ORGANIC STABILIZATION AND NUTRIENTS PRODUCTION WITH RESOURCE RECOVERY FROM ANAEROBIC PASTEURISATION DIGESTER LATRINE

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DECLARATION

Declaration by the Candidate

I declare that this thesis is my original work and has never been presented for a degree or any other academic award in any university. No part of this thesis may be reproduced without prior permission of the author and / or University of Eldoret.

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To my dear family.

ABSTRACT

Pit latrines are the most common human excreta disposal systems in low- income countries. Their use is on the rise as countries aim to meet the sanitation-related target of the Millennium Development Goals. However, there is concern that they discharge chemical and microbial contaminants to groundwater. Furthermore, pit latrines have no option for resource recovery and recycling of materials. This study aimed at assessing the suitability of Anaerobic Pasteurisation Digester latrine (APDLs) in organic matter reduction, organic nutrients production and resource recovery from the final effluent. The study hypothesises that there are no organic reduction, no nutrients produced and no resources can be recovered. Three toilet systems were installed at Sogomo with different digester feed stocks, namely: one with faeces and urine (North station), another with urine, feaces and food scrubs (Central station) and the last one with urine diversion (South station). The three toilet systems were installed for approximately, twenty adult users for each. The Digesters installed consisted of a movable built floating gas holder (dome), heater and heat exchanger. Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) were used to determine the organic reduction. BOD was measured using the winker method and COD was done by the refluxing method. Colorimetric technique was used to analyse total nitrogen and direct method was used for total ammonia analysis, where effluent samples were treated with strong base and the mixture distilled. Ammonia was quantitatively expelled and was absorbed in excess of standard acid solution. The excess acid was back titrated in the presence of methyl red indicator. The ammonia contained in the final effluent was used as the raw material for production of recoverable resources from the system including ammonium hydroxide, ammonium chloride, ammonium sulphate and ammonium nitrate this was done by the acid base reaction. Statistical analysis was carried out using two-way ANOVA by SPSS computer aided programme version 21.0.The BOD percentage reductions in North, South and Central stations were 89.48 %, 92.60 % and 90.09% respectively. The COD reduction in South and Central stations showed a mean of 95 % while the north station had a mean of 93 %. South, North and Central station had mean values of 6.22 mg/l, 5.74 mg/l and 5.50 mg/l of total nitrogen in the digested effluent respectively. Total ammonia values in the digested effluent were 12.35 mg/l, 11.76 mg/l and 10.76mg/l at south, central and north station respectively. The values of total ammonium ions in the digested effluent were 15.91 mg/l, 13.97 mg/l and 15.22 mg/l at south, north and central stations respectively. Therefore, with high and increasing human populations, the ADPLs are suitable for organic matter reduction. The three ADPLs final effluent could be used as organic fertilizer because it contained more than 4.50 mg/l of total nitrogen which is greater than the recommended nitrogen requirement by plants of 3.20 mg/l. The ADPLs technology has a great potential of replacing pit latrines.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

APDL = Anaerobic Pasteurization Digester Latrine

AD = Anaerobic Digesters

BOD = Biochemical Oxygen Demand

COD = Chemical Oxygen Demand

CAN = Calcium ammonium Sulphate

DAP = Diammonium Phosphate

DO = Dissolved oxygen

ELDOWAS = Eldoret water and sewerage company

EMC = Environmental Management Co-ordination

EPA = Environmental Protection Agency

FDA = Food and Drug Administration

GOK = Government of Kenya

GAO = General Accounting Office

ISAT = Information and Advisory Service on Appropriate Technology

MAP = Monoammonium Phosphate

TAPPI = Technical Association of Pulp and Paper Industry

MSW = Municipal Solid Waste

N = Nitrogen

PRA = Participatory Rural Approach

ppm = Parts per million

TSP = Triple Super Phosphate

UNEP = United Nations Environmental Programme

UNESCO = United Nations Educational Scientific and Cultural Organization

WHO = World Health Organization

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Thanks be to God forever.

CHAPTER ONE

INTRODUCTION

1.1 Study Background

Human waste stabilization and disposal has been an activity of major concern globally and more pronounced in the developing world. Approximately 2.6 billion people in the world lack proper sanitation resulting from poor human waste disposal. The greatest percent of these people are poor and live below the poverty line mainly in Africa and Asia (Subhabrata, 2003; Enriquez, 2000).

More than half of the Kenyan population do not have access to improved sanitation while increase in population having access to improved sanitation from 1990 to 2006 has been only 3% (WHO/UNICEF, 2008). Most current human waste studies has moved towards integrated waste management involving recycling, reuse and recovery of important materials. This would aid the poor to meet their daily livelihood needs through waste resource recovery (UNICEF, 1997).

Composting and resource recovery from human excreta has been practised for a long time by reintegrating human waste with the soils (Malkki, 1997). Two main human wastes (excreta) include feaces and urine are majorly collected in pit latrines in most parts the world. Pit latrines usage has proved dismally low in waste stabilization and no resources recovery. Filled pit latrines have only two options namely; one stops the usage and construct a new one or empty the contents and reuse it (Pickford and Shaw, 2007 and Odhiambo *et al*.,2008).

Human urine is usually excreted by the kidneys and it consists of water and excess nutrients. Urine is rich in valuable plant nutrients of which 80% is normally nitrogen. A normal average human being can excrete; 7 g 3.5 kg, 1 g 0.5 kg, 2 g 1.0 kg, 1 g, 0.5 kg 80 mg 40 g and 0.2g 100g of Nitrogen, Phosphorus, Potassium, Sulphur, Magnesium and Calcium per litre per year respectively (Esrey *et al*., 2001). This is almost equivalent to the amount of nutrients contained in 15 kg of compound NPK+ fertilizer (Antonini *et al*., 2009).

On the other hand faecal matter has been partially processed anaerobically, and not yet been fully exploited until in recent times (GTZ, 2007). Pasteur reported the possibilities of methane production from a mixture of human fecal matter combined with urine and small additions of food scrubs. According to a report issued from China, April 26, 1960 the Chinese have used "covered lagoons" to supply methane fuel to communities and factories for decade. However, cultures of most communities in the world take usage of fecal matter as a taboo (Shangwa, 2009). Slowly some communities especially the elites in the community have accepted the use human fecal matter as an important source of organic nutrients and other resources after anaerobic digestion (Fry and Barbara, 1973 and WHO,2006) .

Kenya is having an annual population growth rate of 2.9 and with an urban population of about 17% of its total population (GOK, 2006). A proper human waste management is required, similar to that of other sources of wastes. This therefore, should involve human waste recycling, resource recovery and outreach strategies. High Population density in urban areas, peri urban areas and in many institutions is

the key to understanding the rocketing populations impacts on existing resources like land, water and the general environment (Lopez *et al.*, 2006).

Human waste in Kenya which includes kitchen wastes, (left over foods stale food, and preparation wastes) feaces and urine has not been fully exploited in the agricultural sector, or in biogas energy production or for any resource recovery except for few areas such as Kibera, Ruai and Nakuru. This is because the modes of sanitation for human waste available in the county are pit latrines and normal flush toilets, which do not allow reuse of food waste, feaces and urine. The ADPLs technology involving anaerobic pasteurization digestion of human waste may be used for resource recovery and organic matter reduction (Kazungu, 2010).

The study on APDLs is aimed at contributing to the existing knowledge on potentials of APDLs in organic reduction, organic nutrients production and resource recovery from human waste and food scrubs that will be an additive into the digester at Sogomo in Eldoret, which in the long-run would lead to a reliable integrated management option for human waste and food scrubs.

1.2 Statement of the Problem

Sogomo is a rapidly upcoming centre and provides accommodation for most of students at the University of Eldoret. Land sizes in Sogomo area are sub divided into plots ranging from a quarter to one-acre pieces. Owners of the pieces of plots have constructed mainly single rooms which are occupied by students and families.

At Sogomo every piece of plot has a shallow borehole that provides water to the occupants and pit latrines and bathrooms constructed at one end. Although Sogomo area is served with clean piped water from Eldoret Water and Sewerage Company

(ELDOWAS), this water is usually unavailable in most times, especially in the dry season making boreholes as a reliable source of water for the residents. This results into compounded health and sanitation problems at Sogomo (Elving,2009).

Currently, the student population in the University of Eldoret stands slightly above 10,000 and staff more than 1,000. This will keeps rising every year as the demand for higher education increases hence demand for more accommodation within the vicinity of the University. Sogomo is one of the area that is most favoured by the students for accommodation due to its proximity to the University.

The high populations living in Sogomo village which is comprised of majority of students, some staff members from the University and other residences in Sogomo village generate wastes in terms of feaces and urine that are mostly deposited in pit latrines. Other than these two types of wastes, these populations generate food scrubs which comprises of left over foods, wastes after food preparations and left over foods that are usually a problem to dispose because of their volumes and weight which is a big challenge in transportation to waste collection points.

In Sogomo centre the filled pit latrines are usually emptied by ‘honey suckers’ at a cost of Kes. 2,500 per trip and rarely a new pit latrine can be dug to replace the filled one because of the small land sizes that leaves emptying as the only solution. This operation of emptying of the filled pit latrine is expensive and uneconomical to the plot owners. The emptying operation is done more frequently during the rainy seasons due to storm waters and the quick rise of ground water tables (SuSanA, 2008).

Although organic reduction takes place inside the pit latrines it is disadvantageous because the process can take a long time and it is usually inefficient due to every day new deposition of human waste. Eventually, the waste is not used in agriculture as organic fertilizer and no resource recovery can be done inside a pit latrine. In addition, diverting food waste from landfills or dump sites prevents uncontrolled emissions of its breakdown products, including methane potential greenhouse gas (Eales, 2005).

1.3 Study Objectives

1.3.1 Broad Objective

To explore the suitability of APDLs in removal of organic matter from human waste and nutrients removal and recovery at Sogomo in Eldoret- Kenya

1.3.2 Specific Objectives

1. To determine the BOD and COD of the influent and effluent from the ADPLs
2. To determine ammonium compounds as nutrients in the ADPLs effluent for organic fertilizers production.
3. To determine the recoverable resources in the ADPLs effluent

1.4 Justification of the study

Anaerobic digester for faecal waste and degradable kitchen waste takes an ecosystem approach to the human excreta and food wastes and when fully in operation it will be used as an alternative technology to the current sewage treatment processes which include the preliminary, primary, biological and tertiary treatment processes at Sogomo and other sanitation areas. The microorganisms acclimated

within the digesters usually degrade human waste anaerobically before the waste is removed from the digester after some time period (Vinneras, 2001).

Human waste and food scrubs contains high nutrients that can be recovered and used in boosting crop production using the APDLs technology other than depositing them in pit latrines or dust bins for the case of food scrubs where they get wasted or the nutrients get leached out leading to eutrophication to water bodies. The food scrubs produces bad smell after rotting in waste collection points which poses high health risks or they over load transportation means to dumb sites (Del Porto and Steinfeld, 1999).

Nitrogen is usually among the macro nutrients required for plant growth, a major component in amino acid processing and for enzyme formation (Roberts, 2013). Ammonium ions on the other hand are the hydrolysable content and it can be reduced to nitrogen or used as raw material for the formation of ammonium salts (ammonium chloride, ammonium sulphate and ammonium nitrate). These nutrients are sources of macro nutrients required by plants for growth and reproduction that may be obtained from ADPLs Effluent. Human waste and food scrubs, especially urine that contains over 70% nitrogen content can be used to produce nitrogen molecule or can chemically react with water to form ammonium molecule (Jana *et al*., 2012 and Buckley et al.,2008).

Despite the development of several technologies on pit latrines, there exist several sanitation and health limitations, in their use especially in densely populated areas. Hence, ADPLs can be a viable solution to densely populated settlements where pit

latrines are difficult to construct and it is usually difficult to deposit food scrubs in pit latrines because of their volumes and weight. ADPLs may be a breakthrough to proper sanitation and economically affordable, to operate and maintain (Thye. *et al*., 2009).

Access to cheap fertilizers is important for the agricultural sector to produce sufficient food for the world requirements, mainly with an additional two billion people by 2050 (Mwakubo, 2007). In particular in the developing countries, fertilizers are among the major production factors to increase agricultural output because they have accounted for aproximately 60% of the registered yield increase in the last 50 years (Sartain and Kruse, 2001 ;Foeken and Mwangi 2000 and Emerton,2001). Installation and use APDLs with nutrients recovery from feaces, urine and food scrubs will aid to counter this problem.

The challenges in pit emptying are complex, compounded by the variable and often difficult conditions in which emptying technologies must operate. As more innovations are tested and improved, progress can be made towards a satisfactory solution of the pit latrines (Graham and Polizzotto, 2013). The most viable solution to this problem could be installation and use of ADPLs.

1.5 Study Hypothesis

1. There will be no significant BOD and COD reductions in APDLs effluent after anaerobic digestion

2. There will be no significant nutrients recovery from ADPLs effluent for organic fertilizers production

3. There will be no significant recoverable resources in the APDLs effluent upon anaerobic digestion

1.6 Assumptions of the Study

1. During the study it was assumed each APDL system installed was to be used by twenty adult users and this remained the same throughout the study period.
2. The study assumed also that the users of all the systems installed flushed the faecal waste, urine or food scrubs as inputs into the toilets using only one litre of water for a single use of the toilet.
3. During the study period, it was assumed that the food scrubs which were an extra load into the south digester were the same and consistent throughout the study period.
4. It was also assumed that only tissue paper was used for wiping and the users did not deposit any other wastes such as polythene paper, baby diapers and sanitary pads into the systems

CHAPTER TWO

LITERATURE REVIEW

2.1 Pit Latrines and Sanitation

A pit latrine is used to retain resources in form of feaces and urine underground for approximately two years making which requires space and with densely populated regions such as slum areas and in high sprouting centre's, there are usually cost implications of repeated construction and emptying (Alabaster,2008).

Sanitation systems worldwide can be classified into two major categories, namely: offsite and on-site sanitation systems. The off-site systems include: the conventional sewerage system with proper treatment and disposal, and small-bore sewers. The on-site systems include a number of technology options: dry pit latrines, borehole latrines, ventilated improved pit latrines, eco-san latrines, and pour-flush latrines with single or twin pits, aqua privies, composting latrines, and septic tanks (Drangert, 2008).

Sanitation levels are categorized by the MDGs as open defecation, unimproved facilities, and improved facilities. In order for a facility to be considered "improved," waste should either be removed by a flushing mechanism or be a pit latrine with concrete slab and pit ventilation as a minimum requirement (Nwaneri, 2009).

Municipal sewer systems are the standard of wastewater treatment that is most desired. Human exposure to waste is removed through flush toilets that transport waste to a centralized wastewater treatment facility through piping infrastructure.

Users hardly have direct contact with waste in any way during the process. Though these systems are highly desired, high costs for wastewater infrastructure are a major limitation. Additionally, those not living within range of a municipality's services do not have this option. In low-income countries (with a gross national income per capita of $1,025 or less), a large portion of households use improved or unimproved pit latrines due to their low cost and availability (Mallery *et al.*,2012).

Improved pit latrines are the most basic and inexpensive form of improved sanitation and typically consist of a pit – circular, rectangular or square – dug into the ground and covered with a concrete slab or floor with a hole through which excreta falls. Often, the lack of available space or costs of constructing a new latrine superstructure and this means that pit latrine emptying may be the only practical alternative (Thye, et al, 2009).

Urine is usually considered sterile, free of pathogens. Only a few disease organisms are passed through urine of a normal and healthy human being. In this regard its reuse has an advantage of it being used as nitrogen source organic fertilizer in food production industry (Jana *et al*., 2012).

2.2 Methane Gas from Anaerobic Digestion Process

Anaerobic digestion (AD) has the opportunity to be an integral part of the solution to two of the most pressing environmental concerns of urban centers: waste management and renewable energy. Through AD, organics are decomposed by specialized bacteria in an oxygen-depleted environment to produce biogas and a stable solid. Each of these products can be used for beneficial purposes to close the loop in organic waste management (Colón *et al*., 2012).

Anaerobic digestion dates back as far as the 10th century, when the Assyrians used it to heat bath water. It was historically insignificant before reappearing in 17th century. Europe, when it was determined that decaying organic matter produced flammable gases, again used it to heat water. The first full scale application was in the 1890s when the city of Exeter, UK used it to treat wastewater. From there, it continued to be widely used as a way to stabilize sewage sludge, as it is today (Jana *et al*., 2012).

The full processes of anaerobic digester for feaces, urine or food waste can be considered to occur in four stages namely; hydrolysis, in which complex molecules are broken down to constituent monomers; acidogenesis, in which acids are formed; acetogenesis, or the production of acetate. The stages of Methanogenesis in which methane gas is usually produced from either acetate or hydrogenis as shown in figure 2.1 shows. Digestion cannot be complete until the substrate has undergone all of these stages, each of which has a physiologically unique bacteria population responsible that requires disparate environmental conditions.

