CRANFIELD UNIVERSITY

DANIEL SARPONG

TREATING CONTAINER TOILET WASTE IN KUMASI, GHANA

SCHOOL OF WATER, ENERGY, and ENVIRONMENT

MSc by Research Thesis

Academic Year: 2014 - 2018

Supervisor: Dr Alison Parker and Professor Sean Tyrrel

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This thesis is submitted in fulfilment of the requirements for the degree of MSc by Research

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ABSTRACT

About 2.7 billion people worldwide have access to onsite sanitation technologies, and that number is expected to increase to 5 billion by 2030. In Sub-Saharan Africa, 65-100% of sanitation access in urban areas is provided through the onsite technologies. It is evident that faecal sludge management is of a critical need that must be addressed. Clean Team, a subsidiary company of Water and Sanitation for Urban poor (WSUP), operates in Kumasi, Ghana by providing household portable container toilets at subsidised fees. This research investigated toilet waste treatment options for Clean Team, in the event that it expands into towns where there is no treatment plant at all.

The study presented the results of the performance of the two technologies, Sistema Biobolsa and BIOROCK, installed and operated under the ambient conditions in Kumasi. With hydraulic retention time of 10 days, the Sistema Biobolsa achieved removal efficiency of 79%, 93%, 90%, 61% and 64% for the Chemical Oxygen Demand (COD), Ammonium Nitrogen (NH_4-N), Total Solids, Total Suspended Solid (TSS) and Alkalinity respectively. With regards to BIOROCK system, at hydraulic retention time of 25 days, the system achieved removal efficiency of 73%, 87%, 86% and 51% for the COD, NH_4-N, TS and TSS respectively. The study recorded 46 % biogas (methane) production by volume from the Sistema Biobolsa digesters, in spite of Clean Team's chemical additive (odour suppressant). Furthermore, the study also shown 100% seed germination in the outflow wastewater from the Sistema Biobolsa gravel filter beds, whilst BIOROCK shown a seed germination at 10% dilution of outflow wastewater from the secondary tank (filtration process). Taken together these results , there are strong indication of the occurrence of biological processes in spite of the presence of the chemical additive and provide confidence that waste of this type can be treated by flowsheet which included biological processes.

The effluent quality from the both technologies met some of the Ghana Environmental Protection Agency (GEPA) guidelines but not others. The study suggested that any stand-alone deployment of these systems (thus, where

there is no existing wastewater treatment works), would require a parallel sludge management system such as drying beds.

Keywords: Sistema Biobolsa, BIOROCK, Container Toilet Waste, Treatment, digesters, efficiency.

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LIST OF ABBREVIATIONS

AGFB	Aerobic gravel filter bed
AIT	Asia Institute of Technology
BMGF	Bill & Melinda Gates Foundation
BOD	Biological oxygen demand
BR	BIOROCK
CEO	Chief Executive Officer
COD	Chemical Oxygen Demand
CSTR	Continuous stirred tank Reactor
CT	Clean Team
ECOSAN	Ecological Sanitation
EIA	Environmental Impact Assessment
FSM	Faecal Sludge Management
FSTP	Faecal Sludge Treatment Plant
GEPA	Ghana Environmental Protection Agency
GI	Germination Index
JMP	Joint Monitoring Programme
KATH	Komfo Anokye Teaching Hospital
KMA	Kumasi Metropolitan Assembly
KMWTP	Kumasi Municipal Waste Treatment Plant
KNUST	Kwame Nkrumah University of Science and Technology
KVIP	Kumasi Ventilated Improved Pits
NH4-N	Ammonium Nitrogen

NPK	Nitrogen Phosphorus and Potassium
PF	Plug Flow
PTS	Public Toilet Sludge
SB	Sistema Biobolsa
TS	Total Solids
TSS	Total Suspended Solid
TVS	Total Volatile Solids
TVSS	Total Volatile Suspended Solids
UK	United Kingdom
UDT	Urine Diverted Toilets
UNDP	United Nations Development Programme
WHO	World Health Organization
WSUP	Water and Sanitation for Urban Poor

CHAPTER ONE

1.0 Introduction

1.1 Background

About 2.7 billion people worldwide have access to onsite sanitation technologies, and that number is expected to increase to 5 billion by 2030 (United Nation JMP, 2013). It is widely perceived that onsite technology fulfils sanitation needs for rural areas, but in reality, approximately 1 billion onsite facilities worldwide are in urban areas. In many cities of developing countries, onsite sanitation technologies have much wider coverage than sewer systems. In Sub-Saharan Africa, 65-100% of sanitation access in urban areas is provided through the onsite technologies (Strauss *et al*., 2000). It is evident that faecal sludge management is of a critical need that must be addressed, and that it will continue to play an important role in the management of global sanitation into the future (Strande, 2014).

In the years past, sludge from onsite facilities has not been a priority of engineers, municipalities, and has traditionally received little to no attention. Some generation of engineers have considered waterborne, sewer-based systems as the most appropriate solution to fulfil the long term sanitation needs. Traditionally, onsite facilities have been regarded as a temporary solutions until sewers could be built (Strande, 2014). This practice is a result of the effectiveness of sewer-based systems in the cities, where water is readily available, as well as the preference for large-scale infrastructure investments by Banks and Governments. However, the development and expansion of the conventional sewer networks are not likely to keep pace with the anticipated level of rapid urbanisation. In addition, where sewer and wastewater treatment plants have been built in developing countries, they have most often resulted in failures (Strande, 2014). Over the past two decades, the thinking of some engineers have started to shift, and people have started to consider onsite and decentralised technologies not only as a long-term viable options, but possibly the more sustainable solutions in many ways compared to sewer-based facilities, which are costly and resource intensive. In urban areas, it has been proved that, depending on the local conditions, the cost of faecal sludge management (FSM) technologies are five times less expensive than conventional sewer-based solutions (Dodane *et al*., 2012 and Strande, 2014).

Developing solutions for faecal sludge management is a serious problem that has not received much attention in the past two decades (Strauss and Heinss, 1996). Compared to wastewater management practice, there is about a 100-year gap in knowledge of faecal sludge management in urban areas (Strande *et al*, 2014). Nevertheless, FSM strategies are now rapidly developing and gaining acknowledgement, demonstrated by typical examples (Senegal and Burkina Faso) where municipalities are adopting FSM into their urban planning programmes (Strauss and Heinss, 1996). Now, there is commitment of the Bill & Melinda Gates Foundation, placing substantial resources into research of faecal sludge management. Lately, experiences through pilots and full-scale systems have started becoming available, but the practice is still not up to the desired speed. Awareness of the need for FS management has increased, as well as the need for sustainable solutions. However, information on FS management is generally not readily available (Strande *et al*., 2014).

In many cities of West Africa, the reality is that thousands of tons of faecal sludge from conventional on-site sanitation systems are disposed of untreated and indiscriminately into estuaries, sea, water bodies, drains, and gutters (Figure 2a, 2b and 2c).

These practices of improper disposal of faecal sludge in the developing countries including Ghana could be attributed to factors such as;

- ✓ Lack of tested and suitable waste treatment technologies to treat toilet waste or faecal sludge in developing countries;
- ✓ Lack of treatment plants resulting in an overall shortage of treatment capacity to handle the volume of faecal waste generated.
- ✓ Poor operation and maintenance of existing treatment systems leading to non-functioning and ultimate breakdown of the system. According to (Strauss *et al*., 1997; Heinss *et al*.,1998), the treatment facilities in developing countries, are expected to:

i. Be low cost technology. The capital and operating cost should be low and expertise are available to service them.

ii. Have little or no major spare parts imported.

iii. Use low sources of power/energy.

iv. Treat the waste to at least secondary level, with emphasis on the removal of pathogens and helminth eggs (Strauss *et al*. 1997; Heinss *et al*., 1998)

Having recognised the environmental deficits that resulted from the improper disposal of faecal sludge, efforts were made to find treatment system with technology suitable to the socio-economic conditions of Ghana, to treat and safely dispose of the faecal sludge. In early 1986, research activity to find appropriate treatment options began in Accra, Ghana, under the waste management improvement project for the capital city. Between 1989 to 1990, while these research activities were ongoing, a prototype faecal sludge treatment plant (FSTP) consisting of a solid-liquid separation step in settling/ thickening tanks, followed by a series of four waste stabilisation ponds, trickling filter, maturation pond and a series of evaporation beds was built at Achimota, north of Accra to reduce the incidence of unauthorised dumping and the cost of haulage from the north of Accra to the beach, and obtain adequate operational data for system components of the Achimota plant (Doku, 2002).

The construction of this treatment plant made Ghana became one of the first of developing countries to set up and operate a treatment plant for the separate treatment of sludge from septic tanks, bucket latrines and public toilets (Heinss *et al*., 1998). Since then, three other FSTPs have been built to test new conceptual designs in an attempt to improve upon the operational performance. Under the urban environmental sanitation project, which is partly aimed at improving excreta management by providing facilities for the treatment of nightsoil and faecal sludge, other FSTPs was planned for the five major cities in Ghana. The reports from the monitoring and evaluation of the faecal sludge treatment pond (FSTP) by Heinss *et al*., 1998 showed that the facility was capable of treating septage because there was a settling or thickening tanks that ensured that only the liquid fraction flowed into the Achimota faecal sludge treatment ponds (Figure 1). It was possible for the FSTP to treat a mixture of toilet sludge including the septage provided, because the design and operational guidelines illustrated in (Table 1) were followed strictly.

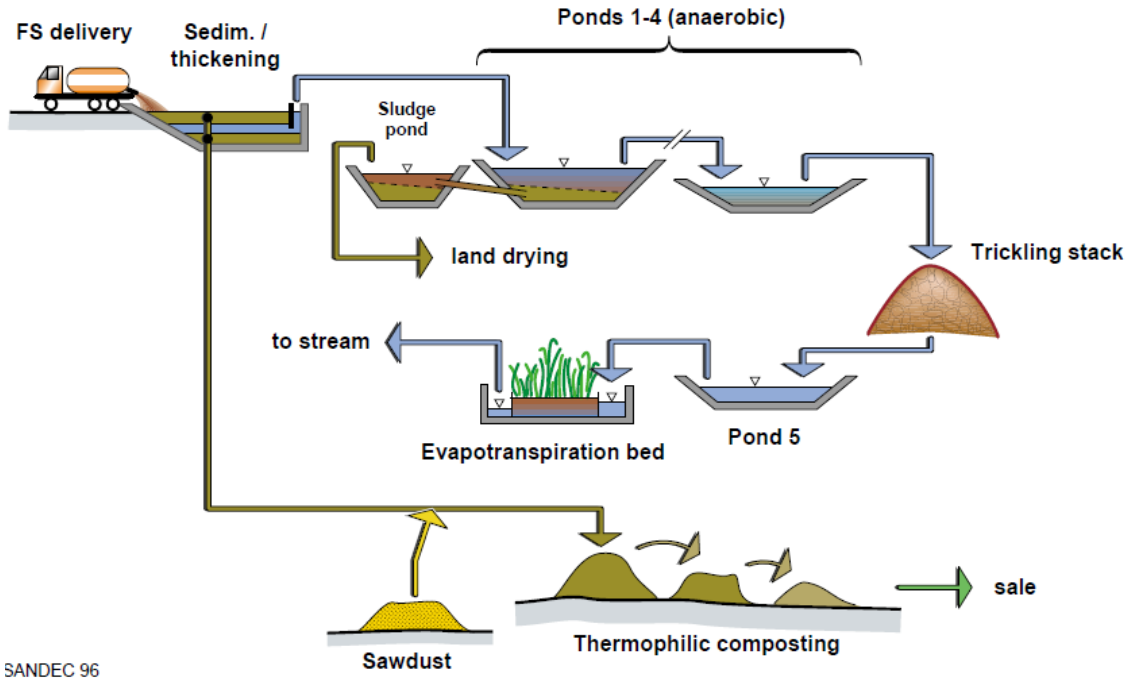


Figure 1. Schematic diagram of Achimota, Accra faecal sludge treatment plant. Source: SANDEC 1996.

The monitoring and evaluation reports also indicated that the FS treatment plant at Achimota, Accra was hardly achieving the solid-liquid separation as designed. The preliminary design parameters considered is shown in Table 1. The results also indicated that the system failed due to overloading of high concentrations of ammonia. The inefficient solid-liquid separation was due to the fresh nature of the sludge from sources. Thus, the sludge was undigested and highly concentrated in comparison with the septage (Heinss et al, 1998).

Table 1. Suggested effluent and sludge quality guidelines for faecal sludge treatment.

	COD [mg/l]	BOD [mg/l]	NH_4-N [mg/l]	Helm. eggs [No./l]	Faecal colif. [No./100 ml]
A: Liquid effluent					
Treatment for discharge into receiving waters:					
• Seasonal stream or estuary - unfiltered	≤ 300-600	≤ 100-200	≤ 10-30	≤ 2-5	≤ 10^4
- filtered	100-150	30-50			
• Perennial river or sea - unfiltered	≤ 600-1,200	≤ 200-500	≤ 20-50	≤ 10	≤ 10^5
- filtered	150-250	50-70			
Treatment for reuse:					
• Restricted irrigation	n.c.	n.c.	*	≤ 1 **	≤ 10^5 **
• Vegetable irrigation	n.c.	n.c.		≤ 1 **	≤ 10^3 **
B: Treated plant sludge					
• Use in agriculture	n.c.	n.c.	n.c.	≤ 3-8/g TS ***	Safe level if egg standard is met

n.c. - not critical

* Irrigation rates and effluent quality must be chosen such that the crop's nitrogen requirements (100 .... 200 kg N/ha·year, depending on the crop) are not exceeded.

** WHO (1989)

*** Based on the nematode egg load per unit surface area derived from the WHO guideline for wastewater irrigation (WHO 1989), and on a manuring rate of 2-3 tons of dry matter/ha·year (Xanthoulis and Strauss 1991)

Sources: Heinss *et al.,* 1998.

Operating conditions that played an important role in the design and operations of the Achimota, Accra FS plant included the inflow concentrations of COD, BOD, Ammonia, TV, TVS, TSS, TVS, and VSS (Heinss *et al.,* 1098). The monitoring and evaluation reports also indicated that the FS treatment plant at Achimota, Accra was hardly achieving the solid-liquid separation as designed. According to (Heinss *et al.,* 1998), the design parameters that were of much concern to the study, comprises of variation in solid loading rates (250kgTS/m^2), sludge loading rate (1/week) and percolate period (6 days). The results also indicated that the system failed due to overloading of high concentrations of ammonia. The inefficient solid-liquid separation was due to high organic strength of the sludge from sources. Thus, the sludge was undigested and highly concentrated in comparison with the septage (Heinss *et al.*, 1998).

Table 2 shows the characteristics of faecal sludge from onsite sanitation facilities (Achimota- Accra), Ghana.

Table 2. Characteristics of faecal sludge from on-site sanitation facilities in Greater Accra region of Ghana (Mean values with minimum and maximum values in parenthesis).

Parameters	Septage (S)	Public Toilet Sludge (PTS)
COD (mg/l)	8,500 (820 - 52,000)	47,600 (10,400 -97,000)
BOD (mg/l)	630 (360 - 1,300)	8,800 (3,800 - 15,000)
TS (%)	1.4 (0.3 - 11.4)	-
TVS (% of TS)	63.0	62.0
TSS (%)	0.7 (0.07 -3.4)	6.4 (2- 19)
VSS (% of TSS)	70.0	58.0
Helminth eggs (no./l)	4,300 (200 -13,000)	29,000 (3,600 - 62,000)

Sources: WRRI/SANDEC, 1994

To tackle some of the world sanitation challenges, the Water and Sanitation for Urban Poor (WSUP) in partnership with Unilever established the Clean Team (CT) sanitation business model. The CT Ghana is presently providing services to about 1000 households with sanitation solutions (Parker *et al.*, 2015). Each of the households has branded, potable container toilet (Figure 2h) and the users pay for collection 2-3 times a week. The waste is collected and transported to Kumasi Municipal Waste Treatment Plant (KMWTP) at Dompoase for treatment. The KMWTP is currently operating beyond its capacity and raw toilet waste flows directly into drains and gutters (Figure 2a).

This research investigated toilet wastewater treatment options for Clean Team, in the event that it expands into towns where there is no treatment plant at all. Furthermore, the prescribed treatment option should be able to treat the toilet wastewater into acceptable levels to meet the Ghana Environmental Protection Guidelines (GEPA) guidelines for final disposal of wastewater into rivers and streams



Figure 2a. Vacuum Tanker discharges FS into drain.



Figure 2b. FS drains through the bush into Stream



Figure 2c. Discharge of fresh faeces into the drains



Figure 2d. Well Managed, Public toilet- Water Closet (WC)



Figure 2e. Aqua Privy-Single room



Figure 2f. Bucket latrine with partition chambers



Figure 2g. Cartridges toilet basin



Figure 2h. Clean Team container toilet

Figure 2. Example of faecal sludge management in Kumasi.

1.2 Clean Team sanitation business model

The Clean Team sanitation business model is being implemented in Kumasi, Ghana. Clean Team provides customers with pre-fabricated plastic urine-diverting portable toilets (Figure 2h) on a subscription fee basis. Prior to delivery, the toilet buckets (Figure 2g) are filled with a biocide chemical that reduces odour. Faeces are deposited into this chemical-filled basin, while urine is diverted outside or collected into plastic container. Clean Team collects the sealed buckets of waste from their customers' homes, replaces them with new clean buckets, and empties the used ones at a central collection point.

Clean Team sanitation business model is illustrated in Figure 3.

The stages 1 to 4 are fully developed except the stage 5, which is yet to be developed. The 5^{th} stage will be developed out of this present study, where the waste will be converted to energy (electricity) and fertilizer to sustain and grow the local business.

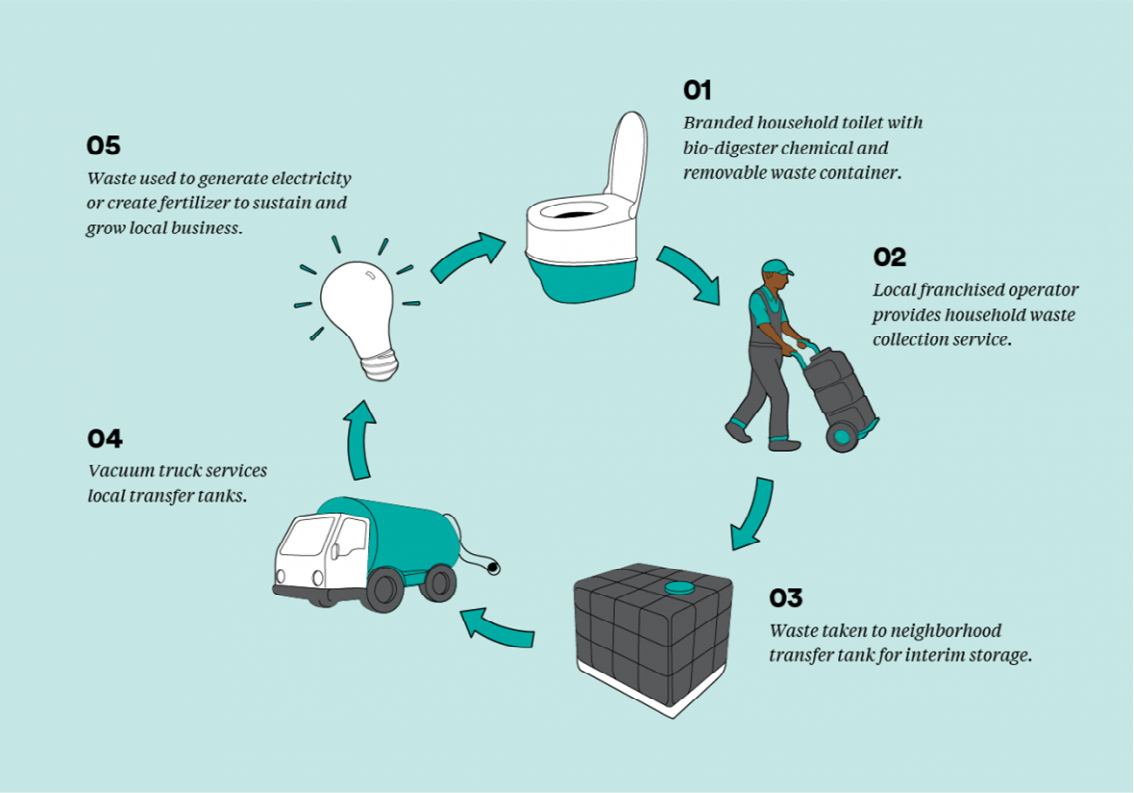


Figure 3. Clean team sanitation business model, 2014

1.3 Objectives of the study

1.3.1 Main objective of the Research

The main objective of the research was to investigate toilet wastewater treatment options for Clean Team, in the event that it expands into towns where there is no treatment plant at all.

1.3.2 Specific objectives

The specific objectives of the research were to;

i. Install, commission and operate the Sistema Biobolsa and BIOROCK systems on the Dompoase site with Clean Team waste.
ii. Determine the effluent quality according to a range of physical, chemical and biological parameters.
iii. Compare the effluent quality with Ghana Environmental Protection Agency (GEPA) guidelines.
iv. Recommend a treatment system suitable for future applications of container based toilets.

1.3.3 Research Questions

i. What is the effluent quality of the different toilet waste treatment technologies with respect to the physical, chemical and biological characteristics?

ii. How much toilet waste can be treated by the technologies within a given period?

iii. Would the effluent quality meet the Ghana Environmental Protection Agency guidelines?

1.4 Selection of toilet waste treatment technologies.

According to (Parker *et al*., 2014), the selection of the Sistema Biobolsa and the BIOROCK Technologies were done by Cranfield University project team in consultation with Dr Guy Norman (WSUP), George Mikhael (WSUP), Andy Narracott (WSUP), Prof Tom Stephenson, Prof Simon Judd (Cranfield University), Prof Bruce

Jefferson (Cranfield University), Alexander Eaton (Sistema Biobolsa) and Dr Moritz Gold (EAWAG). The criteria stated below guided the selection of the technologies;

i. Low energy requirement
ii. Ability to treat the solid-liquid fraction of the effluent before discharge into the environment as per the Ghana Environmental Protection Agency (GEPA) guidelines.
iii. Readiness to be shipped to Kumasi, Ghana and installations completed in short time.
iv. Adequate space to fit at the Clean Team Operation site at Dompoase-Kumasi.

These technologies were considered appropriate owing to the fact that a modular combination of aerobic and anaerobic technology would be easily replicable throughout the world (Parker *et al.*, 2015)

1.4.1 Brief description of the technologies

1.4.2 Sistema Biobolsa technology

The Sistema Biobolsa was originally developed in Mexico for generation of biogas from animal manure, and was then replicated to treat human waste and animal waste in Haiti and Nigeria respectively. It consists of geomembrane of high quality, sanitary PVCs, modular multi-stage treatment system that uses flexible tubes as anaerobic digesters (Figure 4). The pre-fabricated components help to optimise packaging, transportation and easy installation. The design of the system allows for interconnection of other system unit, aiming at increasing the system treatment capacity 50m^3 to 240m^3 liquid phase. Following the anaerobic reactor, aerobic gravel filters provide further treatment.

The system installation consisted of three reactors of capacity 8m^3 each (Figure 4) and three aerobic gravel filter tanks (5 m^3 each) (Figure 5). It can have a higher residence time than other anaerobic systems. However, this may increase the hydraulic retention time (HRT) or the solids retention time (SRT). Sistema Biobolsa have been reported to have displaced liquefied petroleum gas (LPG), wood and electricity at a rate of $ 0.40 to 1.2/m^3 (Sistema Biobolsa, 2014)

To the best knowledge of the author, scientific data on the technology was limited at the time the research was being carried out in Ghana. Little information were found on the manufacturer's website, internet, journals and libraries.



Figure 4. Sistema Biobolsa Installed, Kumasi.



Figure 5. Aerobic gravel filter bed installed, Kumasi.

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1.4.3 BIOROCK system

The BIOROCK System was developed in Luxembourg. It is a household scale domestic wastewater treatment plant. The treatment process is purely biological. The system consist of modular two-stage treatment system where raw faecal sludge first enters the primary tanks (Figure 6), to provide pre-separation and initial breakdown of organic solids in an anaerobic environment. The liquid effluent then pass through an effluent (bristle) filter before discharging into an aerobic tank containing synthetic filtration media, (pre-treated with enzymes), that stimulate the growth of aerobic bacteria. It has a much shorter solids retention time, and the first stage which is effectively a conventional septic tank is not designed to work with high solids waste so will require regular desludging (BIOROCK, 2014 and Parker *et al.*, 2015).

