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ASSESSMENT OF THE SUITABILITY OF SLUDGE FROM DOMPOASE FAECAL SLUDGE TREATMENT PLANT AS A BUILDING MATERIAL

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ASSESSMENT OF THE SUITABILITY OF SLUDGE FROM DOMPOASE FAECAL SLUDGE TREATMENT PLANT AS A BUILDING MATERIAL

By

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DECLARATION

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

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DEDICATION

To the Living God and My Family

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ABSTRACT

Faecal sludge collected from the anaerobic pond at Dompoase Faecal Sludge Treatment Plant (DFSTP) in Kumasi was treated with lime for stabilization. The sludge was characterized by determining its physical, chemical and microbial parameters according to Standard Methods for the Examination of Water and Wastewater. Results showed that 76-79 % and 57-69 % level of stabilization were achieved for BOD and COD respectively. 40% removal of total volatile solids was recorded and up to 75 % removal efficiency of helminth eggs was observed. Optimum stabilization of sludge was achieved at pH 12.3 with a lime dose of 500 g/kg sludge for 120 minutes contact time. Chemical composition analysis of major and minor oxides was carried out on the lime-stabilized sludge and results indicated that the lime stabilized sludge consisted of chemical composition essentially contained in limestone. The lime-stabilized sludge was investigated for its suitability as brick material. The use of the lime-stabilized sludge as brick material provided a viable solution for alleviating disposal problems, closing the sanitation loop, improving economic design of buildings, pollution control and conservation of natural resources. Four different mixing proportions of sludge at 10 %, 20 %, 30 % and 40 % of total weight of sludge-clay and cement-sludge-clay were studied and used as clay supplement in brick making. The hand-moulded bricks were subjected to firing in a heat controlled furnace at high temperatures of 850 ^{o}C, 900 ^{o}C, 950 ^{o}C and 1000 ^{o}C for 10 h. Compressive strength, water absorption and shrinkage of the manufactured sludge-clay brick were determined and evaluated according to British Standard Specifications for Clay Bricks (BS 3921, 2003). Performance evaluation of the burnt bricks as construction materials was also carried out according to standards. The results revealed that between 10 % – 20 % of the lime-stabilized sludge addition could be utilized to make good quality brick for various engineering applications in building and construction. It was also observed that firing temperature and sludge percentage were the main factors that determine the quality of bricks. Increasing sludge content resulted in decreased compressive strength and increased water absorption. The results also demonstrated that increasing the sludge content improved workability of sludge-clay mix.

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LIST OF ABBREVIATIONS

AIA	Alkali-Iodide Azide
AAS	Atomic Absorption Spectroscopy
BOD	Biochemical Oxygen Demand
C_3A	Tricalcium Aluminate
CCA	Calcium Carboaluminate
COD	Chemical Oxygen Demand
DFSTP	Dompoase Faecal Sludge Treatment Plant
FAS	Ferrous Ammonium Sulphate
FS	Faecal Sludge
FSM	Faecal Sludge Management
HRT	Hydraulic Retention Time
LCFA	Long Chain Fatty Acid
MK	Metakaolin
OSS	On-site Sanitation System
RT	Retention Time
SF	Silica Fume
TDS	Total Dissolved Solids
TS	Total Solids
TSS	Total Suspended Solids
TVS	Total Volatile Solids
UNICEF	United Nations Children's Fund
UV	Ultra Violet
VFA	Volatile Fatty Acids
WHO	World Health Organisation
WSP	Waste Stabilization Pond
WWTPS	Wastewater Treatment Plants

CHAPTER 1 : INTRODUCTION

1.1 Background to the Study

The global sanitation needs show that 2.7 billion people are served by on-site sanitation systems that require faecal sludge management, and it is estimated that this number will increase to 5 billion by 2030 (Strande et al., 2014; Strauss, 2000). Based on selected city or town, 65 to 100 % of urban residents in Africa and Asia as well as 20 to 50 % of urban populaces in Latin America are served by on-site sanitation systems (Strauss et al. 1998).

In Sub-Saharan Africa, the urban sanitation coverage estimates 51 % for traditional latrine, 25 % for septic tank, 14 % for improved facilities and 8 % for open defecation while the rural setting covers 51 % for traditional latrine, 2 % for septic tank, 5 % improved facilities and 41 % open defecation (Kjellén et al., 2011).

Progress towards sanitation coverage in Ghana indicates that 20 % of the urban population use improved sanitation facilities, 73 % depend on shared sanitation facilities and 7 % practice open defecation while the rural settings account for 9 % improved sanitation facilities, 45 % shared facilities, 12 % unimproved facilities with 34 % practice of open defecation (UNICEF/WHO, 2015). On-site sanitation systems (OSS) are perceived to satisfying rural sanitation needs, but a substantial number (about one billion) of these sanitation facilities around the globe are located in urban areas with wider coverage than conventional sewer network systems (Strande et al., 2014). The expansion and development of conventional sewer networks is unlikely to keep pace with rapid urbanization especially, in low- and middle-income countries. In Sub-Saharan Africa, 65-100% of access to sanitation in urban areas is provided through on-site sanitation technologies (Strauss et al., 1998).

Faecal sludge (FS) from most of these on-site sanitation systems lack treatment technologies and management mechanisms where there is no faecal sludge treatment plant or the existing plant malfunctions (Strande et al., 2014). The technologies or technical options applied for faecal sludge treatment are categorised into established faecal sludge treatment technologies (co-composting, co-treatment in waste stabilization ponds, deep row entrenchment), transferred sludge treatment technologies (anaerobic digestion, lime addition, sludge incineration, mechanical sludge treatment) and innovative technologies (vermicomposting, black soldier fly, ammonia treatment) for faecal sludge treatment (Strande et al., 2014).

Kumasi Metropolitan Assembly (KMA) is responsible for solid and liquid wastes management in the metropolis. 500 m^3 of faecal sludge is generated daily in Kumasi (KMA, 2015; Obuobie et al., 2006). To manage the faecal sludge generated in the Metropolis, a faecal sludge treatment plant, consisting of six anaerobic ponds, one facultative pond and two maturation ponds to treat faecal sludge and landfill leachate is built at Oti landfill site at Dompoase. The treatment plant has a designed capacity of 300 m^3/day for faecal sludge and 300 m^3/day for leachate from the landfill. With a hydraulic retention time of 3 days, the treatment plant receives a daily discharge of about 52 trips of cesspool emptier, which represent approximately 350 m^3 FS (KMA, 2015). Sludge from the anaerobic pond is charged periodically. Biosolids from faecal sludge tend to saturate and overdose the land with nutrients especially when comparing with manure and industrial biosolids and this limits it agricultural use (Rodríguez et al., 2012). Moreover, sludge composition particularly its metal, organic micro pollutant, pathogen and virus contents, have been recognized as a constraint to its use in agronomy (Rodríguez et al., 2012). Therefore, the use of sludge as construction and building material present an alternative option that transforms the waste into suitable materials which eases disposal difficulties, and has fiscal, environmental and energy-saving advantages (Voglis et al., 2005; Weng et al., 2003).

Extensive studies have been conducted by (Rodríguez et al., 2012; Tay and Show, 1992; Valderramaa et al., 2013; Xu et al., 2014) into the feasible use of sludge and sludge ash as building and construction materials. Additionally, several investigations in the field of cement production (Fytili and Zabaniotou, 2008; Rodríguez et al., 2010), bricks making (Weng et al., 2003) as well as ceramic pellets and ceramic tiles (Zhou et al., 2013) have been carried out.

Due to the composition of sludge particularly its organic micro pollutant, pathogen and virus contents, it is imperative to further treat the sludge with lime. Lime is known to be an amendment material for sewage sludge stabilization, because it plays a considerable role in decreasing the pathogen content, odour, degradable organic matter, precipitate heavy metal content of sludge and lowering the corresponding environmental risks (Samaras et al., 2008; Strande et al., 2014). The process of pathogen reduction during alkaline stabilisation takes into account an increase in ammonia concentration and temperature through exothermic oxidation reactions as well as elevation of pH values (Montangero and Strauss, 2002). Lime effectiveness is improved by longer contact time and higher dosing amount of the lime. However, it is important to consider a number of design parameters like sludge characteristics, lime dose, contact time and pH in order to achieve optimum results from lime stabilisation in the most economical way possible (Strande et al., 2014). Lime stabilization is a cost-effective option with lower capital costs than other treatment options (NLA Fact Sheet, 1999). Other benefits include decreasing hydrogen sulphide generation and reducing metal leachability. Lime treatment of FS also improves biosolids density and physical handling characteristics (NLA Fact Sheet, 1999). An added benefit of lime is that heavy metals can precipitate with the lime. However, the pathogen removing effect of lime also affects desired microbial processes such as composting and other soil processes (Strande et al., 2014). A number of sludge samples dosed with liquid lime indicated that a lime dose in excess of 0.12 kg lime/kg dry solids sludge is adequate to yield stabilized sludge product, provided appropriate mixing is accomplished.

Lime stabilized sludge has been investigated and proved to have exhibited chemical properties (major and minor oxides) contained in limestone (Rodríguez et al., 2012; Tay and Show, 1992; Xu et al., 2014). The chemical effect of limestone shows that the calcium carbonate content within the limestone can interact with aluminate hydrates during hydration process. The process results in the stabilization of the ettringite and possibly increases the volume of the hydration products formed while the porosity of the concrete material is reduced and subsequently intensifies the strength (Meddah et al., 2014). The effects of limestone, as well as other mineral admixtures such as slag, fly ash, silica fume and metakaolin used as partial replacements for Portland cement, have been widely discussed and are now well established and documented (Meddah et al., 2014). Nonetheless numerous areas remain open for research, including the dynamics of crystal growth, the influence of ionic composition and solution concentrations, chemical modelling of phase behaviour of salt mixtures, thermodynamic and kinetic approaches, within the porous material (Cardell et al., 2008).

1.2 Problem Statement

In most developing countries especially Ghana, faecal sludge management still remains a challenge as there is frequent breakdown of treatment plants due to high loading rates.

Sludge from the treatment plant used for agricultural purposes with high levels of viruses, organic micro pollutants, pathogens and metal contents have long term effect on the soil and have been identified as limitation to its agronomic use (Samaras et al., 2008; Sanchez-Monedero et al., 2004). Sludge disposal options used at Dompoase Faecal Sludge Treatment Plant (DFSTP) are landfilling and unlined natural drying beds. Sludge contaminants from these disposal options end in gutters, river bodies, seawaters and have varying degree of public health risks, water bodies contamination and polluting the environment at large (Liew et al., 2004). The utilization of sludge from faecal treatment plant as resource recovery has not gained much social acceptance and recognition despite sludge accumulation in urban and peri-urban areas. However, due to rapid urbanization, building and construction industries consume conventional materials such as clay, sand, gravel, cement, and timber that cause direct or indirect depletion of natural resources and environmental degradation (Lissy and Sreeja, 2014) and with increasing concern over the disposal of sludge onto agricultural land, it seems obvious that the recovery of sewage sludge as a building and construction raw material can be considered as an important step in the right direction (Liew et al., 2004).

1.3 Research Objectives

The main objective of the research is to lime treat anaerobic pond sludge and assess the suitability of the end product as a building material.

The specific objectives are:

- To investigate the physical, chemical and microbial characteristics of the anaerobic pond sludge.
- To determine the lime dosage and contact time required to achieve a pH suitable for stabilisation of the sludge.

- To assess the suitability of the lime-stabilized sludge as a building material.

1.4 Justification

This research seeks to employ treatment technology where faecal sludge from anaerobic pond undergoes stabilization through lime treatment. Lime stabilization of faecal sludge reduces the oxygen demand, odour content, vector attraction and pathogen levels. It improves dewaterability of sludge, produces stable and enhances sludge physical handling characteristics as well as allowing for easy storage and manipulation of sludge (NLA Fact Sheet, 1999; Strande et al., 2014). Lime stabilization process compared to composting, thermal drying, and digestion technologies shows unit cost of 60 % lower than other alternatives (NLA Fact Sheet, 1999). The anaerobic sludge after undergoing lime treatment will serve as a method of protecting environmental pollution and improving public health risks. The limestabilized sludge can then be harnessed for its potential resource recovery and value creation as construction and building material. Due to large demand of building material as a result of rapid urbanization, it is necessary to investigate and convert municipal and industrial wastes to useful materials that can be used in the building and construction industries. Recycling of such wastes (faecal sludge) and integrating into building materials provide a viable solution not only for its pollution control (Lissy and Sreeja, 2014) and closing the sanitation loop, but also the problem of economic design of buildings (Weng et al., 2003) and reduction in the depletion of natural resources (Liew et al., 2004).

1.5 Scope of Research

The thesis considers the characterization of faecal sludge from anaerobic pond based on its physico-chemical and microbial parameters before and after treating the sludge with hydrated lime. During lime treatment of sludge samples, investigations were made to ascertain the amount of lime dosage required to cause stabilization of the sludge from the anaerobic pond. The contact time within which the sludge went through lime stabilization was also determined. Further analyses on the characteristics of the lime-stabilized sludge were conducted and its suitability as a building material examined.

1.6 Organisation of Report

This thesis consists of five chapters. Chapter 1 deals with the introduction, which presents background information of the study and the problem statement. It also highlights the research objectives, justification and the scope of the study. Chapter 2 presents a review of the various literatures relevant to the research. The approach and methodology used to undertake the research work as well as the baseline data of the study area are also described in chapter 3. Chapter 4 also presents detail results and discussions of the main findings of the thesis. The final chapter gives precise account of conclusions and recommendations from the results and discussions outlined in the study.

CHAPTER 2 : LITERATURE REVIEW

2.1 Faecal Sludge

Faecal sludge (FS) is described as human excreta that originates from onsite sanitation technologies such as pit latrines, septic tanks, aqua privies, dry toilets as well as unsewered public ablution blocks, and which has not been transported through any sewer network (Strande et al., 2014). The excreta are either raw, partially digested, a slurry or semisolid. The sludge results from the collection, storage or treatment of combinations of the excreta and blackwater, with or without greywater (Strande et al., 2014). FS is highly variable in consistency, quantity, and with varying concentrations of settleable solids content of faecal as well as non-faecal matter (Eawag and Sandec, 1998; Nkansah, 2009). Furthermore, the sludge exhibits varying degree of biochemical stability attained through anaerobic digestion mainly, depending on the ambient temperature, retention period, and inhibition or enhancement due to the presence of other non-faecal substances. Faecal sludge is generally grouped into high and low strength sludge (Strauss, 2000; Strauss et al., 2002). High strength sludge is mostly fresh with high organics, ammonium and solids concentrations; and originates from non-flush or pour-flush public toilets and bucket latrines which is kept for some days or weeks preceding collection (Strauss et al., 2000). Low strength sludge consists of sludge which has been retained in its containment several months to years and has undergone biochemical digestion to some extent (Strauss et al., 2002). The sludge is considered weak as the solids removed from the pits are usually collected together with flush and greywater stored in the tank (Strauss et al., 2000).

2.2 Sanitation Technologies in Kumasi

Kumasi, the second largest city of Ghana has several sanitation systems. Some of the sanitation facilities in the city are Kumasi Ventilated Improved Pit (KVIP), pour flush, aqua privy and water closet. About 38 % of the inhabitants of Kumasi use public toilet. There are 400 public toilet facilities in Kumasi, equipped with either flush toilet with a holding tank or KVIP with double pits per latrine or single pit per latrine. 26 % of the population use household water closets linked to septic tanks and seepage pits, 8 % of the residents are connected to a sewerage system, while the rest of the inhabitants use other shared sanitation facilities (KMA, 2015; Obuobie et al., 2006). Five separate small-scale sewerage systems currently exist in Kumasi. There is one conventional system at a local university (KNUST) and one connecting the Komfo

Anokye Teaching Hospital (KATH), Golden Tulip Hotel and the central parts of the 4BN Army barracks. There are two satellite systems at Ahinsan and Chirapatre suburbs and one simplified sewerage system at Asafo suburb (Obuobie et al., 2006). Currently, Kumasi Metropolitan Assembly (KMA) is operating a faecal sludge treatment plant at Oti landfill site at Dompoase with a design capacity of 300 m^3/day of faecal sludge and 300 m^3/day of leachate from the landfill. The actual inflow of sludge is about 350 m^3/day of the 500 m^3 collected per day by on-site systems (KMA, 2015; Obuobie et al., 2006).