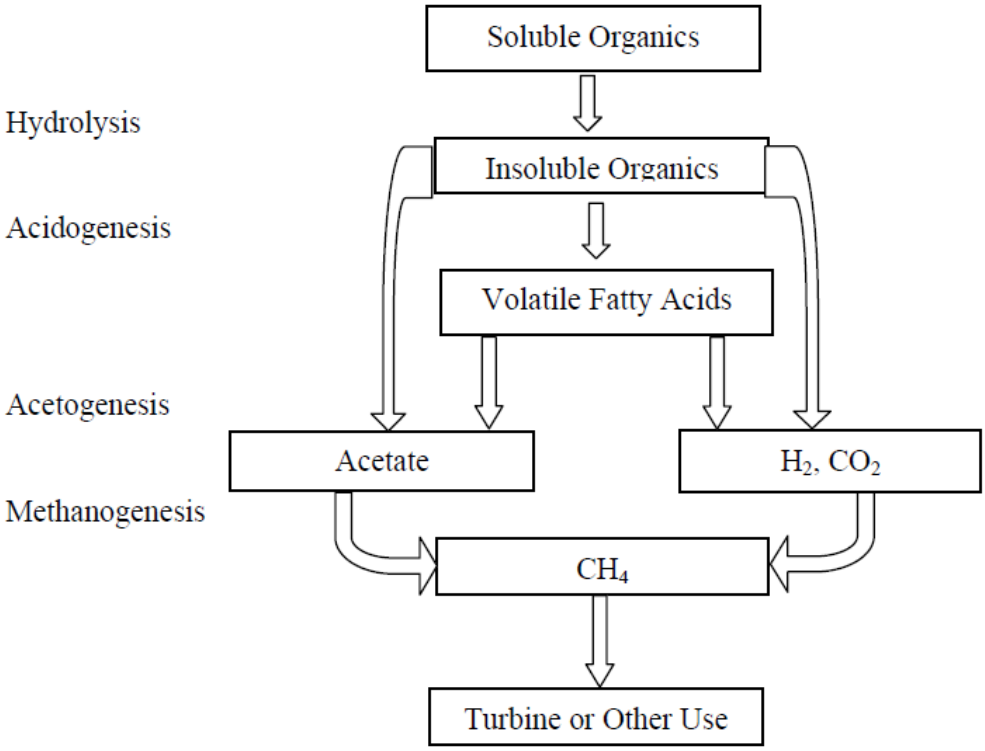

Figure 2.1: Methanogenesis stages

2.2.0 Hydrolysis

In the first stage, complex organic materials are broken down into their constituent parts in a process known as hydrolysis. The result is soluble monomers: Proteins are converted to amino acids; fats to fatty acids, glycerol and triglycerides; complex carbohydrates such as polysaccharides, cellulose, lignin, starch and fiber converted to simple sugars, such as glucose. Fermentive bacteria are responsible for the creation of monomers, which are then available to the next group of bacteria. Hydrolysis is catalyzed by enzymes excreted from the bacteria, such as cellulase, protease, and lipase. If the feedstock is complex, the hydrolytic phase is relatively slow. This is especially true for raw cellulolytic waste, which contains lignin (Gray *et al*., 2008).

Carbohydrates, on the other hand, are known to be more rapidly converted via hydrolysis to simple sugars and subsequently fermented to volatile fatty acids. Equation 1 shows the hydrolysis reaction where organic waste is broken down into a simple sugar such as glucose.

$$C_6H_{10}O_4 + 2H_2O = C_6H_{12}O_6 + 2H_2 \qquad (1)$$

2.2.1 Acidogenesis

Hydrolysis is immediately followed by the acid-forming phase of acidogenesis. In this process, acidogenic bacteria will turn the products of hydrolysis into simple organic compounds, mostly short chain (volatile) acids (e.g., propionic, formic, lactic, butyric, or succinic acids), ketones (e.g., ethanol, methanol, glycerol, acetone) and alcohols. The specific concentrations of products formed in this stage vary with the type of bacteria as well as with culture conditions, such as temperature and pH (Agstar,

2007). Equation 2 shows a typical reaction in the acid-forming stages. In this, glucose is converted to ethanol while equation 3 shows glucose transformation to propionate.

$$C_6H12O_6 \leftrightarrow 2\ CH_3CH_2OH + 2CO_2 \qquad (2)$$

$$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2\ H_2O \quad (3)$$

2.2.3 Acetogenesis

The next stage of acetogenesis will often be considered with acidogenesis to be part of a single acid forming stage. Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are reduced through these pathways. Acetogenesis occurs through carbohydrate fermentation, through which acetate which will be the main product, and other metabolic processes. The results will be a combination of acetate, CO_2, and H_2. The role of hydrogen as an intermediary will be of critical importance to anaerobic reactions. Long chain fatty acids, formed from the hydrolysis of lipids, are oxidized to acetate or propionate and hydrogen gas is formed.

Under standard conditions, the presence of hydrogen in the solution inhibits the oxidation. The reaction will only proceed if the hydrogen partial pressure will be low enough to thermodynamically allow the conversion. The presence of hydrogen scavenging bacteria that consume hydrogen, thus lowering the partial pressure, will be necessary to ensure thermodynamic feasibility and thus the conversion of all the acids. As a result the concentration of hydrogen, measured by partial pressure there will be an indicator of the health of a digester(Pradhan , 2010).

Equation 4 is an example of the free energy value of the reaction that converts propionate to acetate which is +76.1 kJ, so that this reaction will be thermodynamically impractical. When acetate and hydrogen are consumed by bacteria, however, the free energy becomes negative. In general, for reactions producing H_2, it will be necessary for hydrogen to have a low partial pressure for the reaction to proceed.

$$CH_3CH_2COO^- + 3H_2O \leftrightarrow CH_3COO^- + H+ + HCO^{3-} + 3H_2 \qquad (4)$$

Equation 5 is of ethanol formation, equation 6 of bicarbonate formation and equation 7 acetate production. Other important reactions in the acetogenic stage will involve the conversion of glucose.

$$C_6H12O_6 + 2H_2O \leftrightarrow 2CH_3COOH + 2\,CO_2 + 4H_2 \qquad (5)$$

$$CH_3CH_2OH + 2H_2O \leftrightarrow CH_3COO^- + 2H_2 + H^+ \qquad (6)$$

$$2HCO_3 + 4H_2 + H^+ \leftrightarrow CH_3COO^- + 4H_2O \qquad (7)$$

The transition of the substrate from organic material to organic acids in the acid forming stages causes the pH of the system to drop. This is beneficial for the acetogenic and acetogenic bacteria that prefer a slightly acidic environment, with a pH of 4.5 to 5.5, and are less sensitive to changes in the incoming feed stream, but is problematic for the bacteria and other microorganisms involved in the next stage of Methanogenesis (Zielinski *et al*., 2009).

2.2.4 Methanogenesis

Methanogenic anaerobic bacteria are involved in the third stage, known as Methanogenesis or methane fermentation which will be the same fastidious bacteria that occur naturally in deep sediments or in the rumen of herbivores. This population converts the soluble matter into methane, about two thirds of which will be derived from acetate conversion (equation 8 followed by 9), or the fermentation of an alcohol, such as methyl alcohol in equation 10, and one third will be the result of carbon dioxide reduction by hydrogen shown in equation 11 and equation 12.

Methanogenesis are usually very sensitive to any changes and prefer a neutral to slightly alkaline environment . If the pH will be allowed to fall below 6, Methanogenic bacteria will not survive. Methanogenesis will be the rate-controlling portion of the process because Methanogenesis will have a much slower growth rate than acidogens. Therefore, the kinetics of the entire process will be described by the kinetics of Methanogenesis (Guwy , 2004).

$$2CH_3CH_3OH + CO_2 \leftrightarrow 2\ CH_3\ COOH + CH_4 \qquad (8)$$

$$CH_3COOH \leftrightarrow CH_4 + CO_2 \qquad (9)$$

$$CH_3OH + H_2 \leftrightarrow CH_4 + H_2O$$

$$CO2 + 4H2 \leftrightarrow CH4 + 2H2O \qquad (10)$$

$$CH_3COO^- + SO_4^{2-} + H^+ \ 2HCO_3 + H_2S \qquad (11)$$

$$CH_3COO^- + NO^- + H_2O + H+ \ 2HCO_3^- + NH4^+ \qquad (12)$$

2.3 Inorganic Nutrients

Fertilizers are among the major production factors to increase agricultural output and consequently if the agricultural sector is to produce sufficient food for the future requirements, then access to fertilizers particularly in the least developed areas is of major concern.

Ammonia (NH_3) is the foundation for the nitrogen (N) fertilizer industry. It can be directly applied to soil as a plant nutrient or converted into a variety of common N fertilizers. Ammonia as fertilizer from fecal waste for reuse in agriculture has been a normal practice, but there is lack of concrete information on the subject, particularly on farmer's needs, preferences, health and environmental risks (Subhabrata, 2003).

Most fertilizer used in food crop production (58%) in Kenya are usually a combination of various fertilizer types; Di-ammonium phosphate (DAP), triple super phosphate (TSP), mono ammonium phosphate (MAP), calcium ammonium nitrate (CAN), and urea. Decision by farmers to use particular type of fertilizer is usually influenced mainly by demand (94%), fertilizer stock levels were influenced by demand (78%) and affordability (21%) (Kazungu, 2010).

On the production side of the fertilizer market, the input costs usually put upward pressure on fertilizer prices. Chemical fertilizer production is an energy intensive process and requires large amounts of energy. Ammonia used to produce urea and nitrate is particularly energy dependent. Nitrogen as a raw material (78% volume in the atmosphere) is available almost without limit but its transformation into ammonia

(Haber-Bosch process) is highly demanding in terms of energy, particularly natural gas. Natural gas accounts for 72-85% of ammonia production costs (Ulmann, 2001).

Nutrients such as nitrogen, phosphorus and potassium contained in human excreta are very suitable as fertilizer, because they meet most of the plant nutrient needs and the organics function as soil conditioner. Biogas sanitation contributes to closing the nutrient cycle which is a target of sustainable agriculture. Each day, one adult excretes about 30 g of carbon (90 g of organic matter), 10-12 g of nitrogen, and 2 g of phosphorus and 3 g of potassium.

Nitrogen (N) is the motor of plant growth. It makes up 1 to 4 percent of dry matter of the plant. It is taken up from the soil in the form of nitrate ions (NO_3^-) or ammonium ions (NH_4^+). In the plant it combines with compounds produced by carbohydrate metabolism to form amino acids and proteins. Being the essential constituent of proteins, it is involved in all the major processes of plant development and yield formation. A good supply of nitrogen for the plant is important and also for the uptake of the other nutrients (Subhabrata, 2003).

In Africa, closing the gap between actual and potential agricultural yields, which could mitigate food security, depends heavily on improved access to readily available and cheap sources of fertilizers (Ott, 2012).

2.4 Ammonium sulphate

$(NH_4)_2 SO_4$ is one of the important fertilizers produced in India. It contains about 21% N and 24% S and has been traditionally been very popular in various parts of the

country. It is a white crystalline salt having good keeping quality in dry condition (Siminiceanu and Coteț, 2005).

Gaseous ammonia is directly neutralized with H_2SO_4 to produce $(NH_4)_2SO_4$. $2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$The neutralizer reactor and the crystallizer are interconnected so that the heat released during neutralization is used to evaporate water in the slurry. The crystallizer is designed to produce uniformly sized crystals. Amorphous $(NH_4)_2SO_4$ is prepared by reacting gaseous NH_3 and H_2SO_4 in spray towers. The heat of reaction removes all the water present and the dry, fine product is continuously removed from the base of the tower. This product is suitable for making dry-mixed and granular fertilizers (Klasen, 2002).

2.5 Ammonium chloride

This is sometimes called nitrate of ammonia. It is commercially prepared by combining ammonia ions with HCl and the resultant product, NH_4Cl is found to have very good physical condition. Though this fertilizer has not been used extensively as straight fertilizer, it is preferred in preparing many fertilizer mixtures because of its good physical properties. This fertilizer is also obtained as a byproduct of the Solvay process of making sodium carbonate $[(Na)_2CO_3]$ (Antonini *et al*., 2012).

The commercial sample is a white, crystalline salt containing 26% N in the NH_4 form. The fertilizer is suitable for many crops except for those, which are sensitive to high chlorine content. This is physiologically acidic fertilizer (Brentrup *et al.*, 2005). Sodium chloride is treated with ammonia and carbon dioxide to form ammonium

chloride and sodium bicarbonate. The resulting ammonium chloride is then separated as shown in equation 13

$$NaCl + CO_2 + NH_3 \rightarrow H_2O\ NH_4Cl + NaHCO_3 \qquad (13)$$

Ammonium chloride is also obtained as a byproduct of soda ash (Na_2CO_3) and manufactured as Solvay's process. It is prepared by reacting calcium chloride with ammonium carbonate. Ammonium chloride is obtained by double decomposition between ammonium sulphate and sodium chloride at 1300^0 C.

2.6 Ammonium Nitrate

This is mainly manufactured by passing NH_3 gas into HNO_3 and then isolating the product in a solid form suitable for use as fertilizer. The equipment should be stainless steel or other special alloys. $HNO_3 + NH_3\ NH_4\ NO_3$ + Heat NH_4NO_3 is continuously produced with the aid of a neutralization tower. NH_3 gas is introduced near the bottom of the tower, while air is added at a higher point to cool the Soil colloid Soil colloid solution and carry off the water vapor. The solution containing about 80% of NH_4NO_3 is withdrawn and converted to crystals or pellets as the case may be (Klasen, 2002).

Pure $NH_4\ NO_3$ is a white crystalline salt having 33% of N, one half of which is in the NH_4 form and the other half in the NO_3 form. It is readily soluble in water and completely utilized by crops and hence no residues are left in the soil. It is an economical source of fertilizer N, suited to a wide range of crops, soils and climatic conditions. Its NO_3 content contributes to rapid crop response while the NH_4^- N makes

it more resistant to leaching losses than other materials carrying their entire N in the NO_3 form (Ogola *et al*., 2002).

2.4 Organic Fertilizers Rich in Nitrogen and Ammonia

Natural organic fertilizers are commonly made form waste products of various sources ranging from chicken feathers and manures to treated sewage sludge. These materials have very slow release rates, requiring soil bacterial action to convert the organic matter into forms usable by plants. Nutrients released will be excessively slow when cool soil temperatures reduce bacterial activity, however higher application rates may be applied and the fertilizer will last over a longer period of time (Khatib and Al-Khateeb, 2009).

Home owners recognize the need for timely nutrient applications to promote vigorous plant growth in landscapes and gardens. These nutrients may be supplied by either organic or inorganic fertilizers, or a combination of materials. Many nursery and garden supply stores now stock a wide variety of organic fertilizers. Virtually any organic material can be used as a fertilizer; however, materials vary considerably in the concentration of plant nutrients they contain and the rate at which these nutrients are released for plant use (Galloway, 2008).

A common misconception is that organic fertilizers are safer for plants and the environment than inorganic (chemical) products. Improper *organic* fertilizer application can also contribute to surface and ground water pollution, may induce a plant nutrient deficiency, toxicity, or cause salt burn. Properly used, both organic and inorganic fertilizers are safe for plants and the environment. The purpose of this guide

is to provide general selection and use information for organic fertilizers (Koenig and Johnson, 2011).

2.5 Detergents

Detergents serve to disperse and remove soil and organic material from surfaces allowing a disinfectant to reach and destroy microbes within or beneath the dirt. These products also reduce surface tension and increase the penetrating ability of water, thereby allowing more organic matter to be removed from surfaces. Some disinfectants have detergent properties (i.e., chlorine compounds, iodophors, QACs) (Keller *et al*., 2004).

Use of the proper concentration of a disinfectant is important to achieve the best results for each situation. Some products will have different dilutions depending on the desired use of the product. Although some disinfectants may be more efficacious at higher concentrations, these levels may be limited by the degree of risk to personnel, surfaces or equipment, as well as the cost of the chemical. However, over-dilution of a product may render the disinfectant ineffective to the target microorganism. The product label will list the best concentration to use for each situation. Be sure to consider any standing water or other water sources (i.e., rainfall) in the area as a potential dilution source for a disinfectant (Bockmann and Grubmuller, 2004).

The variety of soils encountered by general purpose cleaners can be characterized as oils, fats, waxes, food residues, dyestuffs and tannins, silicates, carbonates (limestone), oxides (sand, rust), soot, and humus. The ingredients commonly found in

general purpose cleaners are surfactants, complexing agents and alkaline salts (builders), organic polymers, solvents, viscosity regulators, pH buffers, anti-microbials, hydrotropes, dyes, and fragrances (Consumer Reports, 1991b).

One can group the general purpose cleaners into five groups: powders, alkaline liquid cleaners, disinfecting cleaners, spray cleaners, and cleaner/degreasers. The vast majority of the general purpose cleaners surveyed were liquids. Liquids which are dispensed from trigger spray bottles are used full-strength, while other liquids are often diluted with water before using (Castro, 2004).

Alkalis raise the pH of the laundry wash water, which assists in breaking up oily and acidic soil components. However since high pH can also damage fabrics the pH of laundry detergents is carefully controlled. Alkalis like ammonium hydroxide raise the pH of the laundry wash water, which assists in breaking up oily and acidic soil components (Scheuerlein and Taborelli, 2006).