Although the technology did not meet all the initial selection criteria as stated in the previous session, it was however, attracted by its ventilation mechanism, operated by natural draft that did not required any external energy sources. A modular combination of aerobic and anaerobic technology is commonly used in Mexico. This study is said to be the first trial of the system for treatment of a non-waterborne sewage (Parker *et al.*, 2015). Information on the BIOROCK system was scanty or limited. After several search from manufacturer's website, internet (google scholar), and articles from libraries, little information was obtained about the system.



Figure 6. BIOROCK installation, Kumasi.

1.5 Organisation of the report

The report has been divided into six major chapters. The first chapter gives the background and the rationale of the research. It also highlights the objectives of the research and the waste treatment technologies.

Chapter 2 deals mainly with the literature reviews on the research topic, treating container toilet waste in Kumasi.

The third chapter deals with the materials and methods used for the experimental study. In the same session, the various laboratory analyses and tests conducted for the study in Kumasi.

The fourth chapter highlights the results obtained from the various experiments.

Chapter 5 deals with the discussion of the results and analysis. In the same session, the results were compared with the Ghana Environmental Protection Agency (GEPA) guidelines for permissible wastewater discharge into the environment.

In chapter 6, the conclusion of the research work has been presented and some recommendations and suggestions for future work are highlighted.

CHAPTER TWO

2.0 Literature review

2.1 Introduction

Globally, about 2.6 billion people do not have access to an improved sanitation system. In sub-Saharan Africa, about 695 million people still do not have improved sanitation facilities (WHO/UNICEF 2015). Approximately 75 % of houses in large cities and nearly 100 % of houses in towns in Sub-Saharan Africa are served by conventional on-site sanitation facilities, which results in the production of faecal sludge which is generated when the on-site systems reach capacity and have to be emptied (Strauss *et al*., 2004).

Cities in West Africa face sanitation challenges due to the huge volumes of faecal sludge, that are disposed of without any form of proper treatment (Vodounhessi, 2006). These facilities produce large quantities of faecal sludge, which are not collected and treated properly due to inadequate faecal sludge management technologies.

Bill and Melinda Gates Foundation, reported that in order to improve faecal sludge collection services, the government must provide monetary incentives to the private sector to support the country in FS management systems (Bill and Melinda Gates Foundation, 2012). Other studies have stated factors such as technical support for FS management facilities (Heinss *et al*., 1998 and Klingel *et al*., 2002), regulatory factors in the countries (Bassan *et al*., 2013) and organisation of the private operators (Bill and Melinda Gates Foundation 2012). All these, included related policies, technologies and manpower are requirements for achieving functional FS management services. Many authors have identified the stakeholders that may have an interest in FS management services at the local government level (Robbins, 2007), at the municipal level (Ludwig and Mohit 2000) and the involvement of private sector (Klingel *et al*., 2002, Frenoux and Tsitsikalis 2014). Due to the high transportation cost and absence of FS treatment facilities, the collection of FS is mostly performed by unlicensed operators. (Bill and Melinda Gates Foundation, 2012). The successful way of FS management practices will depend on positive attitude of people towards FS management practices (Christoph, 2012).

2.2 Overview of faecal sludge management and possible solutions

In urban areas in Africa, the disposal of faeces has become a challenge as large volumes of faecal sludge, are disposed of daily untreated and indiscriminately into drains, streams, rivers and in open urban spaces. Due to a lack or improper faecal sludge management systems in many cities of developing countries, low-income areas are faced in particular with serious health and environmental problems (Steiner *et al*., 2002). This problem has been termed the “faecal sludge crisis”. These crises can be minimised if appropriate faecal sludge management (FSM) is introduced, not only with regards to the handling of the faecal sludge but also pertaining to adequate and safe emptying of sanitation facilities, its transport as well as the safe disposal or reuse (Steiner *et al*., 2002).

In the cities of developing countries, dry on-site sanitation systems dominate over water driven and sewered sanitation. The on-site sanitation system comprises non-sewered household and public toilets, aqua privies and septic tanks. In Sub-Saharan Africa, more than 75 % of houses in large cities and up to 95 % in towns are served by on-site sanitation facilities (Strauss *et al*., 2004). The conventional ways of solving the global sanitation problems is the use of conventional sanitary systems such as sewage system based on flush toilets, and pit latrines used in poor areas in developing countries.

According to Winblad and Simpson-Hébert (2004), water based systems depend on reliable water supply in order to function properly. Water based systems are inadequate and are based on hiding human excreta in deep pits (‘drop and store’) or on flushing them away and diluting them in rivers, lakes and the sea. The result is the damaging of the environment. Over 95% of sewage in developing countries is discharged untreated, polluting rivers, lakes and coastal areas (UNDP, 2005). The other disadvantage of these sewage systems is the exploitation (misuse) of the water resources. It is estimated that 15,000 litres of potable water is use to flush around 400-500 litres of urine and 50 litres of faeces per a person. The wastewater from bathrooms, kitchen and laundry may add up to about 15,000 – 30,000 litres for each person (Winblad and Simpson-Hébert, 2004).

The faecal sludge management processes includes all the important steps starting from planning to ensure closing the faecal sludge loop. The process demonstrated in Figure 7 is based on the definition by (Klundert and Anschütz, 2001).

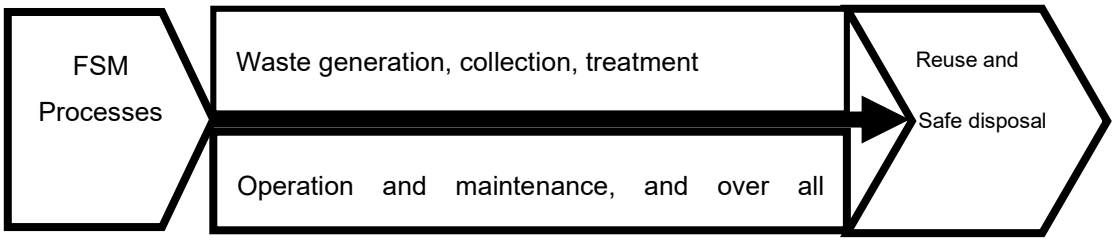


Figure 7. Processes of faecal sludge management based on (Klundert and Anschütz, 2001).

The generation and separation processes consist of the activities related to the toilet facilities, promotions or provisions to the community for the faecal sludge generation and its possible separation from the urine. Collection and transport processes consist of the activities related to the excreta collection from houses and its transport to the FS treatment plant. Treatment and transfer processes consist of the activities related the FS treatment and the final transfer to the landfill site or reuse. The disposal and reuse processes consist of the activities related to the FS reuse or the safe disposal. The operation and management processes consist of the activities necessary for the overall planning and management of FS until up to the production of a safe by-product (Klundert and Anschütz, 2001).

2.3 Faecal sludge characteristics

Faecal sludge characteristics are sludge of variable consistency accumulating in septic tanks, aqua privies, family pit or bucket latrines and unsewered public toilets. The content consists of varying concentrations of faecal solids and non-faecal matter. Additionally, the sludge exhibits varying degrees of biochemical stability attained through anaerobic digestion mainly, depending on the ambient temperature, retention period, and inhibition (enrichment) due to the presence of non-faecal substances (Heinss *et al*., 1998).

2.4 Faecal sludge treatment

2.4.1 Principles of faecal sludge treatment

Faecal sludge has a unique characteristic that makes it difficult to handle. Faecal sludge cannot be discharged into surface waters or be treated like wastewater because its pollutant concentrations are too high. It cannot be land filled or treated like solid waste because its moisture content is high. It cannot be directly used for crop fertilization because its pathogen levels is very high (Klundert and Anschütz, 2001). The first stage of faecal sludge treatment mostly consists of the stabilization of the sludge and the separation of the solid phase from the liquid phase. In this way, the liquid part can be treated exclusively with wastewater treatment technology. The solid part can further be treated to improve its characteristics for either land filling or agricultural purposes. Hence, sludge treatment involves different treatment steps where available techniques can be combined in various ways depending on the existing constraints and the treatment objectives (Klingel *et al*., 2002).

2.4.2 Faecal sludge treatment options

When considering faecal sludge treatment, a clear distinction should be made between the options of with or without solids-liquid separation. Another way of classifying FS treatment option is to distinguish between separate treatment of faecal sludge and co-treatment. The co-treatment option comprises of treating septage or toilet sludge together with municipal wastewater, treatment plant sludge from wastewater, household or municipal solid waste, and with organic residues such as sawdust or woodchips (Heinss *et al*., 1998).

2.4.3 Selecting appropriate treatment option

The methods for treating human waste in developing countries and in newly industrialised countries should be of relatively low-cost. Thus, the capital and operating costs should be as low as possible. The selected systems should be compatible with the expertise available in the locality at various professional levels, with the institutional as well as the entrepreneurial set-up responsible for scheme implementation and other services. The chosen option would comprise of low or moderate level of mechanisations and associated minimal external energy sources input (Heinss *et al*., 1998). The drawback of treatment options of low capital and

operating costs is their large land requirements. This in turn, creates a huge challenge to the fast growing urban areas where land becomes increasingly scarce, hence, relatively costly.

Therefore, when selecting appropriate options for the treatment of faecal sludge (or wastewater), a thoughtful choice must be made with respect to factors such as the economic and technical feasibility versus land requirement. A feasible strategy may consist of establishing an optimum number of decentralised and small to medium-sized treatment plants, serving a selected number of urban districts. Haulage distance for vacuum tankers will thereby also be reduced (Heinss *et al*., 1998).

2.4.4 Benefits for faecal sludge reuse in agriculture

According to (Klingel *et al*., 2002), reuse of sludge should be a preferred option over disposal to landfill for the following reasons: (1) commercialisation of treated sludge can generate revenues; (2) no/little use of landfill space; (3) faecal sludge, in comparison with sewage sludge has little chemical contamination and therefore can be considered as a valuable resource that can be valorized. In a long-term point of view, the recycling of waste is always the preferable option in accordance with the ECOSAN principle of “closing the loop” (Vodounhessi, 2006). One should only consider disposing the treated sludge if there is no market demand for it as a soil conditioner or if the additional expenses for providing the product suitable for agricultural use cannot be justified. It is known that the disposal of treated sludge is not problematic, as long as the sludge is sufficiently dehydrated and a sanitary landfill is available (Cofie, 2003).

2.4.5 Nutrients in faecal sludge

Faecal sludge is rich in organic matter and inorganic plant nutrients such as nitrogen, phosphorus and potassium. Averagely, humans excrete in the order of 30 g of carbon (90 g of organic matter), 10-12 g of nitrogen, 2 g of phosphorus and 3 g of potassium. The faeces contain the organic matter while the nitrogen (70-80%) and potassium are contained in the urine. It has been reported that the phosphorus is equally distributed between urine and faeces (Cofie, 2003). The yearly excretion of 500 litres of urine and 50 litres of faeces can provide an equivalent of 7.5 kg of NPK fertiliser that would be sufficient to grow 230 kg of cereal crop (Winblad and Simpson-Hébert, 2004).

2.4.6 Nutrient as soil conditioner

Treated faecal sludge is not only a fertiliser, but also organic matter content that serves as a soil conditioner and of greater importance. This is an asset that is not shared by chemical fertilisers (Cofie, 2003). Hence, dumping human waste will result to depleting and destroying the limited natural resource of the environment.

2.5 Characteristics of septage

As noted by Metcalf & Eddy (1991), there are varying quantities and constituents of septage from cities that do not properly regulate the collections and disposal of the septage. Ghana is one of the countries in developing countries that suffer from such shortfalls. This is not happening in developed countries where the collection and disposal of septage is regulated.

A typical characterisation of septage found in industrial countries and developing countries' cities is provided in Table 3.

Table 3 depicts a wide range of variations of the constituents.

Table 3. Typical characteristics of septage

Constituent	Concentration in mg/l			
	Strauss and Heinss (1995) Accra, Ghana (Developing countries)		Metcalf & Eddy, Inc (1991) (Industrial countries)	
	Range	Typical	Range	Typical
TS	3000-114000	14000	5000-100000	40000
TSS	700-34000	7000	4000-100000	15000
VSS	490-23800	4900	1200-14000	7000
BOD_5	360-1300	630	2000-30000	6000
COD	820-52000	8500	5000-80000	30000
TKN as N	-	-	100-1600	700
NH3 as N	-	-	50-800	400
TP as P	-	-	100-1000	250
Heavy metals (i.e Al, Zn, Fe)	-	-	-	300
Helminth eggs-(No/l)	200-13000	4300	-	-

Typical values of developing countries are much lower than the typical values reported by Metcalf & Eddy (1991), for the industrialised countries (located in the template climates) as indicated in Table 3. For instance, the BOD_5 ranges 2,000-30,000 reported by Metcalf & Eddy (1991), with an average value of 6,000mg/l whilst that reported by Strauss & Heinss ranges from 360-1,300mg/l with the average value of 630mg/l. The lower values for Accra could be the tendency of the vacuum truck operators to pump only the top clarified liquid portions (Strauss and Heinss, 1995).

Table 4 shows the important characteristics and classification of faecal sludge

Table 4. Important characteristics and classification of faecal sludge

Item Type	Low-Strength	High-Strength	Sewage (for purpose of comparison)
Examples	Septage	Public Toilet and/or Bucket Latrine Sludge	Tropical Sewage
Characterisations	Faecal Sludge of low concentration , usually stored for several years, more stable	High concentrated, mostly fresh faecal sludge, stored for days or weeks only	
COD-mg/l	<10000	20000-50000	500-2500
COD:BOD	5:1-10:1	2:1-5:1	2:1
NH4-N-mg/l	<1000	2000-5000	30-70
TS mg/l	<3%	≥3.5	<1%
TSS-mg/l	≥7000	≥30000	200-700
Helminth eggs - No/l	≤4000	20000-60000	300-2000

Source: Strauss *et al*., 1997

The classification of faecal sludge is based on the concentrations or organic, ammonium, solids and the degree of putrefaction. Table 4 shows higher strength of the FS because of the fresh and high concentration of organic matter, ammonium and solid. These come from the on-site sanitation facilities consisting of bucket latrine, Aqua Privies, Pour flush toilets, and KVIP's. The low strength faecal sludge is relatively weak, old and has undergone considerable digestion. Septage normally fall into this type of category (Doku, 2002)

2.6 Environmental protection agency (EPA) guidelines

Environmental Protection Agency (EPA) has been mandated by the Act 1994, to formulate environmental policy and make recommendations for the protection of the environment in Ghana. It is responsible for ensuring compliance with Environmental Impact Assessment (EIA) procedures in the planning and implementation of the development or existing projects. It is also responsible for the issuance of environmental permits and pollution abatement notice for controlling waste discharge, emissions and deposits of pollutants.

Table 5 shows a summary of the Ghana Environmental Protection Agency guidelines (EPA report, 2016).

Table 5. EPA effluent guidelines for discharges into natural water bodies.

No.	Parameters	Units	Values*
1	Alkalinity	mg/L	150
2	Ammonia	mg/L	1
3	BOD	mg/L	50
4	Chloride	mg/L	250
5	COD	mg/L	250
6	Colour	TCU	200
7	Conductivity	(uS/cm)	1500
8	*E coli*	MPN/100ml	10
9	Fluoride	mg/L	10
10	Nitrate	mg/L	50
11	Oil & Grease	mg/L	5
12	pH	n/a	6-9
13	Phenol	mg/L	2
14	Soluble Arsenic	mg/L	0.1
15	Sulphide	mg/L	1.5
16	TDS	mg/L	1000
17	Total Coliforms	MPN/100ml	400
18	Total Pesticides	mg/L	0.5
19	Total phosphorus	mg/L	2
20	TSS	mg/L	50
21	Turbidity	NTU	75
22	Lead	mg/L	0.11
23	Mercury	mg/L	0.0052
24	Total Arsenic	mg/L	13

* Source: Ghana EPA, 2015, wastewater effluent quality guidelines.

CHAPTER THREE

3.0 Materials and Methods

3.1. Study area

The research work was carried out at Dompoase, Kumasi under the Kumasi Metropolitan Assembly (KMA). Figure 8 shows the map of the site location.

Kumasi Metropolitan covers a total area of about 254 km^2 with population density of 5419 persons per sq.km. The total population is 2,035,064 (KMA Census, 2010) with growth rate of 5.47% per annum. Major rivers and streams are the Subin, Oda, Wiwi, Sisai, Owabi, Aboabo, Nsuben found across the city.

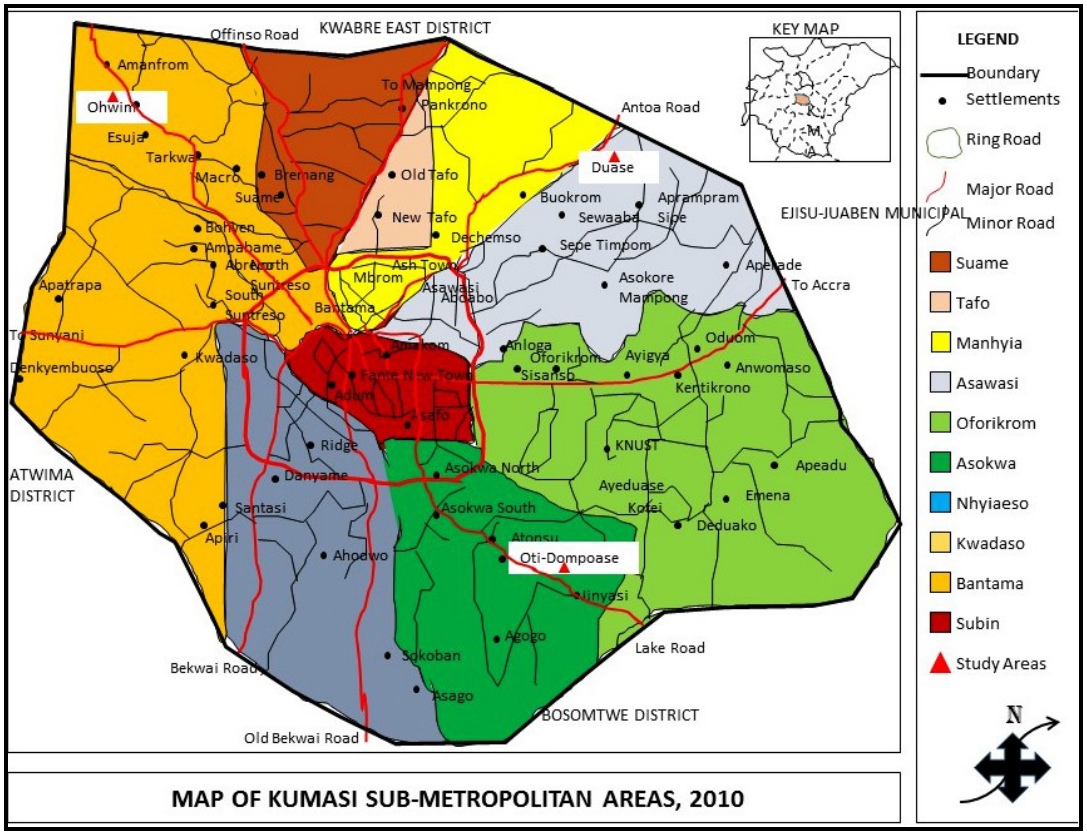


Figure 8. Map of KMA showing the study dumpsite areas (KMA, 2010)

3.2 Technology Testing

3.2.1 Technology installation

The installation of both Sistema Biobolsa and BIOROCK technologies were completed by April 2015.

3.2.1.1 Sistema Biobolsa

Sistema Biobolsa is an anaerobic digester, which consist of a tubular plastic bag, a PVC pipe as inlet and out. A pipeline connects biogas from the digester to a reservoir or a stove. The tubular polyethylene is buried in a trench (Figure 9). The plastic bag sat in shallow trenches, 0.50 m by 0.50 m, which was smoothed after excavation to ensure no sharp stones would rub against the bags. Connected to the digesters are aerobic gravel filters, which sat in an excavated pit, 1.1 m by 3.0 m surface area and depth of 1.5 m (Figure 9). The trenches are lined with geotextile material provided, filled with gravel (which was sourced locally), and backfilled with soil to cover. All the connections were made with 4" sanitary PVC pipes. The system received between 0.1 to 0.4 m^3 of toilet waste in a day, fed from the inflow holding tank. The three digester of Sistema Biobolsa system were installed with the technical support from the Alexander Eaton (inventor) at the site. The accompanied three aerobic gravel beds/filters were installed later with recommendations from the company, as illustrated in (Figure 9 and 10).

Toilet waste flows through the digesters from the inlet to the outlet. There is neither mechanical mixing to avoid material sedimentation inside the digester nor heating to increase the wastewater temperature. The bag is not protected from direct sunlight by roofing or green house. Biogas is accumulated in the upper part of the digester bag and gas is collected by means of gas pipelines, for heating, cooking and lighting. In this study the gas was not connect to reservoir or balloon but was flared periodically.

The size of the digester bag depends on factors such as wastewater, manure and land availability. In poor rural communities of Latin America, where economy depends largely of subsistence farming or agriculture, digester volume ranged from 6-10m^3 (Botero *et al.,* 1987, Marti-Herrero, 2007 and Ferrer *et al.,* 2011). Bigger size digesters ≥70m^3 have been implemented in small scale farms and university campuses in tropical regions (Lansing *et al.,* 2008). In the past decades, efforts have been made to adopt the tubular digesters to the harsh climatic conditions of the Andean Plateau (Marti-Herrero, 2007 and Ferrer *et al.,* 2011). In regions where temperature falls below 5^0C, the digesters are covered with a greenhouse in order to increase temperature and reduced overnight heat loses (Garfi et al., 2001).



Figure 9. Sistema Biobolsa and aerobic gravel beds

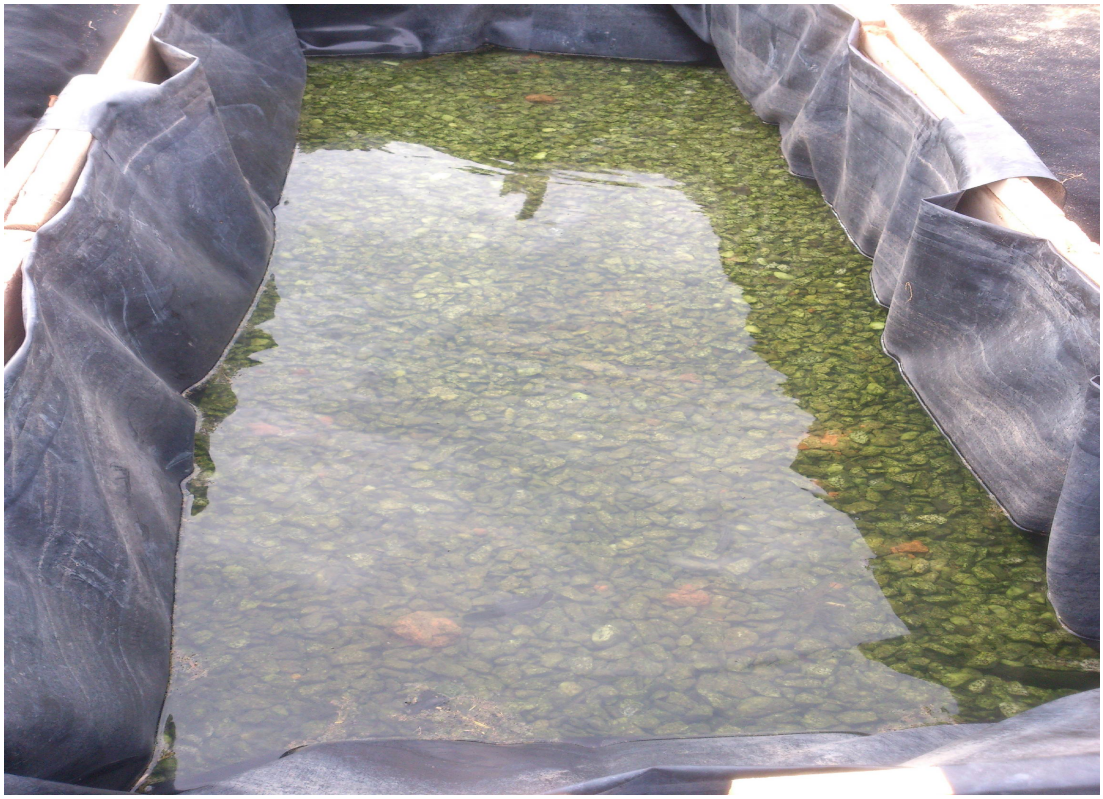


Figure 10. Horizontal flow-Aerobic gravel filter bed (AGFB)

Figure 11 shows the schematic diagram of the flow of toilet waste from the Clean Team holding tank into the Sistema Biobolsa digesters, connected in series. The red

spot shows the sampling points of the study, whilst the arrow indicates the direction of flow of waste in the tubular bags.