2.3 Characteristics of Faecal Sludge

The characteristics of FS generated are to large extent difficult to define and determine as a result of different onsite sanitation technologies in existence (Strande et al., 2014). These onsite sanitation technologies such as pit latrines, public ablution blocks, septic tanks, aqua privies, and dry toilets either are used as separate sanitation facilities or exists side-by-side, and there is generally incidence of different technologies in different geographical regions; with various types of pit latrines as the predominant form of FS containment technology. Parameters considered for the characterisation of FS include solids concentration, chemical oxygen. demand (COD), biochemical oxygen demand (BOD), nutrients, pathogens, and heavy metals (Strande

et al., 2014).

2.3.1 Biochemical Oxygen Demand of Faecal Sludge

BOD is a measure of the oxygen content used by microorganisms to degrade organic matter (Strande et al., 2014). As FS is considered to have much higher BOD values than strong wastewater, it is very imperative to observe its oxygen demand. This is because the discharge of FS into the environment potentially decreases the oxygen content of water bodies that causes possible death of aquatic organisms. The reduction of oxygen demand of FS is through stabilization, and this is achieved through aerobic or anaerobic treatment. However, dewatering of FS does not decrease oxygen demand. BOD determination is an experimental test in which standardized laboratory methods are used to measure the relative oxygen requirement of wastewater (Kruis, 2005). The test measures the oxygen utilized during a specified incubation period for biochemical degradation of organic matter and the oxygen used to oxidize inorganic material. It can also measure the oxygen used to oxidize the reduced form of nitrogen unless an inhibitor prevents its oxidation. The standard BOD analysis involves incubation at 20 ^{o}C for 5 days, and it is reported as BOD_5 in mgO_2/L. If measurement of almost all biodegradable material is required, BOD_{25} is used (Henze and Comeau, 2008).

2.3.2 Chemical Oxygen Demand

In order to permit comparison of stability or biodegradability, different parameters are used to characterize faecal sludge. Chemical Oxygen Demand (COD) defines a measure of the carbonaceous or organic content of faecal sludge (Still and Foxon, 2012). The COD describes the measure of oxygen equivalent of organic material in wastewater which can be oxidized chemically using dichromate in acid solution (Tchobanoglous et al., 2014). Measurement of COD can be carried out in hours as opposed to days for BOD (Henze and Comeau, 2008). The content of COD can be divided into fractions necessary for mass balances, design and treatment processes of wastewater treatment (Tchobanoglous et al., 2014). The higher the COD, the higher the organic matter content and the less stable the sludge. Strauss et al. (1997) describes COD levels of 20,000 to 50,000 mg COD/L for fresh sludge from on-site sanitation systems, < 15,000 mg COD/L for sludge which has been stored for several years and 500 - 2,500 mg/L for sewage sludge as cited by (Kone and Peter, 2014; Still and Foxon, 2012).

2.3.3 Total Volatile Solids

Volatile solids are used as a measure for sludge stabilisation, as they are considered to consist mainly of readily degradable organic matter. Total volatile solids (TVS) can be used to evaluate the level of degradation that has occurred during FS treatment (Fernandes et al., 2007; Strande et al., 2014). Data on TVS content in septage indicates that anaerobic degradability of FS differs significantly. (Strauss et al., 2000) in their work recommended TVS value of 40 - 50 % at temperatures of 26 - 28.5 °C, hinting to a rather stable product. A study conducted on septage quality in tropical and temperate climates reported TVS values about 60 % of TS (Strauss et al., 2000). Findings by the US EPA (1984) tend to support this assumption that anaerobic digestion of septage yielded TVS reductions of 30 - 47 %. The work of (Samaras et al., 2008) highlighted TVS of 72.1 %

2.3.4 Total Solids of Sludge

The total solids (TS) are measured as the material remaining after 24 hours of drying in an oven at 103 - 105 °C (Kone and Peter, 2014; Strande et al., 2014). TS concentration of FS consists of organic (volatile) and inorganic (fixed) matter. Total solid values are important as they are used to design and size the most suitable type of treatment operation and process for FS treatment technologies (Strande et al., 2014) and subsequently used to assess the reuse potential of wastewater biosolids (Kone and Peter, 2014). Results from FS settling tests carried out in Accra by (Strauss et al., 2000) show an average TS concentration of 11,900 mg/L representing 60 % volatile solids (TVS). Based on investigation on physico-chemical properties of sewage sludge, a value of 14.8 % TS is reported by (Samaras et al., 2008) for sewage sludge.

2.3.5 Heavy Metals

To use raw or treated faecal sludge for soil improvement in agriculture or to bring back fertility in damaged soils, it is essential to consider heavy metals. Heavy metal accumulation in soils and crops may be achieved by limiting repeated land application of raw sludge. Several standards for maximum heavy metal concentration required for land application and maximum yearly load (kg/ha.year) of specified heavy metals which may be applied for soils have been investigated (Montangero and Strauss, 2002). Samaras et al. (2008) reported heavy metal concentration of sludge for Cd=0.57 mg/kg, Cr=183 mg/kg, Pb=17.8 mg/kg, Ni=71.3 mg/kg, Cu=101 mg/kg, Zn=721 mg/kg.

2.3.6 Helminth Eggs

The term helminth is usually used to describe worms collectively. These worms are generally classified as roundworms, flatworms and segmented worms (Tchobanoglous et al., 2014). Helminth eggs, which range in size from 10μm to more than 100μm are found in high amount of pond sludge and the fundamental removal mechanisms is through sedimentation, filtration and stabilization processes (Konatéa et al., 2013; Tchobanoglous et al., 2014) and are enhanced by relatively long hydraulic retention time and settling velocities (Konatéa et al., 2013). Ascaris eggs which are exceedingly resistant to environmental conditions require further treatment (Tchobanoglous et al., 2014). The required storage duration for pathogen reduction and die-off depends on the ambient temperature, sorption, UV radiation, dryness and pH (Strauss, 2000). Research conducted by (Niwagaba, 2009; Strande et al., 2014) recommended storage time of ascaris eggs in FS for up to one year at an ambient temperature of 35 ^{o}C, and two years at 20 ^{o}C. A report by (Niwagaba, 2009) indicated longer survival period of two to three years for ascaris at 22-37 °C. Based on current knowledge of ascaris egg survival, several months of storage at temperatures greater than 25 °C or sludge water content less than 5 % (TS ≥ 95 %) is essential to render thorough egg inactivation (Montangero and Strauss, 2002). Helminth eggs concentration of 10^1 – 10^3 eggs/gTS in the sludge of anaerobic pond was reported by (Von Sperling, 2007). Investigations into reduction or removal of organisms revealed that helminth eggs removal of 78 - 99 % was achieved for waste stabilisation ponds (Jimenez-Cisnerosand and Maya-Rendon, 2007). A study on parasite removal by waste stabilisation pond also indicated that anaerobic pond with one to two days hydraulic retention time will remove 90–95 % of the eggs of hookworm and other helminth, while facultative and maturation ponds in series, with a total retention time of five days equally remove all helminth eggs (Konatéa et al., 2013).

2.4 Waste Stabilization Pond

Waste Stabilization Ponds (WSPs) are big, superficial basins consisting of anaerobic, facultative and maturation ponds where raw sewage is treated through natural methods using algae and bacteria (Van der Steen, 2014). WSPs are usually used for the treatment of sewage in moderate and tropical regions, and remain the most costeffective, consistent and simply operated approach for treating domestic and industrial wastewater (Kayombo et al., 2005). WSPs also have the capability of meeting the demand for a high percentage removal of pathogenic organisms and faecal coliform bacteria compared to conventional technologies (Tilley et al., 2014; Van der Steen, 2014). Energy from the sun is the sole prerequisite for its operation. Moreover, its operation needs least supervision and basic cleaning of the outlet and inlet works. Waste stabilization ponds are suitable for tropical low-income countries where conventional wastewater treatment cannot be achieved as a result of a reliable energy supply (Kayombo et al., 2005).

2.4.1 Anaerobic Ponds Treating Faecal Sludge

Anaerobic ponds (APs) are unmixed basins which are specifically designed to enhance the settling and biodegradation of organic substances by anaerobic digestion processes. To decrease the likelihood of oxygen penetration at the pond surface to other layers and ensure thorough anaerobic conditions, APs are usually designed with a depth of 3 m to 5 m and hydraulic retention time (HRT) of 1 to 3 days (Eawag and Sandec, 1998; Kayombo et al., 2005; Van der Steen, 2014; Von Sperling, 2007). Though, organic loading rates for anaerobic ponds treating FS have not been established yet, researchers propose that rate of 600 - 700 g BOD/m^3 per day may be acceptable in warm climatic conditions as opposed to 300 - 350 g BOD/m^3 day for ponds treating wastewater (Strauss et al., 2000). However, depending on the design temperature, anaerobic ponds may receive volumetric organic loading in the range of 100 to 350 g BOD_5/m^3 day (Varón and Mara, 2004; Von Sperling, 2007). Montangero & Strauss, 2002 suggest a safe volumetric BOD loading rate of 300 g BOD/m^3·d for anaerobic wastewater ponds at temperatures above 20 °C with a tolerance value of ≤ 400 g BOD/m^3·d of which odour emissions can still be avoided (Van der Steen, 2014). Accumulation of sludge causes actual pond volume to decrease and this shortens the HRT and result in incomplete settling and incomplete anaerobic degradation (Van der

Steen, 2014). Therefore, pond desludging is required after onethird of the pond volume is filled with sludge (Van der Steen, 2014) and a desludging interval of 0.5 to 2 years, as opposed to facultative ponds with desludging frequency of 3 to 10 years (Eawag and Sandec, 1998). However, a shorter retention time (RT) of 1.0 to 2 days is proposed by (Kayombo et al., 2005; Von Sperling, 2007). Anaerobic ponds are suitable alternative for faecal sludge treatment in tropical countries (Eawag and Sandec, 1998), and are generally linked with facultative ponds. Because of their big size in nature as well as long hydraulic retention periods, anaerobic ponds are considered as low volumetric organic load reactors. The processes of the anaerobic pond operations are comparable to septic tanks and applies similar elementary removal mechanisms. As a result of high organic strength of the faecal sludge, anaerobic ponds with or without preceding solids removal in distinct settling units are viable options for primary pond treatment in tropical regions (Eawag and Sandec, 1998).

2.4.2 Anaerobic Treatment Processes

During anaerobic digestion, a group of facultative and anaerobic microbes through hydrolysis and fermentation convert complex organic compounds like carbohydrates, proteins and lipids into simpler organic materials, mostly volatile fatty acids (VFA), as well as carbon dioxide and hydrogen gases (Van Lier et al., 2008; Varón and Mara, 2004; Von Sperling, 2008). Organic acids mainly VFAs and hydrogen are converted into methane and carbon dioxide by methanogens, that are mainly anaerobic prokaryotes (Van Lier et al., 2008). The methanogens carry out two elemental functions during anaerobic degradation. That is, the methanogens produce an insoluble methane gas that facilitates the elimination of organic carbon from the environment, and also retain hydrogen gas partial pressure as small as possible to permit the environment within the medium for fermenting and acid-producing bacteria to yield more oxidised and soluble products, like acetic acid (Von Sperling, 2008).

2.4.3 Removal Efficiencies of Anaerobic Pond Treating Faecal Sludge

The level of BOD elimination rate in anaerobic ponds typically ranges from 50 % to 70 % (Von Sperling, 2007) while a removal efficiency of 60 to 70 % is reported by (Strande et al., 2014). BOD_5 removal is 40% at temperatures ≤ 10 °C, increasing linearly to 70 % at 25 °C and above, and a retention time of one day is sufficient for wastewaters with a $BOD_5 \leq 300$ mg/L at temperatures above 20 °C (Kayombo et al., 2005; Varón and Mara, 2004). BOD removal efficiency of 40-60 %, TSS 50-70 %, 90 % of faecal coliforms and helminth eggs of 75-90 % are reported by (Van der Steen, 2014). Generally, a reduction in the BOD between 75 and 85 % is realized with effluent BOD concentrations of less than 40 - 50 mg/L. Total removal efficiency regarding COD and TSS are up to 70 – 80 % and sometimes even higher (Van Lier et al., 2008).

2.5 Lime Treatment of Faecal Sludge

2.5.1 Treatment Overview

Quicklime (CaO) and hydrated lime [$Ca(OH)_2$] are the most commonly used products for sludge stabilization. Quicklime is derived from limestone by a high temperature calcination process; quicklime is then hydrated to get slaked lime, also known as hydrated lime, or calcium hydroxide as indicated in the equations below:

$$CaO + H_2O \rightarrow Ca(OH)_2 \quad (2.1)$$

$$Ca(OH)_2 + CO_2 \rightarrow CaHCO_3 + H_2O \quad (2.2)$$

However, quicklime does not mix easily with liquid sludge and needs to be slaked before application. As a result, hydrated lime is often applied to liquid sludge, which facilitates its mixing, enabling sludge solids formation and lime to remain suspended in the reacting vessel. Treatment of sludge with hydrated lime modifies the structure of the sludge through ion exchange process. The calcium cation replaces other cations leading to agglomeration of sludge particles (AustStab, 2010). The net effects of the hydrated lime reacting with the sludge are:

- there is considerable decrease in the adsorbed water layer of the sludge, resulting in lowering the water holding capacity of the sludge
- an increased internal friction among sludge agglomerates leading to greater aggregate shear strength
- much greater workability due to the textural change to sand-like material Moreover, the lime raises the pH above 12, which encourages chemical reactions that lead to the formation of calcium complexes. These complexes are soluble in high alkaline (pH) environment. The calcium complexes form a gel that coats, binds sludge particles as the chemical processes move toward crystallisation (cementitious) stage and hydrates formation. The rate of crystallisation is temperature dependent and takes some time to reach completion. This correlates to a steady strength gain that can be tracked and measured using laboratory test.

The effects of hydrated lime on physico-chemical properties and molecular composition during the stabilization of sewage sludge are increase in $Ca(OH)_2$ concentration that causes enhanced ammonia release and hydrolyses of fats. and proteins from the sludge macro molecular network. Other effects are transformation of free fatty acids contained in the sludge lipids released to calcium salts and accelerates equilibration of the process, thereby reducing the content of pathogenic microorganisms (Czechowski and Marcinkowski, 2006). The high pH due to the formation of $CaHCO_3$ creates an environment that halts or retards microbial degradation of organic matter. Inappropriate mixing of the lime with the sludge has been shown to result in E. Coli concentrations exceeding 1,000 /g dry solids limit and

the risk of Salmonella being found in the final product (http://www.britishlime.org/documents/stratlime.pdf, n.d.). The dosage of lime (CaO) varied according to the moisture in initial sludge. When the moisture content in initial sludge was between 80 % and 85 %, about 20 - 30 % lime dosage was required (Xu et al., 2014).

2.5.2 Lime Stabilization of Faecal Sludge

Stabilisation involves the degradation of putrifiable, readily degradable material, leaving behind more stable, less degradable organics (Strande et al., 2014). Lime stabilization of FS is important as it reduces the oxygen demand, odour content, vector attraction and cause pathogen destruction. Lime stabilization also improves dewaterability of sludge, produce stable and predictable characteristics as well as allowing for easy storage and manipulation of sludge (Schneiter et al., 1982; Spit et al., 2014; Strande et al., 2014). Addition of lime to sludge during stabilization raises the pH above 12 where all biological actions are destroyed (Boost and Poon, 1998; Schneiter et al., 1982). Moreover, addition of alkaline agent in sewage sludge is expected to cause destruction of pathogens as well as immobilization of metal content (Samaras et al., 2008). Series of studies comparing lime stabilization to composting, thermal drying, and digestion technologies found that lime treated biosolids are cost effective, flexible, meet EPA regulations, as well as safe and further promote recycling (NLA Fact Sheet, 1999).

