KWAME NKRUMAH UNIVERSITY OF SCIENCE AND

TECHNOLOGY

Odour Dispersion and Control from Dry On-Site Communal Toilet in Urban Poor Ghana – Case of Ayigya Zongo

by

Kobina Mensah Afful

A Thesis submitted to the Department of Civil Engineering,

College of Engineering

in partial fulfilment of the requirements for degree of

DOCTOR OF PHILOSOPHY

MAY, 2017

DECLARATION

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

Kobina Mensah Afful	.....	.....
(PG20293173)	Signature	Date

Certified by:

Prof. Mrs Esi Awuah	.....	.....
(Principal Supervisor)	Signature	Date

Dr. S.Oduro - Kwarteng	.....	.....
(Second Supervisor)	Signature	Date

Certified by:

Dr. Gnida Sossou	.....	.....
(Head of Department)	Signature	Date

ABSTRACT

Offensive odours from dry onsite sanitation toilet technologies are dispersed into the environment and cause discomfort to residents living nearby. Hydrogen sulfide (H_2S) and ammonia (NH_3) have been regarded as two major odour gases according to their volatile characters and odour strengths. The objectives of the study were to carry out a survey of residents' perception on odour in the community, quantify odour gases released from dry onsite toilet technology by direct field measurement coupled with odour dispersion modeling using the Steady State Gaussian Plume model, quantify the release of H_2S and NH_3 from the storage of fresh faecal matter and examine the limiting effect of addition of coconut fibre ash (CFA) and cocoa husk ash (CHA) on the release of H_2S and NH_3. For the perception survey, structured questionnaires were used to solicit responses from respondents who were selected by purposive random sampling. Regarding the field quantification of odour concentration, field inspectors were selected by the nasal chemosensory test and the Nasal Ranger Field Olfactometer was used for the odour concentration measurements. Model was simulated using the US EPA SCREEN 3 which is a single source Gaussian plume model which provides maximum ground-level odour concentration. Quantification of H_2S and NH_3 was by titrimetric methods. CFA and CHA were added in specific ratios of 1:20, 1:8 and 1:4 g/g of ash to faecal matter to investigate the limiting effects of the additions of CHA and CFA. The results from the perception survey show high perception of odour from onsite communal toilet facilities even in the presence of other sources of odour with odour from these onsite communal toilets being predominant within 50m of these facilities. However beyond the 50m distance other sources of odour such as drains and refuse containers were predominant. Also, results from the direct field odour measurements showed that odour dispersion is less in the mornings but concentrated within a smaller area as compared to dispersion in the afternoon and evening. Modeling studies also revealed that vent pipe height of 3.5 – 4m reduced significantly oduor dispersion within 40m of the downwind side facility. Cocoa husk ash was found to perform better in the reduction of H_2S release than coconut fibre ash with 25% CHA giving the highest reduction.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
BOD	Biochemical Oxygen Demand
CFA	Coconut Fibre Ash
CHA	Cocoa Husk Ash
COD	Chemical Oxygen Demand
D/T	Dilution to Threshold
DMDS	Dimethyl disulfide
DMS	Dimethyl sulfide
EC	Electrical Conductivity
GC	Gas Chromatography
GMT	Greenwich Mean Time
GPS	Global Positioning System
HPLC	High-Performance Liquid Chromatography
ISCST3	Industrial Source Complex Short Term 3
KMA	Kumasi Metropolitan Assembly
KNUST	Kwame Nkrumah University of Science and Technology

LLE	Liquid-liquid Extraction
MC	Moisture Content
MS	Mass Spectrometer
MT	Methanaethiol
SPE	Solid Phase Extraction
SPME	Solid Phase Micro Extraction
SPSS	Statistical Package for the Social Sciences
TKN	Total Kjeldahl Nitrogen
TS	Total Solids
TVS	Total Volatile Solids
UDDT	Urine Diverting Dehydration Toilet
VIP	Ventilated Improved Pit
VOSCs	Volatile Organic Sulphur Compounds

DEDICATION

I dedicate this work to God Almighty in whom I live and have my being.

ACKNOWLEDGEMENT

Firstly, I would like to express my sincere gratitude to my supervising team comprising advisor Prof. (Mrs.) Esi Awuah and Dr. Sampson Oduro-Kwarteng for the continuous support of my PhD study and for their patience, motivation, and immense knowledge. Your guidance helped me through my research and writing of this thesis. I could not have imagined having a better supervision team for my PhD study.

Besides my advisor, I would like to thank the Bill and Melinda Gates Foundation under the "Stimulating Local Innovation on Sanitation for the Urban Poor (SaniUP) in Sub-Saharan Africa and South-East Asia" for sponsoring this PhD study. Having mentioned this, I would also say a big thank you to the entire SaniUP team for their insightful comments and encouragement, which helped shape my work. It is also worth mentioning the encouragement from the local team comprising Dr. Kwabena Nyarko, Dr. Richard Buamah and Dr. Helen Essandoh for their spot on contribution during progress presentations.

My sincere thanks also go to Prof. Ray Bright Voegborlo of the Chemistry Department for his immense help during the laboratory phase of my study. My appreciation also goes to Kingsley Osei Bonsu and Emmanuel Botchway of the Civil Engineering Water and Sanitation Laboratory for aiding in sample analysis. Without their support it would not have been possible to conduct this research.

I thank my fellow PhD students Eugene Appiah-Effah and Peter Owusu Antwi for the stimulating discussions, long hours of working together to meet deadlines, and for all the fun we have had in the past few years.

Last but not the least, I would like to thank my family: my wife Princess Pat Afful and our son Nkunyim Mensah Afful, who have had to survive with an absentee husband and father. I really appreciate your efforts and patience. Also to my parents Mr. Joseph Mensah Afful (of blessed memory) and Miss Margaret Ayekpa – indeed your support and guidance has brought me this far. Not forgetting my siblings Esi and Kwesi.

1 INTRODUCTION

1.1 BACKGROUND

Dry onsite sanitation technologies are designed to operate on the basic principle of no water addition and partial or full treatment on site before disposal. They include Ventilated improved pit (VIP) toilet, Ventilated improved double-pit (VIDP) toilet and the Urine-diversion (UD) toilet. Process control for operating these types of toilet technologies is to enhance the activity of indigenous microorganisms through the control of the environment of the composting matrix. Once the environmental conditions are optimum for microbial activity, microorganisms rapidly utilize the byproduct as a substrate for their metabolism. One of the biggest challenges of these toilet technologies is odour produced during operations. Degradation of organics typically produces a variety of odourous sulfur compounds, nitrogen compounds (amines), hydrocarbons, etc. Dimethyl disulfide (DMDS) and dimethyl sulfide (DMS) are among the most odourous compounds emitted (Rosenfeld & Henry, 2001). This is a result of a combination of high concentrations of these compounds in off gases and their very low human detection threshold. Odours released from operations of these toilets disperse and cause nuisance to neighbours, resulting in complaints.

Biosolids is a general term usually used to describe semi solid or dry bio-waste (including faecal matter) serve as good source of food for microorganism including proteins, amino acids and carbohydrates. These microorganisms in biosolids degrade these energy sources and odourous compounds are formed (Walker, 1991). In the same vain fresh faecal matter which usually has high concentration of solids as all other biosolids also undergo similar conversions to generate odour compounds. Organic and inorganic forms of sulfur, mercaptans, ammonia, amines and organic fatty acids have

been identified in a wide range of literature as the most offensive odour causing compounds associated with biosolids. These compounds are released from the biosolids by heat, aeration and digestion. Under anaerobic conditions hydrogen sulfide and other sulfur containing gases are formed, while alkaline stabilization of the solids release ammonia alongside other volatile compounds. These processes are synonymous to the generation of odourous compounds from the storage of fresh faecal matter (human excreta) in dry onsite sanitation technologies.

The power of odours to modify human approach and avoidance behavior is well known. For example, the perception of a malodour can rapidly render most environments undesirable just as the perception of an unfamiliar odour can elicit rejection and withdrawal. In a study employing six different racial and ethnic groups to determine the universality of any malodour, the smell of human faecal matter was consistently rated as the most intense, the most unpleasant and the most dangerous by all groups (Dalton, 1999). Although the odour from faeces per se cannot transmit disease (per the discredited miasma theory), the association between an odour and potential adverse consequences such as insomnia and irritation is an extremely powerful motivator of behavior (Rheinländer *et al.*, 2013). Thus, malodour from human faeces and urine can serve as a barrier to the utilization of sanitation facilities in many communities and when replaced by open defecation can render the community at large at greater risk from disease.

Human faeces (stool) are waste products of the human digestive system, including plant nutrients and microbes loaded with bacteria. They vary significantly in appearance, according to the state of the digestive system, diet and general health. Normally stool is semisolid, with a mucus coating. Human faeces together with human urine are collectively referred to as human waste or human excreta. The main goal of sanitation is

to prevent spreading of pathogens from human faeces via the fecal-oral route. However, human excreta possess physiological odour, which can vary according to diet and health status. Also the anaerobic decomposition of human excreta further generates malodourous compounds. Though more often than not, most toilet technologies employ onsite degradation of human excreta, the fundamental part of offensive malodours from human waste is usually ignored. The offending malodours may also serve as a barrier for the utilisation of these sanitation facilities, negative public reactions when siting a new facilities and loss of dignity to users.

Experiences with sanitation promotion in Africa and Asia have indicated that foul smell is a barrier for acquiring and using latrines. Surveys conducted in rural Niger and Malawi demonstrated that up to 25 per cent of latrine owners reported awful stench from human faeces to be a major disadvantage of installing a latrine close to their home (Diallo *et al.*, 2007; Grimason *et al.*, 2000). Research among ethnic minorities in Northern Vietnam, school children in Scandinavian and rural Senegal showed that stinking urinals and toilets were perceived as a major barrier keeping children from using school toilets (Lundblad & Hellström, 2005; Sidibe & Curtis, 2007). Perceptions in Ghana and Vietnam also show that adults and children prefer alternatives such as sites at dunes, beaches, fields or hills to latrines, including open defecation, because of their 'fresh air', 'natural ventilation' and absence of bad smell (Hoat *et al.*, 2012). Past and on-going research in Ghana, where 57 per cent of the population uses public latrines, has shown that foul smell is perceived to be a major impediment to household latrine adoption (van der Geest, 2007). In summary, bad smells from latrines is a major barrier to sanitation adoption.

1.2 PROBLEM STATEMENT

Dry on-site toilet systems have the primary purpose of maintaining hygiene and the protection of the environment from land and water pollution. However, during treatment, gaseous wastes are created, which can lead to secondary pollution if not effectively managed. Gaseous wastes, leading to air pollution in the form of odours, can have the greatest impact on the population in the vicinity of the facility. Odour emissions affect quality of life (Brennan, 1993) leading to psychological stress and symptoms such as insomnia, loss of appetite and irrational behavior (Brennan, 1993; Wilson et al, 1980).

Individuals like to use clean toilets. Cleanliness of a toilet is a component of various elements, one of them being non-malodourous. Along these lines toilets that are odourous are regularly thought to be filthy and subsequently individuals might not have any desire to use them. Additionally, the essential component that may effectively figure out if or not individuals use a given sanitation facility is smell and fly annoyance (Oketch, 2005). Usually, smelly toilets also have the presence of flies (Oketch, 2005). Odour may not necessarily cause a health threat but the accompanying flies are leading carriers and transmitters of water and excreta related diseases (Oketch, 2005).

Although key technical aspects are considered by researchers when designing new technologies for developing countries, the basic aspect of offending malodours from human waste is often neglected (Lin *et al.*, 2013). One drawback of many public toilets, particularly those used by large groups of people in a community block model, is the development of malodours resulting from degradation of human waste products.

1.3 JUSTIFICATION OF STUDY

Various dry onsite toilet technologies focus on removal of odour from the privy rooms usually by natural ventilation (basically by the provision of vent pipe and front

openings). However the impact of these odourous gases when removed from the privy rooms on the surrounding environment is usually not considered. Also there is less focus on mechanisms to reduce the generation and release of these odour compounds from the storage of human excreta. Understanding the chemical composition of odours generated by human waste products is a starting point for the development of relevant technologies that can prevent, eliminate, neutralize, or mask the offending odours (Lin *et al.*, 2013).

The control of odour emissions has become an important consideration in the design and operation of new technologies and improvement of existing ones. Notwithstanding the fact that it has been widely reported in literature that odour is a major barrier to the adoption of dry onsite sanitation toilet technologies, the problem has received less attention in terms of research aimed at quantifying the problem and the development of mitigating measures. Given the progressive nature of legislation concerning environmental pollution, it is not unreasonable to expect future legislation targeted at odour emissions.

It is generally recognised that for effective odour control measures to be implemented, the problem must first be quantified (Balling & Reynolds, 1980; Hobson, 1995; Stordeur *et al.*, 1981). Such quantification of the problem allows designers and operators to make informed decisions on the choice of processes, process modifications or the scope of odour control schemes (Clarkson, 1993). The minimisation of odour emissions is becoming one of the most significant challenges and any treatment technology with noticeable odours outside its boundary fence is likely to receive complaints at some time (Schulz & Van Harreveld, 1996).

Rheinländer *et al.* (2013) concluded that odour must be seen as a key factor influencing sanitation behaviours of millions of people across cultures and socio-economic context.

Hence odour must be considered more important in sanitation programmes and it must be clear to sanitation promoters that financial and public health arguments will not be effective if local perceptions of odour, contamination and health hazard carry more weight when choosing and using sanitation facilities. Avoiding bad odour is strong in people's minds and should also be likewise in investigative, design, construction and maintenance phases of sanitation project and promotion.

This work has the aim of measuring odours in the field, particularly discussing how such procedures can be used in alternative or in combination with odour dispersion models for odour impact assessment purposes, and how the results of field odour measurements and model outputs can be related and compared to each other. The research also further explores the evolution of odourous compounds specifically, hydrogen sulfide (H_2S) and ammonia (NH_3) from human excreta and the use of physical amendments, thus ash from cocoa husk and coconut fibre to minimize the release of these two surrogate odour compounds.

1.4 RESEARCH OBJECTIVES

Main Objective

The main objective of this research is to model odour dispersion and examine control mechanism for dry on-site communal toilet technology.

Specific Objectives

1. To assess public perception of odour within an urban poor community;
2. To model the dispersion of odour from onsite communal toilet facility;

3. To determine the release of H_2S and NH_3 from storage of human excreta;

4. To examine the reduction of H_2S and NH_3 release from storage of human storage of human excreta.

1.5 RESEARCH QUESTIONS

Odour has been reported widely in literature as a barrier to uptake of onsite sanitation technologies. However research relating to this issue is inadequate. Though there is quite appreciable work done on odour quantification and control for facilities such as wastewater treatment plants, livestock farms, landfills among others, there is inadequate research into the specific issue of onsite sanitation technologies. In order to contribute to the renewed interest in this subject, this research was commissioned to answer some questions related to the subject. The research questions and their respective sub questions are as follows:

1. What is the perception of odour of inhabitants in an urban poor area relating to onsite toilet technologies?

    - What are the types and condition of onsite sanitation technologies in the community?
    - Are there other sources of odour in the community?
    - What is the frequency of exposure to odour?
    - How annoying is the odour?

- How does the odour from these other sources compare to odour from the onsite sanitation technologies in terms of frequency of exposure and annoyance level

2. What is the applicability of the Steady State Guassian plume model to predicting dispersion of odour from dry onsite toilet technology?

    - How can odour be quantified in ambient air?
    - How ambient odour measurement can be used to validate model outputs?
    - How can the model be used to validate odour perception surveys?
    - How can the model be used to inform design and operations of the dry onsite toilet technologies?

3. What are the limiting effects of addition of physical amendment to the production of H_2S and NH_3 from the storage of fresh faecal matter?

    - Will the addition of the physical amendment reduce the release of H_2S and NH_3?
    - How does the addition of the physical amendment impact on pH?
    - What is the most suitable faecal matter to physical amendment ratio that will ensure the minimum release of H_2S and NH_3?

1.6 THESIS STRUCTURE

This thesis is divided in to five chapters with a list of references and appendices.

Chapter 1 which is the introductory chapter gives a brief background to the study, outlines the problem statement and justification for the study, and the research objectives.

Chapter 2 presents a thorough review of existing literature based on the objectives of the study and states the research gap that this study seeks to address.

Chapter 3 presents step by step materials and methods for both field and laboratory based measurements followed in achieving the research objects.

Chapter 4 presents results of the study and also discusses results to establish relevant relationships based on which conclusions can be drawn. It also presents the implication of study on technology improvement and implications on policy and planning.

Chapter 5 presents summary of findings, research limitations and suggestions for further study.

2 LITERATURE REVIEW

2.1 SANITATION AND ITS IMPORTANCE

The World Health Organization defines sanitation generally as the provision of facilities and services for the safe disposal of human faeces and urine (WHO, 2016). Promotion and provision of low-cost technologies that enable improved sanitation are seen as viable solutions for reducing high rates of morbidity and mortality due to enteric illnesses in low-income countries. There are several transmission routes by which faecal-oral pathogens can cause infection and illness including diarrhoea. The use of an improved latrine and practice of good hygiene creates an effective barrier to faecal-oral transmission of pathogens.

2.2 DRY ONSITE SANITATION TECHNOLOGIES

Dry onsite sanitation toilet technologies do not use water as a carrier; rather, excreta are broken down by anaerobic methods (i.e., decomposition or dehydration). In decomposition systems, microorganisms, worms, and other organisms break down urine and faeces (Esrey *et al.*, 1998). Some dehydration methods separate urine and faeces, and either ash or sawdust is added to absorb excess moisture and reduce smell. For this review, dry onsite sanitation technologies have been grouped as Simple Pit Latrines, Ventilated Improved Pits (VIP) and the Urine Diverting Toilets.

2.2.1 Simple Pit latrines

Pit lavatories are the simplest type of sanitation technology. Structures made out of locally available and accessible materials cover a defecation hole—a pit dug in the ground to collect waste. Figure 2-1 shows a schematic diagram of a simple pit latrine toilet. When full, the pit is covered with available laterite. Health problems related to the

use of pit latrines have been widely documented. The defecation hole which is usually opened attracts mosquitoes and flies and produces bad odour.

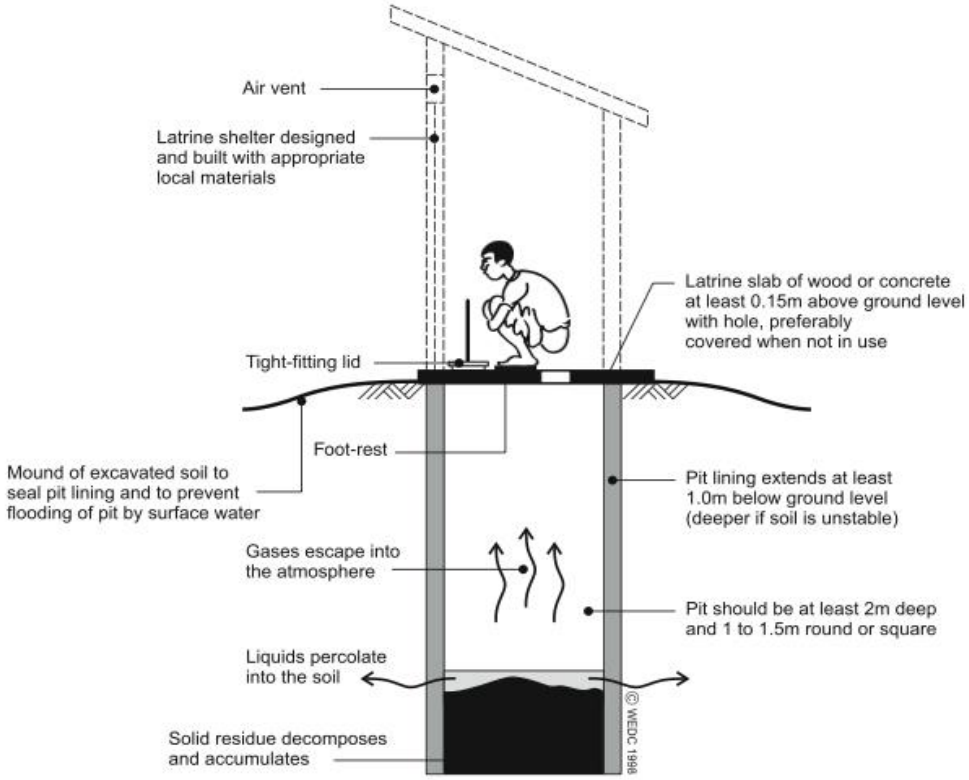


Figure 2-1: Schematic diagram of a Simple Pit Latrine

(*Sources :Boutek (1998)*)

2.2.2 Ventilated Improved Pits Latrines

Ventilated Improved Pit (VIP) latrines are an improvement over simple pit latrines in two vital regards: they are designed to remove the noxious odour within the privy room and reduce the number of flies and other insects usually present in the simple pit latrines. In a VIP latrine, a vent pipe allows fresh air to flow through the latrine to push out warm odourous air, reducing odour. The vent also allows light into the latrine, attracting insects into the pipe, which are trapped by the fly screen at the top of the vent pipe. The screen

also keeps out insects from entering the pipe from the outside. When VIP latrines are constructed with two pits, instead of moving the latrine when the pit is full, users switch to the other pit. After the waste in the full pit composts, it can be reused as fertilizer; the so called *"alternating pit technology"*. Figure 2-2 shows a schematic diagram of single and double pit VIP toilet. Variations in design include the use of above ground vaults (constructed of concrete, brick, or other materials) as against dug pits.

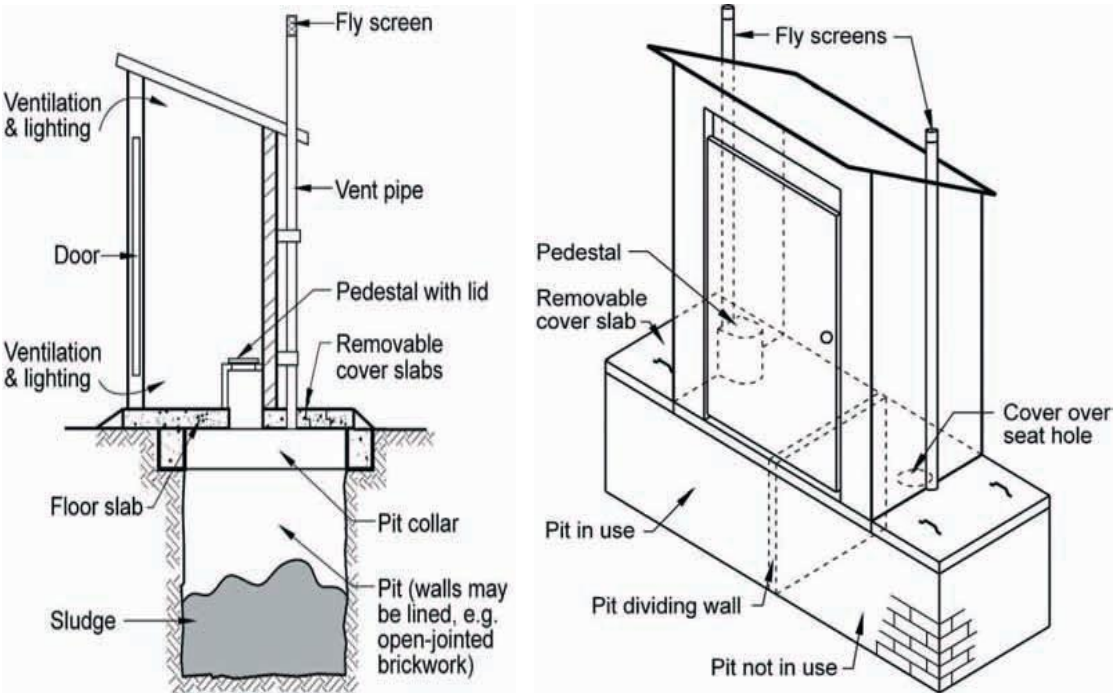


Figure 2-2: Schematic diagram of single and double pit Ventilated Improved Pit Toilet

(*Sources :Boutek (1998)*)

2.2.3 Urine Diverting Toilet

Urine diverting toilet technologies separate urine and faeces using a special pedestal or urine diversion pan. Urine is diverted into a holding container or into a soak field, while a watertight vault collects the faeces. After defaecation, ash or other materials (e.g., lime, dry soil, husks, organic matter) is sprinkled onto the faeces within the vault. Anal

cleansing material is put into another container rather than dropped into the vault. Figure 2-3 shows a schematic diagram of a Urine Diverting Toilet. The urine and the dehydrated faeces can be reused as fertilizer. The absorbent material also helps to deodourize the chamber and reduce flies.

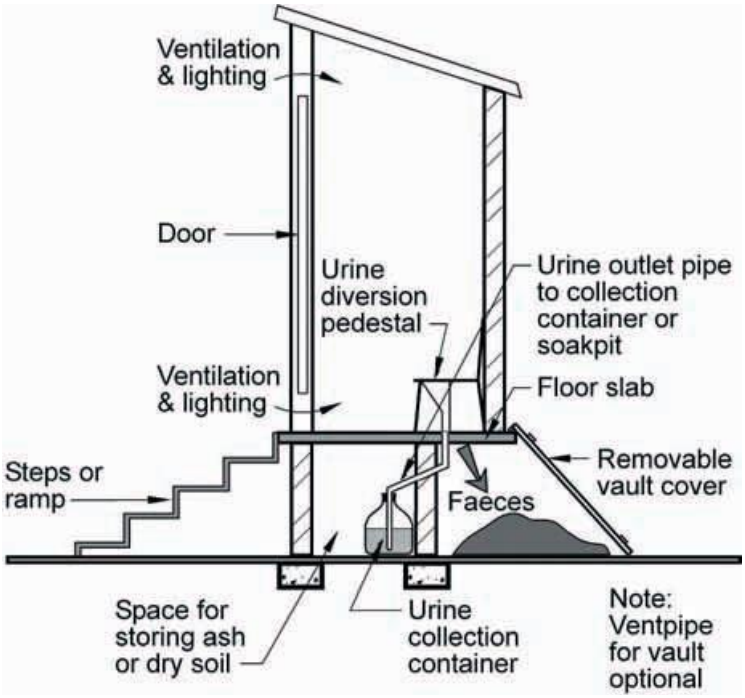


Figure 2-3: Schematic diagram of Urine Diverting Toilet

(*Sources :Boutek (1998)*)

2.3 ODOUR FORMATION

Odours are mainly caused by sulfurous compounds (H_2S, mercaptans, organic sulfides), nitrous compounds (ammonia and organic nitrogen) and acid, aldehyde and ketone type organic compounds (Table 2-1).

Table 2-1: Odourants associated with sewage treatment works

Class	Compound	Formula	Character
Sulphurous	Hydrogen sulphide*	H_2S	Rotten eggs
	Dimethyl suphide*	$(CH_3)_2S$	Decayed vegetables, garlic
	Diethyl sulphide	$(C_2H_3)_2S$	Nauseating, ether
	Diphenyl sulphide	$(C_6H_5)_2S$	Unpleasant, burnt rubber
	Diallyl sulphide	$(CH_2CHCH_2)_2S$	Garlic
	Carbon disulphide*	CS_2	Decayed vegetables
	Dimethyl disulphide*	$(CH_3)_2S_2$	Putrification
	Methyl mercaptan*	CH_3SH	Decayed carbage, garlic
	Ethyl mercaptan	C_2H_5SH	Decayed carbage
	Propyl mercaptan	C_3H_7SH	Unpleasant
	Butyl mercaptan	C_4H_9SH	Unpleasant
	tButyl mercaptan	$(CH_3)_3CSH$	Unpleasant
	Allyl mercaptan*	CH_2CHCH_2SH	Garlic
	Crotyl mercaptan	$CH_3CHCHCH_2SH$	Skunk, rancid
	Benzyl mercaptan	$C_6H_5CH_2SH$	Unpleasant
	Thiocresol	$CH_3C_6H_4SH$	Skunk, rancid
	Thiophenol	C_6H_5SH	Putrid, nauseating, decay
	Sulphur dioxide*	SO_2	Sharp, pungent, irritating
Nitrogenous	Ammonia*	NH_3	Sharp, pungent
	Methylamine	CH_3NH_2	Fishy
	Dimethylamine	$(CH_3)_2NH$	Fishy
	Trimethylamine*	$(CH_3)_3N$	Fishy, ammoniacal
	Diethylamine	$(C_2H_5)_2NH_2$	
	Triethylamine	$(C_2H_5)_3N$	
	Diamines	$NH_2(CH_2)_5NH_2$	Decomposing meat
	Pyridine	C_6H_5N	Disagreeable, irritating
	Indole*	C_8H_6NH	Faecal, nauseating
	Skatole*	C_9H_8NH	Faecal, nauseating
Acids	Acetic (ethanoic)*	CH_3COOH	Vinegar
	Butyric(butanoic)*	C_3H_7COOH	Rancid, sweaty
	Valeric (pentanoic)*	C_4H_9COOH	Sweaty
Aldehydes and ketones	Formaldehyde	HCHO	Acid, suffocating
	Acetaldehyde	CH_3CHO	Fruit, apple
	Butyraldehyde	C_3H_7CHO	Sweaty
	Isobutyraldehyde	$(CH_3)_2CHCHO$	Fruit
	Isovaleraldehyde	$(CH_3)CHCH_2CHO$	Fruit, apple
	Acetone*	CH_3COCH_3	Fruit, sweet
	Butanone*	$C_2H_5COCH_3$	Green apple

(*Source: Abbott, 1993; Bonnin et al., 1990; Brennan, 1993; Cheremisinoff, 1988; Koe, 1989; Metcalf and Eddy, 1991; Vincent & Hobson, 1998; Young, 1984*)

* Odour compounds identified in study of volatile odour compounds from latrines in 3 African countries and India (Lin *et al.*, 2013)

2.3.1 Sulfurous Compounds

Volatile organic sulfur compounds (VOSCs) are key odour causing compounds produced in the degradation of biosolids. These compounds include methanethiol (MT), dimethyl sulfide (DMS), and dimethyl disulfide (DMDS)(Higgins *et al.*, 2006). The production of MT was found to mainly occur from degradation of methionine and the methylation of hydrogen sulfide. DMS is formed through the methylation of MT. DMDS is formed by MT oxidation. All three of the VOSCs are readily degraded by methanogens and a cyclic pathway was proposed to describe the production and degradation of VOSCs (Higgins *et al.*, 2006).

Once MT is formed, oxidation of MT can form DMDS. The degradation of VOSCs would result in the formation of H_2S, which could also participate in other reactions, such as precipitation, binding, or oxidation. An outline of these pathways is shown in Figure 2-4 to summarize the different reactions that could happen in the cycling of VOSCs. These pathways are shown as a cycle to demonstrate both the production and degradation, which are both important in determining the resultant odours. From these pathways and mechanisms, the substrates and reactions to produce VOSCs are better understood, and this can lead to a better understanding of the causes of VOSCs and odours from both anaerobic digestion and dewatering and methods for controlling odours by controlling the reactions, substrates, and/or products.

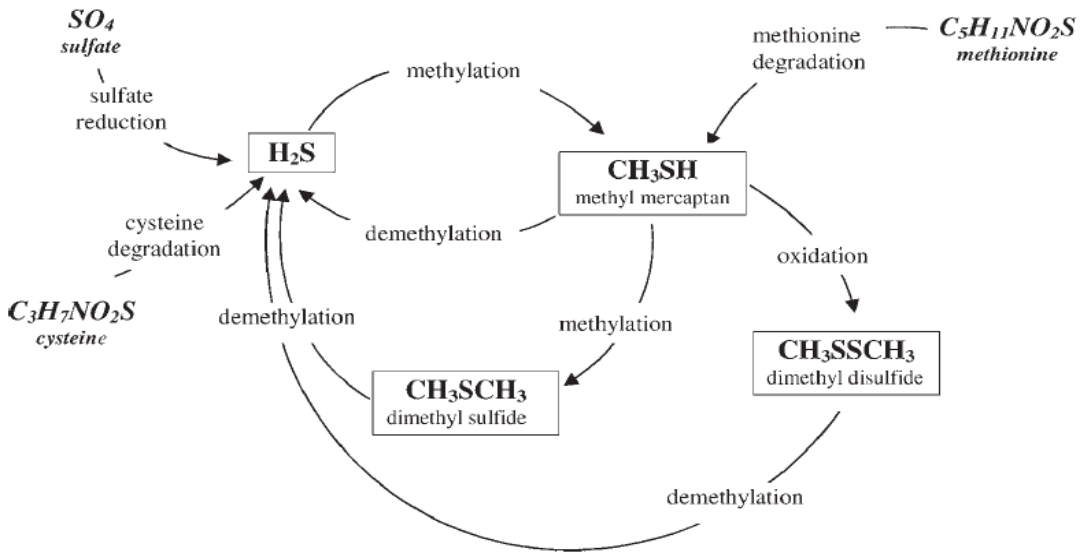


Figure 2-4: Cycling of Volatile Organic Sulfur Compounds in Anaerobically Digested Biosolids and its Implications for Odours

(Source: Higgins et al, 2006)

The anaerobic degradation of sulfur-containing amino acids, specifically cysteine and methionine, can produce hydrogen sulfide and MT, respectively (Yoshimura *et al.*, 2000). Amino acids are the monomers of protein, and both cysteine and methionine have been shown to be present in protein extracted from activated sludges and anaerobically digested sludges (Dignac *et al.*, 1998; Higgins *et al.*, 2004; Higgins & Novak, 1997; Morgan *et al.*, 1990). This mechanism would likely involve consecutive steps of the breakdown of protein to form peptides and degradation of the peptides to form these free amino acids, which could then be broken down to form VOSCs. Since biosolids have a high protein content (up to 50%), the substrate for this reaction is readily available and likely plays a critical role in the production of VOSCs in biosolids.

Another pathway for the formation of VOSCs is the methylation of H_2S and MT. Anaerobic microbes found in freshwater sediments, soils, and water have been shown to methylate H_2S and MT to produce MT and DMS, respectively (Bak *et al.*, 1992). In the case of H_2S, the methylation reaction is thought to happen in two consecutive reactions, with MT as an intermediate, and the source of the methyl groups is often methoxylated aromatic compounds (Bak *et al.*, 1992). This reaction can be written as follows:

$$R\text{-}O\text{-}CH_3 + H_2S \longrightarrow R\text{-}OH + CH_3SH \qquad \text{(Reaction 1)}$$

$$R\text{-}O\text{-}CH_3 + CH_3SH \longrightarrow R\text{-}OH + CH_3SCH_3 \qquad \text{(Reaction 2)}$$

The R depicted in these reactions is the parent compound, generally thought to be an aromatic compound. Therefore, these methylation reactions have the potential to produce MT and DMS from H_2S and MT, respectively, and they are considered one of the main mechanisms for VOSC production in freshwater sediments (Lomans *et al.*, 1997). Since biosolids have a significant amount of humic acid type material (Frølund *et al.*, 1996), which can be a source of methyl group donors, this may also be an important mechanism for VOSC production in biosolids.

The formation of DMDS does not seem to happen through microbial-mediated degradation processes. For instance, no pathways for DMDS formation have been reported in the literature, despite the fact that DMDS is usually found as an odourant in numerous systems, and its presence has led some researchers to suggest it is formed by a direct microbial pathway (Persson *et al.*,1990). Notwitstanding, Persson *et al.* (1990) showed that, when MT producing cultures are grown under anaerobic conditions, no DMDS is formed, and they suggested that researchers reporting direct formation of DMDS as a microbial product were likely measuring DMDS as a consequence of MT

oxidation. Similarly, Chin and Lindsay (1994) reported that abiotic DMDS formation from MT did not happen under anaerobic conditions but did happen in the presence of oxygen. These reports suggest that DMDS is formed by MT in the presence of oxygen, and it is likely that this reaction is catalyzed by certain biosolids constituents, such as metals, because they have been shown to enhance this transformation (Chin & Lindsay, 1994). This reaction can be written as follows:

$$CH_3SH + CH_3SH + 0.5O_2 \longrightarrow H_2O + CH_3S\text{-}SCH_3 \qquad \text{(Reaction 3)}$$

During biosolids storage, researchers have reported that VOSCs can be consumed after their production (Forbes *et al.*, 2003; Higgins *et al.*, 2004); therefore, a mechanism exists for VOSC removal during storage. Research has shown that methanogenic bacteria can degrade or demethylate MT, DMS, and DMDS to form H_2S (Lomans *et al.*, 2001; Lomans, *et al.*, 1999). For example, Lomans *et al.* (1999a) demonstrated that methanogens were the main degraders of MT and DMS in freshwater sediments with low sulphate concentrations (conditions similar to anaerobic digesters). They also isolated the first nonmarine methanogen able to use DMS as a sole carbon and energy source and named the organisms *Methanomethylovorans hollandica* (Lomans, *et al.*, 1999). The stoichiometry for DMS degradations has been given as follows (Lomans, *et al.*, 1999):

$$CH_3SCH_3 + H_2O \longrightarrow 0.5CO_2 + 1.5CH_4 + H_2S \qquad \text{(Reaction 4)}$$

These reactions could be very essential in keeping up low levels of VOSCs in anaerobic conditions, and the inhibition of methanogens could result in greater VOSC production. Hydrogen sulfide produced by this mechanism could be bound by metals in the biosolids or potentially removed by other microbially mediated processes, resulting in deodourization of the biosolids.