Approximately 250-10,000 litres of toilet waste stored temporary in the holding tank (10000 litres), were pumped into the digesters and flow out into the aerobic gravel filters (5000 litres each) for further treatment (Figure 10). “Anaerobic digestion began in the digesters, seeded with manure (200 litres) to activate the anaerobic bacteria

The secondary treatment of Sistema Biobolsa, consist of open plastic tank filled with gravel as filter media. Natural bacteria attach to the gravels and digest the solid materials to improve the quality of the effluent. The functioning of the treatment system (aerobic gravel filter bed) (Figure 10) is comparable to stabilization pond which use natural factors such as sunlight, biodegradation, sedimentation, temperature and absorption to treat the effluent (Mara, 2004). Pathogens are removed or inactivated by various mechanisms, which includes temperature, pH values greater than 9.4 (induced by rapid algal photosynthesis) and a combination of light intensity (greater than 450nm wavelength) and high dissolved oxygen concentration) (Curtis et al., 1992 and Mara, 2004).

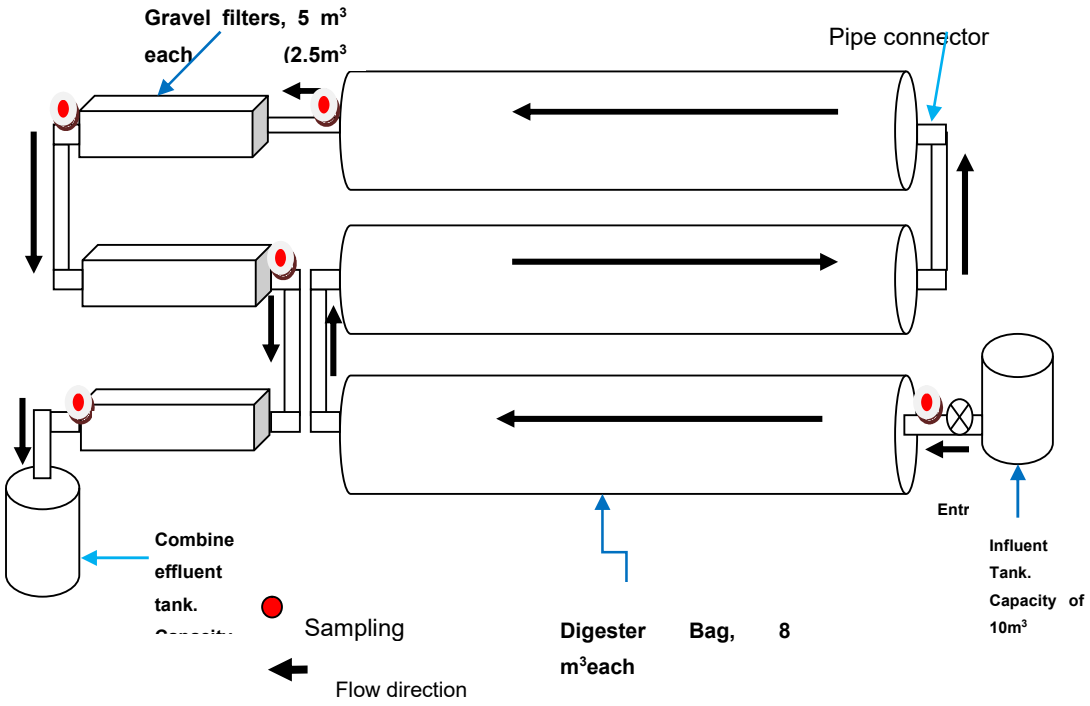


Figure 11. Schematic of the Sistema Biobolsa installation

3.1.1.2 Treatment processes

Sistema Biobolsa operates typically like the plug flow anaerobic digester. Anaerobic microorganisms convert organic waste into stable by-product (carbon dioxide, methane and water) in the absence of oxygen. The degradation process involves two separate but interrelated phase, which is acid formation and methane production. During the acid phase, microbes convert the complex organic compounds such as fats, carbohydrates and protein into simple compounds. These compounds formed are mainly short chain volatile organic acids (VOA), which include acetic, propionic and lactic acids. The anaerobic bacterial involved in the acid phase are term as acid formers and may be classified as non-methanogenic microorganisms. Little chemical oxygen demand (COD) or bacterial oxygen demand (BOD) reduction occur during this phase. This is due to the fact that the short chain fatty acids and alcohols are used by many microorganism and thereby exerting oxygen demand (EPA, 2002).

The methane production phase involves an intermediate step. Firstly, the bacteria converts the short chain organic acids to acetate, hydrogen gas (H_2), and carbon dioxide (CO_2). This intermediate process is referred to as acetogenesis. Subsequently, the acid formers converts the acetate, H_2 and CO_2 into methane gas (CH_4) and this process is refer to as methanogenesis. Waste stabilisation occurred at this stage and is indicated by the formation of methane gas. The breakdown of acetic acid into methane and carbon dioxide is as follows (i) $CH_3COOH = CH_4 + CO_2$ and (ii) $CO_2 + 4H_2 = CH_4 + CO_2$

3.2.1.3 System in equilibrium

When the system is working properly, the two phase of the degradation occur simultaneously in dynamic equilibrium. Thus, the volatile organic acids are converted to methane at the same rate, which are formed from the more complex organic molecules. The growth rate and metabolism of the methanogenic bacteria can be adversely affected by variation in pH of the substrate concentration and temperature. However, the performance of the acid formers are more tolerant over a wide range of conditions. When the process is stressed by shock loads or temperature wide variations, methane bacteria activities occur more slowly than the acid formers. As a results in imbalance occur and intermediate volatile organic acids accumulate and

the pH drops. Methanogens are further inhibited and the process eventually fails without corrective action. For this reason, the methane formation phase is the rate limiting stage and should not be inhibited. For the design of anaerobic digesters to work effectively, it should be based on the limiting characteristics of these microorganisms (EPA, 2002)

Table 6 shows the summary of the design parameters of the Sistema Biobolsa. The key parameters that were considered in this study included the waste type, hydraulic retention time, organic solid reduction, ground liner for digesters, gas lines and waste inlet and outlet.

Table 6. Design parameters of the Sistema Biobolsa.

Parameter	Units	Range Values
Waste type	-	Human faeces, urine, and toilet paper
Average Hydraulic Retention Time	Days	20-25 days
Organic Load Reduction	%	80% Volatile Solids Reduction
Ground Liner for reactors	-	Geotextile Ground Cover (Recycled PET)
Waste Inlet and Outlets	inches	4 inch Sanitary PVC
Biogas Outlet	inches	2 inch Hydraulic PVC w/ 1 inch adaptor
Gas Lines	m	Polyethylene Tubing (or local equivalent)
Biogas Burners	inches	1 and 2 inch hydraulic PVC, treated
Biogas Filters and Gas management	inches	1 and 2 inch hydraulic PVC, treated

Sources: Sistema Biobolsa, 2014

3.2.1.4 Specific assumption for Sistema Biobolsa wastewater treatment

In this research, it was observed that the design of the Sistema Biobolsa sits close to plug flow (PF) as practically as possible. This is because toilet waste enters and circulates through the anaerobic digesters to maintain the reactant temperature. The digesters were in continuous gradient (in contrast to the stepped gradient), which is a typically associated of continuous stirred tank reactors (CSTR) (Hussain, 2015). Plug flow reactors are useful in industrial tubular reactors of gasoline production and oil cracking synthesis of ammonia from its elements (oxidation of sulphur dioxide to sulphur trioxide) (Hussain, 2015). The specific assumption made on the mixing of toilet waste in the digesters were that, no mixing in axial direction, but complete

mixing in radial direction with a uniform velocity profile across the radius (Metcalf and Eddy, 2003, Stenstrom, 2003, and Heinzle, 2009).

3.2.1.5 BIOROCK installation

The two primary tanks of BIOROCK were placed inside a single excavated trench, which needed to be T-shaped, connected in parallel, and the final filter tank afterwards. The primary tank excavation depth was 3.5 m x 4.5 m x 2.0 m deep, with the filter excavation 3.5 m x 2.5 m x 2.0 m (Figure 6). The excavations were backfilled with stabilised sand which was obtained locally. The BIOROCK system used 110 mm pipe connections, and the system received a daily toilet waste ranging from 0.02 to 0.2m^3. There was no site visits by BIOROCK representatives during technology installation. The BIOROCK system was installed with the instructions from the company's installation manual as demonstrated (Figures 12 and 13). Two parallel primary tanks were installed to increase system capacity and avoid overloading the aerobic filter.

Approximately 20-100 litres of toilet waste stored temporary in the influent tank, were discharge manually into the digesters. The flow of the wastewater in the tanks were assumed to be steady and laminar in the direction as indicated by the arrows (in parallel connection) and finally discharged into the filtration tank.



Figure 12. BIOROCK System buried underground (top cover exposed)

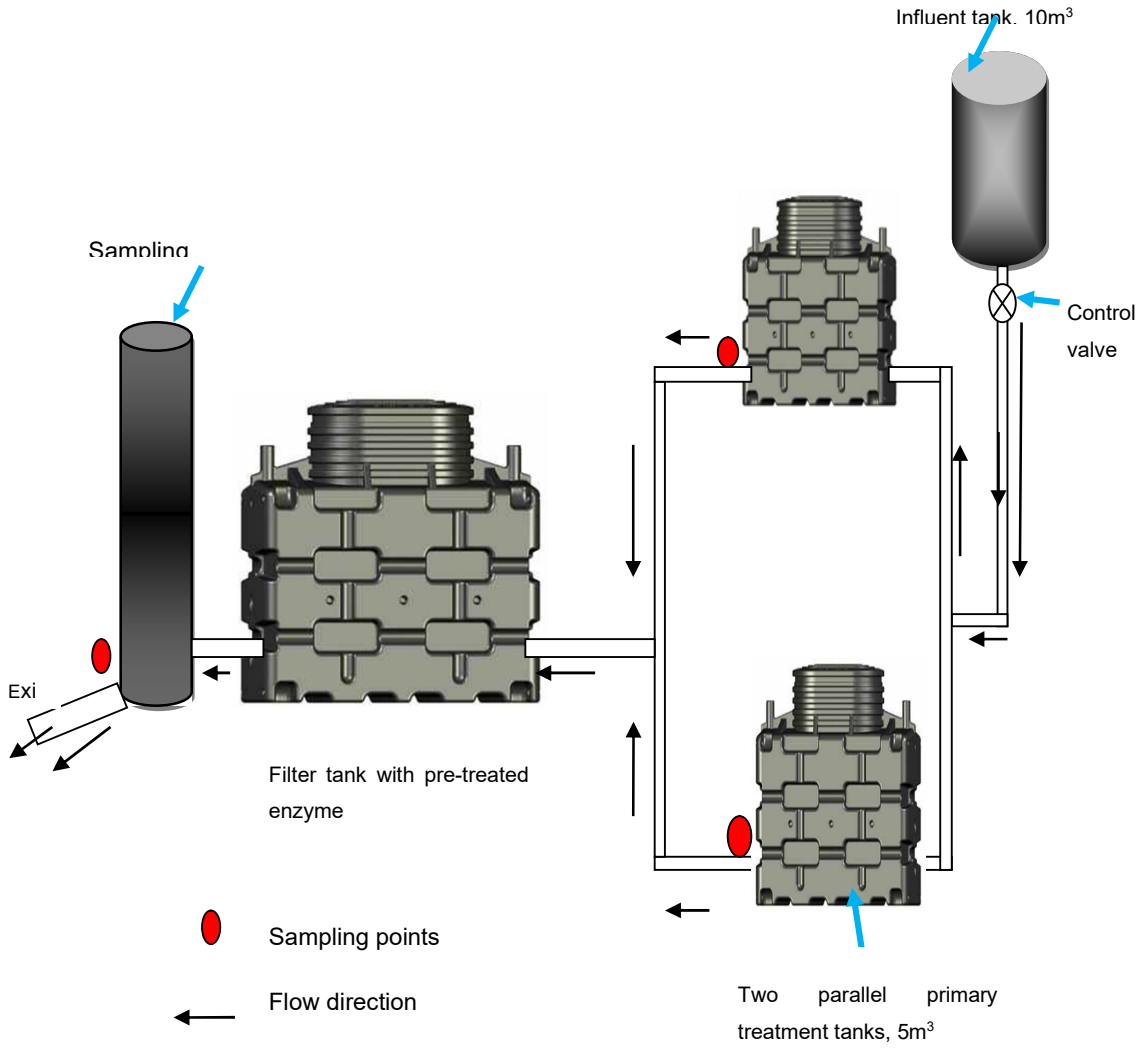


Figure 13 Schematic of the BIOROCK System installation

3.2.1.6 BIOROCK treatment process.

BIOROCK primary tank is an anaerobic deep reservoir with sufficient volume (typical 5000 litres) to allow sedimentation of settlable solids and to digest the retained sludge (Figure 14). The tank operates anaerobically to reduce a large proportion of the soluble organic substrate. Raw waste (toilet waste) enters near the bottom of the tank and mixed with the active microbes in the sludge blanket. The mixing sometimes provide aeration at the surface to control odour. Anaerobic conditions occur at the bottom except the shallow surface layer, where excess undigested grease and scum are concentrated. If aeration is not provided the scum formation

retains some heat and odour. The discharge is located at the opposite side of the influent. The effluent is not suitable for discharge into receiving water bodies until it goes through the purification process in the secondary tank. The anaerobic tanks are followed by aerobic tanks (filtration tank) to provide further treatment and effluent may be discharged into ponds or wetlands.

The secondary treatment of BIOROCK consist of a biofilter tank (5000 litres), which contain synthetic filter media. Primary effluent enters the biofilter, in contact with air to treat the effluent to improve the quality. Bacteria grow on the filter media and digester the organic particles as it trickles down (BIOROCK, 2014).

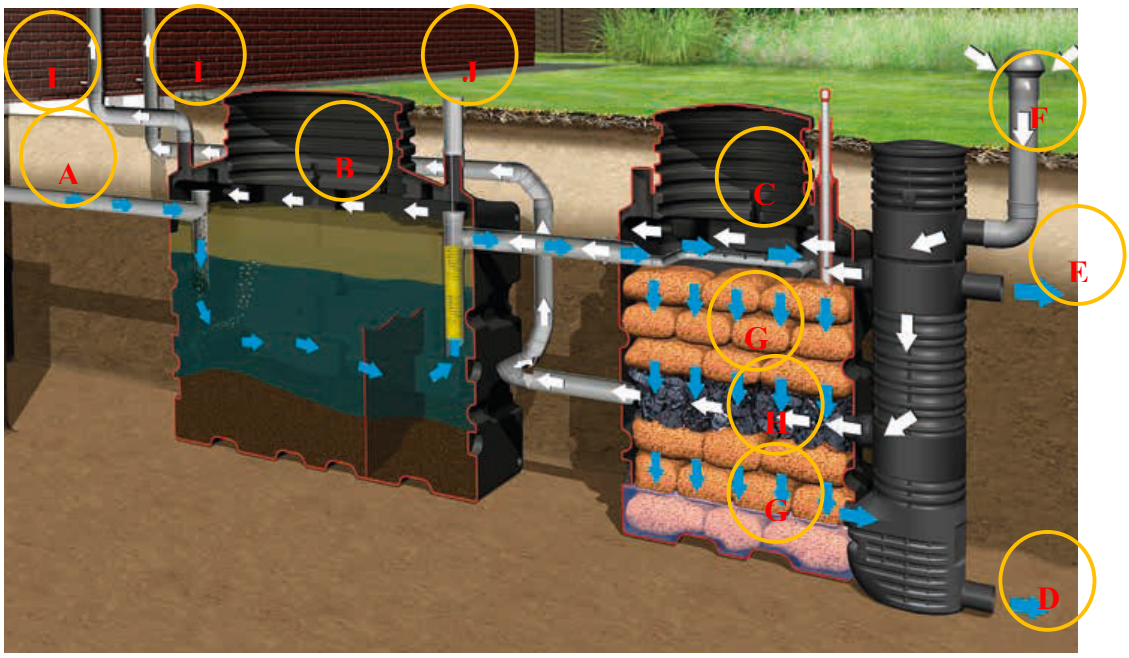


Figure 14 BIOROCK Treatment process. Sources: BIOROCK, 2014

A-Raw toilet waste
B-Primary tank
C-bioreactor
D-Gravity discharge and E-Pump discharge
G-BIOROCK Media (Filter media)
H-Aeration
I-Air inlet
J-Effluent filter

No electricity or external power is required to provide air but rather the BIOROCK biofilter extract air from the atmosphere through a “Chimney drift” (Figure 14). The filtered effluent flows out to join a pipe connected to the effluent holding tank (10,000 litres).

3.2.1.7 Organic loading rate (OLR) of BIOROCK

Typical loading rate of BIOROCK range between 0.3 and 0.36 kg BOD_5/day, with varying water temperature. The recommended inflow BOD is 60 gr.BOD/P.E day^{-1} (BIOROCK, 2014)

3.2.1.8 Detention time

Typical hydraulic loading rate is 0.9 m3/day with detention time range from 1-30 days, depending on the temperature of the wastewater.

3.2.1.9 BIOROCK dimensions

Similar to anaerobic treatment tanks, the BIOROCK require less surface area and ponds since the rate of oxygen transfer is not a major factor. Therefore, the design is minimised to surface area –to- volume ratio. Typical length and width require ranged from 1150 -3550 mm and 1150 mm respectively. Typical height ranged from 2100 to 2175. Primary tank should be practically deep, as greater depth provides enhance heat retention. A typical volume is 1500 litres/p.e (1.5m^3/p.e).

3.2.2.0 Advantages and disadvantage of BIOROCK System

Advantages

Require a relatively large area of land.

- Able to handle high influent organic loading.
- Methane production is possible (bubbles observed during treatment), which can be used to heat building, power engines and generate electricity.
- Do not require external sources of energy to run the system
- Require relatively small space, because it is buried and only the topmost exposed.
- Less expensive to construct and operate. Primary tanks can be connected in parallel

Disadvantage

- Produce relative large biomass per unit of organic material processed. This will require frequent dislodging or increase the cost of handling of accumulated sludge.

Table 7. Design considerations of the BIOROCK System.

Parameter	Units	Range values
Tank capacity	m^3	6.0
Feeding per day	litres/day	20-200
Settlement tank	m^3	5-11
Settlement tank inlet invert	m	0.5
Settlement tank inlet invert	m	0.6
BIOROCK Biofilter	m^3	3-5
BIOROCK inlet invert	m	0.6
BIOROCK outlet invert	m	1.7
Desludging	years	0.5- 4.0

Sources: BIOROCK, 2014.

3.2.2.1 Specific observation for BIOROCK wastewater treatment.

During the study it was observed that the BIOROCK operations falls right in the middle of the plug flow (PF) and continuous stirred tank reactor (CSTR) models. The dimensions do not make it plug flow, but there is no 'active' mixing (vigorous stirring or internal agitation). So, it is a little plug flow, in that the toilet waste enters one end and leaves the other, and a little CSTR, as the waste can move more freely within the tank, and also any biogas generated bubbled through the waste and created a small amount of mixing. CSTR may be connected in series or parallel (Hussain, 2015). In this study the arrangement were done in parallel to maximised space.

The key assumption made on mixing of toilet waste in the BIOROCK tanks was that the flow was steady and laminar, gravity acted vertically downwards and the tanks were not fixed upright underground and tilted (Metcalf and Eddy, 2003, Stenstrom, 2003, and Heinzle, 2009).

3.3 Clean Team operations

Clean Team (CT) Ghana Ltd is a subsidiary sanitation business company managed by Water and Sanitation for the Urban Poor (WSUP) in partnership with the Unilever. Clean Team provides subscription portable toilet to household customers at a fee. Each toilet system contained a plastic bucket that is filled with toilet waste until the time it is collected by CT workers, who replaces the filled bucket with an empty one.

The toilet waste is transported to Clean Team's operations site at Dompoase for treatment. The toilet buckets are cleaned and the liquid wastes are deposited into an underground holding tanks. The operational process is shown in Figure 3.

3.3.1 Clean Team container toilet unit

The Clean Team Toilet, shown in (Figure 2h), is a portable, pre-fabricated plastic toilet that features a removable top and urine diversion. The removal of the top of the toilet discloses the bucket hidden inside. Clean Team toilet buckets were initially white, but they have been changed to black in order to better mask the sight of waste (Knutson *et al*., 2013).

Each bucket has a sealable lid that is screwed on before the waste is transported to final disposal site. Currently, the toilet waste containers are manufactured in China. However, CT has the molds and is searching for a potential manufacturer in Ghana. The toilets cost approximately GHS 200 (US$91) each, plus import duties and shipping costs. The importation of toilets is handled by Unilever, a co-sponsor of the program (Knutson *et al*., 2013). Each bucket receive a biocide, called One Shot Cherry (Chemical 4) that disinfects deposited waste, thus, controlling the risk of pathogen transmission between users.

Each bucket is filled with 75mL of One Shot Cherry and 5 L of water (Knutson *et al*., 2013). The main ingredient of One Shot Cherry is pentane-1, 5, also known as glutaraldehyde, which is an effective sterilizing agent. However, glutaraldehyde has a fairly strong odour, and inhalation of glutaraldehyde vapours can induce throat and lung irritation, asthma episodes, breathing difficulty, sneezing, and wheezing. Since glutaraldehyde is a high concentrations of the biocide, 5-10%, CT denies services to clients who lack a well-ventilated room in where the toilet may be positioned (Knutson *et al*., 2013).

A secondary biocide, Bronopol, or 2-Brono-2-Nitropropane-1, 3-Diol, is also in the CT biocide, but this substance is less concentrated, less than 5%. Its MSDS also contains warnings that it may be irritating if inhaled (Spectrum, 2008).

In addition, problems with reuse of waste for fertilizer and electricity production are complex because One Shot Cherry is of such a large fraction of the final sludge's

volume. At the time of publication, alternative biocide options were being researched by CT in collaboration with Cranfield University (Knutson *et al*., 2013).

3.3.2 Collection process

Depending upon family size and customer's ability to pay, toilet buckets are collected by Clean Team workers 2-3 times per week. Toilet waste are transported with tuk-tuks or small three-wheeled motorized carts, from house to house, collecting used buckets and leaving clean ones in each client's home. As they collect the buckets, they bring them to curbside "transfer stations," where they accumulate before being taken to the final processing point at Dompoase (Knutson *et al*., 2013).

At the final processing point, used buckets are emptied into a large holding tank and then are washed with water and disinfectant by a worker dressed in protective clothing. In order to ensure uninterrupted water supply, CT had drilled a mechanised borehole, and the water is stored in two overhead Poly-tanks. The central collection point uses about 8 m^3 of water per week in order to serve 500 toilets.

Each bucket is refilled with 5 litre solution of biocide and water before being returned to clients. Although CT started operations in Kumasi, Ghana in 2010, as a business, it has not yet generated a profit and therefore relies on funding from the Stone Family Foundation and the UK Department for International Development (Knutson *et al*., 2013).

Owing to WSUP's ideology, the focus of CT has been on the urban poor. However, their clients are mainly traders and businessmen/women who are not monetarily poor but are classified as poor in terms of lack of access to improved toilet facility (Knutson *et al*., 2013). Currently CT operates in areas such as Manhyia, Alabar, Akwatialine, Sabon Zongo, Asywasi, Aboaso, Dichemso Bramposo and parts of Ahinsan (newly added area). The project began in Ashtown, where, due to a history of use of unimproved bucket toilets, many of the houses had existing specified toilet rooms. After finding success there, the business expanded to other areas (Knutson *et al*., 2013).

3.4 Sistema Biobolsa feeding regimes

On the 29 April, 2015, the three digesters (8m^3 each) of Sistema Biobolsa of were initially filled with 230 litres clean water and 200L cow manure manually to activate

the enabling conditions for the microbes. Afterwards, cow manure and Clean Team toilet waste were added each day (except for weekends) as per the designed schedule shown in Table 8.

The schedule was designed to gradually commission the technology and not overload with high concentration waste. On 25th September, 2015 there was a pipe burst (influent tank outflow pipe) on site, which flooded the aerobic gravel filter beds of the Sistema Biobolsa with untreated waste. These were subsequently flushed with clean water.

Table 8 shows the daily feeding scheduled for Sistema Biobolsa Technology

Table 8. Loading schedule for Sistema Biobolsa digester (except for weekends).

