where coarse aggregates were partially replaced by plastic chips to observe the effect on density, water cement ratio and plastic content. And the result showed that introducing plastic fibres reduces density and gives superior deformational qualities making it useful in harsh weather.

Waste PET bottles have also earlier been used in making lightweight aggregates to improve concrete mechanical properties [Choia et al, 2005].

Chowdhury et al (2013) lists some advantages of using shredded PET in concrete as

- Lighter weight than other competing materials leading to overall reduction on transportation costs
- Durability
- Resistance to impacts, chemicals and water
- Less cost of production compared to other materials

Its major disadvantage has however been its low bonding properties. This significantly reduces its strength characteristics such as compressive, flexural and tensile strength. Other disadvantages are its low melting point and cost of processing into aggregates.

Recycled PET used in pervious concrete can be a source of unknown chemical compounds found in filtrate passing through the concrete. All these substances may potentially migrate from the PET bottle wall to the filtrate.

C PALM KERNEL SHELLS

Palm kernel shells (PKS) are obtained after extraction of the palm oil. The nuts are broken and the kernels are removed with the shells mostly left as waste. The PKS are hard stony endocarps that surround the kernel of the oil palm tree (Elaeis guineensis).

They are waste by-products that are normally stockpiled in open fields and are subjected to varying climatic conditions. The shells are flaky and of irregular shape and size that depend on the breaking pattern of the nut (Shehu et al, 2014, Dagwa et al, 2012 and Abiola, 2006).

An investigation by Jagustyn et al (2013) indicated that Silicon compounds are the main components of palm kernel shells.

Osei and Jackson (2012) assert that in Ghana, the shells have no commercial value but create disposal and waste management problems. They are generally free to be obtained in small quantity or low price in huge quantity as identified by Evbuomwan et al (2013) in Nigeria.

Because PKS is hard and it can be utilized to replace conventional coarse aggregate to produce lightweight concrete. Indeed, tests show that the shell has a specific gravity of 1.14 and a loose bulk density of 545 kg m^{-3}, which implies that the shell could be classified as lightweight aggregate.

Due to its relatively high absorption capacity of 21.3% and a porosity of 37%, it implies that the shell would require more water than the conventional gravel aggregate (water absorption = 0.47%) to attain the same consistency.

PKS has a good resistance to wear and thermal conductivity of both the shell and the concrete made with it can be considered low. Hence the material could be considered to be a poor conductor of heat (Okpala, 1990).

Table 7 presents a summary of key properties of the 3 coarse aggregates discussed above

Table 5: Properties of selected coarse aggregates

property	Granite***	Shredded PET	Palm kernel shells*
Bulk Density (kg/m^3)	1355-2650	1380**	640
Specifiv Gravity	2.6-2.8	-	
Thickness (mm)	-	<0.5	0.7-3
Water absorption 24h (%)	0.5-1.5	0	13.7-25%
Ash content (%)		0	2.35

*Yusuf and Jumoh, 2010 and Shehu et al, 2014.
** Chowdhury et al, 2013,
*** Williams et al (2008) , Abdullahi (2012)

Several researches have experimented with using various materials as replacement in traditional concrete products. This research also seeks to use palm kernel shells and shredded PET and coarse aggregate replacement in pervious concrete and assess their potential in the removal of contaminants from black water.

2.8.3 Typical properties of pervious concrete

2.8.3.1 Porosity and Water permeability

Porosity for pervious concrete, also termed as void content or void ratio, in percentage ranges from 15% to 30%. This relatively high porosity leads to a high permeability for the pervious concrete (Yukari Aoki, 2009). The water permeability of pervious concrete is also reported in literature as the permeability coefficient, intrinsic permeability or hydraulic conductivity.

Montes and Haselbach (2006) using a falling-head apparatus , determined the hydraulic conductivity of porous concrete specimens in the laboratory, which ranged between 0.014 cm/s and 1.19 cm/s. Ghafoori and Dutta (1995) found that compaction energy and the aggregate to cement ratio influenced the hydraulic conductivity of pervious concrete.

Aoki (2009) reports a wide range of values for water permeability of pervious concrete from various researches with values ranging from as low as 0.1 cm/s to as high as 4.5 cm/s. The average range commonly obtained being 0.5 mm/s to 2.0 mm/s.

2.8.3.2 Density

The high porosity renders pervious concrete as a lightweight concrete with density between 1,500 kg/m3 and 2,200 kg/m3 (Tennis et al, 2004 and Zhuge, 2006) for gravel orgranite chippings coarse aggregates. The density is influenced by the extent of compaction and the density of the constituent coarse aggregate. Hence coarse aggregates with lower densities than granite chippings or gravel will produce pervious concrete with lower densities.

2.9 ROLE OF BIOFIL TOILETS IN EXCRETA MANAGEMENT

Biofil toilets actively use both micro and macro-organisms to break down human waste into safe end products with high re-use potential as compost or soil amendments. In effect, it eliminates the complex problems associated with safe treatment of human waste. The sludge is converted to compost and any effluent produced is safe enough to be discharged into the environment.

Inspite of the dearth of literature on this subject, this section of the dissertation discusses the concept of biofil toilets, the engineering process, its operation and the role it plays in improving sanitation.

2.9.1 Development of the biofil concept

The use of micro-organisms in wastewater treatment has been in existence since the late 19th century with one of the earliest known biological filter installed near Manchester in the UK in 1893. The use of biofilms spawned the development of other technologies like the trickling filter, intermittent filter, contact bed systems, and the suspended growth process; biofilm systems that have dominated the technology of wastewater treatment for several decades (Henze et al., 2008 and Alleman, 1982).

The nutrient value of human excreta (faeces and urine) is known widely in nearly every society. Rapid population growth led to the development of chemical fertilizer which has been preferred compared to natural organic fertilizer. Recent reported global shortage of phosphate a key ingredient in chemical fertilizer as well as health and environmental implication of continuous use of chemical fertilizer has led to a global renaissance on the use of naturally occurring fertilizer (plant, animal and human waste).

The use of macro-organisms to produce compost was originally developed to deal with unwanted organic materials from agricultural processes and industries. The resulting product was found to be of high nutritional value which, when combined with soil, can restore and improve soil condition by correcting the imbalances caused by the over-exploitation and over-utilization of petro-chemical based fertilizers (OSC, 2012). These macro-organisms, specifically worms, when used to degrade human waste were also found to yield similar results as agricultural waste with the additional benefit of eliminated health hazard associated with raw human waste. Sinha et al.(2010) and Bajsa, et al.,(2003) report that earthworms were able to remove BOD by over 90%, COD by 80-90%, TDS by 90-92% , TSS by 90-95% as well as chemicals including heavy metals and pathogens from wastewater by the general mechanism of ingestion and biodegradation of organic wastes and also by their absorption through their body walls.

The development of the biofil concept comes in two major forms; one to take exclusive advantage of the activities of micro-organisms to clean wastewater and the other to use the synergic effect of both micro and macro-organisms to treat wastewater. Whereas the first uses exclusively liquid substrate, the second uses both solid and liquid substrates. This makes the second concept more versatile compared to the first.

2.9.2 Operation of the Biofil Toilet

The first concept which utilizes micro-organisms exclusively has been widely researched, developed and marketed in different countries under different brand names. Attachment sites (media) are generally provided for the growth of the micro-organisms and these sites may be fixed or suspended and enclosed in an often compact tank. Wastewater is introduced onto the attachment media and the micro-organisms go to work degrading organic matter within their reach.

The second concept, utilizing both micro and macro-organisms, has not caught on as much as the first. This has mainly been due to the fact that the problem of wastewater management escalated faster than the problem of managing waste solids (including faecal sludge).

The system operates on the principle of aerobic decomposition of organic waste by both micro and macro-organisms. Earthworms are currently being used as the macro-organism of choice especially with their known high turnover rates hence the term vermicomposting.

In order to take advantage of modern biosolids composting and vermicomposting systems, organic bulking agents (dry and fibrous materials) such as sawdust, leaf moulds, straw, peat moss, rice husks or coconut fibre are also used. Incorporating the bulking material is aimed at preventing odour, absorbing urine or moisture, and eliminating any potential fly nuisance. These bulking agents also serve as attachment sites or media for the microorganisms as well as suitable bedding for the earthworms. Tripathi & Bhardwaj (2004) and Bhawalkar (1995) recommend deep burrowing, shallow burrowing, and surface dwelling earthworms in vermicomposting applications. A compact system where all key players are present is then created.

A quick solid-liquid separation through a filtering media ensures that the worms have a good environment to degrade the solids. The liquid component of the feed stream undergoes microbial action during filtration through the filtering media and any other media beneath which often serve as polishing filters.

2.9.3 Biofil® Toilet System by K.A. Anno Engineering Limited

This type of biofil toilet system is a result of a decade and half of research and development by K.A. Anno Engineering Limited, a wholly Ghanaian firm based in Ghana, and is based on the second concept of biofil technology. The Biofil ® Digester is the main component of the Biofil® Toilet System. The toilet system in its current form is entirely prefabricated. This makes it easy to transport and install in remote location with minimal inputs. The developers assert that their digester is able to break down organic waste thirty times faster than conventional sceptic tanks which give them their compact nature.

The digester provides an enclosed space where the activities of the self-perpetuating population of earthworms and micro-organisms are optimized.

Pervious concrete is used to facilitate the rapid solid-liquid separation as well as to serve as attachment site for the micro-organisms in addition to coconut fibre which is used as the bulking material.

Any ensuing water from the digester can be piped through a drain field or re-used (Biofilcom, 2012).

Figure 3: The digester of the Biofil Toilet Technology (left) and internal view (right)

2.9.3.1 Role of biofil toilet in resource recovery and public health

By providing a one-stop-shop for the collection and treatment of human excreta, the biofil toilet plays an active role in the protection of public health. Its compact nature and non-reliance on external water or energy inputs means that it can easily be installed anywhere, with the most minimal operational challenges. The problem associated with indiscriminate disposal of untreated human excreta is thus eliminated. By producing reusable products from human waste, the biofil toilet technology helps to close the gap in resource recovery and reuse. Vermicomposts can have substantial contribution in promoting agricultural productivity and conserve the depleting mineral resources especially phosphates.

The benefits of this technology can truly be felt only if the cost of production and roll out is made progressively affordable for the urban poor.

