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Using Biodegradability of Sewage in Ordinary Pit Latrines to Assess their Agricultural Potentials

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Abstract. This research investigated the use of biodegradability of sewage in ordinary pit latrines to assess the performance of such sewage for agricultural purposes. The objective of this paper therefore was to study the biodegradability of faeces in selected pit latrines that would lead to the assessment of the performance of such pits. Both aerobic and anaerobic biodegradability of pit sludges were thus measured. Samples of fresh faecal sludges collected from pit latrines in selected households in Aku community were subjected to laboratory analyses for their physico-chemical and biological characteristics. The results showed that in terms of biochemical oxygen demand (BOD), twelve (12) pits had biodegradability of 80% and above. In the case of chemical oxygen demand (COD) and suspended solids (SS), nine (9) pits had biodegradability of 80% and above. For the volatile solids (VS), eleven (11) pits had biodegradability of 80% and above. Ten (10) pits had ratio of volatile solids to total solids (VS: TS) ranging from 0.90 – 2.93. Using COD: BOD ratio, eleven (11) pits had values ranging from 0.90 – 1.34 indicating that the pits sludges were readily biodegradable and good for agricultural purposes. Lower values showed lower organic contents and lower biodegradability and therefore unsuitable for agricultural purposes. High COD: BOD, VS:TS ratios should therefore be used to assess the performance of pit latrine sludges for higher agricultural productivity considering good user-behaviour, favourable soil and environmental conditions. Excreta collected from such pits should be used to enhance soil fertility.

Keywords: Aerobic and Anaerobic Biodegradability; Best Design Criteria; Pit Sludges; User-Behaviour; Favourable Conditions; Physico-Chemical and Biological Characteristics; Microbial Density; Agricultural Productivity.

I. INTRODUCTION

The use of excreta in agriculture and aquaculture is increasingly considered a method combining water and nutrient recycling, increased household food security and improved nutrition for poor households. Recent interest in excreta use in agriculture and aquaculture has been driven by water scarcity, lack of availability of nutrients and concerns about health and environmental effects. The traditional use of excreta in agriculture and aquaculture has occurred for centuries and continues in many countries including Nigeria.

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In urban and periurban agriculture in less industrialized countries, the use of untreated faecal sludges (i.e. from the contents of on-site sanitation and systems such as unsewered family and public toilets and septic tanks) is widespread. The vast majority of urban dwellers in these countries is served today and will be served in the future by such installations; hence, adequately treating these sludges by appropriate methods to attain safe biosolids or compost constitutes a crucial goal for improving public health. On-site sanitation systems not requiring off-site haulage and treatment, such as double-pit latrines with or without urine diversion (which are being promoted in rural and peri-urban settings in recent years), may also contribute to safeguarding public health. Systems that divert wastes into streams (e.g. urine and faeces) often require less water to operate and are increasingly being seen as alternatives to waterborne sewerage — especially in arid/semi-arid regions. These systems should be managed in such a way as to reduce the potential for disease transmission and maximize the beneficial use of resources. Waste-fed aquaculture occurs mostly in parts of Asia. The intentional use of wastewater and excreta in aquaculture is declining due to urbanization, which reduces the amount of land available for ponds, and the switch to high-input aquaculture, which is not compatible with traditional waste-fed practices. The unintentional use of wastewater, excreta and greywater in aquaculture is probably increasing, because surface waters used for aquaculture are increasingly polluted with human waste, and overall aqua-cultural production is growing.

II. LITERATURE REVIEW

The main disposal routes of sludge are incineration, sanitary landfill, or use for land-based applications including structural soil improvement, soil buffer, and soil amendment Application of treated sewage sludge as amendment to land could account for the larger part of the nitrogen and phosphorus requirements for many crops. Moreover, the use of sludge on land, principally in agriculture, compared to incineration or sanitary landfill, has lower costs. For this reason in Europe, in particular in the Mediterranean region where high summer temperatures combined with intensive and inappropriate cultivation practices promote a constant decrease in the soil organic matter .40% of sewage sludge is used as a soil organic amendment due to its high organic matter content. The use of sludge in the agricultural sector varies greatly among Member States. In some EU15 countries— Walloon Region of Belgium, Denmark, France, Ireland, Spain, and the UK—more than half of all sludge production is used in agriculture, but in three of the EU27 Member States, no sludge is used in the agricultural sector (Romania, Brussels Region, and Flemish Region of Belgium), and in six other countries (Finland, Netherland, Romania, Slovakia, Greece, and Slovenia) the amounts are less than 5% of the total sludge produced.