Date	Type of waste added	Quantity of Waste (Litres)/day
1 May 2015	cow manure	600
4-15 May 2015	cow manure	20
18 May 2015	Clean Team toilet waste	2000*
19 May-30 June 2015	Clean Team toilet waste	200
1 July-31 December 2015	Clean Team toilet waste	400

*The amount of waste added on 18 May was erroneous. It was supposed to be 200 litres/day.

3.5 BIOROCK feeding regimes

On the 29th April 2015, the primary tanks received initial fed of toilet waste (100 litres) and water (2000 litres). The feeding of the system continued each day (except weekends) as summarised in Table 8. This schedule was designed to gradually commission the technology and not overload it with high concentration of waste. On 25th September, 2015 the BIOROCK primary tanks were partially desludged as they were full of sludge.

Table 9 shows a summary of the daily feeding scheduled for BIOROCK System.

Table 9. Loading schedule for each primary tank of BIOROCK

Date	Type of waste	Quantity of Waste fed into the system (Litres)/day
29 April	Clean Team waste, 100L clean water	2000
4-31 May 2015	Clean Team waste	100
1 June – 25 September	Clean Team waste	200
25 September - 6 October 2015	n/a *	0L, ⅔ volume emptied
7 October	Clean Team waste	3000
12 October -31 October 2015	Clean Team waste	20
2 November -31 December 2015	Clean Team waste	50

*The content of the BIORCOK primary tanks were desludged.

The loading waste varied between 20 – 100 litres per day. This was done to avoid possible overloading of the filtration tank and/or shortening the solid retention period. On the 25th September 2015, two thirds volume of the primary tanks were emptied to reduce the sludge accumulated over the period. According to the manufacturer, desludging is recommended in every 3-6 months depending on the loading rates.

The highest loading rate (200 litres/day) occurred in the month of June to September 2015, whilst the lowest loading rate (20 litres/day) occurred around October, 2015. The mean daily loading rate was approximately 57 litres. This mean value does not included the “started up” loading rates (when the tanks were empty).

3.6 Monitoring waste treatment processes

3.6.1 Ammonium Nitrogen (NH_4-N)

The ammonium nitrogen (NH_4-N), occurs partly in the form of ammonium ions (NH_4^+) and ammonia (NH_3) (Spectroquant, 2013). The method is analogous to EPA 350.1,

APHA 4500-NH_3 F, ISO 7150-1, and DIN 38406-5 (Spectroquant, 2013). The samples were filtered with 0.45µm the Minisart Disposable Filter. A 0.1ml of the filtered sample was pipetted into the cell test. A reagent NH4-1 (1 dose, 0.5ml) was added after which the cell test was closed tightly and vigorously shaken until the reagent was completely dissolved. A reaction time of 15 minutes was allowed and then samples were transferred into a 10 mm cuvette and at a wavelength of 630nm in a manually calibrated spectrophotometer.

3.6.2 Ammonia calibration

The ThermoScientific™ GENESYS 20 spectrophotometer was calibrated manually. A stock solution was used. It was then diluted in the range of the cell tests using distilled water and a method of serial dilution. These solutions were then added to the cell tests as samples according to the manufacturer's directives and absorbance values read. Distilled water in a cuvette was used as a blank between each sample readings. Figure 15 shows the calibration curve. The cell tests did not give accurate values outside of the intended range (50-1500 mg/L). Therefore, the calibration curve could not be extrapolated for those values to be considered.

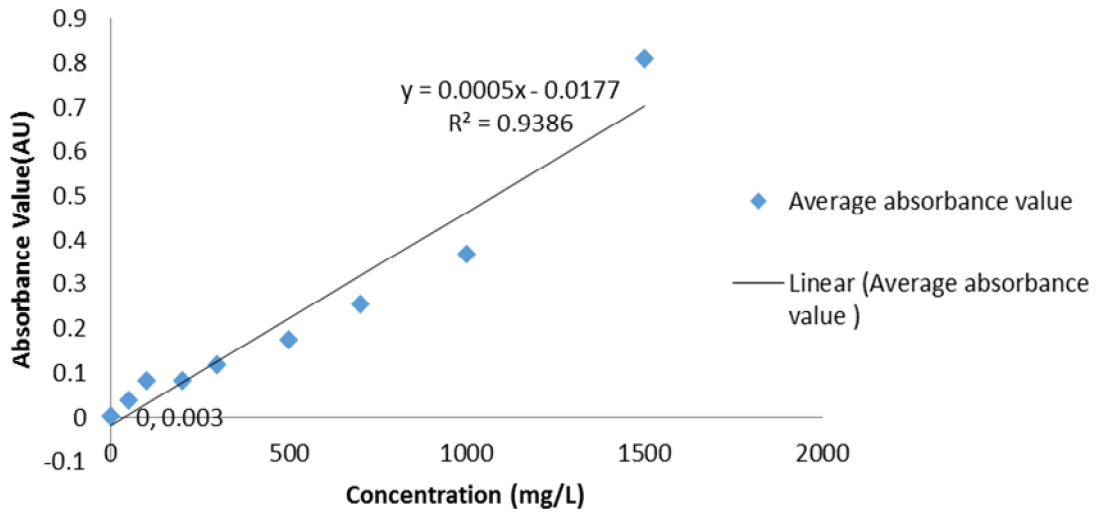


Figure 15. Ammonia calibration curve

Samples were filtered at 0.45 µm (Minisart disposable filters) before analysis. NH_4-N concentration was analysed in the effluent from 8 sampling points as shown in for an interval of 7-10 days. An appropriate dilution with distilled water was used to ensure the absorbance values were within the calibration curve (Figure 15).



Figure 16. Ammonia Calibration process in the lab. (Author, 2015).

The variance in the spectrophotometer was quantified by measuring the absorbance readings of the calibration dilution prepared 5 times in the spectrophotometer, using a blank of distilled water between each readings (±0.010 AU). The NH_4-N analysed in the influent and effluent from 8 sampling points were conducted weekly.

3.6.3 Chemical oxygen demand (COD) calibration

COD calibration was conducted at the initial stage of the experiment using COD cell test kits. Seven (7) sampling points of effluent were considered and one (1) sampling point at the influent tank. A 3ml of sample was added to the cells and then heated for 2 hours at 150^{o}C before cooling for 15 minutes. Measurement was carried out with the ThermoScientific™ GENESYS 20 spectrophotometer at wavelength of 620nm absorbance. This was a manual calibration and the curve obtained is shown in Figure 17

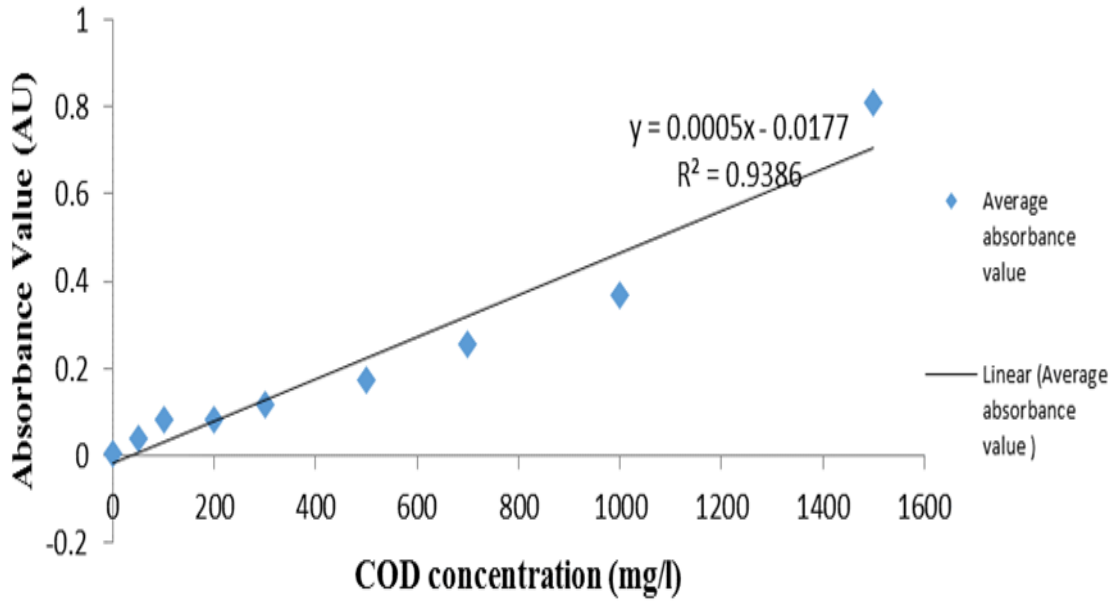


Figure 17. COD calibration curve

3.6.4 Total solids

Analysis of total solids (TS) of the influent and effluent from 8 sampling points were carried out weekly, according to the Standard Methods (APHA Standard Methods, 2005). A homogeneous mixture of sample 25ml was evaporated in the weighed crucible and allowed to dry in an oven at 105^0C for 4 hours (Model 20 GC laboratory oven). The weight was measured using a Mettler Toledo scale (range of measurements from 0.01 to 210 g, error: 0.001 g). 30-50 mL crucibles were used. Due to the limited number of crucibles the oven could contain, no replicates were done. Furthermore, due to the inadequacy of electricity supply during the day, the samples were dried discontinuously for 2-3 days until when they appeared oven dry before cooling in ambient air and weighed.

3.6.5 Total suspended solids.

Total suspended solids (TSS) contents of the influent and effluent samples from Sistema Biobolsa (including aeration gravel beds) and BIOROCK were determined using the TSS dried at 103 - 105 °C method described in method 2540 D in the 19th edition of the “Standard Methods.. Well-mixed samples were filtered through a weighed 1.2 µm glass fibre filter and the residue retained on the filter dried to a constant weight at 105 °C. The increase in weight of the filter paper represented the

total suspended solids. The total suspended solids was calculated using the (Equation 1).

$$\text{TSS (mg/l)} = \frac{(A-B)\ x\ 1000}{Sample\ volume,ml} \quad \text{..... (1)}$$

Equation 1: Total suspended Solids calculation.

Where:

A = weight of filter + dried residue, mg, and

B - Weight of filter, mg.

The TSS analysed in the influent and effluent from 8 sampling points were conducted weekly.

3.6.6 Alkalinity

Alkalinity was determined by titrating the sample with appropriate dilution (dilution factor 1: 5 with distilled water), with sulphuric acid of 0.02N to the end-point of pH value 4.5. (APHA Standard Methods, 2005). Based on the stoichiometry to the reaction and amount of moles of sulphuric acid added to reach the end-point value of pH 4.5, the concentration of the alkalinity of the wastewater was calculated. (APHA Standard Methods, 2005). The Alkalinity analysed in the influent and effluent from 8 sampling points were conducted weekly.

3.7 Methane concentration

Concentrations of oxygen, methane, carbon dioxide and hydrogen sulphide in the biogas from Sistema Biobolsa were measured using a GFM4XX Gas Analyser (Gas Data, Coventry, UK) as shown in Figure 18. The measurements were made every minute for five minutes and the maximum value measured over this time is reported.



Figure 18. Biogas analyser

3.8 Temperature and pH

Daily samples of influent were analysed for pH and temperature at onsite. The pH and temperature of the samples were measured with pH meter and thermometer (pinpoint) respectively according to the standard methods (APHA Standard Methods, 2005).

3.9 Phytotoxicity Analysis

A phytotoxicity test was carried out on the 10/18/2015 and 14/12/2015 in the influent and effluent of the aerobic gravel beds of the Sistema Biobolsa, using cress seeds (Lepidium sativum) to test the rate of germination through root length. The test procedure was varied, according to the material analysed (Arienzoa, *et al*., 2009; Tam *et al*., 1994).

Four dilutions of effluent were prepared by serial dilution with drinking water at 100%, 50%, 10% and 1%. 2 ml of each dilution was added to a filter paper disc of diameter 62 mm and pore size 20 µm (Aeropress filter papers) in an 80 mm petri dish. Ten cress seeds were placed on top of the filter paper and kept in a dark place for 5 days at about 28^{o}C. Controls were prepared, which consisted of 2 ml of drinking water. The germination index (GI) with respect to root length and the control were determined according to (Equation 2) (Arienzoa, Christena and Quaylea, 2009; Tam and Tiquia, 1994).

$$GI = G/G_0 \times L/L_0 \times 100 \text{.....Equation (2)}$$

G= Number of seeds germinated

L= Root length

Equation 2: Germination Index

CHAPTER FOUR

4.0 Results

4.1 Introduction

As stated in the previous chapter, the technology was considered to be in full operation after three months of installation.

4.1.1 Quantity of toilet waste flow and hydraulic retention time for the technologies.

Table 10 shows the total toilet waste treated by the two systems.

Table 10. Quantities (litres) of toilet waste treated by both the technologies.

		Sistema Biobolsa		BIOROCK	
Date	Number of Days	Total Inflow flow (Litres)	Type of Waste	Total Inflow (Litres)	Type of Waste
1st -17th May, 2015	12	400	cow manure	3000	cow manure
19th-31st May, 2015	5	2200	Toilet waste	4200	Toilet waste
1st-30th June , 2015	21	8800	Toilet waste	4400	Toilet waste
1st-31st July, 2015	22	9600	Toilet waste	4400	Toilet waste
1st-31st August, 2015	20	8400	Toilet waste	4000	Toilet waste
1st-30th September, 2015	19	8000	Toilet waste	3400	Toilet waste
1st-31st October, 2015	22	9200	Toilet waste	1820	Toilet waste
1st-30th November, 2015	21	8800	Toilet waste	1100	Toilet waste
1st-31st December, 2015	20	8400	Toilet waste	1050	Toilet waste
Total	162	63,800		27,370	

As indicated in Table 10, the lowest total toilet waste pumped into Sistema Biobolsa and BIOROCK technologies were respectively 400 litres (12 days in May 2015) and 1,050 litres (20 days in December 2015). The highest recorded total toilet waste pumped into Sistema Biobolsa and BIORCOK system were 9,600 litres (in 22 days) and 4,400 litres (in 22 days). All happened in the month of July 2015.

The volume of toilet waste fed into both technologies (Sistema Biobolsa and BIOROCK) over the entire study was 91,170 litres. The mean monthly volume of toilet waste pumped into the Sistema Biobolsa and BIOROCK were respectively 7,090 litres/month and 3,040 litres/month. The total quantity of toilet waste treated by Sistema Biobolsa and BIOROCK in 9 months were 63,800 litres (63.8m^3) and 27,370 litres (27.4m^3) respectively.

4.1.2 The hydraulic retention time for the technologies

The hydraulic retention time (HRT) represents the time that a wastewater stays in the bioreactors (Sundstrom, *et al*., 1979). The HRT is an important parameter that is related to the size of the bioreactors and design of the treatment system (Cho, *et al*., 2005). In this study, the HRT for Sistema Biobolsa was 10 days maximum whilst that of BIOROCK was 25 days. It has been reported that industrial wastewater treatments normally require HRT values of 10.5–389 h (Stephenson *et al*., 2000 and Guo, *et al*., 2004). Studies have also shown that large HRT resulted in a low fouling degree in the whole filtration time (Fangang *et al*., 2007).

The HRT was calculated using the formula;

$$HRT = \frac{V}{Q} \quad \text{..... (Equation 3)}$$

Equation 3: Hydraulic Retention Time.

Where;

HRT = Hydraulic Residence time (days)

V = Reactor volume (m^3)

Q = Flow rate (m^3/day)

4.2 Sistema Biobolsa digesters effluent parameters

Table 11 shows the effluent parameters of Sistema Biobolsa.

Table 11. Outflow of parameter of Sistema Biobolsa without aerobic gravel filter beds

Parameters	Values[a]	
	Mean Values	Standard Deviations
pH	7.38	0.31
Temperature (^{0}C)	29.9	2.1
COD (mg/l)	21,437	8568
NH_4-N (mg/l)	2,069	968
Alkalinity (mg/l)	514	137
TS (mg/l)	2,585	2144
TVS (mg/l)	2,063	1801
TSS (mg/l)	2,434	2335
TVSS(mg/l)	2,408	2019

[a]Analyses were conducted on 11 samples starting from 11/10/2015 to 22/12/2015

The extent of organic removal in the digesters are summarized in Table 11 and the mean COD and NH_4-N is indicated as well. As compared with aerobic gravel treatment, the organic removal in the digesters were less. The mean COD and NH_4-N were 21,437mg/l and 2,069mg/l respectively. The average removal of TS and TVS were respectively 2,585 mg/l and 2,063 mg/l. However, the mean removal of Alkalinity in the digester was 514 mg/l with standard deviation of 137 mg/l.

4.3 Sistema Biobolsa and aerobic gravel beds effluent parameters

Table 12 shows the effluent parameters of Sistema Biobolsa with aerobic gravel beds.

Table 12. Effluent parameters of Sistema Biobolsa with aerobic gravel beds

Parameters	Values[b]	
	Mean	Standard deviation
pH	8.06	0.37
Temperature (^{0}C)	27.1	2.11
COD (mg/l)	9,683	5506
NH4-N (mg/l)	216	252
Alkalinity (mg/l)	231	179
TS (mg/l)	840	990
TVS (mg/l)	268	211
TSS (mg/l)	1,507	1852
TVSS(mg/l)	1,375.6	1638

[b]Analyses were conducted on 11 samples starting from 11/10/2015 to 22/12/2015

As indicated in Table 12, the mean organic removal in the Sistema Biobolsa digester was less as compared with the effluent from the filtration. The average COD and NH_4-N were 9,683 mg/l and 216 mg/l respectively. The mean removal of TS and TVS were only 840 mg/l and 268 mg/l, whilst that of TSS and TVSS were respectively 1507 mg/l and 1376 mg/l. The experimental mean removal of Alkalinity in the primary tank was 231 mg/l with standard deviation of 179 mg/l.

Table 13 illustrates the experimental results for each stage of treatment by Sistema Biobolsa Technology.

Table 13 Summary results of each stage of treatment by Sistema Biobolsa, with and without filtration process.

Parameters	Influent- Raw toilet waste (Initial conc.)	Sistema Biobolsa without aerobic gravel filter beds	Sistema Biobolsa with aerobic gravel filter beds	Treatment (%)
	Mean Values	Mean Values	Mean Values	
pH	6.4	7.38	8.06	n/a
Temperature (^{0}C)	26.6	29.9	27.1	n/a
COD (mg/l)	45,077	21,437	9,683	79
NH_4-N (mg/l)	2,939	2,069	216	93
Alkalinity (mg/l)	595	514	231	61
TS (mg/l)	8,383	2,585	840	90
TVS (mg/l)	6,327	2,063	268	96
TSS (mg/l)	2,932	2,434	1,507	49
TVSS(mg/l)	3,306	2,408	1,375.60	58

As shown in Table 13, the 2nd stage of treatment which involved filtration process show improvement in the quality of the effluent in all the parameters. The highest contaminant removal of NH_4-N was about 93% whilst the least contaminant removal, TSS was 49%.

The mean removal of Alkalinity and COD were 61% and 79% respectively, whilst that of the TS removal was 90%.

4.4 Parameters in discharge effluent from BIOROCK system

Table 14 shows the effluent quality of BIOROCK without filtration process.

Table 14. Parameters in discharge effluent from BIOROCK without filtration process.

Parameters	*Values	
	Mean Values	Standard Deviation
pH	7.78	0.40
Temperature ^{0}C	29.0	1.71
COD (mg/l)	17,037	5,356
NH4-N (mg/l)	1,351	1,019
Alkalinity (mg/l)	416	178
TS (mg/l)	1,680	1,214
TVS (mg/l)	2,329	2,409
TSS (mg/l)	1,496	2,074
TVSS (mg/l)	1,481	2,203
Ratio TVS/TS	1.39	0.40

***Analysis were conducted on 11 samples starting from 11/10/2015 to 22/12/2015**

As indicated in Table 14, the mean organic removal in the primary tanks of BIOROCK is less as compared with the filtration tank process (Table 14). The average COD and NH_4-N were 17,037 mg/l and 5,356 mg/l respectively. The mean removal of TS and TVS were only 1,680 mg/l and 1,214 mg/l, whilst that of TSS and TVSS were respectively 1,496 mg/l and 1,481 mg/l. The experimental mean removal of Alkalinity in the primary tank was 416 mg/l with standard deviation of 178 mg/l.

Table 15 shows the effluent quality of BIOROCK with the filtration process.

Table 15. Parameters in discharge effluent from BIOROCK with the filtration process.

Parameters	*Values	
	Mean values	Standard Deviation
pH	8.26	0.34
Temperature 0C	29.0	1.55
COD (mg/l)	12,269	4,874
NH4-N (mg/l)	369	422
Alkalinity (mg/l)	291	150
TS (mg/l)	1,093	1,045
TVS (mg/l)	1,151	1,091
TSS (mg/l)	980	1,961
TVSS (mg/l)	1,079	1,726
Ratio TVS/TS	1.05	0.34

***Analysis were conducted on 11 samples starting from 11/10/2015 to 22/12/2015**

The degree of organic removal in the combine primary tanks and filtration tank are summarized in Table 15. The mean COD and NH_4-N is also indicated as well. The organic removal in the filtration tank were high as compared with the primary tank treatment only (Table 14). The average COD and NH_4-N were 12,269 mg/l and 4,874 mg/l respectively. The mean removal of TS and TVS were respectively 1,093 mg/l and 1,151 mg/l. However, the average removal of Alkalinity in the filter tank was 291 mg/l with standard deviation of 150 mg/l. As indicated in Table 13, the mean TSS and TVSS removal were 980 mg//l and 1,079 mg/l respectively.

Table 16 illustrates the experimental results for each stage of treatment by BIOROCK system, with and without filtration process.

Table 16 Summary results of each stage of treatment by BIOROCK

Parameters	Influent- Raw toilet waste (Initial conc.)	BIOROCK System without filtration process	BIOROCK System with filtration process	Treatment (%)
	Mean Values	Mean Values	Mean values	
pH	6.4	7.78	8.26	n/a
Temperature ^{0}C	26.6	29	29	n/a
COD (mg/l)	45,077	17,037	12,269	73
NH4-N (mg/l)	2,939	1,351	369	87
Alkalinity (mg/l)	595	416	291	51
TS (mg/l)	8,383	1,680	1,093	86
TVS (mg/l)	6,327	2,329	1,151	81
TSS (mg/l)	2,932	1,496	980	67
TVSS (mg/l)	3,306	1,481	1,079	67

As shown in Table 16, the study observed improvement in the effluent quality of the toilet waste. The 2nd stage of treatment by BIOROCK, which involved filtration process, showed improvement in the quality of all parameters. The highest contaminant removal of NH_4-N was about 73% whilst the least contaminant removal, TVSS was 27%.

The Alkalinity and COD removal was 51% and 73% respectively. The mean TVS removal was 81% whilst the TS removal recorded was 86%.

4.5 Parameters removal efficiency by the technologies

4.5.1 Chemical oxygen demand (COD) removal efficiency by Sistema Biobolsa

Figure 19 shows the profile of COD removal in the influent into the digesters and the effluent from the aerobic gravel filter beds of the Sistema Biobolsa. The COD ranged from 22940 to 140250 mg/L for the influent and 6360 to 23540 mg/L for the effluent. COD removal was never less than 41%. It was as high as 95% and had a mean value of 64% with a standard deviation of 16%. The COD removal in the third digester achieved a removal of 39% with standard deviation of 21%. Digesters combined with the three aerobic gravel filter beds, 1st , 2nd and 3rd connected in series, achieved removal efficiency of 55%, 59% and 73% and standard deviation of 21%, 18% and 16% respectively.