2.5.3 Contact Time for Lime Stabilization of Faecal Sludge

Contact time and pH during stabilization of faecal sludge are directly related. The pH of the sludge ought to be maintained at a particular level usually above 11 for sufficient time to cause destruction of pathogens. The hydrated lime added should offer adequate residual alkalinity to retain pH elevation until the product is used or disposed of because; the high pH prevents regrowth or reactivation of odour producing and pathogenic organisms. The period of time for which a lime stabilized product will be kept should be taken into account when defining lime dose and the possible pH decay. Reduction in pH (pH decay) of lime stabilized sludge, happens when atmospheric carbon dioxide or acid rain that results in weak acid formation dissolved in water is absorbed. This consumes the residual alkalinity in the mixture slowly resulting in gradual drop in pH. Biological activity then recommences when the pH elevation drops to less than 11. The re-established activity eventually causes the pH drop to continue and generates odour production (http://www.britishlime.org/documents/stratlime.pdf, n.d.). Inappropriate sludge mixing with lime has demonstrated the presence of E. Coli concentrations beyond the 1,000 /g dry solids and apparent risk of Salmonella species detected in the end product (http://www.britishlime.org/documents/stratlime.pdf, n.d.).

2.5.4 Lime Dosage

The amount of lime required to stabilized sludge is directly linked with pH elevation. A lime dose that ranged between 100 - 150 g/kg sludge and 300 - 500 g/kg sludge was required to maintain the pH above 11.0 for 14 days for primary and biological sludge respectively (Schneiter et al., 1982). An investigation into the influence of lime stabilisation of sewage treatment on enteric pathogens showed lime dosage of 60 % sludge (600 g/kg): 40 % CaO/PFA (44.44 g/kg / 355.56 g/kg) with the ratio of CaO:PFA 1:8 to be able to inhibit the growth of bacterial pathogens and keep a pH above 11.0 for 7 days has been reported by (Boost and Poon, 1998). The analysis of liquid lime dosed sludge samples has shown that a lime dose in excess of 0.12 kg lime/kg sludge ds is sufficient to produce an "enhanced treated" sludge product, provided effective mixing is achieved. Poor mixing of the lime with the sludge has been shown to result in E. Coli concentrations exceeding the 1,000 /g ds limit and the risk of Salmonella being found in the final product (http://www.britishlime.org/documents/stratlime.pdf, n.d.). The dosage of lime (CaO) varied according to the moisture in initial sludge. When the moisture content in initial sludge was between 80 % and 85 %, about 20 - 30 % lime dosage was required (Xu et al., 2014).

2.6 Chemical Composition of Faecal Sludge as Building Material

Faecal sludge consists of different characteristics due to its variability. Some of which are carbonaceous and non-carbonaceous. Several studies have investigated the characteristics of FS particularly its chemical properties. The main chemical properties of FS considered in this research are the elements and their oxides form. The work of Tay and Show (1992) investigated the use of municipal wastewater sludge treated with lime as building and construction material and reported an average chemical composition of sludge ash. Similar studies conducted by Tay and Show (1992) also showed chemical analysis of sludge in percent by weight as 20.33, 1.75, 14.64, 20.56, 2.07, 0.51, 1.81 and 7.80 for Si_2O, CaO, Al_2O_3, Fe_2O_3, MgO, Na_2O, K_2O and SO_3 respectively in their form. Rodríguez et al (2012) evaluated lime-mediated sewage sludge stabilisation process in a study. The product characterisation and technological validation for its use in the cement industry stated the chemical composition of sludge mixed with calcium hydroxide as 1.30 for SiO_2,

61.76 for CaO, 0.54 for Al_2O, 0.50 for Fe_2O_3, 073 for MgO, 0.04 for Na_2O, 0.08 for K_2O and 0.57 for SO_3.

2.7 Faecal Sludge as a Building Material

Traditionally, faecal sludge has been known in most developing countries for its common resource recovery as soil conditioner and organic fertilizer because of its indispensable plant nutrients and organic matter that intensifies the water retaining capacity of the soil (Dienera et al., 2014; Donatello and Cheeseman, 2013; Kengne et al., 2014; Sanchez-Monederoa et al., 2004; Strande et al., 2014). Utilization of sludge from wastewater treatment plant (Nair et al., 2013; Tay and Show, 1992; Weng et al., 2003) and suitability of sewage sludge (Liew et al., 2004; Xu et al., 2014) as making bricks for building and construction materials have been investigated. In all these investigations, it was concluded that 10 – 40 wt.% proportion of sludge integration can be applied for amendment of clay. Up to 20 wt.% addition of sewage sludge invariably has no substantial changes regarding the major characteristics of brick

(Liew et al., 2004; Sahu et al., 2013) and it is also possible to use 30 % by weight of sludge in mortar and concrete works (Sahu et al., 2013). However, it was recommended that 10 % proportion of sludge addition in brick with moisture content of 24 % fired from 880 ^oC to 960 ^oC yielded good quality brick (Weng et al., 2003). A research directed at the enduse of faecal sludge as a constituent in the brick industry (Dienera et al., 2014) and the mixture of sewage sludge and clay in the manufacture of lightweight fine building aggregate (Tay and Show, 1992) reported feasibility and applicability of sludge as building and construction material. Studies carried out on the utilization of sludge for making energy efficient bricks revealed that sludge can be used for building purposes owing to its good strength (Lissy and Sreeja, 2014). FS can be incorporated into cement production through stabilization and subsequent drying of the sludge treated with lime (Rodríguez et al., 2012). Sewage sludge ash has been utilized to make bricks, to integrate into concrete mixtures and as a fine aggregate in mortar (Fytili and Zabaniotou, 2008; Liew et al., 2004; Xu et al., 2014). In the manufacture of ceramic split tiles, the application of municipal sewage sludge has been instrumental (Zhoua et al., 2013). The quality and durability of the stabilized sludge as a building material depends on some properties of the brick such as firing shrinkage, water absorption and compressive strength.

2.7.1 Firing Shrinkage

Shrinkage is one of the major parameters considered as a quality of a material for building and construction purposes. The quality of a brick material is guaranteed based on firing shrinkage. Clay masonry material with a shrinkage below 8 % is considered as good quality and durable material (Weng et al., 2003). Shrinkage is also affected by firing temperature. A study conducted to investigate the utilization of sewage sludge as a brick material indicated that increasing firing temperature resulted in increased shrinkage (Weng et al., 2003). The study concluded that to minimise shrinkage during firing process, percentage of sludge addition to the mixture and firing temperature are the major factors to consider.

2.7.2 Water Absorption

In the manufacturing of sludge-clay brick, water absorption is one of the major parameters affecting the durability of bricks. The less water infiltrates into brick, the more durable the brick and the higher resistance the brick offers to the natural environment (Anyakora, 2013; Weng et al., 2003). This suggests that the interior structure of the brick ought to be compact to elude water intrusion. However, the degree of firmness and compaction as measured by its water absorption varies according to the type of clay used (Liew et al., 2004). Several studies conducted by different researchers revealed that the effect of percentage of sludge and clay on water absorption of brick manufacturing increases with increased sludge content and decreased firing temperature, resulting in decreasing its weathering resistance (Anyakora, 2013; Nair et al., 2013; Weng et al., 2003).

2.7.3 Compressive Strength

Compressive strength of a material is a performance measure used in designing buildings and other structures. Compressive strength is the property of the material that defines the loading ability and suitability of the material for building and construction purposes. The test result is a means of ensuring engineering quality of a building material. Compressive strength is computed by dividing the failure load by the cross sectional area resisting the load (NRMCA, 2003; Weng et al., 2003; Yerousis, 2011). The recommended minimum compressive strength for lime stabilized blocks is 1.4 N/mm^2 (Hagan and Osei-Frimong, 2006; "www.dainet.org," n.d.) and 5.0 N/mm^2 (BS 3921, 2003). A research conducted to investigate the use of sludge as brick material revealed that compressive strength is depended on firing temperature and amount of sludge addition (Lissy and Sreeja, 2014; Weng et al., 2003). The result indicated that compressive strength attained at 1000 ^oC fell within the range of normal clay bricks for

10 % sludge addition; while 20 % sludge addition produced brick quality that lied in the first class category and 30 % sludge addition met the requirement of second class brick standard (Weng et al., 2003). Another investigation in the application of sludge in manufacturing of energy efficient bricks indicated that bricks cast with sludge as a waste material showed high compressive strength than control bricks (Lissy and Sreeja, 2014).

CHAPTER 3 : RESEARCH METHODOLOGY

3.1 Study Area

Faecal sludge for the study was obtained from Dompoase Faecal Sludge Treatment Plant (DFSTP) located in the Kumasi Metropolis in the Ashanti Region of Ghana. Kumasi Metropolitan Assembly (KMA) is the second largest city in Ghana with a population of 4,780,380 inhabitants (GSS, 2012). To manage the liquid waste generated in the Metropolis, a faecal sludge treatment plant, consisting of six anaerobic ponds, one facultative pond and two maturation ponds to treat faecal sludge and landfill leachate is built at Dompoase. Construction works of the FS treatment plant began in 2002 and the facility became operational in January 2004 (Abuenyi, 2010; Strauss et al., 2002). The treatment plant was designed for faecal sludge capacity of 300 m^3/day and 300 m^3/day for leachate from the landfill site. With a hydraulic retention time of 3 days, the treatment plant receives a daily discharge of about 52 trips of cesspool emptiers, which represent approximately 350 m^3 FS (KMA, 2015). Layout of faecal sludge treatment plant at Dompoase is shown in figure 3.1. The treatment plant that treats faecal sludge and landfill leachate together is presented pictorially in Appendix C, Plate A.

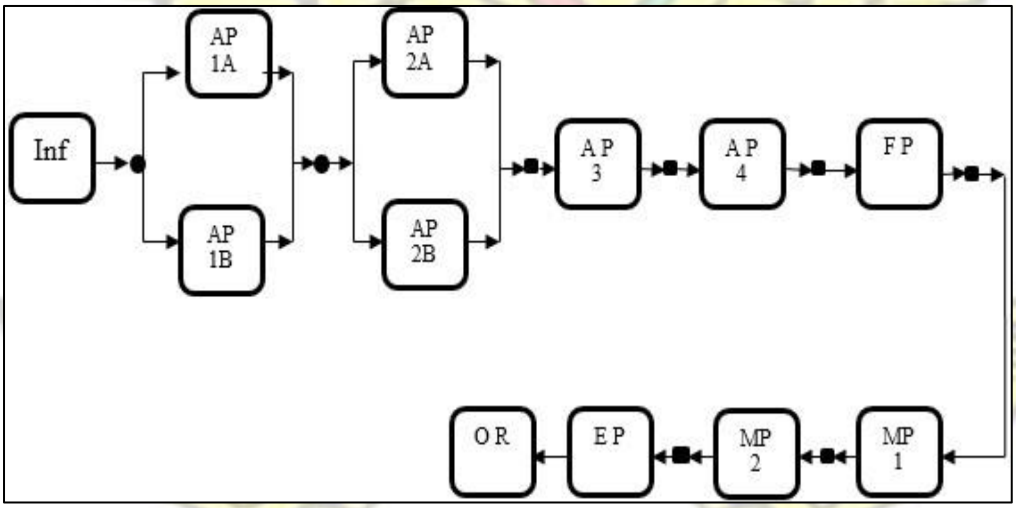


Figure 3.1. Schematic arrangement of faecal sludge treatment plant at Dompoase

●Outlet flow control structure type 1 ■Outlet flow control structure type 2 AP - anaerobic pond, FP- facultative pond, MP- maturation pond EP- effluent pond and OR- Oda river.

3.2 Sampling Materials

50 L containers were used for sample collection. All the sample containers including the lids were cleaned with detergents and thoroughly rinsed with one molar hydrochloric acid (1.0 M HCl) to avoid absorption of detergents and formation of chemical groups with ion-exchange properties onto the surface, followed by rinsing with distilled water and dried before use (Kruis, 2005).

3.3 Sampling Method and Storage

Sludge sample from the anaerobic pond three (AP3) at Dompoase Faecal Sludge Treatment Plant was collected in two weeks' intervals for two months. Sludge samples were collected manually with a help of a scooping pan fitted to the arm of a steel bar. The sludge slurry collected from AP3 was put into the sample containers and transported to KNUST Environmental Quality Laboratory for analysis of physicochemical and microbial parameters. The sludge samples were then treated with hydrated lime for stabilization.

3.4 Physico-chemical Analyses of Faecal Sludge

Summary of laboratory methods used for the analysis of physico-chemical parameters were presented as outlined in standard methods for the examination of water and wastewater (APHA et al., 1999). The physico-chemical parameters carried out were pH, total dissolved solids, moisture content, total volatile solids, biochemical oxygen demand, chemical oxygen demand and heavy metals. Refer to Appendix A for details of laboratory procedures.

3.4.1 Determination of Hydrogen Ion Concentration (pH)

The EUTECH instrument PCS TESTR35 pH meter was used for measuring the pH of the faecal sludge sample from the anaerobic pond. The electrode of the PCS TESTR35 pH meter was rinsed with distilled water and blotted dry. The electrode of the pH meter was placed in the sludge slurry immediately after taking from the anaerobic pond into the sample containers, ensuring that the entire sensing edge of the meter was submerged. The pH values were then recorded when the display on the meter was stable.

3.4.2 Total Dissolved Solids (TDS)

The total dissolved solids of the sludge sample was determined using the method 2540 C outlined in standard methods for the examination of water and wastewater (APHA et al., 1999)

3.4.3 Moisture Content

The equipment used for the determination of the moisture content of the sludge slurry were crucibles (evaporating dish), analytical balance (precision 0.1 mg), water bath, desiccator and drying oven. The wet and dry weights of the sludge sample were measured. The moisture content of the sludge expressed in percentage was determined as follows:

$$\text{Moisture content (\% w)} = \frac{\mathbf{A-B}}{\mathbf{B}} * 100 \qquad (3.1)$$

Where, % w is the percentage of moisture in the sample

A is the weight of wet sample and B is the weight of dry sample.

3.4.4 Total Volatile Solids (TVS)

Three evaporating dishes were heated at 105 ºC for 1 h in an oven and cooled in a desiccator until they were ready for use. The evaporating dishes (crucibles) were labelled and their dry weight measured using the analytical balance. 50 g of homogenized sludge slurry sample each was put in a prepared evaporating dish and the weight of the sludge sample measured using the analytical balance. The evaporating dish and its content were placed on the water bath to evaporate the sludge water content to dryness. The content of the evaporating dish was then dried at a temperature of 105 ^oC for one hour, cooled to balance temperature in a desiccator and weighed. The dried sample was transferred into a muffle furnace and heated to 550 ^oC and then ignited for 1 h. It was then cooled in a desiccator to balance temperature and weighed. Drying (30 min), cooling, desiccating and weighing procedures were repeated until the weight change was less than 50 mg. The TVS was calculated as:

$$\% \text{ Total Volatile Solids (TVS)} = \frac{(A-C)*100}{A-B} \qquad (3.2)$$

Where, A is weight of dried sample and evaporating dish, mg

B is the weight of evaporating dish, mg

C is the weight of sample and evaporating dish after drying, mg

3.4.5 Biochemical Oxygen Demand (BOD)

Determination of biochemical oxygen demand analysis was performed to measure oxygen utilization during five days incubation period for biochemical degradation of organic material and the corresponding oxygen required to oxidize inorganic material in the sludge sample. The Wrinkler Method as outlined by (APHA et al., 1999b; Kruis, 2005) was used for the analysis.