Higgins et al (2006), provided a framework for understanding the mechanisms and pathways of VOSC production and their degradation. The main pathways for production of VOSCs appear to be degradation of protein to form H_2S and MT and the methylation of H_2S and MT to form MT and DMS, respectively.

Another source of H_2S is through sulphate reduction by sulphate reducing bacteria under anaerobic conditions. Hydrogen sulfide (H_2S) is formed by microbial reduction of sulphate (as electron acceptor) and microbial degradation of sulfur-containing organic compounds under anaerobic conditions according to the following equations (Arogo *et al.*, 2000).

$$SO_4^{2-} + \text{Organic matter} \xrightarrow[\text{bacteria}]{\text{anaerobic}} S^{2-} + H_2O + CO_2 \qquad \text{(Reaction 5)}$$

$$S^{2-} + 2H^+ \longrightarrow H_2S \qquad \text{(Reaction 6)}$$

2.3.2 Nitrous Compounds

Other significant sources of odour could be nitrogen-containing odourants. They are often ammonia, amines, indole and scatole. Indole and derivatives (such as scatole) have been reported to have a character similar to the general sewage treatment works odour when considered in isolation (Young, 1984). Urine, proteins and amino acids are sources of nitrogen in sewage. Amines in particular are produced from amino acids by the removal of the carboxyl (COOH) group (Harkness, 1979). The by-products of carbohydrate fermentation which are generally associated with anaerobic treatment include volatile fatty acids, aldehydes, alcohols and ketones, and in particular with the treatment of sewage sludge (Bonnin *et al.*, 1990).

Ammonia (NH_3) is a colourless gas at atmospheric pressure, which is lighter than air and has a strong, penetrating odour. Ammonia readily dissolves in water by ionization to form ammonium ion. Atmospheric pressure, temperature, dissolved or suspended materials influence the solubility of ammonia in water. Ammonia is a major contributor to emissions in livestock production (Arogo *et al.*, 2000). Koerkamp *et al.* (1998) reported that ammonia is usually generated from animal waste and manure according to the following reactions.

Aerobic decomposition of uric acid:

$$C_5H_4O_3N_4 + 1.5O_2 + 4H_2O \longrightarrow 5CO_2 + 4NH_3$$

Urea hydrolysis:

$$CO(NH_2)_2 + H_2O \longrightarrow CO_2 + 2NH_3$$

Mineralization:

undigested protein (bacterial degradation) $\longrightarrow$ NH_3

2.3.3 Acids

Formation of acids from storage of faecal matter occurs under anaerobic conditions. The four main stages of anaerobic digestion involve hydrolysis, acidogenesis, acetogenesis and methanogenesis as shown in Figure 2-5. For the purposes of reviewing literature for this assignment concentration is given to the acidogenesis and acetogenesis stages., Propionic, butyric and Acetic acids which are products of the acidogenesis and acetogenesis have been reported as odourous compounds.

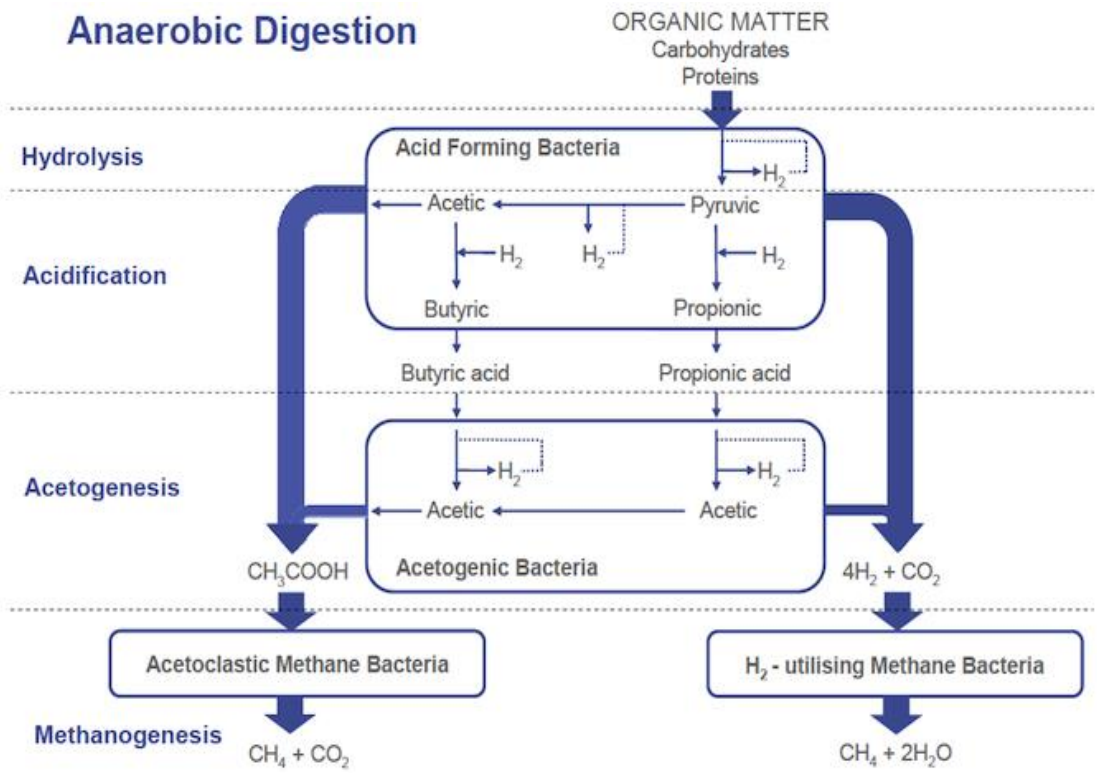


Figure 2-5: Schematic diagram of anaerobic digestion process
(*Source: Sustainable Energy, http://www.ccctelecom.net/sustainable/energy-crops*)

Acidogenesis

The soluble products of hydrolysis are metabolised intracellularly by complex consortium of microorganisms. Acidogenesis is a degradation process, which does not require an additional electron acceptor or donor. (Bastone *et al.*, 2002a). The other products of glucose acidogenesis are lactate and ethanol. The acidogenesis from amino acids is either through anaerobic uncoupled oxidation (with hydrogen ions as the electron acceptor) linked to hydrogen formation or fermentation according to the coupled Stickland reaction (Zeeman and Sanders 2001, Bastone *et al.*, 2002a). Zeeman and Sanders (2001) noted that the former process was dependent on the presence of hydrogen scavengers while the latter was not dependent on the methanogenic activity. In the

normal anaerobic systems, where different kinds of proteins exist, Stickland reaction is more favourable. The Stickland Oxidation-Reduction fermentation reaction as below:

$$\text{Alanine} + \text{ADP} + P_i \longrightarrow \text{Acetate} + \text{ATP} + CO_2 + NH_3 + 4H$$

$$2\text{Glycine} + 4H \longrightarrow 2\text{Acetate} + 2NH_3$$

Acetogenesis

The degradation of higher organic acids formed in acidogenesis is an oxidation step with no internal electron acceptor. Thus, the oxidising organisms (normally bacteria) require an additional electron acceptor such as hydrogen ions or CO_2 for the conversion to acetate, carbon dioxide and hydrogen (Batstone *et al.*, 2002a).

2.3.4 Aldehydes and Ketones

Aldehydes are intermediates in the breakdown of hydrocarbons and are common in the domestic wastes. Ketones are formed by the oxidation of alcohol (Henry & Gehr, 1980).

2.3.5 Odour related to Hydrogen Sulphide and Ammonia

The catabolism of faeces and urine by anaerobic microorganisms may be the source of odour released from human waste. Hydrogen sulfide (H_2S) and ammonia (NH_3) have been identified as two major odour gases as demonstrated by their volatile characters and odour strength (Eikum & Storhaug, 1986). Many different work settings have documented the occupational hazards of these gases. Irritation of eyes, mucous membranes, and respiratory tract are some of the problems of human and animal health associated with H_2S and NH_3 in confinement (Noren, 1986). When ammonia concentration is over 1 ppm, the body will feel uncomfortable whereas when ammonia concentration goes up to 25-30ppm it may result in inflammation of the eyes. In addition,

when ammonia concentration is over 50 ppm, it will cause eye disease. Even under low concentration hydrogen sulfide will also cause the irritation of eyes and respiratory tract (Donham *et al.*, 1982).

Varied results have been produced in research to determine the relationship between H_2S concentration and odour. Jacobson *et al.* (1997) assessed odour and H_2S of various livestock buildings and manure storage facilities and found a low correlation between H_2S and odour. Zhang, *et al.*, (2005) carried out a study to measure odour levels and H_2S emissions from ten hog farms in Manitoba. The results showed that there was a positive correlation between odour levels and H_2S concentrations for both swine barn exhausts and lagoon odour. Guo *et al.*, (2000) determined a correlation coefficient, r, of 0.75 between the odour dilution threshold (DT) and H_2S concentrations for a variety of animal species, demonstrating that H_2S can be used as an odour indicator for some facilities.

On the other hand, research to determine the relationship between NH_3 concentration and odour has also produced varied results. Schulte *et al.*, (1985) found that there was a connection between high levels of ammonia emissions and odour, but Liu *et al.*, (1993) reported that levels of ammonia emissions are not a good indicator of the odour threshold from swine manure. De Bode (1991) examined the relationship between odour intensity and ammonia concentration and found that by covering manure storage units, ammonia emissions were reduced from 75% to 100% (that is a 25% reduction in ammonia concentration) while odour intensity was reduced from 28% to 72% (that is a 44% reduction in intensity due to ammonia release).

2.3.6 Effect of Temperature, Humidity and Moisture Content on Release of H_2S and NH_3

Chung *et al.*, (1996) in their study concluded that concentration of daily emitted ammonia gas and hydrogen sulfide varied at different temperature and humidity and that the influence of temperature was significant on the emission of NH_3 and H_2S above 25°C. However, the influence of humidity on the emission of NH_3 and H_2S was dependent on the change of temperature. Also, when moisture content was higher than 80%, it contributed to NH_3 and H_2S production even at a low temperature (15°C). They proposed that an optimal environmental condition of 25 °C and 60% moisture content for reducing the emission of NH_3 and H_2S.

2.3.7 Effect of pH on release of H_2S and NH_3

By definition, pH is the negative log of the concentration of hydrogen ions present in a solution. It is a measurement that describes the acidity or alkalinity of a solution. As pH decreases, the concentration of hydrogen ions increases and a solution becomes more acidic. When the number of hydrogen ions available increases, HS^- and S^{2-} are converted to hydrogen sulfide, and is volatized. Ammonia gains a hydrogen ion and becomes stable ammonium (NH_4^+). As pH increases, there are lesser hydrogen ions present and a solution is more basic, or alkaline. When the quantity of hydrogen ions available decreases, hydrogen sulfide molecules lose hydrogen ions and become negatively charged. Thus, the hydrogen sulfide concentration decreases as H_2S is converted to HS^- and ultimately S^{2-}. Ammonium (NH_4^+) loses a hydrogen ion, becoming NH_3, which is the gaseous form of ammonia volatilized.

2.4 ODOUR MEASUREMENT

In considering odour measurement, it is imperative to differentiate between odourants and odours. An odourant is the compound responsible for imparting an odour, whereas an odour is the perceived effect of the odourant as detected and interpreted by the olfactory system (Gostelow *et al.*, 2001). The linkage between odourant properties and odour perception is not clear, because of the lack of a comprehensive theory of olfaction. Two broad classes of odour measurement exist as a result: analytical measurements, referring to odourants, and sensory measurements - using human subjects - relating to odours.

2.4.1 The Need for Odour Measurement

Generally, it is recognised that for effective odour control measures to be implemented, the problem must first be quantified (Balling & Reynolds, 1980; Hobson, 1995; Stordeur *et al.*, 1981). Such quantification allows operators or designers to make informed decisions on process modifications or the scope of odour control plans (Clarkson, 1993). Unfortunately, odours are difficult to measure since a person's perception to an odour is highly subjective, different individuals find different odours offensive, and at different concentrations. This is further complicated by the fact that many odourous emissions, including those from sewage treatment works, comprise of numerous individual odourous components, and the overall odour of complex mixtures cannot easily be predicted (Jiang, 1996; Koe, 1989).

2.4.2 Dimensions of an odour

Gostelow *et al.* (2001), explained that the dimensions of an odour refer to the parameters of an odour which can be measured. There are four generally accepted dimensions of an odour:

- concentration (physical concentration of odourants);
- intensity (magnitude of perceived sensation);
- character (characteristic properties distinguishing one odour from another); and
- hedonic tone (pleasantness or unpleasantness)

Odour concentration is the most frequently measured parameter and can be measured analytically or by sensory means. Analytical measurements give the physical concentration for specific odourants, whereas sensory measurements determine the number of dilutions required to reduce an odour to its threshold concentration (Gostelow *et al.*, 2001). The threshold concentration is the lowest concentration at which an odour can either be detected or recognised by a subject. Recognition thresholds are typically higher than detection thresholds by a factor of 1.5-10 (A. Dravnieks & Jarke, 1980).

Odourant concentration is the only odour dimension that can be measured analytically. The remaining parameters can only be measured using sensory methods.

Perceived *odour intensity* is the relative strength of the odour above the recognition threshold (suprathreshold). Odour intensity is measured using several methods including: descriptive word category scales, magnitude estimation, and referencing scales. Descriptive word category scales have the assessor rate the odour on a scale. One such

scale used is a 5-point scale where zero is “no odour” and the other five points correspond to “barely perceptible,” “slight,” “moderate,” “strong,” and “very strong.” The shortcomings of this approach are that the five points on the scale do not represent a linear increase in perception and that each assessor may interpret the scale differently, regardless of the assessor’s training (McGinley *et al.*, 2000).

Intensity and Concentration are related with perceived intensity increasing with increasing odour concentration, although the relationship is not linear. Wright (1982) proposed two laws to explain intensity-concentration relationships, these being the Weber-Fechner law and Steven's law:

Weber-Fechner law:

$$I = a \log C + b \quad (1)$$

Steven's law:

$$I = kC^n \quad (2)$$

where I is the intensity, C the odourant concentration and a, b, k, n are the constants.

The Weber-Fechner law produces a linear plot of intensity against log concentration whereas Steven's law produces a linear plot of log intensity against log concentration. The decision of model relies upon the representation of odour intensity. If a subjective category scale is used, the Weber-Fechner law is appropriate. When magnitude or reference scales are used, Steven's law gives a better fit.

Also the hedonic tone of an odour is subjective and is the degree of pleasantness or unpleasantness associated with an odour (Gostelow *et al.*, 2001). Usually, this will be measured using a relatively large number of individuals and represented using a numeric

scale representing most pleasant at one end and most unpleasant at the other. Often, negative values are used to represent unpleasant odours and positive values represent pleasant odours (Gostelow *et al.*, 2001).

2.4.3 Analytical measurements

Analytical measurements concern the physical or chemical properties of the odourous compounds, although the most common measurement made by far is odourant concentration (Gostelow *et al.*, 2001). With analytical measurements there is the advantage of objectivity, repeatability and accuracy. More importantly they relate directly to theoretical models relating to odourant formation or emission.

Analytical measurements have the following disadvantages (Brennan, 1993; Stordeur *et al.*, 1981; Young, 1984):

- Most environmental odours are complex mixtures of dozens of components. This complicates analysis considerably, and usually necessitates a separation prior to analysis.

- Odourants may be present in very small concentrations. The limit of analytical detection may be below the threshold of smell. Non-odourous compounds will also be present in the sample in much larger concentrations than the odourants.

- It is difficult to relate analytical measurements to the intensity of odour as perceived by a human observer. This is especially the case for mixtures, as interactions between different odourants may lead to synergistic or antagonistic effects.

Analytical measurements for sewage treatment odours fall into two classes, either quantitative measurements of a single odourant or qualitative-quantitative measurements of a range of odourants. Attempts to fully identify and quantify the odourants present in a sample are difficult as a large number of odourants are present, usually at very low concentrations. Analysis of the chemical make-up of an odour requires a separation technique followed by an analytical technique. Gas chromatography-mass spectrometry (GC-MS) is often used to chemically characterise odour samples.

In many cases, a particular odourant may be dominant and can give an indication of the overall odour concentration. This is certainly the case for many sewage treatment odours, as H_2S is often present in concentrations far higher than other odourants.

Despite the fact that systems are currently available with very high resolutions, it is usually important to pre-concentrate the sample prior to analysis. This is usually achieved by passing a relatively large volume of the odourous sample through a porous absorbent material. The odourant molecules are then desorbed from the absorbent polymer at the time of measurement, usually by thermal means. Care must be taken in the choice of absorbent. Tenax G-C, a common absorbent used in gas chromatography, traps a wide range of organic compounds at ambient temperatures, but does not absorb polar molecules (Young, 1984). Where polar or low boiling point gases need to be considered, alternative absorbents such as Poropak Q must be used, or cold trapping must be employed, whereby the absorbent is cooled to sub-ambient temperatures (Young, 1984). Tenax G-C, a common absorbent used in gas chromatography, traps a wide range of organic compounds at ambient temperatures, but does not absorb polar molecules (Young, 1984).

Seperating odourous molecules from the numerous species present in an odour sample can be very difficult, as the compounds imparting a characteristic odour to a sample may only be minor components (Preti *et al.*, 1993). Olfactory gas chromatography is a method whereby some of the chromatography effluent is diverted to a sniffing port, permitting continuous olfactory sampling of the gas chromatographic effluent to be carried out. This permits focusing of the analytical effort on the parts of the effluent which are odourous or the components having characteristics of the overall odour of the sample (Preti *et al.*, 1993).

Vas and Vekey (2004) reported that present analytical and separation techniques can resolve practically all kinds of complex mixtures, from gases to biological macromolecules, with detection limits down to the femtogram range. Generally, analytical methods involve processes such as sampling (collection of the samples), sample preparation (separation from the matrix, concentration and fractionation), separation, detection and data analysis. Studies demonstrate that more than 80% of analysis time is spent on sample collection and sample preparation (Vas & Vekey, 2004). This is essential because in most cases analytical instruments cannot handle the sample matrices directly. The entire analytical process can be wasted if an unsuitable sample preparation method is employed before the sample reaches the chromatograph and the analyser (Lord *et al.*, 2003).

2.4.3.1 Sample Preparation by Liquid–Liquid Extraction and Solid-Phase Extraction

Vas and Vekey (2004) again stated that sample preparation procedures using solvents (liquid–liquid extraction techniques (LLE)) are time consuming, labour-intensive and multi-stage operations. Every stage, especially concentration, can present errors and losses particularly when analysing volatile compounds. Also the disposal of solvents is

an additional problem, adding extra cost to the analytical procedure, extra charge for the environment and creates health hazards to the laboratory personnel. The use of solid-phase extraction (SPE) cartridges and microwell plates has reduced many limitations of classical LLE techniques. SPE requires less solvent however it is a time-consuming multi-step process and often requires a concentration step, which may bring about loss of volatile components. Also long sample preparation times are obviously disadvantageous and multi-step procedures are prone to loss of analytes. Trace impurities in the extraction solvent and adsorption of analytes on the walls of extraction devices can occur. Note that despite the fact that the volume of organic solvents required for SPE is much less than that for LLE, it is still significant.

2.4.3.2 Sample Preparation by Solid-Phase Microextraction

Vas and Vekey (2004) further explained a very successful new approach to sample preparation is solid-phase microextraction (SPME) which was invented by Pawliszyn and co-workers in 1989 in trying to address constraints of the SPE and LLE techniques. SPME incorporates sampling, extraction, concentration and sample introduction into a single solvent-free step. Analytes in the sample are directly extracted and concentrated to the extraction fibre. This technique saves time for sample preparation, costs of disposal and can improve detection limits. It has been used in combination with gas chromatography (GC) and GC/mass spectrometry (GC/MS) and successfully applied to a wide variety of compounds, especially for the extraction of volatile and semi-volatile organic compounds from environmental, biological and food samples. SPME was also introduced for direct coupling with high-performance liquid chromatography (HPLC) and HPLC-MS in order to analyse weakly volatile or thermally labile compounds not amenable to GC or GC/MS. Recently, a new SPME/HPLC system known as in-tube SPMS was developed using an open-tubular fused-silica capillary column as the SPMS

device instead of the SPME fibre for use in HPLC. This is suitable for automation, which not only shortens analysis times but often provides accuracy and precision relative to manual procedures. The main advantage of SPME is good analytical performance combined with simplicity and low cost. SPME produces relatively clean and concentrated extracts, and is ideal for MS applications.

2.4.4 Sensory Measurements

Sensory measurements employ the human nose as the odour detector. In this case, they relate directly to the properties of odours as experienced by people (humans). The issues of complex mixtures, interactions between components and detectability below the threshold of smell become irrelevant as the `total impact' of the overall odour is measured (McGinley *et al.*, 2000).

There are numerous elements other than the properties of the odour sample itself that may influence the perception of an odour. Key amongst these is the variability in the sense of smell between different observers. This is usually overcome to a certain extent by using a panel of several observers, the result being expressed by some measure of central tendency of the individual results. Great care must be taken in the presentation of samples to observers to give repeatable results. Factors such as the order in which samples are presented, the environment in which the testing takes place and the flow rate of the carrying gas stream are all important (McGinley *et al.*, 2000).

Sensory measurement techniques can be divided into two categories (Koe, 1989):

- subjective measurements in which the nose is used without any other equipment and

- objective measurements which incorporate the nose in conjunction with some form of dilution apparatus.

2.4.4.1 Subjective Sensory Odour Measurement

Subjective sensory measurements have the advantage of being quick to obtain at relatively low cost, as no special equipment is required; however interpretation of results is difficult and subjective measurements should be handled with caution due to the inherent variation in odour perception even for well-trained personnel (Koe, 1989).

McGinley (1995) reported three main methods used by facility operators' to determine the impact of their odours on the surrounding community. These include: odour dispersion modelling, neighbourhood 'drive through' by facility operators, and community complaints. Parameters which may be subjectively measured include odour character, hedonic tone and intensity. Indeed, for character and hedonic tone, there are no objective techniques available with the possible exception of the electronic nose (McGinley, 1995).

Intensity is often measured subjectively, typically using ordinal category scales and there are several applications specific to sewage odours in the literature (Draper & Rutt, 1988; Finnigan, 1998). These scales usually employ 3-10 categories, but variations on a 6 category scale shown below are the most common (Cheremisinoff, 1992; Frechen, 1994): 0=no odour perceivable; 1=barely perceivable; 2=faintly perceivable; 3=clearly perceivable; 4=strong; 5=very strong.

Note that these scales are ordinal. The differences between the values are not likely to be equal - for example, an odour with an intensity of 4 is not necessarily twice as odourous as an odour of intensity of 2 (McGinley, 1995). For similar reasons, problems can also

arise when comparing intensities presented using different category scales (Koe, 1989). Despite their limitations, subjective odour measurements are undoubtedly useful. Additional benefits are cost effectiveness, and the raising of awareness of site personnel of the importance of odour.

2.4.4.2 Objective Sensory Odour Measurement

Objective sensory measurements use the nose in conjunction with an instrument which dilutes the odour sample with odour-free air, usually termed an olfactometer (McGinley *et al.*, 2000). There are two categories of dilution-related measurement techniques. The most common is threshold olfactometry, where the sample is successively diluted until it can just be detected (i.e. the threshold concentration). The concentration is then expressed as the number of dilutions required to achieve the threshold concentration (McGinley *et al.*, 2000). The other category of dilution-related measurement is suprathreshold olfactometry, in which the sample odour is compared to a reference odour and the result is expressed as an equivalent concentration of the reference gas (McGinley *et al.*, 2000). The sample or reference odour is diluted until the perceived intensity of each stream is the same. In both cases, the use of an olfactometer removes (or at least, reduces) any subjectivity from the measurement. For dilution to threshold measurement, panellists are required only to decide whether an odour can be detected. For suprathreshold measurement, a panellist decides whether the sample intensity is the same or different from a reference sample.

Dilution may be static or dynamic. Static dilution involves the mixing of fixed volumes of odourous and odour-free air, whereas dynamic dilution involves the mixing of known flows (McGinley *et al.*, 2000). Dynamic dilution is superior to static dilution as the effects of sample adsorption to the internal surfaces of the instrument are minimised (A.

Dravnieks & Jarke, 1980). An additional advantage of dynamic olfactometers is that the sample can be delivered to the sniffing port at a constant flow, a factor which has been shown to improve repeatability of results (Duffee & Cha, 1980; Koe, 1989; Schulz & Van Harreveld, 1996).

Examples of static dilution instruments or techniques which have been applied to sewage odour measurement are the osmoscope (Fair & Moore, 1935), the scentometer (Huey *et al.*, 1960) and the ASTM syringe method (ASTM, 1978). These instruments have largely been superseded by dynamic olfactometry (Brennan, 1993; Koe, 1989), although the scentometer may sometimes be used in field studies as it is specifically intended for this purpose (Dravnieks & Jarke, 1980; Koe, 1989).

2.5 MAKING SENSE OF SMELL

Of the five senses, the sense of smell is the most complex and unique in structure and organization (McGinley *et al.*, 2000). During normal breathing only 10% of inhaled air passes up and under the olfactory receptors in the top, back of the nasal cavity. When a sniffing action is produced, either an involuntary sniff reflex or a voluntary sniff, more than 20% of inhaled air is carried to the area near the olfactory receptors due to turbulent action in front of the turbinate (McGinley *et al.*, 2000). Chemical odourants pass by the olfactory epithelium and are dissolved (transferred) into the mucus at a rate dependent on their water solubility and other mass transfer factors. The more water-soluble the chemical, the more easily it is dissolved into the mucus layer (McGinley *et al.*, 2000). The response created by the reception of a chemical odourant depends on the mass concentration or the numbers of molecules present (McGinley *et al.*, 2000). Each reception creates an electrical response in the olfactory nerves. A summation of these electrical signals leads to an “action potential.” If this action potential has high enough

amplitude (a threshold potential), then the signal is propagated along the nerve, through the ethmoidal bone between the nasal cavity and the brain compartment where it synapses with the olfactory bulb (McGinley *et al.*, 2000)

2.5.1 Odour Perception

A simple model of odour perception is provided by Frenchen (Frechen, 1994). The process is visualised in two steps, physiological reception and psychological interpretation. The end result is a mental impression of the odour.

The sensitivity of physiological reception of odours differs from person to person. Although a random variation in sensitivity is inevitable, some general influences on odour sensitivity have been identified. Sensitivity to odours declines with age (Bliss *et al.*, 1996; Cain *et al.*, 1995; Fortier *et al.*, 2007; Griep *et al.*, 1995; Griep *et al.*, 1997; Patterson *et al.*, 1993) and is also worse for subjects who smoke or have poor health or dental state (Fortier *et al.*, 2007; Griep *et al.*, 1995; Griep *et al.*, 1997). The effects of gender on odour sensitivity have also been investigated, and although differences were found in some studies, they were not statistically significant (Bliss *et al.*, 1996; Cain *et al.*, 1995; Fortier *et al.*, 2007; Griep *et al.*, 1995; Griep *et al.*, 1997)

An additional influence on sensitivity is prior exposure to an odour. This has two conflicting effects. The first is that, under continuing exposure to an odour, the sensitivity to that odour decreases. This is termed adaptation or olfactory fatigue (Dravnieks & Jarke, 1980). A conflicting effect is apparent under repeated (not continuous) exposure to an odour in which case sensitivity is found to increase (Cain, 1980; Laska & Hudson, 1991; Leonardos, 1980). This is most likely due to familiarity with the particular odour and subsequent increased skill in identifying it.

2.5.2 The Mechanism Leading from Smell to Odour Nuisance

Pro-poor sanitation facility providers have a responsibility to minimise the negative impact of operations in the vicinity of these facilities. Odours are likely the dominating nuisance issue for onsite toilet technologies, with the potential to reach well beyond the boundaries of these facilities. Odour nuisance can develop after long-term intermittent exposure to odours that cause a negative appraisal in the individual concerned.

The mechanism that leads from an emission of odourants to the atmosphere to actual odour nuisance is quite complex as shown in Figure 2-6. It involves the following main factors:

- The characteristics of the odour that is released (detectability, intensity, hedonic tone, annoyance potential);
- Variable dilution in the atmosphere through turbulent dispersion (turbulence or stability of the boundary layer, wind direction, wind speed, etc.);
- Exposure of the receptors in the population (location of residence, movement of people, time spent outdoors, etc.);
- Context of perception (i.e. other odours, background of odours, activity and state of mind within the perception context);
- Receptor characteristics (exposure history, association with risks, activity during exposure episodes, psychological factors such as coping behaviour, perceived health and perceived threats to health).

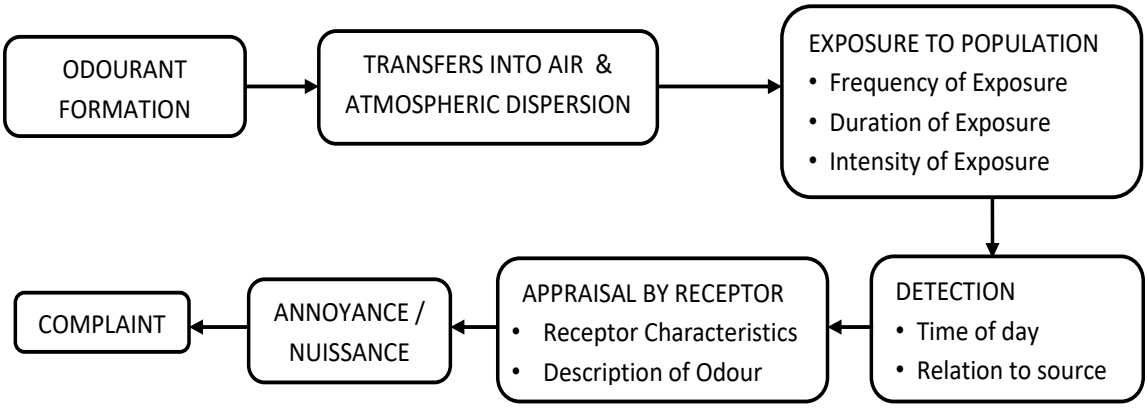


Figure 2-6: Mechanism leading from Emission of Odourants to Complaint

Adapted from Reports: (Environmental Research, Research &Development Report Series No. 14, 2001)

2.5.3 Odour and Annoyance

Research suggests that environmental stimuli, such as noise and odours, can have significant effects on an inndividual's psychological and health status (Berglund, Hassmen, & Job, 1996; Andrew Dravnieks & O'NEILL, 1979; Staples, 1996). If the exposure is prolonged or the intensity increased, the feeling of unpleasantness can develop into a feeling of annoyance. Annoyance has been defined as a feeling of displeasure associated with any agent or condition believed to adversely affect an individual or group (Lindvall, 1974; Punter, 1986). According to this definition, the environmental agent or condition has an effect on the psychological state of the individual but need not have a direct effect on his or her health. Winneke (1992) and Cavalini (1994) in their study of determinants of odour annoyance in populations exposed to industrial emissions in Germany and the Netherlands respectively found that odour exposure was the single most important predictor of annoyance.

In addition to annoyance from perceived odour, however, volatile chemicals can produce sensory and respiratory irritations (Koren *et al.*, 1992; Warren, Walker *et al.*, 1994). Thus, although most environmental odours are not considered to be health hazards because they are usually present in low concentrations, they can nonetheless cause a number of unpleasant physical reactions in people, such as nausea, vomiting, headaches, disturbances of sleep, appetite loss, and irritation of eyes, nose and throat.

2.6 ODOUR DISPERSION USING GAUSSIAN DISPERSION MODEL

Atmospheric dispersion models have been proven to be a very powerful tool to predict the odour concentration downwind of an odour emitting facility. There are several models (e.g. ISC3, ADMS3, AUSPLUME, INPUFF and CALPUFF) that are commercially available and often particular models are favoured in different parts of the world.

Traditionally, the Gaussian plume model is the most common air pollution model and regarded as the cornerstone of most dispersion calculations in regulatory applications, which are based on this Gaussian dispersion model for a continuous point source in a uniform flow with homogeneous turbulence. In a general reference system, the Gaussian plume formula is expressed as:

$$C_{(x,y,z)} = \frac{E}{2\pi\sigma_y\sigma_z u}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}$$

where: C(x,y,z) is the concentration at point located at co-ordinate x,y,z, E is the emission rate, σ_y is the horizontal dispersion parameter, σ_z is the vertical dispersion parameter, u is the wind speed, H is the Emission height.

Some work has been done in using the air dispersion models for predicting the odours from industrial or urban sources, particularly from composting facilities. ISCST model was used to simulate the odours from a composting facility (Engel *et al.*, 1997). This methodology appears to generate reasonable results in terms of predicting the frequency of nuisance conditions and the model results correlated with quantitative measurements obtained from field sampling studies. Also, a Gaussian plume model was applied in predicting the local distribution of odours emanating from mushroom composting facilities. A composter survey was conducted to verify the model and the results appeared to be reasonable, however only one odourous gas (dimethy1 disulfide) was modeled to indicate odour (Heinemann & Wahanik, 1998).

Many researchers simplified and modified the Gaussian plume model and applied in agricultural odour dispersion. Guo *et al.*, (2006) reported that Stoke (1977) applied the Pasquill's equation (equation [2]) to predict odour dispersion from 10 pig barns. Equation 2 was used to calculate the distance for 1 OU/m^3 with measured emission rate and odour panels were employed to determine the downwind distance where odour concentration was equal to 1 OU/m^3 which meant that 50% of the panel can detect odour. Agreement between predicted and measured distance for 1 OU/m^3 was reasonable

$$\frac{C(x,y,0,H)U}{Q} = \frac{1}{2\pi\sigma_y\sigma_z}\exp -\frac{1}{2}\left[\frac{y^2}{\sigma^2{}_y} + \frac{H^2}{\sigma^2{}_z}\right] \qquad [2]$$

where: C is the concentration at point located at co-ordinate, E is the emission rate, σ_y is the horizontal dispersion parameter, σ_z is the vertical dispersion parameter, u is the wind speed, y is the is the horizontal distance in the wind direction, H is the Emission height.

Again, Guo *et al.* (2006) reported that Majer and Krouse (1985) conducted research on using modified Gaussian dispersion model to predict emissions from agricultural sources. They considered the difference between the gas dispersion from industrial sources and odour dispersion from agricultural sources and convinced that the Gaussian plume formula should be used only for those downwind distances for which the empirical diffusion coefficients have been determined by standard diffusion experiments. They developed a modified Gaussian plume model suitable for predicting the concentration of pollutants on the centerline in the downwind direction (Equation [3]), although the validation of this modified model was not conducted.

$$C_c = \frac{C_s v}{\pi U \sigma_x \sigma_y}\left(1 - \frac{H^2 \sigma_x^2}{2x^2 \sigma_z^2}\right) \exp\left(-\frac{H^2}{2\sigma_z^2}\right), \qquad [3]$$

where: C_c is the downwind concentration on the centerline, g/m^3; v is the volume emission rate at the source, m^3/s; C_s is the source concentration g/m^3; σ_y is the horizontal dispersion parameter, σ_z is the vertical dispersion parameter.

Similarly, Guo *et al.* (2006) reported that Williams (1985) simplified the Gaussian plume model to estimate the odour concentration emanating from animal buildings and land application of manure. This model (Equation [4]) described the downwind ground level concentration on the plume centerline for a ground level source (H=0)

$$C_c = \frac{C_0 D v}{\pi \sigma_y \sigma_z U} \qquad [4]$$

Where: C_c is the downwind concentration on the centerline, D is the number of dilutions to detection threshold; C_0 is the detection threshold concentration, g/m^3, σ_y is the horizontal dispersion parameter, σ_z is the vertical dispersion parameter

The distance that odour complaints might be expected was calculated by equation [5]. Comparison with empirical formulae relating distance of complaint to odour emission obtained from a large number of experimental studies showed that dispersion modeling approach provided reasonably accurate results.

$$\sigma_y \sigma_z = (\frac{R}{S}) \frac{DF}{\pi U} \quad [5]$$

where: R is the peak to mean ratio; S is the factor by which recognition or annoyance threshold causing odour complaints is larger than the detection threshold.

Modified Gaussian plume models were applied to evaluate the ground level odour concentration downwind a point source by using the same equation as equation [2] and a linear source by equation [6] (Carney & Dodd, 1989). Comparisons were made between the model predicted concentrations with actual odour emission rate and odour plume measurement data for various agricultural sites including a point source (a slurry tank), a line source (a strip of land spread with slurry), an aerial source (field spread with slurry), and a 450-sow swine production unit. Since there was no equation for the areal source, the model for the linear source was used and the answer multiplied by the width of the area. Results showed that the model had a good indicator of how an odour dispersed from a point source and a linear source.

$$C(x, y, 0, H) = \left(\frac{2}{\pi}\right)^{0.5} \frac{Q}{\sigma_z U} \exp\left[-0.5\left(\frac{H}{\sigma_z}\right)^2\right] \quad [6]$$

Gassman (1993) reviewed the Gaussian plume methodology, its inherent problems in estimating odour dispersion, and previous attempts to model the dispersion of agricultural odours. He discussed the shortcomings of the commonly used Gaussian

method of modeling dispersion, which are that the Gaussian method does not take into account non-steady-state flow, topography, inconsistent wind velocities or the fact that odour moves in puffs rather than in continuous flow. Gassman (1993) stated that the Gaussian method was adequate when comparing differences between different scenarios, but was not recommended for finding absolute odour concentrations.