Liquid water in its neutral state (pH 7) is primarily composed of water as molecules. These contain one atom of oxygen bound to two atoms of hydrogen. But there is also a very small number (1×10^{-14}) of water molecules which have broken up into H+ and OH- ions (charged particles). If a substance is added to the water to make the concentration of H+ ions increase, the water solution becomes more acidic, and the pH falls. If a substance is added to the water to make the concentration of OH- ions increase, the water solution becomes more alkaline and the pH rises. Alkalis increase the concentration of OH- ions and so raise the pH of the laundry wash (Hilleret *et al*.,2003).

Soils and fabric surfaces generally have an overall negative charge. With an increase of negative ions in solution, the negative charge of the surface is increased, and because like charges repel each other, dirt removal from the surface is facilitated examples of these detergents are Sodium carbonate, sodium bicarbonate, sodium silicate, sodium citrate and ammonium hydroxide, may be used to increase detergent pH (Bailey, 2011).

When ammonia is added to water, it readily forms the hydroxide form (ammonium hydroxide). In this state the ammonia does not have the aroma impact as the straight compound. Aqueous forms of ammonia are also known as ammonia solution, aqua ammonia, and liquid ammonia. It is available in a variety of concentrations (1-30%) in this form. The pH and the relative density of the ammonium solution will vary with concentration. As concentration increases, pH will increase to 13.5 at 30% concentration (Consumer Reports, 1992).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

3.1.1 Study Area location

Three APDLs were located in the neighbourhood of the University of Eldoret at Sogomo Village, Eldoret East sub-county, Eldoret, Uasin Gishu (Fig 3.1). Sogomo Village lies at the on latitude 0.58^{O}N and longitude 35.31^{O}E and was the desired project location because of its proximity to the University of Eldoret. Rainfall in this study area is substantially high (1000 to1500 mm per annum) and peaks during the months of July–August. Due to relatively high altitude, the project region experiences warm to cool climate conditions, January hottest (average of 26^{O}C) and July is the coolest (night minimum temperature of 8^{O}C) (Ojany and. Ogendo, 1988).

The rocks in this area are predominantly agglomerates and phonolites. The Uasin Gishu Plateau was formed by the slow cooling volcanic flows over the original basement system, and as a result in phonolites, pyroclasts, tuffs and volcanic rock outcrops are found within the Plateau area. Soils in Sogomo are predominantly nitisols, rich in organic matter and friable, and therefore susceptible to erosion (GOK, 1989).

3.1.1 Background of the Study Area

Current sanitation systems in this estate include septic systems with indoor flush toilets and pit latrines. Municipal piping reticulation for human waste sewerage services is not available in this estate. Municipal clean water is supplied through central taps each serving residents in a radius of approximately ten meters. Water

Services through these taps are usually inconsistent and onsite shallow wells are often used as alternatives water sources because they are between 10 to 20 meters deep and the water tables get even much higher during rainy seasons.

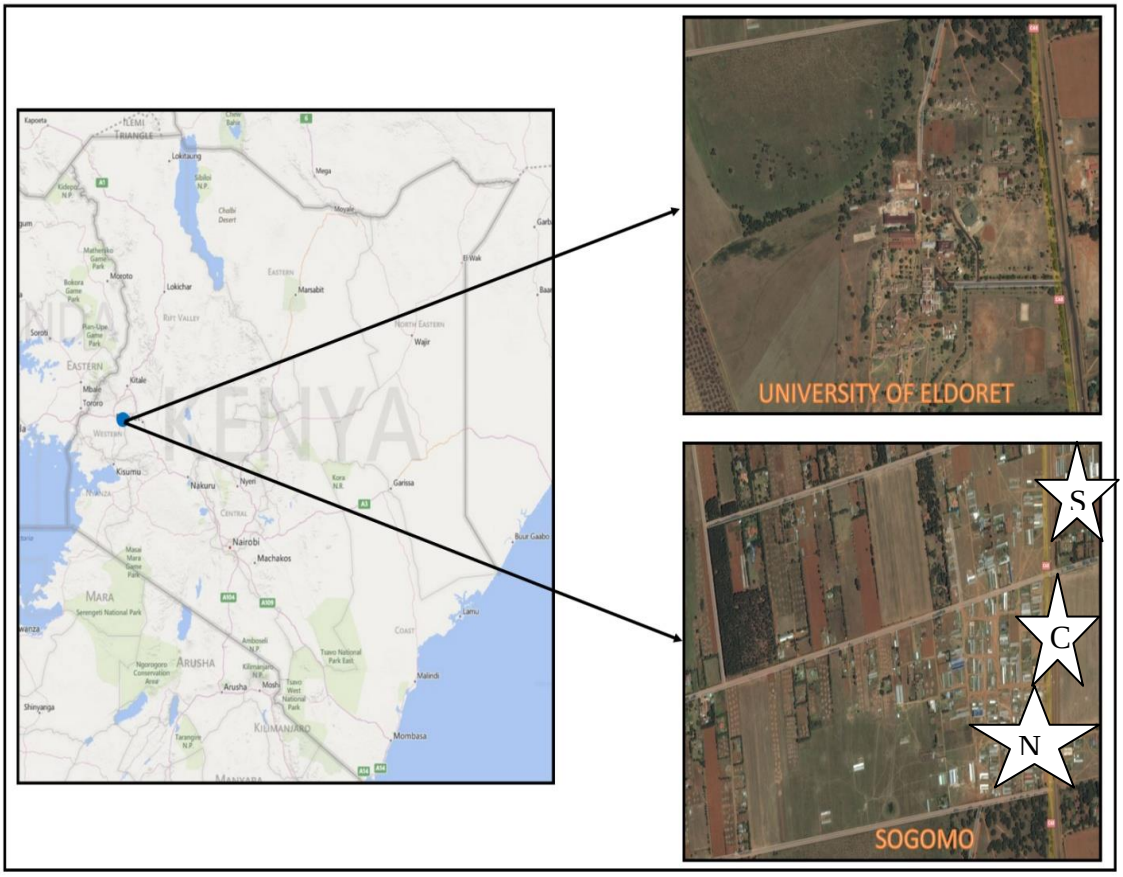

Figure 3.1: Map of Sogomo Village (Source: goggle map)

Sogomo village is mainly inhabited by students from University of Eldoret and family members. The type of residences in Sogomo vary from the single rooms that are favoured by most students, the double rooms which are mostly occupied by family members and the self contained rooms that are occupied by few small family members and the students.

3.2.2 Plot Area Selection

Three residential sites with around 20 residents whose main sanitation for human waste disposal was a pit latrine and dust bins for kitchen waste in Sogomo village were selected for the study. Further, site selection was based on the interest of residents and landlords or landladies and availability of demonstration plots for installation of anaerobic digester latrines (APDLs). A single complete system of APDL was installed in each of the three plot areas and all the residents in each plot were required to use the APDL systems as new modes of sanitation.

The APDLs were named North, South and Central stations. The North system had urine, flush water and faeces as the influent entering the digester, the South station system had all its urine diverted directly into the heating tank and only faeces and flush water entered the digester. The Central station system had urine, faeces, flush water and food scraps as input materials entering the digester the food scrubs used were generated by the APDL users only. The food scrubs was a mixture of proteins, carbohydrates and lipids from the toilet users and were fed into the digester once a day. The pre-processing of the food scrubs before being fed into the digester included: screening to remove larger objects, a magnet to remove ferrous metals, and grinding to reduce particle size.

Following site selection, a Participatory Rural Approach (PRA) was pursued to design a desirable user interface with the APDL system, and systems were then installed. Users were educated on how the system operated and trained on how to do minor upkeep that was expected to be minimal. After installation the monitoring phase began which included organic reductions, total nitrogen and total ammonia in the final

effluent as nutrients rich in the organic fertilizers and recoverable resources using distilled ammonia as a raw material.

3.2.3 Digestion Equipment

A sketch of an improved sanitation system used in this study referred to as Anaerobic Digestion-Pasteurization Latrine developed by the Deshusses research group in the Civil and Environmental Engineering Department of Duke University is shown in figure 3.2. The system operates by using an anaerobic digestion tank to receive human excreta from the latrine. Anaerobic microorganisms metabolize influent wastes and produce final treated effluent, organic fertilizer and recoverable resources. The digester's effluent enters a heating tank where it is heated or pasteuralized to 75°C by burning the biogas produced. The efficiency of the process is enhanced by adding a counter-flow heat-exchanger between the anaerobic digestion tank and the heating tank. The effluent leaving the system is therefore heat sterilized, making it safe for environmental discharge.

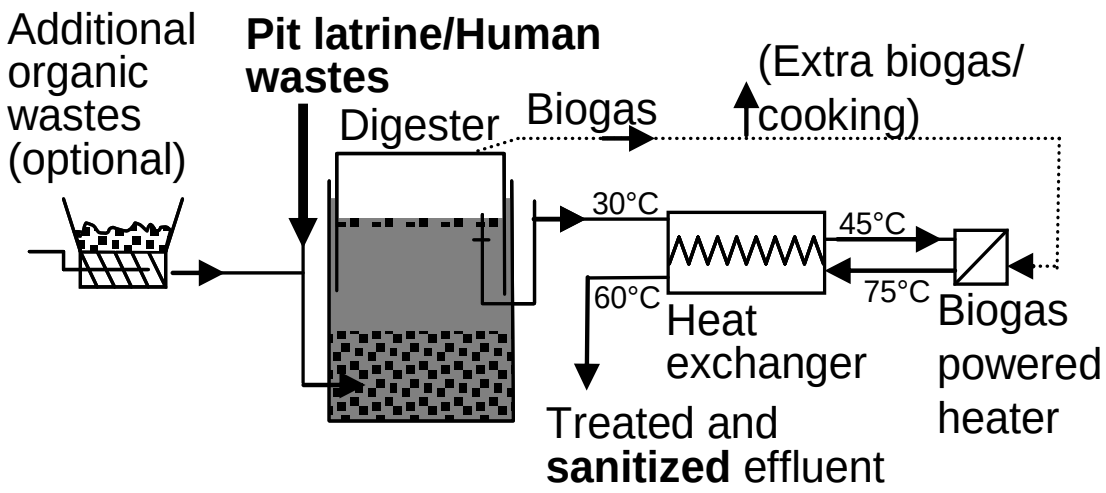

Figure 3.2: Flow sheet and Concept of The Anaerobic Latrine.

3.3 Anaerobic Digester Acclimation Process

Part of the acclimation process using metallic tanks is as displayed in figure 3.3 which involved fetching 200 litre of slurry from an active digester and poured all these into 400 litre volume metallic gallons. The conditions inside the tanks were made completely anaerobic by tightly fitting the corks back. Acclimation process commenced which involved feeding of the 400 litre capacity tanks twice a day with half a litre of water, two litres of raw sewage from the university of Eldoret sewage treatment plant, topped up with 0.50 liters of water and 100 grams of Urea fertilizer bought from an agro vet. This feeding was continued daily for three weeks in order to establish appropriate culture of the digester's anaerobic microorganisms. After the acclimation period the tanks content were distributed to all the three 2000 litre dome digesters provided by Sim Gas Company in the three stations. This was followed by addition of 400 litres of water and the anaerobic digester systems were ready for use by the residents as new sanitization systems. A single use of the system required a litre of water for flushing.

Figure 3.3: Researchers and Barrels Acclimation Tanks (Source : Author)

3.4 Sample Collection and testing

Two sampling points were selected within the anaerobic digester system set up, which include: before the digester and after the digester. This was done for all the three different types of anaerobic digesters systems.

Organic reductions in the influent and in the final effluent were measured on a weekly basis. Organic reduction which a primary indicator of sewage treatment. Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) were used for organic reductions monitoring. COD was measured by the standard dichromate method while BOD was measured by the Winkler method.

Total Nitrogen and total ammonia concentrations in the final effluent were measured weekly. Total nitrogen, total ammonia and total ammonium concentrations within the final effluent were nutrient content indicators of organic fertilizers produced by the systems installed. Total ammonia and total ammonium were determined by direct method where the effluent sample was treated with strong base for example sodium hydroxide and the mixture distilled. Ammonia was quantitatively expelled and was absorbed in excess of standard acid solution.

The excess acid was back titrated in the presence of methyl red indicator. Each volume cm^3 of N acid consumed in the reaction was equivalent to 0.0017032 mg/l of ammonia. Just before the analysis for ammonia, the samples collected from the final effluent were warmed to room temperature and neutralized with 0.05 N Sodium Hydroxide Standard Solution for good end point results.

Total ammonium from the final effluent used for the recovery process of ammonium nitrate, ammonium chloride, ammonium sulphate and ammonium hydroxide and the acids used for the recovery were nitric acid, sulphiric acid, hydrochloric acid and distilled water. Most reliable results were obtained when samples were analyzed as soon as possible after collection. Samples were transported to the laboratory using insulated icebox (approximately 4^oC) within 24 hours and refrigerated until analysis (UNESCO/WHO, 1978: and Arudel, 2000).

3.5.0 Organic Reduction and Resource Recovery

3.5.1. Chemical Oxygen Demand

A sample of 25.00 ml of wastewater (influent or effluent) was put into a 250 ml-refluxing flask with boiling chips and 1.00 g of mercuric sulphate added. A standard solution of H_2SO_4prepared of 500.00 ml of concentrated sulphuric acid and 22.00 g of silver sulphate was added slowly while cooling. Thereafter, 25.00 ml of standard prepared 0.10N potassium dichromate was added and the content "refluxed" for two hours. Afterwards, the residual mixture was cooled to room temperature and diluted to twice its volume. The whole amount was titrated with 0.1N ferrous ammonium sulphate, using ferroin indicator to a reddish brown end point. A blank was obtained by titrating 25.00 ml of 0.1N standard potassium dichromate after adding sulphuric acid / silver sulphate mixture with 0.1N standard ferrous ammonium sulphate. COD was calculated using equation 14 (Greenberg *et al.*, 1992).

$$\text{COD mg/l} = \frac{(a-b)N \text{ x } 8000}{V} \quad \text{---------- (14)}$$

Where,

a is the volume of Fe $(NH_4)_4(SO_4)_3$ used for the blank (ml)

b is the volume of $Fe(NH_4)_4(SO_4)_3$ used for the sample (ml)

N is the normality of ferrous ammonium sulphate

V is the volume of sample (ml)

8000 is the multiplier to express COD (mg/l)

(TAPPI standards, 1992).

3.5.2 Biochemical Oxygen Demand

Two litres of standard dilution water was siphoned into a plastic container, part of this water was then siphoned into two 300-ml BOD bottles (control). To the remaining dilution water (1.40 litres), 1.40 ml of each nutrient and 7.00 ml (0.5 %) seed was then added and mixed well avoiding air entrainment. Nutrients are standard prepared phosphate buffer solution containing magnesium sulphate, calcium chloride and ferric chloride solutions. The mixed dilution was siphoned into one litre volumetric flask containing 20.00 ml of sample acidified with H_2SO_4 and filled to titre mark. The mixture was then quickly siphoned from the volumetric flask into two BOD bottles one for incubation and the other for determination of initial DO in the mixture. The bottles were stoppered tightly and incubated for 5 days at 20^o C. The BOD bottles were water sealed throughout the five-day period, after which the DO was determined. Equation 15 was used to determine BOD after determining initial and final dissolved oxygen of the blank and sample (TAPPI standards, 1992).

$$\text{B.O.D} \qquad \frac{(D_1 - D_2) - (B_1 - B_2)\,\text{x}1000}{V} \qquad \text{---------- (15)}$$

Where D_1 is dissolved oxygen in sample at 15 minutes after preparation.

D_2 is dissolved oxygen concentration in sample after 5 days.

V is the volume of the sample used (ml)

B_1 is dissolved oxygen of seeded dilution water before incubation,

B_2 is dissolved oxygen of seeded dilution water after incubation at 20^0C for five days

3.5.3 Total Ammonia Determination

The requirements for total ammonia determination were ammonium sulphate, zinc granules, 10% sodium hydroxide, methyl red indicator and 0.1 M sodium hydroxide. 50.00 ml of the final effluent was accurately weighed and put in a volumetric flask. Two hundred milliliters of distilled water was added and thoroughly shaken. 25.00 ml of aliquot of the solution was transferred into a 250.000 ml distillation flask and diluted with 100.00 ml of distilled water. 1.00 g of granulated zinc was added to the content in order to promote regular abolition in the subsequent distillation. Exactly 50.00 ml of standard 0.1N of acid (hydrochloric, nitric and sulphiric) was placed in receiver as illustrated schematically in figure 3.4 and the flask was adjusted such that the end of the condenser just dipped into the acid while making sure that all the corks were tightly fitted.

Fifty milliliters of 10% sodium hydroxide was placed in the separating funnel and the sodium hydroxide was run into the distillation flask by opening the tap. The tap was later closed as soon as the alkali had entered.