A. Faecal Biodegradability in Pit Latrines

Biodegradability of faecal sludge in pit latrines involves the conversion of over 90% material into carbon dioxide and water by the action of micro-organisms. In his work, Sims et al., (1999) found out that during biodegradation process, there is the disintegration of materials by bacteria, fungi, or other biological means. Faecal matter deposited into the pit latrine undergoes some level of biodegradability [35]. The extent to which this occurs depends on several factors such as type of food nutrient, population of users, type of anal cleansing materials, soil characteristics and ground conditions, age of depositors, total solids and suspended solids contents, amount of moisture in the substrate, pH of the sludge, microbial density, inflow and infiltration capacity of the soil, characteristics of the surrounding soil, etc.

Excreta deposited into a pit latrine is subject to some level of biodegradability which substantially reduces the volume of the sludge [30]. There have been a limited number of studies reported on decomposition within pit latrines, and only anecdotal evidence into factors that can slow down or speed up decomposition (Couderc et al., 2008; Nwaneri et al., 2008; Ugwu, 2015) [7]. Regardless, microbial communities will play an important role in organic matter degradation within pit latrines, though little is known about the microbial communities present in pit latrines and their association with faecal decomposition within the pit environment [31]. The physico-chemical and biological characteristics of faecal sludge are critical in assessing the effect of sewage co-treatment with domestic sewage in a municipal wastewater plant or its co-digestion with sludge [32]. Work on the degradation of faeces in VIP latrine was carried out by Nwaneri et al (2008) [25]. Another work on the degradation of faeces in ordinary pit latrine was carried out by Ugwu (2015) [29].

In their work, they carried out the physico-chemical and biological characteristics of fresh faeces from a household and established four stages of sludge decomposition [18]. Biodegradation of pit sludge is mainly anaerobic with aerobic decomposition occurring at the surface [33]. Anaerobic digestion involves the degradation and stabilization of organic materials under anaerobic conditions by microorganisms leading to the formation of biogas (a mixture of CO_2 and CH_4) a renewable energy source and microbial and biomass (Kelleher et al., 2002) [26]. Anaerobic decomposition provides relatively little energy to the microorganisms, resulting in a slow growth rate and a small portion of the waste being converted to new biomass [34]. Moreover, anaerobic digestion generally produces gaseous methane as an energy resource (Lettinga, 1995; Sekiguchi et al. [27], 2001) [20]. The biodegradability for the faecal sludge in each pit latrine can be computed using the following expression:,

$$\%\ Biodegradability = \frac{surface\ value - bottom\ value}{surface\ value}\ x\ 100 \quad \dots \quad (1)$$

B. Characteristics of Pit Sludge

Biodegradability relates to the level of disintegration of materials by bacteria, fungi, or other biological means [36]. Organic material can be degraded aerobically with oxygen, or anaerobically, without oxygen. Biosurfactant, an extracellular surfactant secreted by microorganisms, enhances the biodegradability process [37].

Earlier studies have been done by Foxon et al (2008) to characterize pit contents but will be repeated here due to variations in dietary intake [15]. Studies done by (Lopez et al. [22], 2002) and (Lopez et al [23], 2004) to characterize faeces and to describe the biodegradability of organic matter present in faeces showed that 75-80% of human faeces comprised of slowly biodegradable organic matter while 15-20% is inert material. Readily biodegradable organic matter was not regarded as a component of faeces (i.e. = 0%). The study went further to show that only 15% of the slowly biodegradable material was easily hydrolysable whereas 65% was slowly hydrolysable (Lopez et al., 2014). Human faeces is high in organic matter, contributing about 44% of COD load in domestic wastewater (Almeida et al., 1999) [2]. The slowly biodegradable portion cannot be utilized directly by microorganisms and so has to be made accessible through cell external hydrolyte (enzymatic) reaction (Lopez et al., 2004).

Biodegradable matter is generally organic material that serves as a nutrient for microorganisms. Microorganisms are so numerous and diverse that, a huge range of compounds are biodegraded, including hydrocarbons (e.g. oil), polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), pharmaceutical substances. Decomposition of biodegradable substances may include both biological and abiotic steps. The value of the ratio of volatile solids to total solids helps to reveal the extent to which faecal sludge has been biodegraded. If the concentration of volatile solids is higher than that of the total solids, there is more likely that the biodegradability will be higher considering other favourable conditions such as temperature, moisture content, pH, microbial density, soil conditions and of course good user-behaviour. This will also result in lower filling rate and longer life span of the pits. The higher the value, the more the organic content and subsequently greater biodegradability.