3.4.6 Chemical Oxygen Demand (COD)

The standard open reflux titrimetric method was used for the analysis of the chemical oxygen demand of the sludge sample. Procedure followed was in line with procedures described in standard methods for the examination of water and wastewater (APHA et al., 1999) and procedures outlined in selected analytical methods (Kruis, 2005).

3.4.7 Heavy Metals

10 mL of nitric acid (HNO_3) was used to digest the sludge sample by heating until the nitrous fumes escaped. The digested sample was filtered with Whitemann number one filter paper. Analyses of heavy metals such as Copper, Lead, Iron, Nickel, Arsenic and Zinc were carried out with the Atomic Absorption Spectrometry (3111 B) procedures described in standard methods for the examination of water and wastewater (APHA et al., 1999) .

3.5 Microbiological Analyses

3.5.1 Total Coliform Determination

The membrane filter technique using Chromocult Coliform Agar was used to determine the total coliforms. Serial dilution technique by Hilten and Sanders (1993) was applied and the final solution was filtered through a sterile micro pore filter by suction. After incubation for 24 h, the number of salmon to red colonies was recorded as coliforms by visual examination whiles dark-blue to violet colonies are recorded as *E. coli*. The sum of these two colonies is recorded as total coliforms. Refer to appendix A for detail process description.

3.5.2 Helminth Eggs

Helminth eggs determination procedure used was according to the Modified EPA method (Roussel et al., 2003). Helminth eggs were enumerated using a combination of the floatation and sedimentation method Schwartzbrod (1998). The eggs were identified on the basis of their shape and size and compared with the aid bench aids for the

Diagnosis of Intestinal Parasites (WHO, 1994). The counting was done under a light microscope in both chambers of a haemocytometer at X40 magnification. Refer to appendix for full details of the method.

3.6 Lime Treatment of Anaerobic Pond Sludge

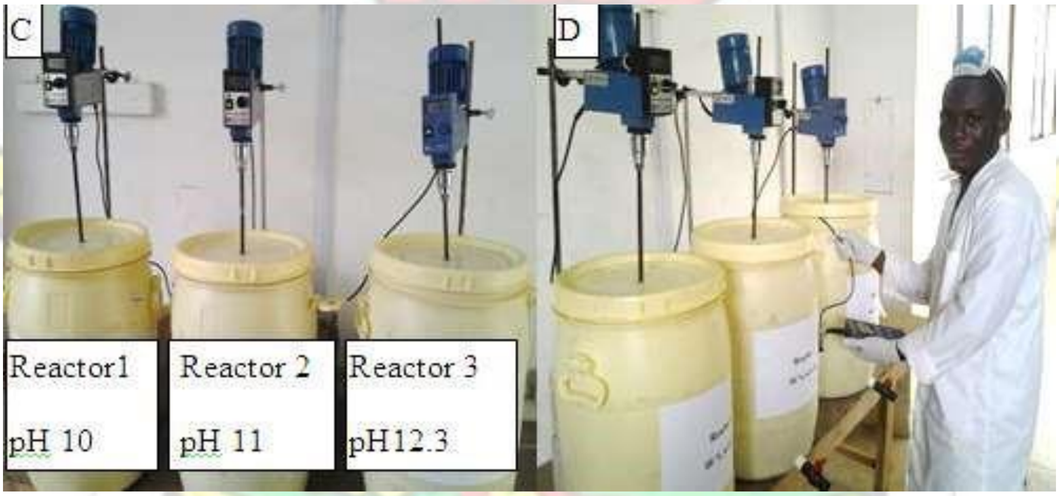
The experiment was carried out with lime dosage based on the solid content of the faecal sludge and was conducted using analytical grade hydrated lime [$Ca(OH)_2$] with 90 % purity obtained from Central Drug House (P) Ltd., New Delhi, India.

3.6.1 Experimental Set-up for pH Control

Three 50 L Plastic Drums, Electric Mixer with agitator (including extension cable), Stirring Stick (50 cm length), Hydrated Lime (90 % purity), Shovel, pH meter, weighing devices, Bathroom scale (5-200 kg) and Kitchen scale (0-5 kg), three 1L plastic sampling bottles, 25 x 60 mL plastic sampling bottles and four sealable bags.

Procedure

Each of the three 50 L drum was filled with approximately 20L of faecal sludge collected from anaerobic pond at DFSTP. The drums were labelled as control, pH 10.0, pH 11.0, pH 12.0 and pH 12.3. The drum labelled control contains the raw faecal sludge from the anaerobic pond without any lime addition. Each of the drum was weighed using the bathroom scale and the sludge weight determined by subtracting the empty drum weight. The sludge in each of the drums was stirred using the electric motor at 120 rpm to make the sludge as homogeneous as possible. Initial samples from each drum were taken using the 1L plastic sampling bottles for pH, moisture content, COD, BOD, TVS, helminth eggs, total coliforms and heavy metals analyses. The initial pH of each sample in the drum was measured using the pH meter and the value recorded. A hydrated lime dose of 100 g was added to each of the 20 L sludge sample as labelled above. The content of the drum was stirred continuously and change in pH was measured at contact time intervals of 10 min, 30 min, 60 min, 90 min and 120 min. 50 g of hydrated lime were added to each of the 20 L drum of sludge sample for similar contact time until a consistent pH of 12.3 was obtained, corresponding to hydrated lime dose of 500 g. Samples at pH 12.3 were taken for the analyses of pH, moisture content, COD, BOD, TVS, and Helminth. The sludge samples were stored for 45 days while pH was monitored following stabilisation.



Sludge mixing during lime treatment C pH measurement during lime

3.7 Determination of Chemical Composition of Faecal Sludge

The chemical composition of FS after treating with hydrated lime was determined using the Atomic Absorption Spectrometry (AAS). The AAS analyzer was used to determine the Si, Ca, Al, Fe, Mg, K, Na, Mn and S of the sludge sample. This was by measuring the content of the metal in a digest obtained by treating the samples with acid mixture made from concentrated nitric acid, concentrated sulphuric acid and per chloric acid (60 – 62) %. The procedure followed for the determination of the metal content followed by the oxide form was outlined by (Chemist, 1979; Corporation et al., 1996; Piper, 1994; Pratt, 1961). The oxide form was then computed using the relation

$$\text{Oxide form} = \frac{\text{Formular weight}}{\text{Element atomic weight}} \qquad (3.3)$$

3.8 Experimental Procedures for Sludge as Brick Material

3.8.1 Materials

The sludge used in this research was collected from the anaerobic pond at Dompoase Faecal Sludge Treatment Plant, Kumasi, Ghana. The sludge was then treated with 90 % purity of hydrated lime and the resulting sludge was sun-dried for one week at average temperature of 33 ^{o}C. The lime stabilized sludge was used at different proportions in moulding the brick. The clay used in this study was also obtained from

Mfensi by Building and Road Research Institute (BRRI), Council for Scientific and Industrial Research (CSIR), Kumasi, Ghana. The clay sample was air-dried for seven days in a cool dry place. The lumps present in the clay sample were crushed using the ball mill. Both samples were sieved using a sieve aperture of 2.36 mm in diameter. Sludge and clay materials passing through the sieve diameter were collected and batched at different proportions of 10 %, 20 %, 30 % and 40 % for the brick moulding. Water absorption, firing shrinkage and compressive strength were tested to determine the quality and suitability of the sludge-clay and cement sludge-clay mix samples as building material according to British Standard Specification for Clay Bricks (BS 3921, 2003) and Chinese National Standard (CNS 1127, 1999), methods of test for general types of bricks for building.

3.8.2 Compressive Strength

Three sets of bricks were moulded for each proportion and fired in the brick kiln at varying temperatures of 850 ^{o}C, 900 ^{o}C, 950 ^{o}C and 1000 ^{o}C for 10h and brick specimens were finally cooled to ambient temperature. The cross sectional area of the fired sludge-clay brick specimens was determined. The compressive strength of the fired sludge-clay brick specimens were determined and compared to British Standard Specification for Clay Bricks (BS 3921, 2003).

3.8.3 Water Absorption

Three sludge-clay bricks each was completely immersed in clean water at room temperature for 24 hours. The brick specimens were removed from the water and allowed to drain for one minute by placing them on a 10 mm or coarser wire mesh. Visible surface water was removed with a damp cloth. The saturated and surface dry brick specimens were weighed immediately. After weighing, all the brick samples were dried in a ventilated oven at 100 – 115 ^{0}C for not less than 24 hours. The brick samples were reweighed until two successive weighing at intervals of 2 hours showed an increment of loss not greater than 0.2 percent of the previously determined mass of the specimen. The water absorption was calculated as given in equation 3.4 below:

$$\text{Absorption percent} = \frac{(\mathbf{A}-\mathbf{B})}{\mathbf{B}} * 100 \qquad (3.4)$$

Where, A = wet mass of unit (kg) and B = dry mass of unit(kg).

3.8.4 Firing Shrinkage

Hand moulding method was used in brick moulding. The wooden mould size used for casting the sludge-clay bricks was 50 mm x 50 mm x 60 mm. The interior of the mould was lubricated with oil to enhance extrusion of the moulded bricks. After lubricating the mould, the moist mixture was placed in each mould and then compacted by tamping.

Nine sludge-clay bricks specimens were made from each proportion of sludge-clay brick mixture with sample having only clay mixture as control. Initial weight of each moulded sludge-clay bricks was determined and subjected to natural air drying for 7 days at an average temperature of 23 ^{o}C in the BRRI laboratory. Shrinkage on air drying and firing were determined as outlined in Chinese National Standards for Methods of Test for General Types of Bricks (CNS,
1999).

3.9 Data Analysis

Analytical procedure for faecal sludge parameters were based on 18th edition of the Standard Methods for the Examination of Water and Wastewater. Data obtained from experimental set up were subjected to statistical analysis using Microsoft Excel 2016.

CHAPTER 4 : RESULTS AND DISCUSSIONS

4.1 Characteristics of Anaerobic Pond Sludge

Three set of faecal sludge samples from the anaerobic pond were collected at two weeks regular intervals and used to characterize the sludge; based on physicochemical and microbial characteristics of faecal sludge before lime treatment. Parameters analysed were conductivity, total dissolved solids, temperature, chemical oxygen demand, biochemical oxygen demand, total coliforms, total volatile solids, helminth eggs, heavy metals and pH (Table 4.1). Conductivity and pH were determined in-situ. COD, BOD, total coliforms were also determined within 24h of sample collection. Total solids, total volatile solids, helminth eggs and heavy metals were analysed after one week of sample collection. The samples were stored at room temperature.

Table 4.1. Characteristics of faecal sludge before lime stabilization

Parameter		Range of Values
Moisture content (% ds)		76.7 – 81.6
Temperature ^{o}C		29.5 – 30.5
pH		7.85 - 7.97
Total solids (TS % ds)		18.4 – 23.3
Total volatile solids (% TS)		77 - 82
COD (mg/L)		976 - 1064
BOD (mg/L)		598 - 660
COD/BOD_5		1.6 – 1.7
Helminth eggs (No/g TS)		10 - 18
Heavy metals (mg/kg)		USEPA, 1994 (mg/kg)
As	0.013 - 0.701	75
Pb	0.064 - 0.214	840
Fe	0.400 - 2.087	n/a
Cu	0.321 - 2.818	4300
Zn	0.026 - 0.347	7500
Ni	3.252 – 5.001	420

4.1.1 Moisture Content and Total Solids of Sludge

The moisture content of the sludge ranged from 76.7 % to 81.6 %. Total solids content of sludge ranged between 18.4 % and 23.3 % dry weight of sludge at 105 ^{o}C (Table 4.1). This indicates that about 18 to 23 % of sludge content will remain as inorganic (stable) material. Based on investigation on physico-chemical properties of faecal sludge, a value of 14.8 % TS was reported by (Samaras et al., 2008) for sewage sludge.

4.1.2 Chemical Oxygen Demand of Sludge

The raw faecal sludge samples from the anaerobic pond had COD values that ranged from 976 mg/L to 1040 mg/L (Table 4.1). Sludge sample two (2) recorded the highest COD value while sample 3 had the least COD value. The difference in COD values of the sludge samples might be attributed to different sources of the sludge and represented faecal sludge variability. The recorded COD values fell within the range of 500 - 2,500 mg/L for faecal and sewage sludge as observed by (Kone and Peter, 2014; Still and Foxon, 2012).

4.1.3 Biochemical Oxygen Demand of Sludge

The study showed that sludge sample 2 recorded the highest BOD value of 660 mg/L followed by sludge sample 1 with BOD value of 624 mg/L while sample 3 had the least BOD value of 598 mg/L of faecal sludge. The COD/BOD ratio of 1.6 illustrates how the faecal sludge readily undergoes anaerobic stabilization and level of organic biodegradation present in the raw sludge before lime treatment.

4.1.4 Total Volatile Solids and Total Solids of Sludge

The total volatile solids of the sludge ranged from 77 to 82 % ds (Table 4.1). The TVS value (77 - 82 % ds) recorded is slightly higher compared to 50-73 % ds reported by

(Strande et al., 2014). This shows that a considerable stabilization of sludge will occur, as readily degradable organic content in the sludge is substantial.

4.1.5 Helminth Eggs Concentration

Table 4.2 as shown in Appendix B summarizes the concentration of helminth eggs at different pH before and after lime treatment of sludge. The four species of helminth eggs analysed showed a high count of Schistosoma 18 eggs/gTS representing 35 %, 12 eggs/gTS of Strongyloides stercoralis in the samples accounting for 23 %, 11 eggs/gTS of Ascaris indicating 22 % and 10 eggs/gTS of Hookworm representing 20 % in the sludge samples and the results are presented in Figure 4.1. Sludge needs to be treated further to be sanitized and render it more hygienic to avoid the spread of diseases.

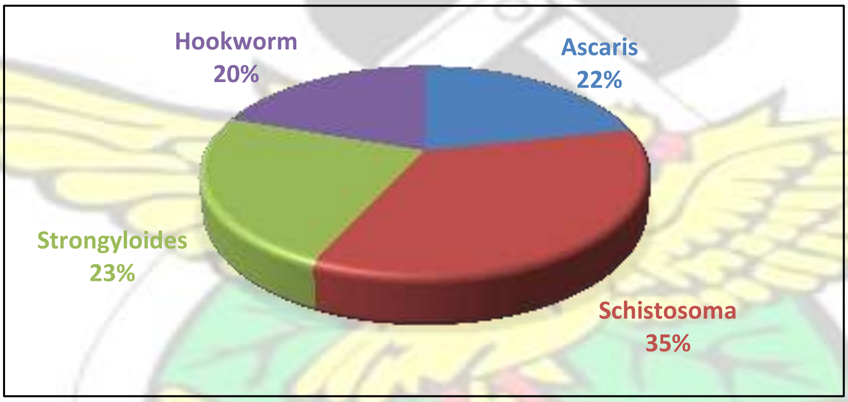


Figure 4.1. Helminth ova concentrations of sludge before lime treatment

4.1.6 Heavy Metal contents of the Sludge

The raw sludge recorded heavy metal concentrations of 0.013 mg/kg for arsenic, 0.064 – 0.214 mg/kg for lead, 0.400 – 2.087 mg/kg for iron, 0.321 – 2.818 mg/kg for copper, 0.026 – 0.347 mg/kg for zinc and 3.252 – 5.001 mg/kg for nickel (Table 4.1).

These concentrations of heavy metals were slightly lower compared with USEPA Standard for biosolids (USEPA, 1994).

4.2 Lime Stabilization of Faecal Sludge

The results of the quantity of lime [$Ca(OH_2)$] dose required to raise the pH of sludge from anaerobic pond to 12.3 and this pH was maintained over a contact time of 120 min were presented in Figure 4.2. The initial pH of the sludge was 7.9. The quantity of lime was successively added to the sludge until a constant pH of 12.3 was obtained.