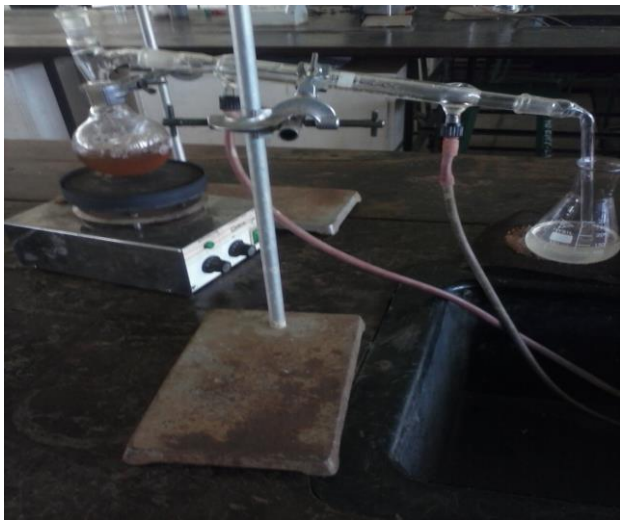

Figure 3.4: Total Ammonia Digestion and Distillation Equipment Set-up (Source : Author)

The flask was heated so that the contents boiled gently and the distillation process was continued for 60.00 minutes until half or a third of the original volume remained. By this time it was assumed that all the total ammonium had passed over into the receiver contents. The excess acid was titrated in the solution with standard 0.1M sodium hydroxide. This was repeated thrice in order to get titre values and total ammonia in mg/l was calculated as shown in equation 16.

$$\text{Total ammonia in mg/l} = \frac{(A-B)\ N \times F \times 1000}{S} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 16$$

Where:

A is milliliters of standard 0.020 N acid solution used in titrating sample.

B is milliliters of standard 0.020 N acid solution used in titrating blank.

N is normality of acid solution.

F is milli equivalent weight to ammonia (17 mg).

S is milliliters of sample digested.

3.5.4 Ammonia Acid Reaction

The acid solution (sulphuric, nitric and hydrochloric) was made to 10%, 20% and 50% concentrations and put in a 100.00 ml standard flask. The solution was then thoroughly shaken to get a uniformly concentrated solution. The burette was washed and rinsed with distilled water and rinsed again with the respective acids before being filled with the given acid (sulphuric, hydrochloric or nitric).

The initial reading of the burette was noted and exactly 20.00 ml of the ammonium hydroxide was pipetted out into a clean conical flask. To this solution two drops of phenolphthalein indicator was added. The solution was then titrated against the acids (sulphuric, nitric and hydrochloric acids). The end point of the titration was the disappearance of the pink colour that gave colorless solution. The titration was repeated to get the concordant value. From the titre value, the normality of the acids and the amount of acids present in 400.0 ml of the given solution was calculated as shown below. N_1 is normality of ammonium hydroxide while N_2 is normality of acid (sulphuric, hydrochloric and nitric).

g is amount of acid present in 400ml of the given solution and concordant value the titre number of titres in an experiment

V_1 is volume of acid (sulphiric, hydrochloric and nitric)

N is normality of acid (sulphiric, hydrochloric nitric)

V_2 is 20.0 ml volume of ammonium hydroxide

N is unknown normality of ammonium hydroxide

By the principle of volumetric mass analysis, $V_1 M_1 = V_2 M_2$

3.5.5 Total Nitrogen Determination

Digestion mixture was prepared from 0.21 g of selenium powder was added to 7.00 g of lithium sulfate this was followed by addition of 175.00 ml of 30% hydrogen peroxide and the solution mixed well. Two hundred and ten milliliters of concentrated sulfuric acid was carefully added while cooling the contents in an ice-bath and subsequently stored at 4 ^{0}C.

Fifteen milliliters of final effluent samples was put into labeled dry, clean digestion tubes. 4.40 ml of the digestion mixture was added to each tube and also to reagents blanks for each batch of samples. The tubes were heated in a block digestion at 350 ^{0}C for 2 h. The digestion was completed when the digest became colorless. The tubes were removed from the digester and cooled to room temperature. Twenty five milliliters of distilled water was the added, mixed well and made up to 50.00 ml with distilled water. The contents were then transferred into a 50.00 ml volumetric flask for analysis of nitrogen.

Colorimetric analysis method was used for total nitrogen determination. Standards containing 0.00, 2.50, 5.00, 7.50, 10.00 and 15.00 mg / litre of NH_4^+ were used for calibration of the calorimeter instrument. The absorbance was measured at 655 nm in the colorimeter. Reagent **N1** was prepared by taking, 17.00 g of sodium salicylate, 12.50 g sodium citrate and 12.5 g sodium tartarate and were then dissolved together in 350 ml of distilled water and then 0.06 g Sodium nitropruside was added and the mixture was made up to 500 ml with distilled water. Reagent **N2** was prepared by dissolving, 15.00 g sodium hydroxide in about 375 ml distilled water. It was allowed to cool then 10.00 ml of sodium hypochlorite was added, mixed well and make up to 500 ml.

Using a micropipette, 0.10 ml of each standard, sample digest and blanks were transferred into clearly labeled test tubes. Five mililiters of reagent N_1 was added and left to stand for about 15 minutes. In the same way 5.00 ml of reagent N_2 solution was then added into each test tube, mixed well and left for one hour for full colour development. Each standard and sample absorbance was read at 655 nm using a

colorimeter. A graph of absorbance against concentration of total nitrogen was plotted and the sample concentration was determined Total nitrogen in the sample was determined using the following formula:

%N = concentration X {factor/ volume of sample}

3.6 Data Analysis and Presentation

Data was collected according to the stratified random sampling experimental design with replicates. For organic reduction the experiments were laid down in a stratified random design, with two sampling points. One-way ANOVA was employed for organic reduction (BOD and COD) and resource recovery (total nitrogen, total ammonium and total ammonia). Two-way ANOVA was employed for rest of the resource recovery (ammonium hydroxide, ammonium chloride, ammonium nitrate and ammonium sulphate). Statistical analysis was carried out using statistical package for social scientists (SPSS) computer programme, version 21.0. Turkey post hoc was employed to separate means of these parameters.

The analyzed data was presented in bar graphs and tables. The COD and BOD data for organic reductions, total nitrogen, total ammonia and total ammonium as nutrients rich in organic fertilizer were presented in simple bar graphs and tables were used to display the one-way ANOVA variation results. Data for ammonium chloride recovery, ammonium sulphate, ammonium chloride and ammonium hydroxide using 10 %, 20 % and 50 % concentrations of acids and distilled water was presented using bar graphs and the two-way ANOVA data was presented in tables.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Organic Reduction

4.1.1 Chemical Oxygen Demand

Chemical Oxygen Demand mean Influent values were high at all the three stations of study. The mean values were 1483.69 mg/l, 1454.33 mg/l and 1414.74 mg/l for central, south and north digesters respectively as displayed in figure 4.1. The central station recorded the highest values followed by south and finally the north station. The surplus food scrubs also known as food waste, or organic materials that were an additional input into the south digester, included uneaten food and food preparation leftovers from the residences at south station. The south digester contributed greatly in improving the environment and providing benefits by reducing, reusing, and recycling uneaten or unused food rather than being thrown away or overloading waste collection bins and addition of extra costs during transportation, sorting and treatment because they are voluminous and heavy.

Normal human stool consist of roughly 70-80% water and around 20-30% solid matter, though the water content of faeces is dependent on dietary intake and digestive function (Marteau, 2001). Majority (84%) of the solid matter in faeces is organic in nature and residual dietary fibre (17%). The solid matter in feaces usually has high COD values before any dilution or very low dilution and this can be reason attributed to the South digester that followed in high COD values after the central digester (Levis, 2010). On the other hand, human urine consists of over 80 % water and of a wide range of substances that vary with diet for example, proteins, hormones, water

and a wide range of metabolites that forms a good mixture with feaces. The water contained in urine and the various substances easily mixes and dilutes the organic in feaces and in the process the COD levels in the feaces are lowed (Karagiannidis, 2008). This can be a reason why the North digester was the best in COD reduction.

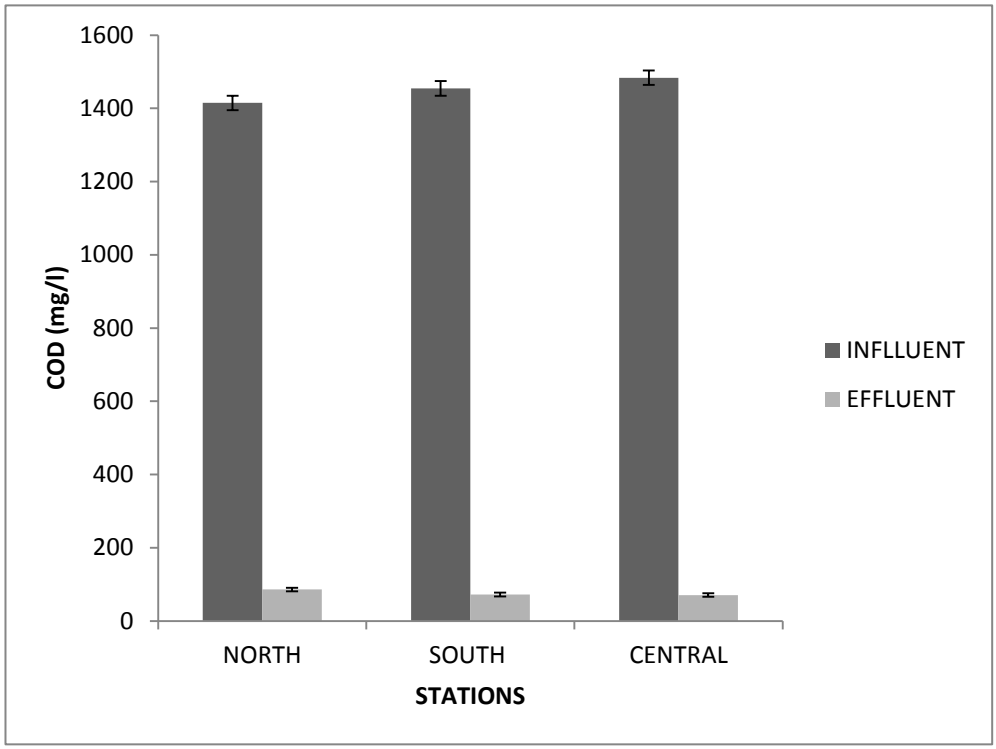

Figure 4.1: Chemical Oxygen Demand for influent and effluent

Digesters effluent mean COD values ranged from 60.00 mg/l to 150.00 mg/l. Among the three digesters, central station recorded the best values of final effluent COD of 70.78 mg/l, followed by south station with 72.43 mg/l and finally north station with 86.18 mg/l. South and central stations showed a mean value of 95 % COD reduction, while the north station had a mean of 93 % COD reduction.

Final effluent COD was highest in central station followed by north station and finally the south station. The difference in final effluent COD was probably because of the

different digester inputs that varied among the digesters. For example food scrubs added in the central station formed an extra organic load for anaerobic micro organisms in the digester as compared to the north digester that had urine and feaces as digester inputs or the south digester that had only feaces as digester input.

The south digester proved that food scrubs can be anaerobically digested by anaerobic micro organisms and reduced to low COD levels in the same manner urine and feaces would be reduced in an anaerobic digester. Effects of different organic loads such as different sources of food scrubs enrichment on micro organisms in anaerobic conditions showed that they can be degraded and reduced anaerobically to carbon dioxide, water and methane gas (Larsen *et .al*., 2009).

The south digester was the best in COD removal efficiency because the feaces were the only input into the digester which are mostly by-products of digested food from the stomach by bacteria and other micro organisms found within the gut such as gasterol bacteria and this makes it easily degraded anaerobically because it has low predigested organic loads as compared to food scrubs combined with urine and feaces or urine and feaces as digester inputs (Prado and Almeida, 2009).

Statistical analysis of variance for COD indicated a significant difference ($p \leq 0.05$) among the three stations of the study. Central and south digesters were significantly different ($p \leq 0.05$) from north digester. Feaces that was the only digester input for south digester consisted of hydrolyzed materials that were easily acted upon by anaerobic micro organisms within the digester and similarly food scrubs, urine and

feaces as digester inputs for central digester were also easily mixed up and anaerobically degraded (Eckenfelder *et al.,* 1998).

Anaerobic digestion in the North digester that combined feaces and urine was low probably because the urine entering the digester had very high levels of urea that in the presence of flushing water formed ammonia making anaerobic process slow because high concentrations of ammonia raises the pH and anaerobic micro organisms are sensitive to pH variations (Liu and Sung, 2002). Various feed stocks into digesters showed that the anaerobic micro organisms are usually sensitive to pH and this result to low performance of the anaerobic digesters in organic reduction (EPA, 2008; Novak *et al*., 2003 and Nielson *et al*., 2006).

4.1.2. Biological Oxygen Demand

Influent and effluent BOD in all the stations studied is shown in figure 4.2. North, south and central stations had an influent BOD of 745.70 mg/l, 744.90 mg/l and 743.00 mg/l respectively. Mean values for BOD were not significantly different ($p \leq 0.05$) probably because most of the inputs were similar in their organic constituents. Digested BOD for north, south and central stations were 78.50 mg/l, 55.50 mg/l and 73.70 mg/l respectively.

The BOD percentage reductions in North, South and central stations were 89.48%, 92.60% and 90.09% respectively. The best BOD reduction was at south station because the influent materials was only feaces, which were already partially degraded unlike the central with added food scrubs and north with additional urine. Thus north and central stations had higher BOD loading as compared to the south station. Fresh

organic matter normally has higher BOD load as compared to partially digested material such as feaces from human and animals (Robinson *et al*.,2007).

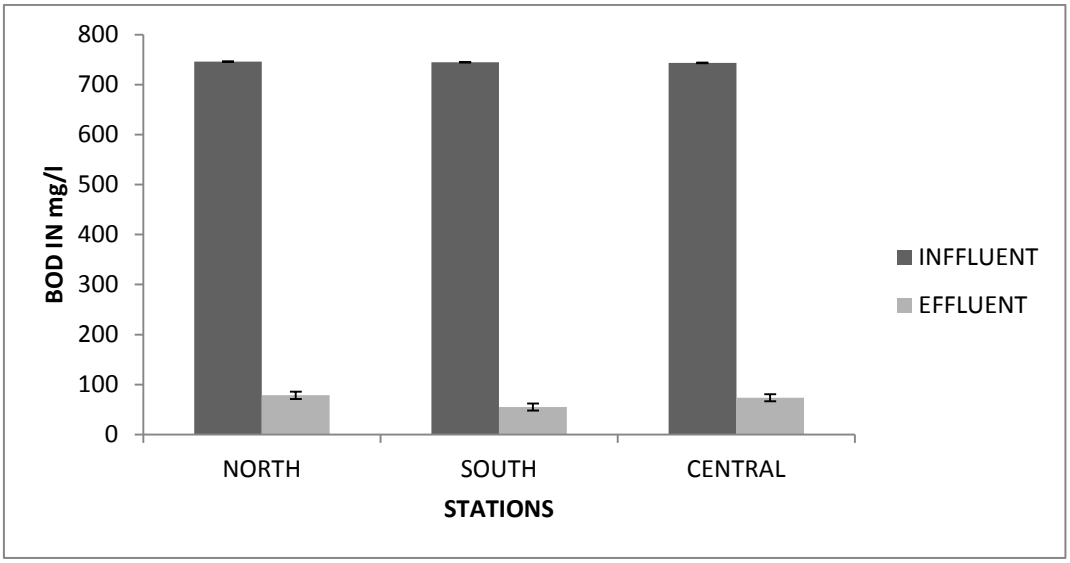

Figure 4.2: Digesters influent and effluent BOD

Variance analysis of BOD in the three stations of study showed there was a significant difference ($p \leq .05$) in BOD reduction among the three stations. However on separation of BOD means, it was found that south was significantly different ($p \leq 0.05$) from north and central stations.

Anaerobic digestion is a complex Biochemical reaction carried out in a number of steps by several types of microorganisms that require no oxygen to live (Caveat, 2010). Anaerobic digestion of feaces, urine and food scrubs as digester inputs occurs in three main stages which are hydrolysis, acetogenesis and Methanogenesis (Zielinski 2009).

During the hydrolysis stage, the carbohydrates were hydrolyzed to alcohol, while the proteins were hydrolyzed to amino acids and peptides, fats were hydrolyzed to fatty acids and glycerol and finally cellulose were hydrolyzed to glucose and cellobiose (Bouallagui, 2009a).

BOD reductions within the digesters proceeded in two stages. In the first stage almost all the carbonaceous organic matter like carbohydrates and fats were anaerobically oxidized to simple sugars, fatty acids and water. In the second stage, all matter rich in nitrogen such as proteins were anaerobically oxidized by anaerobic microorganisms in the digesters to amino acids (Ahmadun *et al*., 2008).

The influent BOD values from all the digesters were almost the same. BOD values of raw feaces, urine or food scrubs vary within a small range because the microbial activity has not yet been initiated (Tembhurkar, 2007). This study on APDLs proved that food scrubs were reduced anaerobically by biological micro organisms in the digester through the same processes feaces and urine would be digested and reduced (Giust, 2009).

4.2 Recovery of ammonium Nutrients

4.2.1 Total Nitrogen

Total nitrogen obtained from the three stations is shown in figure 4.3. South station gave the highest total nitrogen mean value of 6.22 mg/l followed by north with 5.74 mg/l and lowest central with 5.50 mg/l.