Significant differences in predicted odour concentrations have been shown in comparisons between two widely used models ISCST3 and ADMS 3.1 (Atmospheric Dispersion Modeling System) (Curran *et al.*, 2002). Sheridan *et al.*, (2004) selected ISCST3 as the most appropriate model to use in predicting where odour nuisance is likely to occur near pig units in Ireland because of the previous validation study.

2.7 REDUCTION AND CONTROL OF ODOUR ASSOCIATED WITH ON-SITE SANITATION TECHNOLOGIES

Odours associated with on-site sanitation technologies are often the primary trigger for complaints made by users and individuals living in nearby communities. In particular, complaints about odourous emissions from these facilities are a focal point, likely due to both the perceived and actual potential for odours to be emitted. For this reason, the monitoring of odour emissions has become a priority for the pro-poor sanitation interventions and the neighboring communities. Unfortunately, in many instances, quantifying and objectively determining the odour impact has posed challenges.

Odour is a common complaint for users of the dry toilet, resulting from ammonia emissions from urine and likely sulfide and organic emissions from the ventilation pipes (Flores *et al.*, 2009). Flores *et al.* (2009) stated that dry sanitation technology is less mature than the waterborne system, and therefore requires further improvements particularly with regards to odour control, toilet design, and faecal material handling.

They further stated that the dry system suffers from low user acceptability due to the more complex design of the UDD toilet, odours, and the prevailing view of the flush toilet as the "gold standard" and also technological improvements of the ventilation system (for odour control), UDD toilet design, and faecal management will also contribute to improved sustainability from a societal perspective. The ventilation system used for controlling odours from the ventilation pipes is still underperforming and the design needs to be improved. A study carried out in Kumasi, Ghana, reported complains of odour and presence of insects associated with the Kumasi Ventilated Improved Pit (Oduro-Kwarteng *et al.*, 2009).

Various measures have been suggested to aid in reducing odour from toilet blocks. These include improving ventilation and use of additives to reduce production of odour compounds.

2.7.1 Toilet Ventilation and Odour

Toilets privy rooms are one of the most frequently used installations; consequently, toilets privy room design is a high priority for engineers and designers. Without proper ventilation, the room will, without a doubt, begin to emit unwanted odours of all kinds. Indoor air quality has a great impact on the health of human inhabitants (Chung *et al.*, 1997; Dols *et al.*, 1992). Studies also revealed that indoor air pollutants are normally found at higher concentrations than their outdoor counterparts (Sandberg & Blomqvist, 1985). However, effective ventilation systems are able to improve the indoor air quality and solve the embarrassing problems of toilet odours and moist air.

Ventilation is the process by which natural air which is usually fresh is introduced into a confined space. Ventilation serves several purposes such as preserving the air quality,

removing odours, drying out contents in composting toilets, providing oxygen for decomposition among others. Ventilation may also be used to lower the temperature inside an occupied area.

Ventilation systems may be categorized into two namely natural ventilation and mechanical ventilation. Natural ventilation is the process of supplying and removing air by means of purpose-provided aperture (such as windows, louvers, ventilators and vent pipes) and the natural forces of wind and temperature difference. Mechanical ventilation on the other hand is the process of supplying and removing air by means of mechanical devices, such as fans. It may be arranged to provide supply, extract or balanced ventilation for an occupied space. Extract ventilation aims at extracting bad air from a given space.

2.7.1.1 Principles of Natural Ventilation (in a vent pipe)

For air to move into and out of a building, a pressure difference between the inside and outside of the building is required. Natural ventilation conditions occur either through combined stack effect and wind or through wind only at air speed in excess of 3m/sec (Oketch, 2005). For stack effect, warm air is lighter than cool air and it rises being replaced by cooler air. In an ecosan toilet for instance, when the solar radiation heats the black vent pipe, the pipe heats the air inside it and its density lowers and it rises upwards out of the vent. A downward draught of cooler air of higher density then flows in through the squat plate hole replacing the vacuum space created after warm air rising. The flow is along the path of least resistance. The rate of ventilation is directly proportional to the size of the openings and the height difference between inlet and outlet. Wind ventilation on the other hand occurs when wind rushes past the air vent, due to the speed at which the wind is moving in addition to the air passing out of the pipe relative to the air in the

vent, a negative pressure is created and thus establishing a suction phenomenon. Thus the air in the pipe is drawn out and is replaced by fresh air. In most cases, natural ventilation depends on a combined force of wind and stack effects. A vent pipe should have a diameter of 10-15cm (Esrey *et al.*, 1998) in humid climates with large amount of liquid to be evaporated, the diameter could be larger, up to 25cm. The pipe should be as straight as possible and reach 30-90cm above the roof.

2.7.1.2 Principle of Mechanical Ventilation

The air pressure difference created by fans and other mechanical ventilators, between the inside and the outside of a structure causes air exchange in mechanically ventilated facilities. For example exhaust fans create a slight negative pressure or vacuum in a structure which causes air to enter the structure through designed inlets for example louvers and the squat hole in a latrine.

2.7.2 Effects of Additives for Odour Reduction

Over the years, various studies have been carried out to test the effect of various additives on various biosolids with regards to reducing odours produced from the storage of these biosolids. The biosolids include sludge from primary and secondary tanks, anaerobic sludge, and compost, among others. The purpose of introducing these additives is to either alter conditions that aid in the production and release of odour compounds or destroy these odour compounds after they have been formed. Substances that have been used as addditives with the aim of reducing odour in biosolids include wood ash, saw dust, coal ash, sludge ash, etc. Toffey *et al.*, (2007) in their study of odour characteristics of biosolids cake to identify effective mitigating measures for odour control, reported that no single mitigating measure provides compelling control over odourant production. Steps taken in response included blending high carbon coal ash to

reduce odourant emissions among others. They further reported that addition of sludge ash with high carbon content, coal ash with medium carbon content and coal ash with high carbon content gave 85%, 75% and 98% reduction in odourant concentration.

Rosenfeld and Henry (2000) also carried out a pilot study on the feasibility of using high carbon wood ash to control composting odour emissions at a green material composting facility. The study's treatments consisted of adding 0%, 12.5%, and 25% high carbon wood ash by volume to green material compost feedstock in three separate windrows. The wood ash had properties similar to activated carbon with an active surface area of 105 square metres per gram on a dry weight basis. The odourant emission data suggested that the higher percentage wood ash treatment results in the most effective control of most compost odours and that wood ash provides effective treatment of volatile fatty acids and some aldehydes and ketones. The 25% wood ash treatment resulted in more effective treatment of odours for a longer time period than the 12.5% treatment.

2.8 RESEARCH GAP

A review of existing literature reveals that considerable studies have been carried out with regard to odour emissions and control mechanisms. The use of dispersion models together with analytical or sensory measurements to predict ground level from mainly livestock farms, compost plants and landfills has also been reported widely in literature. Odour control mechanisms reviewed include:

- prevention: which involves avoiding the formation and release of odourants (eg. use of additives such as enzymes, ashes)
- control: which involves either capture, destroy or transform odourants after they have been formed (eg.use of biofilters)

- sensory methods: which involves masking or interference with pleasant smelling gases

However literature on the application of these techniques in the specific area of storage of human excreta onsite is quite limited if not non-existent. Also with regards to dispersion models there is lack of literature on its applicability to odour from public/communal toilet facilities for prediction of odour levels and also improve design of these facilities. Also, there is limited literature on the use of additives to reduce odour produced from fresh human excreta.

This thesis seeks to address these research gaps by;

- carrying out objective field odour measurement and dispersion modeling to predicit dispersion from a communal toilet facility and recommend improvement,
- investigating the effects of physical conditioners (coconut fibre ash and cocoa husk ash) on the release of H_2S and NH_3 from the storage of human excreta as a control measure.

2.9 CONCEPTUAL FRAMEWORK

Due to low concentrations and fluctuating environmental conditions, odour compounds are often difficult to measure under ambient conditions. Instruments can provide information on individual constituents (e.g., NH_3, H_2S, skatole) but not on the total perception of odour per se (Dalton, 1999). Thus, the most sensitive and reliable way to obtain data on the frequency, intensity, duration and quality of an odour is to use the human nose as the detection instrument, a well-established method known as olfactometry (Chen *et al.*, 2004). This method is the most relevant for understanding the odour impact on a community that may serve as a barrier to utilization of a facility.

In this regard, this research is in two main parts being direct field assessment employing the human nose as the assessor and laboratory scale assessment of limiting effects of physical amendment on hydrogen sulfide (H_2S) and ammonia (NH_3) release. The field assessment on the other hand involves a perception survey (usually very subjective), field olfactometry measurements (more objective and scientific) and odour dispersion modeling. The dispersion seeks to test the applicability of Steady State Gaussian Plume model in modeling odour from a communal toilet facility. Data from the field olfactometry study is used to validate the model. Figure 2-7 presents the conceptual framework of this study.

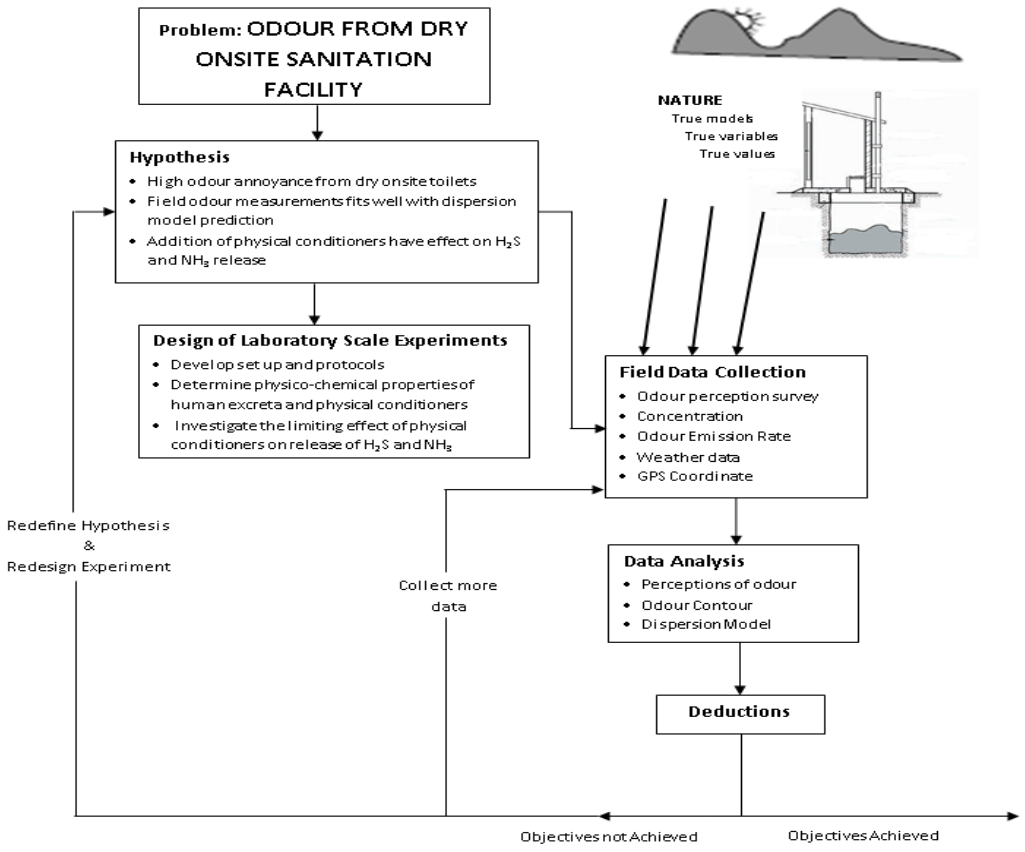


Figure 2-7: Conceptual framework of the study

3 METHODOLOGY

This chapter presents a description of the study area and presents the methods followed at meeting the specific objectives of this assignment.

3.1 THE STUDY AREA

Ayigya Zongo was selected for this study. The selection was based on a purposive convenient sampling. Purposive because, the project under which this study is being undertaken targets urban poor communities and Ayigya Zongo is classified as an urban poor area. Also the area has various dry onsite communal toilet technologies. Convenient because, Ayigya Zongo is close to the Kwame Nkrumah University of Science and Technology from where the researcher works and hence most convenient (in terms of cost, travel time and distance for field visits) location for this study.

3.1.1 Location and Demographics of Study Area

Ayigya Zongo is a suburb in the Oforikrom Sub-metro of Kumasi Metropolis of Ashanti Region. A map of the sub metropolitan areas in Kumasi showing Ayigya is presented in Figure 3-1. It is located in the eastern part of Kumasi along the 24th February Road (Kumasi–Accra road) and shares boundaries with Kwame Nkrumah University of Science and Technology (KNUST) to the south, Susanso to the west, Kentinkrono to the east and Asokore Mampong to the north. In 2000 the population stood at 30,283, increasing to 40,548 in 2010, representing an intercensal growth rate of about 3.0%. This is a higher percentage compared to the national and regional intercensal growth rate of 2.4% and 2.6% respectively (Ghana Statistical Service).

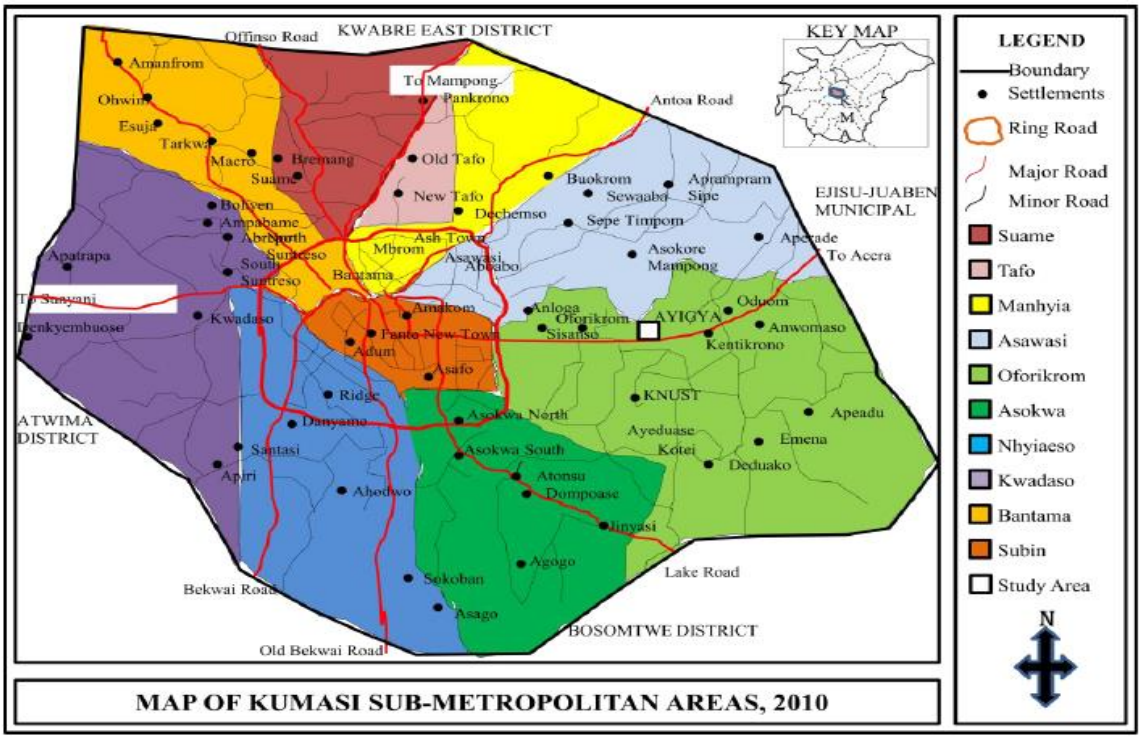


Figure 3-1: Map of showing Sub-Metropolitan Areas of Kumasi

(*Source: Kumasi Metropolitan Assembly, 2010*).

3.1.2 Existing Sanitation Situation

Most residents do not have household toilet facilities and as such patronize the public toilet facilities. This put excessive pressure on the existing public toilet facilities. According to KMA (2011), there are a total of 11 public toilets in Ayigya shown in Figure 3-2. Dinye and Acheampong (2013) reported 69.7% of residents who use communal toilet facilities indicated that they were in bad condition with cracked walls, holes blocked with faeces, and no proper cleaning of the place. This makes it uncomfortable to use these facilities but that was the only option for them. Waiting in queues to access communal toilets was a common feature. This was particularly evident during the early mornings between the hours of 5.30–7.30 GMT and in the evenings between 18.00 and 19.30 GMT. On average there is a user rate of 56 persons per day per

squat hole which is more than twice the design standard of 25 persons per day per squat hole.

Figure 3-2: Spatial map of Public Communal Toilet Facilities in Ayigya Zongo (*Source: KMA & WSUP*)

Regarding liquid waste disposal, Dinye and Acheampong (2013) reported that two-thirds (66.7%) of residents disposed of their liquid waste in drains outside the house while nearly one-third (29.3%) disposed of their liquid waste in drains inside the house. These drains are in poor condition and choked with solid waste. As a result, flow of waste water (mainly grey water) through the drains is stagnant, serving as breeding grounds for mosquitoes and other disease-causing organisms. Furthermore, there is foul smell that emanates from these drains.

3.2 SURVEY OF TOILET TECHNOLOGIES

The survey was carried out to identify the types and conditions of toilet technologies within the study area. Direct observations were conducted through visits to the communal toilets for detailed condition survey. The condition survey focused on frequency of cleaning, faecal storage systems, opening hours, fees charged and odour perception of the observer. This was complemented by photography of the communal toilet blocks.

3.3 SURVEY FOR PUBLIC PERCEPTION OF ODOUR

The survey was carried out in the month of October 2013. The survey was carried out to identify sources of odours, both specific to the toilet facility and those from other facilities within the study community. Communal latrine sites were identified and the inhabitants living or working within an approximate radius of 200m of these facilities were considered for the study. This radius was chosen because during a transect walk in the community, odour from the communal toilet was noticed as we approach about 100 – 120m of the facility.

3.3.1 Sampling for the survey on Public Perception of Odour

From the 2010 population and housing census data of Ghana, the population of residents within this purposive age range was estimated. The sample size was determined using the sampling model, $n = N/[1 + N(\alpha)^2]$, where n is the sample size, N is the sample frame, α is the margin of error and 1, a constant (Miller & Brewer, 2003). Using the regional intercensal growth rate of 3.0%, the population was projected using the compound growth rate formula $P_t = P_o\ (1 + r)^t$, where P_t is the projected population after time, t, P_o is the current population, r is the population growth rate, and t is the time in years between the last known population figure and the year for which the projection is being

estimated. Respondents were selected by purposive random sampling technique. Purposive being that the respondent should live within an approximate of 200m radius of a communal toilet block. The sample size estimation is presented in Table 3-1. The approximate radius of 200m within which the survey was conducted was further zoned into three as follows; Zone 1 - respondents within the first 50m radius of the toilet facility, Zone 2 – respondents within 50 – 100m radius of the toilet facility and Zone 3 – respondents within 100 – 200m of the toilet facility.

Table 3-1: Estimation of sample size for survey

Description	**Value**
2010 population of Ayigya	40,548
Regional intercensal growth rate (2000–2010)	3.0%
Projected population to 2013	44,308
National percentage of adult population (above 18 years)	55.2%
Estimated adult population of Ayigya	24,458
Sample size	804
Confidence level (margin of error)	96.5% (0.035)

Enumerators who could interpret the survey questions in the local language were recruited and trained. Structured questionnaires (Appendix 1) were prepared and pre-tested. Four (4) enumerators were used and in all 800 questionnaires were administered over a 5 day period. For each facility, enumerators were apportioned to carry out survey within the defined zones. To solicit responses from individuals, they are first asked if they are above or below 18. Only those above 18 were considered and a brief explanation of the survey was given. The enumerator then investigated the individual's awareness of odours in the community. The questions asked were created to investigate the

community's awareness of and annoyance about odours in their neighbourhood without taking up a great amount of time.

If residents were able to name or describe the odour source (e.g. drain, public toilet, refuse dump in the neighbourhood) and/or describe the odour quality correctly (such as offensive, chemical, fishy etc.), they were counted as being exposed and their odour annoyance was taken into account.

3.3.2 Data analysis

Data from the questionnaires were entered into the Statistical Package for the Social Sciences (SPSS) software program (Version 20.0) for further analysis.

Chi-square (χ^2) test of independence was used to measure if there was a relationship between categorical variables in the survey.

3.4 MODELING DISPERSION OF ODOUR FROM A COMMUNAL TOILET FACILITY

Dispersion modeling was carried out to test the applicability of the Gaussian steady state plume model in predicting ground level odour from a communal toilet facility and also carry out simulations to test the sensibility of some meteorological and design parameters considered in design and constructing communal toilet facilities and make recommendations based on the outcomes to improve design and operations.

Based on results from perception survey, one of the communal toilet facilities located in Ayigya Zongo was selected for the modeling studies. From the perception survey, there were responses of odour perception from other sources such as drains and refuse containers. As a quality assurance procedure, the communal toilet which has no drains and refuse dump close to it and was selected to ensure that odour strength measurement

was solely from the communal toilet facility. This communal toilet is a dry toilet with sixteen privy rooms (eight for males and eight for females) as shown in Plate 3-1. The vault which is partially offset from the privy room is fitted with sixteen 100 mm diameter PVC vent pipes of 3 m height equally spaced and centrally placed behind each privy room.

(a) Front View (b) Back View

Plate 3-1: Photo of selected communal toilet for modeling studies.

The modeling study involved two main activities which were:

- Objective sensory field measurement of odour and
- Model build-up and validation with data collected from the sensory field measurement.

3.4.1 Objective Sensory Field Measurement of Odour

This involved using nasal chemosensory performance in selecting panelist for field measurement of odour using the Nasal Ranger Equipment in the field.

The Dynamic Plume Method (see Appendix 2) of field odour measurement was used in this study. The plume determines the extent of the downwind odour plume, under defined meteorological conditions. The measurement team comprised of a field supervisor, two trained odour inspectors and GPS assistant. The two odour inspectors each contributed approximately equal shares of the measurement results while the GPS assistant picked coordinates of various locations where odour is measured. A measurement cycle consisted averagely of 50 single measurements, from which an average of 20 transition points (absence to presence) for were determined. The maximum plume (that is the point at which odour is no more present) each was determined from the observations obtained during two crossings, one of which including at least one odour presence point observation and another crossing where only absence point observation are recorded.

The measurements were carried out over a period of one month, thus from mid-May to mid-June 2015, but not every day of the month. Measurements were carried out for 3 days in the first and second weeks and 2 days in the third and fourth weeks. This was done to protect inspectors from odour fatigue. Measurements were also deliberately carried during different periods of the day. No readings were taken at night because the security of the field team and equipment could not be guaranteed.

Field odour monitoring data sheet is presented as Appendix 3.

3.4.1.1 Selection of Field Measurement Panelists - Nasal Chemosensory Performance

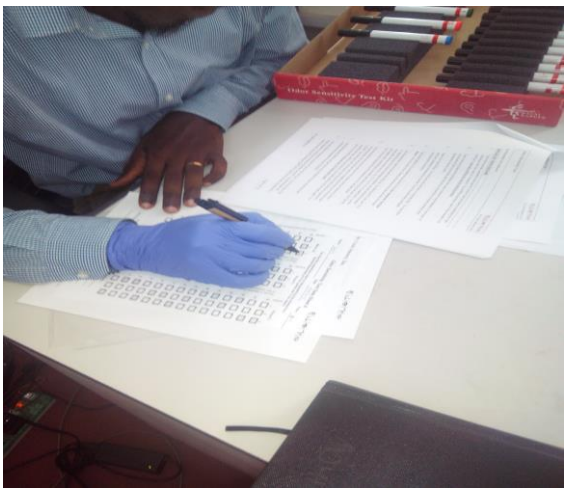
Odour screening was conducted using the Odour Pen Kit (from St. Croix Sensory, Inc), which is a commercially available method for measuring the olfactory sensitivity. The Odour Pen Kit is shown in Plate 3-2. The Odour Pen Kit contains one set of “Sniffing

Sticks", a blindfold for the test individual, and odourless non-latex gloves for the test administrator. The "Sniffing Sticks" pens are felt tip markers in which the pen is impregnated with an odour agent. The odour agent used for olfactory threshold screening is n-butanol. Fourteen pens contain the n-butanol solution at different concentrations and two pens are odourless. The "Sniffing Sticks" manufacturer performed the preparation of the test solutions of n-butanol.

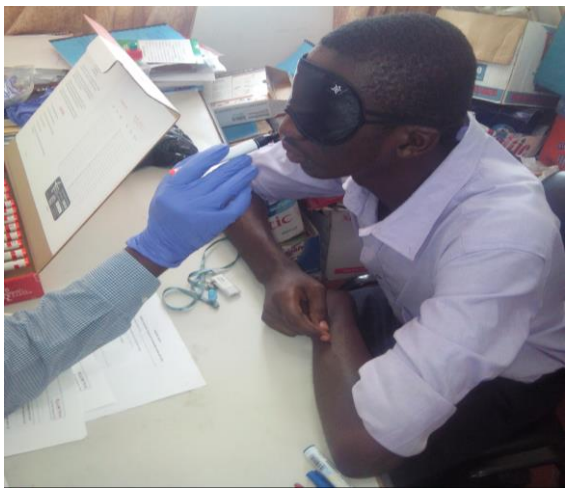
Plate 3-2: The Odour Pen Kit

All test individuals were tested following the same procedure. The procedure is called the "Standard Procedure for Testing Individual Odour Sensitivity". The objective is to identify the detection threshold of the test individual by correct detection of the odour pen in a triad. The presentation method of the odour pens is a triangular force choice method, also known as 3-Alternative Forced Choice (ASTM, 1997). A pen triad is made up of three pens, two are blank pens and a third is an odour pen. The test individual is required to distinguish between the three pens by declaring which pen contains an odour. If no odour is perceived, the test individual is to assign a response of guess to one of the

three odour pens. After a response is made, the test proceeds to the next pen triad. The next triad contains an odour pen with a greater n-butanol concentration than the previous series. The logic of the test is that the potential for the test individual to identify the odour pen increases as the test moves to the next concentration level. The increasing concentration levels will continue until the test individual correctly identifies the odour pen in a triad for two test levels. The level where a pen is first correctly identified as the odour pen is the score for the test individual and thus the odour threshold score of the individual. The odour sensitivity score for each of the participants was calculated by averaging the odour pen number (concentration level) associated with their first correct detection of the n-butanol pen in the triad. The odour pens were sorted and presented in ascending concentrations of n-butanol. The concentration values of the odour pens is undetermined, therefore, quantitative n-butanol values are not available. Plate 3-3 shows an individual being taken through the Nasal Chemosensory Performance Test



(a) Recording Odour sensitivity Score



(b) Blinfolded Inspector undertaking test

Plate 3-3: An individual being taken through the Nasal Chemosensory Performance Test

The Odour Inspector study group was made up graduating class of selected undergraduate students of Kwame Nkrumah University of Science and Technology. One test administrator was used throughout the study. The test administrator learned the test

method as described by the Standard Procedure. There was no consideration given to the age or sex of the Odour Inspector tested in the study. A total of ten odour inspectors were assessed for their odour detection threshold. Each inspector was tested five times on five different days (once a week) over a period of one month. A one sample t-test with a test value of 9.5 (mean odour threshold of field supervisor) was carried out to select inspectors for the study.

Procedure for testing sensitivity of odour inspectors is presented as Appendix 4.

3.4.1.2 Odour Strength Measurement

The Nasal Ranger® Field Olfactometer which is used for measuring and quantifying odour strength in the ambient air was used for this study. The portable odour detecting and measuring device, determines ambient odour "Dilution-to-Threshold" (D/T) values objectively and reported in odour units per cubic meter (ou/m^3).

Nasal Ranger olfactometers used in this study were provided by the manufacturer, St. Croix Sensory, Inc. Figure 3-3 shows the Nasal Ranger® Field Olfactometer. They were calibrated by the manufacturer at the beginning of the monitoring period. During the monitoring season, routine maintenance of the equipment was the responsibility of the field supervisor, who inspected the equipment regularly and changed the air filters and the O-rings according to the manufacturer's recommended schedule.

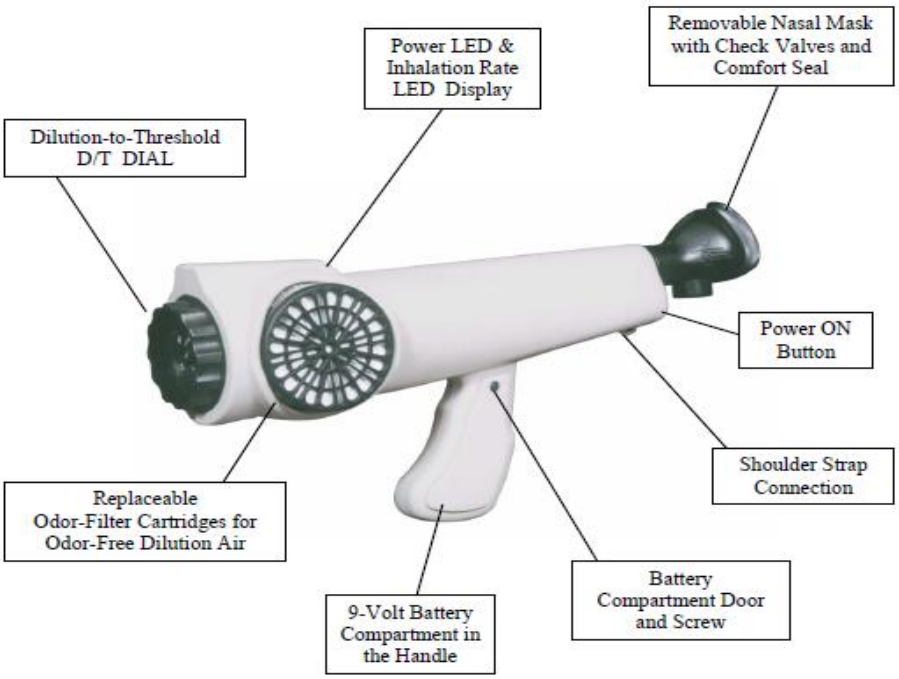


Figure 3-3: The Nasal Ranger® Field Olfactometer
(*Source: Nasal Ranger Operating manual, Version 6.2*)

The Nasal Ranger® Field Olfactometer, a nasal organoleptic instrument which directly measures and quantifies odour strength in the ambient air using the Operating Principle of mixing odourous ambient air with odour-free filtered air in discrete volume ratios was used. The discrete volume ratios are called "Dilution-to-Threshold" ratios (D/T ratios). The odour inspector's nose is placed firmly inside the nasal mask against the replaceable "comfort seal". The inspector inhales at a flow rate of 16-20lpm which is within the factory calibrated flow rate range through the nasal mask while standing at rest. The nasal mask has an outlet for exhaled air to exhaust downward. Therefore, the user inhales through the Nasal Ranger and exhales downward through the outlet check valve (St.

Croix Sensory Nasal Ranger Field Olfactometer-Operation Manual, 2008). Plate 3-4 show odour inspectors taking odour strength measurement with the Nasal Ranger.

Plate 3-4: Odour inspectors taking odour strength measurement with the Nasal Ranger

In order to protect panel members from odour fatigue, measurements were deliberately carried out during different periods of the day. No readings were taken in the dark hours of the day (that is from 6pm - 6am) because the security of the field team and equipments could not be guaranteed. A typical day (thus 6am - 6pm) was divided into 5 cycles as follows; Early morning (6am - 8am), Late morning (9am - 11am), Midday (11am - 1pm), Late afternoon (2pm - 4pm) and Sunset (4pm - 6pm).

3.4.1.3 GPS Data

The location of the facility and the odour observation points were coordinated using GPS referenced to the WGS84 datum. A dual frequency GPS device was used to pick the precise location of the toilet facility. Plate 3-5 shows the dual frequency GPS device being used to pick locations

Plate 3-5: The dual frequency GPS device being used to pick locations

A hand-held GPS device with a precision of ±1m was used to locate where the dial readings were taken with respect to a particular direction. The data was then transformed to fit into the local coordinate system (Ghana Grid) using Franson CoordTrans. A map of the parcel was produced from the data using AutoCAD Civil 3D 2014. The daily dial readings with their respective location were also plotted unto the map. Contours were generated using the dial readings used in place of the elevation of the point to show points of equal dial readings (smell) within a particular time within an interval of 50 dial readings. A plume was defined based on the direction of the wind at the time range of observation.

3.4.1.4 Weather Condition Data

Weather conditions were recorded using a Kestrel® 4500 Pocket Weather® Tracker. Data collected included the wind speed, wind direction, relative humidity, and temperature. These set of data were collected to help appreciate and explain the results of the ambient odour measurements. Plate 3-6 shows the Kestrel® 4500 Pocket Weather® Tracker

mounted in the field. Weather data were collected each day at each site. Data stored on the Kestrel® 4500 Pocket Weather® Tracker is downloaded via bluetooth into MS Excel. Analysis was carried out using SPSS Version 20.0. Regression analyses of odour strength measured (dependent variable) and meteorological data (independent variables) were done. These analyses included the effect of different meteorological variables on odour strength.

Plate 3-6: the Kestrel® 4500 Pocket Weather® Tracker mounted in the field

3.4.2 Development and Application of Odour Dispersion Model

For air dispersion analysis, the US EPA SCREEN3 model (USEPA, 1995a) was employed. This is a screening version of the ISC3 model. It was used to simulate the dispersion of odour into the atmosphere. SCREEN3 is a single source Gaussian plume model which provides maximum ground-level concentrations for point, area, flare, and volume sources, as well as concentrations in the cavity zone, and concentrations due to inversion break-up and shoreline fumigation. The dispersion model requires

parameterisation for the dimensions of the emission source and the emission velocity or rate. The Gaussian plume model is as follows:

$$C_{(x,y,z)} = \frac{E}{2\pi\sigma_y\sigma_z u}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}$$

where: C(x,y,z) is the concentration at point located at co-ordinate x,y,z, E is the emission rate, σ_y is the horizontal dispersion parameter, σ_z is the vertical dispersion parameter, u is the wind speed, H is the Emission height.

3.4.2.1 Model Input Parameters and Assumptions

Several simplifying and limiting assumptions were made in performing the modelling: (a) odourous gases displayed a Gaussian distribution in both lateral (crosswind) and vertical directions; (b) no gravitational deposition is assumed; (c) the source was assumed to be continuous; (d) the wind velocity and direction were the averages measured over the period of measurement and kept constant over the modelled time and distance; (e) the modelled surface was relatively flat. The results must therefore be viewed in the light of these substantial simplifications and methodological constraints.

Model inputs and various assumptions made in building the model based on observations made in the field are presented in Table 3-2.

Table 3-2: Model inputs and assumptions made

Input Parameter	Comment and Assumptions	Value	Unit
Source Type	Area source: It was assumed that emissions from the source are spread over an area	3	m^2
Dispersion Coefficient	Urban: The land use has more than 50% of the surrounding area with residential buildings and various commercial activities and also with a population density greater than 750 people/m^2	>750	people/m^2
Emission Rate	Emission Rate = C_{od} x V_{air}, Where C_{od} is measured odour concentration (ou/m^3) V_{air} is mean speed of air at exit of vent (m/s)	17600	$ou/m^2/s$
Source Release Height	The average height of the vent pipes	3	m
Receptor Height	This was set as the average height of the field odour inspectors	1.7	m
Wind direction relative to long dimension	Measured wind direction with the highest frequency	247.5	degrees
Terrain Option	**Simple Flat Terrain:** This was chosen because terrain heights do not exceed stack base elevation	-	-

3.4.2.2 Validation of the Odour Dispersion Model

In evaluation of the accuracy of odour dispersion model, the model predictions were compared with the field plume measurement data. As discussed previously, the field odour concentrations were measured with the Nasal Ranger® Field Olfactometer at various points within the identified plume. Since the model predicts an hourly ground concentration, the validation process was developed by averaging data in order to obtain hourly concentrations. Another simplification made was the assumption that source emission rate over each one hour period was the same.

3.4.2.3 Sensitivity Analysis

A sensitivity analysis was performed on the model to have an understanding of how the model parameters affect odour dispersion. Results that demonstrate the influence of release height and odour source strength are presented.

The sensitivity analysis was performed using release height values ranging from 2m to 4m and odour source strength values ranging from 100 to 1,000 OU/m^3.

3.5 CHARACTERISATION OF FAECAL MATTER SAMPLES AND ADDITIVES

3.5.1 Faecal Matter Samples

Faecal matter samples were taken from a communal toilet. The sample was taken by scrapping off the top to best represent "fresh" faecal matter. Plate 3-7 shows fresh faecal matter collected for characterization prior to experiments. The samples were collected into 10 litres plastic containers. The samples were transported to the laboratory and analyzed for physico-chemical parameters which include Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), pH, Total Kjeldahl Nitrogen (TKN), Ammonium (NH_4^+), Sulphate (SO_4^{2-}), Carbon, Total solids (TS) and Total Volatile Solids (TVS). Parameters were analyzed in triplicates.