The amount of lime required to raise the pH of the raw sludge from 7.9 to 9.17 was 100 g/kg sludge at contact time between 10 min and 120 min. Similarly, 250 g/kg sludge was required to raise the pH from 9.52 to 9.97 with the same contact time.

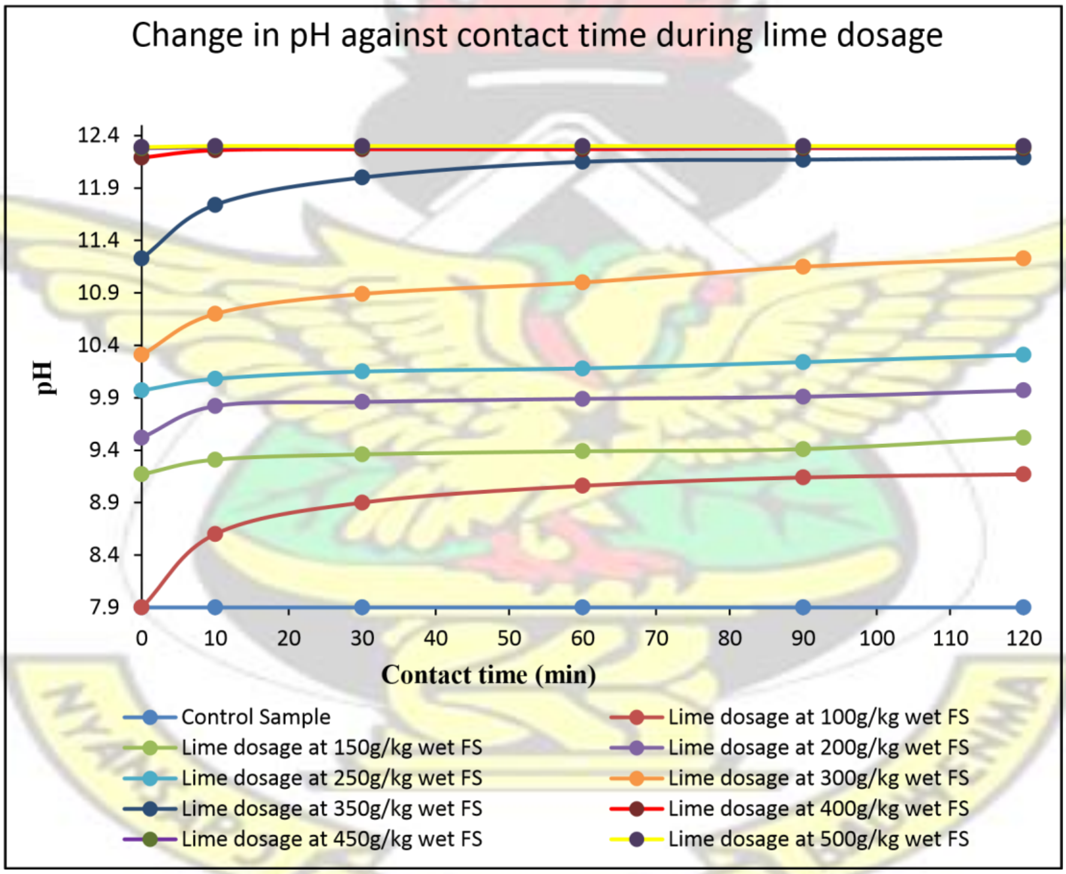


Figure 4.2. change in pH against contact time during lime dosage of sludge

The quantity of lime required to raise the pH from 11.0 to 12.3 and maintained over duration of 120 min contact time ranged from 350 to 500 g/kg sludge slurry during stabilization process. The quantity of lime dosage obtained agreed with similar value for biological sludge reported by (Schneiter et al., 1982). However, at a lime dosage of 500 g/kg sludge slurry, the change in pH values was observed to be relatively constant at 12.3 corresponding to a consistent contact time of 120 minutes for all the sludge samples during the lime stabilization process. This shows that an optimum lime dosage of 500 g/kg sludge at 120-minutes contact time is required to raise the pH value to 12.3, despite any further addition of lime. Results obtained from this research was analogous to that specified in literature to be a lime dose in excess of 0.12 kg lime/kg sludge to produce an "enhanced treated" sludge product, provided effective mixing was achieved (NLA Fact Sheet, 1999).

4.3 Change in Temperature of Sludge during Lime Treatment

The temperature of FS ranged between 29.5 – 30.5 ^{o}C and 33.8 – 36.1 ^{o}C before and after lime treatment respectively (Figure 4.3). The difference in temperature change was due to the reaction between the hydrated lime and the inorganic content of the sludge. The temperature required for pathogen inactivation in sludge treated with hydrated lime is 50 ^{o}C at 128 min contact time as reported by (Capizzi-Banas et al., 2004). Though the change in temperature was statistically significant, the temperature of sludge after lime treatment that ranged from 33.8 ^{o}C to 36.1 ^{o}C was not adequate to cause pronounced pathogen inactivation or bacterial die off (Boost and Poon, 1998). The heat from exothermic reaction produced to raise the temperature high enough to cause pathogen inactivation or die-off was low since the lime was already slaked.

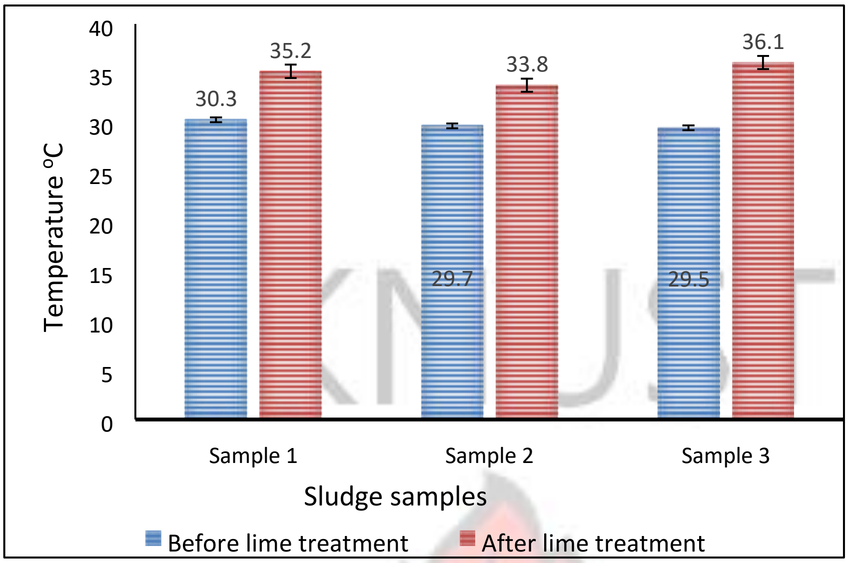


Figure 4.3. Temperature variations during lime treatment of faecal sludge

4.4 Characteristics of Sludge from Anaerobic pond after lime stabilization

Parameters that were analyzed after lime treatment were moisture content, sludge temperature, pH, total and total volatile solids, concentration of COD and BOD and helminth eggs concentration of the sludge as presented in Table 4.3 of Appendix B.

4.4.1 Moisture Content and Total Solids of Sludge

The moisture content after lime treatment of sludge ranged from 75.2 % - 76.4 % of dry solids (Figure 4.4). A decrease in water content of the raw sludge from 81.7 % to 76.4 %, 79.5 % to 75.5 % and 76.7 % to 75.2 % for stabilized sludge were observed from the three sludge samples. The decrease in moisture content of the sludge might be due to the addition of hydrated lime during stabilization causing absorption of the water content in the sludge and subsequent increase in dry solids content.

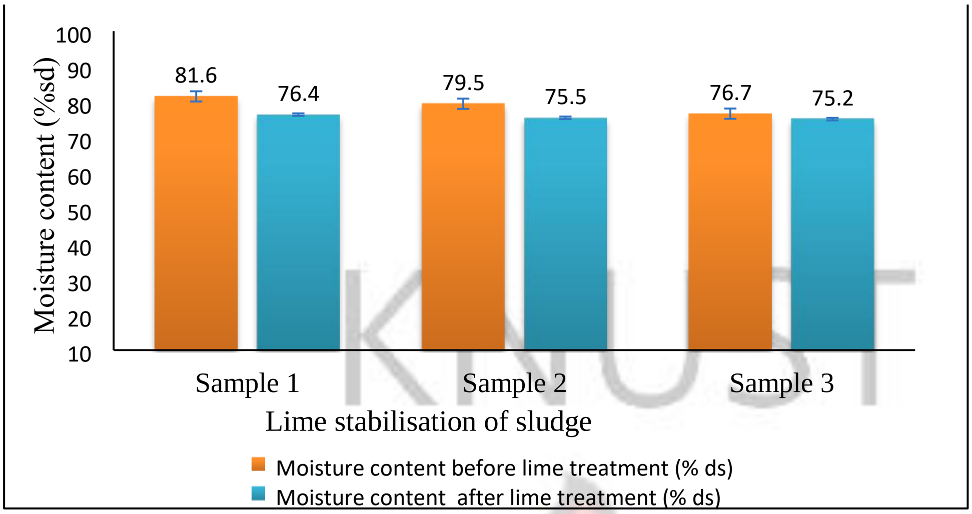


Figure 4.4. Moisture content of sludge before and after lime treatment

While the total solids content of raw sludge increased from 18.4 % to 23.6 %, 20.5 % to 24.5 % and 23.3 % to 24.8 % dry solids for stabilized sludge samples (Figure 4.5). It was observed that the addition of the hydrated lime during the stabilization process contributed to the increase in total solids content of the sludge.

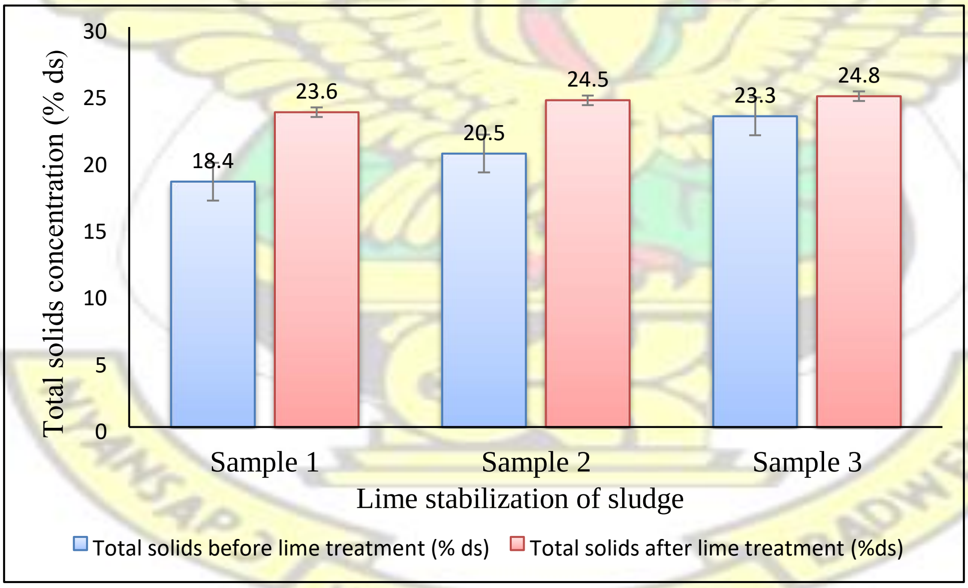


Figure 4.5. Total solids concentration of sludge before and after lime treatment

4.4.2 Removal Efficiency for Total Volatile Solids

The raw sludge had TVS value that ranged from 77 % to 82 % before lime treatment (Figure 4.6). The TVS value of the raw sludge recorded was higher compared to a raw value of 72.1 % obtained by (Samaras et al., 2008) during an investigation of sewage sludge stabilization by lime addition. After lime treatment, the stabilized sludge recorded TVS value that ranged between 46.2 % and 49.2 %. The reduction in TVS values of sludge samples before and after lime treatment (Figure 4.6) indicated that organic material in the sludge was oxidised during the stabilization process. This implied that a more stable sludge in the form of inorganic material was produced after the stabilization process. A TVS reduction of 25.5 - 27.6 % in the lime stabilized sludge obtained was about 2.4 to 4.5 % lower than that observed in treating faecal sludge in ponds by (Strauss et al. 1998). 40 % level of stabilization was achieved for

TVS after lime treatment of FS (Figure 4.6).

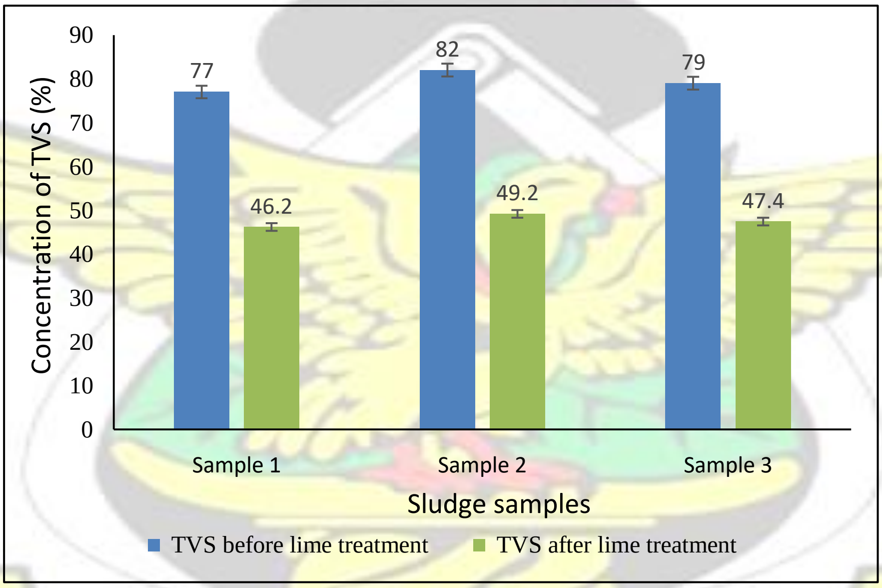


Figure 4.6. Total volatile solids concentration of sludge before and after lime treatment

4.4.3 Helminth Eggs Concentration of Faecal Sludge

During lime treatment of FS, a significant reduction of the number of helminth ova were observed for Schistosoma, Strongyloides and Hookworm species at pH 9 and 11 (Figure 4.7). A complete inactivation of these species was achieved at pH 12 and

12.3. Ascaris eggs inactivation occurred and remained relatively constant at pH 12. The low removal of ascaris eggs/gTS at pH 9 and 11 was due to buoyancy effect triggered by fermentation gases that hampered the settling of eggs and led to prolonged egg suspension (Eawag and Sandec, 1998), as their removal mechanisms are sedimentation and filtration (Konatéa et al., 2013; Tchobanoglous et al., 2014). At pH 11, helminth species of Strongyloides, Hookworm and Schistosoma were completely inactivated or died off owing to high pH (alkalinity content) (Figure 4.7). Though ascaris egg concentration of 1/gTS was detected after lime stabilization of FS, it satisfies the French legislation of less than 3 viable helminth eggs per 10 g of TS reported by (Capizzi-Banas et al., 2004). Results of ascaris egg concentration after lime stabilization of FS showed a total removal efficiency of 75 % which confirmed a range of helminth eggs removal efficiency of 75 to 90 % stated by (Van der Steen, 2014), with a log removal value of 0.6 (Figure 4.7).