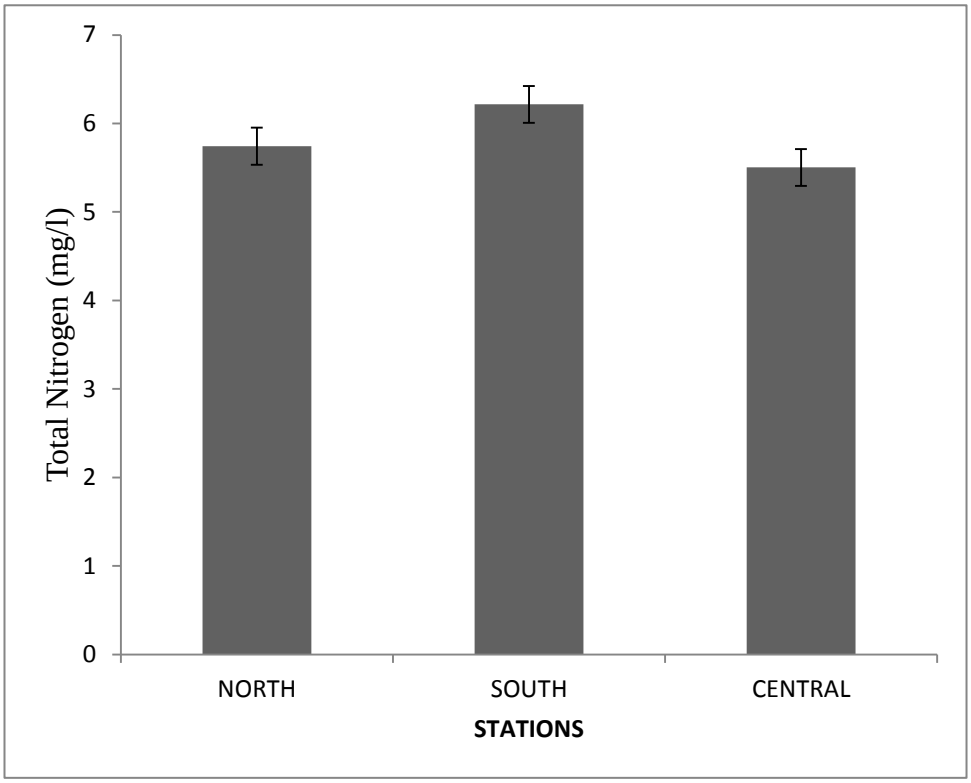

Figure 4.3: Total Nitrogen

Analysis of variance of total nitrogen obtained from the three stations indicated a significant difference ($p \leq 0.05$) of total nitrogen among the three stations of the study. However on separation of means variations within and between the stations realized that south station had a significant difference ($p \leq 0.05$) from central and north stations. The main reason for high content of nitrogen in south station was due to the urine diversion to the final effluent (Ahn, 2006). Most studies indicate nitrogen forms the highest percentage constituent of urine, feaces nitrogen is 10-20% and food scrubs nitrogen content varies with the type, source and nutrient content of the food scrubs (Guest *et al*.,2009).

All stations produced sufficient amounts of total nitrogen compared with set standards. The highest nitrogen content required by plants for maximum crop yield

for short rotation crops should be greater than 2.50 mg/l, moderate amount should be between 1.20 and 2.50 mg/l and least should be 1.20 mg/l (Okalebo et al., 2002).

All stations may be a good source of organic fertilizer rich in nitrogen because urine formed composed part of the final effluentin all the digesters installed. South station had a urine diversion where all the urine combined with the digesters final effluent at the heater while for north and south digester urine directly formed the final effluent. One person produces annually approximately 500 litres of urine. The urine fraction excreted by a normal human being in a day contains 98 % of the nitrogen. Most of the nitrogen in human urine is in a form suitable for plants, for example ammonia nitrogen (Kirchmann and Pettersson 1995; Claesson and Steineck 1996). A normal human being feaces contain 5-7% total nitrogen while food scrubs usually contain 3-4 % total nitrogen as reported by (Marteau *et al*., 2001)

Main portion on nutrients in the household waste is found in the urine, feaces and in the biodegradable solids contained in the food wastes. If all of these fractions were collected and recycled, then 92% of nitrogen contained in urine, feaces and in the biodegradable solids of the food wastes would be recycled (Nigawaba *et al*., 2009).

4.2.2 Total Ammonia

Figure 4.4 show that south digester registered the highest mean values of 12.35 mg/l of total ammonia. This was followed by central digester that produced 11.76 mg/l of total ammonia and least by north digester with 10.86 mg/l of total ammonia. However on analysis of variance as showed there was a significant difference ($p \leq 0.05$) among the three digesters installed. The difference in variation may have been due to the composition of the different effluent of the three digesters. Studies have indicated that

urine contains 80-90 % nitrogen of its total solute, which is unstable and in presence of water gets oxidized to ammonia (Malkki, 1999).

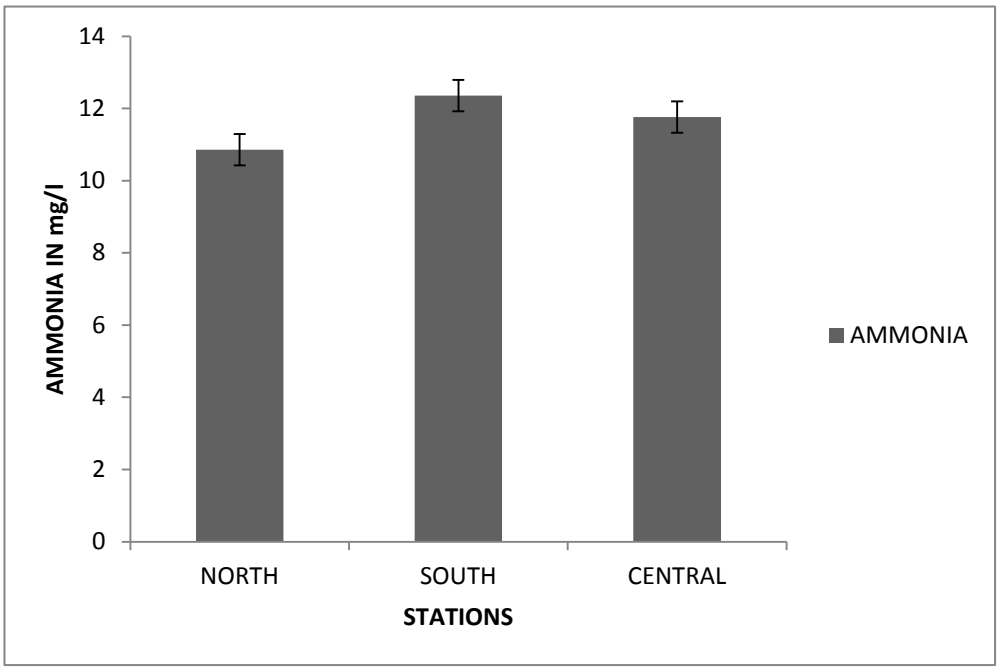

Figure 4.4: Total Ammonia

The food scrubs, feaces and the urine inputs contained the macro elements like proteins hormones, amino acids and worn out cells that were anaerobically reduced during methanogesis stage to nitrogen. The nitrogen was later anaerobically oxidized to ammonia by hydrogen gas released during acetogenesis and by the hydrogen ions contained in the flushing water which formed total ammonia in the final effluent (Bayshtok,2009 and Elefsiniotis, 2004).

4.2.3 Total Ammonium ions

Total ammonium obtained is shown in figure 4.5. North, central and south station gave 13.97 mg/l, 15.22 mg/l and 15.91 mg/l respectively of total ammonium. The highest value of total ammonium was from south station and least from north.

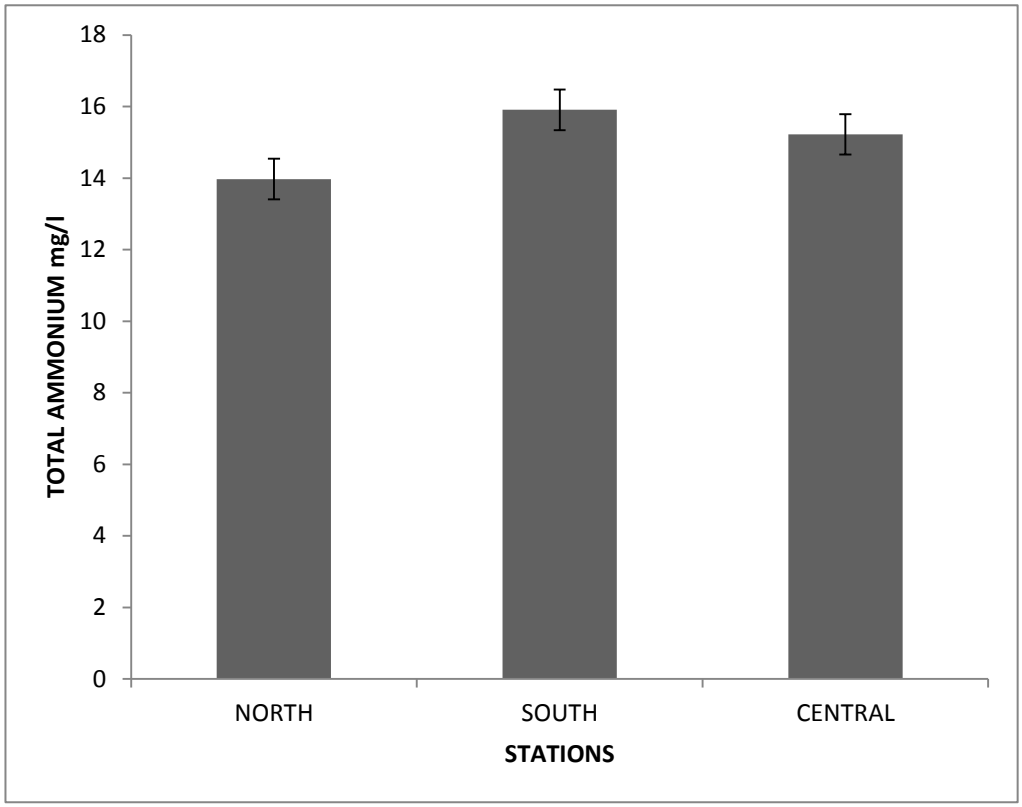

Figure: 4.5: Total Ammonium

Statistical analysis of variance showed a significant difference ($p \leq 0.05$) among and within the stations study. On means separation, all stations were significantly different ($p \leq 0.05$) in total ammonium contained in the final effluent. South station recorded the highest amount of total ammonium because diverted urine formed part final effluent sampled. Thus digester with urine diversion final effluent had higher amounts of total ammonium content that combined with hydrogen ion either in the flushing water or with the final effluent water to ammonium compound (Constantine ,2006).

Total ammonium in human urine in south was more than 15.00 mg/l and total ammonium contained in a normal human being producing 0.50 litres of urine contains more than 12.00 mg/l of total ammonium (Garner *et al.*, 2010). (Chakrabarti and

Jana, 1998) found out that human urine total ammonium can be used for agricultural production when they studied the effects of ammonium and other fertilizer types on gross primary productivity of pytoplankton and planton.

The studies on APDLs proved that there are sufficient nutrients for reuse for sustainable development in agriculture. The Swedish University of Agricultural sciences found out that for a sustainable society to be created, the nutrients from household wastes, biodegradable solid wastes and wastewater have to be recycled to agriculture. This will result to greater environmental protection because the use and dependency on fossil sources would go down and consequently would the negative effects rising from discharge of nutrients to water recipients (Vinnera and Jönsson, 2001).

Human excreta and animal manure are a good soil conditioner and a renewable source of plant nutrients, such as nitrogen, phosphorus and potassium. However, animal manure is becoming a problem due to lack of grazing lands for the animals especially in slums and most urban areas. The only option that remains is human waste as a potential source of nutrients for agriculture in urban and peri urban areas where populations are large and pit latrines result to resource wastage (Maurer *et al.,* 2006).

Urine largely consist of water but the nutrients contained in urine excreted by a normal human being are nitrogen and the nitrogen is usually 80% in form of urea, 7% in ammonia form and the rest of the nitrogen is normally contained in the shorter peptides and in free amino acids (Clemens *et al*., 2006). However, recovery and utilization of nitrogen, ammonia and ammonium nutrients found in food scrubs is

slowly being accepted in many parts of the world because they contain 3-4 % of total nitrogen and in Kenya the APDLs having food scrubs as additional digester input will help in more organic fertilizer rich in nitrogen, ammonia and ammonium being recovered other than these nutrients being left to rot in dust bins or in waste collection points (Shang *et al*., 2006).

At present, anaerobically treated toilet human waste is of little significance as fertilizer or soil conditioner from households (Löfgren *et al*., 1998). Utilization of the nutrients contained in feaces, urine and in food scrubs for agriculture is still low in Africa and outside Africa. Faeces can be collected at various degrees of dilution, with flush water like in the case of a urine diversion system at south station; mixed with urine like in the north station; or food scrubs added together with urine and feaces like the case of central station and be treated anaerobically for organic reduction, organic fertilizer recovered rich in nitrogen, ammonia and ammonium or alternatively resources recovered (Hagalund and Olofsson 1997).

Nutrients from human excreta and those contained in food scrubs should be returned to the soil to fertilize crops. Safe processing of the urine, food scrubs and faeces into fertilizer should however be done properly for example by anaerobic pasteurization digestion latrine (APDLs) for them to be low in organic content (Jonsson, 2004).

A normal grown up can produce between 800-2500 ml of urine per day whose main nutrient constituent is ammonia (Jana *et al*., 2012). This could be taken up by plants directly or converted to nitrates before uptake by agricultural plants. The up taken

ammonia can be used by plants for amino acid synthesis, chlorophyll formation and for general growth of plants (Stewart, 2005).

4.3 Recoverable Resources from APDLs

4.3.1 Ammonium Nitrate Recovery

Ammonium nitrate recovered is shown in Figure 4.6. At 10 % concentration of nitric acid north, south and central recovered 5.07 mg/l, 6.05 mg/l and 5.65 mg/l of ammonium nitrate. At 20 % concentration of nitric acid, north, south and central recovered 11.01 mg/l, 1.37 mg/l and 10.79 mg/l of ammonium nitrate respectively. At 50 % concentration of nitric acid, south station recovered highest ammonium nitrate (27.83 mg/l), followed by central station (26.16 mg/l) and lastly north station (25.09 mg/l).

The explanation for this variation of ammonium nitrate recovery with various concentrations of nitric acid is that the higher nitric acid concentrations the higher were hydrogen and nitrate ions released in solution that reacted with ammonium ions to form ammonium nitrate and water. Nitric acid and ammonium hydroxide are base-acid reactions in which the acid is a proton donor while the base is a proton acceptor and the reaction proceeds forward with the nitrate anions binding with the ammonium ions as their concentration increases (Perez, 2003).

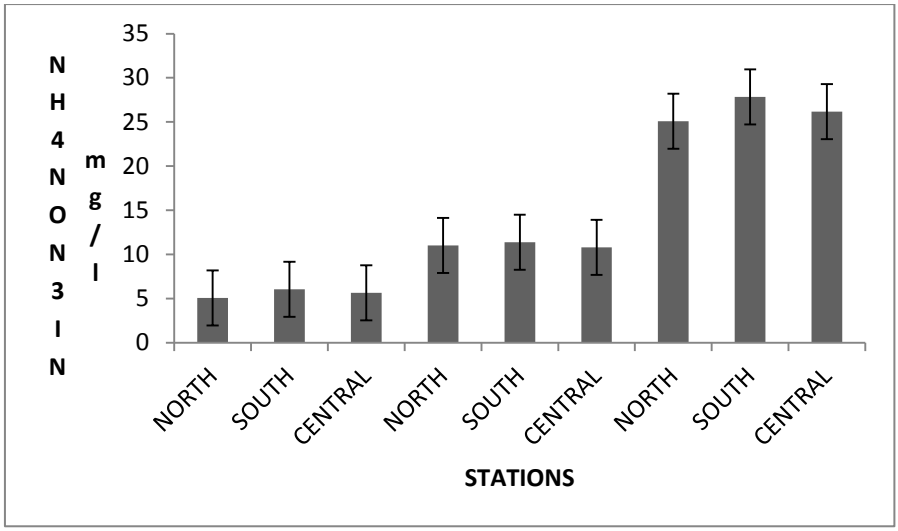

Figure 4.6: Ammonium Nitrate Recovery

There was a significance difference ($p \leq 0.05$) among the various concentrations of nitric acid used for recovery of ammonium nitrate. The reason that can be attributed to this variation among various acid concentrations is that lower nitrate ions in solution reacted with few ammonium ions in solution to yield low ammonium nitrate while on the other hand higher concentrations of nitric acid dissociated to more nitrate anions and hydroxide ions in solution.

Separation of means indicated found out that south was to be significantly different ($p \leq 0.05$) from north and central stations. The south digester produced 20 % more ammonium nitrate as compared to north and central stations. The central station was the second best in ammonium nitrate recovery and it is the best recommended because it utilizes food scrubs that would result to compounded environmental problems. Although the north digester was last in ammonium nitrate recovery it can also be used for ammonium nitrate recovery.

4.3.2 Ammonium Chloride Recovery

Figure 4.7 shows the amount of ammonium chloride recovered from each of the three stations. At 10 % hydrochloric acid, the north station gave 4.18 mg/l of ammonium chloride, south 4.19 mg/l and finally central station gave 3.90 mg/l of ammonium chloride. Central station produced 7.81 mg/l of ammonium of chloride; south produced 8.44 mg/l of ammonium chloride and from north station 8.25 mg/l of ammonium chloride was recovered with 20 % hydrochloric acid.