2.10 KEY COMPONENTS OF BIOFIL TOILETS FOR VERMICOMPOSTING

2.10.1 BULKING MATERIALS IN BIOFIL DIGESTER

Some few commonly used bulking materials during the composting of human waste include: Lime, Ash, sawdust, Agriculture residue, Horticulture waste, Rice Husk and plant fibre. The digester of the Biofil Toilet Technology in its current state uses coconut fibre as the main starting bulking material.

These materials help in the management of the different types of waste, adjust C/N ratio and increase the porosity of the compost (Anand and Apul, 2013). Yadav et al (2011) report that bulking material is needed for improving the physical environment for the sustenance of reactors, in addition to enrichment of the diversity of microbial population and enzymatic activities. They also provide structural support and prevent the physical compaction of the pile and increase air voids for aeration.

When used in vermicomposting, the bulking material serve as a comfortable 'bedding' with ideal conditions for the sustenance and movement of the worms involved in the process. They have low protein and/or nitrogen content (high C:N ratio) to avoid excessive heating which may result in an inhospitable environment often fatal to the worms. Generally good bedding must provide protection from extremes in temperature and pH, the necessary levels and consistency of moisture, and an adequate supply of oxygen.

Coconut fibre (coir) comprises 30% of the husk obtained from the coconut fruit. The fibre can be extracted by several process including mechanical, chemical and the use of bacteria and fungi. The end use of the fibre usually determines the method of extraction (Narendra and Yigi, 2005). Often during mechanical or manual exteaction processes, pith (dust) is attached to the fibre which requires chemical methods to be removes.

The density of coconut fibre varies widely between 670 -1370kg/m^3. In terms of chemical composition, Coconut fibres contain cellulose, hemi-cellulose and lignin as major composition.

With continuous usage, vermicast and vermicompost produced take over as the dominant bulking materials that exist within the digester.

2.10.2 FILTERING MEMBRANE IN BIOFIL DIGESTER

Key pervious concrete pollutant removal mechanisms include absorption, straining, and microbiological decomposition. Water quality may be improved, because the pervious concrete provides a habitat, within the substrate matrix, for beneficial bacteria to thrive. These bacteria are capable of degrading compounds and destroying harmful pathogens found in the wastewater. Beneficial bacteria are able to survive by using the nutrients and carbon present in faecal matter and urine.

The filtering membrane operates as fixed-film system, in that attached growth microorganisms are encouraged to colonize and reproduce in the media. Over time, fixed film systems appear to produce a more consistent effluent under peaked sewage inputs and periods of no use compared to suspended growth systems with similar flow regimes.

Fixed film processes are more superior when compared to suspended processes in several aspects. Small reactor size, simple operation and high reliability make this process a cost-effective system for biological treatment. Biomass accumulation and retention in biomass systems are enhanced by attachment to a fixed medium (Manoj and Vasudevan, 2012).

Depth of filtration/ filtering membrane is a key factor is determination of the extent of contaminant removal. Invariably, a greater depth of filtration results in higher effluent quality due to increased contact between liquid substrate and microbes.

2.11 KNOWLEDGE GAP

Obviously, the Biofil toilet system has enormous potential in providing affordable sanitation services to the urban poor. Though its use is gaining grounds, no detailed studies have been done to fully assess the contaminant removal potential of the constituent parts of the digester. There is also a lack of reference data on specific operational parameters necessary for optimal performance of the entire toilet system.

As a relatively new technology, knowledge of these studies will enhance optimization of toilet system and possible use in the treatment of more complex wastewaters.

This research critically assesses the contaminant removal potential of the filtering membrane and the bulking material; two key components of the filtering unit of the biofil digester. The study also looks at the potential on the use of other materials to replace the conventional filtering membrane currently in use.

CHAPTER THREE

3 RESEARCH METHODOLOGY

3.1 Study site description

The study was conducted on models of the filtering units of the biofil digester in Kwame Nkrumah University of Science and Technology (KNUST) in Kumasi. Two components of the BTT digester, the bulking material and the filtering membrane, were studied.

Fresh faecal matter was collected from inspection chambers of a private facility in Ayigya which is used by 120 persons. The setups were installed and operated in a controlled environment behind the Environmental Quality Laboratory to facilitate operations. The natural operation of the digester was simulated in the setups. Analysis of materials and analysis of influents/effluents were conducted in Geotechnical and the Environmental Quality laboratory of the Civil Engineering department of KNUST.

3.2 Characterization of Materials

Four different materials were collected from various sources in Accra and Kumasi and used in the experiments. The materials were classified into two groups of 1 material for the bulking material and 3 materials for the filtering membrane.

For bulking materials, coconut fibre (coir) was collected from Accra. For the filtering membrane, Palm kernel shells were collected from the Civil Engineering Department Structures laboratory in Kumasi whereas ¼ inch granite chippings and shredded PET bottle were brought in from Accra. These materials are widely available and were randomly collected.

The various materials were characterized based on their physical properties and in the case of the materials for the filtering membrane, additional sieve analysis was conducted on them using AASHTO T27 and BS 812 part 103 (1985) standards. Since the filtering membranes are made of pervious concrete, the materials collected were cast into concrete before the determination of physical characteristics.

3.2.1 FILTERING MEMBRANES

The filtering membranes are moulded from 3 types of pervious concrete with the 3 different coarse aggregates. A mix ratio of 1:3 was used. Where one part of cement is mixed with 3 parts aggregate (selected materials) using a water-cement (w/c) ratio of 0.3-0.4 (depending on prevailing humidity). Ordinary Portland cement of class 32.5R was used in all concrete mixes as is used in the original mix.

A Mixing, Casting, and Curing of Concrete

A 50 litre pan was used for mixing concrete. Based on the amount of concrete needed for casting cylinders and membrane slabs, the amount of materials (cement, water, aggregate) needed are calculated and measured by volume.

All pervious concrete slabs and cylinders were made and cured as per ASTM C192 and BS 1881 part 113 (1983). The freshly consolidated pervious concrete specimens were kept in the mould under wet jute bags for one day. After one day, the samples were removed from the mould and kept under wet jute bags. The concrete samples were kept moist and before testing, the samples were wiped to remove excess water and then tested for necessary physical and hydrologic investigations. A total of 6 concrete cylinder specimens (110 mm x 100 mm) were made for analysis of the physical and hydrologic properties and another 6 slabs (330 mm x 330 mm x 50 mm) for the assessment of contaminant removal.

B Testing Methods

Permeability

Considering the larger than usual large interconnected pore network, the conventional methods that are used to evaluate the hydraulic conductivity of normal concrete were not applicable. To determine the hydraulic conductivity of the pervious concrete cylinders, a constant-head permeameter designed in the laboratory was used to measure the permeability. The specimens were placed in the apparatus, which was designed to maintain a vertical column of water above the surface of each specimen. The apparatus was clamped around each specimen and seals restricted the flow of water such that water entered and exited only through the top and bottom of each specimen. A head of 80mm was maintained above the specimen surface. This ensured that turbulence on the surface would not affect the flow of water into the specimen. The flow rate was measured using a stopwatch and a measuring cylinder.

When flow equilibrium was reached, the rate of flow through the specimen (ml/s) was recorded. (Luck and Workman, 2007).

The coefficient of permeability (k) was calculated by using the following equation:

$$k = \frac{QL}{hAt}$$

Where, Q is the discharge in millilitres, L is the length of sample being tested, h is the head of water maintained over the sample during the experiment, A is the cross-sectional area of the sample and t is the fixed elapsed time for a specific discharge, Q.

Falling head permeability test was performed on cylindrical samples of each of the filtering membranes made from 3 different types of coarse aggregates to determine permeability coefficients.

Density

The bulk density (kg/m^3) of each specimen was calculated by dividing the weight of the specimen by the respective volume.

3.2.2 BULKING MATERIAL

One bulking material was assessed and used for the experiments for contaminant removal. The material (coconut fibre) was used in its natural state at the time of collection.

The material was washed in distilled water only to remove any dirt in the materials, where necessary, without compromising on the chemical or physical integrity of the materials.

Due to its fluffy nature, the bulking material used was sampled by weight using a digital scale prior to assessing their physical properties. Assessment of the chemical components of the materials are beyond the scope of this experiment and were not performed. However, they are relied on through literature study to explain phenomenon associated with contaminant removal in the black water.

3.3 EXPERIMENTAL SETUP DESCRIPTION

In order to determine the contaminant removal properties of the filtration unit of the digester, two experiments were run simultaneously; first with the bulking materials and later with the filtering membrane.

The setup for both experiments was designed to mimic the natural operation of the digester of the Biofil Toilet Technology on a miniature scale.

The setup is constructed with wood in the form of a tabular frame. Each compartment has an internal area of 300 mm x 300 mm. Just like the digester, it has an operating height of 600 mm.

An overboard of 100 mm was added to make room for manipulation during feeding and measurements.

A rail is placed 100 mm from the bottom of the frame to support both the bulking material and the filtering membrane during the running of the experiment. A plastic receptacle, with a diameter of 400mm, is placed under the filtering membranes and the coconut fibre to collect any filtrate passing through the membrane or the bulking material for analysis. A spirit level was used to level the top of all the filtering membrane slabs to ensure that the flow of water is not skewed in one particular direction. This was necessary as any significant slope of the slaps will affect the performance of the filter.

WRC (2011) and Weaver (1988) estimate an average excreta production of 0.4kg per capita per day and this is used to estimate the solids loading. Though the GSS (2008) estimates that an average household in Ghana has 4 members, a worst case scenario of 10 persons per household is used to estimate both the solids loading rate and the hydraulic loading rate.

The bulking material was fed on top with 150g of solids per day and 3.3 litres of water per day, for solid and hydraulic loading. The filtrate from the bulking material is fed onto the 3 filtering membranes separately with 500ml of liquid per membrane.

The raw faecal matter was collected, mixed with the commensurate water and fed onto the setups every morning between 6.30am and 8.00am based on the peak toilet utilization time for twenty-five (25 consecutive days. Twenty-five days was selected based on the recommendation of 18 (preferred) to 30 days runs as ideal for a particular feed run (Zheng and Li ,2009) and to allow time for appropriate laboratory analysis of samples.