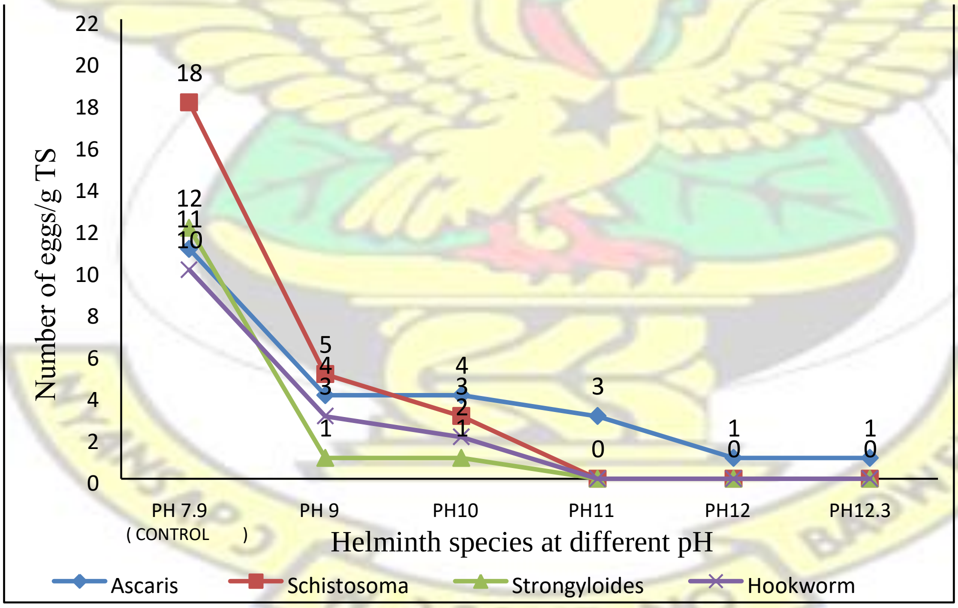


Figure 4.7. Inactivation of helminth eggs after lime stabilization of sludge

4.4.4 Level of Stabilization of COD and BOD After Lime Treatment

The raw sludge had COD value that ranged between 976 mg/L – 1064 mg/L and after lime treatment of the sludge, the COD value recorded ranged between 592 mg/L - 736 mg/L (Figure 4.8). This shows about 57 % to 69 % level of stabilization was achieved and presents 31 % - 43 % removal efficiency of COD after lime treatment of sludge. Other reasons that might contribute to this low COD removal efficiency is concentration of soluble unbiodegradable COD which cannot be removed by either physico-chemical or biological processes (Strande et al., 2014).

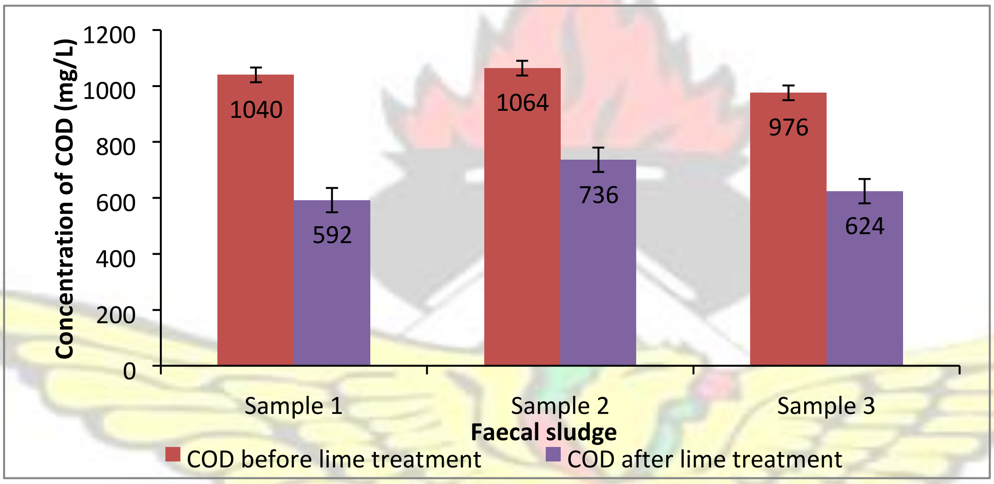


Figure 4.8. Concentration of COD before and after lime stabilization of sludge

The raw sludge had a BOD value that ranged from 598 mg/l to 660 mg/L and after lime treatment of the sludge, the BOD value recorded ranged from 128 mg/L - 160 mg/L. A significant reduction of BOD value was observed. 76 % - 79 % level of stabilization of BOD after lime treatment of sludge (Figure 4.9). A COD to BOD ratio of 1.6 before lime treatment of faecal sludge indicates that the sludge is biodegradable while a ratio of 4.6 after lime stabilization suggests more stable faecal sludge product as a result of longer storage period (Bassan et al., 2013; Eawag and Sandec, 1998).

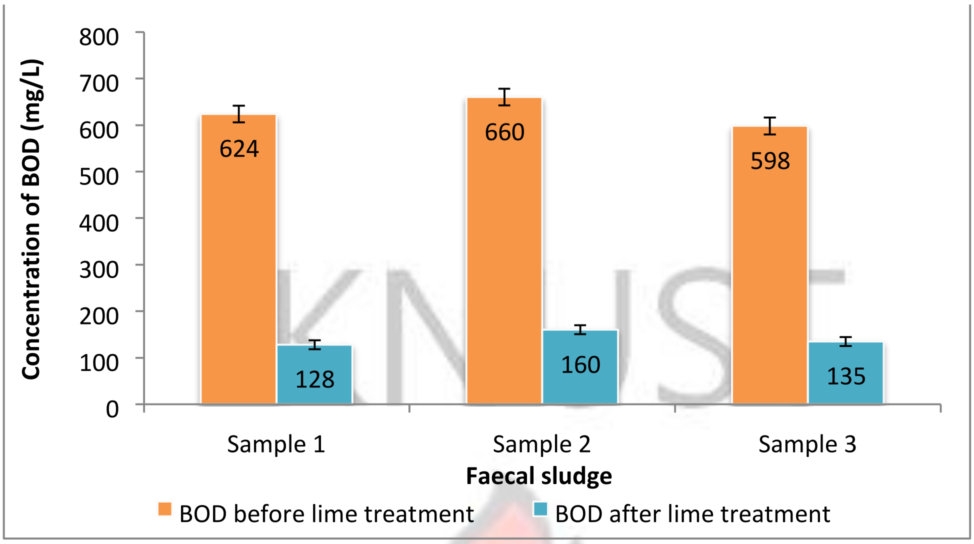


Figure 4.9. Concentration of BOD before and after lime stabilization of sludge

4.5 pH decay during storage of lime stabilized faecal sludge

A lime-stabilized sludge at pH12.3 was monitored under storage over a period of 45 days. This was done to monitor pH decay during storage of the stabilized sludge. The pH values were monitored for 45 days of storage. The results indicated that the pH of the lime stabilized sludge remained relatively constant for the first 3 days of storage. This suggests that a pH of 12.3 was enough to inhibit the growth of all bacterial pathogens, thus satisfying the condition for pH to remain stable for at least 24 h to prevent regrowth of pathogens (Boot and Scott, 2008). Though a decline in pH from 12.3 to 12.28 was observed after 3 to 7 days of storage, that was not significant enough. Subsequently, a downward trend of pH value from 12.28 to 12.26 was observed between 7 and 14 days of storage. The reduction in pH values during storage of lime stabilized sludge might be attributed to:

- microbial activities which produced organic acids and carbon dioxide leading to drop in pH value

- hydrolysis of complex organic material to simple organic acids resulting in pH reduction
- ion-exchange process might occur due to lime addition, where hydrogen ions surrounding the colloids may be replaced by calcium ions and the hydrogen ions then react with hydroxyl ions to produce water.

The pH remained constant at 12.26 from 14 to 45 days of storage. This constant value of pH could be attributed to high alkaline environment caused by the hydrated lime that inhibited biological activities and the development of ammonia bicarbonate during hydrolysis of urea, which prevented the drop in pH (Montangero and Strauss, 2002).

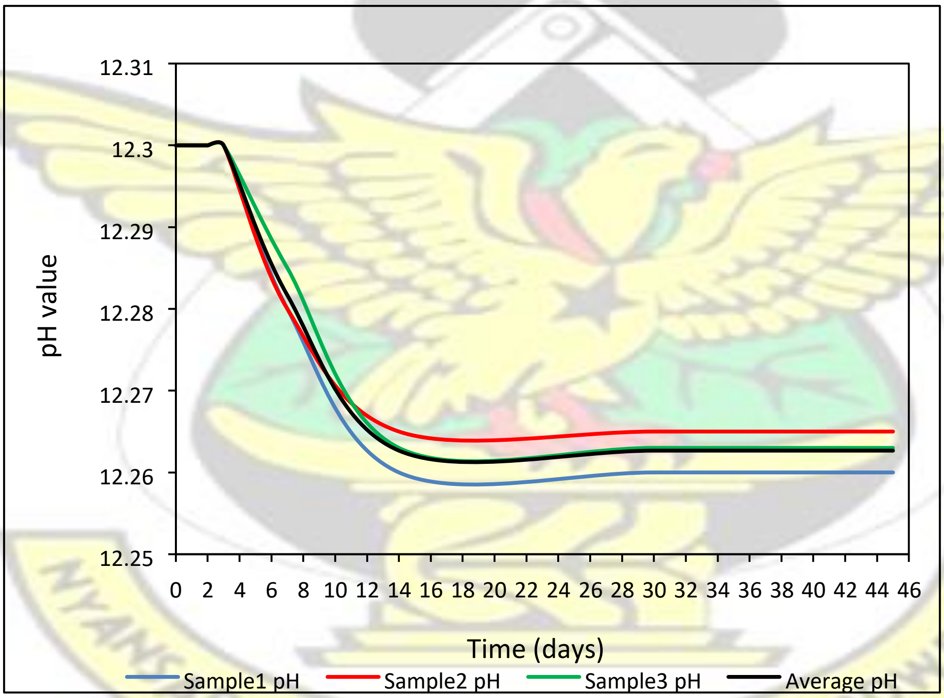


Figure 4.10. Change in pH during storage of lime stabilized sludge

4.6 Chemical Composition of Lime-stabilized Sludge

The lime stabilized sludge generally consists of Si, Fe, Al, Ca, Mg and other trace metal oxides such as Na, K and S. The inorganic chemicals outlined in the lime stabilized sludge were not destructive to concrete materials, with the exception of sulphur that might influence volume instability (Tay and Show, 1992). Levels of Si, S, Fe and Al in the chemical composition of lime stabilized sludge observed as listed in Table 4.4 were significantly low in comparison with the average values of municipal sewage sludge reported by (Tay and Show, 1992). Conversely, average levels of 23.4 g/kg for Mg, 26.4 g/kg for K, 28.0 g/kg for Na and 2.0 g/kg for Mn recorded in the sludge ash were high above the range of values observed in the work of Tay & Show, 1992.

Table 4.4. Chemical composition of lime-stabilized sludge

Element (g/kg)	Range of values[a]	Average values[a]	Range of values[b]	Average values[b]
Si	1.2 - 1.5	1.4	80.1 - 141.o	102.8
S	0.5 - 0.6	0.6	62.4 - 110.9	80.8
Fe	45.4 - 62.3	53.9	80.0 - 81.3	80.6
Al	4.0 - 5.7	4.9	42.3 - 55.9	50.3
Ca	40.2 – 44.6	42.4	25.0 - 31.0	29.2
Mg	22.0 - 24.8	23.4	7.7 - 8.1	7.9
K	22.7 – 30.0	26.4	5.8 - 6.4	6.1
Na	22.3 – 33.7	28.0	2.2 - 2.8	2.5
Mn	1.8 - 2.2	2.0	0.8 - 1.5	1.1

[a]Own experimental values; [b]Tay & Show, 1992

However, chemical analysis of the main and other trace oxides of lime stabilized sludge were carried out and the results are summarized in Table 4.5. The lime stabilized sludge had CaO content of 59.57 % w which compared well with values reported by ("Cement

Engineers' Handbook," n.d.) and improves the strength and durability of the sludge. Al_2O_3 and Fe_2O_3 oxides of the lime treated sludge in comparison with ("Cement Engineers' Handbook," n.d.; Rodríguez et al., 2012; Tay and Show, 1992; Xu et al., 2014) were extremely high while oxides such as MgO, Na_2O, K_2O and SO_3 met the recommended values reported by ("Cement Engineers' Handbook," n.d.).

Table 4.5. Chemical analysis of lime treated sludge in percent by weight

Oxide	Lime treated sludge[1]	Rodríguez et al. 2012	Tay & Show 1992	Xu et al 2014	Reference value
SiO_2	3.09	1.3	20.33	6.09	18 -24
CaO	59.57	61.76	1.75	6.09	60 – 69
Al_2O_3	18.45	0.54	14.64	3.22	4 – 8
Fe_2O_3	71.65	0.5	20.56	5.72	1 – 8
MgO	0.0040	0.73	2.07	0.98	< 5.0
Na_2O	0.0048	0.04	0.51	0.39	< 2.0
K_2O	0.0037	0.08	1.81	0.60	< 2.0
SO_3	1.08	0.57	7.8	3.21	< 3.0

[1]Own experimental values

4.7 Composition and Comparison of Lime Stabilized Sludge to Limestone

Table 4.6 demonstrates the results of chemical analysis of lime stabilized sludge in comparison with similar chemical analysis carried out on limestone documented in literature. Levels of oxide measured in the lime treated sludge correlated with literature values reported by (Gao et al., 2015; Kae-Long and Chung-Yi, 2005; Rodríguez et al., 2012; Voglis et al., 2005). The results as presented in Table 4.6 indicated that there was no significant change between the mean values for chemical analyses of limestone reported in literature and lime stabilized sludge observed in the study. Values of 3.09 % w for SiO_2, 1.08 % w for SO_3 and 59.57 % w for CaO recorded for lime treated sludge agreed with values documented by (Gao et al., 2015; Kae-Long and Chung-Yi, 2005; Rodríguez et al., 2012; Voglis et al., 2005). Levels of major oxides such as Al_2O_3, Fe_2O_3, MgO, CaO and SiO_2 as well as minor oxides like Na_2O, SO_3 and K_2O recorded in the lime treated sludge also correlated with limestone values recommended by (Gao et al., 2015; Kae-Long and Chung-Yi, 2005; Rodríguez et al., 2012; Voglis et al., 2005). This showed that the chemical analysis of the major and minor oxides of lime treated sludge showed chemical composition essentially contained in limestone and it was feasible to utilize lime stabilized sludge as the mineral components of raw materials in the building and construction industries.

Table 4.6. Chemical analysis of lime stabilized sludge in comparison with limestone

Oxide % w	Lime treated sludge[1]	Gao et al 2015	Rodriguez et al 2012	Kae-long & Chung-yi 2007	Voglis et al 2005	Ref. value
SiO_2	3.09	0.84	5.00	7.30	0.54	18-24
Al_2O_3	0.22	0.24	2.40	1.10	0.34	4-8
Fe_2O_3	0.17	0.32	0.74	0.66	0.12	1-8
CaO	59.57	53.96	50.00	62.10	51.95	60-69
MgO	1.04	1.01	0.63	1.23	1.16	< 5.0
SO_3	1.08	-	0.10	0.18	-	< 2.0
Na_2O	0.02	0.21	0.03	0.22	0.02	< 2.0
K_2O	0.03	0.34	0.44	0.01	-	< 2.0

4.8 Lime Stabilized Sludge as Building Material

The sludge used in the manufacturing of the brick was stabilized with 500 g dosage of hydrated lime. The stabilization was intended to reduce odour threshold, destroy pathogens and biological activities, improve sludge texture, and render the sludgeclay amendment more workable. The clay was obtained from Mfensi by Building and Road Research Institute (BRRI), Council for Scientific and Industrial Research (CSIR), Kumasi, Ghana. The results of mass of raw materials and amount of water required per brick for various proportions of sludge-clay mixture are shown in Table 4.7. The burnt bricks were moulded using clay and sludge proportions of 100 %, 90%, 80 %, 70 %, 60 % and 0 % 10 %, 20%, 30%, 40% respectively of the total weight of the mixture.