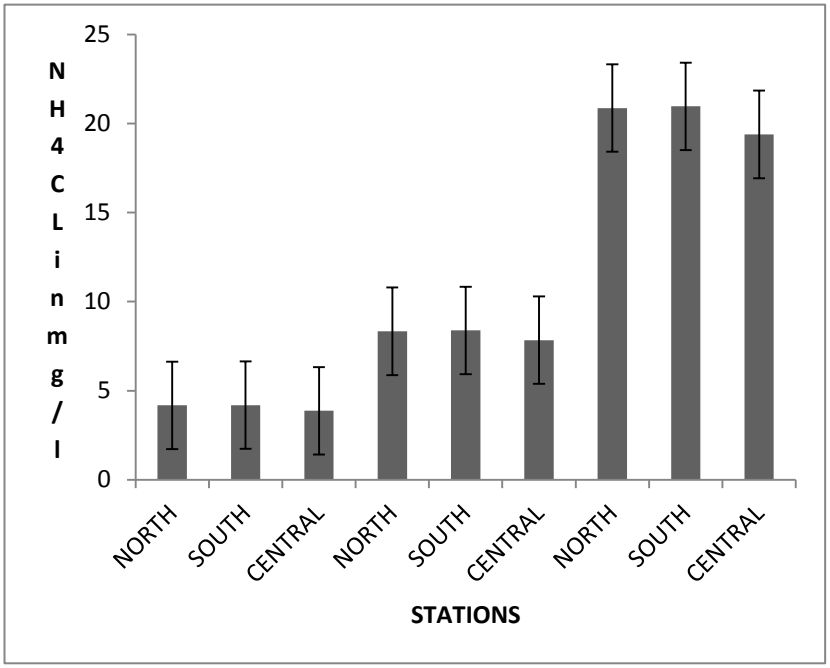

Figure 4.7: Recovery of ammonium chloride

When 50 % of hydrochloric acid was used north station recovered 20.86 mg/l, south station recovered 21.56 mg/l and finally central station recovered 20.90 mg/l of ammonium chloride. There was an increasing amount of ammonium chloride recovery with increasing concentrations of hydrochloric acid in all the stations.

Analysis of variance indicated a significant difference ($p \leq 0.05$) among the various stations of study. The main reason for this variation among the stations of study was the difference in total amounts of total ammonium initially distilled from the final effluent of each station.

Analysis of variance for ammonium chloride depicted a significant difference (≤ 0.05) among the different concentrations of hydrochloric acid used for recovery of ammonium chloride in all stations. This was because as the concentration of hydrochloric acid was increased the higher were the chloride anions that were released in solution to combine with ammonium ions in solution to give ammonium chloride and water (perez, 2003).

On separation of means it was found that north, south and central stations were significantly different ($p \leq 0.05$). The reason for this was because the system fitted with urine diversion recovered much higher amounts of total ammonium from the final effluent that was used for in the reaction with hydrochloric acid to form ammonium chloride.

On the same, mean separation of hydrochloric acid concentrations used for the recovery were significantly different ($p \leq 0.05$). The reason that can be attributed to this variation in various concentrations of hydrochloric acid and recovery of ammonium chloride was the 10%, 20% and 50% hydrochloric acid concentrations dissociated differently giving in solution different concentrations of chloride anions and hydrogen ions that reacted with ammonium in solution to give ammonium (Funaba *et al*., 2001)

4.3.3 Recovery of Ammonium Sulphate

Figure 4.8 indicates that north digester recovered 7.58 mg/l of ammonium sulphate; south digester recovered 7.77 mg/l, while the central digester recovered 7.23 mg/l of ammonium sulphate using 10 % concentration of sulphuric acid. At 20 %of the sulphuric acid was used 21.05 mg/l of ammonium sulphate was recovered from the north digester, 21.67 mg/l of ammonium sulphate from south digester and finally 21.04 mg/l of ammonium sulphate was recovered from the central digester. At 50 % sulphuric acid was used 36.94 mg/l of ammonium sulphate was recovered from the north digester, 37.37 mg/l of ammonium sulphate was recovered from the south digester and finally 37.04 mg/l of ammonium chloride was recovered from the central digester.

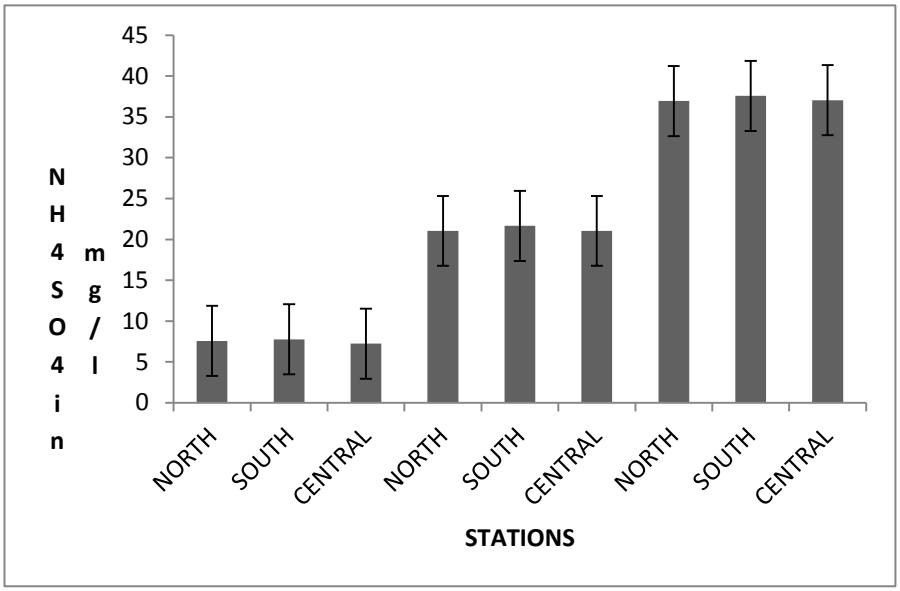

Figure 4.8: Recovery of ammonium sulphate

The difference between ammonium sulphate recovered from a urine diversion system and the one that used feaces, urine and food scrubs as digester inputs was less than 1

%, while the difference between the urine diversion system and that of urine and feaces combined was about 1 % of ammonium sulphate recovered. This APDLs results on ammonium sulphate recovery showed that all the systems installed can be used for ammonium sulphate recovery with the one fitted with a urine diversion being the best followed by the one that inputs urine, feaces and food scrubs and finally the system that uses urine and feaces as digester inputs. (Hastings, 2005).

4.2.4 Ammonium Hydroxide Recovery

Ammonium hydroxide recovered from all the stations of study is shown in figure 4.9. At 10 % distilled water north station recovered 2.16 mg/l of ammonium hydroxide while with the same percentage of distilled water south station recovered 2.22 mg/l of ammonium hydroxide and finally the central station recovered 2.30 mg/l of ammonium hydroxide. Figure 4.3.4 also shows that when the percentage of distilled water was 20 % the north station recovered 3.97 mg/l of ammonium hydroxide. The south station recovered 4.41 mg/l and the central station recovered 4.47 mg/l of ammonium hydroxide with the same 20 % distilled water.

The recovery of ammonium hydroxide with 50 % distilled water and the results indicates that the south station had the highest ammonium hydroxide recovery of 9.99 mg/l, followed by the central station with 26.16 mg/l and finally the north station with 25.09 mg/l of ammonium nitrate 9.93 mg/l of ammonium hydroxide and finally the north digester recovered 9.28 mg/l ammonium hydroxide.

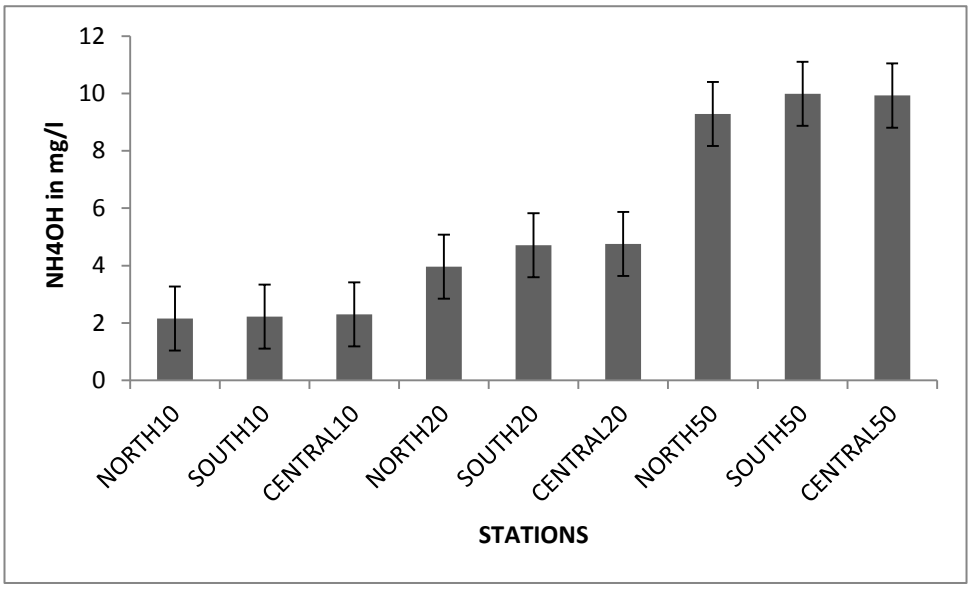

Figure: 4.9: Recovery of Ammonium Hydroxide

A significance difference ($p \leq 0.05$) among various distilled water percentages used for the recovery of ammonium hydroxide was noted. The main reason for this variation was that as the percentages of distilled water were increased from 10 %, 20 % and 50 % the higher hydroxyl ions were in solution that reacted with ammonium ions to form ammonium hydroxide (Huang,2004).

There was also a significance difference ($p \leq 0.05$) among the various percentages of distilled water used for the recovery of ammonium hydroxide. The reason for these variations can be attributed to the hydroxyl anions produced after dissociation of distilled water that combined with ammonium ions in solution to form ammonium hydroxide. The higher were the hydroxyl anions in solution the more the ammonium hydroxide formed and vice versa (Slade *et al*., 2009).

On separation of means it was however found that there was a significance difference ($p \leq 0.05$) among the stations of study. The main reason for this variation among the stations of study was the difference in total amounts of total ammonium initially distilled from the final effluent of each station that was used as raw material for ammonium hydroxide recovery using hydrochloric acid. For example the south station recovered 15.91 mg/l, central station recovered 15.22 mg/l and finally north station recovered 13.97 mg/l of total ammonium.

Analysis of variance for ammonium hydroxide also indicated a significance difference ($p \leq 0.05$) among the different concentrations of distilled water used. This was because as the concentration of distilled water was increased the higher were the hydroxyl

anions that were released in solution to combine with ammonium ions in solution to give ammonium hydroxide (Kim, 2005).

Aqueous ammonia may be generated in solution from a variety of sources that include the release of anhydrous ammonia to water and the dissociation of ammonium salts in water. The solution is readily reactive with acids resulting in production of ammonium salts such as ammonium chloride, ammonium sulfate, and others (WHO, 2004a).

Derived ammonium recoverable resources from the APDLs in this study may have a variety of uses. Ammonium nitrate ($NH4NO_3$) is produced by neutralizing nitric acid (HNO_3) with ammonia (NH_3). In 1991, there were 58 U. S. ammonium nitrate plants located in 22 states producing about 8.2 million mega grams (Mg) (9 million tons) of ammonium nitrate. Approximately 15 to 20 percent of this amount was used for explosives and the balance for fertilizer. Ammonium nitrate can be marketed in several forms, depending upon its use. Liquid ammonium nitrate may be sold as a fertilizer, generally in combination with urea (EPA, 2008).

Ammonium nitrate is a popular fertilizer like the Yara fertilizers since it provides half of the N in the nitrate form and half in the ammonium form of fertilizer for plants. Also it can be used in the manufacture of match boxes, explosives and antibiotics. The Jericho Diamond Project (Jericho) in Canada required ammonium explosives for blasting at the mine during operation (Simmons, 2006).

Ammonium chloride can be used as an acidity regulator in feeding stuffs for all species of bovines, sheep, cats and dogs (without limitations of age) at a minimum content of 0.2 % and a maximum content of 2 % of complete feeding stuff and in pharmacologically as active substance in veterinary medicinal products, in the United states of America. Ammonium chloride has been used in the synthesis various kinds of high molecular water treating compounds used for flocculation, adsorption, decolourlization and purification in Asia, Europe and in the USA (Tiquia *et al*., 1998)

Ammonium sulphate is used in a variety of applications including fertilizers, leather tanning, textile dyeing, cellulose and fiberglass insulation, fire extinguisher chemicals, and fermentation processes Ammonium sulfate has been used over the years as a nitrogen fertilizer material, accounts for about 4.7% of the world nitrogen fertilizer market and it is valued as an important source of nutrient sulfur as well (Vanchiere *et al*., 2005).

Ammonium sulphate contains the sulphur element that has made it become increasingly recognized as an essential nutrient for plant growth since it supports the synthesis of amino acids, proteins, enzymes, vitamins and chlorophyll. It has been found to be beneficial to a variety of crops, including canola, alfalfa, corn, potatoes, rice, vegetables and wheat (Biswas *et al*., 2006).

Ammonium hydroxide has been widely used in food processing for many years. The Food and Drug Administration (FDA) first evaluated ammonium hydroxide's health and safety status in the early 1970s (WHO, 1986). It is used directly in baked goods, cheese, chocolates, and puddings. In addition, ammonium hydroxide is a processing

aid in dairy products, confections, baked goods, breakfast cereals, eggs, fish, sports drinks, beer, and meat (FDA, 2003).

Aroma threshold for ammonia has been reported from 0.60 to 1.5ppm (WHO, 2003 and Hammer and Clemens, 2007) while taste threshold in pure water is 35 ppm and ammonium hydroxide can be used as a preservative for ground meat. (Gupta *et al.*, 1988).

Ammonium hydroxide can be a raw material for manufacture of ammonium fertilizers and salts for example ammonium chloride from the reaction of ammonium hydroxide with hydrochloric acid, ammonium sulphate from hydrochloric acid reaction with ammonium hydroxide and ammonium nitrate from the nitric acid reaction with ammonium hydroxide (Heinonen-Tanski *et al*., 2007).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The findings of this study suggest that there is an alternative to a long- standing problem of the current pit latrines that are used as modes of sanitation. All the three types of APDLs installed in Sogomo proved that they could reduce the organics contained in feaces, urine and in food scrubs anaerobically, produce organic fertilizer in the final effluent rich in nitrogen and ammonia and still resources could be recovered from the final effluent.

All the APDLs installed in Sogomo village could attain up to 92 % organic reduction of the digester inputs. This showed that the APDLs could be used as alternatives for domestic wastes which include feaces, urine and food scrubs treatment option.

APDLs final effluent can be used as organic fertilizer in farms and gardens because it is rich in nitrogen (>3.20 mg/l) which is even more than the plant requirements, ammonia and ammonium that are all nutrients required by plants for protein synthesis, amino acids formation and chlorophyll.

Moreover, can be recovered from the APDLs by distillation of the ammonia contained in the final effluent and using it as raw material for production of recoverable resources or alternatively be used in fertilizer industry, food industry, tannin industry, bleach industry among other uses.

5.2 Recommendations

5.2.1 Specific recommendations for this research

The APDLs proved well in organic reduction of feaces, urine and food scrubs in terms of COD and BOD, other indicator parameters of organic reduction such as solids, turbidity, pH and colour should also be tested for concrete and affirming results on the APDLs ability in organic reduction of wastes.

More of the APDLs should be installed in many places especially where pit latrines are used as modes of sanitation by many people so that they can be used for organic reduction of domestic wastes which include feaces, food scrubs and urine as a new waste management option.

Large sized digesters should be installed that can accommodate many people like in schools, institutions of higher learning and in highly living populated places for large scale organic reduction of waste and food scrubs , organic fertilizer production and for resource recovery. Since the APDLs produced final as organic fertilizer rich in nitrogen, ammonia and ammonia, more APDLs should be installed for large quantities of organic fertilizer production. The resources recovered from the APDLs like the ammonium sulphate, ammonium chloride, ammonium nitrate and ammonium hydroxide are of a wide industrial usage and application, more APDLs should be installed for large scale recovery.

5.3. Areas of Further Research

Areas of further research on APDLs include;

1. The organic reduction of organics within the digester were monitored using the COD and BOD which are major parameters of organic reduction, however other parameters of organic reduction should also be done which include turbidity, electrical conductivity, colour, total solids and suspended solids.
2. Planting of both long term and short term and long term food crops using the organic fertilizer rich in nitrogen and ammonia contained in the final effluent should be done and compare the yields with other types of organic fertilizer like the manure, and inorganic fertilizers.
3. The total amounts of food scrubs that were used as digester additives for the south digester should be quantified, moisture taken and the carbohydrates, proteins and fatty acids determined. This will help determine the best levels and quantities of the food scrubs as digester additive.
4. All the recovered resources from the final effluent distillation should further be tasted for fertilizer production, dye making, water and wastewater treatment and food industry to approve these applications.