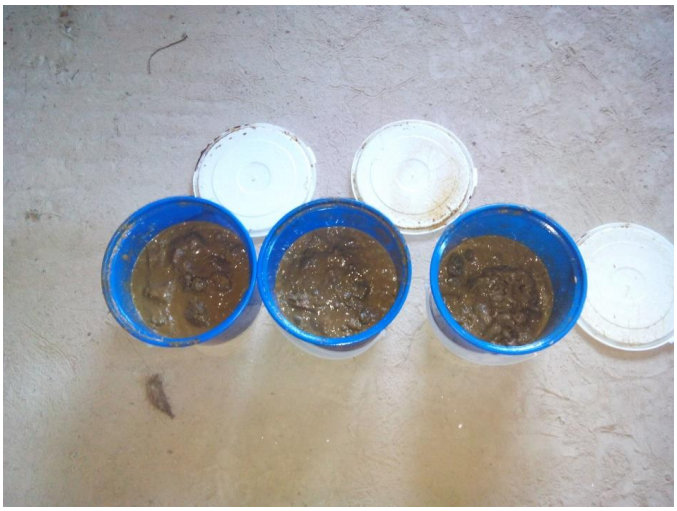


Plate 3-7: Fresh faecal matter collected for characterization prior to experiments

3.5.2 Preparation and Characterization of Additives

Nowadays, environmental concerns and an interest in reducing waste have led to using some recycled materials instead of conventional materials, resulting in favorable outcomes in terms of both economic and technical aspects. In this light, cocoa husk ash, and coconut fibre ash which are common organic waste readily available were used as additives to investigate their effect on reducing H_2S and NH_3 production due to storage of faecal matter in sets of laboratory tests.

3.5.2.1 Cocoa Husk Ash (CHA)

Dry cocoa husk was collected from a cocoa farm in Achiase in the Ejisu-Juaben district of the Ashanti Region and sent to the Ceramics department of Kwame Nkrumah University of Science and Technology (KNUST) for firing. The dry cocoa husk placed in a ceramic container and packed into the kiln for firing. Firing was done up to 700^0C at a rate of 140^0C per hour for 5 hours (temperature of kiln rises at 2.33^0C per minute). All carbonaceous components of the material start to leave in the form of smoke from 200^0C. At 700^0C, the kiln was switched off and allowed to cool to about 60 to 80^0C. The ashes

were then taken out and collected into a sealed plastic container and transported to the laboratory for pH, Electrical Conductivity (EC) and Alkalinity. Plate 3-8 shows cocoa husk ash

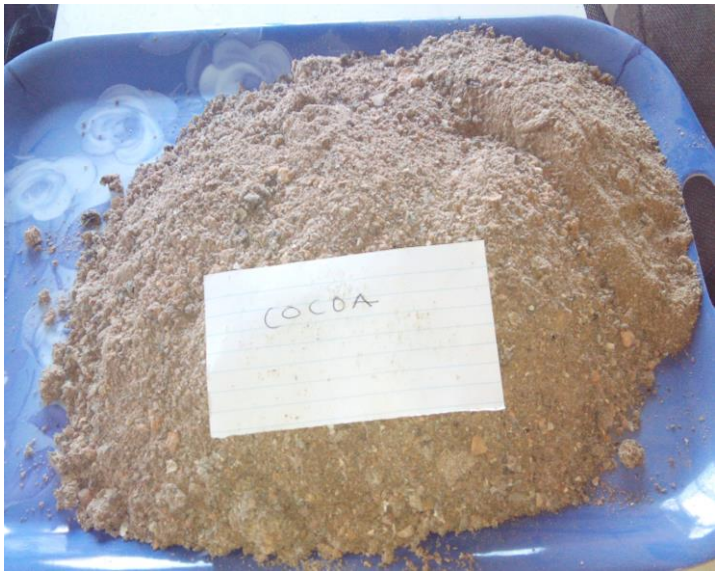


Plate 3-8: Cocoa husk ash

3.5.2.2 Coconut Fibre Ash (CFA)

Coconut fibre was collected from a number of coconut selling points within around KNUST and sent to the Ceramics Department of Kwame Nkrumah University of Science and Technology (KNUST) for firing. The dry coconut fibre husk placed in a ceramic container and packed into the kiln for firing. Firing was done up to 700^0C at a rate of 140^0C per hour for 5 hours (temperature of kiln rises at 2.33^0C per minute). All carbonaceous components of the material start to leave in the form of smoke from 200^0C. At 700^0C, the kiln was switched off and allowed to cool to about 60 to 80^0C. The ashes were then taken out and collected into a sealed plastic container and transported to the laboratory for pH, Electrical Conductivity (EC) and Alkalinity. Plate 3-9 shows the coconut fibre ash.

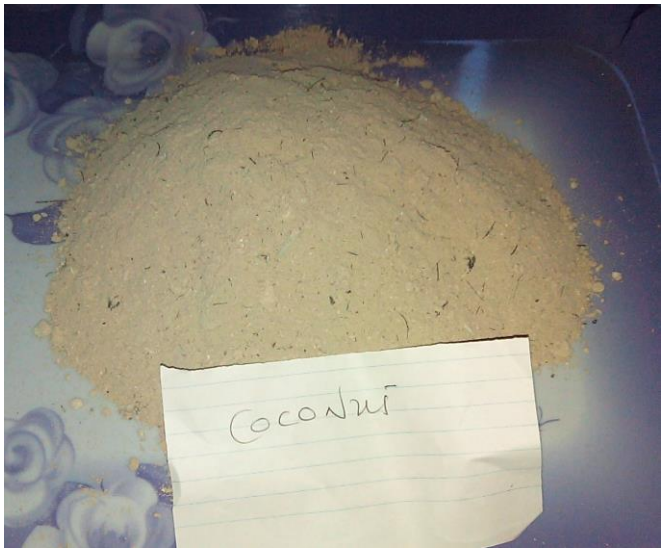


Plate 3-9: Coconut fibre ash

3.6 EXPERIMENTAL SET-UP AND PROCEDURES

About 10kg of fresh faecal matter was collected from a communal toilet into a bucket and transported to the laboratory. The sample was taken by scrapping off the top to best represent "fresh" faecal matter. The collection was done early in the morning at about 5:00am which is about the peak time for usage of the communal toilet facility to ensure the faecal matter is as fresh as possible. Ash-to-Fresh Faecal matter (Ash:FM) in weight (g/g) ratios of 1:20 (5%), 1:8 (12.5%) and 1:4 (25%) were respectively prepared in 1000ml plastic containers for both coconut fibre ash (CFA) and cocoa husk ash (CHA). There was one (1) container with only faecal matter which served as the control experiment. This set up of seven (7) containers was duplicated. 400g of faecal matter was used for each experimental set up. One (1) was used for sampling for H_2S and NH_3 analysis and the other second set of seven (7) was used for sampling for TKN, NH_4^+, SO_4^{2-} and pH analysis. Plate 3-10 shows experimental set up with different faecal matter to ash ratio.

Plate 3-10: Experimental set up with different faecal matter to ash ratio.

3.6.1 Hydrogen Sulfide (H_2S) Measurement

The experimental set up to determine release of H_2S included 1000ml cylindrical plastic containers, silicon tube, peristaltic pump and a conical flask. A hole was drilled in the cover of the plastic containers and the silicon tube connected to the peristaltic pump carefully inserted in a manner to siphon gas from the headspace of the plastic container (see Plate 3-11). The siphoned gas was bubbled through iodine solutions to trap H_2S. The peristaltic pump was set at a flow rate of 200 RPM.

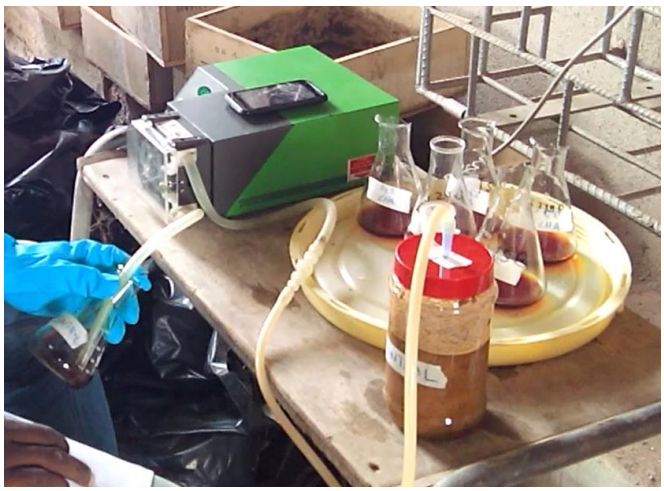


Plate 3-11: Set up of peristaltic pump for siphoning of gas from headspace of sample

The concentration of trapped H_2S was determined by titration (Awuah *et al.*, 2014) . Total sulfide was titrated using the iodometric method (back-titration using sodium thiosulphate as titrant into an acidified iodine solution.). The indicator was starch solution that will give a clear end point.

$$\text{mg } S^{2-}/m^3 \text{ of air} = \frac{(A-C)\times 0.4\text{mg}}{V \times 24}$$

Where: A = ml of iodine solution
C = ml of $Na_2S_2O_3$
V = volume of air pumped

3.6.1.1 Preparation of Iodine Solution (0.025N)

20g of potassium iodide was dissolved in 30ml of distilled water. 3.175g of iodine crystals was added and allowed to dissolve. To acidify the iodine solution, 50ml of 9M of concentrated H_2SO_4 was added and the resulting solution was then diluted to 1 litre with distilled water.

3.6.1.2 Preparation of Thiosulphate Solution (0.025N)

6.205g of sodium thiosulphate ($Na_2S_2O_3.5H_2O$) was dissolved in 30ml distilled water. 0.4g of solid NaOH was added and allowed to dissolve. The resulting solution was diluted to 1litre.

3.6.1.3 Iodine Solution Standardization

Using a volumetric pipette, 20ml of 0.025N iodine solution was measured into conical flask. The iodine solution was titrated to a light straw colour using 0.025N sodium thiosulphate ($Na_2S_2O_3$.). 1-2 ml of starch indicator was added titration continued to a clear end point.

The normality of iodine was calculated as follows:

$$NI_2 = \frac{Volume\ of\ Na_2S_2O_3\ used\ x\ 0.025}{Volume\ of\ Iodine\ used}$$

3.6.2 Ammonia (NH_3) Measurement

The experimental set up to determine release of NH_3 included 1000ml cylindrical plastic containers, silicon tube, peristaltic pump and a conical flask. A hole was drilled in the cover of the plastic containers and the silicon tube connected to the peristaltic pump carefully inserted in a manner to siphon gas from the headspace of the plastic container (see Plate 3-11). The siphoned gas was bubbled through boric which traps the gas and turns the pale lavender colour to green depending on the amount present. 0.02N H_2SO_4 was used for the titration until the original colour was obtained (Awuah *et al.*, 2014).

$$\text{mg } NH_3\text{-N/m}^3 \text{ of air} = \frac{(A-B)\times 280}{V \times 24}$$

Where: A = Volume of H_2SO_4 titrated for sample
B = Volume of H_2SO_4 titrated for blank
V = Volume of air pumped

3.6.3 Measurement pH, TKN, NH_4^+, SO_4^{2-}

For the measurement of pH, TKN, NH_4^+, SO_4^{2-}, samples were collected daily and oven dried prior to analysis. The oven dried samples were taken to the Soil Science laboratory, Department of Crop & Soil Sciences of the Kwame Nkrumah University Science & Technology for analysis. Plate 3-12 shows samples collected in small plastic containers after oven drying. Details of experimental procedures are presented as Appendices 6, 7 & 8.

(a) Faecal matter samples in oven (b) Dried faecal matter samples prior to analysis

Plate 3-12: Samples being dried in oven and collected in small plastic containers for analsyis at the soil science laboratory

3.6.4 Experimental Design and Data Analysis

The experimental design was a completely randomized design with three replicate measurements. Trends in measured concentrations of H_2S and NH_3 for the various mixing ratios for the two ashes used were compared and measurements for pH, TKN and SO_4^{2-} were measured to check substrate depletion.

One–way analysis of variance (ANOVA) was used to determine statistical differences between treatments for each of the response variables (H_2S and NH_3 concentrations).

4 RESULTS AND DISCUSSION

4.1 ASSESSMENT OF TOILET TECNOLOGIES AND PUBLIC PERCEPTION OF ODOUR

4.1.1 Assessment of Communal Toilet Facilities in the survey area

Eleven (11) communal toilet observations were conducted. These 11 communal toilets comprise 2 water closets connected to holding tanks, 2 pour flush systems connected to holding tanks (1 with holding tank offset and the other with holding tank directly beneath squatting pan), 1 enviroloo, 2 ventilated pit latrines and 4 simple pit latrines. Communal toilets varied with respect to the technology, cost per use, number of patrons, opening hours, and prevailing conditions such as odour. The cost of using a toilet facility was wither 30 or 40 pesewas per use depending on the type of anal cleansing material provided to the user, thus old newspapers went for 30 pesewas and toilet roll went for 40 pesewas. Such costs appeared consistent across all the communal toilets. Opening hours for the use of the toilets generally ranged from 4am to 10pm. The morning and evening periods were reported to be the peak periods for toilet usage. Toilet conditions differed between facilities. A toilet facility was considered clean if there were no visible faeces anywhere in its stalls. All the simple and ventilated pit facilities observed had some form of visible faeces in their stalls. All caretakers of the various toilets facilities reported cleaning their toilet facilities three times in a day. Desludging for the water closet toilets with holding tanks was once a week, however desludging frequency for all the other toilet technologies is once a month. Based on the perception of the data collection assistant, odour from the water closet toilet and holding tank, pour flush toilet with holding tank offset was described as mild. Odour perception for all other dry toilet technologies identified was strong to very strong.

From these observations it shows that the dry toilet facilities were perceived to have stronger odour compared to the wet toilet facilities. Also the toilet blocks with higher desludging frequency were perceived to be less odourous. The types of toilets observed and their respective operational practices are summarized in Appendix 12.

4.1.2 Respondent characteristics

Characteristics of respondents with respect to age group and sex are shown in Table 4-1. The survey focused on adults (respondents aged 18 years and above). There were 42.7% (342) of male respondents and 57.3% (458) of female respondents. Though respondents were picked randomly, the results showed a fairly even spread across the various age brackets. The results further showed that the 18–50 years age group forms the majority of respondents [90.7% (725)] of which the 31–40 years age group was the largest [42.2% (338)]. This confirmed that urban poor communities have a higher percentage of the population in the working age group, which is 18–59 (Ghana Statistical Service,2010).

Table 4-1: Sex and age group of respondents

Age (years)	**Male, % (n)**	**Female, % (n)**	**Total, % (n)**
18–30	12.2 (97)	17.5 (140)	29.7 (237)
31–40	18.8 (151)	23.4 (187)	42.2 (338)
41–50	8.0 (63)	10.8 (87)	18.8 (150)
51–60	3.8 (31)	5.5 (44)	9.3 (75)
Total	42.7 (342)	57.3 (458)	100.0 (800)
Mean = 34 years; standard deviation = ±0.963			

4.1.3 Notice of odour by gender

From the survey, about 89% (713) of respondent responded “YES” to notice of presence of odour within their vicinity as against 11% (87) responded “NO”. This clearly tells that a huge majority of residents living within the 200m radius of the communal toilet facilities were exposed to odour.

The response to notice of presence of odour by gender indicated that out of the 800 respondents who were exposed to odour, 37.6% (301) were males and 51.5% (412) were females (Table 4-2). Results of a chi-square, $\chi(1) = 1.067$, $p = 0.303$, showed that there was no statistically significant association between gender and notice of odour; meaning that is both male and female were equally exposed to odour. Studies carried out by various researchers on the effects of gender on odour sensitivity showed that although differences were found in some studies, they were not statistically significant (Bliss *et al.*, 1996; Cain *et al.*, 1995; Fortier *et al.*, 2007; M. Griep *et al.*, 1995; M. I. Griep *et al.*, 1997).

Table 4-2: Response to notice of presence of odour by gender

Gender	**Yes, % (n)**	**No % (n)**	**Total % (n)**
Male	37.6 (301)	5.1 (41)	42.7 (342)
Female	51.5 (412)	5.8 (46)	57.3 (458)
Total	89.1 (713)	10.9 (87)	100 (800)

There have been a number of authors who have found no difference in odour sensitivity between male and female. However, some authors have also reported women were more sensitive to odour than men. Koster and Koelega (1976) in their discussion on the differences in olfactory sensitivity between male and female suggested that authors who used specific odour compounds for their respective studies usually had results pointing to

the fact that there indeed is a difference between male and female sensitivity to odour. Similarly, Nováková *et al.*, (2014) also reported that differences in odour awareness between male and female appears to only apply to certain olfaction-related activities. However, in this study, specific odour compounds were not considered but rather odour as a mixture of various compounds. Results therefore fit with the body of knowledge that suggests that there is no difference in odour sensitivity between male and female.

4.1.4 Notice of odour by age

Responses to notice of odour by age group based on results of a chi-square, $\chi(4) = 2.263$, $p = 0.687$, showed that there was no statistically significant difference between the age groupings and notice of odour; and that all age groupings were equally exposed to odour (Table 4-3).

Table 4-3: Response to notice of odour by age groups

Age (years)	**Yes, % (n)**	**No, % (n)**	**Total, % (n)**
18-30	26.1 (209)	3.5 (28)	29.6 (237)
31-40	38.1 (305)	4.1 (33)	42.3 (338)
41-50	16.4 (131)	2.4 (19)	18.8 (150)
51 >	8.5 (68)	0.9 (7)	9.4 (75)
Total	89.2 (713)	10.9 (87)	100.0 (800)

Increasing age is correlated with higher odour detection thresholds (Greenberg, Curtis, & Vearrier, 2013), thus an individual's odour sensitivity decreases with increase in age. However, results from this study showed otherwise. This could be due to the subjectivity which is difficult to control and possibly large bias of respondents in respect to perception of responses of odour.

4.1.5 Sources of odour

Aside perceptions of odour from communal toilets, various odour sources were reported within the 200m radius of the communal toilet facilities. As expected, 62% (441) of respondents' perceived odours in their vicinity emanated from communal toilets blocks, 25% (176) from drains, 8% (61) from refuse dump containers and 5% (35) from other sources (Figure 4-1).

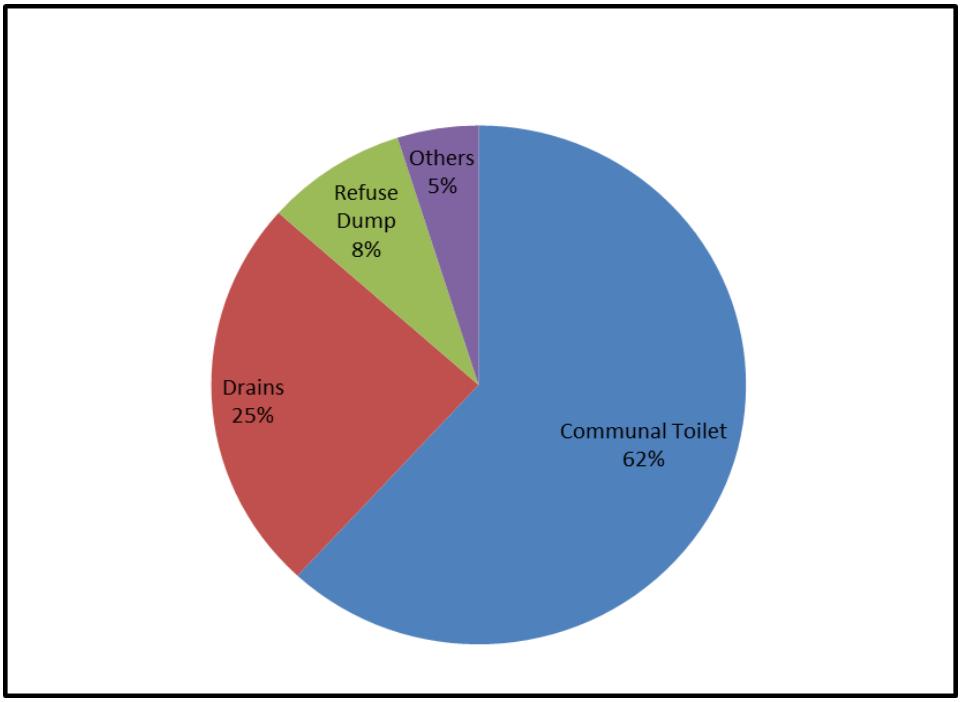


Figure 4-1: Reported sources of odour

A further analysis of the distribution of respondents who responded 'YES" to the notice of presence of odour with respect to distance from communal toilet facility showed that 57.1% (407), 17.7% (126) and 25.2% (180) were within 0 - 50m, 50 – 100m and more than 100m respectively away from the communal toilet facilities (Table 4-4). Of those who lived within the 0 – 50m radius, 96.5% (393) perceived that odour emanated from communal toilet facility while 30.1% (38) for those within the 50 – 100m radius and

5.5% (5.5) for those living beyond 100m radius. This result pointed to the fact that odour from communal toilet facilities was predominant irrespective of other possible odour sources within the first 0 – 50m of the facility. However as distance increases away from the facility, drains are the predominant source of odour (Table 4-4).

Table 4-4: Distribution of source of odour with distance from communal toilet facility

Approximate Distance from Communal Toilet (m)	Sources of Odour				Total, % (n)
	Communal Toilet, % (n)	Drains, % (n)	Refuse Container, % (n)	Others, % (n)	
0 – 50	96.5 (393)	3.0 (12)	0.5 (2)	0.0 (0)	100 (407)
50 – 100	30.1 (38)	59.5 (75)	10.4 (13)	0.0 (0)	100 (126)
>100	5.5 (10)	49.5 (89)	25.6 (46)	19.4 (35)	100 (180)

Odour from drains may be due to the direct disposal of human excreta, solid waste, grey water and urine into these drains. The biological decomposition of all these waste streams produces odourous gases. Covered drains could be considered over open drains to prevent the direct disposal of other waste streams such as human excreta and solid waste and also contain the odour produced from drains. Another common feature in Ayigya Zongo is refuse containers spilling over and left to sit at their location for a long time. There is decomposition of organic fractions of the waste which generate odour. Refuse containers need to be emptied regularly and also covers could be incorporated in the design of the containers to prevent on rain water ingress and also minimise odour dispersion. Other sources of odour reported include crude small-scale activities such as corn mills, manufacturing of insecticides, livestock rearing (sheep and poultry) and brewing of local drinks (popularly called *pito*).

4.1.6 Perceived frequency of odour exposure from reported sources of odour

The results of the study showed that 28.3% (202), 5.9% (42), 3.6% (26) and 2.2% (16) of the sample population were exposed to odour all the time from communal toilet blocks, drains, refuse containers and other sources respectively. Thus 40.1% (286) of the sample population were exposed to odour all the time. Of the sample population 25% (178), 31.4% (224) and 3.5% (25) were exposed to odour from the identified sources often time, sometime and seldom respectively (Figure 4-2).

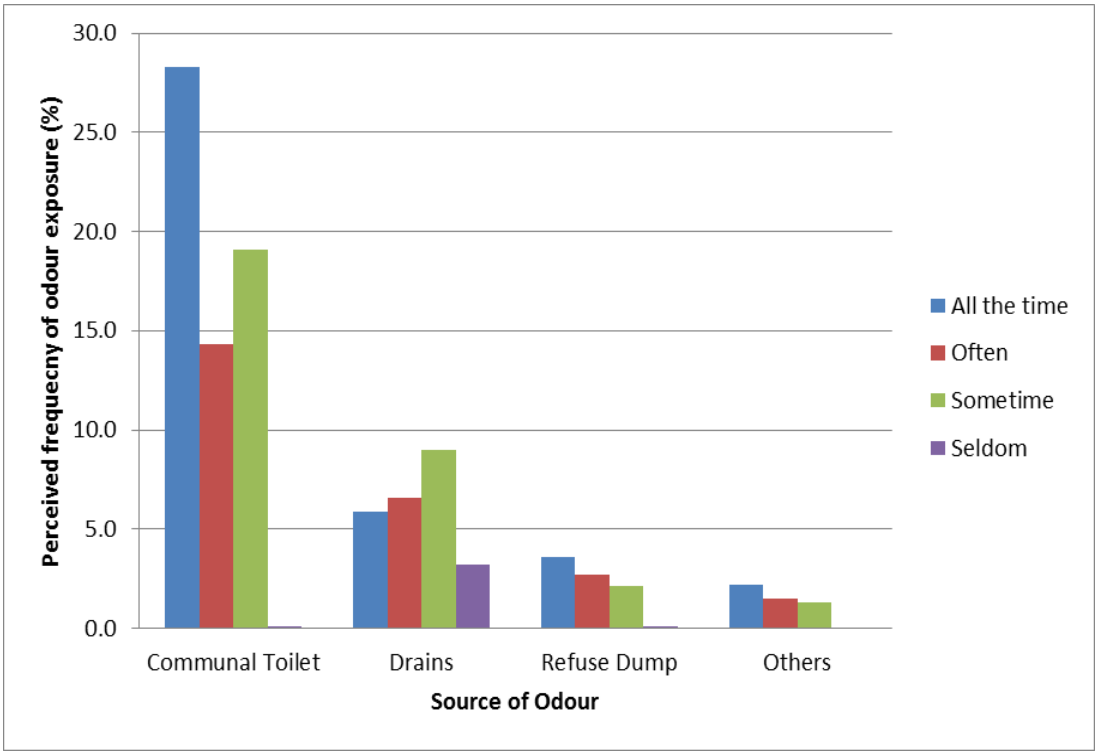


Figure 4-2: Perceived frequency of odour exposure from reported sources

Odour from communal toilet contributed the most to odour exposure, with 61.8% (441) of the sample population being exposed to odour from communal toilet blocks. Results of a chi-square, $\chi(81) = 106.7$, $p = 0.029$, tells that there is statistically significant association between the source of odour and frequency of exposure; that the population do not have an equal exposure to odour from the various sources.

4.1.7 Perceived level of annoyance from reported sources of odour

The results of the study on sources of odour as related to odour annoyance showed that of the 61.9% (441) of respondents who perceive odour from communal toilets blocks, 19.5% (139) found it extremely annoying, 20.8% (148) very annoying, 13.2% (94) annoying and 8.3% (59) some annoyance (Figure 4-3). The bars for the other sources can be explained in a similar manner.

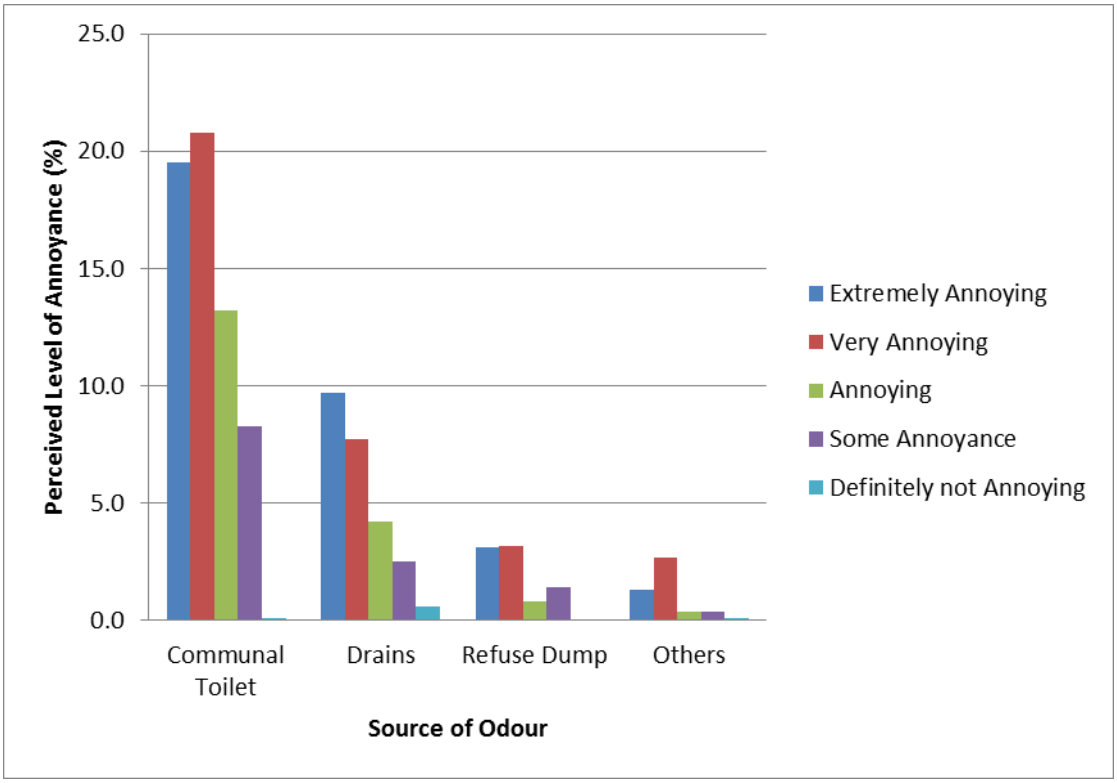


Figure 4-3: Perceived level of annoyance from reported odour sources

A chi-square test to test the null hypothesis: "There is no significant difference in responses to odour annoyance level from the respective sources gave probability values of less than 0.05 ($p<0.05$) for all the cases. This shows that there is significant association between perceived level of odour annoyance and source of odour and that odour annoyance levels is different among respondents based on the source of odour.

4.1.8 Frequency of Exposure and Annoyance

From the results of the study, 39.7% (279) perceive some level of annoyance all the time, 22.1% (155) often time, 37.0% (260) some of the time and 1.1% (8) seldom time (Figure 4-4).

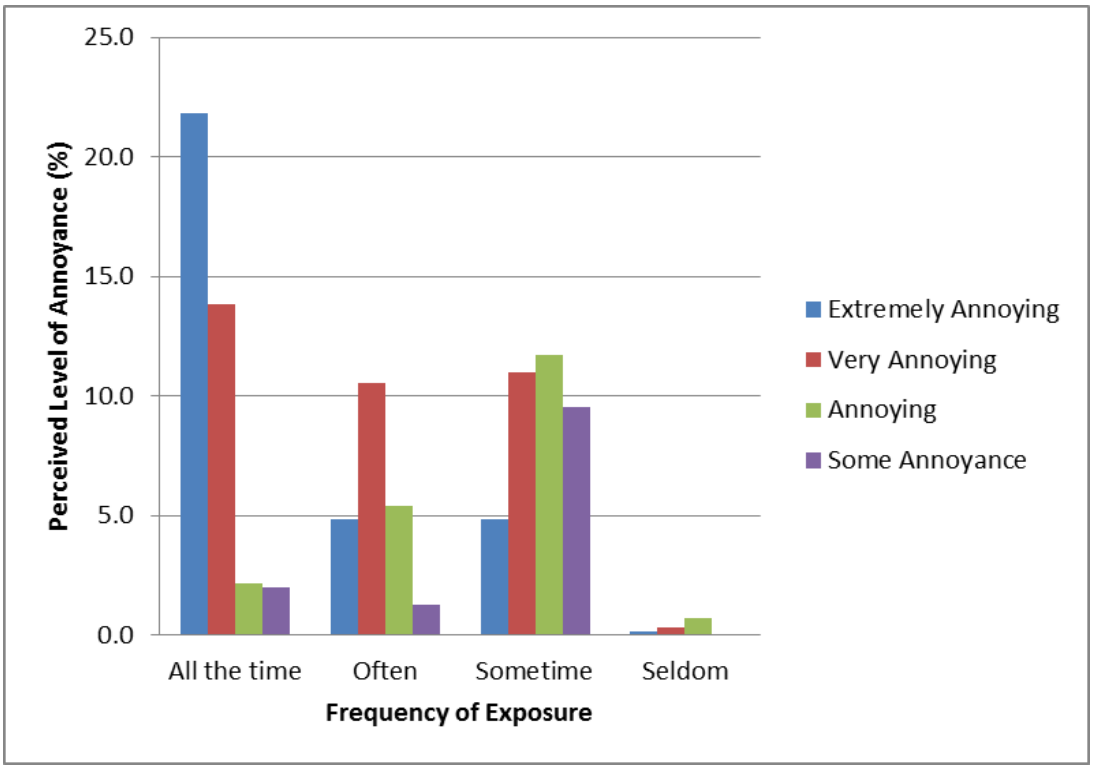


Figure 4-4: Frequency of odour exposure against degree of annoyance

Results of a chi-square, $\chi(12) = 238.1$, $p < 0.01$, showed that there was statistically significant association between the frequency of exposure and annoyance. Odour annoyance was dependent on frequency of exposure. A Spearman's rank-order correlation was run to determine the relationship between frequency of exposure and annoyance. There was a weak, negative correlation between frequency of exposure and annoyance, which was statistically significant ($r_s = -0.495$, $p < .01$). This meant that the

longer inhabitants got exposed to odour, the less annoying it would become; the so called "odour fatigue" phenomena.

Sucker *et al.* (2008), in their study to establish a relationship between exposure to odour and annoyance in the vicinity of six odour emitting plants reported that exposure-annoyance associations are strongly influenced by whether an odour is pleasant or unpleasant and that whereas pleasant odours induced little to no annoyance, unpleasant ones did induce annoyance. Greenberg *et al.* (2013) also reported olfactory fatigue occurs as a result of repeated inhalation of any chemical over relatively short time frames and that leads to a decreased ability to accurately detect and identify an odour. Also, exposure to relatively high concentrations of a chemical has been shown to affect sensitivity to that particular odourant, altering subsequent detection thresholds by up to three orders of magnitude (Greenberg *et al.*, 2013).

Based on the results and discussions of the odour perception survey, which also presents various inconsistencies as have been reported in literature, it is fair to conclude odour exposure intensity based on odour perception survey report can be unreliable due to large degree of subjectivity and biases.

4.2 FIELD OLFACTOMETRY STUDIES

This section presents results of processes followed in collecting data for model validation (which include nasal chemosensory performance of inspectors, meteorological data, odour concentration measurements presented in contours) and establishing relationship between odour intensity and concentration based on the Weber-Fechner law.

4.2.1 Nasal Chemosensory Performance

The olfactory detection threshold of the Odour Inspectors varied. The mean scores of the individuals ranged from 8.3 to 9.4, with a mean of 8.62 (n=10, s^2=1.27). No mean scores were distributed between 2 to 5 and 12 to 15. The mean odour detection threshold of inspectors is shown in Figure 4-5. The mode of the Odour Inspector group was odour pen 9. The frequency of detection scores followed a normal distribution and was dispersed roughly in the middle of the odour pen range and spread across six pens (pen level=6-11). The mean odour detection threshold for frequency of scores was dispersed towards the left of the threshold range.

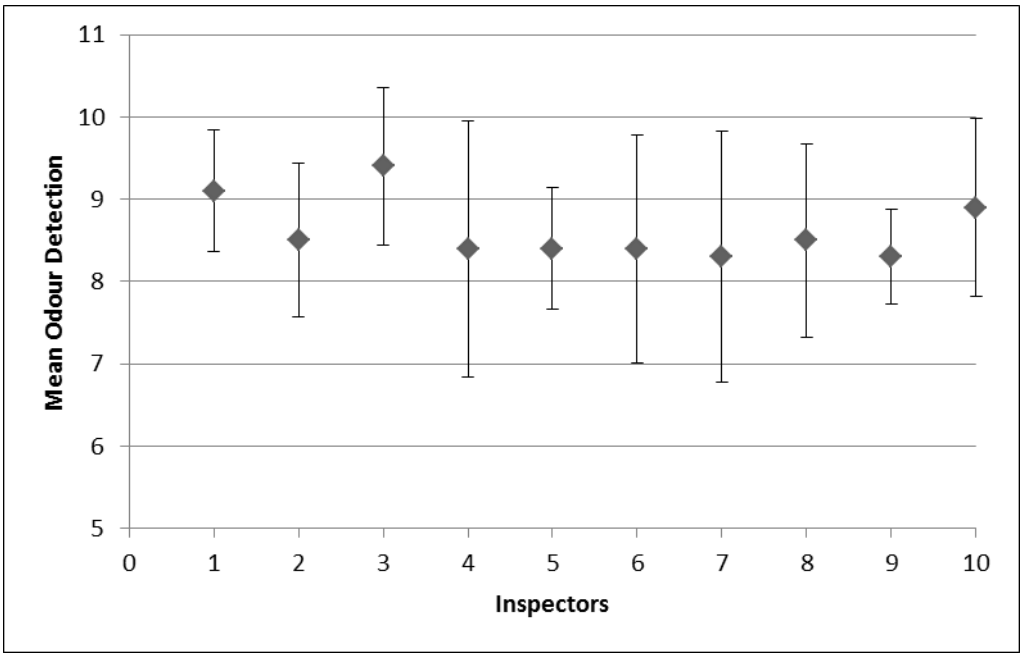


Figure 4-5: Mean odour detection threshold of inspectors

Results of the t-test with a test value of 9.5 (the mean odour detection threshold of the field supervisor) showed that there was no statistically significant difference between the odour threshold of 3 (thus inspectors 1, 3 and 10) out of the 10 inspectors and the field

supervisor. However inspectors 1 and 3 were selected since they had a smaller standard deviation as compared to inspector 10 (Table 4-5).

Table 4-5: Results of One sample t-test for the selection of odour inspectors

Inspector	**T**	**Df**	**Sig. (2-tailed)**	**Comment**
1	-1.714	9	0.121	*Accept*
2	-3.254	9	0.010	Reject
3	-.327	9	0.751	*Accept*
4	-2.310	9	0.046	Reject
5	-4.125	9	0.003	Reject
6	-2.577	9	0.030	Reject
7	-2.539	9	0.032	Reject
8	-2.683	9	0.025	Reject
9	-5.622	9	0.000	Reject
10	-1.724	9	0.119	*Accept*
NB: Test value= 9.5				

Results brought to the fore how subjectivity can be reduced in using the human nose for objective odour studies (calibration of the human nose). Simply measuring one or more individual constituents that may be contributing to the perception of an odour can lead to an incomplete picture of the odour impact to a human observer, as odour plumes from toilet facilities may contain numerous of odourous compounds (Lin *et al.*, 2013). Unlike analytical instrumentation, which is capable of separately analyzing emission constituents, the human nose integrates the odours of the various constituents, combining the myriad compounds from an odour source into a unitary odour percept, which can then be quantified as to intensity and identified based on perceptual quality. The use of

resident observers to monitor odour events (Afful *et al.*, 2015), although practical and inexpensive, has additional drawbacks which include lack of quality control for the data (i.e., no sensitivity calibration, no objective odour detection measurement).