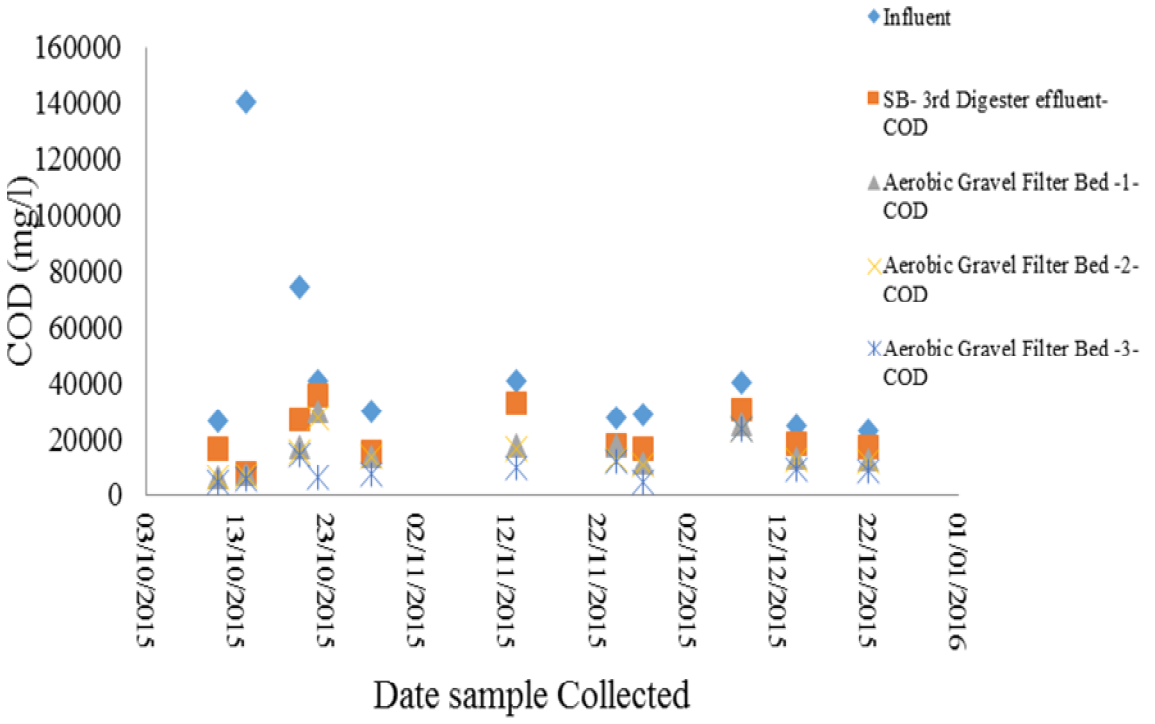


Figure 19.Trend of COD removal by Sistema Biobolsa.

4.5.2 Ammonium Nitrogen (NH_4-N) removal efficiency by Sistema Biobolsa

Figure 20 shows the trend of Ammonium Nitrogen removal efficiency in the influent into the digesters and the effluent from the aerobic gravel filter beds. The Ammonium Nitrogen ranged from 457 to 6778 mg/L for the influent and 34 to 1335 mg/L for the effluent. NH_4-N removal efficiency was not less than 60%. It was as high as 98 % and had a mean value of 88% with a standard deviation of 12%.

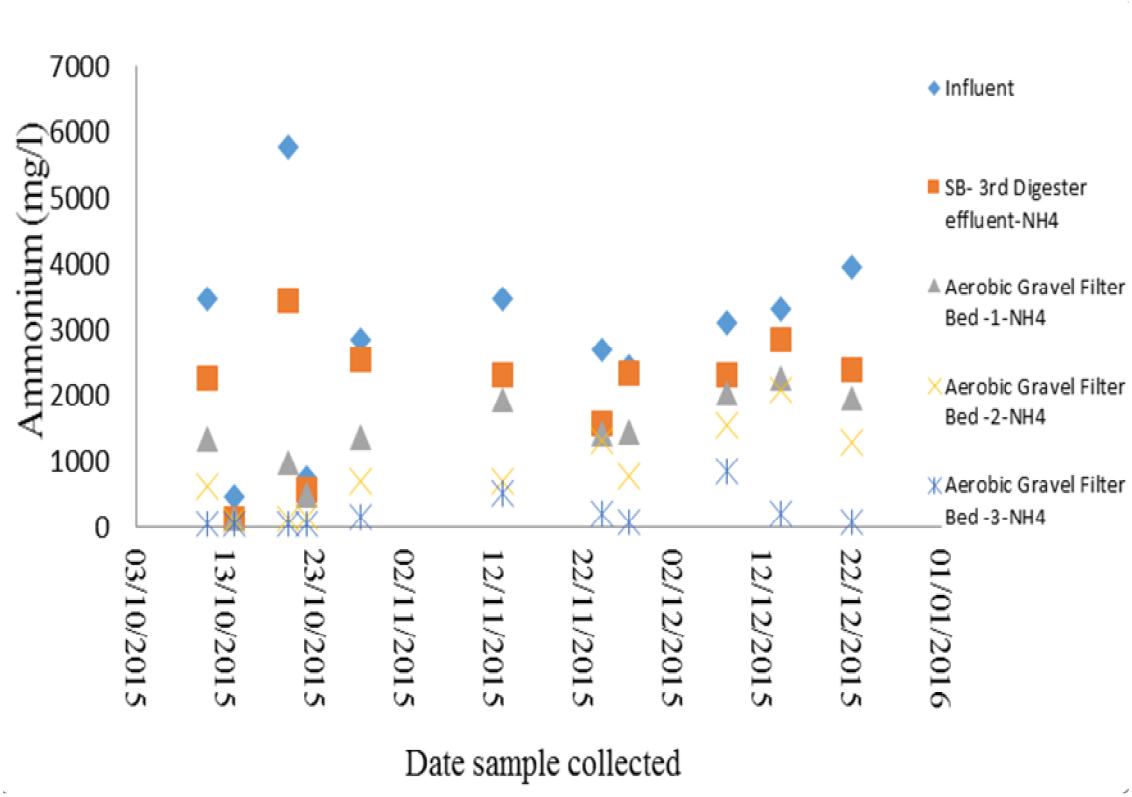


Figure 20. Trend of NH_4-N removal by Sistema Biobolsa

4.5.3 Total solids (TS) removal efficiency

Figure 21 show the results obtained in determination of the total solid (TS) content in the influent into the digesters and the effluent from the aerobic gravel filter beds. The TS ranged from 3292 to 25138 mg/L for the influent and 226 to 3132 mg/L for the effluent. TS removal was not less than 23%. It was as high as 97% and had a mean value of 83% with a standard deviation of 22%.

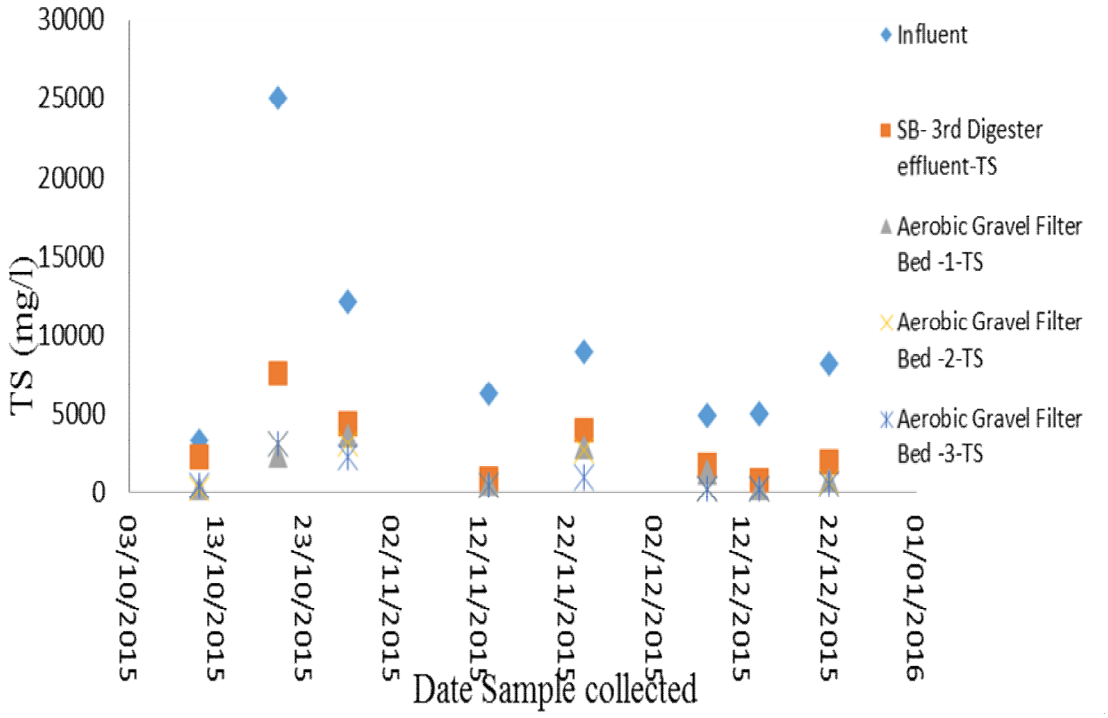


Figure 21.Trend of Total Solids removal by Sistema Biobolsa

4.5.4 Total volatile solids (TVS) removal Efficiency

Figure 22 show the results obtained in determination of the total volatile solid (TVS) content in the influent into the digesters and the effluent from the aerobic gravel filter beds. The TVS ranged from to 2550 to 17192 mg/L for the influent and 206 to 3320 mg/L for the effluent. TVS removal was not less than 35%. It was as high as 96% and had a mean value of 77% with a standard deviation of 22%.

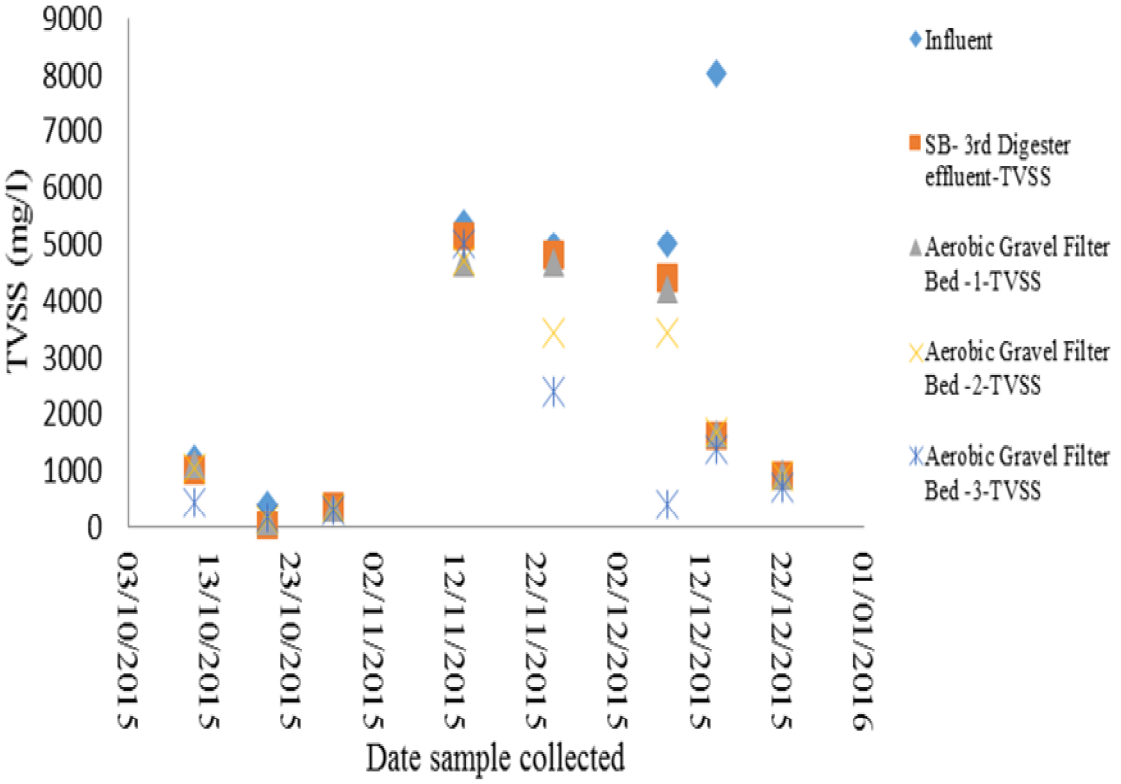


Figure 22. Trend of Total Volatile Solids removal by Sistema Biobolsa

4.5.5 Alkalinity removal effciency by Sistema Biobolsa

Figure 23 show the results obtained in determination of the Alkalinity content in the influent into the digesters and the effluent from the aerobic gravel filter beds. The Alkalinity ranged from 307 to 760 mg/L for the influent and 131 to 533 mg/L for the effluent. Alkalinity removal was never less than 27%. It was as high as 81% and had a mean value of 51% with a standard deviation of 19%.

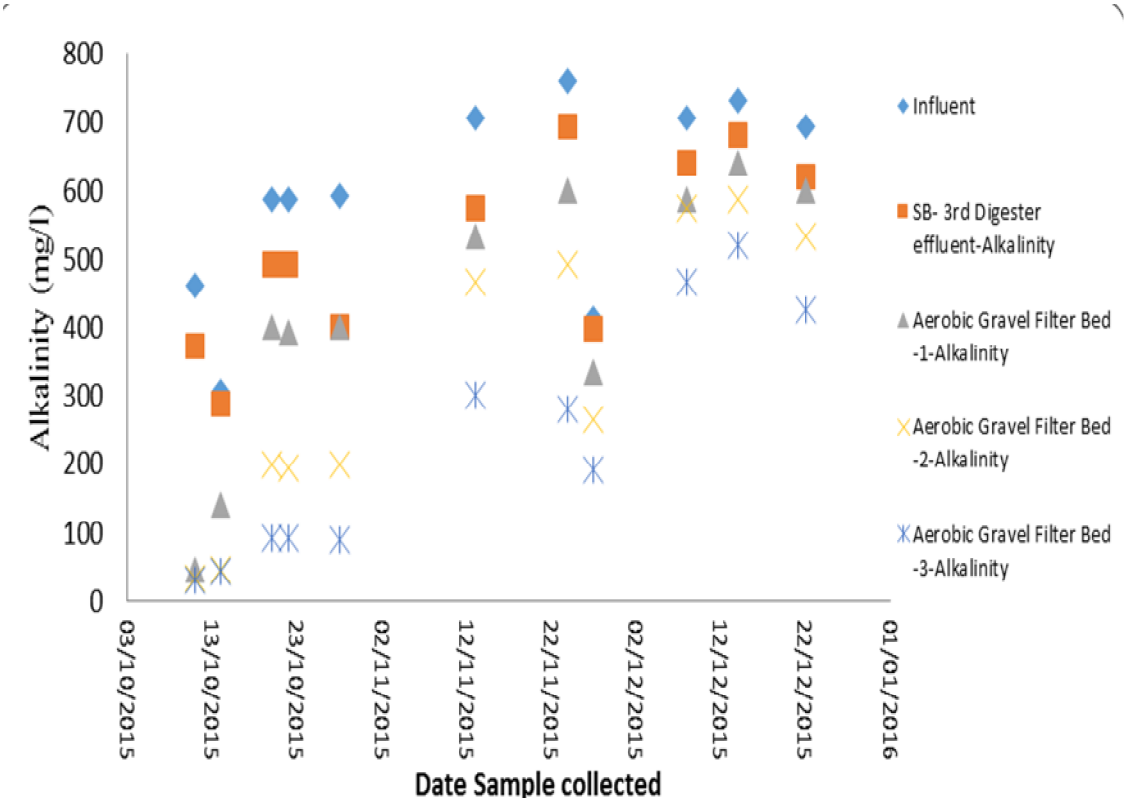


Figure 23. Trend of Alkalinity removal by Sistema Biobolsa.

4.5.6 Total suspended solid removal effciency by Sistema Biobolsa

Figure 24 show the results obtained in determination of the total suspended solid (TSS) content in the influent into the digesters and the effluent from the aerobic gravel filter beds. The TSS ranged from 608 to 8220 mg/L for the influent and 16 to 5812 mg/L for the effluent. TSS removal was never less than 29%. It was as high as 99% and had a mean value of 74% with a standard deviation

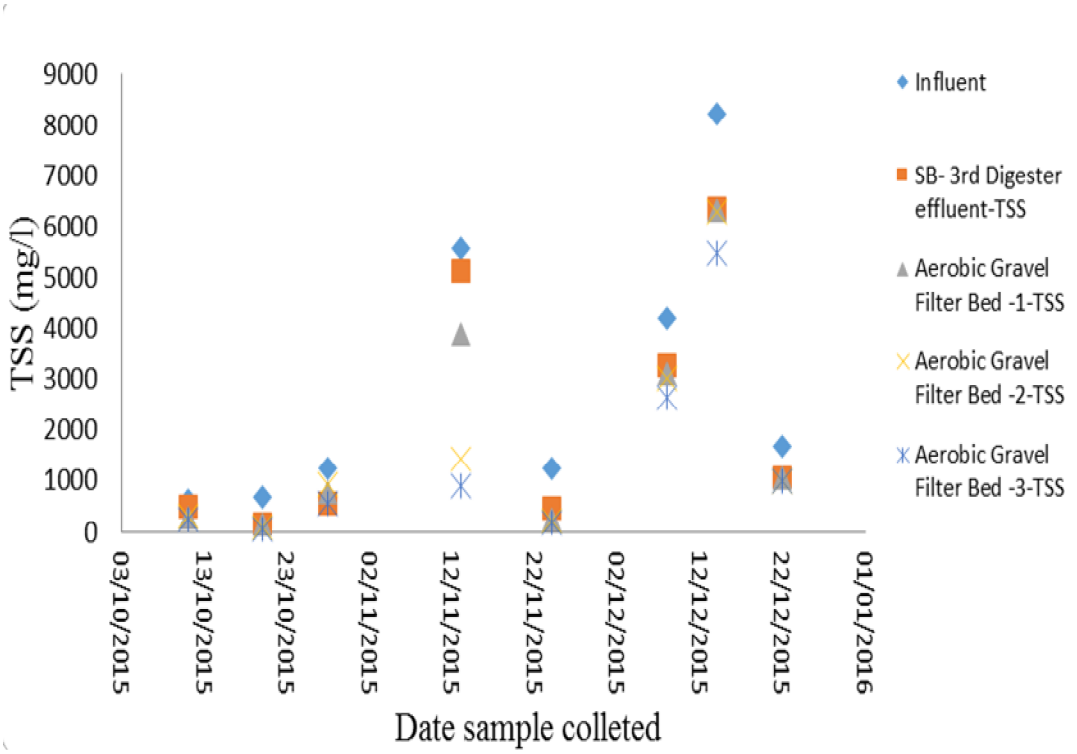


Figure 24.Trend of Total Suspended Solids removal by Sistema Biobolsa

4.5.7 Total volatile suspended solid removal efficiency by Sistema Biobolsa.

Figure 25 show the results obtained in determination of the total volatile suspended solid (TVSS) content in the influent into the digesters and the effluent from the aerobic gravel filter beds. The TVSS ranged from 386 to 8042 mg/L for the influent and 34 to 401 mg/L for the effluent. TVSS removal was never less than 83%. It was as high as 98% and had an average value of 93% with a standard deviation of 5%. The mean effluent TVSS concentration of the 3rd aerobic Bed was 1,363 mg/l The mean percentage removal of TVSS for 3rd aerobic gravel bed was 49.4% with standard devaition of 31%

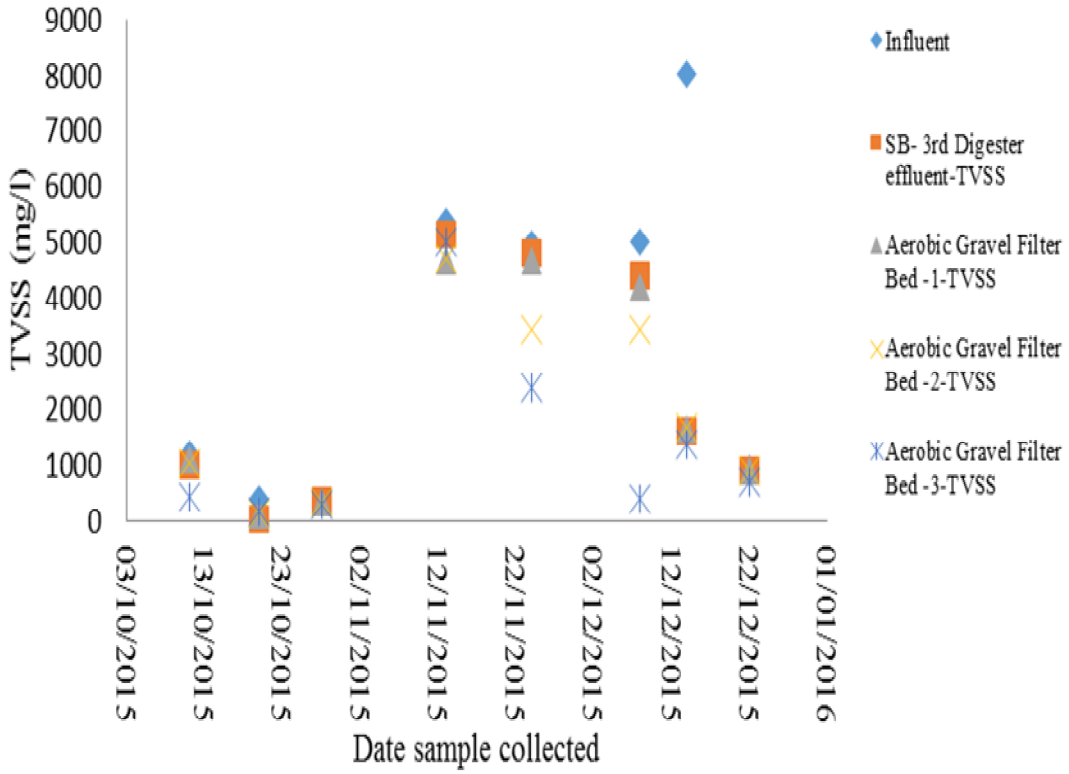


Figure 25. Trend of total volatile suspended solids removal by Sistema Biobolsa

4.6 Removal efficiency by BIOROCK

4.6.1 COD removal efficiency by BIOROCK

Figure 26 show the results obtained in determination of the chemical oxygen demand (COD) content in the influent into the primary tanks and the effluent from the filtration tank. The COD ranged from 6510 to 23740mg/L for the influent and 6360 to 23540mg/L for the effluent. COD removal was never less than 41%. It was as high as 95% and had a mean value of 64% with a standard deviation of 16%. The mean effluent COD concentration of the 3rd Gravel Bed was 1,363 mg/l. The mean percentage removal of COD by the filtration process was 64% with standard devaition of 16%.

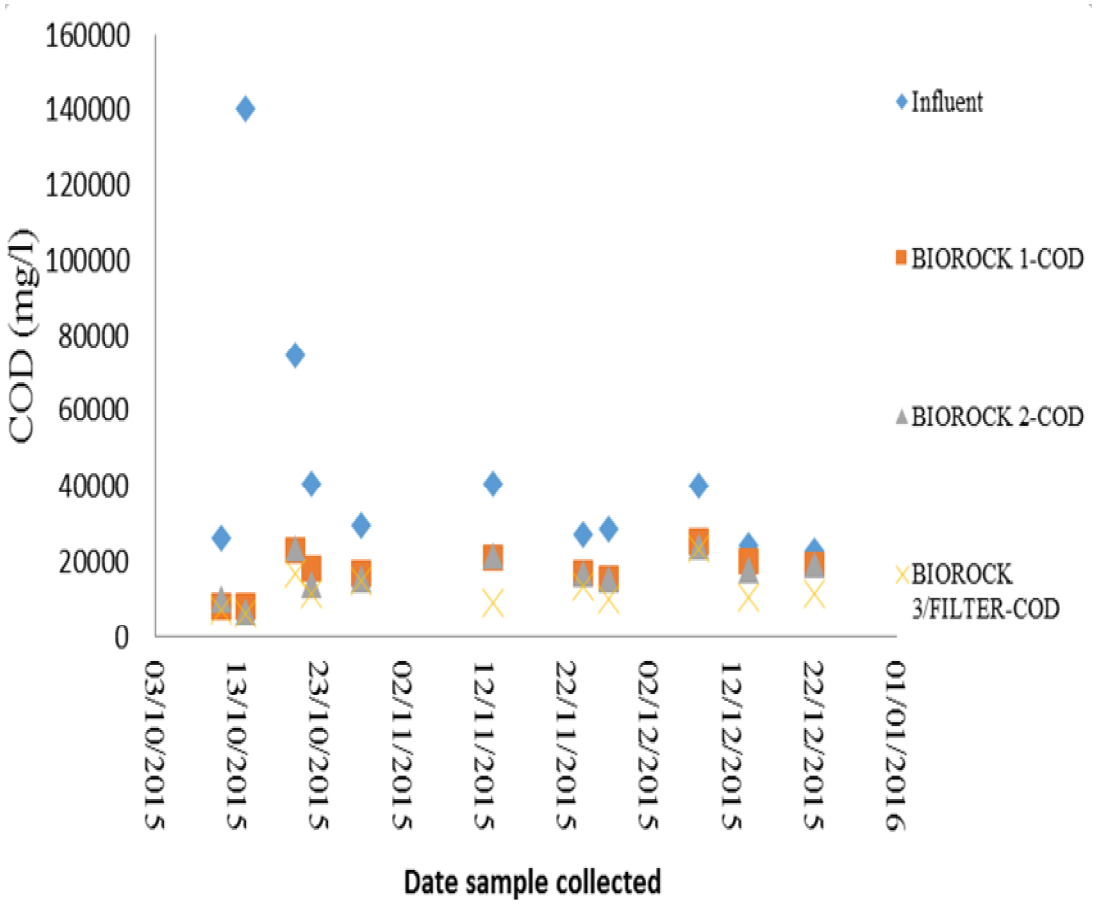


Figure 26. Trend of COD removal by BIOROCK

4.6.2 Ammonium-Nitrogen removal efficiency by BIOROCK

Figure 27 show the results obtained in determination of the Ammonium-Nitrogen (NH_4-N) content in the influent into the primary tanks and the effluent from the filtration tank. The Ammonia Nitrogen ranged from 181 to 2703mg/L for the influent and 60 to 98mg/L for the effluent. Ammonia Nitrogen removal was never less than 60%. It was as high as 98% and had a mean value of 88% with a standard deviation of 12%. It is apparent from the graph that there was upward trend in the influent concentration on the 8th to 12th December, 2015. The mean effluent NH_4-N concentration of filtration process was 369 mg/l. The mean percentage removal of NH_4-N by the filtration tank was 88% with standard devaition of 12%.