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Appendix I: Analysis of Variance of Chemical Oxygen Demand

Descriptive statistics COD

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	25	93.90480	.443632	.088726	93.72168	94.08792	92.680	94.610
2	25	95.02040	.292111	.058422	94.89982	95.14098	94.320	95.500
3	25	95.23520	.289542	.057908	95.11568	95.35472	94.690	95.590
Total	75	94.72013	.680708	.078601	94.56352	94.87675	92.680	95.590

Test of Homogeneity of Variances			
COD			
Levene Statistic	df1	df2	Sig.
.477	2	72	.623

ANOVA					
COD					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	25.506	2	12.753	104.539	.000
Within Groups	8.783	72	.122		
Total	34.289	74			

Post Hoc Tests

Multiple Comparisons						
Dependent Variable: COD						
Tukey HSD						
(I) STATION	(J) STATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-1.115600*	.098789	.000	-1.35201	-.87919
	3	-1.330400*	.098789	.000	-1.56681	-1.09399
2	1	1.115600*	.098789	.000	.87919	1.35201
	3	-.214800	.098789	.083	-.45121	.02161
3	1	1.330400*	.098789	.000	1.09399	1.56681
	2	.214800	.098789	.083	-.02161	.45121
*. The mean difference is significant at the 0.05 level.						

Homogeneous Subsets

COD

Tukey HSD[a]

STATION	N	Subset for alpha = 0.05	
		1	2
1	25	93.90480	
2	25		95.02040
3	25		95.23520
Sig.		1.000	.083

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 5.000.

Appendix II: analysis of variance of Biological Oxygen Demand

Descriptive
BOD

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	18	89.4728	.66354	.15640	89.1428	89.8027	88.41	90.81
2	18	92.6006	.92559	.21816	92.1403	93.0608	91.22	93.85
3	18	90.0889	.99787	.23520	89.5927	90.5851	88.15	91.51
Total	54	90.7207	1.61247	.21943	90.2806	91.1609	88.15	93.85

Test of Homogeneity of Variances
BOD

Levene Statistic	df1	df2	Sig.
1.818	2	51	.173

ANOVA
BOD

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	98.826	2	49.413	64.656	.000
Within Groups	38.977	51	.764		
Total	137.803	53			

Post Hoc Tests

Multiple Comparisons
Dependent Variable: BOD
Tukey HSD

(I) STATION	(J) STATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-3.12778*	.29140	.000	-3.8312	-2.4243
	3	-.61611	.29140	.097	-1.3196	.0873
2	1	3.12778*	.29140	.000	2.4243	3.8312
	3	2.51167*	.29140	.000	1.8082	3.2151
3	1	.61611	.29140	.097	-.0873	1.3196
	2	-2.51167*	.29140	.000	-3.2151	-1.8082

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

BOD
Tukey HSD[a]

STATION	N	Subset for alpha = 0.05	
		1	2
1	18	89.4728	
3	18	90.0889	
2	18		92.6006
Sig.		.097	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 18.000.

Appendix III: Analysis of Variance of Total Ammonia

Descriptive
TOTAL AMMONIA

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	18	10.8611	.64416	.15183	10.5408	11.1814	9.52	11.90
2	18	12.3556	.41404	.09759	12.1497	12.5615	11.51	12.92
3	18	11.7606	.65632	.15470	11.4342	12.0869	10.43	12.42
Total	54	11.6591	.84306	.11473	11.4290	11.8892	9.52	12.92

Test of Homogeneity of Variances
TOTAL AMMONIA

Levene Statistic	df1	df2	Sig.
1.811	2	51	.174

ANOVA
TOTAMMONIA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	20.378	2	10.189	30.053	.000
Within Groups	17.291	51	.339		
Total	37.669	53			

Post Hoc Tests

Multiple Comparisons
Dependent Variable: TOTAMMONIA
Tukey HSD

(I) STATION	(J) STATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-1.49444*	.19409	.000	-1.9630	-1.0259
	3	-.89944*	.19409	.000	-1.3680	-.4309
2	1	1.49444*	.19409	.000	1.0259	1.9630
	3	.59500*	.19409	.010	.1265	1.0635
3	1	.89944*	.19409	.000	.4309	1.3680
	2	-.59500*	.19409	.010	-1.0635	-.1265

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

TOTAMMONIA
Tukey HSD[a]

STATION	N	Subset for alpha = 0.05		
		1	2	3
1	18	10.8611		
3	18		11.7606	
2	18			12.3556
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 18.000.

Appendix IV: Analysis of Variance of Total Ammonia

Descriptive
TOTAL AMMONIUM

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	18	13.9728	.81145	.19126	13.5693	14.3763	12.71	15.41
2	18	15.9078	.46397	.10936	15.6771	16.1385	15.35	16.67
3	18	15.2206	.68716	.16196	14.8788	15.5623	13.69	16.02
Total	54	15.0337	1.04178	.14177	14.7494	15.3181	12.71	16.67

Test of Homogeneity of Variances
TOTAL AMMONIUM

Levene Statistic	df1	df2	Sig.
3.056	2	51	.056

ANOVA
TOTAMMONIUM

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	34.641	2	17.320	38.607	.000
Within Groups	22.880	51	.449		
Total	57.521	53			

Post Hoc Tests

Multiple Comparisons
Dependent Variable: TOTAL AMMONIUM
Tukey HSD

(I) STATION	(J) STATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-1.93500*	.22327	.000	-2.4740	-1.3960
	3	-1.24778*	.22327	.000	-1.7867	-.7088
2	1	1.93500*	.22327	.000	1.3960	2.4740
	3	.68722*	.22327	.009	.1483	1.2262
3	1	1.24778*	.22327	.000	.7088	1.7867
	2	-.68722*	.22327	.009	-1.2262	-.1483

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

TOTAMMONIUM
Tukey HSD[a]

STATION	N	Subset for alpha = 0.05		
		1	2	3
1	18	13.9728		
3	18		15.2206	
2	18			15.9078
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 18.000.

Appendix V: Analysis of Variance for Total Ammonium chloride

Univariate Analysis of Variance

Between-Subjects Factors

		N
STATION	6	36
	7	36
	8	36
CONCENTRATION	1	36
	2	36
	3	36

Descriptive Statistics
Dependent Variable: AMMONIACHLORIDE

STATION	CONCENTRATION	Mean	Std. Deviation	N
6	1	4.1833	.35356	12
	2	8.2483	.89841	12
	3	20.8592	.99108	12
	Total	11.0969	7.24198	36
7	1	4.1925	.55219	12
	2	8.4408	.78757	12
	3	21.5617	1.08853	12
	Total	11.3983	7.54185	36
8	1	3.8767	.34953	12
	2	7.8075	.80252	12
	3	20.7983	1.20793	12
	Total	10.8275	7.38087	36
Total	1	4.0842	.44235	36
	2	8.1656	.85048	36
	3	21.0731	1.12388	36
	Total	11.1076	7.32361	108

Levene's Test of Equality of Error Variances[a]

Dependent Variable: AMMONIACHLORIDE

F	df1	df2	Sig.
4.959	8	99	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + STATION + ONCENTRATION + STATION * CONCENTRATION

Tests of Between-Subjects Effects

Dependent Variable: AMMONIACHLORIDE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5670.229[a]	8	708.779	1020.676	.000
Intercept	13324.890	1	13324.890	19188.493	.000
STATION	5.871	2	2.936	4.228	.017
CONCENTRATION	5662.604	2	2831.302	4077.213	.000
STATION * CONCENTRATION	1.754	4	.438	.631	.641
Error	68.748	99	.694		
Total	19063.867	108			
Corrected Total	5738.976	107			

a. R Squared = .988 (Adjusted R Squared = .987)

Estimated Marginal Means

Grand Mean
Dependent Variable: AMMONIACHLORIDE

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
11.108	.080	10.948	11.267

Post Hoc Tests
STATION

Multiple Comparisons
Dependent Variable: AMMONIACHLORIDE
Tukey HSD

(I) STATION	(J) STATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
6	7	-.3014	.19642	.279	-.7688	.1660
	8	.2694	.19642	.360	-.1979	.7368
7	6	.3014	.19642	.279	-.1660	.7688
	8	.5708*	.19642	.012	.1035	1.0382
8	6	-.2694	.19642	.360	-.7368	.1979
	7	-.5708*	.19642	.012	-1.0382	-.1035

Based on observed means.
The error term is Mean Square(Error) = .694.
*. The mean difference is significant at the .05 level.

Homogeneous Subsets

AMMONIACHLORIDE
Tukey HSD[a,b]

STATION	N	Subset	
		1	2
8	36	10.8275	
6	36	11.0969	11.0969
7	36		11.3983
Sig.		.360	.279

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square(Error) = .694.
a. Uses Harmonic Mean Sample Size = 36.000.
b. Alpha = .05.

CONCENTRATION

Multiple Comparisons

Dependent Variab

le: AMMONIACHLORIDE

Tukey HSD

(I) CONCENTRATION	(J) CONCENTRATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-4.0814*	.19642	.000	-4.5488	-3.6140
	3	-16.9889*	.19642	.000	-17.4563	-16.5215
2	1	4.0814*	.19642	.000	3.6140	4.5488
	3	-12.9075*	.19642	.000	-13.3749	-12.4401
3	1	16.9889*	.19642	.000	16.5215	17.4563
	2	12.9075*	.19642	.000	12.4401	13.3749

Based on observed means.

The error term is Mean Square(Error) = .694.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

AMMONIACHLORIDE

Tukey HSD[a,b]

CONCENTRATION	N	Subset		
		1	2	3
1	36	4.0842		
2	36		8.1656	
3	36			21.0731
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

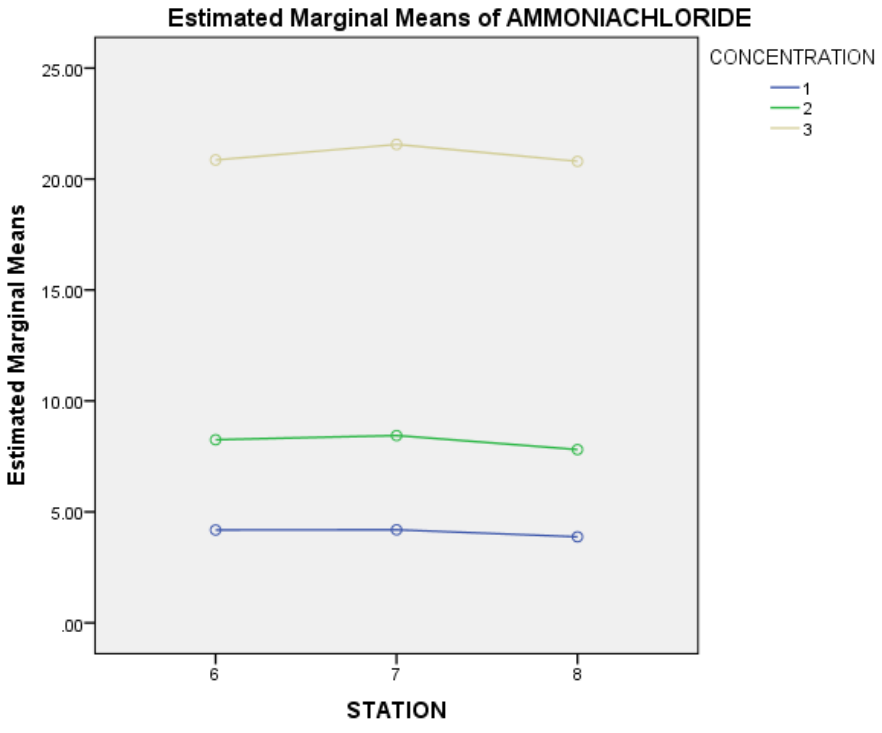
Based on observed means.

The error term is Mean Square(Error) = .694.

a. Uses Harmonic Mean Sample Size = 36.000.

b. Alpha = .05.

Profile Plots



Appendix VI: Analysis of Variance for Total Ammonium nitrate

Univariate Analysis of Variance

Between-Subjects Factors

		N
STATION	6	36
	7	36
	8	36
CONENTRATION OF ACID	1	36
	2	36
	3	36

Descriptive Statistics

Dependent Variable: AMMONIANITRATE

STATION	CONENTRATION OF ACID	Mean	Std. Deviation	N
6	1	5.0742	.21778	12
	2	11.0117	1.00467	12
	3	25.0825	1.43210	12
	Total	13.7228	8.56653	36
7	1	6.0517	.30942	12
	2	11.3792	1.15643	12
	3	27.8333	.76152	12
	Total	15.0881	9.43609	36
8	1	5.6542	.34302	12
	2	10.7900	1.13229	12
	3	26.1558	1.26946	12
	Total	14.2000	8.88713	36
Total	1	5.5933	.49767	36
	2	11.0603	1.09599	36
	3	26.3572	1.62831	36
	Total	14.3369	8.90437	108

Levene's Test of Equality of Error Variances[a]

Dependent Variable: AMMONIANITRATE

F	df1	df2	Sig.
8.040	8	99	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + STATION + CONCENTRATION + STATION * CONCENTRATION

Tests of Between-Subjects Effects

Dependent Variable: AMMONIANITRATE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	8394.334[a]	8	1049.292	1161.297	.000
Intercept	22199.181	1	22199.181	24568.808	.000
STATION	34.564	2	17.282	19.127	.000
CONCENTRATION	8340.277	2	4170.138	4615.275	.000
STATION * CONCENTRATION	19.493	4	4.873	5.393	.001
Error	89.452	99	.904		
Total	30682.967	108			
Corrected Total	8483.786	107			

a. R Squared = .989 (Adjusted R Squared = .989)

Estimated Marginal Means

Grand Mean

Dependent Variable: AMMONIANITRATE

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
14.337	.091	14.155	14.518

Post Hoc Tests

STATION

Multiple Comparisons

Dependent Variable: AMMONIANITRATE

Tukey HSD

(I) STATION	(J) STATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
6	7	-1.3653*	.22405	.000	-1.8984	-.8322
	8	-.4772	.22405	.089	-1.0103	.0559
7	6	1.3653*	.22405	.000	.8322	1.8984
	8	.8881*	.22405	.000	.3549	1.4212
8	6	.4772	.22405	.089	-.0559	1.0103
	7	-.8881*	.22405	.000	-1.4212	-.3549

Based on observed means.

The error term is Mean Square(Error) = .904.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

AMMONIANITRATE

Tukey HSD[a,b]

STATION	N	Subset	
		1	2
6	36	13.7228	
8	36	14.2000	
7	36		15.0881
Sig.		.089	1.000

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = .904.

a. Uses Harmonic Mean Sample Size = 36.000.

b. Alpha = .05.

CONENTRATION OF ACID

Multiple Comparisons

Dependent Variable: AMMONIANITRATE

Tukey HSD

(I) CONENTRATION OF ACID	(J) CONENTRATION OF ACID	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-5.4669*	.22405	.000	-6.0001	-4.9338
	3	-20.7639*	.22405	.000	-21.2970	-20.2308
2	1	5.4669*	.22405	.000	4.9338	6.0001
	3	-15.2969*	.22405	.000	-15.8301	-14.7638
3	1	20.7639*	.22405	.000	20.2308	21.2970
	2	15.2969*	.22405	.000	14.7638	15.8301

Based on observed means.

The error term is Mean Square(Error) = .904.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

AMMONIANITRATE

Tukey HSD[a,b]

CONENTRATION OF ACID	N	Subset		
		1	2	3
1	36	5.5933		
2	36		11.0603	
3	36			26.3572
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

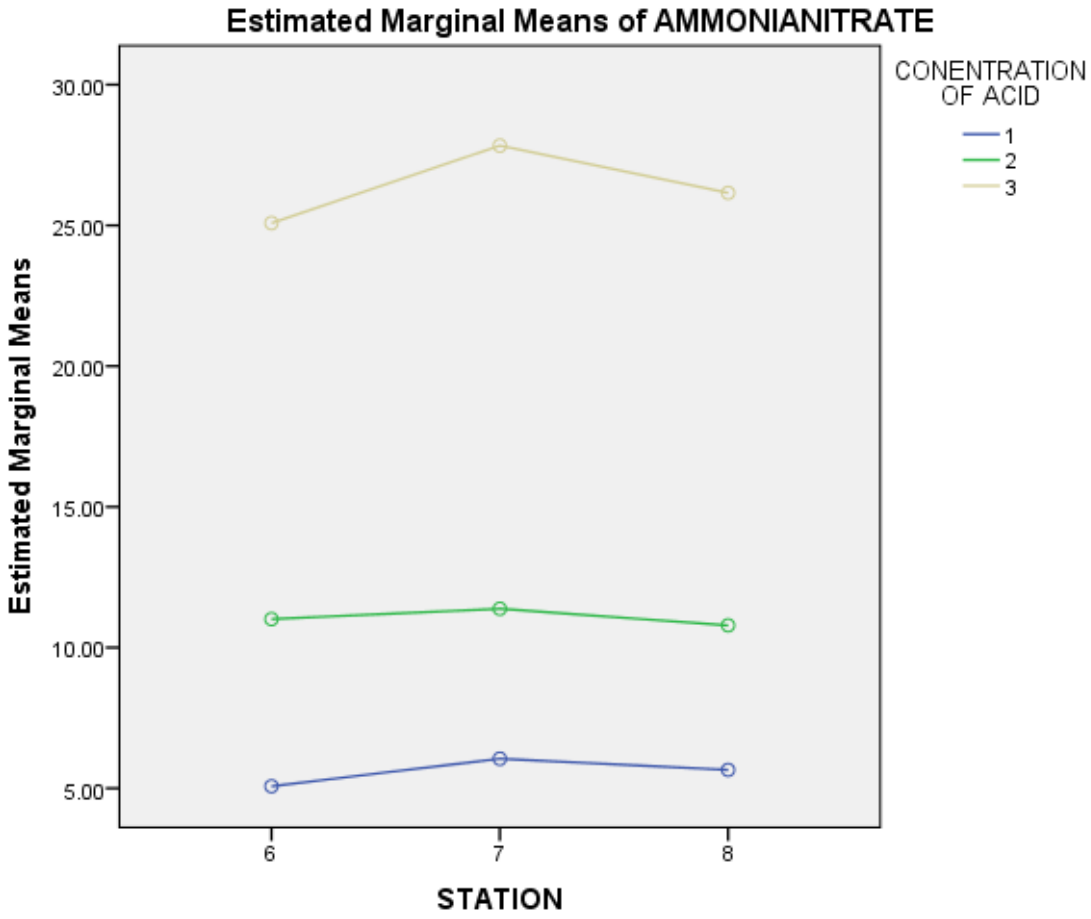
Based on observed means.