4.2.2 Meteorological Data

There were 670 observations each of wind direction, wind speed, temperature and relative humidity over the 10 days period. The frequency of wind directions ranged between SSE and WNW blowing towards the NNW and WNW range (157.5 degrees) with highest frequencies between SW and WSW blowing towards NE and ENE range (45.0 degrees). Frequency distribution of wind direction is presented as Appendix 6.

Other weather variables that were measured included wind speed, temperature and relative humidity. The description of these variables is presented in Appendix 7. A scatter plot of the odour strength against these weather variables (wind speed, temperature and relative humidity) showed no correlation. However the wind speed measured at the source correlated well with how far the plume travelled along the centre line of the direction of wind. This showed that predicting the effect of temperature and relative humidity at source of odour on downwind odour strength can be misleading. However, there was a strong inverse correlation between relative humidity and temperature (R = -0.981) whereas there was no correlation between wind speed and the other two variables (relative humidity and temperature). Many factors have been reported to affect the degree to which odours from a source will impact a community, such as distance from receiver , and meteorological conditions, including ambient temperature, wind speed and wind direction (Dalton *et al.*, 2011).

4.2.3 Measurement of Odour Concentration with Nasal Ranger

There were 175 odour strength measurements made over the 10 days period. These measurements were taken at various distances within the identified plume. 160 of the 175 odour strength measurements were greater than 7 OU/m^3. Though there are no standards for ambient odour in Ghana, ambient odour ranging from 15 OU/m^3 and more was considered by the trained inspectors as offensive. A regression analysis carried out showed a strong inverse correlation between odour strength and distance from source and 66.6% of the total variation in odour strength can be explained by distance from the source ($R = -0.816$, $R^2 = 0.666$). With the possibility of establishing a regression model between odour strength and distance, the minimum distance of toilet facility from inhabitants can be determined before siting the facility.

The average wind speed during mornings was 0.76m/s. From the plot of odour contours, the plume travel a distance of about 73m long and a maximum width of about 24m with dense contours (Figure 4-6). The plume covered an area of approximately 452 m^2 and an angle of 37 degree (thus between 21 NE and 56NE).

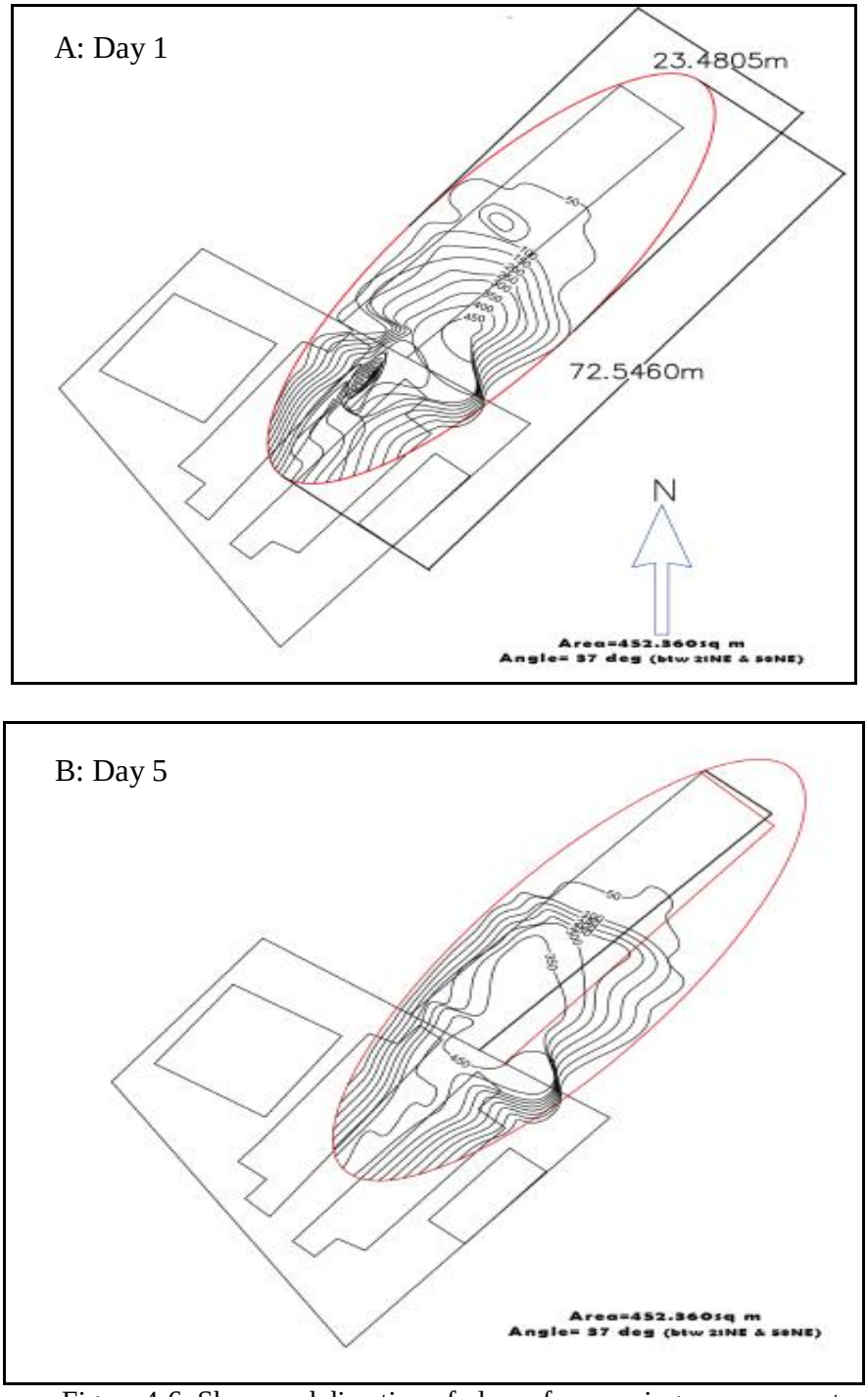
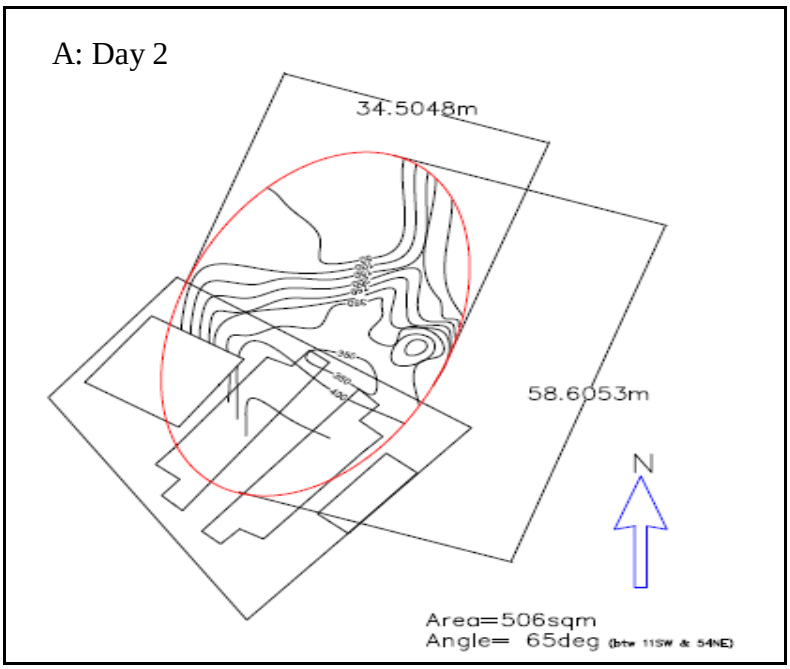


Figure 4-6: Shape and direction of plume for morning measurements

The average wind speed during afternoons was 1.2m/s. From the plot of odour contours, the plume travel a distance of about 59m long and a maximum width of about 34m with contours less dense compared to the morning contour plots (Figure 4-7). The plume

covered an area of approximately 506 m^2 and an angle of 67 degree (thus between 21SW and 54NE).



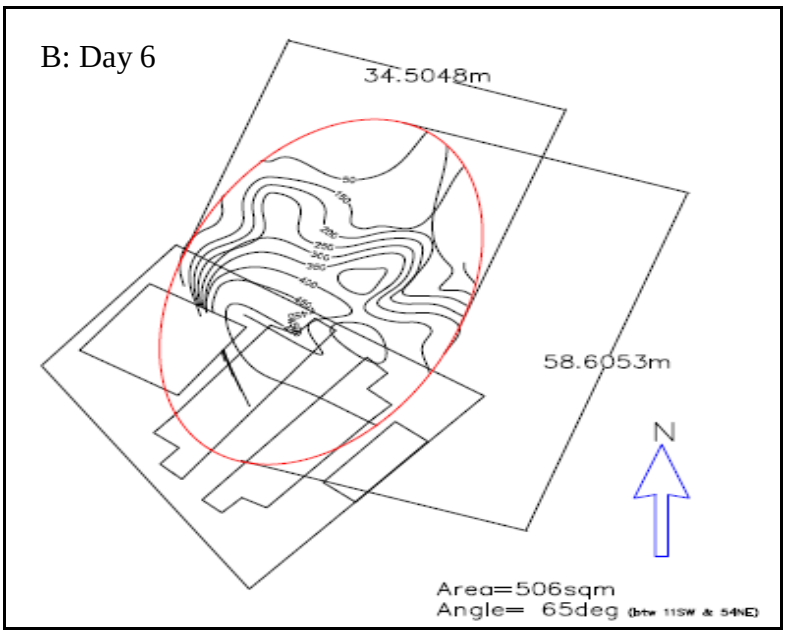


Figure 4-7: Shape and direction of plume for afternoon measurements

The average wind speed during evenings was 0.8m/s. From the plot of odour contours, the plume travel a distance of about 87m long and a maximum width of about 23m with

contours even spread along the distance (Figure 4-8). The plume covered an area of approximately 428 m^2 and an angle of 32 degree (thus between 29NE and 51NE).

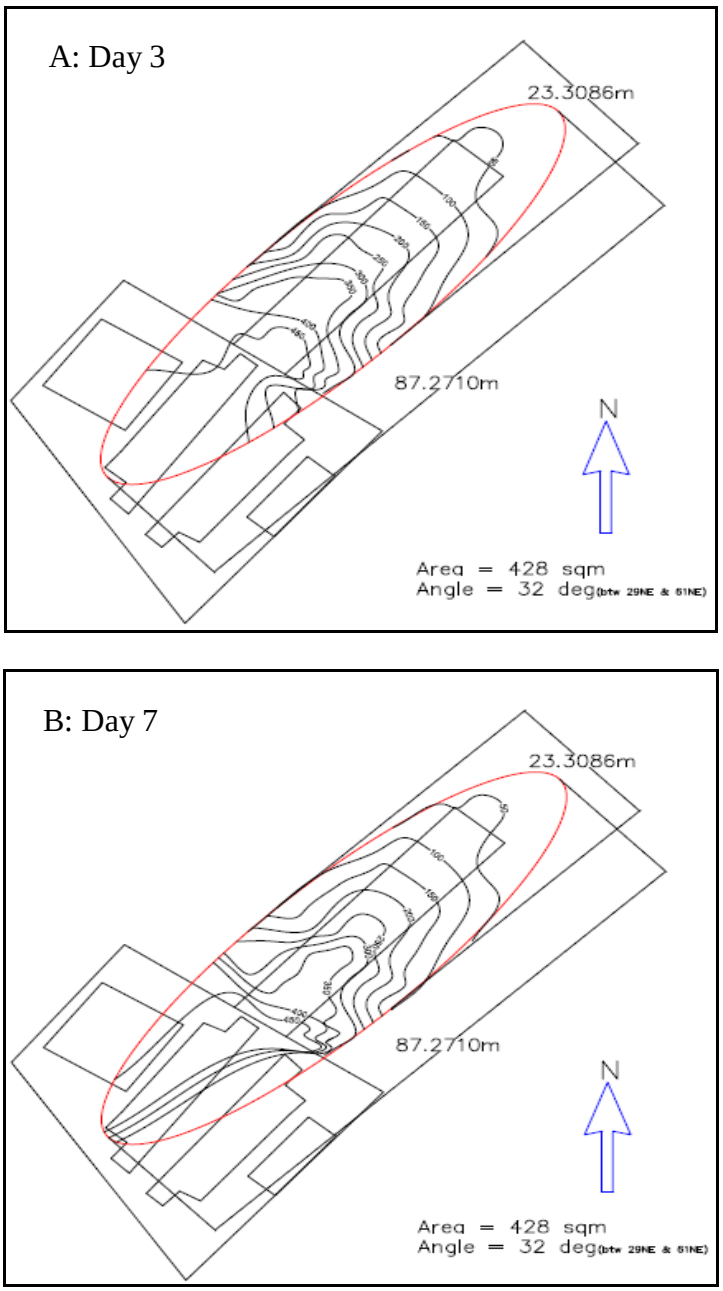


Figure 4-8: Shape and direction of plume for evening measurements

Comparing the results of the odour contours, it showed that odour was intense mostly in the mornings. However in the afternoons, the odour was dispersed widely due to the high wind speeds. This might also be due to the usually higher temperatures in the afternoon

which made air molecules lighter hence increasing dispersion and rapid air mixing. In the evening also when the average wind speed was mid-range compared, odour particles travelled farther in a more laminar and evenly dispersed way. It is also important to note that the distance away from the facility is not equal in all directions around the facility and that it is highly dependent on the wind direction for the specific site. Further to this it is worth noting that site specific meteorological data is critical in determining the extent of odour rather than relying on district or regional data.

4.2.4 Relationship between odour Intensity and Concentration based on the Weber-Fechner law

The Weber-Fechner Law. The Weber-Fechner law which is expressed as $I = a\log C + b$, where I is the Intensity, C is concentration and a,b the constants. The study showed that, there was positive correlation between ($R^2 = 0.89$) odour intensity and concentration for the measured data (Figure 4-9). With this graph, an operator or regulator can have a fair idea of the odour concentration when complaints are made based on the intensity reported for a given facility.

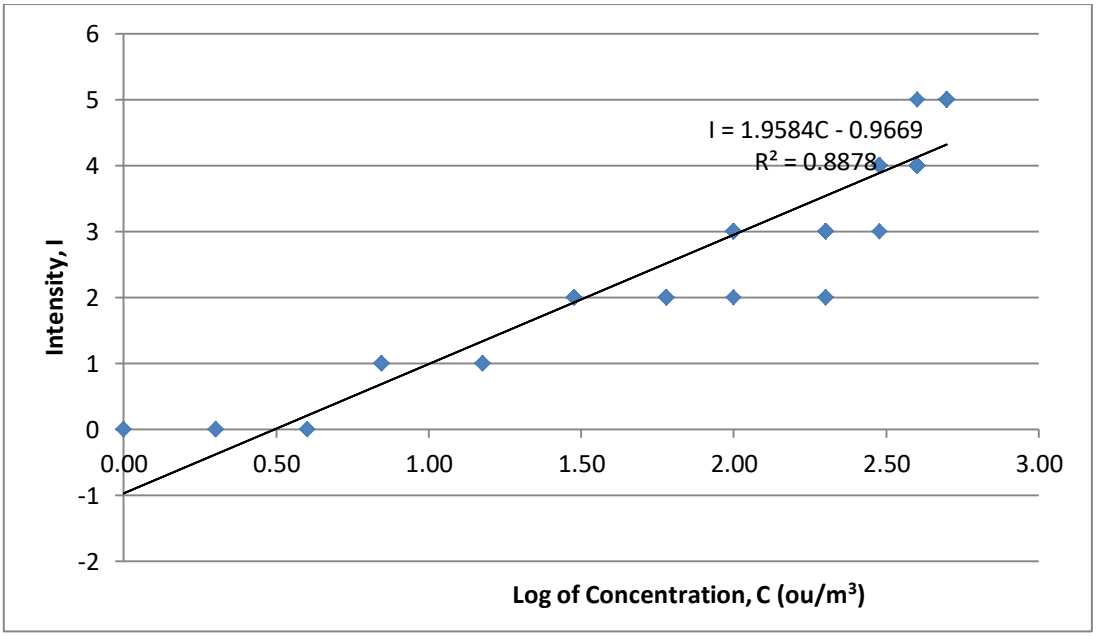


Figure 4-9: Relationship between Odour Intensity and Concentration based of the Weber-Fechner Law

4.3 SIMULATION OF ODOUR DISPERSION

This section presents results of model simulation using the SCREEN 3 which is based on the Steady State Gaussian Plume Model and the use of data from the field olfactometry study to validate the model.

4.3.1 Model Simulation and Comparison with Measured Data

As discussed earlier, the input to the dispersion model which is a mathematical simulation of the physics of the atmosphere consist of emission information, meteorological data and receptor information. The outputs from the model were the maximum concentration at specified distances (Figure 4-10). The results of the field odour measurement were compared with the results of the odour dispersion simulation by dispersion modeling (Figure 4-10). A paired t-test, $t(5) = -1.29$, $p = 0.902$ ($p>0.05$), showed that there was no statistically significant difference between simulated model

output and measured data. The results of the odour dispersion simulation can therefore be used to suggest improvements in the design (such as height of vent pipe) of the toilet facility in relation to odour impacts.

It must be noted however that the model output gives the odour concentration along the centre line of the wind direction (worst case scenario) and that it does not reflect the condition around the facility. The assumption of Gaussian flow is not always true in the environment (Chastain & Wolak, 2000). Galvin *et al.*, (2011) reported that field odour survey results compared satisfactorily to dispersion modeling. They went further to suggest that with appropriate design and practical steps to maximise data integrity field surveys have the potential to provide useful quantitative data for model verification.

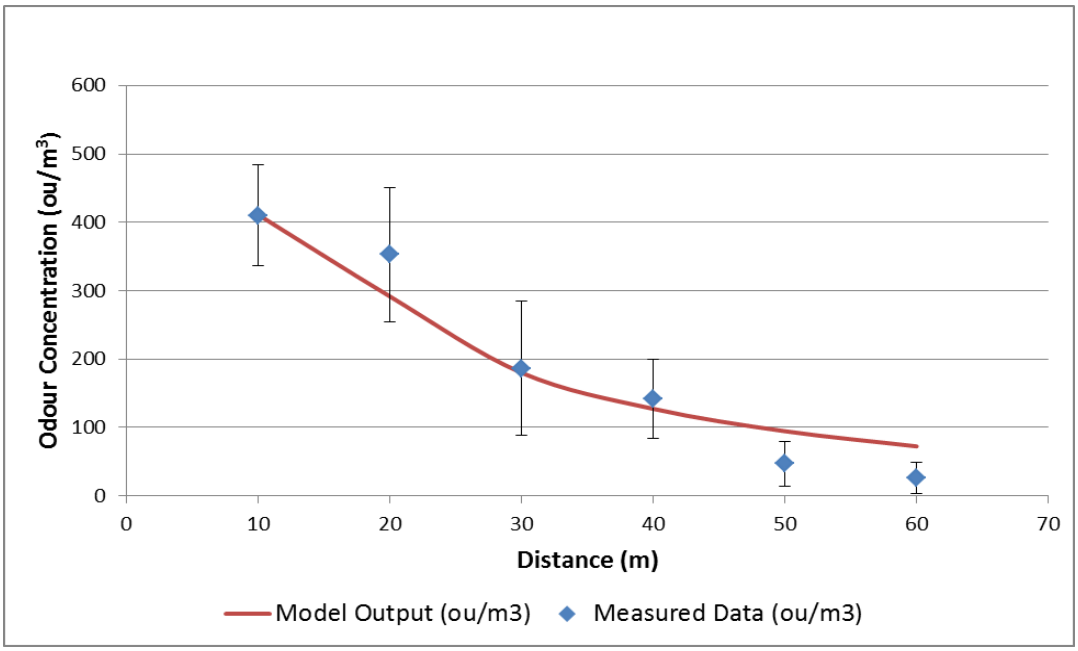


Figure 4-10: Comparison between simulated model output and measured data.

4.3.2 Sensitivity Analysis

Results of sensitivity analysis carried out with respect to release height (thus height of the vent pipe) and odour source strength are presented. These two (2) parameters were considered because in the view of the author, these are parameters which we can have

some control over as designers and operators of communal toilet facilities. Even though sensitivity analysis of an odour dispersion model is enough to show the influence of input parameters on the length of the odour plume, the input parameters are not well defined. Input variables such as the dispersion coefficients, roughness heights, and in particular the source strength of the odour are at best order-of-magnitude estimates (Chastain & Wolak, 2000).

4.3.2.1 Release Height

Generally there was a decrease in ground level odour concentration with increasing release height (Figure 4-11). There was statistically significant differences between group means as determined by one-way ANOVA ($F(7,32) = 5.314$, $p < 0.001$).

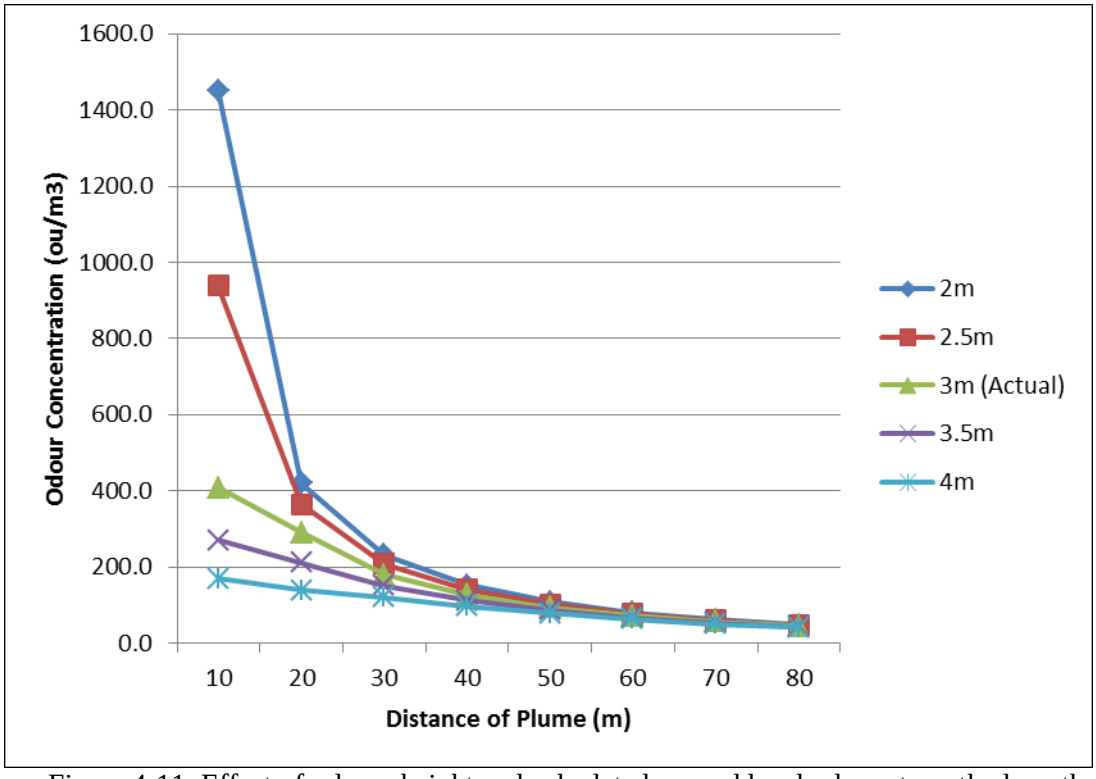


Figure 4-11: Effect of release height and calculated ground level odour strength along the plume distance

Although results of ANOVA test showed statistically significant difference between calculated ground odour concentration and with change in release height, post hoc analysis showed that this difference is actually seen within the 40m of the source of odour. The difference in calculated ground odour concentration beyond the 40m point was found not to be significant.

4.3.2.2 Odour Source Strength

The variation of odour source strength and calculated ground level odour strength along the plume distance is shown in Figure 4-12. Generally there was a decrease in ground level odour concentration with decreasing odour source strength. There was statistically significant differences between group means as determined by one-way ANOVA ($F(7,32) = 13.254$, $p < 0.001$).

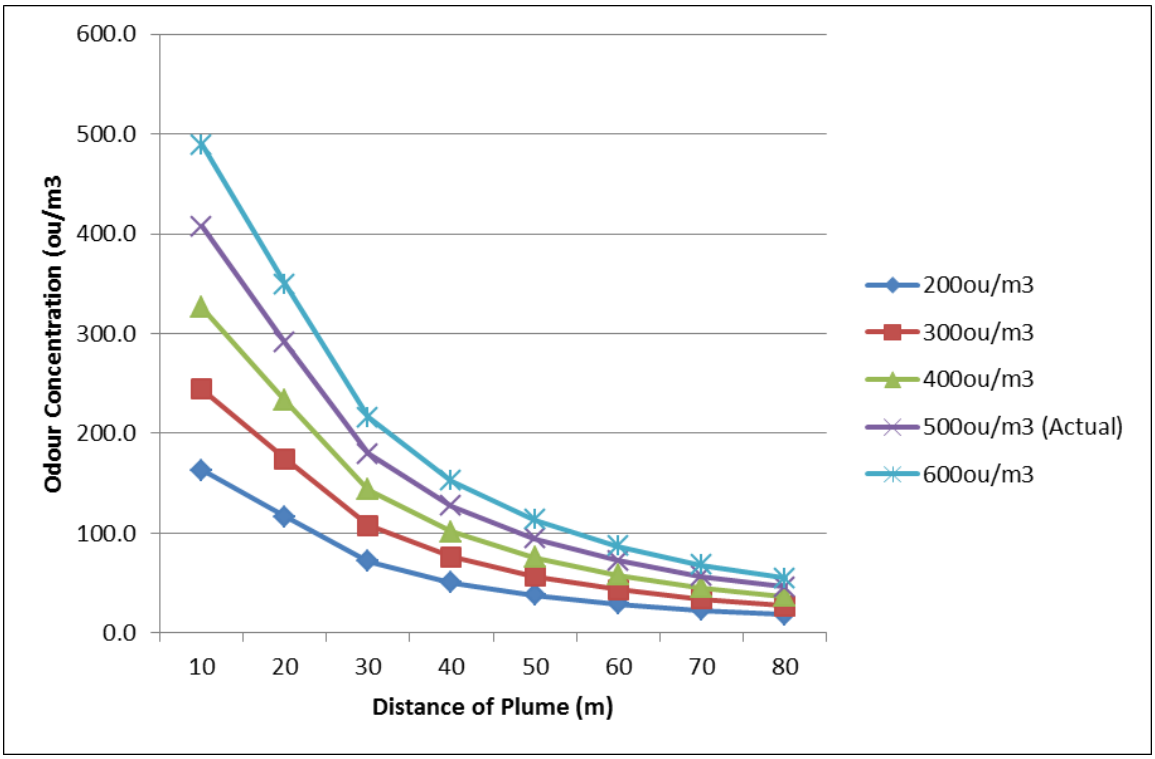


Figure 4-12: Variation of odour source strength and calculated ground level odour strength along the plume distance

Also for changes in odour source strength, although results of ANOVA test showed statistically significant difference between calculated ground odour concentration and with change in release height, post hoc analysis showed that this difference is actually seen within the 60m of the source of odour. The difference in calculated ground odour concentration beyond the 60m point was not found to be significant.

4.4 EFFECTS OF ADDITION OF ASHES OF COCOA HUSK AND COCONUT FIBRE ON REDUCING RLEASE OF H_2S AND NH_3

This section presents results of laboratory experiments on the production of H_2S and NH_3 due to the storage of "fresh" faecal matter. Aside the measurement of these gases, there were also measurement of other parameters such as pH, SO_4^{2-}, TKN, NO_3^- to aid in the explanation of the trends observed. Results were also presented for the characteristics of faecal matter and ashes used for the experiments.

4.4.1 Characteristics of "Fresh" Faecal Matter

Analyses were carried out in triplicates. Solids fractions of the samples were reported on mass percent (%) due to the thick slurry nature of the sample (Table 4-6).

Table 4-6: Characteristics of fresh faecal matter used for experiment

Parameter	Unit of Measurement	Mean	Standard deviation
COD	mg/l	19,874	±1108
BOD	mg/l	4,830	±403
TKN	mg/kg	66.71	±10.91
Ammonium (NH_4^+ - N)	mg/kg	55.83	±6.04
Sulphate (SO_4^{2-})	mg/l	169	±8.2
pH		6.41	±0.09
Moisture Content (MC)	%	43.6	±2.8
Organic Matter (OM)	%	88.3	±5.4
Carbon	%	52.5	±2.7
Total Solids	%	79.4	±5.2
Total Volatile Solids	%	4.88	±0.56
Ash	%	11.36	±1.05

4.4.1.1 Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

The mean BOD measured for the fresh faecal matter sample was 4,830mg/l whereas the COD measured was 19,874mg/l. This results in a COD / BOD ratio of 4:1. The BOD and COD measured is lower than that reported by Koné and Strauss (2004), who reported 7,600mg/l and 49,000mg/l for BOD and COD respectively for public toilet matter in Accra (COD /.BOD ratio of 6:1). The variability could also be due to the type of onsite technology used, the way in which the system is used, the storage duration, inflow and infiltration, and the local climate. For instance Koné and Strauss (2004), sampled from

emptying trucks which collected faecal matter which is about 3 – 4 weeks old, whereas in this study, faecal matter was sampled fresh from the surface of the vault in the early hours of the day (similar to fresh stool).

4.4.1.2 pH

The pH is a very important parameter in determining the formation of H_2S and NH_3 within the faecal matter sample. The mean pH measured was 6.41 (±0.09) showing that the fresh faecal matter was slightly acidic. On average humans eliminate 128 g of fresh faeces per person per day with a pH value of around 6.6 (Rose, Parker, Jefferson, & Cartmell, 2015).

4.4.1.3 Total Kjeldahl Nitrogen (TKN) and Ammonium (NH_4^+ - N)

Total Kjeldahl Nitrogen (TKN) is the sum of organic nitrogen, ammonia (NH_3), and ammonium (NH_4^+) in the faecal matter. Urine and breakdown of protein are the main source of nitrogen compounds in faecal matter. The mean ammonium concentration in the faecal matter was 55.83 mg/kg (±6.04). According to Rodhe *et al.*, (2004) and Rotz (2004) latrine waste and digestate are often rich in nitrogen, with substantial amounts in the form of ammonia/ammonium. However, at neutral or slightly alkaline pH, only a small fraction of the ammonia is present as NH_3, irrespective of temperature.

4.4.1.4 Moisture Content

The mean moisture content of the faecal matter was 43.6% (±2.8). However, Nishimuta *et al.* (2006) in their study on moisture and mineral content of human faeces reported that moisture content of faeces ranged between 53 and 92%. The lower moisture content of

human faeces for this experiment may be due to moisture lost between the time of collection of sample and the time sample analysis took place.

4.4.2 Release of H_2S and NH_3 due to Storage of "Fresh" Faecal Matter

Peak H_2S emission was seen after 24 hours. It must be noted however that analysis begun 24 hours after experimental was set up due to the long hours in the set up and recognizing that measurement were only taken after every 24 hours. The decline was from a high of 108 µg/m^3 to 56 µg/m^3 (Figure 4-13).

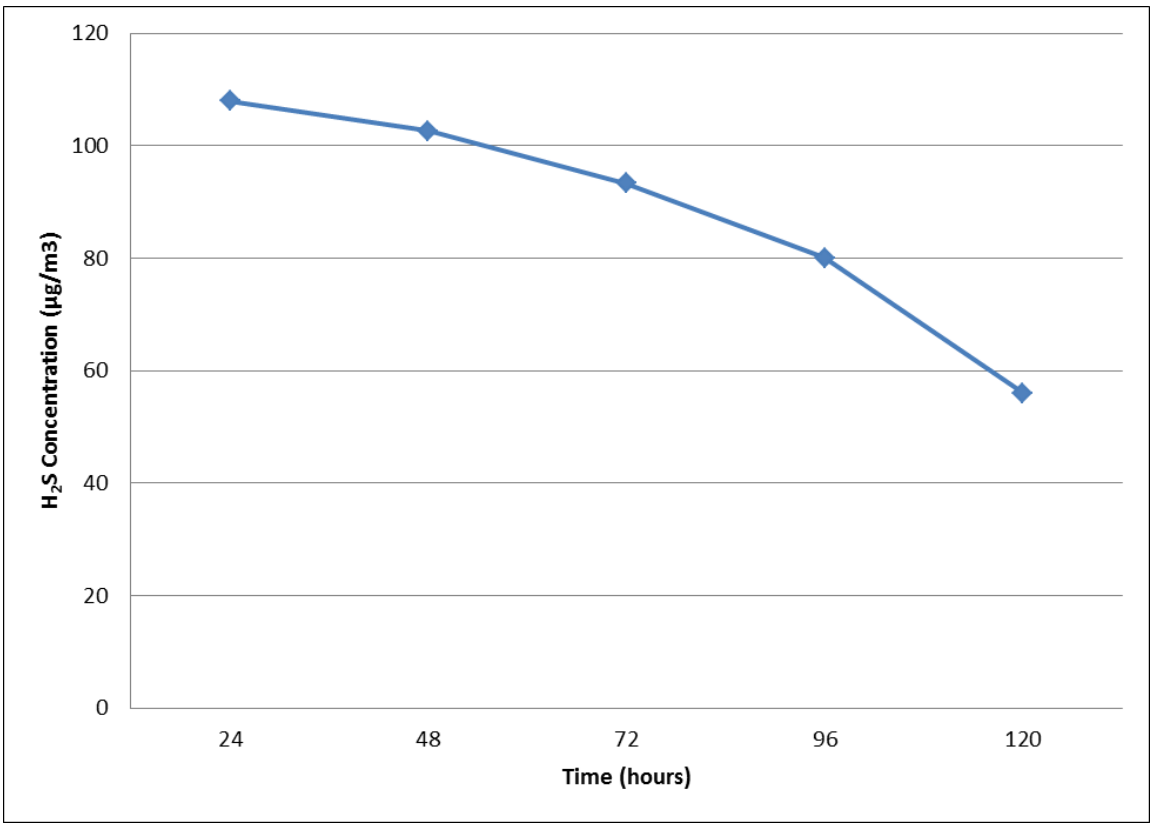


Figure 4-13: Rate of release of H_2S during storage of fresh faecal matter

Generally the emission pattern for H_2S showed a steady decline in its production. Analysis of sulphate concentration also showed a steady decline (see Figure 4-14). A possible explanation to the decline in H_2S production could be the decline in sulphate

concentration. It has been reported widely in literature that H_2S production in waste streams is largely due to the reduction of sulphate by sulphate reducing bacteria which reduce sulphate to sulfide ions and at low pH these sulfide ions combine with hydrogen ions to form the volatile compound H_2S. Relating the trend in H_2S production with pH supports the widely reported inverse relation between H_2S release and pH.

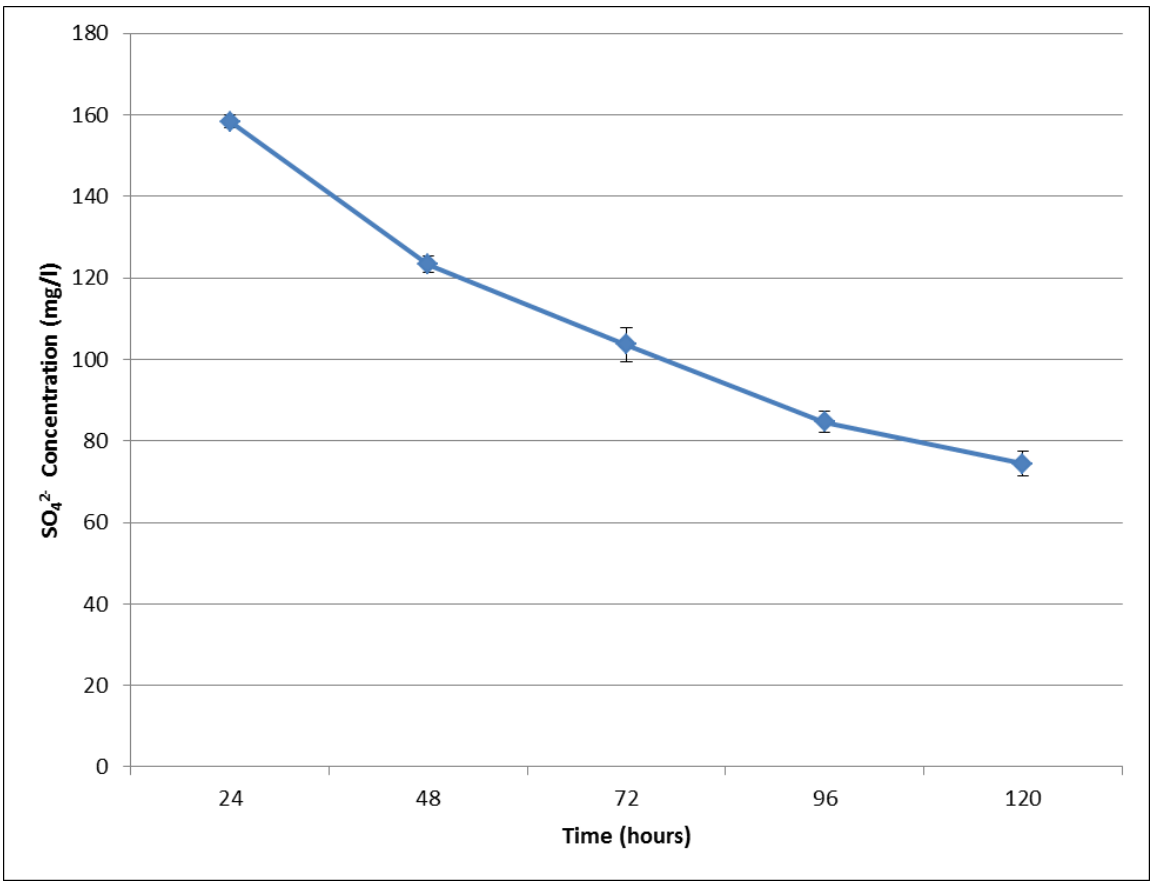


Figure 4-14: Rate of Sulphate reduction during storage of fresh faecal matter

pH measured over the 120 hour time of the experiment is presented in Figure 4-15. The pH ranged from a minimum of 6.23 to a maximum of 6.56. This could explain the low rate of release of H_2S though there is evidence of sulfur reduction. Rzeczycka and Blaszczyk (2005) reported that sulphate reducing bacteria (SRB) had a growth range of pH 5.5 to 7.0 and were found to exist in temperatures of 0^0 to 100^0C with an optimum

range of 24 to 42^{0}C. Again at pH 7, hydrogen sulfide was approximately 50% of the total dissolved sulfides; at pH 5, it was practically 100% of the total; at pH 9, it was nearly all hydrosulfide ions (HS^-). A linear correlation calculated between H_2S release and SO_4^{2-} reduction on one hand and H_2S release and pH on the other hand gave R^2 of 0.544 and 0.199 respectively. This showed that H_2S released for this set of experiments depended more on SO_4^2.reduction than the pH.