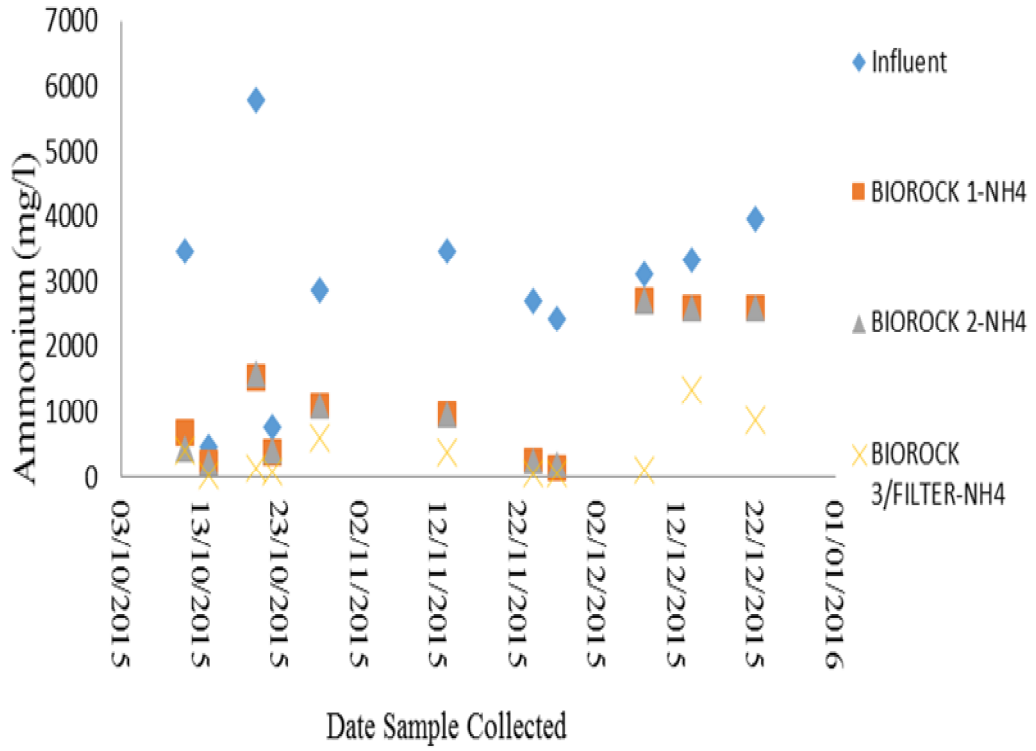


Figure 27.Trend of Ammonium removal by BIOROCK

4.6.3 Total solids removal efficiency by BIOROCK

Figure 28 show the results obtained in determination of the Total Solids (TS) content in the influent into the primary tanks and the effluent from the filtration tank. The total solids ranged from 302mg/L to 3706mg/L for the influent and 23mg/L to 97mg/L for the effluent. The mean effluent TS concentration from the filtration tank (effluent) was 1,093 mg/l. The mean percentage removal of TS by the filtration process was 83% with standard deviation of 22%.

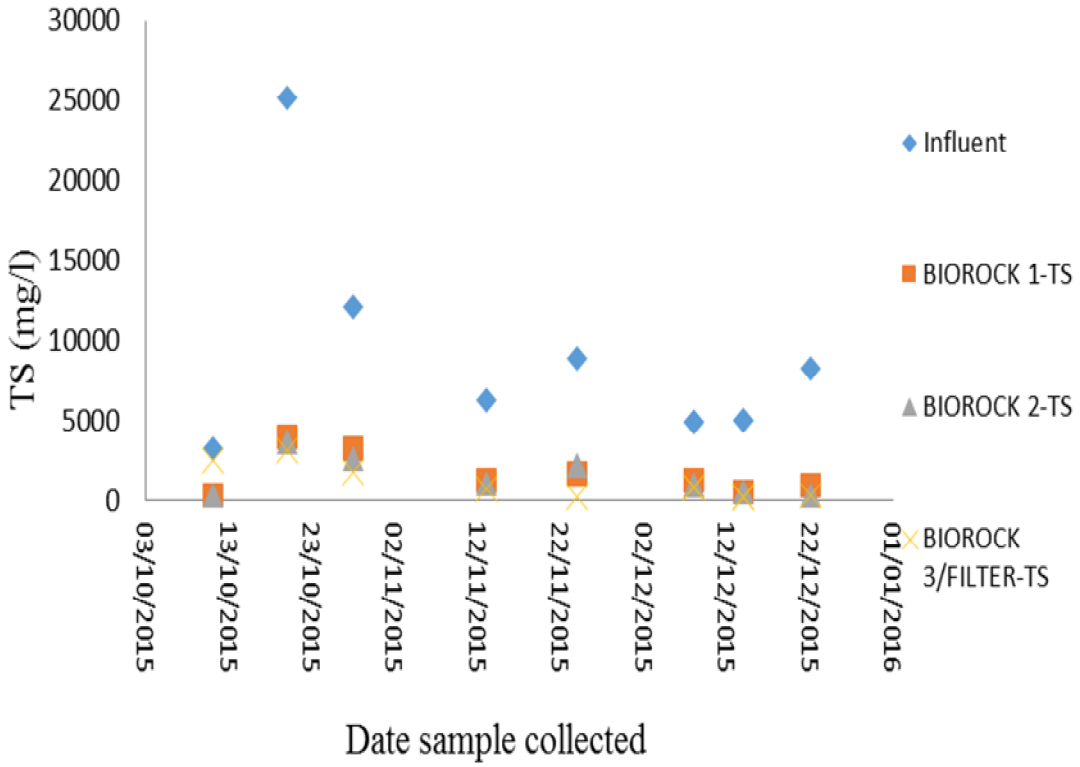


Figure 28. Trend of Total Solids removal by BIOROCK

4.6.4 Total Volatile Solids removal efficiency by BIOROCK

Figure 29 show the results obtained in determination of the Total Volatile Solids (TVS) content in the influent into the primary tanks and the effluent from the filtration tank. The TVS ranged from 2550 mg/L to 17192 mg/L for the influent and 206 mg/L to 3320 mg/L for the efluent.The mean effluent TVS concentration from the filtration tank (effluent) was 1151 mg/l. TVS removal was never less than 35%. It was as high as 96% and had a mean value of 77% with a standard deviation of 22%.

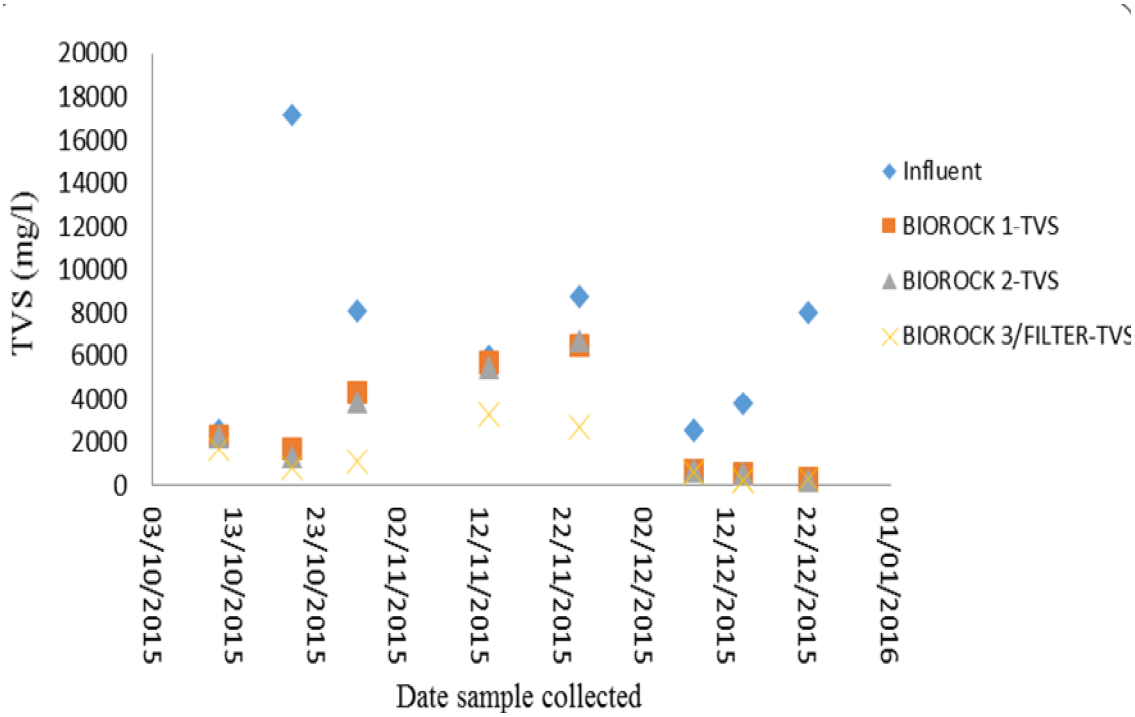


Figure 29. Trend TVS treatment of primary tanks with the filteration process

4.6.5 Alkalinity removal effciency by BIOROCK system

Alkalinity content was measured in the influent into the primary tanks and effluent from the the filtration tank as indicated in Figure 30. The influent concentraion of Alkalinity ranged betweeen 307 mg/L to 760 mg/L with standard devaition of 147 mg/L. With regards to effluent the Alkalinity ranged from 206 to 533 mg/L and had a mean value of 291mg/L with standard devaition of 150 mg/L. As evidence from the Figure 30, the effluent concentration varied slightly compared with the influent, which show an upward trend from the start and decreased towards the end of the experiment.

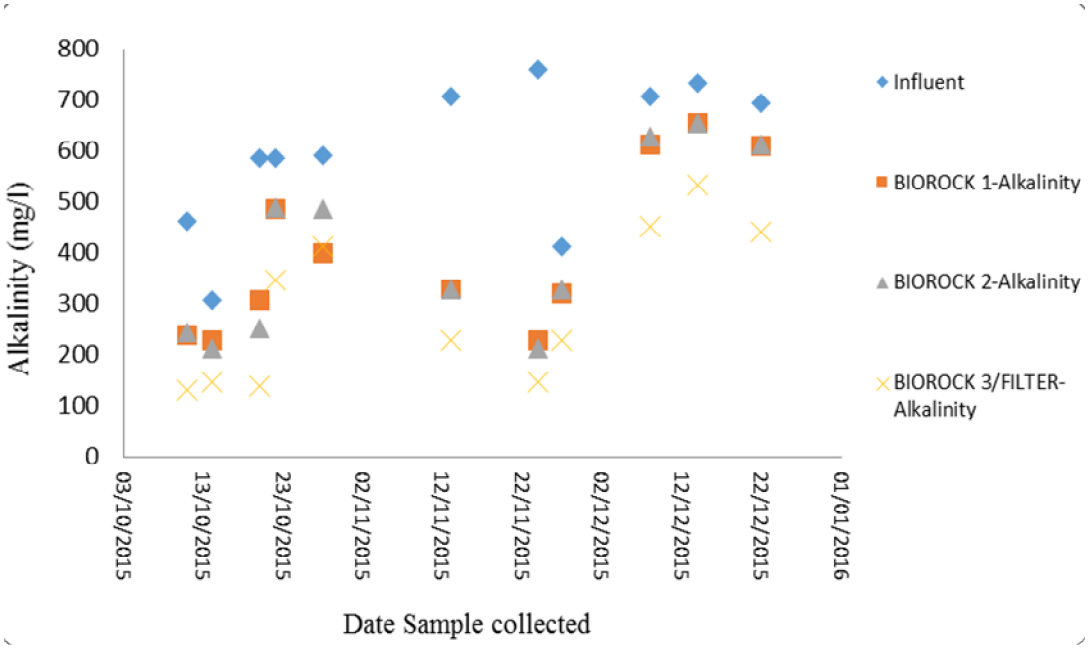


Figure 30. Trend of Alkalinity removal by BIOROCK

4.6.6 Total suspended solid removal effciency by BIOROCK

Figure 31 show the results obtained in determination of the Total suspended Solids (TSS) content in the influent into the primary tanks and the effluent from the filtration tank. The TSS ranged from 608 mg/L to 8220 mg/L for the influent and 16 mg/L to 5812 mg/L for the efluent.The mean effluent TSS concentration from the filtration tank (effluent) was 980 mg/l. TSS removal was never less than 29%. It was as high as 99% and had a mean value of 74% with a standard deviation of 25%.

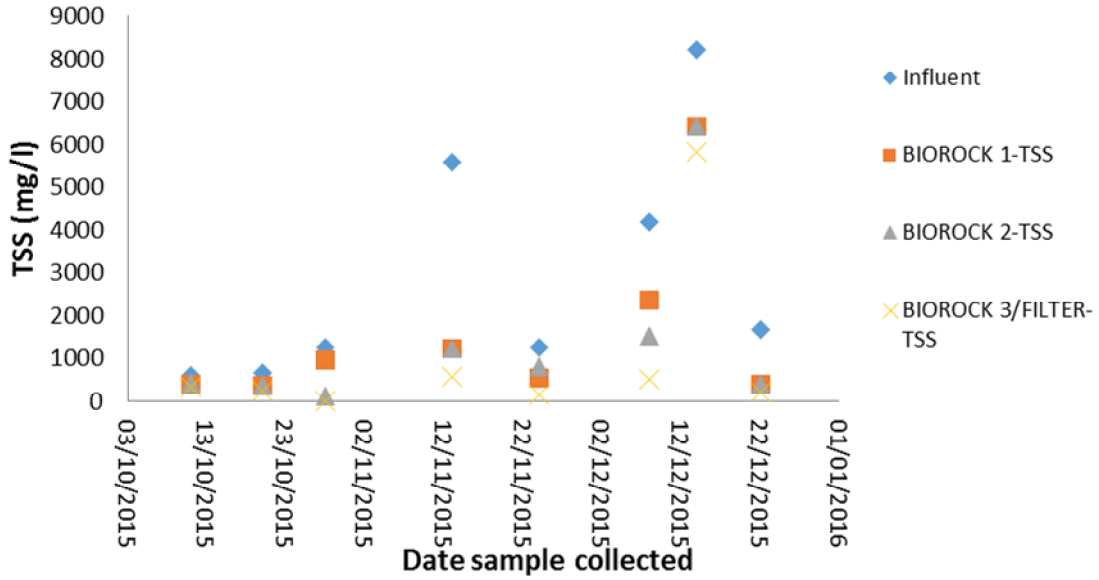


Figure 31. Trend of Total Suspended Solids removal by BIOROCK

4.6.7 Total volatile suspended solid removal effciency by BIOROCK

Total volatile suspended solid (TVSS) content was measured in the influent into the primary tanks and effluent from the the filtration tank as shown in Figure 32. The influent concentraion of TVSS ranged betweeen 386 mg/L to 8042 mg/L with standard devaition of 147 mg/L. With regards to effluent the TVSS ranged from 34 to 401 mg/L and had a mean value of 170 mg/L with standard devaition of 146 mg/L As evidence from the graph the effluent concentration varied compared with the influent, which show general upward trend from the start to the end of the experiment. TVSS removal was not less than 83%. It was as high as 98% and had a high mean value of 93% with a standard deviation of 5%.

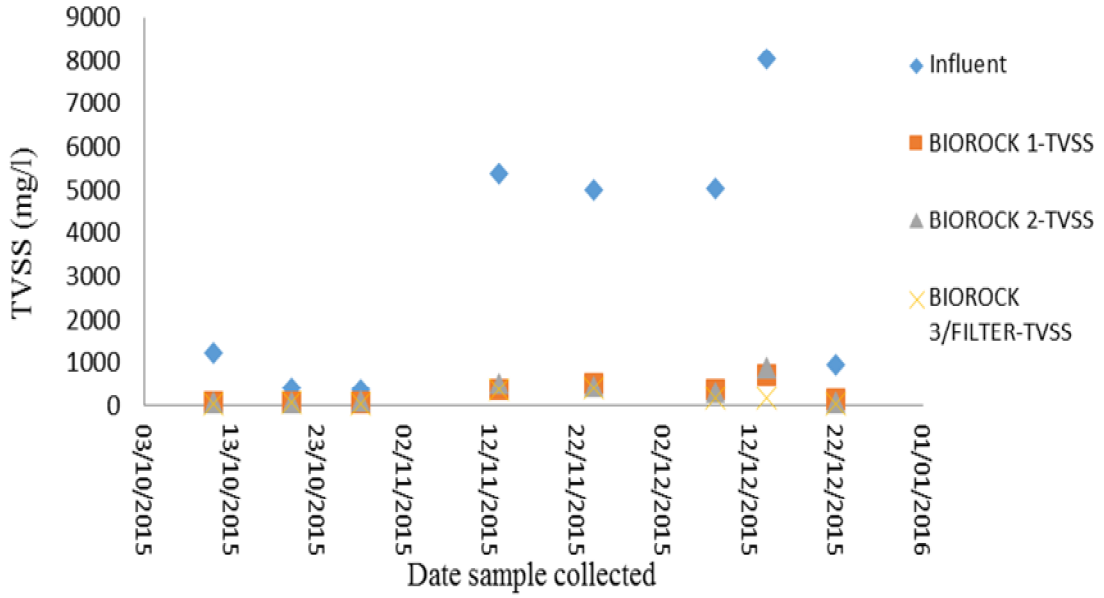


Figure 32. Trend of total volatile suspended solids removal by BIOROCK

4.7 Comparing removal efficiencies of Sistema Biobolsa and BIOROCK.

Table 17 shows the summary removal efficiencies of both Sistema Biobolsa and BIOROCK technology.

Table 17. Summary of parameters removal efficiencies for Sistema Biobolsa and BIOROCK

Parameters	Sistema Biobolsa		BIOROCK	
	Mean Reduction	Standard Deviation	Mean Reduction	Standard Deviation
COD	73%	16%	64%	16%
NH_4-N	92%	8%	88%	12%
Alkalinity	64%	23%	51%	19%
Total solids (TS)	92%	5%	83%	22%
Total volatile solids (TVS)	95%	3%	93%	5%
Total suspended solids (TSS)	61%	24%	74%	25%
Total volatile suspended solids (TVSS)	49%	31%	93%	5%

Interestingly, Sistema Biobolsa show remarkable TS removal efficiency (92%), which is higher than BIOROCK system TS removal efficiency of 83%. As compared to Sistema Biobolsa technology, the TVS removal from toilet waste in the BIOROCK was less. The average removal of TVS from BIOROCK system was 93% whilst that

of Sistema Biobolsa was 96%. The mean COD removal efficiency of Sistema Biobolsa and BIOROCK were 73% and 64% respectively.

With regards to NH_4-N removal, BIOROCK system shown less removal efficiency as compared with Sistema Biobolsa technology. The NH_4-N removal efficiency in Sistema Biobolsa and BIOROCK system were 92% and 88% respectively. The Alkalinity removal efficiency of Sistema Biobolsa is 64% with standard deviation of 23% and that of BIOROCK system is 51% with standard deviation of 19%, showing removal efficiency difference of 13%. The high removal rate of Sistema Biobolsa is an indication of a high conversion of organic matter during the anaerobic digestion in the reactors.

4.7.1 Temperature

The temperature of the waste water in the Sistema Biobolsa digesters were measured. The mean temperature ranged from 24.6^{0}C to 32.2 ^{0}C whilst that of BIOROCK ranged from 28.5 ^{0}C to 30.9 ^{0}C. As demonstrated by Van der Last (1991), below 15^{0}C, the removal of organic matter decreases significantly. In this study the ambient temperature recorded was above 28 ^{0}C, which was adequate to support treatment (Lettinga, 1994). Seghezzo *et al*., 1998, show that digesters can be operated at both laboratory and full-scale with varying temperatures 7 ^{0}C to 32 ^{0}C in anaerobic conditions. The testing of the technology in Kumasi was carried out under the ambient environmental conditions.

4.7.2 pH values

Anaerobic processes are pH dependent. It is important to keep the pH ranged in a condition that would support the microorganisms responsible for anaerobic digestion (Lettinga, 1994). During the experiment, the pH of the solutions were measured. The pH ranged from 6.7 to 7.1 for influent and from 7.6 to 8.9 for effluent from (aerobic gravel filters) of Sistema Biobolsa. The mean pH values for the influent and effluent were respectively 6.7 and 8.1. For BIOROCK, the pH ranged from 6.7 to 7.1 for influent and from 7.6 to 8.5 for effluent of filtration tank. The mean pH value for the influent and effluent were respectively 6.7and 7.9. The pH variations of the influent and effluent is of great significance in anaerobic treatment of toilet wastewater (Gani *et al*., 2016). Doku (2002), reported low pH value (acidic conditions), indicating the

first stage of anaerobic digestion which involved the hydrolysis of protein into amino acids and lipids into fatty acids.

4.7.3 Alkalinity values

Alkalinity is one of the parameters that define the stability potential of the anaerobic treatment processes. A high alkalinity value is desirable as it gives a better support against a drop in pH as a result of fatty acid increase (Metcalf and Eddy, 2003). In this study, the mean influent alkalinity slightly decrease from 595mg/L as $CaCO_3$ to 514 mg/L as $CaCO_3$ in the Sistema Biobolsa. Similarly, the mean influent alkalinity slightly decrease from 595mg/L as $CaCO_3$ to 413mg/L as $CaCO_3$ in the BIOROCK. The drop in alkalinity may be due to the formation of bicarbonates from the combination of ammonia and carbon dioxide, released during the biodegradation process that compensated the decrease in the alkalinity due to fatty acids (Doku *et al.,* 2002).

4.7.4 COD removal efficiencies

The mean COD removal for Sistema Biobolsa was 75% and that of BIOROCK was 64%. The influent COD shows a contribution of degradation in the removal of organic matter. The COD in the influent ranges from 22,940 to 140,250mg/l. However, the COD in the effluent ranged from 4340mg/l to 23540mg/l for Sistema Biobolsa and 6360mg/l to 23500mg/l for BIOROCK. This is a good indication that when a steady state and optimal operating conditions are established for both technologies, significant removal efficiencies of COD can be achieved. In this study the testing of the technologies were conducted under the ambient conditions. Generally, a high COD removal efficiency gives indication that the technologies could be used as pre-treatment option of faecal sludge before the conventional faecal sludge treatment plants (Gani *et al*, 2016). Similarly, both technologies can serve as a pre-treatment plant to reduce the high strength of faecal sludge to acceptable degrees before its final discharge into the aerobic ponds at Dompoase, Kumasi.

4.7.5 Ammonium nitrogen removal efficiencies

The removal of Ammonium- Nitrogen (NH_4-N) concentrations were appreciable. The influent ammonium nitrogen concentration ranged from 458mg/l to 5778 mg/l with the mean value of 2939 mg/l. The mean removal efficiency of NH_4-N was 92 % and

88 % by the Sistema Biobolsa and BIOROCK respectively. The NH_4-N concentration ranged from 56mg/l to 860mg/l for Sistema Biobolsa and 34mg/l to 1335 mg/l for BIOROCK. The results obtained indicated that organic matter concentration decreased as a result of the anaerobic degradation process. This means that the organic nitrogen in organic compounds has been consumed by bacteria and has been converted into amino acids and ammonia gas.