The error term is Mean Square(Error) = .904.

a. Uses Harmonic Mean Sample Size = 36.000.

b. Alpha = .05.

Profile Plots



Appendix vii: Analysis of Variance for Total Ammonium Sulphate

Univariate Analysis of Variance

Between-Subjects Factors

		N
STATION	6.00	36
	7.00	36
	8.00	36
CONNCETRATION OF ACID	1.00	36
	2.00	36
	3.00	36

Descriptive Statistics

Dependent Variable: AMMONIA SULPHATE

STATION	CONNCETRATION OF ACID	Mean	Std. Deviation	N
6.00	1.00	7.5767	.77417	12
	2.00	21.0467	1.05501	12
	3.00	36.9400	1.22064	12
	Total	21.8544	12.21264	36
7.00	1.00	7.7683	.37837	12
	2.00	21.6617	1.55372	12
	3.00	37.5692	1.24395	12
	Total	22.3331	12.40023	36
8.00	1.00	7.2383	.71460	12
	2.00	21.0383	.88630	12
	3.00	37.0400	1.32428	12
	Total	21.7722	12.38903	36
Total	1.00	7.5278	.66575	36
	2.00	21.2489	1.20126	36
	3.00	37.1831	1.25863	36
	Total	21.9866	12.22098	108

Levene's Test of Equality of Error Variances[a]

Dependent Variable: AMMONIA SULPHATE

F	df1	df2	Sig.
2.676	8	99	.011

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + STATION + CONCENTRATION + STATION * CONCENTRATION

Tests of Between-Subjects Effects

Dependent Variable: AMMONIA SULPHATE

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	15866.764[a]	8	1983.345	1723.508	.000
Intercept	52208.219	1	52208.219	45368.448	.000
STATION	6.604	2	3.302	2.870	.061
CONCENTRATION	15859.225	2	7929.612	6890.758	.000
STATION * CONCENTRATION	.935	4	.234	.203	.936
Error	113.925	99	1.151		
Total	68188.909	108			
Corrected Total	15980.689	107			

a. R Squared = .993 (Adjusted R Squared = .992)

Estimated Marginal Means

Grand Mean

Dependent Variable: AMMONIA SULPHATE

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
21.987	.103	21.782	22.191

Post Hoc Tests

STATION

Multiple Comparisons

Dependent Variable: AMMONIA SULPHATE

Tukey HSD

(I) STATION	(J) STATION	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
6.00	7.00	-.4786	.25285	.146	-1.0803	.1230
	8.00	.0822	.25285	.943	-.5194	.6839
7.00	6.00	.4786	.25285	.146	-.1230	1.0803
	8.00	.5608	.25285	.073	-.0408	1.1625
8.00	6.00	-.0822	.25285	.943	-.6839	.5194
	7.00	-.5608	.25285	.073	-1.1625	.0408

Based on observed means.

The error term is Mean Square(Error) = 1.151.

Homogeneous Subsets

AMMONIA SULPHATE

Tukey HSD[a,b]

STATION	N	Subset
		1
8.00	36	21.7722
6.00	36	21.8544
7.00	36	22.3331
Sig.		.073

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = 1.151.

a. Uses Harmonic Mean Sample Size = 36.000.

b. Alpha = .05.

CONNCETRATION OF ACID

Multiple Comparisons

Dependent Variable: AMMONIA SULPHATE

Tukey HSD

(I) CONNCETRATION OF ACID	(J) CONNCETRATION OF ACID	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-13.7211*	.25285	.000	-14.3228	-13.1195
	3.00	-29.6553*	.25285	.000	-30.2569	-29.0536
2.00	1.00	13.7211*	.25285	.000	13.1195	14.3228
	3.00	-15.9342*	.25285	.000	-16.5358	-15.3325
3.00	1.00	29.6553*	.25285	.000	29.0536	30.2569
	2.00	15.9342*	.25285	.000	15.3325	16.5358

Based on observed means.

The error term is Mean Square(Error) = 1.151.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

AMMONIA SULPHATE

Tukey HSD[a,b]

CONNCETRATION OF ACID	N	Subset		
		1	2	3
1.00	36	7.5278		
2.00	36		21.2489	
3.00	36			37.1831
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

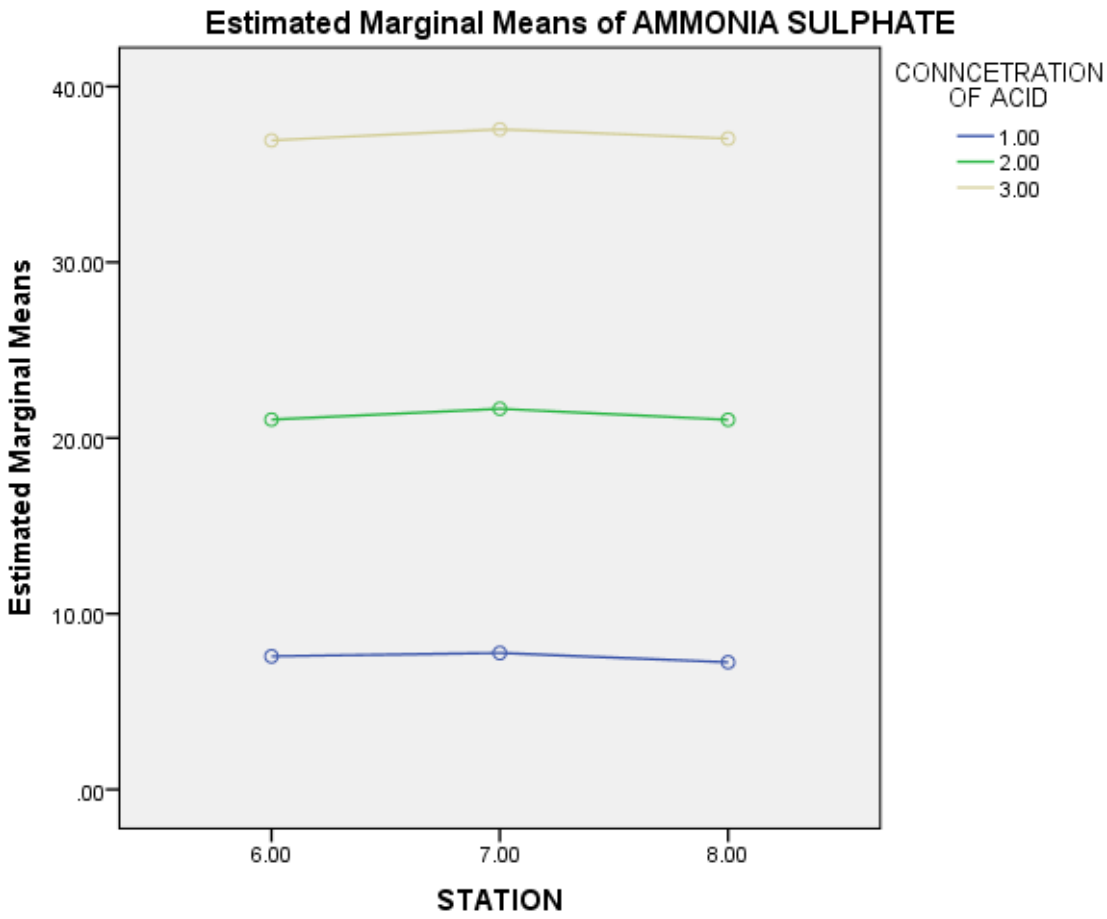
Based on observed means.

The error term is Mean Square(Error) = 1.151.

a. Uses Harmonic Mean Sample Size = 36.000.

b. Alpha = .05.

Profile Plots



Appendix VIII: Analysis of Variance for Total Ammonium Hydroxide

Univariate Analysis of Variance

Between-Subjects Factors

		N
STATIONS	6	36
	7	36
	8	36
CONCETRATION OF ACID	1	36
	2	36
	3	36

Descriptive Statistics

Dependent Variable: AMMONIAHYDROXIDE

STATIONS	CONCETRATION OF ACID	Mean	Std. Deviation	N
6	1	2.1583	.38428	12
	2	3.9675	.78738	12
	3	9.2800	.85444	12
	Total	5.1353	3.14111	36
7	1	2.2283	.43461	12
	2	4.7067	.94923	12
	3	9.9885	.62792	12
	Total	5.6412	3.35247	36
8	1	2.3033	.33524	12
	2	4.7600	.76713	12
	3	9.9258	.86478	12
	Total	5.6631	3.29168	36
Total	1	2.2300	.38040	36
	2	4.4781	.89305	36
	3	9.7314	.83300	36
	Total	5.4798	3.24159	108

Levene's Test of Equality of Error Variances[a]

Dependent Variable: AMMONIAHYDROXIDE

F	df1	df2	Sig.
2.122	8	99	.040

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + STATION + CONCENTRATION + STATION * CONCENTRATION

Tests of Between-Subjects Effects

Dependent Variable: AMMONIAHYDROXIDE

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	1075.609[a]	8	134.451	273.112	.000
Intercept	3243.086	1	3243.086	6587.705	.000
STATION	6.419	2	3.210	6.520	.002
CONCENTRATION	1067.082	2	533.541	1083.786	.000
STATION * CONCENTRATION	2.108	4	.527	1.070	.375
Error	48.737	99	.492		
Total	4367.432	108			
Corrected Total	1124.347	107			

a. R Squared = .957 (Adjusted R Squared = .953)

Post Hoc Tests

STATIONS

Multiple Comparisons

Dependent Variable: AMMONIAHYDROXIDE

Tukey HSD

(I) STATIONS	(J) STATIONS	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
6	7	-.5059*	.16538	.008	-.8994	-.1124
	8	-.5278*	.16538	.005	-.9213	-.1343
7	6	.5059*	.16538	.008	.1124	.8994
	8	-.0219	.16538	.990	-.4154	.3716
8	6	.5278*	.16538	.005	.1343	.9213
	7	.0219	.16538	.990	-.3716	.4154

Based on observed means.

The error term is Mean Square(Error) = .492.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

AMMONIAHYDROXIDE

Tukey HSD[a,b]

STATIONS	N	Subset	
		1	2
6	36	5.1353	
7	36		5.6412
8	36		5.6631
Sig.		1.000	.990

Means for groups in homogeneous subsets are displayed.

Based on observed means.

The error term is Mean Square(Error) = .492.

a. Uses Harmonic Mean Sample Size = 36.000.

b. Alpha = .05.

CONCETRATION OF ACID

Multiple Comparisons

Dependent Variable: AMMONIAHYDROXIDE

Tukey HSD

(I) CONCETRATION OF ACID	(J) CONCETRATION OF ACID	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-2.2481*	.16538	.000	-2.6416	-1.8545
	3	-7.5014*	.16538	.000	-7.8950	-7.1079
2	1	2.2481*	.16538	.000	1.8545	2.6416
	3	-5.2534*	.16538	.000	-5.6469	-4.8599
3	1	7.5014*	.16538	.000	7.1079	7.8950
	2	5.2534*	.16538	.000	4.8599	5.6469

Based on observed means.

The error term is Mean Square(Error) = .492.

*. The mean difference is significant at the .05 level.

Homogeneous Subsets

AMMONIAHYDROXIDE

Tukey HSD[a,b]

CONCETRATION OF ACID	N	Subset		
		1	2	3
1	36	2.2300		
2	36		4.4781	
3	36			9.7314
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

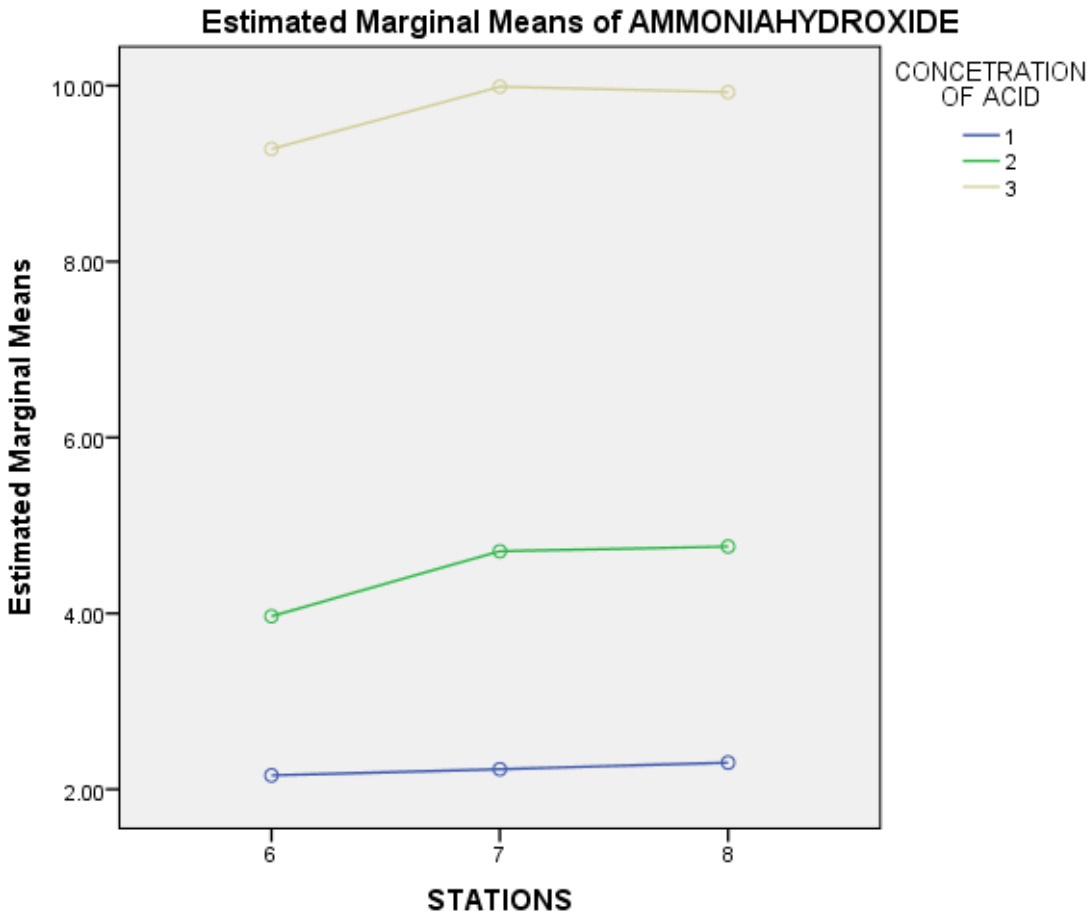
Based on observed means.

The error term is Mean Square(Error) = .492.

a. Uses Harmonic Mean Sample Size = 36.000.

b. Alpha = .05.

Profile Plots



Appendix IX: Analysis of Variance for Total Nitrogen

Descriptive

TOTAL NITROGEN

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
1	27	5.7427	.71560	.13772	5.4596	6.0258	4.49	6.93
2	27	6.2154	.46168	.08885	6.0327	6.3980	5.36	7.03
3	27	5.5028	.91735	.17654	5.1399	5.8657	3.21	6.72
Total	81	5.8203	.77326	.08592	5.6493	5.9913	3.21	7.03

Test of Homogeneity of Variances

TOTAL NITROGEN

Levene Statistic	df1	df2	Sig.
5.698	2	78	.005

ANOVA

TOTAL NITROGEN

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7.098	2	3.549	6.795	.002
Within Groups	40.736	78	.522		
Total	47.834	80			

Post Hoc Tests

Multiple Comparisons

Dependent Variable: TOTAL NITROGEN

Tukey HSD

(I) STATIONS	(J) STATIONS	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.47265*	.19669	.048	-.9426	-.0027
	3	.23988	.19669	.445	-.2301	.7098
2	1	.47265*	.19669	.048	.0027	.9426
	3	.71254*	.19669	.001	.2426	1.1825
3	1	-.23988	.19669	.445	-.7098	.2301
	2	-.71254*	.19669	.001	-1.1825	-.2426

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

TOTAL NITROGEN

Tukey HSD[a]

STATIONS	N	Subset for alpha = 0.05	
		1	2
3	27	5.5028	
1	27	5.7427	
2	27		6.2154
Sig.		.445	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 27.000.