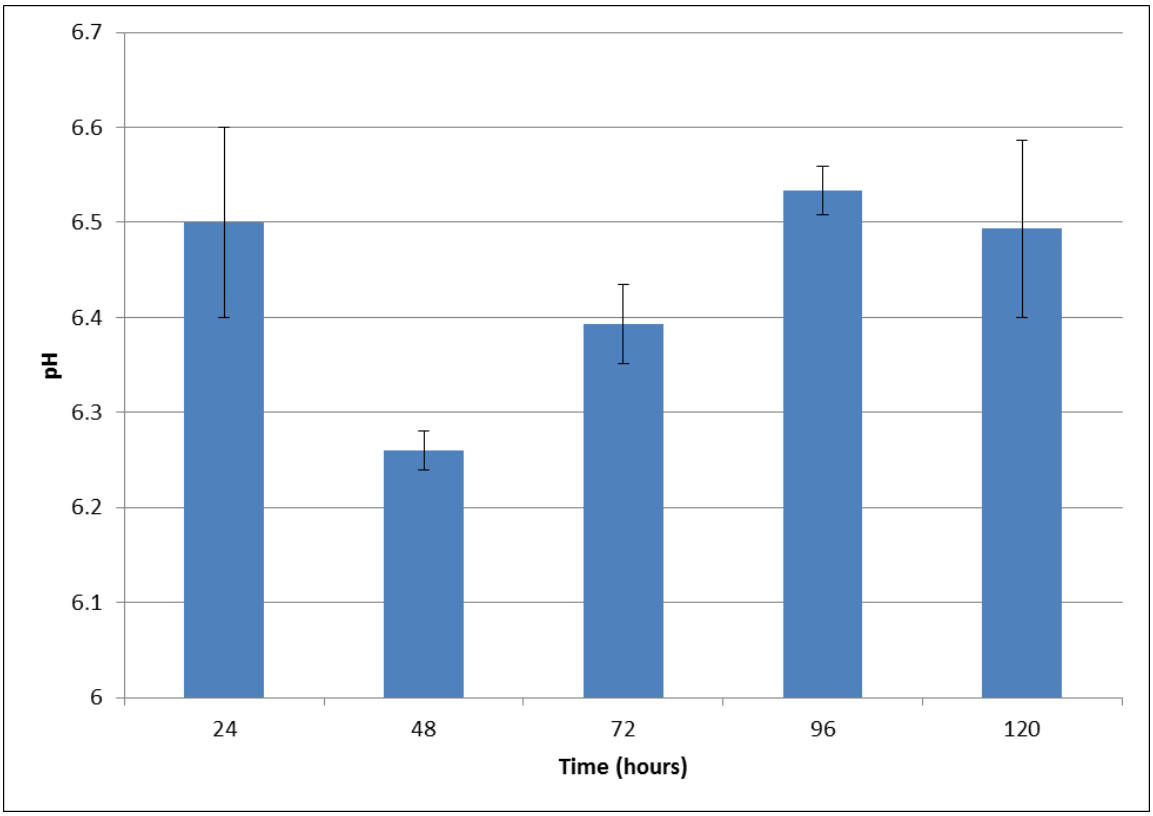


Figure 4-15: Change in pH during storage of fresh faecal matter

Peak NH_3 emission was seen after 96 hours (37.7µg/m^3). There was a drop in NH_3 release after 48 hours to 23.7µg/m^3. However, there was a steady increase in NH_3 production afterwards (Figure 4-16).

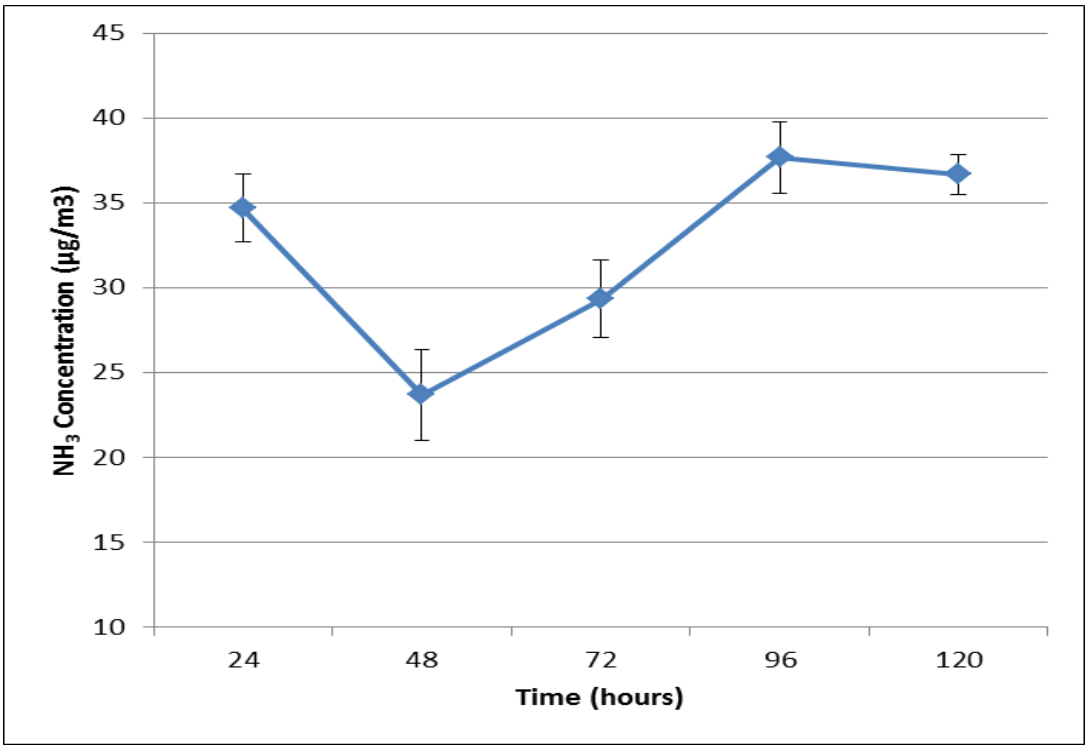


Figure 4-16: Rate of release of NH_3 during storage of fresh faecal matter

Comparing the rate of NH_3 production to pH shows the direct relationship between NH_3 and pH. A linear correlation calculated between NH_3 release and pH showed a strong positive correlation (R^2 = 0.97). It could therefore be deduced that though the range of pH change relatively small, it still had a high impact on NH_3 release.

The rates of NH_4^+ and TKN in the experimental sample are shown in Figure 4-17 and Figure 4-18 respectively. Generally as rate of NH_3 release increase, NH_4^+ and TKN concentrations also decrease. These two parameters were measured to serve mainly as a quality control check to release of ammonia NH_3. By definition, TKN is the sum of NH_3, NH_4^+ and Organic Nitrogen.

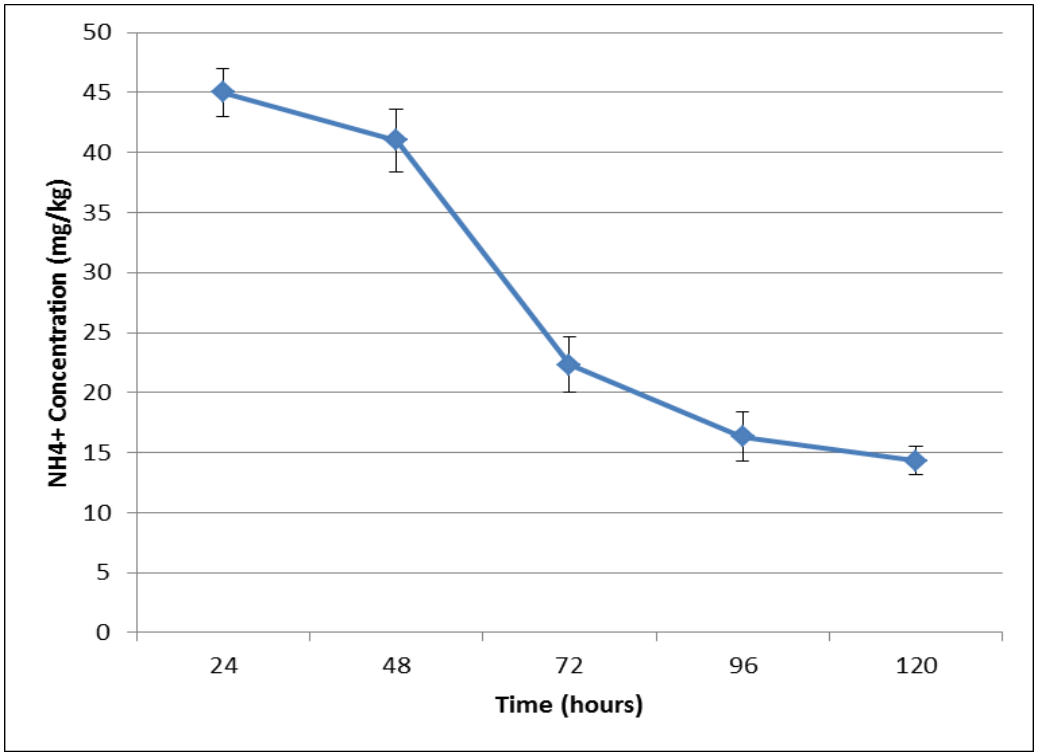


Figure 4-17: Rate of NH_4^+ reduction during storage of fresh faecal matter

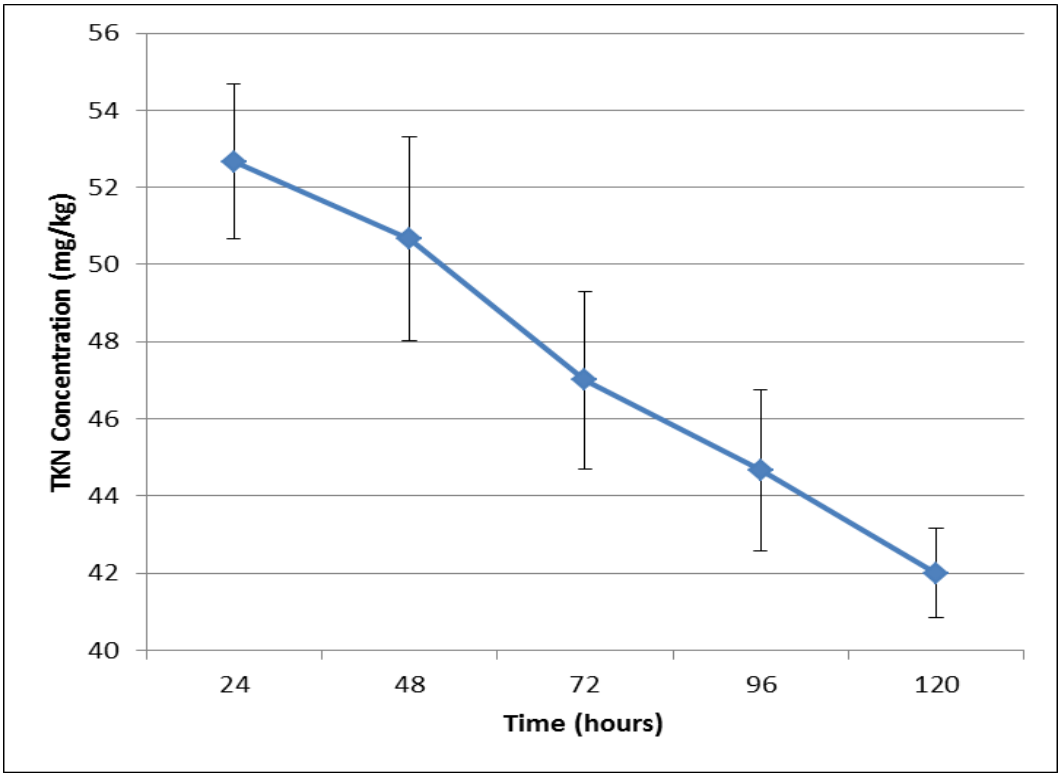


Figure 4-18: Rate of TKN reduction during storage of fresh faecal matter

4.4.3 Effect of addition of Ashes on release H_2S and NH_3

This section presents results of the effects of addition of Coconut Fibre Ash and Cocoa Pod Ash to fresh faecal matter in specific ratios of 5%. 12.5% and 25% by weight respectively based on similar works that have been carried out using ash remedy on biosolids to reduce odour prodution.

4.4.4 Characteristics of Ashes of Cocoa Husk and Coconut Fibre

The ashes were strongly alkaline, with a mean pH of 10.49 and 10.35 for CHA and CFA respectively (Table 4-7). The combustion process forms carbonate, bicarbonate and hydroxide, which results in the alkalinity in the ash. The relative proportion of these compounds varies with combustion temperature. Carbonates and bicarbonates predominate at combustion temperature below 500°C, whereas oxides become more prevalent when combustion temperatures exceed 850°C (Rosenfeld & Henry, 2000). Because CHA and CFA materials used in this experiment were combusted at temperatures greater than 500°C but less than 850°C (thus 700°C), it was likely that they might contain an equal mix of carbonate, bicarbonate and hydroxide. However with respect to alkalinity, which was basically the acid absorbing property, CHA showed a higher capacity than CFA (Table 4-7).

Table 4-7: Characteristics of ashes of Coconut Fibre and Cocoa Husk

Ash	pH	EC (µS/cm)	Alkalinity ($CaCO_3^-$ mg/l)
Coconut Fibre Ash (CFA)	10.49	51,100	146.4
Cocoa Husk Ash (CHA)	10.35	38,000	744.8

4.4.4.1 Effect of addition of Ashes on release of H_2S

Effects of addition of CHA and CFA on reduction of release of H_2S are shown in Figure 4-19 and Figure 4-20 respectively. Generally there was a reduction in H_2S released due to the addition of ashes. Also for each of the ashes, reduction in H_2S released increased with increase in ratio of ash to faecal matter.

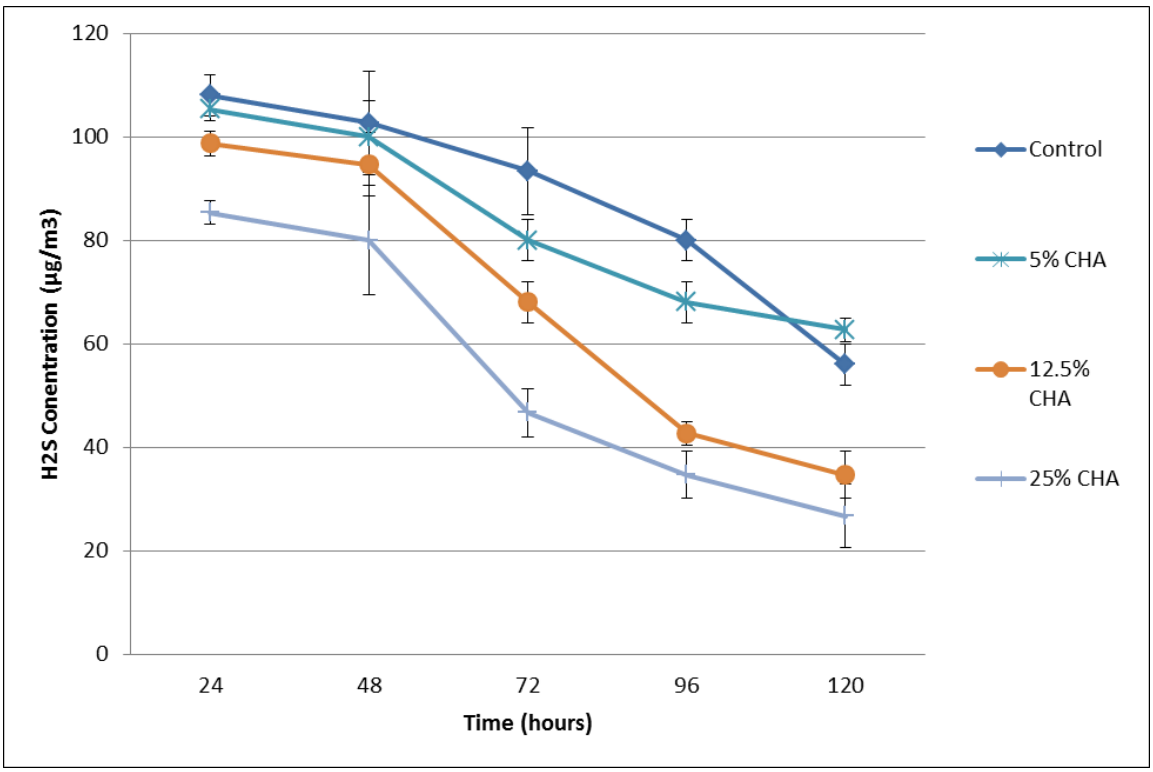


Figure 4-19: Effect of addition of cocoa husk ash on release of H_2S during storage of fresh faecal matter

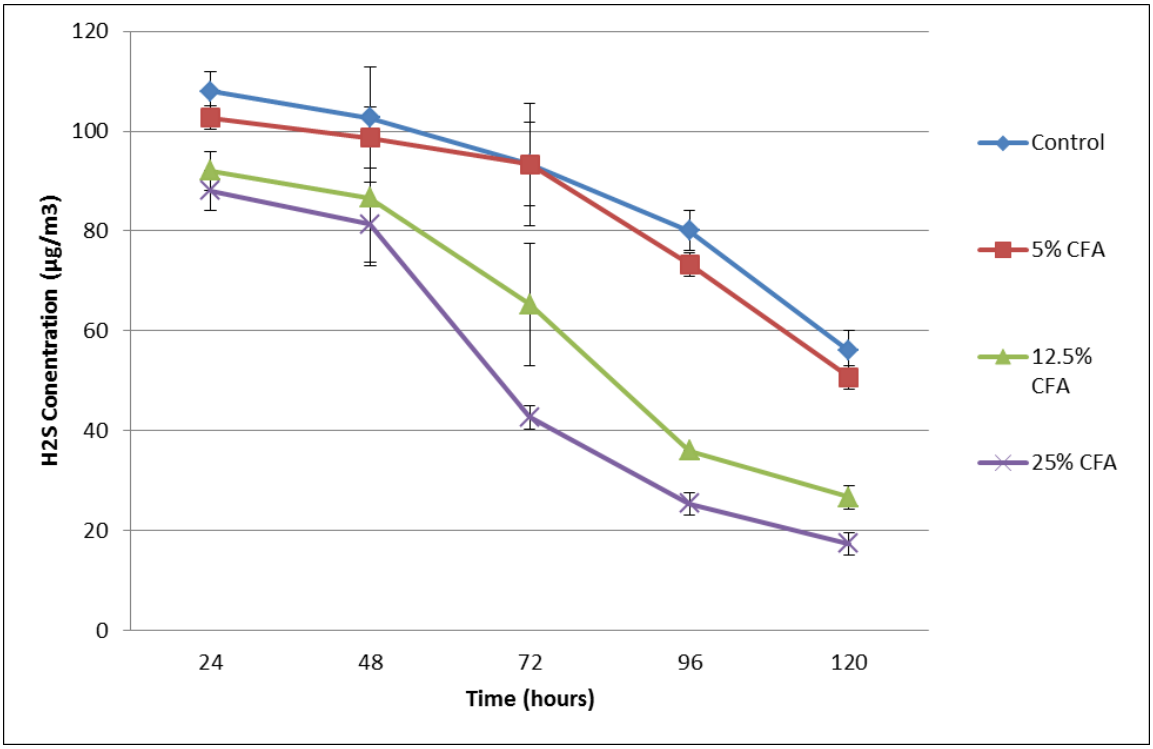


Figure 4-20: Effect of coconut fibre ash additions on release of H_2S during storage of fresh faecal matter

To ascertain whether the differences in treatment amendments were statistically significant, a paired t-test was carried out between the control experiment and the various mixing ratios (Table 4-8).

Table 4-8: Results of paired t-test between control experiment and various mixing ratios for H_2S reduction

Description of Comparison	**t-stat**	**df**	**p**	**Comment**
COCONUT FIBRE ASH (CFA)				
Control & 5%	3.72	4	0.01	Significant difference
Control & 12.5%	5.15	4	0.003	Significant difference
Control & 25%	5.15	4	0.003	Significant difference
COCOA HUSK ASH (CHA)				
Control & 5%	1.31	4	0.12	No significant difference
Control & 12.5%	3.73	4	0.01	Significant difference
Control & 25%	6.27	4	0.001	Significant difference

From the results of the statistical analysis, all the mixing ratios showed a statistically significant difference in reduction of H_2S release, apart from the 5% CFA mix. In addition, 12.5% and 25% CFA mixes showed the same significant difference (same t-stat and p-value). Also 5% CFA and 12.5% CHA showed the same significant difference (same t-stat and p-value). However, 25% CHA resulted in the most significant difference between the control experiment and the mixing ratios.

With respect to the changes in pH based on the various ratios of the physical amendments, as expected, the higher the mixing ratio, the higher the pH of the mixture (Figure 4-21). Also per a specific mixing ratio, CHA mixes resulted in a higher pH compared to their respective CFA mixes. This could be due to the high alkalinity of the CHA. A paired t-test was carried out to test statistical differences between pH values of the respective mixing ratios of CHA and CFA (Table 4-9). The results show that there is statistically significant difference in pH for the 12.5% and 25% mixing ratios whereas the 5% mixing ratios showed no difference (Table 4-9).

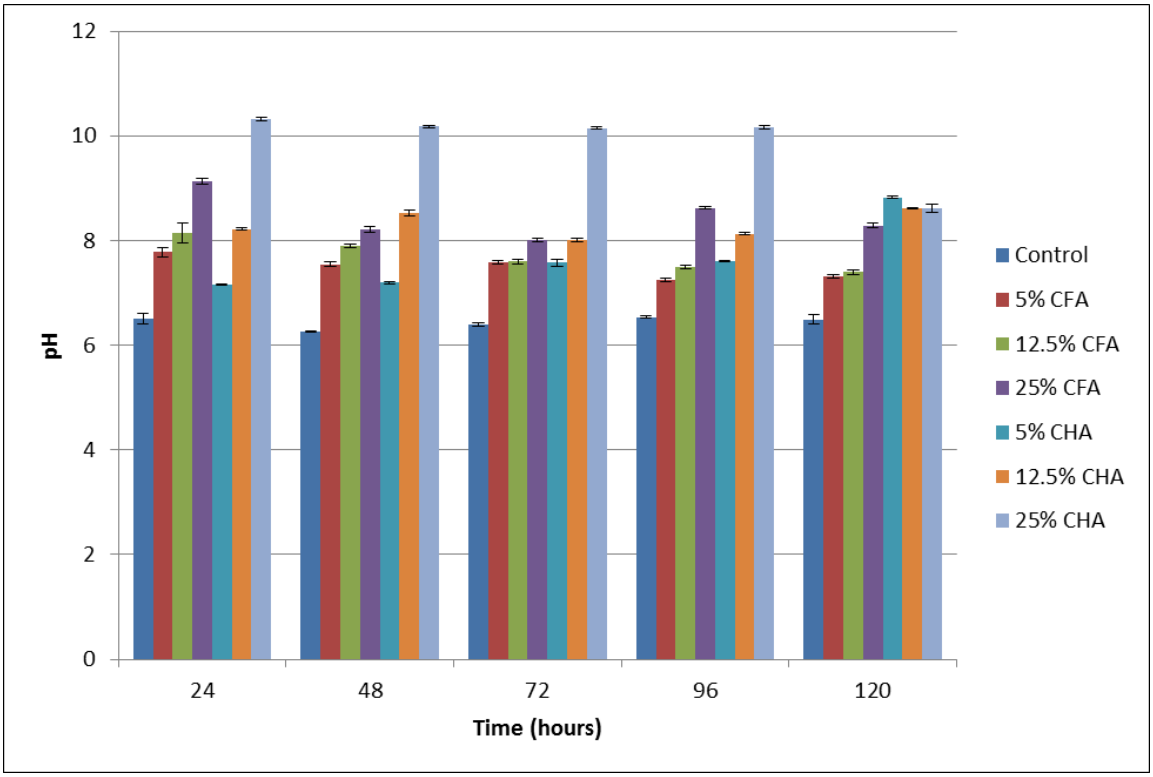


Figure 4-21: Effect of ash additions on pH during storage of fresh faecal matter

Table 4-9: Results of paired t-test for pH values of the respective mixing ratios of CHA and CFA

Description of Comparison	**t-stat**	**df**	**p**	**Comment**
5% CFA & CHA	-0.475	4	0.330	No significant difference
12.5% CFA & CHA	-3.17	4	0.017	Significant difference
25% CFA & CHA	-4.474	4	0.005	Significant difference

From the result of SO_4^{2-} reduction from addition of ashes (Figure 4-22), there was no statistically significant differences between group means as determined by one-way ANOVA ($F(6,28) = 0.027$, $p = 0.999$). Therefore it could be argued that the reduction in H_2S release might not be due to inhibition in the process of involved in the reduction of SO_4^{2-}. Das, Melear, Kastner, and Buquoi (2003) in their study concluded that addition of

ash resulting in a mixture of 25%, 53%, and 22% of biosolids, wood shavings, and ash, respectively, did not negatively impact biological activity.

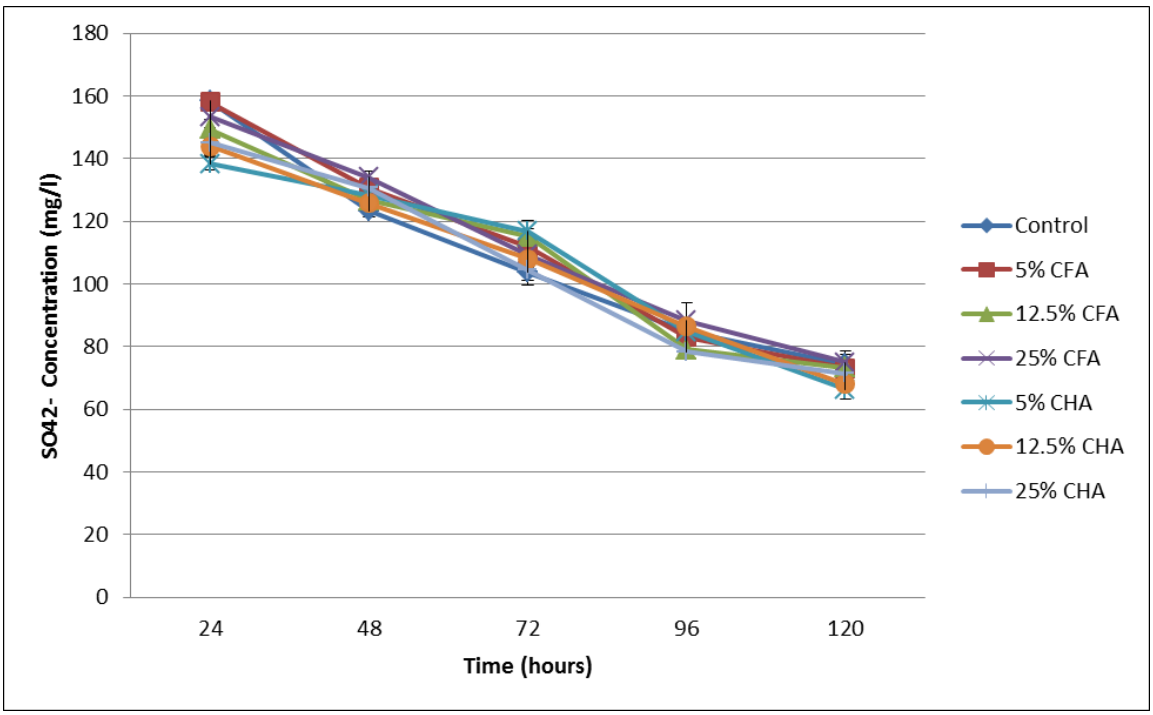


Figure 4-22: Effect of ash additions on sulphate reduction during storage of fresh faecal matter

4.4.4.2 Effect of addition of Ashes on release of NH_3

Effects of addition of CHA and CFA on reduction of release of NH_3 are shown in Figure 4-23 and Figure 4-24 respectively. Generally there was an increase in NH_3 released due to the addition of ashes. Also for each of the ashes, there was increase in NH_3 released with increase in ratio of ash to faecal matter. Mixing of 25% CHA showed the highest release of NH_3.

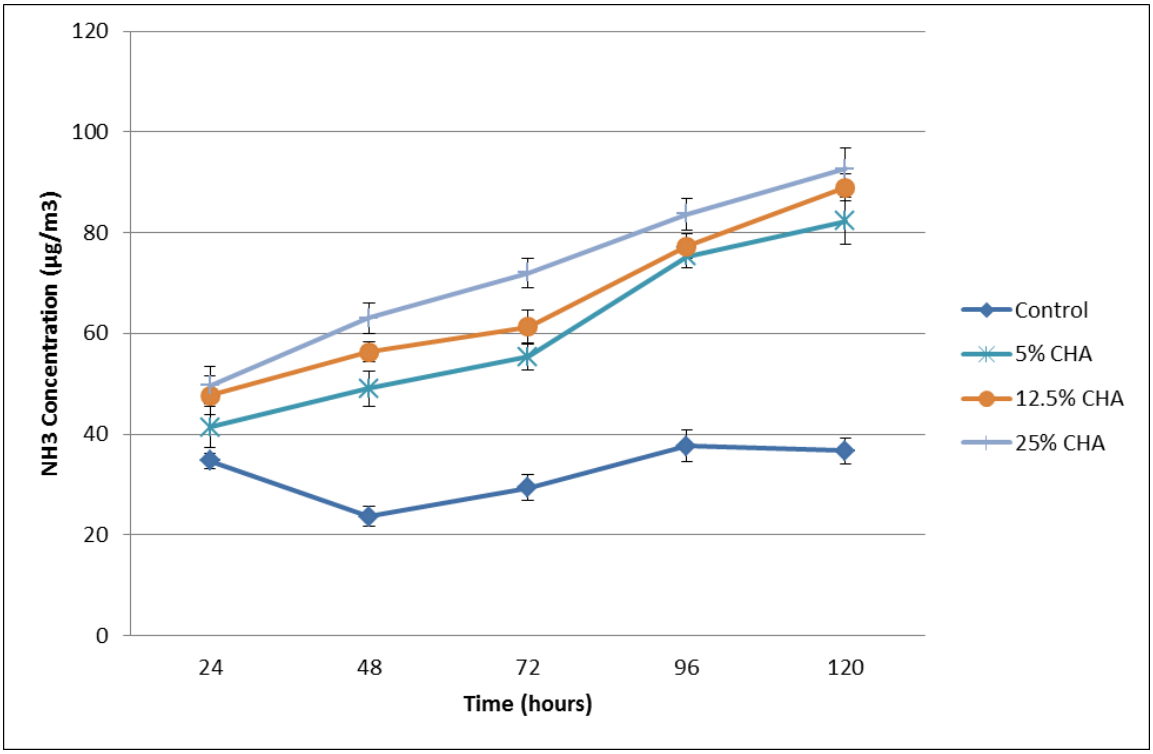


Figure 4-23: Effect of addition of cocoa husk ash on NH_3 release during storage of fresh faecal matter

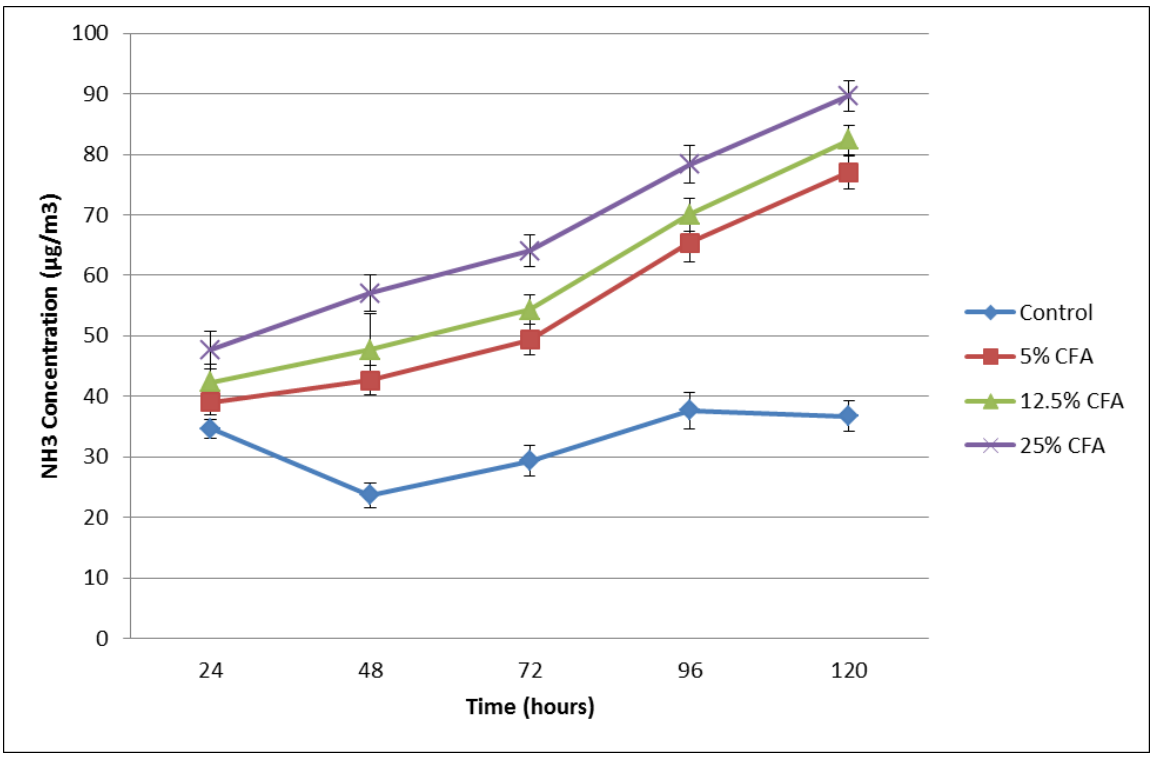


Figure 4-24: Effect of addition of coconut fibre ash on NH_3 release during storage of fresh faecal matter

To ascertain whether the differences in treatment amendments were statistical significance for NH_3 release, a paired t-test was carried out between the control experiment and the various mixing ratios (Table 4-10).

Table 4-10: Results of paired t-test between control experiment and various mixing ratios for NH_3 release

Description of Comparison	**t-stat**	**df**	**P**	**Comment**
COCONUT FIBRE ASH (CFA)				
Control & 5%	-3.78	4	0.009	Significant difference
Control & 12.5%	-4.36	4	0.006	Significant difference
Control & 25%	-5.38	4	0.003	Significant difference
COCOA HUSK ASH (CHA)				
Control & 5%	-4.28	4	0.006	Significant difference
Control & 12.5%	-5.32	4	0.003	Significant difference
Control & 25%	-4.28	4	0.002	Significant difference

Results of the statistical analysis showed that, all the mixing ratios showed a statistically significant different in release of NH_3. CHA mixing ratios contributed more to release of NH_3 as compared to their respective corresponding ratios of CFA (Table 4-10).

The results suggested that NH_3 release was very sensitive to pH increase and thus a slight increase in pH caused the release of NH_3. Nordin (2010), reported that ammonia in human excreta is mainly due to urea. Therefore as a first step, urine separation could be considered in reducing odour due to ammonia from storage of human excreta.