Samples of the black water and effluent from the bulking material and filtering membranes were collected and analyzed based on the parameters presented in table 7 prior to feeding and after feeding to assess the contaminant removal capacity of the filtering unit. This was done every five (5) days.

This was done to closely monitor and understand any process involved in the removal of any contaminant in the feed. This was also done to observe the removal efficiency as a function of time.

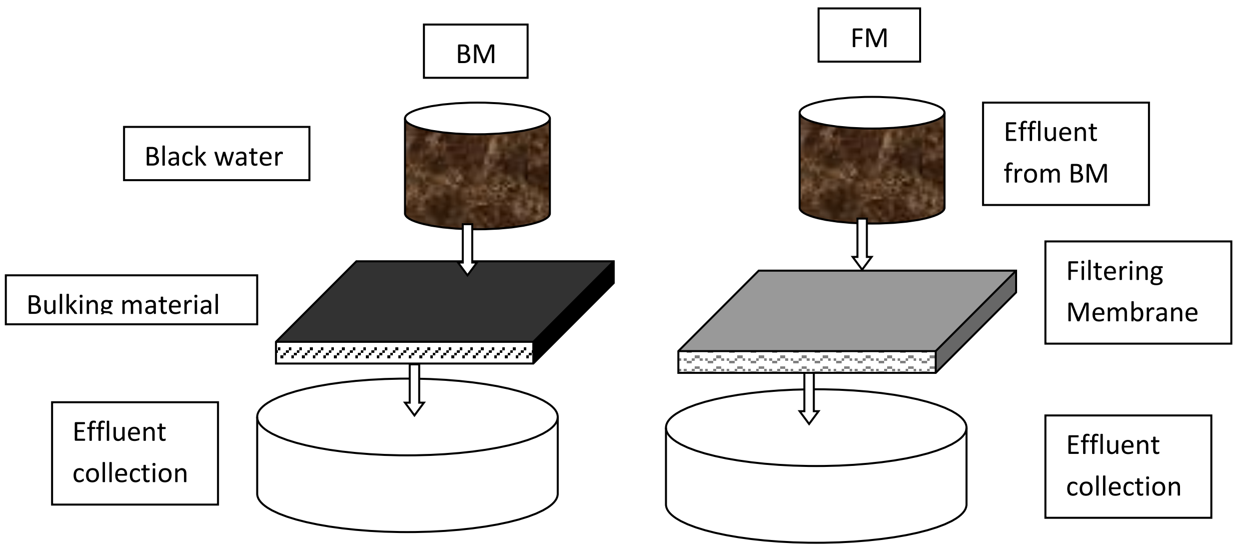

Figure 4: Scheme for determination of contaminant removal

3.3.1 Effluent Testing

The effluent from the bulking material and filtering membranes were captured after filtration.

All analyses were performed in accordance with the Standard Methods for the Examination of Water and Wastewater 20th ed. (APHA, 1998). This process was performed everyday for 25 consecutive days.

The effluents were analyzed every five days. The purpose of this test was to compare how the pervious concretes and the bulking material performed in the removal of predetermined contaminants.

3.3.2 Bacteriological Analysis

Membrane filter and pour plate technique were used in monitoring the microbial population in both raw water and effluent samples. The method consisted of filtering a diluted sample (10^{-6} - 10^{-8}) on a sterile filter paper with a 0.45-µm pore size which retains bacteria. This filter was then incubated at (37 ± 1) °C on a selective medium (Chromocult ® coliform agar) and enumerating typical colonies on the filter after 24 ± 1 hours of incubation (Rompre et al, 2002, Finney et al, 2003, Schets et al, 2001).

The Chromocult ® coliform agar (Chromocult; Merck, Germany) was prepared in accordance with the manufacturer's instructions. The agar is a chromogenic media and is specific, rapid and sensitive for use on the most important water and food borne pathogenic microorganism such as E.coli, Staphylococcus aureus, etc. This media eliminates the need of subculture and further biochemical test for identification pathogenic agent and at the shortest period of time pathogenic agent can be identified.

Dark blue to violet colonies were counted as E. coli and the salmon to red colonies as other coliforms. The total of all red and blue colonies is the total coliform count (Merck, 2008) .

Removal efficiencies were calculated as follows

$$Log\ Removal\ (LR) = \log\left(\frac{Influent\ Concentration}{Effluent\ Concentration}\right)$$

$$\%\ Removal = 100 - \frac{100}{10^{LR}}$$

Table 6: Summary of sampling and analytical schedules

		Filtering membrane			Bulking Material
Parameters	**Black Water**	**PKS**	**SP**	**GR**	**FF**
pH	6x2	6x2	6x2	6x2	6x2
Temp.	6x2	6x2	6x2	6x2	6x2
EC	6x2	6x2	6x2	6x2	6x2
TDS	6x2	6x2	6x2	6x2	6x2
TSS	6x2	6x2	6x2	6x2	6x2
TN	6x2	6x2	6x2	6x2	6x2
K	6x2	6x2	6x2	6x2	6x2
Cl^-	6x2	6x2	6x2	6x2	6x2
TP	6x2	6x2	6x2	6x2	6x2
NO_3 -N	6x2	6x2	6x2	6x2	6x2
NO_2-N	6x2	6x2	6x2	6x2	6x2
NH_4-N	6x2	6x2	6x2	6x2	6x2
SO_4^{2-}	6x2	6x2	6x2	6x2	6x2
COD	6x2	6x2	6x2	6x2	6x2
BOD_5	6x2	6x2	6x2	6x2	6x2
E. coli	6x2	6x2	6x2	6x2	6x2
Helminth eggs	5x1	5x1	5x1	5x1	5x1

*6*2 refers six sampling times and duplicate analysis considered; FF refers to the coconut fibre*

Table 8 presents a summary of all relevant materials, reagents and analytical methods used in this research to measure contaminant load levels.

Table 7: Summary of materials, reagents and analytical methods

s/n	Parameter	Methods/Equipment	Chemical reagent
		A Physical Parameters	
1	Temp, pH, Conductivity, TDS, Salinity	Direct onsite reading (PC 300 waterproof handheld digital meter)	N/A
2	TSS	Gravimetric (Filtration -evaporation)	N/A
		B Chemical parameters	
3	NH_4-N, NO_3--N, NO_2-N, T-N	Spectrophotometeric (DR/2400 Spectrophotometer)	Ammonia Salicylate Powder Pillow, Ammonia Cyanurate Powder Pillow, NitraVer 5 Nitrate Reagent Powder Pillow
4	TP	Spectrophotometeric (DR/2400 Spectrophotometer)	PhosVer 3 Phosphate Powder Pillow
	Cl^-	Titrimetric method	
	SO_4^{2-}	Spectrophotometeric (DR/2400 Spectrophotometer)	
		C Biological Parameters	
6	BOD_5	Winkeler's titration method	H_2SO_4, $AgSO_4$, $FeCl_2$, KOH, $HgSO_4$, KHP, etc …
	COD	Open reflux method	$K_2Cr_2O_7$, H_2SO_4, $AgSO_4$, $FeCl_2$, KOH, $HgSO_4$, etc
7	E-coli, Salmonella, Total Coliform	Membrane filtration and culturing in selective chromogenic media	Chromocult ® coliform agar
8	Helminth eggs	Microscopic examination and counting	Aceto-acetic buffer, Ether or ethylacetate, Saturated zinc sulfate solution, etc.

3.4 Statistical Analysis

The results for all the analyses were subject to varying statistical tests to establish any trends, relationships and treatment effects that exist with the materials being assessed. Sieve analysis, density and permeability were tested and verified as normally distributed data. Because the results were normally distributed, the statistical analysis proceeded with testing for trends and relationships. In addition, t-tests were conducted to determine if the use of an aggregate type as filtering membrane resulted in a significant difference in the removal of any of the contaminants. The t-tests were conducted using the two-tailed least significant difference (LSD) and differences were considered significant at an alpha value equal to 0.05 (Montgomery, 1997).

3.5 DATA QUALITY ASSUARANCE AND ETHICAL CONSIDERATIONS

The experiments were performed in triplicate or duplicate where necessary and the average determined to ensure representative and reliable results. Standard methods and procedures for the Examination of water and wastewater as described by (APHA, 1998) was followed for all analytical procedures. For quality assurance purpose, sampling bottles were washed thoroughly with detergent, clean tap water, rinsed with non-ionized water and finally sterilized prior to usage for next sampling. The samples were analyzed immediately upon collection for most cases. However, in the event that the samples could not be analyzed promptly, the samples were appropriately preserved. Preservation methods included pH control, chemical addition, and refrigeration.

Professional integrity and academic honesty were maintained throughout the study and to also safeguard the interest of all persons involved.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

The summary of results of tests conducted during the experimental study are presented in this chapter with discussions to expand on their significance. The results are organised according to the specific objectives. The first part presents and discusses results of tests performed for the determination of physical properties of the various filtering membranes. Findings from the contaminant removal test are then presented in the second section. An in-depth discussion is then presented by performing a comparative analysis between filtering materials with respect to the physico-chemical and bacteriological parameters. Efforts are also made to compare the results obtained with similar results reported in literature where necessary.

4.1 PERVIOUS CONCRETE PROPERTIES

This section of this dissertation was to determine the physical and hydraulic properties of the pervious (porous) concrete used as filtering membranes in the digester of the Biofil Toilet System.

4.1.1 PARTICLE SIZE DISTRIBUTION OF AGGREGATES

The grading curves for palm kernel shells (PKS), shredded PET bottles (SP) and 1/4”crushed granite (GR) coarse aggregates are shown in Figure 1. The coefficient of uniformity was 1.625, 1.848 and 1.510 for palm kernel shells, shredded PET bottles and 1/4”crushed granite respectively with corresponding effective aggregate particle size of 4.8mm, 3.41mm, 4.9mm. The grading curve shows that the 3 aggregate types are uniformly graded with a relatively wide range of aggregate sizes from 2- 19mm.