The ammonium nitrogen produced is by the conversion of the organic nitrogen that was consumed by microorganisms for their growth (Grady Jr, 1999). The values obtained from this study indicated that the concentrations of the Ammonium-Nitrogen were below the inhibiting levels and free ammonia concentrations should not pose any challenge to the anaerobic treatment processes. The rise in the concentration of ammonia would be expected during the anaerobic degradation of organic nitrogen, which is converted into ammonia as nitrogen bacteria consume soluble organic matter containing nitrogen. Doku (2002) stated a rise in the ammonia concentration in domestic wastewater treatment during the anaerobic digestion processes.

4.7.6 Total solids removal efficiencies

The influent concentrations ranged from 3,292 mg/l to 25,138 mg/l with a mean value of 8,383 mg/l over the entire treatment process. The mean removal efficiencies by Sistema Biobolsa and BIOROCK were 92 % and 83% respectively. As shown in (Figure 28), the highest concentration of TS in the influent were recorded on the 2nd 3rd, 5th and 8th week. The values obtained were expected owing to the high organic strength of waste received during that time. The TS concentration removal increased gradually towards the end of the treatment. This indicates that with time the effluent quality could be improved.

In both technologies, the TS removal efficiencies never went below 20 %. This indicates some level of TS treatment in both Sistema Biobolsa and BIOROCK. However, the treatment of TS varied slightly as the treatment proceeded week by week. Both technologies demonstrated the possibilities of handling varying influent solid loads, the minimum TS removal efficiencies by Sistema Biobolsa was 82% and BIOROCK with removal efficiency of 23%.

4.7.7 Total volatile solids

The influent TVS concentration ranged from 2,550 mg/l to 17,192 mg/l with mean value of 6,327 mg/l. The TVS removal efficiencies by Sistema Biobolsa was 95%. The effluent concentration removal varied from 126 mg/l to 858 mg/l with mean value of 268 mg/. There was variation in the treatment of TVS in the Sistema Biobolsa but the removal efficiencies never went below 90%. The removal efficiency of TVS was 93% by BIOROCK. The effluent concentration removal varied from 34 mg/l to 401 mg/l with mean value of 170 mg/l. As shown in Figure 29, there were variations in the treatment of TVS in week 2, 3, 5 and 8 of the influent but the removal efficiencies never went below 80%. This demonstrated that both technology have the ability to handle varying load applications over longer periods.

4.7.8 Total suspended solids

The removal efficiencies of TSS were lower than that of the TS in both technologies. The actual concentrations of TSS in influent were between 606 mg/l to 8,229 mg/l with a mean value of 2,932 mg/l. The TSS removal efficiency was 61% by Sistema Biobolsa. The effluent concentration was between 42 mg/l to 5466 mg/l with mean value of 1382 mg/l.

The TSS concentration in BIOROCK was between 16 mg/l to 5812 mg/l with a mean value of 980 mg/l. The removal efficiency of TSS by BIOROCK was 74%. The removal efficiencies of TSS in Sistema Biobolsa were lower than BIOROCK by 13 %. In terms of TSS removal efficiencies, the BIOROCK performance better than that of Sistema Biobolsa. The wide variation between the influent and the effluent TSS was due to the varying strength of the toilet waste received from Clean Team. Coincidently, the TSS of the influent and effluent went up on the 4^{th} and 7^{th} week as shown Figure 31, due to the high strength toilet waste pumped into the system over the period.

4.8 Percentage composition of biogas from the Sistema Biobolsa digesters.

4.8.1 Biogas Production in the Sistema Biobolsa

The highest mean of methane recorded during the testing was 61.6% (1st digester), 67.7% (2nd digester) and 67.4% (3rd digester) on the 08/12/2015, 04/08/2015 and 30/06/2015 respectively. Bodkhe, (2009) recorded a methane proportion of 70% during anaerobic treatment of wastewater by anaerobic baffled reactor. The methane fraction in the biogas from the 3rd digester was about 59% (Table 18). The minimum mean carbon dioxide fraction was 11.9% and hydrogen sulphide was 185ppm. The 3rd digester recorded, higher percentages of methane, probably due to the treatment capacity of the digester (8000 L). The lower values recorded for 1st and 2nd digesters may be due to biogas escape along with the effluent. The COD removal by sulphate-reducing bacterial and unavoidable biogas measurement limitations. An escape greater than 50% was observed when treating domestic wastewater (Lettinga *et al*., 1993).

Table 18 shows the principal composition of biogas produced from Sistema Biobolsa digesters.

Table 18. Percentage composition of biogas produced by three digesters

Type	Biogas Composition	Periods of Gas Analysis					
		30/06/2015	04/08/2015	14/08/2015	21/09/2015	26/10/2015	08/12/2015
1st Digester	CH_4 (%)	44.9	14.0	42.9	49.5	49.3	61.6*
	CO_2 (%)	32.0	4.8	38.3	33.9	31.1	24.4
	O_2 (%)	20.7	21.0	19.1	26.2	19.5	0.6
	H_2S (ppm)	675.0	385.0	1835.0	2205.0	80.0	575.0
2nd Digester	CH_4 (%)	62.8	64.7*	59.1	50.7	56.4	61.6
	CO_2 (%)	24.5	26.0	28.2	23.0	28.7	24.4
	O_2 (%)	0.1	20.3	0.7	26.2	17.1	0.6
	H_2S (ppm)	1130.0	55.0	1375.0	145.0	695.0	430.0
3rd Digester	CH_4 (%)	67.4*	67.3	66.9	67.0	59.4	63.1
	CO_2 (%)	11.9	18.6	20.1	62.9	24.8	22.1
	O_2 (%)	0.1	0.5	0.8	10.1	12.9	0.1
	H_2S (ppm)	570.0	730.0	805.0	185.0	970.0	1165.0

*The highest mean proportion of methane recorded during the testing.

A summary of bi-weekly biogas measurement from the field is shown in Table 18. Biogas production was observed and the volume of the biogas produced was recorded with Biogas analyser (GFM4XX Gas Analyser). Other miscellaneous data is shown in Appendix 3. The biogas production is an indication of anaerobic digestion in the digesters. The biogas production ranged between 59 to 76% for the 3rd digester. The highest volume of biogas recorded was 67.4% in the 3rd digester of Sistema Biobolsa, whilst the lowest recorded was 14% in the 1st digester. The average biogas recorded throughout the experiment was about 56%.

4.8.2 Trend of biogas concentration in the three digesters of Sistema Biobolsa.

Figure 33 show the trend of methane concentration over the experimental period. Biogas produced in the 1st digester ranged from 14 to 62%. The 2nd digester recorded biogas ranging from 50 to 64%, whilst the 3rd digester recorded biogas ranged between 59 to 67.4%. The mean percentage biogas produced for 1st, 2nd and

3rd digesters were respectively 44%, 59% and 65%. The mean percentage methane production by first, second and third digesters were 44 %, 59% and 65% respectively in paralleled connection.

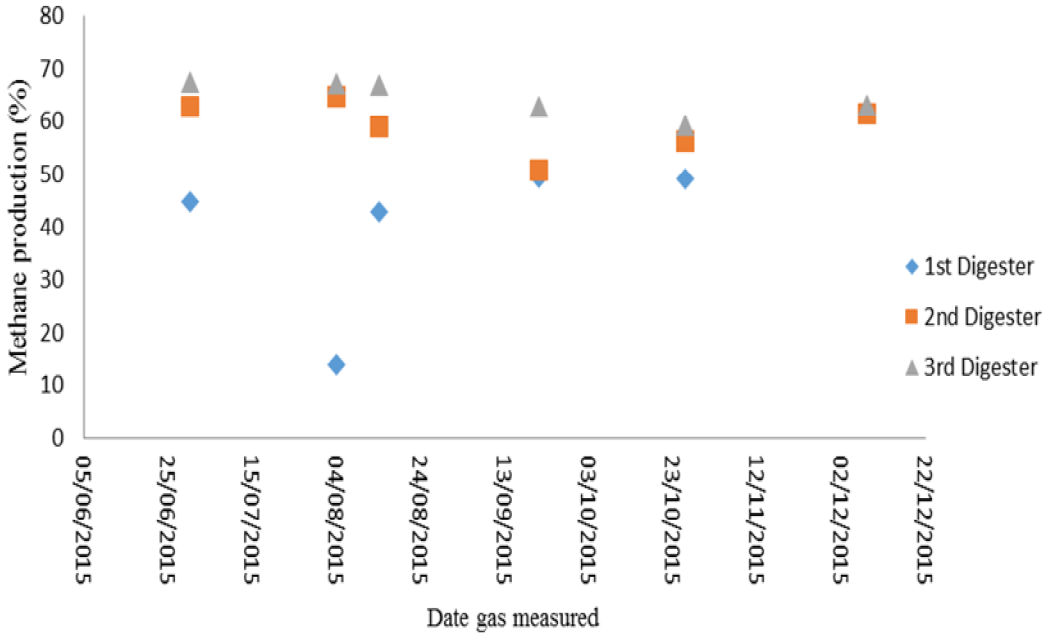


Figure 33. Methane concentrations produced by Sistema Biobolsa digesters

4.8.3 Phytotoxicity

Figure 34 shows the phototoxicity test carried out during the experiment. The phototoxicity analysis demonstrated seed germination with the effluent from Sistema Biobolsa aerobic gravel filter beds (without any dilution). In the 3rd aerobic gravel filter bed, the number of seeds germinated (out of 10) in dilutions of 10 %, 50% and 100% were 8, 9 and 10 respectively.

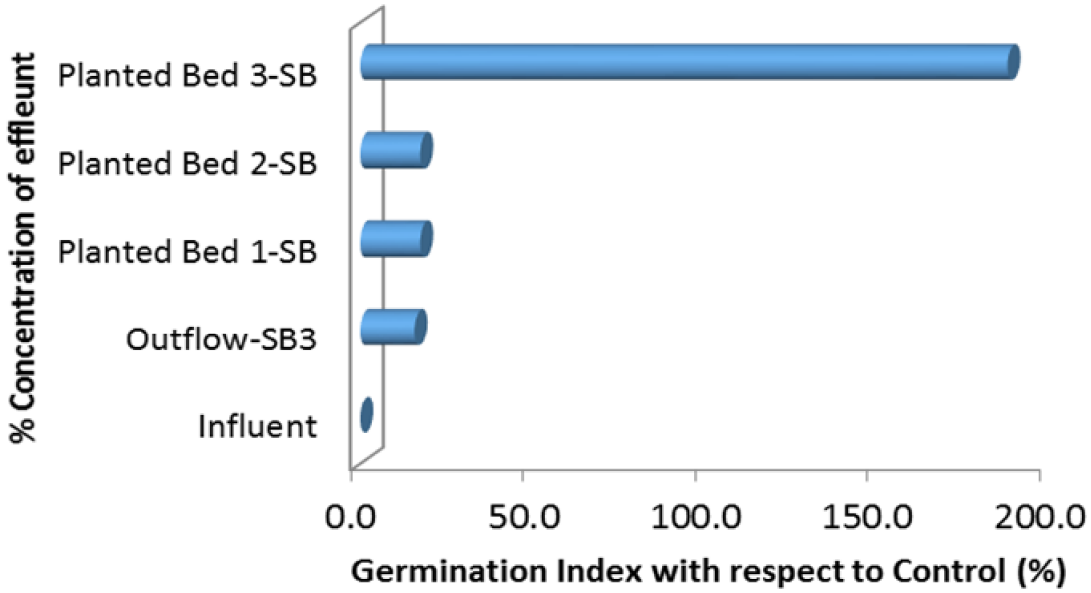


Figure 34. Germination in dilution of Sistema Biobolsa outflow waste.

Figure 35 demonstrated the phytotoxicity test on the outflow of BIOROCK. The test did not show any possible germination of the influent except 10% dilutions where 3 seeds germinated. The GI of the cress/seed in the control (drinking water) was 100%. (10 out of 10 seeds germination). Phototoxicity test on the waste samples from the primary tanks of the BIOROCK recorded germination at 10% dilutions with four seed germination. The number of germinated seeds (out of 10) in dilutions of 10 %, 50% and 100% were 9, 9, 10 for the outflow of BIOROCK after filtration process. Fearn (2015) reported successful germination of cress seeds of percolate/ effluent of BIOROCK in combination treatment with modified drying beds.

Phytotoxicity tests indicate that the input material was toxic, germination was not possible at all, except, 1 germinated seed at 75% dilution (Figure 35). Values above 100% could indicate a positive impact of the effluent on the germination process (Cabañas-Vargas *et al*., 2013).

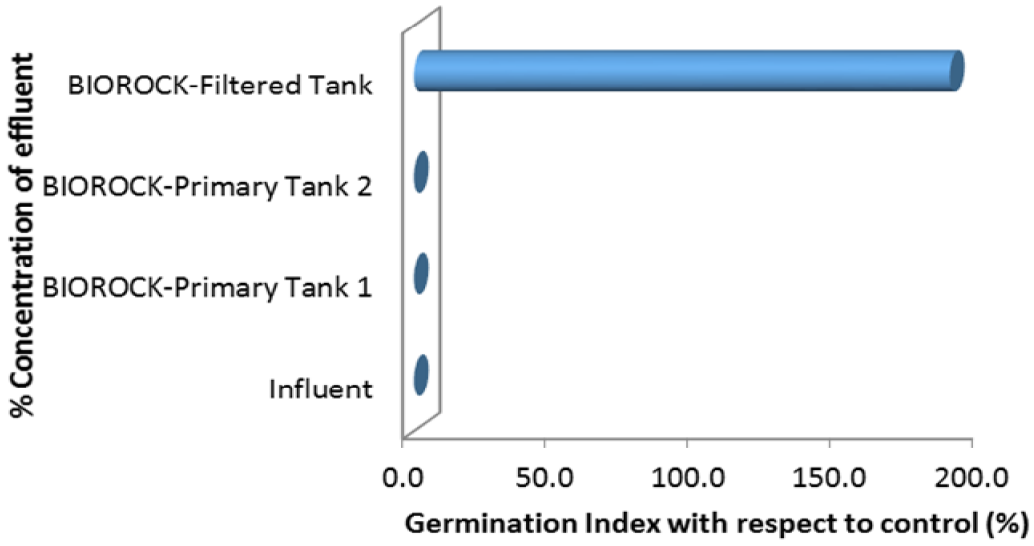


Figure 35. Germination in dilution of BIOROCK outflow waste.

The interest in the use of treated toilet waste is getting much attention due to the possibility of recycling of the valuable nutrients such as Nitrogen, Potassium and Phosphorus, which are essential nutrients for plants (Deepankumar *et al*., 2014). The germination test carried out on both technologies showed a good indication that the final effluent quality support germination of seeds. It was observed 100% germination of effluent from aerobic gravel filters beds of Sistema Biobolsa and 100% germination of effluent from the combine primary tanks and secondary treatment (filtration process) of the BIOROCK.

4.8.4 Comparison of technologies contaminant removal in relation to Ghana Evironmental Protection Agency Guidelines.

Table 19 shows the performance of Sistema Biobolsa and BIOROCK as against the Ghana Environmental Protection Agency guidelines.

Table 19. Summary of technologies performance against Ghana EPA guidelines

Parameter	Ghana EPA values	Minimum and Maximum values measured	
		Sistema Biobolsa	BIOROCK
pH	6-9	7-8	8-9
Ammonia (mg/L)	1	162-2701	34-1335
COD (mg/l)	250	7410-24540	6360-23540
TSS (mg/L)	50	248-6420	16-5812
Alkalinity (mg/L)	150	220-653	131-533

Source: Ghana EPA, (2015), effluent quality guidelines for discharges into natural water.

Although reduction of total solids, Total Volatile solids and NH_4-N exceeded 92%, indicating high performance of the treatment technologies, the final effluent discharged did not meet the Ghana Environmental Protection Agency (GEPA) guideline values. Some of the effluent quality parameters (pH, TSS and Alkalinity) as indicated in Table 19 were found to have met the Ghana EPA permissible values. One way Analysis of Variance (ANOVA) statistical test indicated that, the differences between means of the final effluent COD of Sistema Biobolsa and BIOROCK were statistically not significant (*p-value* =0.25; df = 20 ; p >0.05).

Further statistical test (ANOVA) on the final effluent NH_4-N of the two technologies did not show any significant difference between their means (*p-value*=0.37; df=20; p>0.05). The ability of the technologies to treat Clean Team toilet waste under the ambient conditions, suggests that the technologies have a promising future.

The final effluent quality for COD and NH_4-N could be much better if the aeration gravel beds (Sistema Biobolsa) and aerobic filter bed (BIOROCK) were occasionally cleaned or backwashed. Ghana EPA guidelines may be stricter on direct discharge of wastewater into river bodies. For instance, the maximum standard discharge of NH_4-N in Ghana is 1mg/L and that of UK is 20 mg/L (Fearn, 2015). Therefore, the study is of the view that, considering the nature of waste and the level of treatment as shown in Table 18, the final effluent could be discharge into the aerobic ponds of a wastewater treatment plant. However, the study suggests that further treatment with larger (8-10m^3) aerobic filters, or wetlands, will be required to get closer to the GEPA guidelines.

CHAPTER FIVE

5.0 Discussion

5.1 Treatability of Clean Team Waste

The Sistema Biobolsa and BIOROCK systems (including ancillary components such as gravel beds) are designed to separate, retain and / or anaerobically digest organic solids and to encourage aerobic processes that will further reduce the COD and ammoniacal nitrogen. Therefore, the discussion of the results focuses principally on the solids removal, the COD removal and the ammoniacal nitrogen removal as indicators of the success of treatment. Analysis of the results show a mean removal of 79%, 93% and 90% for COD, NH_4-N and TS respectively in the Sistema Biobolsa. Further analysis of the results from the BIOROCK show a mean removal of 73%, 87% and 86% for COD, NH_4-N and TS respectively. Assessment of the results indicated that a greater proportion of total solid were removed in the digesters of the Sistema Biobolsa as compared with the aerobic gravel filter beds. The results achieved was expected to happen in such a system. The study also observed a greater removal of TS in the primary treatment of the BIOROCK as compared with the secondary treatment.

Rose *et al*, (2015) questioned the possible inhibition of biological treatment of Clean Team toilet waste due to the chemical additive. Assessment of the results suggests treatment by both systems through biological processes is occurring. Analysis of the data collected show a mean COD removal of 62% in the Sistema Biobolsa digesters. The aerobic gravel filter beds further removed 11% of COD in effluent. The study revealed a 52% removal of COD in the BIOROCK primary tanks. Further analysis show 26% COD removal in the aerobic filtration tank. There was evidence of biogas (methane) production in all the three digesters of Sistema Biobolsa. The mean percentage methane volumes in 1^{st}, 2^{nd} and 3^{rd} digesters connected in series were 14%, 56% and 67% respectively.

In this study, ammoniacal nitrogen removal in the Sistema Biobolsa digesters was about 54% and was 33% in the aerobic gravel beds. The study also revealed that, ammoniacal nitrogen removal in the BIOROCK primary and secondary tanks were

54% and 46% respectively. The results achieved was as expected in an anaerobic treatment process. .

With regard to seed germination, the study showed improved seed germination in the effluent waste in both systems compared to the influent. Sistema Biobolsa recorded 100% germination in the outflow wastewater whilst BIOROCK show a seed germination at 10% dilution of outflow waste. Taken together these results, there are strong indicative of the occurrence of biological processes in spite of the presence of the chemical additive and provide confidence that waste of this type can be treated by flowsheet which include biological processes.

Previous authors (Rose *et al.*, 2015) have questioned the treatability of the toilet waste that contained chemical additive, used as an odour suppressor. The authors explained that ingredients of these chemical additives are glutaraldehyde (≥100 mg/L) and Bronopol (≥50 mg/L) which can inhibit methane production.

Gardner and Stewart (2002) also reported that a dose of glutaraldehyde (500mg/L) for seven hours could stop sulphide production completely.

Furthermore, Leung, (2001) reported that glutaraldehyde inhibited the metabolic activities of microbes in wastewater at concentration ≥16mg/L. In this study, the concentration of glutaraldehyde and Bronopol in the effluent was not assessed. The results obtained from the analysis of biogas production and COD removal, support the fact that microbial activities happened in both systems.

The study reported a mean biogas (methane) production by volume of 46% (Table 15), despite Clean Team's chemical additive in the toilet waste. Van Haandel and Lettinga (1994) reported methane production between 20 to 50% in the UASB reactor. The higher values reported in this study could be influenced by the cow manure added at the initial state of treatment as a seed to activate the enzymes in the digesters.

This study attempted to assess the level of pollution and the quality of effluent from the treatment system. To achieve that a phototoxicity test was conducted bi-monthly assess quality of the effluent and safe disposal of the waste into the immediate environment. The study reported a successful seed germination (100%) of the waste from aerobic gravel filter beds of the Sistema Biobolsa. BIOROCK system reported

100 % seed germination after serial dilution ratio of 10% of the effluent from the filtration tank. The successful seed germination suggests that the phytotoxicity of the effluent was reduced by the treatment process. Fearn (2015) reported successful germination of cress seeds of percolate/ effluent of BIOROCK in combination treatment with modified drying beds. The results obtained in this study was consistent with the literature.

5.2 Treatment processes at work in Sistema Biobolsa and BIOROCK

The findings of the study can indicate the probable mechanisms of removing key parameters in Sistema Biobolsa and BIOROCK systems discussed in the previous section.

TS removal

The study reported TS removal of 87% in the Sistema Biobolsa digesters and 7 % removal in the aerobic filter beds. The study also shown that TS removal in the BIOROCK primary tank was 80% and secondary tank was 20%. Total solid accumulation was greater in the digesters than the aerobic tanks of both systems. This was expected to happen in facility of that nature (Raju et al., 2017). Removal of total solids was primarily due to sedimentation processes, prior to secondary treatment systems. Raju *et al.,* 2017 reported evidence of TS accumulation in digesters prior to application of purification treatments like filtration and disinfection. Sedimentation processes in the digesters and primary tanks resulted in the removal of small particulate suspended matter. Other biological constituent (microbes) in the toilet waste are also removed under the influence of gravity. The longer the retention time of sediment, the more the suspended solid and pathogens would settle at the bottom of the digesters.

Total volatile solid removal

The study investigated the total volatile solid (TVS) removal from the treatment system. The study reported 82% removal of TVS from the Sistema Biobolsa digesters and 19% removal of TVS from the aerobic filter beds. It was also found that the TVS removal from BIOROCK primary tank was 63% and the secondary tank was 37 %. The TVS removal was due to the solid retention processes and then biological

degradation processes. Furthermore, the presence of high concentrations of methane indicates biodegradation of faecal solids which led to the reduction of TVS. Further analysis of the results showed that solids were retained in the system through sedimentation and filtration processes. Once retained there was biological degradation of the most volatile fraction of the solids evidenced by the reduced TVS and the production of methane which can only happen biologically.

COD reduction

COD reduction is one of the key parameters used to assess the level of faecal solids retention and degradation that occurs during the faecal sludge treatment. Analysis of the results indicated that COD reduction largely occurred in the Sistema Biobolsa digesters and the sedimentation tanks of BIOROCK. Biodegradation of organic matter in faecal sludge varies depending on the sources. Stabilization of faecal sludge which involve degradation of degradable materials, leaving behind the more stable and less degradable material is important in order to reduce the oxygen demand (Vasilind, 2001). Stabilised sludge consist of particles such as lignin, cellulose, inorganic matter and cellular matter of microorganisms. On the other hand, unstabilised sludge contains degradable compounds like protein, carbohydrates and sugar (Kopp and Dichtl, 2001).

Methane production

In this study, biogas (methane) production occurred in the Sistema Biobolsa digesters as reported in the previous sections. Methane production occurred as a result of anaerobic digestion (a biological process), which is characterised by hydrolysis, fermentation, acidogenesis, acetogenesis and methanogenesis processes (Madigan *et al.,* 2003 and Arthur *et al.,* 2011). The authors further explained that hydrolysis is an enzymatic process through which particulate matter is degraded and at the same time, protein and lipids are converted into amino acids and fatty acids. During fermentation (acidogenesis), acidogenic microorganisms degrade amino acids further into sugar and then fatty acids into methogenic substance such as CO_2, H_2, methanol, acetate and methylamines. Madigan *et al.,* (2003) reported a split of one group of acetate into methane and carbon dioxide and another group produce methane through the use of H_2 and CO_2. The author further

explained that methanogenesis occurs largely at mesophilic temperature ranged (30-38^{O}C) and thermophilic temperature ranged between 49-57^{O}C.

The equations of methanogenesis processes are state below.