5 CONCLUSIONS AND IMPLICATIONS

5.1 CONCLUSION ON RESEARCH OJECTIVES

5.1.1 Assessment of toilet facilities and odour perception survey

Odour from communal toilets was perceived to be the most offensive within 50m radius. Also aside odour from communal toilets, there were other source of odour nuisance in the community beyond 50m radius of the communal toilets which included open drains, refuse dump and small scale chemical and pesticides production. Again, odour perceived to emanate from communal toilets reduces with distance from the communal toilet facility.

Chi-square statistics of responses showed no difference between male and female perception of odour. Responses showed that odour in the morning were perceived to be the most intense, followed by evening and then the afternoon. Also results of Spearman's rank-order correlation showed that there was a weak, negative correlation between frequency of odour exposure and annoyance, which showed that the longer inhabitants get exposed to odour the less annoying it would become; the so called "odour fatigue" phenomena.

5.1.2 Field olfactometry and odour dispersion modeling

Odour perception surveys have been largely regarded as subjective. However, the Nasal chemosensory test showed how subjectivity could be reduced by the so called "calibration of the human nose" for objective field odour measurements and how measured odour concentrations could be presented as odour contours. Also the study showed the applicability of the Gaussian Steady state plume model to model the dispersion of odour from a communal toilet facility and how further modeling studies

could be carried out to improve on design and operations of the toilet facilities such as increase in height of vent pipe, minimum distance for siting a communal toilet facility from residence and use of physical amendments to reduce the release of odour compounds.

Results from the odour contour plots confirmed the perception that odour is most intense in the morning as compared to other times of the day.

Increase in the release height (height of vent pipe) and also decrease in odour strength can reduce considerably ground level odour concentration especially within the first 50m.

5.1.3 Limiting effects of ash additives on the production of H_2S and NH_3 from storage of human excreta.

Generally, the various ashes to faecal matter ratios caused a reduction in the release of H_2S and increase in the release of NH_3. However CHA was found to perform better in the reduction of H_2S release than CFA with 25% CHA ratio giving the highest reduction. On the other hand, there was more release of NH_3 from CHA than CFA. However with the practice of urine separation from human excreta, CHA can be considered as a more effective odour reduction amendment (using H_2S as a surrogate) than CFA by about 20%.

5.2 IMPLICATIONS OF THE STUDY

Generally before effective odour control can be implemented for any facility, in this case a communal toilet facility, there is the need for quantification of the problem. An odour audit will accomplish the following:

Quantify odours from odour emission source: For odours to cause nuisance, they must be transported from source to receptor. Although odours may be measured at receptor locations, for assessment and control purposes, it is more useful to measure at source. This is because little dispersion will have occurred and concentrations will be higher. In addition, there is less opportunity for odours from other sources to interfere with measurement.

Analyse for odour causing compounds: Odour perceived by receptors is a mixture of numerous odour compounds. It is therefore necessary to carry out measurement of these compounds to find out the predominant odour compounds to aid in proposing mitigating measures to counteract the predominant compounds.

Obtain data for odour emissions air dispersion modeling: Modeling the dispersion of atmospheric pollutants in this case odour has become very key in establishing limit values for emissions into the atmosphere in some developed countries. Also, the use of dispersion models helps in the prediction of the impacts on air quality from odour emission sources and it is a valuable argument to propose effective control strategies.

Determine the most cost effective odour management plan: Based on the results of the quantification of odour, analysis of predominant compounds and dispersion modeling, a cost effective management plan aimed at either reducing release of odour compounds using physical amendments or odour masking strategies may be developed instead of the current ad hoc measures.

5.2.1 Implication for Technology Improvement

Good management practices or modification to the operation may reduce odour emission; however, odour containment from communal toilets facilities may be

necessary to control downwind effects. The value of air dispersion modeling prior to final design should not be underestimated. Information obtained from modeling may result in design changes such as increasing height of vent pipes to reduce downwind odour nuisance.

5.2.2 Implications for Policy and Planning

Odour annoyance score and objective field measurement coupled with dispersion modeling of ambient odour can be a useful proxy for assessing the within-area variability of air quality and could be used for evaluating the implementation of environmental policies. Odour annoyance can also be utilized as a complementary tool for determining exposure and concerns of residents in high exposure environments like Ayigya Zongo. There is need for policy makers to pay attention to residents' complaints and concerns regarding pollution exposure for better policy implementation. Assumption of the greatest odour source strength and worst case of odour dispersion can be an easy approach in determining the nearness of toilet facilities to residents, in this particular case of Ayigya Zongo an approximate distance of 60 – 80 metres.

Currently there are no standards and guidelines regarding ambient air odour in Ghana. Some developed countries have these standards and guidelines developed. For instance in Australia, a level of 7 OU/m^3 is deemed to be the appropriate exposure level for a single affected residence and for larger population an acceptable odour level of 2 OU/m^3 is deemed appropriate. In Denmark and New Zewland, a range of 5 to 10 OU/m^3 is specified; where as in the Netherlands less that 0.5 OU/m^3 is specified.

Smell must be seen as a key factor influencing sanitation behaviours of millions of people across cultures and socio-economic contexts. Hence smell must be taken more

seriously in future sanitation programmes and it must be clear to sanitation promoters that financial and public health arguments will not be effective if local perception of odour, contamination and health hazards carry more weight when choosing and using sanitation facilities. Avoiding bad odour is strong in people's minds and should also be in investigative, design, construction and operational phases of sanitation projects and promotion.

5.3 LIMITATIONS OF THE STUDY

Critical to any odour studies is good quality input data. However, it is important to note that this study had a number of limitations. These are enumerated as follows:

- Although great efforts was made to ensure that time between sampling for analysis was 24 hours, it was practically impossible since time taken for sampling was relatively long and samples had to be kept for a little more time before analyzing.

- Regarding the field odour survey, surveys were not done during the rainy season since the rains could damage and reduce the effectiveness of the Nasal Ranger readings and even damage it and more importantly the health of the field inspectors.

- Other odour compounds (especially volatile organic compounds) were not considered due to the high cost for sample analysis.

5.4 SUGGESTIONS FOR FURTHER RESEARCH

- This study focused on H_2S and NH_3 measurement as surrogate compounds for odour. However, numerous other odour compounds have been mentioned in

literature, hence further research should be carried out on other odour compounds to better understand the release of these compounds from human excreta.

- This study also focused on dry onsite communal toilets. Similar studies could also be carried out on other onsite toilet technologies and also household toilets for comparison to be made across technologies and user rates.

- Finally other physical additives aside cocoa husk ash and coconut fibre ash could be used to investigate their potential of reducing odour compounds.

REFERENCES

Abbott, N., Bayonove, C., Etievant, P., & Issanchou, S. (1993). Production of wine extracts for chemical and sensory analysis with an odour representative of that of the original wine. In *Connaissance aromatique des cepages et qualite des vins, Montpellier (France), 9-10 Fev 1993*. Revue Francaise d'Oenologie.

Afful, K., Oduro-Kwarteng, S., & Awuah, E. (2015). Assessing public perception of odours in a community: case of Ayigya Zongo, an urban poor community in Ghana. *Journal of Water, Sanitation and Hygiene for Development, 5*(2), 244-251.

Arogo, J., Zhang, R., Riskowski, G., & Day, D. (2000). Hydrogen sulfide production from stored liquid swine manure: a laboratory study. *Transactions of the ASAE, 43*(5), 1241.

Awuah, E., Gyasi, S. F., Nettey, W., Attiogbe, F., Lubberding, H. J., & Gijzen, H. J. (2014). Atmospheric air pollution associated with macrophyte and algal-based wastewater stabilization ponds in Kumasi, Ghana. *Journal of Energy and Natural Resources Management 1*(2), 88-92.

Bak, F., Finster, K., & Rothfuß, F. (1992). Formation of dimethylsulfide and methanethiol from methoxylated aromatic compounds and inorganic sulfide by newly isolated anaerobic bacteria. *Archives of microbiology, 157*(6), 529-534.

Balling, R. C., & Reynolds, C. E. (1980). Evaluating Odor Reduction Technologies: Model. *Journal of the Environmental Engineering Division, 106*(5), 901-906.

Bastone, D. J., Keller, J., Angelidaki, I., & Kalyuzhnyi, S. V. (2002a). *Anaerobic Digestion Model No.1*. London: IWA Publishing.

Berglund, B., Hassmen, P., & Job, R. S. (1996). Sources and effects of low ‐ frequency noise. *The Journal of the Acoustical Society of America, 99*(5), 2985-3002.

Bliss, P., Schulz, T., Senger, T., & Kaye, R. (1996). Odour measurement—factors affecting olfactometry panel performance. *Water Science and Technology, 34*(3), 549-556.

Bonnin, C., Laborie, A., & Paillard, H. (1990). Odor nuisances created by sludge treatment: problems and solutions. *Water Science & Technology, 22*(12), 65-74.

Boutek, C. (1998). Guidelines for human settlement planning and design. *Known as the Red Book. Compiled by Boutek, CSIR for the Department of Housing*.

Brennan, B. (1993). Odour nuisance. *Water and Waste Treatment, 36*, 30-33.

Cain, W. S. (1980). The case against threshold measurement of environmental odors. *Journal of the Air Pollution Control Association, 30*(12), 1295-1296.

Cain, W. S., Stevens, J. C., Nickou, C. M., Giles, A., Johnston, I., & Garcia-Medina, M. R. (1995). Life-span development of odor identification, learning, and olfactory sensitivity. *Perception-London-, 24*, 1457-1473.

Carney, P., & Dodd, V. (1989). A comparison between predicted and measured values for the dispersion of malodours from slurry. *Journal of Agricultural Engineering Research, 44*, 67-76.

Cavalini, P. M. (1994). Industrial odorants: the relationship between modeled exposure concentrations and annoyance. *Archives of Environmental Health: An International Journal, 49*(5), 344-351.

Chastain, J. P., & Wolak, F. J. (2000). Application of a Gaussian plume model of odor dispersion to select a site for livestock facilities. *Proceedings of the Water Environment Federation, 2000*(3), 745-758.

Chen, Y., Bundy, D. S., & Hoff, S. J. (1999). Using olfactometry to measure intensity and threshold dilution ratio for evaluating swine odor. *Journal of the Air & Waste Management Association, 49*(7), 847-853.

Cheremisinoff, P. N. (1992). Industrial odour control. *Butterworth-Heinemann Ltd. Oxford*, 222.

Chin, H.-W., & Lindsay, R. C. (1994). Ascorbate and transition-metal mediation of methanethiol oxidation to dimethyl disulfide and dimethyl trisulfide. *Food chemistry, 49*(4), 387-392.

Chung, K.C., Chiang, C.M., & Wang, W.A. (1997). Predicting contaminant particle distributions to evaluate the environment of lavatories with floor exhaust ventilation. *Building and Environment, 32*(2), 149-159.

Chung, Y., Huang, C., & Tseng, C. (1996). Reduction of H2S/NH3 production from pig feces by controlling environmental conditions. *Journal of Environmental Science & Health Part A, 31*(1), 139-155.

Clarkson, C. (1993). Odour taken to task at WWT plants. *Water Wastewater Treatment, 36*, 44.

Curran, T., Sheridan, B., Hayes, E., & Dodd, V. (2002). *Comparison of two dispersion models for odour nuisance prediction from pig units. ASAE.* Paper presented at the CIGR Annual International Meeting, Chicago, Paper.

Dalton, P. (1999). Establishment of Odor Response Profiles: Ethnic, Racial and Cultural Influences Report Submitted to the U. S, Army Chemical Research, Development and Engineering Center February 4, 1999.

Dalton, P., Caraway, E. A., Gibb, H., & Fulcher, K. (2011). A Multi-Year Field Olfactometry Study Near a Concentrated Animal Feeding Operation. *Journal of the Air & Waste Management Association, 61*(12), 1398-1408.

Dalton, P., & Smeets, M. (2004). Olfactometry: The human nose as a detection instrument. *Handbook of Human Factors and Ergonomic Methods*, 1-8.

Das, K., Melear, N., Kastner, J., & Buquoi, J. (2003). Influence of ash amendment on odor emissions and aerobic biodegradation of biosolids mixes. *Transactions of the ASAE, 46*(4), 1185.

De Bode, M. (1991). Odour and ammonia emissions from manure storage. *Odour and ammonia emissions from livestock farming, 5*, 59.

Diallo, M. O., Hopkins, D. R., Kane, M. S., Niandou, S., Amadou, A., Kadri, B., Zingeser, J. A. (2007). Household latrine use, maintenance and acceptability in rural Zinder, Niger. *International journal of environmental health research, 17*(6), 443-452.

Dignac, M.-F., Urbain, V., Rybacki, D., Bruchet, A., Snidaro, D., & Scribe, P. (1998). Chemical description of extracellular polymers: implication on activated sludge floc structure. *Water Science and Technology, 38*(8), 45-53.

Dinye, R. D., & Acheampong, E. O. (2013). Challenges of slum dwellers in Ghana: The case study of Ayigya, Kumasi. *Modern Social Science Journal, 2*(2).

Dols, W., Persily, A., & Nabinger, S. (1992). Environmental evaluation of a new federal office building. *San Francisco, CA: IAQ, 92*, 85-93.

Donham, K. J., Knapp, L., Monson, R., & Gustafson, K. (1982). Acute toxic exposure to gases from liquid manure. *Journal of Occupational and Environmental Medicine, 24*(2), 142-145.

Draper, D., & Rutt, P. (1988). *Operational experience with management of odours in Thames Water*. Paper presented at the Second CIWEM National Conference on Odour Control in Sewage Treatment.

Dravnieks, A., & Jarke, F. (1980). Odor threshold measurement by dynamic olfactometry: significant operational variables. *Journal of the Air Pollution Control Association, 30*(12), 1284-1289.

Dravnieks, A., & O'neill, H. J. (1979). Annoyance potentials of air pollution odors. *The American Industrial Hygiene Association Journal, 40*(2), 85-95.

Duffee, R. A., & Cha, S. S. (1980). Consideration of physical factors in dynamic olfactometry. *Journal of the Air Pollution Control Association, 30*(12), 1294-1295.

Eikum, A., & Storhaug, R. (1986). Odour problems related to waste water and sludge treatment. *Odour prevention and control of organic sludge and livestock farming/edited by VC Nielsen, JH Voorburg, and P. L'Hermite*.

Engel, P. L., Williams, T. O., & Muirhead, T. (1997). *Utilizing ISCST to model composting facility odors.* Paper presented at the AIR & WASTE MANAGEMENT ASSOCIATION 90. ANNUAL MEETING.[np]. 1997.

Environmnental Protection Agency, Odour Impacts and Odour Emission Control Measures for Intensive Agriculture. (2001), Ireland.

Esrey, S. A., Gough, J., Rapaport, D., Sawyer, R., Simpson-Hébert, M., Vargas, J., & Winblad, U. (1998). *Ecological sanitation*: Sida.

Fair, G. M., & Moore, E. W. (1935). Measurement of intensity and concentration of odors associated with sewage treatment processes. *Sewage Works Journal*, 182-199.

Finnigan, J. (1998). *Odour measurement and minimisation within the west of Scotland.* Paper presented at the 2nd CIWEM National conference on Odour Control in Sewage Treatment, London.

Flores, A., Rosemarin, A., & Fenner, R. (2009). Evaluating the Sustainability of an Innovative Dry Sanitation (Ecosan) System in China as Compared to a Conventional Waterborne Sanitation System. *Proceedings of the Water Environment Federation, 2009*(8), 6734-6751.

Forbes, R. H., Adams, G., Witherspoon, J., Hentz, L., Murthy, S., Glindemann, D., Erdal, Z. (2003). Impacts of in-plant operational parameters on biosolids odor quality: preliminary results of WERF phase 2 study. *Proceedings of the Water Environment Federation, 2003*(1), 836-857.

Fortier, I., Ferraris, J., & Mergler, D. (2007). Measurement precision of an olfactory perception threshold test for use in field studies. *American journal of industrial medicine, 20*(4), 495-504.

Frechen, F. B. (1994). Odour emissions of wastewater treatment plants- recent German experiences. *Water Science & Technology[WATER SCI. TECHNOL.]. 30*(4).

Frølund, B., Palmgren, R., Keiding, K., & Nielsen, P. H. (1996). Extraction of extracellular polymers from activated sludge using a cation exchange resin. *Water Research, 30*(8), 1749-1758.

Gostelow, P., Parsons, S. A., & Stuetz, R. M. (2001). Odour measurements for sewage treatment works. *Water Research, 35*(3), 579-597. doi: http://dx.doi.org/10.1016/S0043-1354(00)00313-4

Greenberg, M. I., Curtis, J. A., & Vearrier, D. (2013). The perception of odor is not a surrogate marker for chemical exposure: a review of factors influencing human odor perception. *Clinical Toxicology, 51*(2), 70-76.

Griep, M., Mets, T., Vercruysse, A., Cromphout, I., Ponjaert, I., Toft, J., & Massart, D. (1995). Food odor thresholds in relation to age, nutritional, and health status. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 50*(6), B407.

Griep, M. I., Mets, T. F., Collys, K., Vogelaere, P., Laska, M., & Massart, D. L. (1997). Odour perception in relation to age, general health, anthropometry and dental state. *Archives of gerontology and geriatrics, 25*(3), 263-275.

Grimason, A., Davison, K., Tembo, K., Jabu, G., & Jackson, M. (2000). Problems associated with the use of pit latrines in Blantyre, Republic of Malawi. *The journal of the Royal Society for the Promotion of Health, 120*(3), 175-182.

Guo, H., Jacobson, L., Schmidt, D., & Nicolai, R. (2000). *Correlation of Odor Dilution Threshold and H2S and NH3 Concentrations for Animal Feedlots. ASAE Meeting Presentation Paper No. 004043.* Paper presented at the ASAE Annual International Meeting, Milwaukee, WI July.

Guo, H., Yu, Z., & Lague, C. (2006). *Livestock odour dispersion modeling: a review.* Paper presented at the CSBE/SCGAB 2006 Annual Conference.

Harkness, N. (1979). Chemistry of septicity. *Septic Sewage: Problems and Solutions. IWPC, Maidstone, Kent*, 7-17.

Heinemann, P., & Wahanik, D. (1998). Modeling the generation and dispersion of odors from mushroom composting facilities. *Transactions of the ASAE, 41*(2), 437-446.

Henry, J., & Gehr, R. (1980). Odor control: an operator's guide. *Journal (Water Pollution Control Federation)*, 2523-2537.

Higgins, M. J., Adams, G., Card, T., Chen, Y.-C., Erdal, Z., Forbes, R. H., McEwen, D. (2004). Relationship between biochemical constituents and production of odor causing compounds from anaerobically digested biosolids. *Proceedings of the Water Environment Federation, 2004*(3), 471-486.

Higgins, M. J., Chen, Y.-C., Yarosz, D. P., Murthy, S. N., Maas, N. A., Glindemann, D., & Novak, J. T. (2006). Cycling of volatile organic sulfur compounds in anaerobically

digested biosolids and its implications for odors. *Water environment research, 78*(3), 243-252.

Higgins, M. J., & Novak, J. T. (1997). Characterization of exocellular protein and its role in bioflocculation. *Journal of Environmental Engineering, 123*(5), 479-485.

Hoat, L. N., Rheinländer, T., Dalsgaard, A., & Konradsen, F. (2012). Sanitation behavior among schoolchildren in a multi-ethnic area of Northern rural Vietnam. *BMC Public Health, 12*(1), 1.

Hobson, J. (1995). The odour potential: a new tool for odour management. *Water and Environment Journal, 9*(5), 458-463.

Huey, N. A., Broering, L. C., Jutze, G. A., & Gruber, C. W. (1960). Objective odor pollution control investigations. *Journal of the Air Pollution Control Association, 10*(6), 441-446.

Jacobson, L., Clanton, C., Schmidt, D., Radman, C., Nicolai, R., & Janni, K. (1997). Comparison of hydrogen sulfide and odor emissions from animal manure storages. *Proc. of Ammonia and Odour Emissions from Animal Production Facilities, eds. JAM Voermans and G. Monteny*, 405-412.

Jiang, J. K. (1996). Concentration measurement by dynamic olfactometer. *Water environment & technology, 8*(6), 55-59.

Koe, L. C. C. (1989). Sewage odors quantification. *Encyclopedia of Environmental Control Technology, Wastewater Treatment Technology, 3*, 423-446.

Koné, D., & Strauss, M. (2004). *Low-cost options for treating faecal sludges (FS) in developing countries–Challenges and performance.* Paper presented at the 9th International IWA Specialist Group Conference on Wetlands Systems for Water Pollution Control and to the 6th International IWA Specialist Group Conference on Waste Stabilisation Ponds, Avignon, France.

Koren, H. S., Graham, D. E., & Devlin, R. B. (1992). Exposure of humans to a volatile organic mixture. III. Inflammatory response. *Archives of Environmental Health: An International Journal, 47*(1), 39-44.

Koster, E., & Koelega, H. (1976). Sex differences in odour perception. *J. Soc. Cosmet. Chem, 27*, 319-327.

Laska, M., & Hudson, R. (1991). A comparison of the detection thresholds of odour mixtures and their components. *Chemical senses, 16*(6), 651-662.

Leonardos, G. (1980). Selection of Panelists. *Journal of the Air Pollution Control Association, 30*(12), 1297-1297.

Lin, J., Aoll, J., Niclass, Y., Velazco, M. I. s., Wünsche, L., Pika, J., & Starkenmann, C. (2013). Qualitative and quantitative analysis of volatile constituents from latrines. *Environmental science & technology, 47*(14), 7876-7882.

Lindvall, T. (1974). Monitoring odorous air pollution in the field with human observers. *Annals of the New York Academy of Sciences, 237*(1), 247-260.

Liu, Q., Bundy, D., & Hoff, S. (1993). *Utilizing ammonia concentrations as an odor threshold indicator for swine facilities.* Paper presented at the Livestock Environment. Fourth International Symposium.

Lomans, B. P., den Camp, H. J. O., Pol, A., van der Drift, C., & Vogels, G. D. (1999). Role of methanogens and other bacteria in degradation of dimethyl sulfide and methanethiol in anoxic freshwater sediments. *Applied and environmental microbiology, 65*(5), 2116-2121.

Lomans, B. P., den Camp, H. J. O., Pol, A., & Vogels, G. D. (1999a). Anaerobic versus aerobic degradation of dimethyl sulfide and methanethiol in anoxic freshwater sediments. *Applied and environmental microbiology, 65*(2), 438-443.

Lomans, B. P., Luderer, R., Steenbakkers, P., Pol, A., van der Drift, C., Vogels, G. D., & den Camp, H. J. O. (2001). Microbial populations involved in cycling of dimethyl sulfide and methanethiol in freshwater sediments. *Applied and environmental microbiology, 67*(3), 1044-1051.

Lomans, B. P., Maas, R., Luderer, R., den Camp, H. J. O., Pol, A., van der Drift, C., & Vogels, G. D. (1999). Isolation and characterization of Methanomethylovorans hollandica gen. nov., sp. nov., isolated from freshwater sediment, a methylotrophic methanogen able to grow on dimethyl sulfide and methanethiol. *Applied and environmental microbiology, 65*(8), 3641-3650.

Lomans, B. P., Smolders, A., Intven, L. M., Pol, A., Op, D., & Van Der Drift, C. (1997). Formation of dimethyl sulfide and methanethiol in anoxic freshwater sediments. *Applied and environmental microbiology, 63*(12), 4741-4747.

Lord, H. L., Grant, R. P., Walles, M., Incledon, B., Fahie, B., & Pawliszyn, J. B. (2003). Development and evaluation of a solid-phase microextraction probe for in vivo pharmacokinetic studies. *Analytical chemistry, 75*(19), 5103-5115.

Lundblad, B., & Hellström, A. L. (2005). Perceptions of school toilets as a cause for irregular toilet habits among schoolchildren aged 6 to 16 years. *Journal of School Health, 75*(4), 125-128.

McGinley, C. M., McGinley, M. A., & McGinley, D. L. (2000). *Odor Basics - Understanding and Using Odor Testing*. Paper presented at the The 22nd Annual Hawaii Water Environment Association Conference, Honolulu, Hawaii.

McGinley, M. A. (1995). *Quantifying Public Perception of Odors in a Community–Utilizing Telemarketing Protocol.* Paper presented at the Air and Waste Management Association International Specialty Conference: Odor and Environmental Air. Bloomington, MN.

Metcalf, E., & Eddy, H. P. (1991). Wastewater Engineering: Treatment. *Disposal, and Reuse, 3*.

Miller, R. L., & Brewer, J. D. (2003). *The AZ of social research: a dictionary of key social science research concepts*: Sage.

Morgan, J., Forster, C., & Evison, L. (1990). A comparative study of the nature of biopolymers extracted from anaerobic and activated sludges. *Water Research, 24*(6), 743-750.

Nishimuta, M., Inoue, N., Kodama, N., Morikuni, E., Yoshioka, Y. H., Matsuzaki, N., Ohki, K. (2006). Moisture and mineral content of human feces-high fecal moisture is associated with increased sodium and decreased potassium content. *Journal of nutritional science and vitaminology, 52*(2), 121-126.

Nordin, A. (2010). *Ammonia sanitisation of human excreta* (Vol. 2010).

Noren, O. (1986). Design and use of biofilters for livestock buildings. *Odour prevention and control of organic sludge and livestock farming/edited by VC Nielsen, JH Voorburg, and P. L'Hermite*.

Nováková, L., Valentova, J. V., & Havlíček, J. (2014). Engagement in olfaction-related activities is associated with the ability of odor identification and odor awareness. *Chemosensory Perception, 7*(2), 56-67.

Oduro-Kwarteng, S., Awuah, E., Nyarko, K., & Shaw, R. (2009). *Shifting from public shared toilets to home toilets in urban settlements: implications of household demand in Kumasi, Ghana*. Paper presented at the Water, sanitation and hygiene: sustainable development and multisectoral approaches. Proceedings of the 34th WEDC International Conference, United Nations Conference Centre, Addis Ababa, Ethiopia, 18-22 May 2009.

Oketch, M. (2005). Systems for Enhancing Ventilation for Improved Control of Odour and Fly Nuisance in Dry urine Diverting Ecological Sanitation Toilets, Water Director, Uganda

Patterson, M. Q., Stevens, J. C., Cain, W. S., & Cometto-Muñiz, J. E. (1993). Detection thresholds for an olfactory mixture and its three constituent compounds. *Chemical senses, 18*(6), 723-734.

Persson, S., Edlund, M. B., Claesson, R., & Carlsson, J. (1990). The formation of hydrogen sulfide and methyl mercaptan by oral bacteria. *Oral microbiology and immunology, 5*(4), 195-201.

Preti, G., Gittelman, T. S., Staudte, P. B., & Luitweiler, P. (1993). Letting the nose lead the way. Malodorous components in drinking water. *Analytical chemistry, 65*(15), 699A-702A.

Punter, P. H. (1986). Setting up and use of population panels for measuring and monitoring annoyance. *Developments in toxicology and environmental science, 15*, 105-116.

Rheinländer, T., Keraita, B., Konradsen, F., Samuelsen, H., & Dalsgaard, A. (2013). Smell: an overlooked factor in sanitation promotion. *Waterlines, 32*(2), 106-112.

Rodhe, L., Stintzing, A. R., & Steineck, S. (2004). Ammonia emissions after application of human urine to a clay soil for barley growth. *Nutrient Cycling in Agroecosystems, 68*(2), 191-198.

Rose, C., Parker, A., Jefferson, B., & Cartmell, E. (2015). The characterization of feces and urine: a review of the literature to inform advanced treatment technology. *Critical reviews in environmental science and technology, 45*(17), 1827-1879.

Rosenfeld, P. E., & Henry, C. L. (2000). Wood ash control of odor from biosolids application. *Journal of Environmental Quality, 29*(5), 1662-1668.

Rosenfeld, P. E., & Henry, C. L. (2001). Activated carbon and wood ash sorption of wastewater, compost, and biosolids odorants. *Water environment research, 73*(4), 388-393.

Rotz, C. (2004). Management to reduce nitrogen losses in animal production. *Journal of animal science, 82*(13_suppl), E119-E137.

Rzeczycka, M., & Blaszczyk, M. (2005). Growth and activity of sulphate-reducing bacteria in media containing phosphogypsum and different sources of carbon. *Polish Journal of environmental studies, 14*(6), 891.

Sandberg, M., & Blomqvist, C. (1985). A quantitative estimate of the accuracy of tracer gas methods for the determination of the ventilation flow rate in buildings. *Building and Environment, 20*(3), 139-150.

Schulte, D., Kottwitz, D., & Gilbertson, C. (1985). Nitrogen content of scraped swine manure.

Schulz, T., & Van Harreveld, A. (1996). International moves towards standardisation of odour measurement using olfactometry. *Water Science and Technology, 34*(3), 541-547.

Sheridan, B., Hayes, E., Curran, T., & Dodd, V. (2004). A dispersion modelling approach to determining the odour impact of intensive pig production units in Ireland. *Bioresource technology, 91*(2), 145-152.

Sidibe, M., & Curtis, V. (2007). Can hygiene be cool and fun. *Understanding school children's motivations to use their school toilets and wash their hands with soap in Dakar, Senegal in The Faculty of Medicine. London: The University of London*, 238.

Staples, S. L. (1996). Human response to environmental noise: Psychological research and public policy. *American Psychologist, 51*(2), 143.

Stordeur, R., Stordeur, C., Levine, S., & Hoggatt, J. (1981). A new microprocessor-controlled dynamic olfactometer. *Journal of the Air Pollution Control Association, 31*(4), 377-380.

Sucker, K., Both, R., Bischoff, M., Guski, R., Krämer, U., & Winneke, G. (2008). Odor frequency and odor annoyance Part II: dose–response associations and their modification by hedonic tone. *International archives of occupational and environmental health, 81*(6), 683-694.

Toffey, W., Higgins, M., & Tyagi, R. (2007). An Odor Odyssey: Review of Scientific Progress toward Eliminating Odorant Emissions from Philadelphia's Biosolids *Moving forward wastewater biosolids sustainability: technical, managerial, and public synergy* (pp. 795-800): GMSC.

van der Geest, S. (2007). Not knowing about defecation. *On knowing & not knowing in the anthropology of medicine. Oxford: Berg*, 75-86.

Vas, G., & Vekey, K. (2004). Solid‐phase microextraction: a powerful sample preparation tool prior to mass spectrometric analysis. *Journal of mass spectrometry, 39*(3), 233-254.

Vincent, A., & Hobson, J. (1998). *Odour control*: Chartered Institution of Water and Environmental Management.

Walker, J. M. (1991). Fundamentals of odor control. *BioCycle (USA)*.

Warren, D. W., Walker, J. C., Drake, A. F., & Lutz, R. W. (1994). Effects of odorants and irritants on respiratory behavior. *The Laryngoscope, 104*(5), 623-626.

Wilson, G. E., Schroepfer, T. W., & Huang, J. Y. C. (1980). Atmospheric sublayer transport and odor control. *Journal of the Environmental Engineering Division, 106*(2), 389-401.

Winneke, G. (1992). Structure and determinants of psychophysiological response to odorant/irritant air pollution. *Annals of the New York Academy of Sciences, 641*(1), 261-276.

World Health Organisation. (2016). Sanitation Retrieved 7 April, 2016, from http://www.who.int/topics/sanitation/en/

Wright, R. H. (1982). *The sense of smell*: CRC Press Boca Raton, FL.

Yoshimura, M., Nakano, Y., Yamashita, Y., Oho, T., Saito, T., & Koga, T. (2000). Formation of Methyl Mercaptan froml-Methionine by Porphyromonas gingivalis. *Infection and immunity, 68*(12), 6912-6916.

Young, P. (1984). Odours from effluent and waste treatment. *Effluent & water treatment journal, 24*(5), 189-195.

Zhang, Q., Zhou, X., Guo, H., Li, Y., & Cicek, N. (2005). Odour and greenhouse gas emissions from hog operations. *Final Report Submitted to Manitoba Livestock Manure Management Initiative Inc*.

APPENDICES

APPENDIX 1: QUESTIONNAIRE FOR ODOUR IMPACT ASSESSMENT

GENERAL INFORMATION

NAME OF ENUMERATOR: …….....

SUB-METRO: .....COMMUNITY: .....

HOUSE NO.: ..... DATE: .....

1	**RESPONDENT CHARACTERISTICS**	
1a	Sex of Respondent	
	Male	1
	Female	2
1b	How old are you?	
	Below 18 years	1
	Above 18 years	2
1c	Do you have a household or communal toilet facility?	
	Household	1
	Communal	2
2	**ODOUR IMPACT INVESTIGATION**	
2a	Do you notice odour or smell around your home?	
	Yes	1
	No	2
2b	How often do you notice an odour or smell in or around your home?	
	All the time	1

	Often	2
	Sometimes	3
	Seldom	4
2c	During what time of the day is do you experience the odour most?	
	Morning	1
	Afternoon	2
	Evening	3
	Dawn	4
2d	To what degree does this odour annoy you?	
	Definitely not annoying	1
	Some annoyance	2
	Annoying	3
	Very annoying	4
	Extremely annoying	5
2e	What do you think is/are the most common source of this odour?	
	.....	
	.....	
	.....	
2f	Can you describe this odour?	
	Floral :	
	Medicinal:	
	Chemical:	
	Fishy:	
	Offensive:	
	Earthy:	
	Vegetable:	
	Fruity:	
2e	Would you like a communal toilet situated closer to your house	

	Yes No If NO, Why?	1 2

APPENDIX 2: DESCRIPTION OF DYNAMIC PLUME METHOD OF FIELD ODOUR MEASUREMENT

This European Standard describes the Plume Method for determining the extent of detectable and recognisable odours from a specific source using direct observation in the field by human panel members under specific meteorological conditions.

With the plume method the presence or absence (YES/NO) of recognisable odours in and around the plume originating from a specific odour emission source, under a specified emission situation and meteorological conditions (specific wind direction, wind speed and boundary layer turbulence) is determined. The unit of measurement is the presence or absence of recognisable odours at a particular downwind location. The extent of the plume is assessed as the transition of absence to presence of recognisable odour.

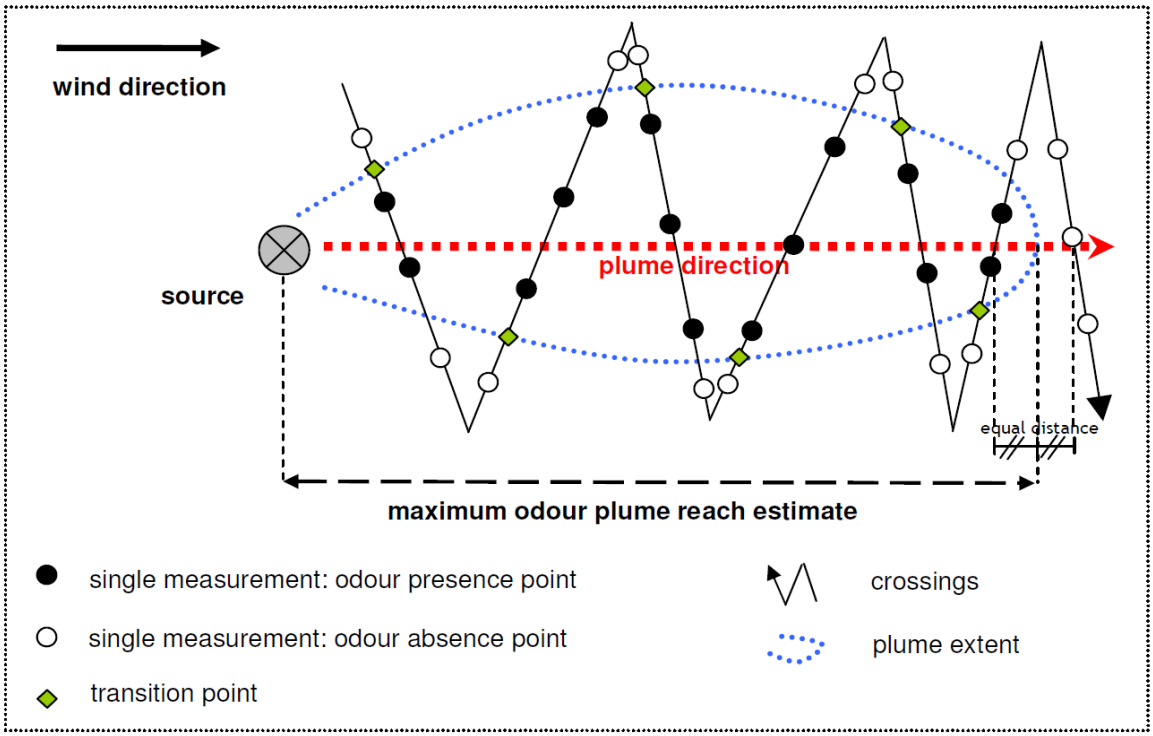
The primary application of this standard is to provide a common basis for the determination of the plume extent in the member states of the European Union. The results are typically used to determine a plausible extent of potential exposure to recognizable odours, or to estimate the total emission rate using reverse dispersion modelling.

The plume method includes two approaches, the stationary and the dynamic method. For this assignment, the dynamic approach was used and described as follows:

Dynamic plume method

A measurement cycle shall be conducted by at least two panel members who each contribute approximately equal shares of the single measurement results. A measurement

cycle shall consist of at least 40 single measurements, from which at least 20 transition points (absence to presence) can be determined. The maximum plume reach estimate shall be determined from observations obtained during two crossings, one of which including at least one odour presence point observation, and another crossing where only odour absence point observations are recorded. The distance between the crossing without odour presence point observations and the nearest crossing with odour presence point observation(s) shall be less than 20% of the maximum odour plume reach as determined from these observations. At least 8 transition points (absence to presence), 4 at either side of the plume, shall be recorded at distances along the plume direction between 30% and 70% of the maximum odour plume reach.