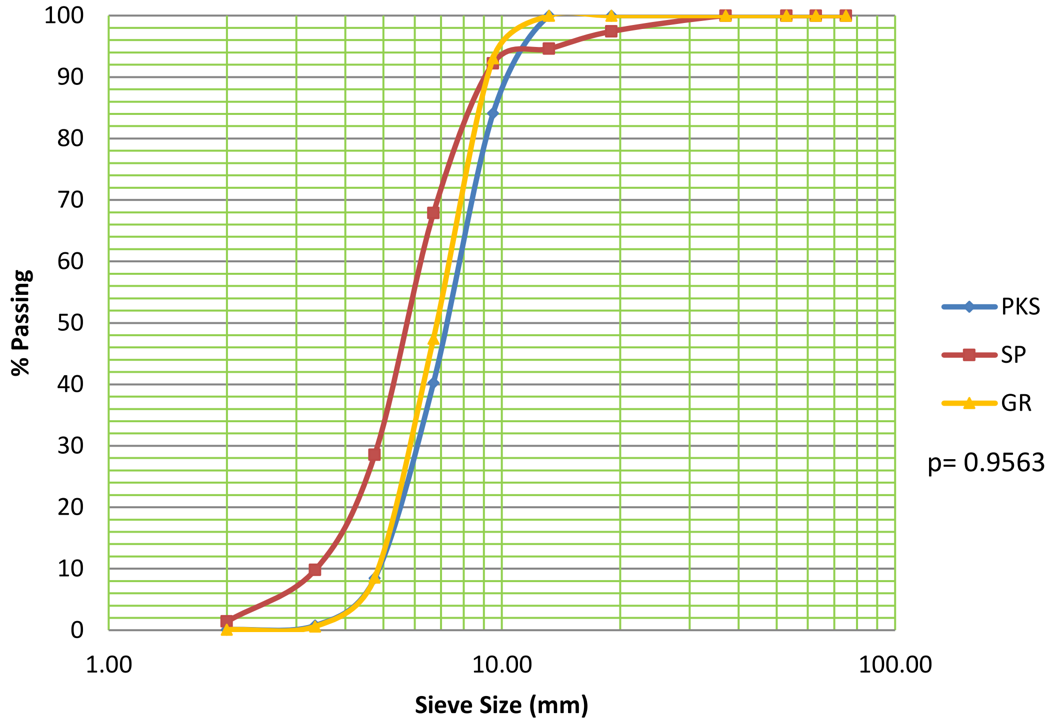

Figure 5: Grading curve for Palm kernel Shells (PKS), Shredded PET bottles (SP) and 1/4" Granite chippings (GR)

Aggregate particle size has been found in several researches to be inversely linked to the porosity and permeability of pervious concrete. The bigger the aggregate sizes, the higher the porosity and permeability.

A correlation matrix generated from Excel ® 2007 software shows that the highest correlation exists between palm kernel shells and granite chippings. This gives a strong indication that the particle sizes of the palm kernel shells are very close to the particle sizes of the ¼" granite chippings.

Table 8: Correlation Matrix between aggregate particle sizes

	GR	*PKS*	*SP*
GR	1		
PKS	0.977964	1	
SP	0.878581	0.808132	1

SP has nearly equal correlation with the other two aggregates which reinforces the fact that PKS and GR are very similar in size gradation. The high correlation between the various coarse aggregate particles is reinforced by the statistically insignificant variation recorded between the samples (p= 0.9563) at a 95% confidence interval.

4.1.2 DENSITIES

The density of any concrete product is directly proportional to the density of the constituent aggregates especially the coarse aggregates (Zhuge, 2006). In the case of pervious concrete, the coarse aggregate determines the density of the ensuing product. Of the 3 pervious concrete types, granite chippings (GR) based pervious concrete had the highest density of 1944.34kg/m^3 and shredded PET (SP) based pervious concrete having the lowest density of 781.45kg/m^3 as indicated in table 10.

SP is nearly 2.5 times (2.488) lighter than the traditional GR pervious concrete and c.a. 1.5 times lighter than PKS pervious concrete. This has significant implications for costs related to transportation. The lighter the material, the more can be transported and the lower the overall transport costs.

4.1.3 PERMEABILITY TESTS

The hydraulic conductivity of the pervious concrete specimens ranged 0.0352 and 0.0392 cm/s. Granite chippings based pervious concrete had the lowest conductivity with PKS based pervious concrete having the highest. The range of the hydraulic conductivity was calculated to be 0.004 cm/s. This value is relatively insignificant compared to the actual values. With reasonably high correlation between the particle sizes, this is also expected. A simple regression model for specimen density and hydraulic conductivity suggests that if the density of the pervious concrete mixture increases ($R^2 = 0.464$), the hydraulic conductivity would reduce. This is corroborated by a similar research by Luck et al (2006) with a higher R^2 value (0.89). They attributed the loss of permeability to the lack of interconnected voids in the pervious concrete at high densities.

Table 9: Results for density and permeability of pervious concrete specimens

Sample	**Mean Permeability (cm/s)**	**Mean Density (kg/m^3)**
GR	0.0352	1944.34
SP	0.0372	781.45
PKS	0.0390	1171.34

4.2 INFLUENT CHARACTERISTICS

The results of influent analysis are tabulated in Table 10. These values represent the average of five samples taken over the entire experimental period. The last column in the table represents the acceptable discharge quality. As is clearly seen, the influent concentrations far exceed these standards hence the need for treatment.

The analysis of the influent showed an average BOD_5 concentration of 360 mg/l and an average COD concentration of 5729 mg/l. Accordingly, the COD/BOD_5 ratio for the feed water was calculated and found to be 15:1. According to Samudro and Mangkoedihardjo (2010), the ratio of COD/BOD is a useful tool in selecting a treatment system and environmental monitoring strategies of receiving environment. This high COD/BOD ratio gives an indication of a higher than normal content on non-biodegradable or slowly biodegradable matter in the influent. This can be attributed to a high concentration of urine in the blackwater. Since urine contains high concentration of salts and other chemicals which exert substantial oxygen demand.

The results obtained showed that the average pH of the raw black water collected as 6.83 at an average temperature of 27.6 ^{o}C. A corresponding conductivity of 660.5μS/cm was measured for the raw black water.

Various physicochemical and biological parameters were also measured from the raw black water to fully assess the load coming unto the elements of the filtration unit. Table 11 summarizes the results obtained from this analysis.

High concentrations such as 11904 mg/l of COD, 390 mg/l of BOD_5, and electrical conductivity of 14525μS/cm were measured at different times during the analysis of raw black water.

The presence of urine in the blackwater introduces high concentrations of ions and nutrients in the blackwater. This accounts for the high Chloride, TDS and Electrical conductivity readings recorded in the analysis of the blackwater. The high Total Phosphorous concentration in the blackwater is also attributed to urine which contains about 50 % of TP in human excreta (Gethke et al, 2006). Chlorine also showed high variability with concentrations ranging from as low as 175mg/l to as high as 1600mg/l.

The results also indicate that during the entire experimental period, no salmonella bacteria were detected in the blackwater sample. Their complete absence in the blackwater is ruled out. However, it is most probable that they were in very low concentration and were further thinned out during serial dilution for their determination.

Table 10: Characteristics of fresh full flush blackwater

Parameters	Mean Values	St. Dev.	Ghana EPA guidelines
Temperature (°C)	27.6	1.43	<3^0C above ambient
pH	6.83	0.41	6-9
EC (μS/cm)	660.5	340.94	750
TDS (mg/l)	444.6	200.70	
TSS (mg/L)	3954	4499.81	
BOD_5 (mg/L)	360	26.83	50
COD (mg/L)	5729.14	3377.71	250
COD/BOD	14.87	9.78	
E. Coli (10^8)	5	4	0
Other Coliforms (10^8)	10	4	
Salmonella (10^8)	0	0	
Helminth egg count (no./ml)	19	11	
NH_4-N (mg/L)	151.98	30.38	
NO_3-N (mg/L)	53.82	17.11	0.1
NO_2-N (mg/L)	23.763	2.45	
Total-N (mg/L)	589.16	185.35	
Total-P (mg/L)	68.10	66.31	2
Cl^- (mg/L)	683.33	607.49	
SO_4 (mg/L)	289.18	271.99	1

Various researches have established that the composition of blackwater varies from geographical location and dependent on the type of diet and prevailing environmental conditions (Louis et al., 2007; Belen, 2010).

In comparison to studies by Mara (1978) and Strauss et al. (1997)(Table 4), based on the average concentrations, the raw blackwater used in this study best fits in the category of Low strength waste water, though it is fresh excreta.

This low strength classification is erroneous as the raw excreta is highly diluted with flush water. The flush water thins out most concentrations hence the low strength characteristic.

Apart from COD/BOD ratio and Helminth egg count, the influent blackwater used in this study compares well with tropical sewage as described in the table 11.

Table 11: Faecal sludges from on-site sanitation systems in tropical countries

Item	Type "A" (High Strength)	Type "B" (Low Strength)	Sewage - for comparison's
Type of wastewater	Public toilet or bucket latrine sludge	Septage	Tropical sewage
Characteristics	Highly concentrated, mostly fresh FS; stored for days or weeks only	FS of low concentration; usually stored for several years; more stabilised than Type "A"	
COD (mg/l)	20, - 50,000	< 15,000	500 - 2,500
COD/BOD	5: 1.... 10 : 1		2 : 1
NH4-N (mg/l)	2, - 5,000	< 1,000	30 - 70
SS (mg/l)	≥ 30,000	≅ 7,000	30 - 70
Helminth eggs (no./l)	20, - 60,000	≅ 4,000	300 - 2,000

Adapted from Montangero and Strauss (2004)

Inspite of its "Low strength "classification, release of this blackwater into the environment can have adverse effect on the biological and chemical processes in the receiving environment. The use of treatment methods for high strength wastewater may also prove to be inappropriate for this type of blackwater.

Compositional variability of the blackwater should be taken note of in assessing the contaminant removal of the filtering units (bulking material and filtering membranes). Li et al (2012) observed that steady contaminant loading provided the best operating conditions for filters.

4.3 HYDRAULIC PERORMANCE OF FILTERING UNIT COMPONENTS

After being discharged unto the bulking material (coconut fibre), the blackwater percolated rapidly downward through the fibre and into the effluent collection bowl underneath. The flow rate was so rapid that within 1 minute of feeding, c.a.94% of the liquid volume is collected. The remaining liquid is trapped within the pores of the fibre and the biosolids retained on the fibre from previous feeding. Over the experimental period, no deterioration of the coconut fibre was observed. Biosolids build up on the fibre was directly related to solids content present in the blackwater prior to feeding.