Equation 4: $4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$

Equation 5: $CH_3OH + H_2 \rightarrow CH_4 + H_2O$

Equation 6: $CH_3COO^- + H_2O \rightarrow CH_4 + HCO_3^-$

Analysis of the results showed a percentage increase of methane production by volume in the Sistema Biobolsa digesters, connected in series. The 1st, 2nd and 3rd digesters recorded 14 %, 56 % and 67 % methane production by volume. The study revealed a pattern of lower methane concentration in digester 1 and then higher concentration in digester 2 and 3. This suggest that hydrolysis and acidogenesis was predominant in digester 1 and methanogenesis did not get going until digester 2 and 3. This pattern is expected in a plug flow reactor**.**

Ammonical Nitrogen reduction

Ammoniacal nitrogen removal from the wastewater is another biological process that would be desirable in both systems. Nitrification is an aerobic process and therefore is most likely to occur in the filtration parts of the systems. In nitrification, ammoniacal nitrogen is oxidised by autotrophic bacteria (Metcalf and Eddy, 2003). Ammonia oxidising bacteria oxidize the ammonia to nitrite and then nitrate oxidising bacteria, oxidise the nitrite to nitrate as shown in Equations below.

Equation 7: $2NH_2 + 3CO_2 + \text{Nitrosomonas} \rightarrow 2NO_2^- + 2H_2O + 2H^+$

Equation 8: $2NO_2^- + O_2 + \text{Nitrobacter} \rightarrow 2NO_3^-$

The study recorded greater removal of ammoniacal nitrogen in the aerobic gravel filter beds of the Sistema Biobolsa. Similarly, a greater proportion of ammoniacal nitrogen was removed from the secondary tanks of the BIOROCK system. The study showed 96% ammonical removal from Sistema Biobolsa. Out of that value, 30 % removal of ammoniacal nitrogen was from the Sistema Biobolsa digesters alone and the remaining 63 % from the aerobic filter beds. With regards to BIOROCK, 86% ammonical nitrogen removal was reported, out of which 46% of ammoniacal nitrogen

was removed from the primary tank and 40% removal of NH_4-N from the secondary tank.

Phytotoxicity reduction

Autotrophic nitrification of ammoniacal nitrogen and heterotrophic degradation of glutaraldehyde or bronopol. In this study there was no analysis of glutaraldehyde and bronopol. However, the study is of the view that most of the toilet waste treated might have been as a result of biological degradation of the organic matter through the nitrification processes.

5.3 Treatment performance of Sistema Biobolsa and BIOROCK by comparison to analogous systems

The study assessed the treatment efficacy of the Sistema Biobolsa and BIOROCK systems and compared with relevant literature as shown in Table 20. It is evident that there is no uniformity in reporting in terms of variables as shown in Table 20. Authors reported on parameters relevant to their specific research and did not follow any minimum standard of reporting variables. In the past, a number of toilet waste treatment processes with anaerobic digestion has been reported in Netherlands, Japan, Korea and tropical regions as discussed.

The COD removal in Sistema Biobolsa was greater than those reported in literature, with the exception of a study by Pretorius *et al.,* (1996), conducted in South Africa who obtained 90% COD removal using anaerobic digestion process to treat active sludge.

An assessment of NH_4-N removal show a mean value of 1,351mg/l and 369mg/l of the effluent for the Sistema Biobolsa and BIOROCK respectively. It is possible a fraction of NH_4-N could be in the dissolved nitrogen in the settled sludge contents. Influent values for COD from the container toilet waste were found to be higher than most of the faecal sludge values in the literature. The mean influent COD for the study was 45,077 mg/L, while literature values ranged from 1,200 to 50,000 mg/L (Table 20). However, total solids values from the study were lower than literature values. The study influent average was 8,383 mg/L whilst the literature cited values from 12,000 to 52,500 mg/L. The low total solids, but high COD of the container toilet sludge compared to other faecal sludge in the literature may suggest the odour-

suppressing chemical in the container toilet is adding COD to the sludge, as this would not also increase the total solids.

It was found that the influent values for ammoniacal nitrogen from the container toilet waste was in the middle of the range of faecal sludge values in the literature. The mean influent ammoniacal nitrogen for the study was 2,939 mg/L, while literature values ranged from 600 to 5,000 mg/L (Table 20). The effluent values of ammoniacal nitrogen from the study were lower than literature values, except the value 80mg/L reported by (Kengne *et al.,* 2009) on faecal sludge treatment using vertical flow constructed wetlands in Cameroon.

The study effluent mean value range was 216 to 1,351 mg/L whilst the literature cited values from 2,430 to 3,500 mg/L. The low ammoniacal nitrogen of the container toilet sludge compared to other faecal sludge in the literature may suggest that nitrification and filtration process in the aerobic filter beds was efficient. Comparing the ammoniacal nitrogen removal efficiencies by Sistema Biobolsa (93%) and BIOROCK (87%), with the reported value in literature (82 %), it is suggested that the systems performed better than those reported in the literature.

Table 20 Application of anaerobic digestion to toilet waste treatment processes

Feed	Location	Process Type	Flow rate	HRT	pH	Mean Temp	COD			BOD			TS			Ammonia			Ref
							Inf	Eff	Rem rate	Inf	Eff	Rm rate	Inf	Eff	Rm rate	Inf	Eff	Rm rate	
			$m^3.d^{-1}$	d		°C	$mg.l^{-1}$	$mg.l^{-1}$	%	$mg.l^{-1}$	$mg.l^{-1}$	%	$mg.l^{-1}$	$mg.l^{-1}$	%	$mg.l^{-1}$	$mg.l^{-1}$	%	
Public toilets	Various	N/A	*	*	6.6 to 9.3	*	20,000 to 50,000	*	*	7,600	*	*	30,000 to 52,500	*	*	2,000 to 5,000	*	*	[1]
Septic tanks	Various	N/A	*	*	*	*	1,200 to 22,000	*	*	840 to 2,600	*	*	12,000 to 35,000	*	*	150 to 1,200			[1]
Toilet/ septic mix	Ghana	Unplanted drying bed	0.5	15	8.1	*	38,200	3,600 to 5,600	85 to 90	10,000	870 to 1,350	86 to 91	30,450	5,700 to 6,100	80 to 81	1,500	*	*	[2]
Faecal sludge	Cameroon	Vertical-flow constructed wetland	0.1	7	7.5	*	31,100	600	99	*	*	*	370	*	92	600	80	82	[3]
Toilet sludge	Japan	Anaerobic digestion	*	*	8.5	*	*	*	*	*	10,190	*	*	30,100	*	*	3,471	*	[4]
Toilet sludge	Japan	Anaerobic digestion	*	*	*	*	*	*	*	*	12,900	*	*	31,400	*	*	*	*	[5]
Toilet sludge	Korea	Single stage sequencing batch	*	*	7.2	*	*	*	*	*	8,030	*	*	18,150	*	*	2,430	*	[6]
Toilet sludge	Korea	Anaerobic digestion	*	*	7.5	*	*	13,000	*	*	15,900	*	*	38,150	*	*	*	*	[7]
Toilet sludge	Korea	Unheated digestion	*	*	*	*	*	50,200	*	*	16,000	*	*	*	*	*	*	*	[8]
Toilet sludge	China	Anaerobic digestion	*	*	*	*	*	29,500	*	*	16,500	*	*	*	*	*	3,500	*	[9]
Toilet sludge	Tropical	Batch operated settling tank	*	*	*	*	*	*	*	*	35,000	*	*	*	*	*	3.500	*	[10]
Toilet sludge	Ghana	Batch operated settling/ thickening tank	*	*	*	*	*	*	*	*	47,600	*	*	8.800	*	*	*	*	[11]
Container toilet	Kumasi	Sistema Biobolsa	0.3	10	8.0	27.1	45,077	9,683	79	*	*	*	8,383	840	90	2,939	216	93	[12]
Container toilet	Kumasi	BIOROCK	0.1	25	8.3	27.3	45,077	12,269	64	*	*	*	8,383	1,680	83	2,939	1,351	87	[12]

*Values not available

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12. Present study, (2016

5.4 Implications of the findings for the design of container waste treatment facility flowsheet

The study sought to find out the implications of the findings for the design of container waste treatment facility flowsheets. The findings from this study would serve as a basis for container waste facility installation, operation and implementation or support any other projects in future across the globe.

The study revealed that the Sistema Biobolsa and BIOROCK systems are capable of treating Clean Team's waste through a combination of physico-chemical and biological processes. Although substantial reductions in key parameters were achieved by both systems, they were not able to treat all parameters to Ghana EPA standards for discharge to a watercourse as shown in Table 19 above.

The study suggested that in order to reach Ghana EPA standards using these systems alone the size of the aerobic parts of the system relative to the sedimentation parts of the systems would need to be extended which that would mean a high land requirement.

The study further suggested that any stand-alone deployment of these systems (thus, where there is no existing wastewater treatment works), would require a parallel sludge management system such as the drying beds as reported by (Fearn, 2015 and Génevaux, 2015) in theses from Cranfield University, UK.

To help to protect the existing overloaded ponds such as the one at Dompoase or any other sewage treatment technologies, it is also plausible to install and operate a similar treatment system to serve a pre-treatment for Clean Team waste.

5.5 Technology Applicability

5.5.1 Criteria from Clean Team perspective.

Table 21 shows how the two tested technologies met the some of the selection criteria.

Table 21. Technology selection criteria and outcome of the study

No.	Some selected criteria	Outcome of the study
I	Low energy input	Both technologies did not depend on external (artificial) energy to enhance treatment. The treatment of the toilet waste was done under the ambient conditions.
II	Ease of transportation and installation at the treatment site.	Both technologies were transported to Kumasi in the same period. However, it was observed that it was much easier to install the Sistema Biobolsa than the BIOROCK. The unfolding of the Sistema Biobolsa digester bags were done with ease but placing the BIOROCK tanks in the excavated pits required extra care and attention to avoid any damage to the system.

III	Operation and maintenance	Both technologies were simple and easy to operate and maintain. However, it was laborious to load the system manually due to the unavailability to suitable wastewater metering system. In view of that, both technologies had to be manually fed to record the actual volumes of waste added. At a point, BIOROCK primary tank caved in (approximately 30 days after installation). This could be due to the poor soil compaction and that called for extra repair works to be done. The top opening section of the BIOROCK primary tank was deformed due to expansion and contraction. This might be due to the extreme hot weather conditions at the site during the initial stage of installation. This did not have any impact on the treatment performance since mouth part of the tanks were covered with black rubber (polyethylene) underneath the manufacturer's plastic cover. This was done to ensure that the system is protected from direct rainfall and run off.

III	Adequate space to fit at the Clean Team Operation site at Dompoase- Kumasi	BIOROCK occupied (91.7m^2) and Sistema Biobolsa (24m^2). In terms of volume per unit area, BIOROCK occupied 0.16m^3/m^2 and Sistema Biobolsa occupied 0.13m^3/m^2. Using the formula: [Volume/Area] = Total volume of digesters/total area occupied by the technology. At the end of the whole study period, Sistema Biobolsa was fed with about 63.8m^3 of toilet waste, whilst the BIOROCK was fed with approximately 27.4 m^3 of toilet waste, Considering the present toilet waste generation (10m^3/week), it is estimated that Clean Team will require a treatment technology with capacity to treat 30-60m^3 toilet waste with hydraulic retention time (HRT) of 7-21 days. The estimated land area requirement will be approximately 72m^2 to 275.1 m^2

5.5.2 Practical problems encountered and possible sources of error in the study

The influent tank at the site has a volume capacity of 10 m^3. It was filled with Clean Team toilet waste, which was pre-screened to remove debris such as pads, razor blades and other unwanted materials. The influent tank was refilled when the level was less than 1m^3 (approximately at 30 day intervals).

The feeding of the technology would have been much easier and faster if it had been done mechanically. Feeding the technologies were done manually (Appendix 1).Toilet waste was pumped from Clean Team underground holding tank (approximately 50m^3) to fill graduated container (95 litre) before feeding the technology per scheduled volumes. There were frequent spillages and splashes on the researcher in the course of feeding both technology. However, the researcher was fully protected by wearing PPE at all times. The feeding of the technology could be improved in future research by providing flow switch and metering system.

The amount of toilet waste added to the digester on the 18th May 2015 was erroneous. Therefore, it was subsequently flushed with clean water. On the 25th September 2015, a pipe burst at the base of the influent tank caused flooding around the Sistema Biobolsa aerobic gravel beds, diluting the content. It was subsequently flushed with clean water.

In future projects, the loading of waste into the technologies should be considered in the design of treatment plants, as well as the treatment technologies. This is to make is easier to control, and also in case of unsupervised workers to make sure their job is as easy as possible to avoid problems.

The analysis was done in a field laboratory where the power supply was erratic and could therefore cause problems. For instance, samples for total solids and total volatile suspended solids were dried discontinuously for two to three days until they appeared oven dry, cooled at ambient air and weighed. Future

research should consider alternative power supply for the field laboratory such as solar power or extension of electricity to the site.

CHAPTER SIX

6 Conclusions and Recommendations

6.1 Conclusion

As discussed in the previous chapters, both technologies removed considerable proportions of pH, TSS, and Alkalinity. The effluent quality of COD and NH_4-N from Sistema Biobolsa and BIOROCK did not meet the Ghana Environmental Protection (EPA) permissible values of wastewater discharged into water bodies. However, the study is of the view that the technology achieved substantial level of treatment and therefore the final effluent from both technology could be discharged into the waste stabilisation ponds. The EPA guidelines may be stricter for discharge of wastewater into watercourse.

The Sistema Biobolsa in combination with the aerobic gravel filter beds removed 79% of COD, 93% of NH_4-N, 90% of TS, 61% of TSS, and 64% of Alkalinity whilst the BIOROCK primary tanks in combination with the secondary tank (filtration processes) removed 73%, 87% ,86%, 74% and 51% of COD, NH_4-N, TS, TSS and Alkalinity respectively.

The phototoxicity test on final effluent of the Sistema Biobolsa technology recorded 100% seeds germination. The study also reported methane was produced in Sistema Biobolsa digesters in spite of Clean Team's chemical additive. The mean methane production by volume was 46%. The yield of methane could be improved if less concentration of chemical additive (odour suppressant) was used.

6.2 Recommendations

The recommendations were based on the outcome of research work. They are as follows;

- The Sistema Biobolsa technology would be much appropriate for Clean Team's operation, based on the outcome of this study, nature of waste to deal with, volumes of waste to be treated (within the shorted hydraulic retention time) as well as its resources recovery potential. The final effluent could be improved if much bigger (8-10m^3) aerobic gravel or sand filter beds are used.
- The Sistema Biobolsa can be installed, operated in communities and cities where there is no conventional faecal sludge treatment plant to provide a good initial treatment but will require further treatment for discharge into rivers and streams.
- The BIOROCK technology can be installed and operated in areas where there is limited land and would require a supplementary technology, for instance drying beds to deal with the sludge accumulation.

6.3 Suggestion for further work

This study has clearly showed that it is possible to use the Sistema Biobolsa and BIOROCK systems to anaerobically treat toilet waste.

This holds a great potential for toilet waste treatment in developing countries like Ghana, where most of the sanitation systems are on-site. However, before its adoption on a large scale, it would be important to carry out additional experimental studies. In this regard the following suggestions for further research work have been made:

- Experimental study similar to this research should be undertaken over a much longer period to establish steady state conditions that will enable correct assessments of long-term treatment efficiencies, optimal loading rates, optimal hydraulic retention times and sludge accumulation rates. Such a long term experiments will provide the required information for

improvement in design, operation and maintenance for Sistema Biobolsa and BIOROCK.

- Research efforts should be made to find out the dewatering properties of toilet waste when subjected to anaerobic treatment and dry beds filtration processes.
- Future studies should consider removal efficiencies of heavy metals (for instance, Zn, Cu and Cr) in both technologies.
- Further studies should look into methane gas (Biogas) collection and, storage for utilisation such as lighting, heating and electricity to supplement power supply to support Clean Team's operations.
- Further research on phototoxicity testing and Coliform should be conducted to establish the effect of Clean Team's chemical additive on flora and fauna.

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Appendices

Appendix 1



Figure 36. Pumping of toilet waste from Clean Team underground holding tank.



Figure 37. Manual inputting of toilet waste into Sistema Biobolsa

Appendix 2

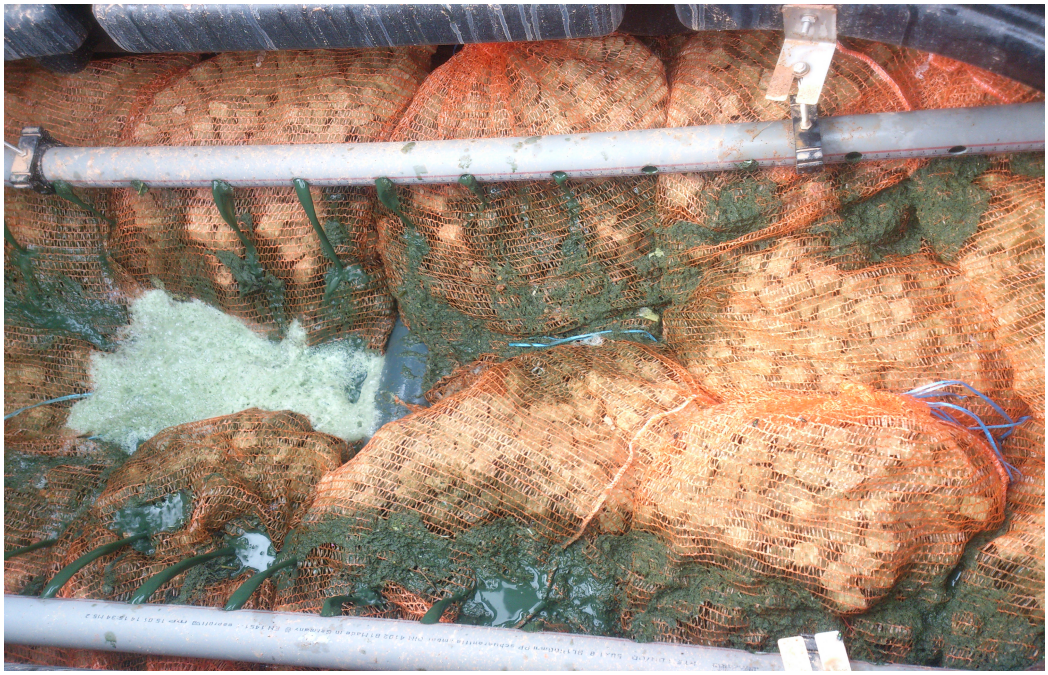


Figure 38. Secondary tank (filtration process)-BIOROCK System



Figure 39. Content of BIOROCK Primary tank.

Appendix 3



Figure 40. Biogas production and testing during the study.

Table 22. Methane (CH_4%) parallel connection with sulphur extractor/refiner

Parallel Connection with sulphur extractor/refiner (CH4 (%))							
Date samples collected	**30sec**	**1min**	**2min**	**3min**	**4min**	**5min**	**Max**
31/06/2015	0	1.5	0.6	2.3	44.9	37.6	44.9
04/08/2015	14	2.9	1.6	0.8	0.4	0.4	14.0
14/08/2015	42.1	42.9	0.4	25.3	0.4	41.9	42.9
21/09/2015	49.4	49.5	49.1	49	0.2	23.2	49.5
26/10/2015	46.6	4.5	49.3	0	0	0	49.3
08/12/2015	46.4	47.7	47.9	47.8	47.6	47.9	47.9
18/12/2015	56.7	60	52.9	53.5	53.6	53.7	60.0

Appendix 4

Table 23. Coliform test results

Date sample collected	sampling points	Dilution Factor	Plate No./labelled	Counts	counts/ (dilution factor)
"28/10/2015"	Influent	Raw	386	28	
"28/10/2015"	Influent	1:50	317	50	
"28/10/2015"	Influent	1:100	312	20	
"28/10/2015"	SB3	Raw	176	50	
"28/10/2015"	SB3	1:50	125	56	
"28/10/2015"	SB3	1:100	102	22	
"28/10/2015"	FB1	Raw	84	38	
"28/10/2015"	FB1	1:50	19	40	
"28/10/2015"	FB1	1:100	151	35	
"28/10/2015"	FB2	Raw	111	38	
"28/10/2015"	FB2	1:50	16	38	
"28/10/2015"	FB2	1:100	2B	29	
"28/10/2015"	FB3	Raw	116	53	
"28/10/2015"	FB3	1:50	49	49	
"28/10/2015"	FB3	1:100	56	56	
"28/10/2015"	BR1	Raw	9	65	
"28/10/2015"	BR1	1:50	6A	27	
"28/10/2015"	BR1	1:100	39	41	
"28/10/2015"	BR2	Raw	N/A	N/A	
"28/10/2015"	BR2	1:50	N/A	N/A	
"28/10/2015"	BR2	1:100	N/A	N/A	
"28/10/2015"	BR3	Raw	1A	35	
"28/10/2015"	BR3	1:50	119	74	
"28/10/2015"	BR3	1:100	83	32	

Appendix 5

Table 24. Seed germination observed (cm) from Sistema Biobolsa effluent-10th August, 2015.

Unit No.	Influent				3rd Digester of SB				Aerobic gravel filter Bed 1				Aerobic gravel filter Bed 2				Aerobic gravel filter Bed 3			
	"1:10	"1:50	"1:100	Raw sample	"1:10	"1:50	"1:100	Raw sample	"1:10	"1:50	"1:100	Raw Sample	"1:10	"1:50	"1:100	Raw Sample	"1:10	"1:50	"1:100	Raw Sample
1	6.6	5.0	4.5	No growth	6.4	3.2	5.3	2.1	2.3	5.3	2.9	0.5	4.3	7.0	1.3	0.5	2.9	5.5	4.7	2.3
2	6.8	5.0	2.0		7.5	3.6	4.0	0.5	3.9	6.0	6.6	0.5	3.7	5.7	1.3	0.5	4.6	7.4	5.5	7.0
3	7.4	1.4	6.0		6.5	0.3	5.5	2.1	3.3	5.1	5.5	0.6	4.8	4.5	1.2	0.6	4.9	4.1	2.1	7.5
4	7.0	3.3	6.4		5.9	3.5	3.1		5.1	4.1	7.2	0.5	3.7	4.0	1.2	0.5	4.0	3.2	2.8	4.6
5	8.3	1.1	3.4		6.5	3.5	3.6		6.0	2.6	5.6	1.0	4.6	5.0	1.5	1.0	6.7	3.7	5.7	6.1
6	8.1	3.8	4.0		0.4	4.2	5.4		5.1	4.4	5.5	0.8	5.6	5.5	0.2	0.8	2.3	5.2	4.6	7.3
7	6.1	0.5	3.3		2.0	5.0	4.8		2.2	0.7	5.2	0.5	4.3	4.2	0.4	0.5	1.2	1.0	4.1	3.5
8	1.5	0.3	2.2		2.8	4.7	4.3		4.9	3.1	3.5	0.8	5.4	5.5	0.6	0.8	1.2	0.5	2.9	6.8
9	5.2		0.3			0.6	1.0		3.2	5.5	2.0		4.2	5.0			1.9	1.4	2.5	2.9
10			1.3			0.9	0.7		3.9	1.0	3.3		1.7	6.0				1.1		8.2
G0	90	80	100	0	80	100	100	30	100	100	100	80.0	100	100	80	80	90	100	90	100

Table 25.Seeds germination observed (cm) from BIOROCK effluent-10th August 2015

Unit No.	BIOROCK Primary Tank 1				BIOROCK Primary Tank 2				BIOROCK Primary/Filtered Tank 3			
	"1:10	"1:50	"1:100	Raw Sample	"1:10	"1:50	"1:100	Raw Sample	"1:10	"1:50	"1:100	Raw Sample
1	1.7	5.4	3.0	No growth observed	2.2	4.6	7.4	No growth observed	3.0	3.5	4.0	2.3
2	6.2	5.3	5.2		2.3	4.9	4.5		5.1	5	4.7	7.0
3	5.5	5.5	4.5		0.7	6.3	5.0		5.9	3.5	5.4	7.5
4	4.5	6.0	5.7		4.2	4.5	4.5		5.0	1.4	1.0	4.6
5	3.4	2.4	4.2		4.0	7.8	6.6		4.0	0.5	5.0	6.1
6	5.6	5.5	5.2		3.6	2.6	4.7		0.6	0.6	2.0	7.3
7	1.0	0.7	1.8		2.5	4.0	4.5		0.6	0.5	5.4	3.6
8	0.5	0.5	4.0			5.2	2.0		5.0	0.2	3.5	6.8
9	0.5		0.6			3.0	2.1		0.3	2.0	5.3	2.9
10	0.6		0.5			5.3	4.0			1.8	0.2	8.2
G0	100	80	100	0	70	100	100	0	100	100	100	100