APPENDIX 3: ODOUR MONITROTING DATA SHEET

ODOUR MONITORING DATA SHEET Page _____ of _____

Date: _____ Inspector Code: _____ Signature: _____

Name: _____

	Time	Location	60-2	<2	ND	H.T.	Descriptors 1	2	3	4	5	Wea	Prec	Wind	Speed	Temp	RH	BP	Comments
1																			
2																			
3																			
4																			
5																			
6																			
7																			
8																			
9																			
10																			
11																			
12																			
13																			
14																			
15																			
16																			
17																			
18																			
19																			
20																			

Additional comments:

KEY: ***Weather:*** Mostly **S**unny; **P**artly Cloudy; Mostly **C**loudy; **O**vercast; **H**azy

Precipitation: **N**one; **F**og; **R**ain; **Sl**eet; **Sn**ow

Wind Direction (blowing from): **N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, NNW**

Wind Speed: **C**alm (<1); **L**ight Breeze (1-5 mph); **M**oderate Wind (5-15 mph); **S**trong Wind (>15 mph)

APPENDIX 4: PROCEDURE FOR TESTING INDIVIDUAL ODOUR SENSITIVITY

1. Test administrator presents odour pen 4 to the test individual to familiarize the test individual with the odour of n-butanol. The sniffing technique used in the evaluation is to sniff as if naturally sniffing the end of a felt tip marker.

2. Test individual places blindfold over eyes to prevent visual detection of odour pens.

3. Test administrator is to complete the top portion of the Odour Sensitivity Test Data Sheet. Fill in the name of the testing individual and the date of the test.

4. Test administrator starts Pretest, Test #1, with odour pen 15 and will furthermore present every other odour pen dilution level (i.e. 15, 13, 11). Lay the pen triplets (odour containing pen, one blank used twice) on the table that will be presented for the beginning dilution series in the order corresponding to the sequence on the Test Data Sheet.

5. Test administrator states the first pen of the triplet verbally to the test individual as "Number One Pen." The test individual will smell each odour pen twice, once under each nostril. The administrator will remove the pen cap and the statement "Sniff" will be made when the pen is presented to the right and left nostril. The pen is to be held for three seconds, 1/4" below each nostril. Note: Test Administrator does not allow the odour pen to contact skin or facial hair on the individual.

6. Test individual will sniff the odour pen when directed and is required to remember the pen number that was presented (Number One Pen).

7. Test administrator replaces the cap on the odour pen. The second pen in the triplet sequence is verbally announced as "Number Two Pen". The administrator will remove the pen cap and the statement "Sniff" will be made when the pen is presented to the right and left nostril. The pen is to be held for three seconds, 1/4" below each nostril.

8. Test individual will sniff the odour pen when directed and is required to remember the pen number that is presented (Number Two Pen).

9. Test administrator replaces the cap on the odour pen. The third pen is verbally announced as "Number Three Pen". The administrator will remove the pen cap and the statement "Sniff" will be made when the pen is presented to the right and left nostril. The pen is to be held for three seconds, 1/4" below each nostril.

10. Test individual will sniff the odour pen when directed and is required to remember the pen number that is presented (Number Three Pen).

11. Test individual indicates which one pen of the three presented (One, Two, Three) is different from the other two pens. The test individual must indicate their response as a guess or detect.

12. Test administrator records the individual's observation in the first, second or third box in the dilution level row on the Test Data Sheet. The response is recorded as "G" for guess and "D" for detect.

13. Test administrator replaces the 15 odour pen in the "Sniffin Sticks" box and selects odour pen 13, the next odour pen dilution level to be observed. Lay the pen triplets (odour containing pen, two blanks) on the table in the order corresponding to the sequence on the Test Data Sheet.

14. Test administrator waits thirty seconds before proceeding to the presentation of the odour pen 13 and blank pen triplet, following the same procedure as used for the odour pen 15 (see above steps 3-11)

15. Test administrator concludes the Pretest, Test #1 when the test individual has indicated two correct consecutive detects. Correct guesses are not considered correct detects.

16. Test administrator waits three minutes before starting Test #2. Start Test #2 with the odour pen three dilution levels above the first correct detect of the Pretest, Test #1 [refer to attached example that indicates odour pen 5 as the first correct detect, odour pen 4 as the second correct detect (refer to step 15), therefore, select odour pen 8 to begin Test #2]. Proceed by laying the pen triplets (odour containing pen, two blanks, where one odour pen is used as both blanks) on the table in the presentation order corresponding to the sequence on the Test Data Sheet. NOTE: Test #2 requires the odour pen level to proceed in sequence, thus the test administrator will furthermore select the odour pen at the next dilution level lower than the preceding level. Example: In Test #2, the presentation following odour pen 8 will be odour pen 7.

17. Test administrator follows the Pretest, Test #1 procedure for Test #2 with the exception of not skipping every-other odour pen, as noted above.

18. Test individual continues to observe the pens when presented and indicates guess or detect for the different pen in the triplet.

19. Test administrator concludes Test #2 when the test individual has indicated two correct consecutive detects. Correct guesses are not considered correct detects.

20. Test administrator scores Test #2. The dilution level of the first of two consecutive correct detects is the score (refer to attached example that indicates a scored Test #2).

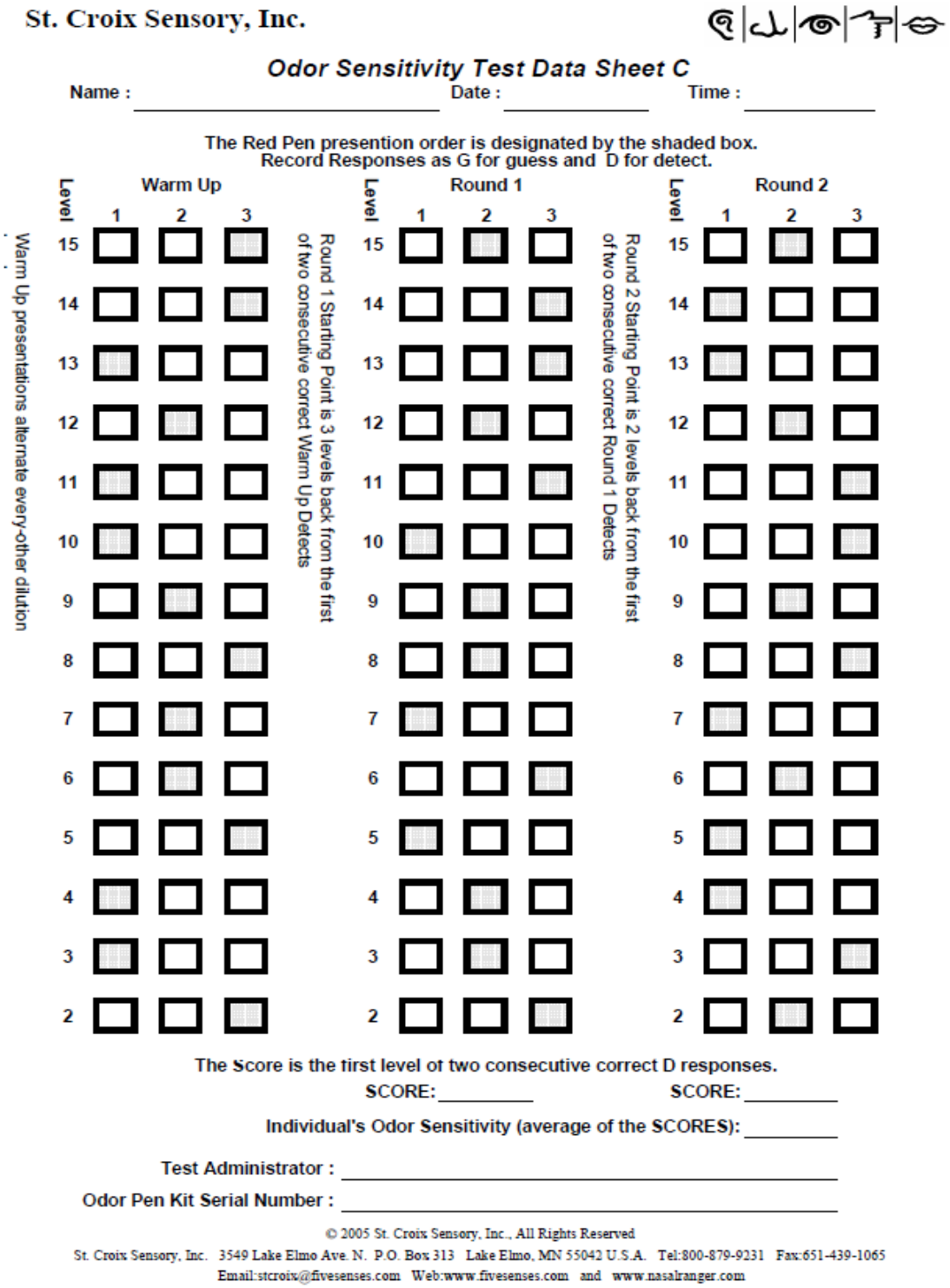
21. Test administrator waits five minutes before starting Test #3. Start Test #3 with the odour pen two dilution levels above the first correct detect of Test #2 (refer to attached example that indicates odour pen 6 as the first correct detect; therefore, select odour pen 8 to begin Test #3). Proceed by laying the pen triplets (odour containing pen, two blanks, where one blank pen is used twice) on the table in the presentation order corresponding to the sequence on the Test Data Sheet. NOTE: Test #3 requires the odour pen level to proceed in sequence, thus the test administrator will furthermore select the odour pen at the next dilution level lower than the preceding level. Example: the presentation following odour pen 8 will be odour pen 7.

22. Test administrator concludes Test #3 when the test individual indicated two correct consecutive detects. Correct guesses are not considered correct detects.

23. Test administrator scores Test #3. The dilution level of the first of two consecutive correct detects is the score (refer to attached example that indicates a scored Test #3).

24. Test administrator averages the scores of Test #2 and Test #3 to generate the tested individual's olfactory (odour) threshold estimate (refer to attached example that indicates the tested individual's odour threshold).

APPENDIX 5: ODOUR SENSITIVITY TEST DATA SHEET



St. Croix Sensory, Inc.

Odor Sensitivity Test Data Sheet C

Name : _____ Date : _____ Time : _____

The Red Pen presention order is designated by the shaded box.
Record Responses as G for guess and D for detect.

Warm Up presentations alternate every-other dilution

Level	Warm Up 1	Warm Up 2	Warm Up 3	Round 1 1	Round 1 2	Round 1 3	Round 2 1	Round 2 2	Round 2 3
15			■		■			■	
14			■			■	■		
13	■					■			■
12		■			■			■	
11	■					■			■
10	■			■					■
9		■			■			■	
8			■						■
7		■		■			■		
6		■				■			
5			■	■			■		
4	■				■		■		
3	■				■				■
2			■			■		■	

Round 1 Starting Point is 3 levels back from the first of two consecutive correct Warm Up Detects

Round 2 Starting Point is 2 levels back from the first of two consecutive correct Round 1 Detects

The Score is the first level of two consecutive correct D responses.

SCORE:_____ SCORE:_____

Individual's Odor Sensitivity (average of the SCORES): _____

Test Administrator : _____

Odor Pen Kit Serial Number : _____

St. Croix Sensory, Inc. 3549 Lake Elmo Ave. N. P.O. Box 313 Lake Elmo, MN 55042 U.S.A. Tel:800-879-9231 Fax:651-439-1065
Email:stcroix@fivesenses.com Web:www.fivesenses.com and www.nasalranger.com

APPENDIX 6: FREQUENCY DISTRIBUTION OF WIND DIRECTION

Wind Direction (N = 670)	Frequency	Percent	Cumulative Frequency	Cumulative Percent
E	1	0.1	1	.1
ENE	1	0.1	2	.3
SE	1	0.1	3	.4
ESE	3	0.4	6	.9
N	3	0.4	9	1.3
NNE	6	0.9	15	2.2
NE	10	1.5	25	3.7
NNW	12	1.8	37	5.5
NW	14	2.1	51	7.6
SSE	15	2.2	66	9.9
WNW	37	5.5	103	15.4
S	56	8.4	159	23.7
W	78	11.6	237	35.4
SSW	91	13.6	328	49.0
SW	169	25.2	497	74.2
WSW	173	25.8	670	100.0
Chi square = 1171.30, df = 15, p = 0.005 (p < 0.05)				

APPENDIX 7: DESCRIPTIVE STATISTICS OF WEATHER VARIABLES

Statistic (N = 670)	Temperature (^{o}C)	Wind Speed (m/s)	Relative Humidity (%)
Mean	28.47	0.83	75.14
Median	29.10	0.80	72.55
SD	2.69	0.527	11.93
Range	11.20	2.60	45.50
Minimum	22.80	0.00	53.90
Maximum	34.00	2.60	99.40

APPENDIX 8: DETERMINATION OF SOIL pH

INTRODUCTION

The pH value of a solution is defined, by the Sorenson Equation as the negative logarithm (to base 10) of the hydrogen ion (H^+) activity (concentration), or the logarithm of the reciprocal of the H ion concentration in a given solution.

ie $pH = \log [H+] = \log \frac{1}{[H+]}$ ⟶ Sorenson Equation

OR $H^+ = 10^{-pH}$ molar

There Electrometric method of pH determination was used

APPARATUS

$_P{}^H$ meter, Glass electrode, beakers (100ml, 150ml, 250ml) stirring rods, spatula, distilled water.

PROCEDURE

1. 10 g air- dried sample was weighed into a 50 ml beaker.
2. 10 ml of distilled water was added.
3. Suspension was stirred vigorously for the next 20 minutes.
4. The sample – water suspension was allowed to stand for 30 minutes by which time most of the suspended matter would have settled out from the suspension.
5. pH meter was calibrated with blank at pH of 7 and 4 respectively.
6. Electrode of the pH meter was inserted into the partly settled suspension.
7. pH value was read on the pH meter and results recorded

APPENDIX 9: DETERMINATION OF PERCENT TOTAL NITROGEN BY KJELDAHL METHOD

INTRODUCTION

Almost all of the soil Nitrogen is bound up in the organic matter (O.M), and the basic principle involved in assessing or estimating the quantity held up in this manner is to boil a weighed quantity of the soil with concentrated sulphuric acid. The nitrogen is thus converted into sulphate of ammonia [$(NH_4)_2SO_4$] and at the same time, the carbonaceous matter is oxidized to carbon dioxide (CO_2) with the sulphuric acid being reduced to sulphur dioxide (SO_2).

This is essentially a wet – oxidation process which involves two main steps:

1. The sample was digested to convert organic N to ammonium – N by sulphuric acid
2. Determination of the ammonium in the acid digest - The digestion was performed by heating the sample with H_2SO_4 containing substances which promote the oxidation of organic matter.

The completion of the reaction is shown by the liquid becoming clear and colourless or light green.

REAGENTS AND EQUIPMENT

1. Conc. H_2SO_4 (ammonia – free grade)
2. 40 % % Boric acid solution ($H_3\ BO_3$)
3. Catalyst: selenium : 1

   : copper sulphate ($CuSO_4$) : 10

   : Potassium or sodium sulphate (K_2SO_4/Na_2SO_4) : 100
4. Mixed indicator or Bromocresol green (**0.066 g**) and methyl red (**0.099 g**) in 100 ml ethyl alcohol. Add 20 ml of mixed indicator to each litre of 2 % boric acid solution.
5. 0. l N Standard HCl (***Dilute 8.6 ml conc. HCl in 1 litre deionised water)***
6. Kjeldahl flask, 500ml

7. Steam Distillation system unit
8. Volumetric flask

10. Conical flask, 200ml.

PROCEDURE

DIGESTION:

1. 10 g of air dry sample was weighed into a 500 ml long – necked Kjeldahl flask. Sample was mixed uniformly before weighing.
2. 10 ml of distilled water was added and allowed to stand for 10 minutes to moisten.
3. One spatula full of Kjeldahl catalyst [mixture of l part Selenium + 10 parts $CuSO_4$ + 100 parts Na_2SO_4] was added
4. 30 ml conc. H_2SO_4 was added
5. Resulting sample was digested until clear and colourless or light greenish (1-1 1/2 hrs)
6. Flask was allowed to cool
7. Digest was decanted into a 100 ml volumetric flask and made up to the mark with distilled water with rinsings from the digestion flask.

DISTILLATION

1. Aliquot was transfer of 10 ml of digest by means of pipette into the Kjeldahl distillation apparatus provided.
2. 20 ml of 40 % NaOH was added
3. Distillate was collected over 10 ml of 4 % Boric acid and three (3) drops of mixed indicator in a 500 ml conical flask for 5 minutes. About 200 ml of distillate was collected. The presence of Nitrogen gives a light blue colour.

TITRATION

1. Collected distillate was titrated (about 100 ml) with 0.l N HCl till blue colour changes to grey and then suddenly flashes to pink.

NB: A blank determination must necessarily be carried out without the soil sample.

CALCULATION

14 g of N contained in one equivalent weight of NH_3

:. Weight of N in the soil = $\frac{14 \times (A - B) \times N}{1000}$

NB: Weight of soil sample used, considering the dilution and the aliquot taken for distillation = $\frac{10\text{ g} \times 10\text{ ml}}{100\text{ ml}}$ = l.0 g

Thus, the percentage of Nitrogen in the soil sample is,

$$\% N = \frac{14.01 * (V - B) * N * R * 100}{1000 \times \text{Wt. of sample}}$$

Where,

R= ratio between total volume of digest and digest volume (aliquot) for distillation

N = normality of HCl = 0.1 N

V = volume of HCl titrated for the sample

B = digested blank titration volume

NB:

When N = 0. l and B = 0

$$\% \text{ Nitrogen} = A*R* 0.14$$

APPENDIX 10: DETERMINATION (NH_4-N AND NO_3-N)

REAGENTS

A. Potassium Chloride Solution (KCl), 2 M

B. Magnesium Oxide (MgO), powder

C. Devarda's Alloy (50 Cu: 45 Al: 5 Zn)

D. Boric Acid Solution (H_3BO_3), saturated

E. Sulfuric Acid Solution (H_2SO_4), 0.01 N

F. Standard Stock Solution

• Dry reagent-grade ammonium sulphate [$(NH_4)_2SO_4$], and potassium nitrate (KNO_3), in an oven at 100°C for 2 hours, cool in a desiccator, and store in a tightly stoppered bottle.

• Dissolve 5.6605 g ammonium sulphate and 8.6624 g potassium nitrate in DI water, and transfer to a 1-L volumetric flask, mix well, and bring to volume with DI water. This solution contains 1.2 g NH_4-N, and 1.2 g NO_3-N per Liter (Stock Solution).

• Prepare a Standard Solution from the Stock Solution as follows:

Dilute 50 mL Stock Solution to 1-L volume by adding 2 M potassium chloride solution (Diluted Stock Solution).

• A 20-mL aliquot of Diluted Stock Solution contains 1.2 mg NH_4-N and 1.2 mg NO_3-N.

Procedure

1. Weigh 10 g air-dry soil (2 mm) into a 250-mL Plastic bottle, and add 50 mL 2 M potassium chloride solution (1:5 soil: solution ratio).

2. Stopper bottle, shake for 1 hour on an orbital shaker at 200 - 300 rpm.

3. Centrifuge at 3000 rpm for 15 minutes.

4. Before starting distillation, the distillation unit should be steamed out for at least 10 minutes. Adjust steam rate to 7 - 8 mL distillate per minute.

5. Water should flow through the condenser jacket at a rate sufficient to keep distillate temperature below 22°C.

6. Carry out distillations as follows:

• Dispense 1 mL saturated boric acid solution and 1 mL DI water into a 100-mL Pyrex evaporating dish, placed underneath the condenser tip, with the tip touching the solution surface.

• Pipette 20 mL aliquot of the clear supernatant into a 100-mL distillation flask.

• To determine NH-N in solution, add 0.2 g heavy magnesium oxide with a calibrated spoon to the distillation flask.

• Immediately attach the flask to the distillation unit with a clamp, start distillation, and continue for 3 minutes. Lower the dish to allow distillate to drain freely into the dish.

• After 4 minutes, when about 35 mL distillate is collected, turn off the steam supply, and wash tip of the condenser into the evaporating dish with a small amount of DI water.

• Titrate the distillate to pH 5.0 with standardized 0.01 N H_2SO_4 using the Auto-Titrator.

• After finishing titration, wash the Teflon-coated magnetic stirring bar, the burette tip, and the combined electrode into the dish.

• To determine NO_3-N (plus NO_2-N) in the same extract, add 0.2 g Devarda's alloy with a calibrated spoon to the same distillation flask.

• Attach flask to distillation unit with a clamp, and start distilling. Further proceed as for ammonium-N.

• Between different samples, steam out the distillations. Disconnect distillation flasks containing the KCl extracts, and attach a 100-ml empty distillation flask to distillation unit, and place a 100- mL empty beaker underneath the condenser tip, turn off cooling water supply (drain the water from the condenser jacket), and steam out for 90 seconds. Steaming-out is done only between different samples, not between distillation for ammonium (MgO) and nitrate (Devarda's alloy) in the same sample.

• Each distillation should contain at least two standards and two blanks, i.e., 2 M KCl extracts with no soil added (reagent blanks).

CALCULATIONS

For Ammonium-N in air-dry soil:

$$NH_4 - N\ (ppm) = \frac{(V - B) \times N \times R \times 14.01 \times 1000}{Wt} \quad \text{..... (28)}$$

For Ammonium-N in oven-dry soil:

NH_4 - N (ppm) = $\frac{(V - B) \times N \times R \times 14.01 \times 1000}{Wt - \theta}$ ..... (29)

For Nitrate-N in air-dry soil:

NO_3 - N (ppm) = $\frac{(V - B) \times N \times R \times 14.01 \times 1000}{Wt}$ ..... (30)

For Nitrate-N in oven-dry soil:

NO_3 - N (ppm) = $\frac{(V - B) \times N \times R \times 14.01 \times 1000}{Wt - \theta}$ ..... (31)

Where: V = Volume of 0.01 N H_2SO_4 titrated for the sample (mL)

B = Blank titration volume (mL)

N = Normality of H_2SO_4 solution.

14.01 = Atomic weight of N.

R = Ratio between total volume of the extract and the extract volume used for distillation.

Wt = Weight of air-dry soil (10 g)

θ = Weight of water (g) per 10 g air-dry soil.

APPENDIX 11: QUANTITATIVE RESULTS OF ANALYSIS OF EXPERIMENTAL SMAPLES

5-1: Control Experiment

	Day 1					Day 2					Day 3					Day 4					Day 5				
Parameter	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD
H2S (ug/m3)	108.0	112.0	104.0	108.0	4.0	92.0	112.0	104.0	102.7	10.1	84.0	96.0	100.0	93.3	8.3	80.0	76.0	84.0	80.0	4.0	60.0	52.0	56.0	56.0	4.0
NH4+	47.0	45.0	43.0	45.0	2.0	44.0	39.0	40.0	41.0	2.6	25.0	21.0	21.0	22.3	2.3	14.0	18.0	17.0	16.3	2.1	15.0	13.0	15.0	14.3	1.2
pH	6.40	6.50	6.60	6.50	0.1	6.26	6.24	6.28	6.26	0.02	6.44	6.38	6.36	6.39	0.0	6.53	6.51	6.56	6.53	0.03	6.60	6.45	6.43	6.49	0.1
NH3 (ug/m3)	33.0	35.0	36.0	34.7	1.5	26.0	23.0	22.0	23.7	2.1	27.0	29.0	32.0	29.3	2.5	41.0	37.0	35.0	37.7	3.1	39.0	37.0	34.0	36.7	2.5
Sulphate	157.0	160.0	158.0	158	1.5	124.0	125.0	121.0	123.3	2.1	107.0	105.0	99.0	103.7	4.2	87.0	85.0	82.0	84.7	2.5	75.0	77.0	71.0	74.3	3.1
TKN	55.0	52.0	51.0	52.7	2.1	49.0	53.0	50.0	50.7	2.1	48.0	48.0	45.0	47.0	1.7	46.0	43.0	45.0	44.7	1.5	44.0	40.0	42.0	42.0	2.0

5-2: 5% Coconut Fibre Ash Addition

	Day 1					Day 2					Day 3					Day 4					Day 5				
Parameter	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD
H2S (ug/m3)	104	104	100	102.7	2.309	92	104	100	98.67	6.11	80.0	96.0	104.0	93.33	12.22	72	76	72	73.33	2.309	52	48	52	50.67	2.309
NH4+	39	44	43	42	2.646	39	35	38	37.33	2.082	37	30	31	32.67	3.786	31	26	25	27.33	3.215	25	24	21	23.33	2.082
pH	7.81	7.68	7.85	7.78	0.09	7.6	7.52	7.52	7.55	0.05	7.63	7.58	7.55	7.59	0.04	7.29	7.25	7.22	7.25	0.04	7.34	7.3	7.28	7.31	0.03
NH3 (ug/m3)	37	39	41	39	2	40	45	43	42.67	2.517	47	49	52	49.33	2.517	66	68	62	65.33	3.055	79	78	74	77	2.646
Sulphate	156	159	159	158	1.732	129	130	133	130.7	2.082	115	109	111	111.7	3.055	79	84	86	83	3.606	74	70	75	73	2.646
TKN	50	51	47	49.33	2.082	46	44	44	44.67	1.155	40	40	36	38.67	2.309	34	33	31	32.67	1.528	30	31	27	29.33	2.082

5-3: 12.5% Coconut Fibre Ash Addition

	Day 1					Day 2					Day 3					Day 4					Day 5				
Parameter	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD
H2S (ug/m3)	88	96	92	92	4	72	96	92	86.67	12.86	52	68	76	65.33	12.22	36	36	36	36	4E-14	28	24	28	26.67	2.309
NH4+	43	37	38	39.33	3.215	34	35	30	33	2.646	32	26	30	29.33	3.055	24	27	23	24.67	2.082	18	21	19	19.33	1.528
pH	7.94	8.21	8.29	8.15	0.18	7.93	7.86	7.91	7.90	0.04	7.65	7.6	7.55	7.6	0.05	7.47	7.53	7.46	7.49	0.04	7.44	7.39	7.36	7.40	0.04
NH3 (ug/m3)	39	45	43	42.33	3.055	42	47	54	47.67	6.028	52	54	57	54.33	2.517	69	68	73	70	2.646	82	80	85	82.33	2.517
Sulphate	150	152	146	149	3.055	130	126	124	126.7	3.055	112	117	116	115	2.646	76	79	82	79	3	74	71	75	73.33	2.082
TKN	45	47	45	45.67	1.155	44	40	39	41	2.646	38	36	35	36.33	1.528	29	34	30	31	2.646	27	22	22	23.67	2.887

5-4: 25% Coconut Fibre Ash Addition

	Day 1					Day 2					Day 3					Day 4					Day 5				
Parameter	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD
H2S (ug/m3)	92	84	88	88	4	72	84	88	81.33	8.327	44	44	40	42.67	2.309	28	24	24	25.33	2.309	16	16	20	17.33	2.309
NH4+	35	33	37	35	2	25	26	30	27	2.646	23	25	22	23.33	1.528	17	22	19	19.33	2.517	14	18	15	15.67	2.082
pH	9.08	9.11	9.2	9.13	0.06	8.15	8.25	8.23	8.21	0.05	8.01	7.97	8.05	8.01	0.04	8.61	8.65	8.6	8.62	0.03	8.26	8.33	8.25	8.28	0.04
NH3 (ug/m3)	47	51	45	47.67	3.055	54	60	57	57	3	65	66	61	64	2.646	75	81	79	78.33	3.055	87	92	90	89.67	2.517
Sulphate	157	153	150	153	3.512	132	134	136	134	2	112	109	107	109.3	2.517	90	82	93	88.33	5.686	79	74	72	75	3.606
TKN	44	41	40	41.67	2.082	39	39	40	39.33	0.577	37	33	35	35	2	25	25	30	26.67	2.887	19	24	20	21	2.646

5-5: 5% Cocoa Husk Ash Addition

	Day 1					Day 2					Day 3					Day 4					Day 5				
Parameter	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD
H2S (ug/m3)	108	104	104	105.3	2.309	92	104	104	100	6.928	80	84	76	80	4	64	72	68	68	4	60	64	64	62.67	2.309
NH4+	44	41	39	41.33	2.517	39	40	36	38.33	2.082	35	32	31	32.67	2.082	29	27	24	26.67	2.517	24	20	19	21	2.646
pH	7.14	7.18	7.15	7.16	0.02	7.17	7.21	7.2	7.19	0.02	7.5	7.63	7.59	7.57	0.07	7.6	7.62	7.62	7.61	0.01	8.8	8.85	8.83	8.83	0.03
NH3 (ug/m3)	37	42	45	41.33	4.041	52	50	45	49	3.606	53	55	58	55.33	2.517	78	74	74	75.33	2.309	84	77	86	82.33	4.726
Sulphate	139	140	136	138	2.082	132	127	126	128.3	3.215	120	113	117	116.7	3.512	87.0	85.0	82.0	84.67	2.517	70	64	65	66.33	3.215
TKN	47	49	44	46.67	2.517	45	42	44	43.67	1.528	38	37	38	37.67	0.577	30	32	29	30.33	1.528	26	25	22	24.33	2.082

5-6: 12.5% Cocoa Husk Ash Addition

	Day 1					Day 2					Day 3					Day 4					Day 5				
Parameter	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD
H2S (ug/m3)	100	100	96	98.67	2.309	88	100	96	94.67	6.11	64	72	68	68	4	40	44	44	42.67	2.309	32	32	40	34.67	4.619
NH4+	29	34	30	31	2.646	28	30	24	27.33	3.055	25	24	22	23.67	1.528	20	17	21	19.33	2.082	19	15	14	16	2.646
pH	8.2	8.24	8.22	8.22	0.02	8.5	8.58	8.48	8.52	0.05	8	8.04	7.98	8.01	0.03	8.1	8.14	8.13	8.12	0.02	8.61	8.63	8.6	8.61	0.02
NH3 (ug/m3)	52	45	46	47.67	3.786	54	57	58	56.33	2.082	65	60	59	61.33	3.215	80	75	77	77.33	2.517	87	92	88	89	2.646
Sulphate	141	147	144	144	3	129	122	126	125.7	3.512	111	107	106	108	2.646	88	87	84	86.33	2.082	69	68	67	68	1
TKN	45	44	42	43.67	1.528	39	38	41	39.33	1.528	33	34	30	32.33	2.082	27	23	25	25	2	19	22	20	20.33	1.528

5-7: 25% Cocoa Husk Ash Addition

	Day 1					Day 2					Day 3					Day 4					Day 5				
Parameter	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD	1	2	3	Avg.	SD
H2S (ug/m3)	84	84	88	85.33	2.309	68	84	88	80	10.58	44	44	52	46.67	4.619	32	32	40	34.67	4.619	28	32	20	26.67	6.11
NH4+	29	27	27	27.67	1.155	22	24	21	22.33	1.528	20	17	17	18	1.732	13	16	15	14.67	1.528	11	13	12	12	1
pH	10.3	10.35	10.3	10.32	0.03	10.17	10.17	10.2	10.18	0.017	10.12	10.16	10.15	10.14	0.02	10.15	10.19	10.13	10.16	0.03	8.59	8.7	8.55	8.61	0.08
NH3 (ug/m3)	54	47	48	49.67	3.786	60	66	63	63	3	69	75	72	72	3	85	80	86	83.67	3.215	92	89	97	92.67	4.041
Sulphate	142	149	144	145	3.606	130	133	129	130.7	2.082	108	103	102	104.3	3.215	77	79	79	78.33	1.155	67	74	73	71.33	3.786
TKN	41	40	41	40.67	0.577	37	33	35	35	2	29	33	30	30.67	2.082	25	23	23	23.67	1.155	18	19	15	17.33	2.082

APPENDIX 12: TYPES OF TOILETS OBSERVED AND THEIR RESPECTIVE OPERATIONAL PRACTICES

Type of Toilet	**Opening hours**	**Frequency of Cleaning**	**No. of Cubicles**		**Frequency of desludging**	**Fee Charged (GHS)**	**Odour Perception**
			Male	Female			
Water Closet Toilet with holding tank	4am – 10pm	Three times a day	11	11	Once a week	0.40	Mild
Water Closet Toilet with holding tank	4am – 10pm	Three times a day	10	10	Once a week	0.40 with old newspaper and 0.50 with toilet roll paper	Mild
Pour flush toilet with holding tank offset	4am – 10pm	Three times a day	10	10	Once a month	0.40 with old newspaper and 0.50 with toilet roll paper	Mild
Pour flush toilet with pit directly beneath	5am – 10pm	Three times a day	5	6	Once a month	0.30	Strong
Simple pit latrine	5am – 8pm	Three times a day	12	4	Once a month	0.30	Strong
Ventilated Pit	3am – 10pm	Three times a day	6	6	Every 2 weeks	0.40	Strong
Enviroloo	5am – 10pm	Three times a day	5	5	Once a month	0.30	Strong
Simple pit latrine	5am – 9pm	Three times a day	5	6	Once a month	0.30	Very strong
Simple pit latrine	4am – 10pm	Three times a day	10	10	Once a month	0.30	Very strong
Simple pit latrine	5am – 9pm	Two times a day	8	8	Once a month	0.40	Very strong
Ventilated Pit	4am – 10pm	Two times a day	8	8	Once a month	0.30	Very Stong

APPENDIX 12: DATA FOR DETERMINNG RELATIONSHIP BETWEEN ODOUR INTENSITY AND CONECENTRATION.

Odour Concentration (ou/m^3)	Log_{10} (Odour Concentation)	Odour Intensity
500	2.70	5
400	2.60	4
400	2.60	4
400	2.60	4
300	2.48	4
400	2.60	5
500	2.70	5
400	2.60	4
500	2.70	5
500	2.70	5
300	2.48	4
400	2.60	4
400	2.60	4
500	2.70	5
500	2.70	5
400	2.60	4
400	2.60	4
400	2.60	4
500	2.70	5
300	2.48	4
300	2.48	4
400	2.60	4
300	2.48	4
400	2.60	4
400	2.60	4
500	2.70	5
500	2.70	5
500	2.70	5
300	2.48	4
400	2.60	4
400	2.60	4
500	2.70	5
500	2.70	5
500	2.70	5
60	1.78	2
400	2.60	4
500	2.70	5
500	2.70	5
400	2.60	4

Odour Concentration (ou/m^3)	Log_{10} (Odour Concentation)	Odour Intensity
400	2.60	4
400	2.60	4
500	2.70	5
500	2.70	5
400	2.60	4
500	2.70	5
300	2.48	4
200	2.30	3
400	2.60	4
500	2.70	5
500	2.70	5
400	2.60	4
300	2.48	4
500	2.70	5
500	2.70	5
100	2.00	3
400	2.60	4
500	2.70	5
300	2.48	4
400	2.60	4
400	2.60	4
300	2.48	4
500	2.70	5
400	2.60	4
200	2.30	3
100	2.00	3
500	2.70	5
400	2.60	4
400	2.60	4
400	2.60	4
300	2.48	4
200	2.30	3
400	2.60	4
400	2.60	4
200	2.30	3
100	2.00	3
200	2.30	3
200	2.30	3
400	2.60	4
300	2.48	4
100	2.00	3
100	2.00	3
100	2.00	3
60	1.78	2

Odour Concentration (ou/m^3)	Log_{10} (Odour Concentation)	Odour Intensity
400	2.60	4
300	2.48	3
400	2.60	4
500	2.70	5
400	2.60	4
400	2.60	4
200	2.30	3
200	2.30	3
100	2.00	3
300	2.48	4
300	2.48	4
300	2.48	4
300	2.48	4
400	2.60	4
400	2.60	4
400	2.60	4
2	0.30	0
0	#NUM!	0
300	2.48	4
200	2.30	2
400	2.60	4
200	2.30	2
100	2.00	2
300	2.48	4
200	2.30	2
300	2.48	4
300	2.48	4
300	2.48	4
300	2.48	4
300	2.48	4
200	2.30	3
60	1.78	2
300	2.48	4
200	2.30	3
300	2.48	4
100	2.00	3
300	2.48	4
100	2.00	3
60	1.78	2
60	1.78	2
100	2.00	3
300	2.48	4
200	2.30	3
200	2.30	3

Odour Concentration (ou/m^3)	Log_{10} (Odour Concentation)	Odour Intensity
200	2.30	3
200	2.30	3
200	2.30	3
200	2.30	3
100	2.00	3
100	2.00	3
100	2.00	3
100	2.00	3
30	1.48	2
60	1.78	2
60	1.78	2
60	1.78	2
60	1.78	2
30	1.48	2
60	1.78	2
7	0.85	1
15	1.18	1
15	1.18	1
30	1.48	2
30	1.48	2
15	1.18	1
7	0.85	1
30	1.48	2
30	1.48	2
100	2.00	3
100	2.00	3
100	2.00	3
100	2.00	3
30	1.48	2
30	1.48	2
30	1.48	2
30	1.48	2
2	0.30	0
4	0.60	0
4	0.60	0
4	0.60	0
15	1.18	1
7	0.85	1
7	0.85	1
7	0.85	1
60	1.78	2
60	1.78	2
60	1.78	2
60	1.78	2

Odour Concentration (ou/m^3)	Log_{10} (Odour Concentation)	Odour Intensity
0	#NUM!	0
0	#NUM!	0
2	0.30	0
2	0.30	0