[1] Own experimental values

Table 4.7. Mass of raw materials and amount of water as required per brick for various proportions of sludge-clay mixture

Mass of raw materials and water required as per brick				
Ratio of Cement - sludge-clay mixture (wt.%)	Sludgeclay (kg)	Cement (kg)	Total mass of raw material (kg)	Water added (L)
0 - 100	0	7.0	7.0	0.75
10 - 90	0.7	6.3	7.0	1.25
20 - 80	1.4	5.6	7.0	1.75
30 - 70	2.1	4.9	7.0	2.25
40 - 60	2.8	4.2	7.0	3.00

4.8.1 Firing Shrinkage of Sludge-Clay Mixture

Table 4.3 in Appendix B shows the shrinkage of sludge-clay burnt brick at different temperatures. The initial temperature of the kiln was 120 ^{o}C and was increased at 50 ^{o}C successively for every 2 h intervals until the preferred temperature was achieved to ensure consistent and steady firing of bricks to avoid rapid breaks at brick surface.

The results indicated shrinkage increases with increasing temperature. The quality of a brick material is guaranteed based on firing shrinkage. Usually, a brick which is of good quality and durability shows firing shrinkage of below 8 % (CNS, 1999; Weng et al., 2003). As illustrated in Figure 4.11, percentage of shrinkage increases with increasing percentage sludge addition. It was observed that brick specimens of 0 % and 10 % sludge addition met the Chinese National Standards (CNS1127, 1999) for methods of test for general types of bricks for building at all the firing temperatures of 850 ^{o}C, 900 ^{o}C, 950 ^{o}C and 1000 ^{o}C. Sludge addition of up to 20 % also met CNS 1127, 1999 at firing temperatures of 850 ^{o}C, 900 ^{o}C and 950 ^{o}C. Sludge addition of 30 % can be recommended at temperature range of 850 ^{o}C and 900 ^{o}C. However, brick specimens containing up to 40 % sludge addition showed higher shrinkage compared to other brick specimens. This is because the organic content of sludge is higher than that of clay resulting in downgrade of brick quality.

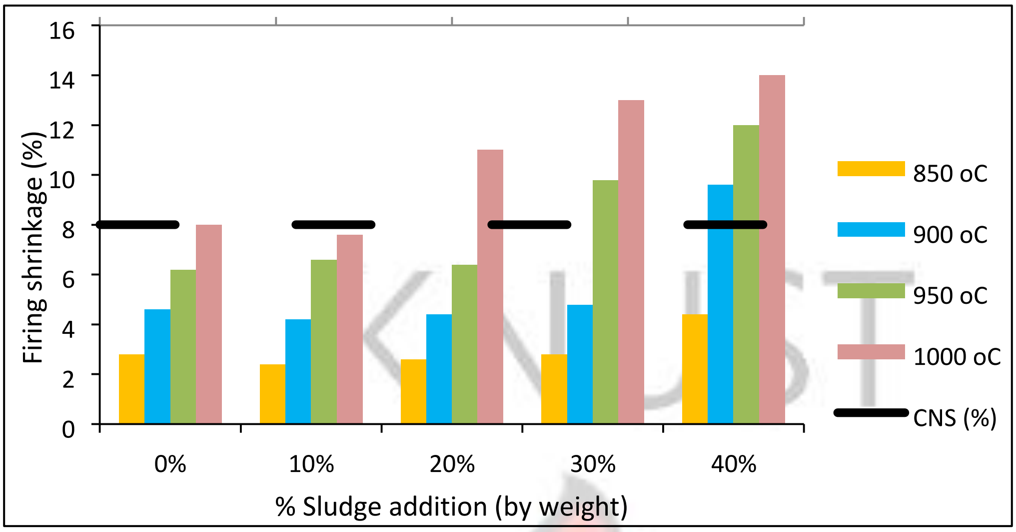


Figure 4.11. The effect of firing shrinkage on sludge addition of brick at varying temperature

4.8.2 Water Absorption of Sludge-clay Brick

Table 4.4 in Appendix B shows the results of water absorption of sludge-clay brick which is one of the major parameters in determining the soundness and durability of brick. Figure 4.12 shows that water absorption of the sludge-clay brick specimen decreases with increasing sludge addition and increasing firing temperature. It was observed that the brick specimen without any sludge addition (0 % or control) met the recommended reference value for both first and second class brick standards. The water absorption of the 0 % brick specimen decreased from 15 % to 11 % when the temperature was increased from 850 ^{o}C to 1000 ^{o}C. Brick specimen with up to 10 % sludge mixture met the CNS, 1999 Standard for second class bricks at firing temperature of 950 ^{o}C to 1000 ^{o}C. A decrease in water absorption from 26 % to 24 % with corresponding increase in sludge addition was observed for 20 % sludge-clay brick specimen when the firing temperature was increased from 850 ^{o}C to 1000 ^{o}C. However, sludge addition ranging from 20 % to 40 % did not meet the CNS, 1999 water absorption standard for amended brick because the high proportion of sludge addition decreased the adhesiveness while the internal pore size of the amended brick increased. Also, increase in firing temperature means the crystallization process is complete resulting in closing up of open pores in amended brick.

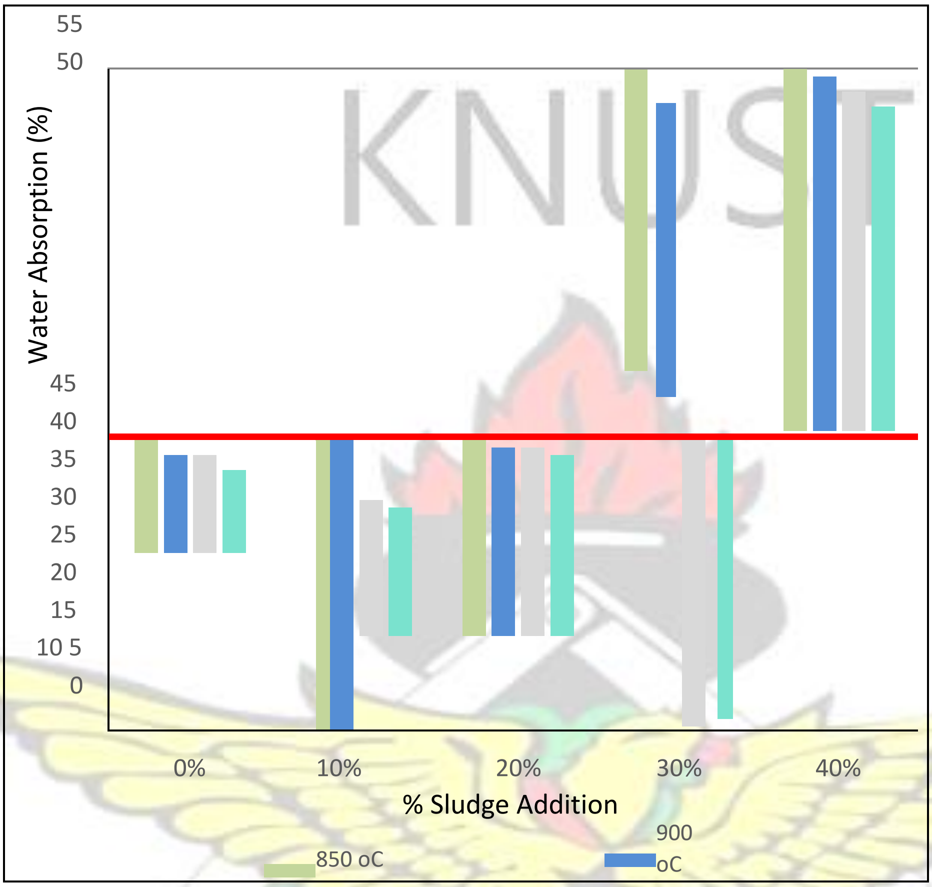


Figure 4.12. Water absorption of sludge-clay brick at varying sludge addition and temperature

4.8.3 Compressive Strength of the Sludge-Clay Brick

Table 4.5 in Appendix B shows the results of the compressive strength of the sludgeclay amended brick. The results indicated that compressive strength depends on the amount of sludge addition and firing temperature in the sludge-clay brick specimen. The strength values ranged between 5.6 N/mm^2 and 8.4 N/mm^2 for the control (0 %) brick specimen at firing temperature of 850 ^{o}C to 1000 ^{o}C. With up to 10 % sludge addition, the strength achieved at 950 ^{o}C and 1000 ^{o}C were 6.0 N/mm^2 and 6.4 N/mm^2 (Figure 4.13) respectively higher than the British Standard Specification for clay bricks of 5.0 N/mm^2. With 20 % sludge addition, the compressive strength of the sludge-clay brick achieved increased from 5.2 N/mm^2 to 5.6 N/mm^2 at 950 ^{o}C and 1000 ^{o}C respectively. However, sludge addition of 30 % to 40 % fell below the standard value. This means that compressive strength decreased with increase in percentage sludge addition but increased with increasing firing temperature.

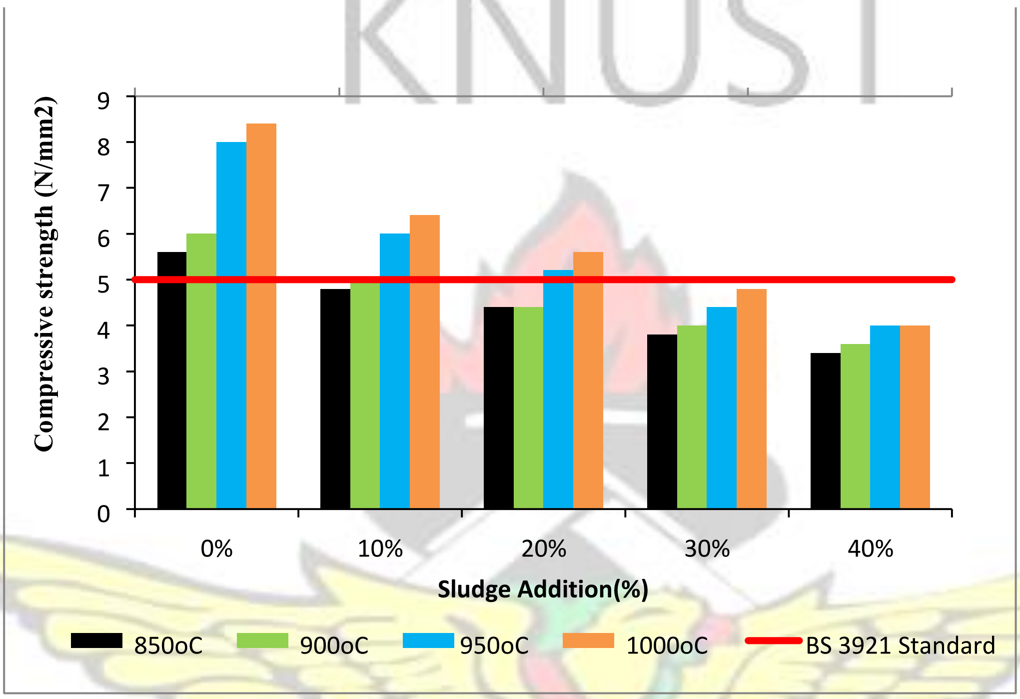


Figure 4.13. Compressive strength of sludge-clay brick at varying temperatures

Based on the results of shrinkage on firing, water absorption and compressive strength, it was observed that up to 10 % sludge addition was suitable to produce sludge-clay brick product that could be used for building purposes at firing temperatures ranging from 850 ^{o}C to 1000 ^{o}C. However, 20 % sludge addition was also possible to obtain a brick product that can be used for building at firing temperatures of 850 ^{o}C to 950 ^{o}C for shrinkage and 1000 ^{o}C for compressive strength.

CHAPTER 5 : CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Assessment of the suitability of sludge from Dompoase Faecal Sludge Treatment Plant as a building material was conducted. The faecal sludge was treated with hydrated lime to determine the quantity of lime dose required to achieve the optimum pH and contact time necessary to obtain a lime stabilized sludge. Physical, chemical and microbial characteristics of the faecal sludge were investigated. Properties such as firing shrinkage, water absorption and compressive strength of the stabilized sludge were also determined to assess the suitability of the stabilized sludge as a building material. The main findings from the study are summarized as follows:

- 76 - 79 %, 40 % and 31 - 43% level of stabilization were achieved after lime stabilization of faecal sludge for BOD, TVS and COD respectively. However, a

COD to BOD ratio of 4.6 after lime stabilization suggested that the faecal sludge samples were biologically stable with improved handling characteristics.

- Inactivation of Schistosoma, Strongyloides and hookworm species were achieved at pH 12 and 12.3.
- The chemical levels of major and minor oxides in lime treated sludge showed that, it was feasible to utilize lime-stabilized sludge as a building material.
- A lime dosage of 500 g/kg sludge at a contact time of 120 minutes was required to raise the pH value to 12.3 and maintain the pH at 12.26 for 45 days of storage.
- Sludge addition of 10 % and 20 % were found to be suitable and could be used as replacement for normal clay brick that met both BS 3921 specification and CNS for general types of bricks for building. Generally, addition of sludge in the sludge-clay mixture and the firing temperature are the two major factors affecting the quality of brick.

5.2 Recommendations

- Investigations into amendment materials that could improve water absorption capacity of the sludge-clay bricks should be conducted.
- Further studies should be carried out on the cost of sludge treatment, its affordability and acceptability of the sludge-clay burnt brick for use.
- Regulatory bodies and institutions should collaborate effectively to develop standards for sludge classification and disposal options to close the sanitation loop.
- Sludge morphology and mineralogical properties must be conducted to discover the microstructure of the burnt brick material produced for building purposes.

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APPENDICES

APPENDIX A

A1: Apparatus and Procedure for Moisture Content

The equipment used for the determination of the moisture content of the sludge slurry were crucibles (evaporating dish), analytical balance (precision 0.1mg), water bath, desiccator and drying oven. The crucibles were washed with detergent followed by rinsing with distilled water and then dried using the oven. Three crucibles were labelled and their dry weight measured with the analytical chemical balance. 50g of well-mixed sludge slurry each was put into a pre-weighed crucibles and the weight of the sludge sample measured using the analytical balance. This was labelled as weight of wet sample. The crucible and its content were placed on the water bath to evaporate the sludge water content. The content of the crucible was then transferred to the drying oven to dryness at a temperature of 105°C for one hour before it was taken out (depending on the water content of the sludge). The crucible containing the dried sludge sample was placed in the desiccator to cool. This was to balance temperature and avoid absorption of atmospheric moisture into the sludge sample. The content of the crucible was again weighed to determine the dry weight of the sludge sample using the analytical balance. The moisture content of the sludge sample was calculated as follows:

Moisture content (% w) = $\frac{A - B}{B} * 100$

Where, % w is the percentage of moisture in the sample

A is the weight of wet sample and B is the weight of dry sample.

A2: Apparatus and Procedure for Experimental Set-up of Lime Dosage

Apparatus used for the experiment include 50 L Plastic Container Reactors, Electric Mixer with agitator (including extension cable), 1,000 mL measuring cylinder, 100 mL sampling bottles, Sprayer Stirring Stick (50 cm length), pH meter and weighing devices such as Bathroom scale (5-200 kg) and Kitchen scale (0-5 kg) were used.

Procedure

Each 50 L drum was filled with approximately 20 L of faecal sludge collected from anaerobic pond (AP3). Sample of FS was taken and analysed for pH, conductivity, TS and TVS at the laboratory using the methods outlined in previous sections. Each of the treatment drums were weighed using the bathroom scale and their mass recorded. Based on the total solids content (%TS) determined and the sludge weight in the various treatment drums, the hydrated lime additions were weighed using the kitchen scale to create the equivalent of 40 %, 50 %, 60 % w/w and added to the content of the drum containing the sludge. The lime dosage was determined using the relation:

Lime dosage (kg) $= \frac{\text{TS \%} \times \text{Sludge mass (kg)}}{\text{Purityof lime (\%)}}$

Initial sample from each of the three drums was taken and the pH recorded. The measured lime dosages of 40 %, 50 % and 60 % w/w were added to reactors 1- 3 respectively. Each drum reactor was mixed subsequent to lime addition using the electric mixer at 120 rpm and 100 mL samples were taken from the outlet at the base of the drum after 10 min, 30 min, 60 min, 90 min and 120min following mixing of the three reactors (drums).