Consistent volume of effluent collected from the coconut fibre indicates consistent moisture content of the fibre and the accumulated biosolids.

Filtration of the effluent from the coconut fibre through the 3 filtering membranes (GR, PKS, and SP pervious concrete slabs) also occurred rapidly. Similar to the coconut fibre, an average of 80% of effluent was collected from each of the filtering membranes within 1 minute of feeding. SP delivered its effluent fastest among the 3 filtering membranes with GR being the slowest. Collection of effluent through SP started within 1 second of feeding whereas GR had a lag of between 3-5 seconds before yielding any effluent. Consistent yield of effluents from the filtering membranes indicate consistent moisture absorbing properties.

For the same volume of feed, SP yielded the most effluent of 84% followed by 79% for PKS and 75% for GR. This shows that GR has the most moisture retaining property of the 3 filtering membranes.

The hydraulic retention time (HRT) computed for both bulking materials and filtering membranes was between 1-5 seconds. This is due to the very rapid rate of filtration and the relatively large pore sizes of the materials. This rather small HRT gives a clear indication that contaminants which depended on higher HRT for removal were unlikely to be removed or reduced in these membranes or the bulking material.

4.4 PHYSICO-CHEMICAL CONTAMINANT ASSESSMENT

To adequately assess the contaminant removal capacity of the bulking material and the various filtering membranes, analysis was done on effluents from each of these elements every 5 days over the 25 days of experimental run. In order to account for any variations in the feed characteristics, the common influent fed onto the filtering membranes was analyzed for the same physico-chemical, organic and microbiological parameters.

The discharge of unstable organic matter into environment has dire consequences, especially on receiving waters. They deplete the dissolved oxygen, speed up undesirable chemical reactions and create anoxic conditions which are not favourable for aquatic life, plant growth or drinking water supply. Oxygen concentration levels, pH and Temperature together regulate a host of chemical reactions with any increase or decrease having different effects on the occurrence of chemical species in the water or soil.

It is therefore important to assess the potential of the bulking material and the various filtering membranes in removing the pre-identified contaminants which in turn influences optimization effluent treatment in the Biofil toilet technology.

The capacity of the bulking materials and the three types of filtering membranes in removing physicochemical contaminants has been assessed and underlying mechanisms in the various materials are discussed and presented in this section.

4.4.1 Physical Parameters

Though the parameters monitored are not used to directly evaluate blackwater, they are however key in determining to a large extent, any biological or chemical processes that occurs during the filtration process.

Due to the relative ease of measurement with a portable digital device, these parameters were measured nearly every day and presented in table 12.

Significant variations (p= 2.2911 x10^{-10}) were recorded in temperature reading among all the samples. The highest variation (p=3.5527 x10^{-9}) was between temperature reading in the effluent from the SP filtering membrane and the effluent for the coconut fibre. This is to say that among the filtering membranes, SP pervious concrete had the most influence on the temperature.

The variations in pH among the samples collected were not found to be statistically significant (p=0.1662) over the experimental period. Though was significant variations in temperature, this was unable to impact on the pH. Insignificant variations in pH imply that the chances of pH influenced processes occurring in the filtering media are minimal. Effluent from GR had the highest pH increase of 0.58 compared to effluent from the coconut fibre (FF). The pervious concrete had a rather cooling effect leading to a reduction of temperature for all 3 filtering membranes.

Total Dissolved Solids (TDS) and Electrical Conductivity (EC) also increased for all the filtering membranes compared to the bulking material. PKS had the highest readings of these two parameters. The inability of strong ion removal mechanisms such as precipitation sorption, or ion exchange during the rapid filtration process through a relatively short depth accounts for this. The effluents from either the bulking material or the filtering membranes simply carry the ions responsible for EC along.

Measurements taken and their trends are presented below.

Table 12: Physical Parameters measured in various effluents

Parameter	FF		GR		PKS		SP	
	Mean	**St. Dev**	**Mean**	**St. Dev**	**Mean**	**St. Dev**	**Mean**	**St. Dev**
Temperature (^oC)	26.52	0.92	25.29	0.94	25.47	0.92	25.64	0.92
pH	6.99	0.51	7.57	1.31	7.52	1.30	7.31	1.07
EC (µS/cm)	837.16	250.89	905.31	349.06	1004.32	300.99	884.66	330.94
TDS (ppm)	594.26	177.71	642.11	247.45	712.42	213.47	627.73	234.80

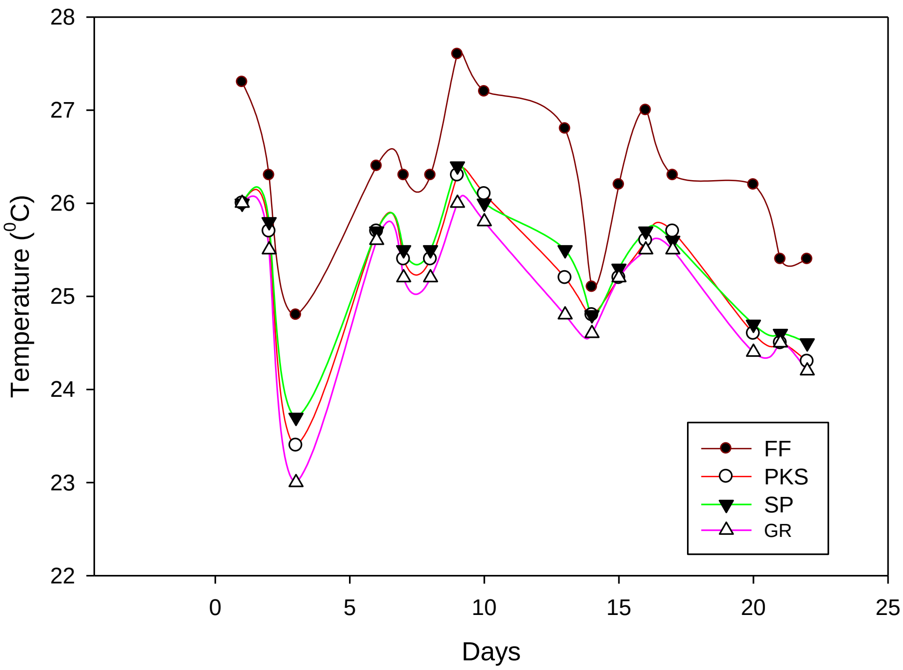

Figure 6: Temperature variations in effluent samples over experimental period

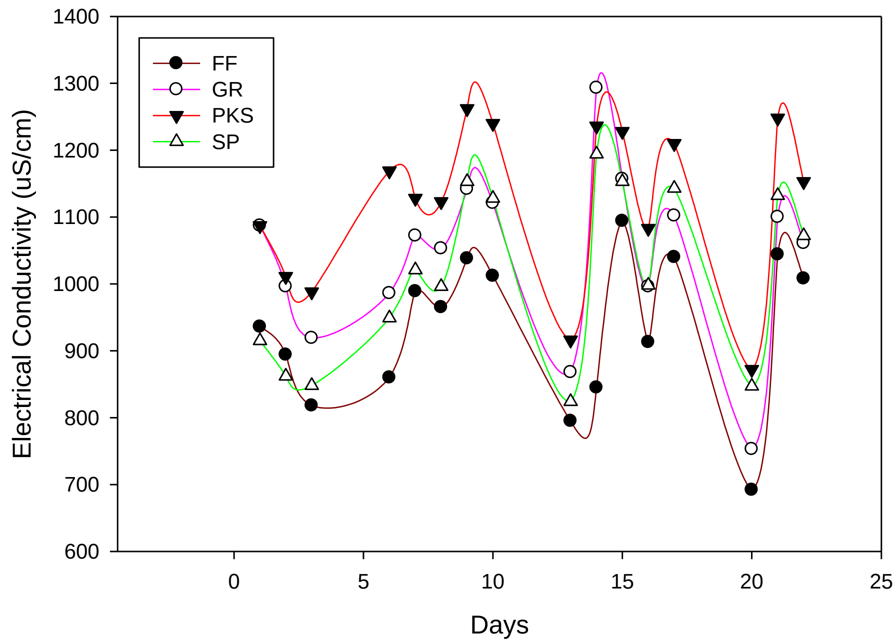

Figure 7: EC variations in effluent samples over experimental period

4.4.2 Organics

Various researches have found that substantial removal of organic contaminants cannot be expected from bio-digester systems with insufficient retention time. COD/BOD ratios do not have sufficient retention time especially for dissolved substances to interact with the adsorbent or media surfaces. Similarly, nutrient removal potential would be limited as the contact time of the wastewater stream in the biofil unit is very short.

As the wastewater percolates through the filtering unit, organic matter in the influent as well as in bio-solids retained on the bulking material may leach out as TSS, BOD and COD. This phenomenon appears to limit the performance of the filtering unit of the biofil digester.

Generally, none of the 3 filtering membranes caused any reduction in BOD_5 or COD from the effluent of the coconut fibre. PKS filters managed only 4.9% average removal of BOD_5 which is insignificant. Trends do not show any significant removal. Compared to the influent blackwater, there was substantial increase in organics in effluents of the bulking material and the filtering membranes.

One-way ANOVA showed a high variation in BOD concentration ($p=3.47x10^{-6}$) within the samples. Further t-tests conducted on the samples indicated that there was significant variation between the BOD concentration of the blackwater influent and the effluent from the coconut fibre. Indeed, the BOD concentration increased by 213% as it filtered through the coconut fibre. This can be attributed to the leaching of degraded biosolids retained on the coconut fibre from previous feeding. A packing density of 555.56g/m2 of the coconut fibre is also not adequate to retain any particulate solids. COD also increased substantially by an average of 31.7% as the blackwater was filtered through the coconut fibre. There were days with actual removal of COD which ranged from 13.8% to 84.9%. The increase in COD is attributable to the leaching of particles of the coconut fibre itself over the operational period. The coconut fibre comprises mainly cellulose and lignin which are known not to be readily biodegradable hence the increase in COD. However, there is no statistically significant difference ($p=0.642$) in the COD concentrations between the all the samples. This indicates that neither the bulking material nor the filtering membranes was able to attenuate the COD concentration in the raw blackwater.