C. Factors Affecting the Efficiency of Faecal Decomposition Process in Pit Latrine

A number of factors determine the degradation rate of organic compounds (Sims et al., 1999) [28]. If the population of viable micro-organisms present in the waste heap is high and environmental conditions are suitable, a high rate of stabilization of feed material will be achieved. Thermophilic anaerobic digestion at between temperatures of 55^0C – 65^0C has additional benefits including a high degree of waste stabilization and destruction of viral and bacterial pathogens (Lo, K. et al., 1985) [8]. Rates of biological degradation are also temperature dependent, and rates increase with warmer temperatures [9].

Total solids concentration of faecal sludge comes from a variety of organic (volatile)

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and inorganic (fixed) matter, and is comprised of floating material [21], settleable matter, colloidal material, and matter in solution [10]. The ratio of VS to TS is used as an indicator of the relative amount of organic matter and the biochemical stability of faecal sludge [11].

Dumping of different kinds of household waste into the pit has also been observed and is consistent with literature (Buckley et al., 2008) [5]. This affects biodegradability to a reasonable extent.

Climate has a direct influence on faecal sludge characteristics, mainly due to temperature and moisture. The moisture content of faecal sludge in the pit latrine affects the rate of degradation. Geological characteristics of the surrounding soil where the pit latrines are placed can have an important influence in the processes happening inside the pit (Bhagwan et al., 2008) [3]. A latrine system should be located in areas where the slope is not excessive (Bouma, 1974 [4]; Coutera et al., 1979) [6].

In terms of soil porosity, microflora and microfauna (higher organisms such as protozoa, metazoan and worms) may move into the pit from the surrounding soil and contribute to decomposition of organic material.

Oxygen is extremely toxic to the obligate anaerobic methanogens and these bacteria are inhibited by even small concentrations (Bitton, 1994; Muyima et al., 1997) [24]. Household habits associated with toilet usage influence the variability of faecal sludge in the pit latrine. The length of time that faecal sludge is stored in the pit latrine system before the samples are collected and analyzed will greatly affect the characteristics due to the digestion of organic matter that occurs during storage. The concentration and volume of faecal sludge is also greatly influenced by inflow and infiltration of leachate into the environment from the system and or ground water into the system.

D. Benefits of Excreta Use

Excreta is increasingly used for agriculture and aquaculture in both developing and industrialized countries. The principal forces driving this increased use are:

- recognition of the resource value of excreta.

In many cases, it is better to use excreta and greywater in agriculture because crops benefit from the nutrients they contain. Most population growth is expected to occur in urban and peri-urban areas in developing countries (United Nations Population Division, 2002). Population growth increases the demand for the amount of wastes that are discharged into the environment, thus leading to more pollution of clean water sources. The use of excreta and greywater in agriculture and aquaculture can act as a low-cost treatment method that increases food production to supply growing urban and per-urban populations. More use of excreta and greywater will occur in urban and peri-urban agriculture, because this is where the excreta is generated and available and where the demand for food is highest.Excreta and greywater are often reliable the year round and they contain the nutrients necessary for plant and fish growth. In most situations, excreta and greywater supply all the nutrients required for crop growth. The value of these substances has long been recognized by farmers worldwide. Their direct use in agriculture and aquaculture is a form of nutrient and water recycling, and this often reduces downstream environmental impacts on water resources and soil, as well as potential health impacts on downstream communities. The water and nutrient resources help people to grow more food without the costs of using more fertilizers. The reliability of the water supply means that crops can be grown year-round in warm climates. It also represents an important asset in situations where climate change will lead to significant changes in patterns of precipitation. The use of excreta and greywater will be an important component of a package of coping strategies in areas affected by such change.

E. Risk in the Use of Faecal Sludge in Agriculture

While the use of sewage sludge to bring nutrients and organic matter could be beneficial for the soil, it also represents a risk due to the content of contaminants like heavy metals, organic compounds, and pathogens. Among the organic compounds, the most frequently detected in the municipal sewage sludge include absorbable organic halogens (AOX), linear alkylbenzenesulfonates (LAS), nonylphenols and nonylphenolethoxylates (NP and NPnEOs), di-ethylhexylphthalate (DEHP), polyaromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), polychlorinated dibenzo-pdioxins and -furans (PCDD/F) as listed in Kapanen et al.