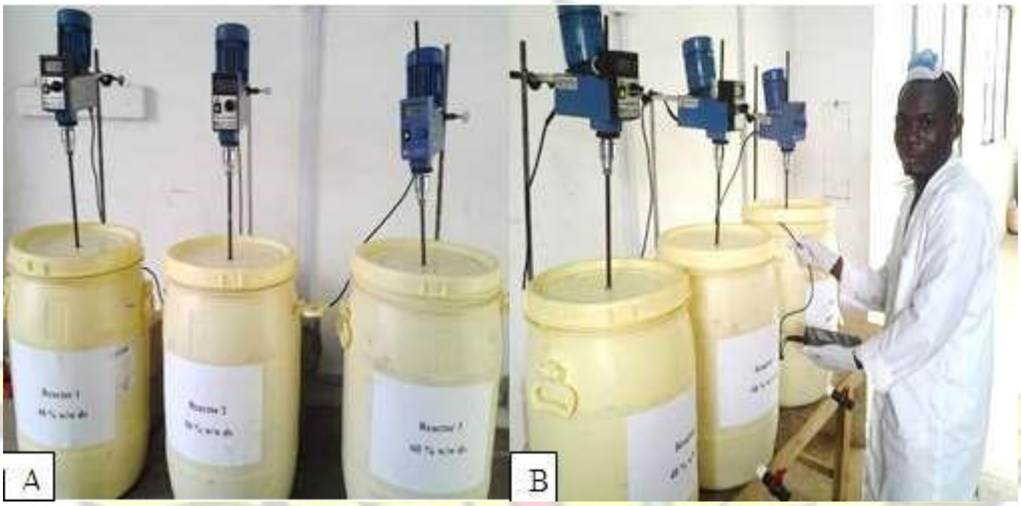


Figure 0.1: Laboratory set up for determination of lime dose in % dry solids

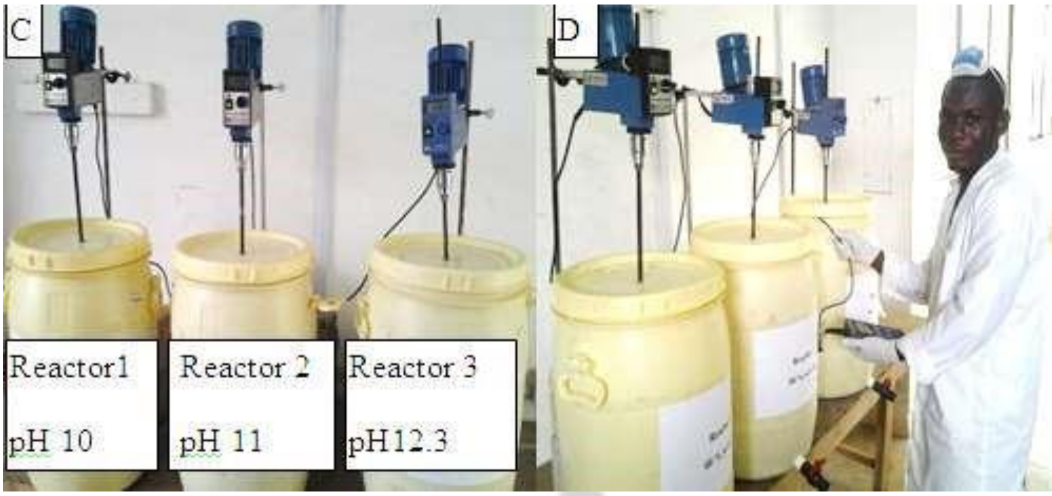
A3: Apparatus and Procedure for pH Control Experiment

Apparatus

Three 50 L Plastic Drums, Electric Mixer with agitator (including extension cable), Stirring Stick (50 cm length), Hydrated Lime (90 % purity), Shovel, pH meter, weighing devices, Bathroom scale (5-200 kg) and Kitchen scale (0-5 kg), three 1L plastic sampling bottles, 25 x 60 mL plastic sampling bottles and four sealable bags.

Procedure

Each 50L drum was filled with approximately 20L of faecal sludge collected from anaerobic pond at DFSTP. The drums were labelled as control, pH 10.0, pH 11.0, pH 12.0 and pH 12.3. The drum labelled control contains the raw faecal sludge from the anaerobic pond without any lime addition. Each of the drum was weighed using the bathroom scale and the sludge weight determined by subtracting the empty drum weight. The sludge in each of the drums was stirred using the electric motor at 120 rpm to make the sludge homogeneous as possible. Initial samples from each drum were taken using the 1L plastic sampling bottles for pH, moisture content, COD, BOD, TVS, helminth eggs, total coliforms and heavy metals analyses. The initial pH of each sample in the drum was measured using the pH meter and the value recorded. A hydrated lime dose of 100 g was added to each of the 20 L sludge sample as labelled above. The content of the drum was stirred for 10 min, 30 min, 60 min, 90 min and 120 min and in each case the change in pH with contact time was measured. 50 g of hydrated lime was added to each of the 20 L drum of sludge sample for similar contact time until a consistent pH of 12.3 was obtained, corresponding to hydrated lime dose of 500 g. Table 3.1 shows quantity of lime dosage at different contact times resulting in change in pH. Samples at pH 12.3 for were taken for the analyses of pH, moisture content, COD, BOD, TVS, Helminth eggs, total coliforms. The sludge samples were stored for 45 days while pH was monitored following
stabilisation.



Sludge mixing during lime treatment C   pH measurement during lime treatment D

A4: Procedure for Atomic Absorption Spectrometry (AAS)

One gram of lime-stabilized faecal sludge sample was weighed, oven dried at 60^oC and put into 125 mL Erlenmeyer flask which has been previously washed with acid and distilled water. 10 ml of ternary mixture in a ratio of (20 mL $HClO_{4:}$ 500 mL $HNO_{3:}$ 50 mL H_2SO_4) was added and put under a fume hood. The content of the mixture was mixed thoroughly and heated gently at low to medium heat on a hot plate under a perchloric acid fume hood. Heating was continued until dense white fumes appeared (fumes of sulphuric acid). The mixture was finally heated strongly (medium to high heat) for half a minute and it was allowed to cool. 50 mL of distilled water was added and boiled for half a minute on the same plate at medium heat. The solution was cooled and filtered (using Whiteman No.42 filter paper, 9 cm) completely with the wash bottle into 100 mL volumetric flask and then topped up to the mark with distilled water. The solution was stored for heavy metal determination using the AAS analyzer.

A5: Procedure for Sludge Digestion

Two different dewatered sludge samples from the anaerobic pond at DFSTP were collected and a composite sludge sample was also prepared from the two samples. One gram of each sample was weighed and transferred to an Erlenmeyer flask. 10 mL of nitric acid (HNO_3) was added to each sample and the samples were placed on a hot plate to heat until the nitrous fumes escaped. The samples were allowed to cooled and filtered to remove any insoluble material using the Whitemann number one filter paper. The filtered samples were transferred to a volumetric flask and topped to the 50 ml mark using distilled water. Analyses of heavy metals such as Copper, Lead, Iron, Nickel, Arsenic and Zinc were carried out with the Atomic Absorption Spectrometer.

APPENDIX B

Table B1: Characteristics of Faecal Sludge from Anaerobic Pond before Lime Treatment

Parameter	Sample 1	Sample 2	Sample 3	Mean values	Standard deviation
M.C. (% ds)	81.6	79.5	76.7	79.27	2.46
Temperature oC	30.3	29.7	29.5	29.83	0.42
TDS (%)	6	6.25	6.03	6.09	0.14
pH	7.85	7.89	7.97	7.90	0.06
TS (% ds)	18.4	20.5	23.3	20.73	2.46
TVS (% TS)	77	82	79	79.33	2.52
COD (mg/L)	1040	1064	976	1026.67	45.49
BOD (mg/L)	624	660	598	627.33	31.13
OD/BOD_5 ratio	1.7	1.6	1.6	1.63	0.06
T.C (cfu/100mL)	19500	20000	20900	20133.33	709.46
H. eggs (No/gTS)	4	3	1	2.67	1.53

Table B2: Characteristics of Faecal Sludge from Anaerobic Pond after Lime Treatment.

Parameter	Sample 1	Sample 2	Sample 3	Mean values	Standard deviation
M.C (% ds)	76.4	75.5	75.2	75.70	0.62
Temperature oC	35.2	33.8	36.1	35.03	1.16
pH	12.3	12.3	12.3	12.30	12.30

TS (% ds)	23.6	24.5	24.8	24.30	0.62
TVS (% TS)	46.2	49.2	47.4	47.60	1.51
COD (mg/L)	592	736	624	650.67	75.61
BOD (mg/L)	128	160	135	141	16.82
COD/BOD5	4.6	4.6	4.6	4.60	0
T.C (cfu/100mL)	19.5	20	20.9	20.13	0.71
H. eggs (No/gTS)	1	0	1	1	1

Table B3: Level of Stabilization of Anaerobic Pond Sludge

Parameter	Mean values (BLT)	Mean values (ALT)	% Removal	Log Reduction Value
BOD (mg/L)	627	141	76 - 79	0.6- 0.7
COD (mg/L)	1027	651	31 - 39	0.2
TVS (%)	79	48	40	0.22
T. C. (cfu/100mL)	20133	20	99.9	4
H.E. (No/gTS)	3	1	75	0.6

Table B4: Change in pH of Faecal Sludge during Lime Dosage to Obtain Optimum Contact Time

Lime Dose (g/kg sludge slurry)	Contact time (min)				
	10	30	60	90	120
100	8.60	8.90	9.06	9.14	9.17
150	9.31	9.36	9.39	9.41	9.52
200	9.82	9.86	9.89	9.91	9.97
250	10.08	10.15	10.18	10.24	10.31
300	10.70	10.89	11.00	11.15	11.23
350	11.74	12.00	12.15	12.17	12.19
400	12.26	12.27	12.27	12.28	12.28
450	12.29	12.29	12.29	12.29	12.29
500	12.30	12.30	12.30	12.30	12.30

Table B5: pH Variation During Storage of Lime Stabilized Sludge

Storage time (days)	pH				Mean
	2 h	6 h	12 h	24 h	
1	12.30	12.30	12.30	12.30	12.30
2	12.30	12.30	12.30	12.30	12.30
3	12.30	12.30	12.30	12.30	12.30
7	12.28	12.28	12.28	12.28	12.28
14	12.26	12.26	12.26	12.26	12.26
30	12.26	12.26	12.26	12.26	12.26
45	12.26	12.26	12.26	12.26	12.26

Table B6: Concentration of Helminth Species before and after Lime Stabilization of Faecal Sludge

	Ascaris		Schistosoma		Strongyloides		Hookworm	
	Before	After	Before	After	Before	After	Before	After
pH 9	2	0	7	0	5	0	4	0
pH10	4	0	5	0	3	0	2	0
pH11	3	0	3	0	2	0	2	0
pH12	1	1	2	0	1	0	1	0
pH12.3	1	1	1	0	1	0	1	0

Table 4.5: Compressive Strength of Sludge-Clay Brick Specimen

	Compressive strength (N/mm^2) at different temperatures				Reference
Sludge-Clay Mixture (%)	850 ^oC	900 ^oC	950 ^oC	1000 ^oC	BS 3921
0	5.6	6.0	8.0	8.4	5.0
10	4.8	5.0	6.0	6.4	5.0
20	4.4	4.4	5.2	5.6	5.0
30	3.8	4.0	4.4	4.8	5.0
40	3.4	3.6	4.0	4.0	5.0

Table 4.3: Characteristics of Faecal Sludge after Lime Stabilization

Parameter	Range of values
M.C (% ds)	75.2 - 76.4
Temperature oC	33.8 - 36.1
pH	12.3
T S (% ds)	23.6 - 24.8
TVS (% TS)	46.2 - 49.2
COD (mg/L)	592 - 736
BOD (mg/L)	128 - 160
COD/BOD5	4.6
Helminth eggs (No/gTS)	0 - 1

Table B7: Shrinkage of Sludge-Clay Brick at various Temperatures

Proportion of Sludge in brick (%)	Shrinkage on firing (%)				Reference
	850 ^oC	900 ^oC	950 ^oC	1000 ^oC	CNS, 1999 (%)
0	2.8	4.6	6.2	8	8
10	2.4	4.2	6.6	7.6	8
20	2.6	4.4	6.4	11	8
30	2.8	4.8	9.8	13	8
40	4.4	9.6	12	14	8

Table 4.4: Water Absorption of Sludge-Clay Brick at Varying Temperatures

Proportion of Sludge in brick (%)	Water Absorption (%)				Reference
	850 ^oC	900 ^oC	950 ^oC	1000 ^oC	CNS- 2^{nd} Class Bricks
0	15	13	13	11	19
10	20	19	18	17	19
20	26	25	25	24	19
30	40	39	38	37	19
40	48	47	45	43	19

Table 4.2: Helminth Eggs Concentration of Sludge during Lime Stabilization

Sample	Ascaris	Schisto-soma	Strongy-loides	Hook worm	Mean	Standard deviation
pH 9	4	5	1	3	3.25	1.71
pH10	4	3	1	2	2.50	1.29
pH11	3	0	0	0	0.75	1.5
pH12	1	0	0	0	0.25	0.5
pH12.3	1	0	0	0	0.25	0.5

APPENDIX C

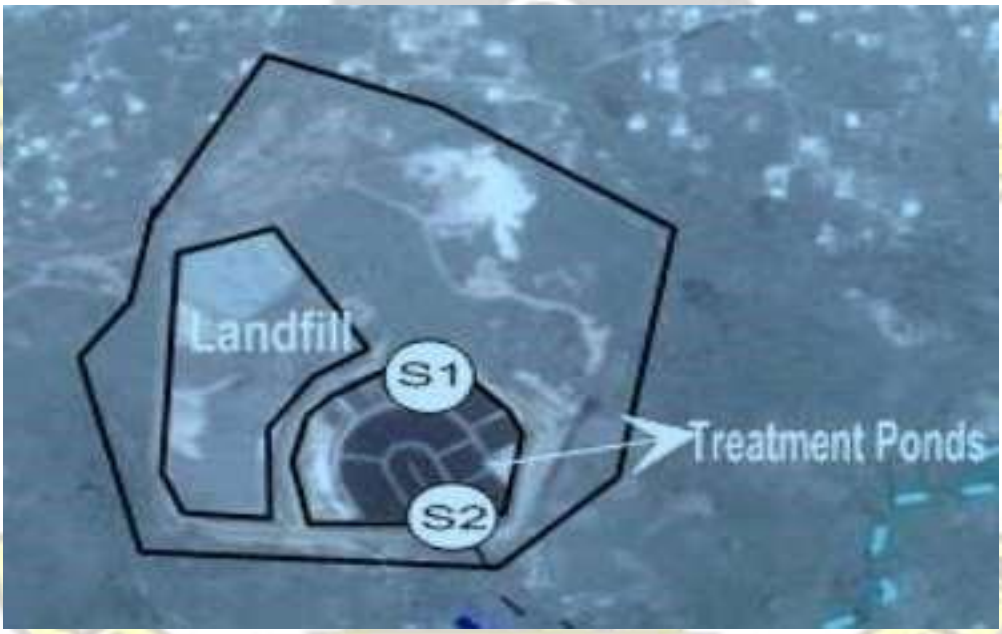


Plate A:

Pictorial View of Dompoase Faecal Sludge Treatment Plant.

Plate B: Raw Faecal Sludge Slurry from The Anaerobic Pond

Plate C: Sun Dried Faecal Sludge Stabilized with Lime

Plate D: Lime Stabilized Sludge Ready for Chemical Analysis

Plate E: Sample Preparation and Sludge-Clay Brick Moulding

Plate F: Weighing and Air Drying of Sludge-Clay Brick

Plate G: Firing and Testing of Compressive Strength of Sludge-Clay Brick