All 3 filtering membranes recorded mixed performance in both BOD_5 and COD reduction during the experimental period. Averagely the filtering membranes performed better in handling BOD_5 than COD. PKS filtering membrane was able to remove 3.2% of the BOD whereas SP filtering membrane rather increased the BOD by 3.2%. Analysis of their trends however indicates very mixed results with as much as 45.9% reduction of BOD on some days and an increase of 34.2% BOD on other days. The relatively high hydraulic loading rates and large pore sizes of the filtering membranes reduced the likely hood of straining or adsorption; dominant organic contaminant removal mechanisms.

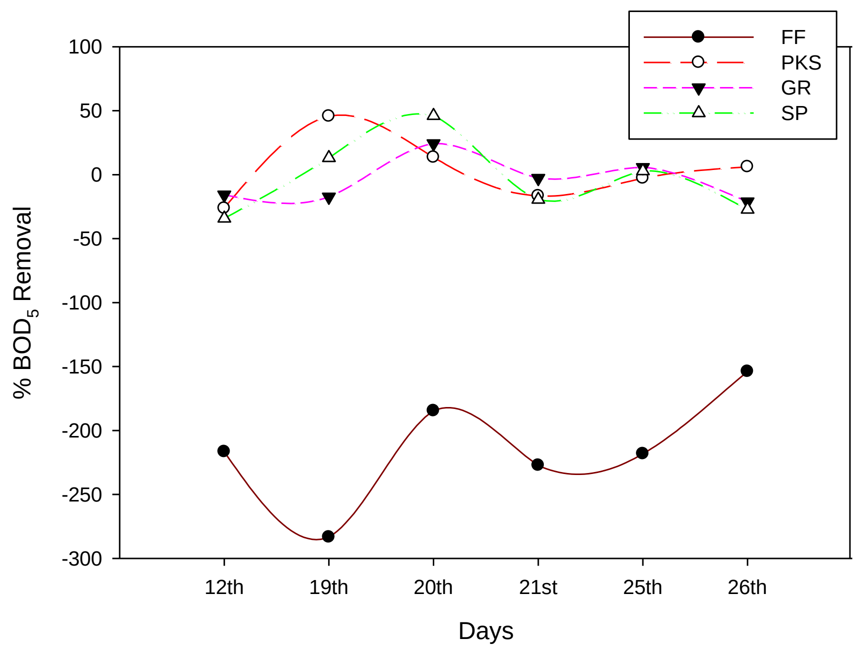

Figure 8: Variations in BOD_5 Removal from various effluents

The filtering membranes also showed similar patterns in handling COD. The performance was however poorer. There was significant increase in COD in the effluent from the filtering membranes. PKS had an average increase of 65.6%, 57.5% for GR and 40.1% for SP. In addition to the reasons advanced for BOD increment in the effluent, there is also a high probability of leaching of residual cement and aggregate particles from the membranes into the effluent.

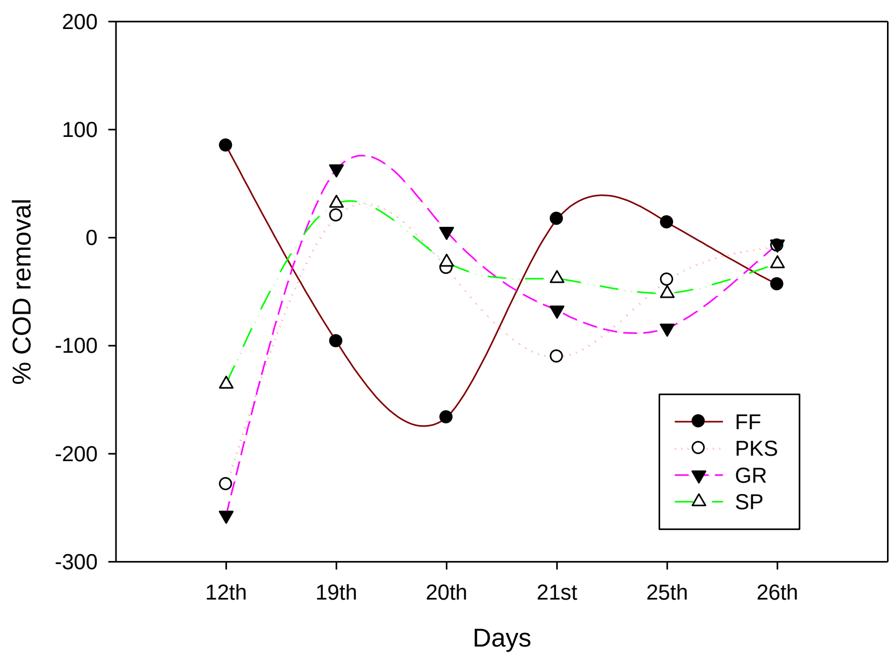

Figure 9: Variations in COD removal

TSS measured may consist of inorganic and organic particles with the latter being less dominant (as indicated by the relatively high COD/BOD5 ratio).

Average TSS values of 2342.7 mg/l, 2253 mg/l, 2107 mg/l was recorded for SP, PKS and GR respectively after filtering with 2.0µm filter paper. There is no statistically significant difference ($p=0.730$) in the TSS concentrations between the all the samples. These values far exceed the acceptable value of 50mg/l for discharge into surface waters for which the filtrate may be applied. The high TSS is however not surprising considering the performance of the bulking material and filtering membranes in removal of COD and BOD. This again is attributed to the addition of particulates from the coconut fibre itself and from the breakdown of accumulated biosolids retained on the coconut fibre. By filtering distilled water through the coconut fibre setup, it was realised that 450mg/l of TSS was added to the effluent for every 3300ml of hydraulic load.

The filtering membranes are ineffective in causing any substantial reduction in TSS concentration in their influent. The relatively large pore sizes of the various membranes and the process of rapid filtration easily allow any particulates to pass through the filtering membranes. High TSS in a water body can often mean higher concentrations of bacteria, nutrients, pesticides, and metals in the water. These pollutants may attach to particles on from the biofil unit and be carried into water bodies. In the water, the pollutants may be released from the sediment or travel farther downstream creating environmental hazards. (Federal Interagency Stream Restoration Working Group, 1998).

Albuquerque and Labrincha (2008) observed that the contaminant removal performance during filtration are strongly dependent on the design of the filter medium with respect to type of medium, size, depth, filtration rate, pressure available for driving force and method of filter operation. For turbidity /TSS removal, a higher filtering depth (45.5cm) was found to be the most effective in their research.

Performance of the elements of the filtering unit with respect to organic removal are presented in tables 13 and 14; and figure 10

Table 13: Concentration of organic parameters in sampled effluents

Parameter	**FF**		**GR**		**PKS**		**SP**	
	Mean	**St. Dev**	**Mean**	**St. Dev**	**Mean**	**St. Dev**	**Mean**	**St. Dev**
TSS (mg/L)	2344.33	1170.75	2107	624.50	2253	577.26	2342.67	1045.45
BOD_5 (mg/L)	1125	135.17	1180	272.10	1070	247.87	1150	315.60
COD (mg/L)	4477.71	1761.17	7924.00	4888.94	6042.29	1602.46	5345.14	2008.61

Table 14: COD and BOD removal from effluents compared to influent (for FF) and FF for others

Sample	% COD removal	% BOD removal
FF	-31.74	-213.99
PKS	-65.67	3.23
GR	-57.54	-4.52
SP	-40.11	-3.18

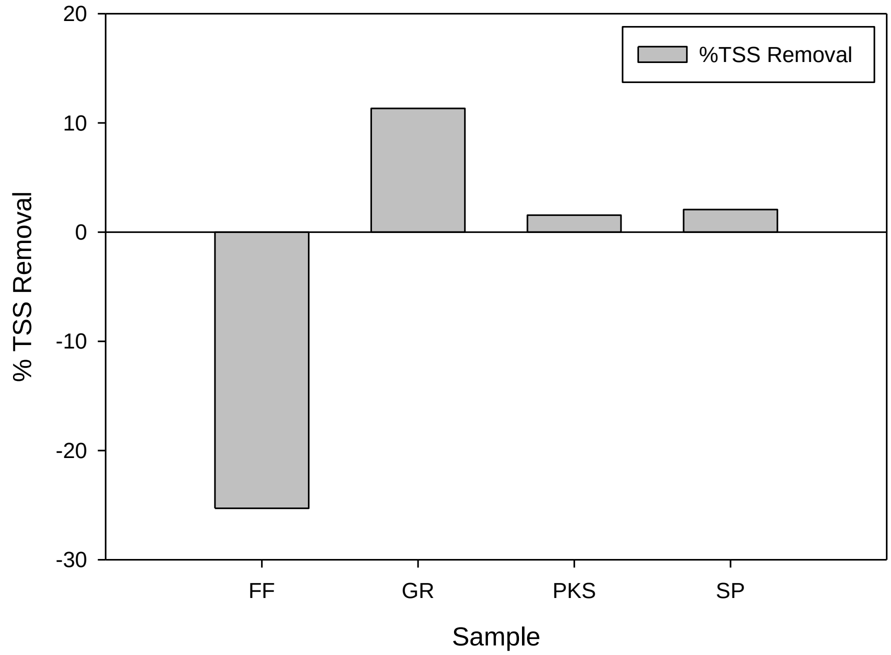

Figure 10: TSS removal observed in the various effluents

4.4.3 Nutrients

Although the setup was fully aerated, complete nitrification of Ammonium was not achieved. As biological activities play major roles in filtration systems, nitrification processes are expected to take place under aerated conditions as within the Biofil digester. Due to its toxicity, nitrate (NO_3) is typically the major nitrogen parameter of concern in effluent expected to be used in irrigation (Abbassi et al, 2011). Generally the removal efficiency was rather poor for all the nutrients analyzed in all the filters. The concentrations of all the nutrients exceed the guideline values set by the EPA, making the effluent from the filters unsuitable for use for any purpose.

Monitored nutrient concentrations in the effluent from the different filtering membranes and the bulking material are presented in table 15. The performance for the filtering membranes and the bulking material were mixed.

There was no significant difference between the concentration of all the nutrients measured in the blackwater influent and in the effluent from any of the filtering media. At 95% confidence level, the p value from t-tests ranged from 0.302 to 0.9918.

Nitrogen conversion takes place in two major steps.