F. Health Implications of Excreta and Greywater Use

The health risks most studied in the context of the use of excreta and greywater are those associated with excreta-related infectious diseases. The evidence base is less extensive for the transmission of vector-borne diseases and schistosomiasis through reuse activities. The planning and development of projects for the use of excreta and greywater in agriculture and aquaculture should include a health impact assessment or an environmental impact assessment with a sound health component. National environmental/health impact assessment policies should explicitly refer to this type of project and the associated risks in the screening criteria they list. Scoping of such projects for impact assessment should include the identification of vulnerable groups. Three different community groups are at risk from excreta and greywater use activities in agriculture and aquaculture: • farm or pond workers (and their families, if they all participate in the activities or live at the site where the activities take place); • local communities in close proximity to activities, and people who otherwise may have contact with fields, ponds, wastewater, excreta, greywater or products contaminated by them;• product consumers.

G. Guidelines for the Safe Use of Excreta and Greywater

Due to changes in the characteristics of sewage, It may be necessary to update the guidelines in the safe use of this waste to take into account scientific evidence concerning pathogens, chemicals and other factors, including changes in population characteristics, changes in sanitation practices, better methods for evaluating risk, social/equity issues and sociocultural practices.

i. Agriculture

In countries or regions where poor sanitation and

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hygiene conditions prevail and untreated wastewater and excreta are widely used in agriculture, intestinal worms pose the most frequently encountered health risks. Other excreta-related pathogens may also pose health risks, as indicated by high rates of diarrhoea, other infectious diseases, such as typhoid and cholera, and incidence rates of infections with parasitic protozoa and viruses.In countries where higher sanitation and hygiene standards prevail, infrastructure for waste treatment is available and treatment processes are well managed, viral illnesses pose greater health risks than other pathogens. This is partly because viruses are often difficult to remove through wastewater treatment processes due to their small size, but also because of the resistance of some viruses in the environment and their infectivity at low concentrations. Additionally, people living in conditions where higher sanitation and hygiene standards prevail often have no prior exposure to viral pathogens and therefore have no acquired immunity and are more vulnerable to viral infection and illness.

ii. Aquaculture

Studies of health risks associated with waste-fed aquaculture have rarely been conducted. There is limited evidence that links exposure to waste-fed aquaculture or its produce to illness in product consumers and local communities in intense contact with contaminated pond waters. Skin diseases such as contact dermatitis (eczema) may also occur in farmers with high contact with faecally contaminated ponds while harvesting aquatic plants. In general, fish and plants raised in contaminated waters may passively transmit pathogens on their surfaces to product handlers or consumers. The fact that fish concentrate bacteria and other microbes (including viruses and protozoa) in their intestines is, however, of greater public health importance. The greatest risk to consumers is likely to result from cross-contamination from the gut contents to the edible fish flesh during unhygienic fish processing. Unhygienic fish processing can increase the levels of microbial contamination by 100-fold or more in edible portions of the fish. In certain regions of the world, food borne trematodes may pose a significant health risk in relation to waste-fed aquaculture. In areas where such infections as clonorchiasis, opisthorchiasis, fascioliasis and fasciolopsiasis are common and where fish or plants are frequently eaten raw, incidence rates can be attributed to this practice. In vulnerable groups such as children, food borne trematodes can cause severe illness and, occasionally, death. A number of animals may serve as reservoirs, and their presence will help to sustain their presence and transmission in affected areas. A recent systematic literature review indicates that food borne trematode infections are on the rise in areas where freshwater aquaculture is also increasing (Keiser & Utzinger, 2005). Excreta and greywater use. The risks associated with the use of excreta (including source-separated urine and faeces) stem mostly from excreta-related pathogens. Urine usually does not contain high concentrations of pathogens but may have some as a result of faecal cross-contamination during collection. Eggs of the parasitic blood fluke Schistosoma haematobium are an exception to this rule. The use of faecal matter from on-site sanitation installations such as septic tanks and the pits of unsewered family and public toilets can pose significant health risks if it has not been adequately treated. The primary health hazard arises from the presence of worm eggs in areas where intestinal worms are common. The eggs of these parasites can survive for months or even years in the faecal matter and in the soil.