Nitrification: where Ammonium (NH_4^+) ions are oxidized to Nitrate (NO_3) in an unsaturated or aerated zone of a filtering media. Denitrification then follows in a saturated or anoxic zone where Nitrate is converted to Nitrite (NO_2) and subsequently to Nitrogen gas (N_2) (Metcalf and Eddy, 2003 and Robertson and Anderson, 1999). The digester of the biofil toilet technology is designed to operate under fully aerobic condition hence there is no development of anoxic conditions. Denitrification therefore is not expected to play a dominant role in nitrogen conversion. This can be seen in the relatively high concentration of nitrates measured in the effluents of the bulking material and the filtering membranes.

The likelihood of ammonia to be adsorbed to the filtering media is very low or negligible as discovered by Sato et al (2010). He argued that the concentration of ammonia nitrogen increased with an increase in the flow rate of wastewater into the filtering system due to the decreased contact time of the wastewater as it passes through the packing material (the filtering membrane in this case).

As the blackwater passes through the filtering unit of the biofil digester, organic nitrogen undergoes rapid ammonification reaction and hence a rise in ammonia nitrogen can be observed. Various researchers have also observed that under aerobic conditions heterotrophic bacteria convert organic nitrogen into NH_4-N (Cheremisinoff, 1996, Sawyer et al., 2003; WEF, 2005 and Henze et al., 2008).

The poor performance in organic and TSS removal is translated in the performance in the removal of NO_3-N and NO_2-N.

Nitrite and nitrate might be embodied within the particulates. Probably these forms of nitrogen might have been adsorbed onto the TSS and drained from the digester during the rapid filtration. Studies by LENNTECH (2013) and WHO (2004) indicate that nitrates can be removed from solution phase through adsorptive ion exchange in the presence of strong anionic species like the Cl-. These ions occur in wastewater systems that use detergents and other household cleaning chemicals whose active ingredient is chlorine. In the case of the blackwater used in the experiment, the salt content in the diet of users also might have contributed to the presence of such ions within the system. The mechanism of removal is attributed to the higher exchange capability of nitrate ion over chloride and bicarbonate ions (Chabani et al., 2010) whereby nitrate might then be transformed into solid phase or adsorbed onto solid matter. Results from the effluent analyses do not however indicate any significant removal of nitrogen species inspite of the relatively high Chloride concentration.

As much of the contaminants in faecal wastewater are attached to the solid content of the blackwater, the inability to remove TSS means that the contaminants are potentially carried along into the receiving environment.

Similar to the nitrogen species, Total Phosphorous (TP) analysis for the influent and effluent samples were conducted. The average TP for the effluent for the coconut fibre (influent for filtering membranes) was found to be 58.68 mg/l. However, the average concentration from the effluent of the filtering membranes was found to be 52.21mg/l indicating marginal reduction on TP concentration.

Apart from TP, there was also marginal reduction in NH_4^+, and SO_4 concentration across the filtering membranes. The remaining parameters gave mixed results generally indicating increase in concentrations.

According to US EPA (1993), removal of chloride ions occurs rapidly through precipitation. However, considering the very short hydraulic retention time and the small filtering depth of the filtering membranes, removal of chloride by precipitation is unlikely to occur in these filters.

Table 15: Nutrient and chemical concentration in sampled effluents

Parameter	**FF**		**GR**		**PKS**		**SP**	
	Mean	**St. Dev**	**Mean**	**St. Dev**	**Mean**	**St. Dev**	**Mean**	**St. Dev**
NH4-N (mg/L)	217.57	36.0	181.39	76.17	208.24	66.97	207.67	64.96
NO3-N (mg/L)	54.76	11.57	55.07	13.63	59.18	15.48	56.41	13.04
NO2-N (mg/L)	23.92	2.73	23.69	4.01	26.18	3.46	21.95	1.45
Total-N (mg/L)	576.24	175.36	551.62	156.71	598.29	161.56	522.28	190.25
Total-P (mg/L)	58.68	17.30	52.86	19.30	55.11	21.99	48.66	13.66
Cl^- (mg/L)	774.53	570.11	840.02	675.90	738.23	537.99	711.24	522.00
SO_4 (mg/L)	280.79	238.56	239.62	176.84	239.01	192.04	250.79	155.92

4.4.4 Pathogen Removal

Although there are many pathogens which can be transmitted through water, bacteria and protozoa are some of the most common microorganisms that cause disease. Faecal contamination is the major source of pathogenic micro-organisms including Escherichia coli, in wastewater.

Because humans often shed very low numbers of pathogenic bacteria when they are infected, monitoring for waterborne disease can be difficult.

Wastewater treatment systems, like the Biofil Toilet Technology, are designed to reduce the concentration on contaminants including pathogens, in the effluent prior to discharge in the receiving water bodies. Untreated effluents could still contain high concentrations of pathogens and becoming a threat to public health (Frigon et al, 2013). Bacteria, virus, protozoa and helminthic parasites are major groups of pathogens that are frequently associated with human excreta and are the most monitored in effluents.

These microorganisms are removed during filtration by adsorption, straining, or they die off due to the absence of suitable substrates or by predation.

The levels of these indicator pathogens of public health significance were analyzed in this study. The potential of the elements of the filtering unit in controlling or promoting the growth of these pathogens are assessed and presented.

4.4.4.1 FAECAL AND TOTAL COLIFORMS

Two distinct types of coliforms were analyzed for in the influent blackwater as well as the effluents from the filtering units; E.Coli and Other Coliforms. This classification is based on the classification of Merk, produces of the Chromocult agar used to culture the coliforms.

Effluent from the PKS and GR gave the highest count of E.Coli of $26x10^8$ cfu/100ml with corresponding Other coliform count of $9x10^8$ cfu/100ml and 12 $x10^8$ cfu/100ml respectively. This represented a 0.85 log increase from the influent blackwater concentrations.

Quite remarkably, SP yielded the least coliform concentration with an E.Coli concentration of 6 $x10^8$ cfu/100ml and other coliform concentration of 4 $x10^8$ cfu/100ml. SP and FF recorded outliers in the determination of other coliforms. This can be attributed to chance or an error in the determination.

Faecal coliform measurements are consistent with measurements cited by Jiménez et al (2007) of 10^4–10^9 cfu/100ml of wastewater for Ghana.

One-way ANOVA showed a very high variation in the counts of E.Coli colony forming units (cfu) ($p=8.334x10^{-12}$) within the samples. Further t-tests conducted on the samples indicated that there was significant variation between the E.Coli population the blackwater influent and the effluent from the coconut fibre (p= 0.000373). Results show a remarkable increase (767%) from the influent blackwater count to the effluent from the coconut fibre. Another significant variation was realised between E.coli number between the effluent from the coconut fibre and effluent from SP filtering membrane ($p=4.154x10^{-5}$). There was profound decrease in E.Coli population in the effluent from SP compared to the effluent from coconut fibre which was used as influent. Apart from SP, none of the other materials recorded any reduction on coliform concentrations compared to the influent.

E.Coli concentrations increased significantly (by a factor of 3.4) in the effluent of the coconut fibre compared to the influent blackwater. This increased concentration is then passed on to the filtering membranes. The retention of solids on the coconut fibre could serve as a primary growth substrate and suitable environment for the rapid multiplication of the coliforms which are then washed out during the filtration process.

The likely hood of straining reducing the microbial count of the coliforms, as proposed by Scha¨fer et al (1998) is not turnable as the pores of the media are infinitesimally large compared to the size of the micro-organisms. The microbes can simply not be strained out. Straining phenomena are of minor importance in these large pore sized filtering membranes.

Other mechanisms such as attachment and deposition and are possible but were unlikely to have played any significant role considering the increased microbial numbers for the coconut fibre, PKS and GR filtering membranes.

Table 16: Pathogen population in sampled effluents

Parameter	No. of Samples	FF		GR		PKS		SP	
		Mean	**St. Dev**	**Mean**	**St. Dev**	**Mean**	**St. Dev**	**Mean**	**St. Dev**
E. Coli	6	22	3	26	4	26	5	6	3
Other Coliform	6	13	5	12	3	9	4	4	5
Salmonella	6	0	0	0	0	0	0	0	0
Helminth egg count (no./ml)	6	15	10	11	5	10	7	11	9

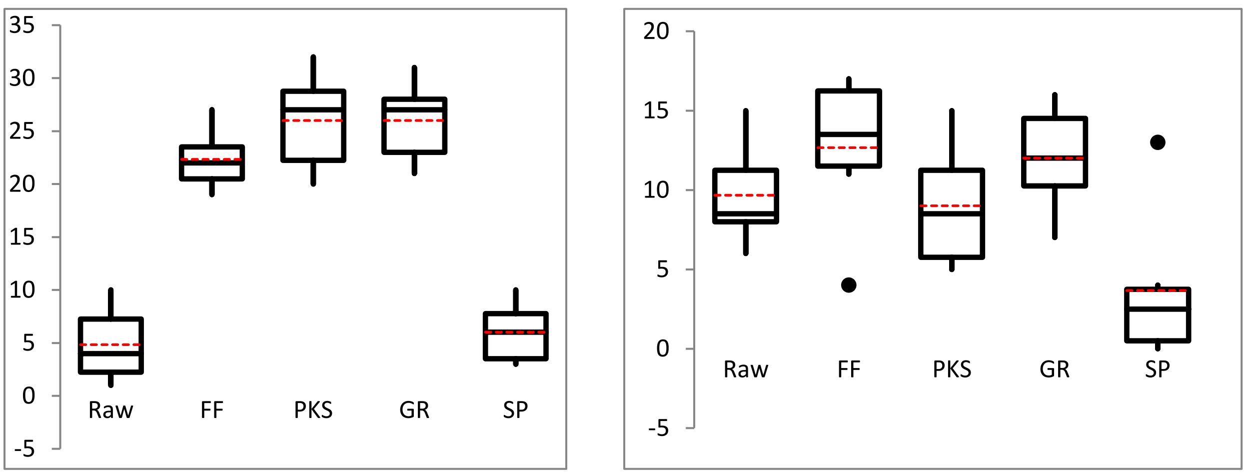

Figure 11: Box-plots showing the range, 25th, 50th and 75th percentiles on the occurrence of: E.Coli (Left) and Other Coliforms (Right) in blackwater and effluent

The intriguing reduction of coliform population in effluent from the SP filtering membrane (73% removal from coconut fibre effluent) is noteworthy. Considering that the likely hood of straining and deposition has been rule out for the other filtering membranes and bulking material, that argument cannot be used in this case.

Scha¨fer et al (1998) indicated that hydrophobic interactions between filtering media particles and microbial cells can promote attachment. The sum of these interactions can explain the retention of bacteria in water-filled porous media, of the SP pervious concrete.

Further more, Gargiulo et al (2007) explained that the rate and the extent of bacteria attachment to surfaces and air–water interfaces are governed by molecular-scale interactions between the bacteria outer layer and a particular interface.

The inhibition or promotion of this attachment is in accordance with affinity of the microbes for the interface and depending on the aqueous solution chemistry.

Harkes et al (1991) found in their study that a very high number of adherent bacteria were found on to positively charged surfaces when compared to the number of adherent bacteria on to uncharged and negatively charged surfaces. This was attributed to electrostatic interactions playing an important role in the adhesion process. Ionic strength of the liquid medium was found by Janjaroen et al (2013) to play an important role in the increase in adhesion rates of E.Coli cells. High ionic strength led to the compression of the double layer charge boundary which in turn leads to better adhesion between the negatively charged bacteria and the positively charged particle surface. These explanations was relevant when Butot et al (2007) found out in their research that PET bottles retained 75% of inoculated bacteria compared to 18-73% for glass bottles after an equal exposure time of 20 days. Their study concluded that PET bottles adsorbed higher numbers of bacteria and viruses compared to glass bottles.

Based on the forgone reasons, it can be explained that the rather high Electrical Conductivity (EC) of the effluent coupled with the high chloride concentration, created positive charges on the particles of the SP filtering membrane. These particles then easily attracted the negatively charged coliforms onto their surfaces hence their reduction in the effluent.

4.4.4.2 HELMINTH EGGS COUNT

Helminth eggs, especially viable Ascaris sp. eggs, have been used worldwide as indicators of the sewage sludge quality for agricultural application since it is the most resistant helminth to most forms of treatment (Velásquez et al. (2004) and Jimenez-Cisneros (2007)).

In this work, the prevalence of viable helminth eggs was the focus since their effective doses are very low.

Four types of helminth eggs were isolated for analysis in the samples; Ascaris, Tinea, hookworm and Strongyloides. Helminth eggs were identified in all water samples and the populations exceeded the recommended level of ≤ 1 egg L^{-1} for unrestricted irrigation (WHO, 2006).

As expected, the helminth eggs population was highest in the influent blackwater (RAW) with reductions in the subsequent effluents.

There was no significant difference observed in the mean helminth eggs populations recorded in effluent of the 3 filtering membranes (Table 17). Though was some removal in helminth egg population across the bulking material and filtering membranes, they removal did not make any significant difference (p= 0.4750).

Table 17: Arithmetic mean of Helminth eggs enumerated in effluent samples

Arithmetic mean1 of helminth eggs/L					
		Species of helminth eggs			
Samples	**Average of all species**	***Ascaris***	***Teania***	***Hookworm***	***Strongyloides***
RAW	19	8	4	5	3
FF	15	3	5	6	0
GR	11	5	3	2	1
PKS	10	4	1	5	0
SP	11	4	3	4	1

Both bulking material and filtering membranes performed well in removal of Strongyloides with PKS filtering membrane performing best.

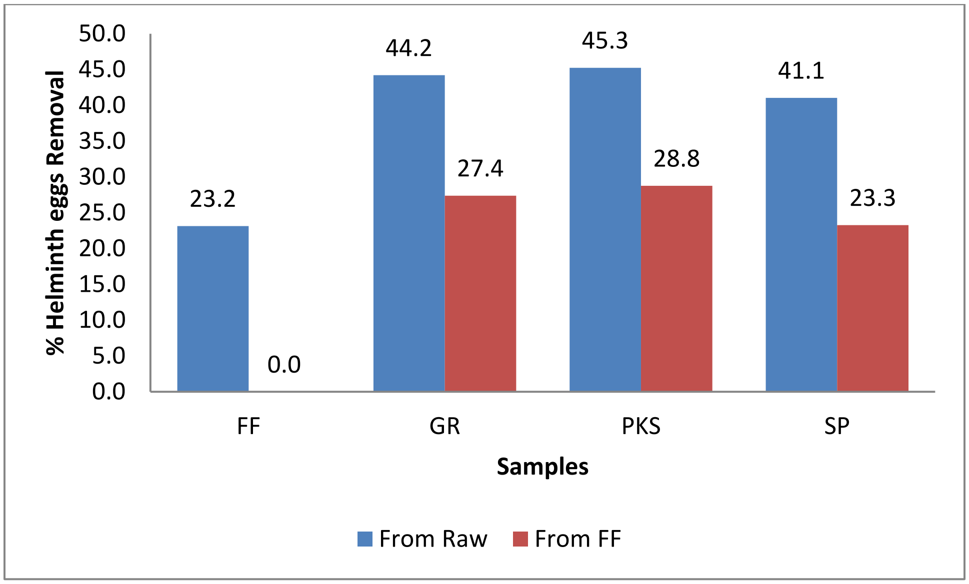

Figure 12: % Helminth eggs removal from effluent samples compared to raw influent and effluent from bulking material (FF)

The filtering membranes were found to have similar performance in the reduction of helminth egg population (fig.12) from both the effluent from the bulking material (average of 26.5% removal) and from the blackwater influent (43.5%). Helminth egg population attenuation in SP filtering membrane however was the least of the 3 filtering membranes. The bulking material managed an average of 23.2% removal of helminth eggs from the influent blackwater.

Though highly resistant, the helminth eggs can also be destroyed at low pH , high temperature (Velásquez et al, 2004) with temperature being The most important environmental factor influencing helminth egg development and survival.

The reduction in the population of helminth eggs in all the effluent samples suggests that the elements of the filtering unit were effective in using known removal mechanisms of adhesion and sedimentation (Sengupta, 2012) with adhesion being the most probable method of removal.

The adhesion according to Sengupta (2012) is attributed to sticky appearance of the eggs and the physical-chemical surface properties of eggs and media constituents. Since the effect of physical-chemical surface properties is not well studied for helminth eggs, it can be safely postulated the sticky appearance of the eggs to the media surfaces is responsible for most of the adhesion and their subsequent removal.

The effect of temperature on the reduction of viable eggs in the effluents does not hold in this case. Velásquez et al (2004) attribute the rapid kill of helminth eggs to elevated temperatures of 70°C to 80°C. This temperature range was never recorded in any of the effluents. Indeed the highest recorded effluent temperature was 26.5 °C, from the bulking material.

Jimenez-Cisneros and C. Maya-Rendon (2007) report a high positive correlation ($R^2 = 0.92$) between Helminth eggs population and TSS concentration in wastewaters in Mexico. This research could not however reach the same conclusion. The correlation attained was negative and low ($R^2 = 0.41$). This can be attributed to the relatively small sample size of this study in comparison to theirs. None the less, because helminth ova from wastewater form a fraction of the suspended solids (particles measuring 20-80 μm), suspended solids content (TSS) can be used to reasonably predict occurrence of helminth eggs (Jimenez-Cisneros, 2007)

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATIONS

The conclusion of the study and accompanying recommendations are presented in this chapter. It presents a summary of the contaminant removal efficiency of the filtering unit (comprising the bulking material and filtering membranes) and proposed recommendations.

5.1 CONCLUSION

The raw black water sampled in this study was found to be strong (COD of 5729 mg/l, BOD 360mg/l and COD/BOD of 15:1). The BOD was found to be nearly consistent whereas the COD showed variability.

The experiments conducted give a clear indication of the inability of the elements of the filtering unit, of the biofil digester, alone to adequately remove contaminants in the influent to acceptable standards.

5.1.1 BULKING MATERIAL

Experimental work done on the bulking material showed that it contributes to the significant increase of organics (BOD, 213%; COD, 31.7 %) and pathogens (E.Coli, 767 %) from the influent blackwater prior to discharge unto the filtering membranes. The overall performance of the filtering unit was found to be dependent on the performance of the bulking material since it is the first recipient of the influent blackwater. The increase of analytes in the effluent is attributed to the leaching of retained solids from previous feeding regimes or particulates of the bulking material itself.

5.1.2 FILTERING MEMBRANES

Similar to the bulking material, the three filtering membranes were unable to cause any significant reduction in the parameters monitored. For most of the analytes, there were no consistent significant differences between influent and effluent values irrespective of the type of filtering membrane. There were slight increase in organics in the effluent but this was found not to be statistically significant. In terms of pathogen removal, their performance was similar with the exception of Shredded PET bottle (SP) filtering membrane. SP was found to significantly remove E.Coli and other coliforms from its influent (73%). All the filtering membranes had similar hydraulic performance though SP that a slightly higher filtration rate.

The use of different aggregates in the pervious concrete did not result in any consistent significant differences in nutrient concentrations. Based on the experimental results, different aggregate types would not significantly affect effluent nutrient levels from blackwater percolating through the pervious concrete.

The performance of the filtering membranes with respect to various parameters measured exceed the guideline values recommended by both WHO guidelines for effluent discharge into surface waters and Ghana-EPA general effluent quality guideline values for discharge to natural water bodies.

Observation from the experiment could not confirm reports by the manufacturer that clogging of filtering membrane surface was a major problem in the operation of the digester.

From the studies conducted, it can be concluded that all the filtering membranes and bulking material assessed are ineffective in reducing contaminant concentration to the recommended guideline values. However they effectively play their role of providing rapid solid-liquid separation in the biofil digester.

5.2 RECOMMENDATIONS

- Considering that the primary function of the filtering membranes is solid-liquid separation, shredded PET bottles, Palm kernel shells or other light weight and inexpensive coarse aggregates should be used. Incorporation of Shredded PET would aid in better pathogen removal as found out during the experiments.
- The poor performance of the filtering unit in removing contaminants can be improved by increasing the packing density of the bulking material. A more compact bulking material will lead to better contaminant removal which affects the overall contaminant removal of the filtering unit.
- Effluent from the digester of the biofil toilet should undergo further treatment prior to discharge into the environment.
- It is recommended that further work be done to determine optimum packing density of the bulking material for contaminant removal without impeding movement of earthworms.
- Further work should also be done on the assessment of contaminant removal of vermicompost and its potential of clogging the filtering membranes.

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APPENDICES