H. Policy and Regulatory Aspects

The health risks associated with the use of greywater in agriculture are considered to be lower than those for wastewater or faeces. Greywater generally has lower concentrations of pathogens in it than wastewater, but it may still contain some pathogens, which are introduced into the greywater from washing babies' diapers, laundry, personal hygiene or other sources.

I. Controlling Negative Health Impacts

Measures from a range of categories may be applied at different points during the cycle, and they are normally used in combination to reach the desired goals:

- Treatment of wastewater, excreta and greywater is used to prevent the contaminants from entering the environment.
- Crop/produce restriction (i.e. only crops that are not eaten directly by people or that are always processed or cooked before they are eaten) is used to minimize health risks to product consumers.
- Waste application techniques (e.g. drip irrigation) and withholding periods aim to reduce contamination of the products or allow sufficient time for pathogen die-off in the environment prior to harvest.
- Exposure control methods (e.g. protective equipment, good hygiene) will prevent environmental contamination from reaching exposed groups.
- Produce washing/rinsing/disinfection and cooking reduce exposures for product consumers.
- Vector control reduces exposures for workers and local communities.
- Chemotherapy and immunization can either prevent illness for those who are exposed or treat those who are ill and thus reduce future pathogen inputs into the wastewater, excreta or greywater.

III. MATERIALS AND METHODS

Faecal sludge samples were collected from 15 pit latrines using a well-designed sampler at six different vertical layers namely at the surface layer, and at depths of 0.2m, 0.4m, 0.6m, 0.8m and 1.0m. Sludge samples were taken across each pit layer to allow for heterogeneity of the contents. Samples collection was carefully done to ensure that bioactivity of the samples was not altered in the process. These samples were then analyzed for their physico-chemical and biological characteristics namely moisture contents, temperature, volatile solids, BOD, COD, total solids, plate count, pH, suspended solids and phosphorous content using standard methods of measurement of faecal parameters (ALPHA, 1998) [1].

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A. Description of the Sampler

The length of the Sampler was 1.5m to allow 1.0m sludge column be sampled from the pit. It measured 100mm x 100mm square in cross-section and calibrated into six segments. The segments of the tube have openings through which the sludge enters into them. It was constructed in such a way that these segments were sealed up by a sliding device when being lowered into the pit and opened up after the lowering to allow the sludge enter into the openings through rotating the sampler gently for a few times and sealed up again after the sludge had entered into the segments before withdrawal from the pit. After withdrawing the sampler, the sliding cover was removed with care and small plastic containers well washed and sterilized were used to collect samples from the different segments as designed and wrapped in a black cellophane bag to imitate the natural dark environment of the pit until it was time for analysis.

IV. RESULTS AND DISCUSSIONS

Results and discussions in this study were based on biodegradability in terms of measured faecal parameters namely BOD, COD, TS, VS, SS, pH, moisture content, plate count, phosphorus content and temperature.

A. Analysis of Laboratory Data

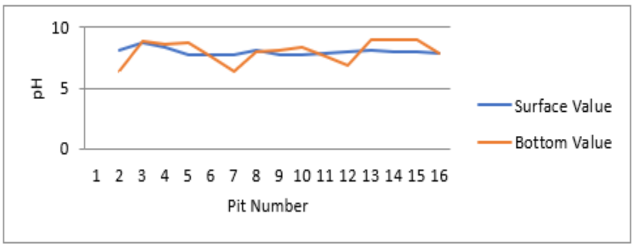
For the purpose of this analysis, the surface and bottom values of each parameter obtained from laboratory analysis were tabulated and the difference calculated.

B. Results and Discussions

Biodegradability of faecal sludge in the 50 pit latrines were determined using the result of parameters obtained in the laboratory analyses. Biodegradability of the various pit sludges analyzed was calculated using Equation 1.

i. Variation of pH in the Pit Sludge with Depth

Figure 1 showed the variation of pH of the pit sludge. Pit 6 had pH value of 7.98 at the surface and 6.42 at the bottom with pH range of 1.56 while Pit 11 had pH of 7.93 at the surface and 6.85 at the bottom with a range of 1.08. Next was pit 4 with pH of 7.77 and 8.77 at the surface and bottom respectively with a range of 1.0 value. pH ideally falls within the range 7.5-8.5 (Jenkins, 1994). It was reported that for appropriate microbiologic activity, pH should be within a range of 6.5 – 8 (Bhagwan et al., 2008). Frickle et al (2007) in their study recommended an optimal pH of between 6.4 and 7.2 for an anaerobic digestion process as against 6.42 - 8.95 in this study with reference to ordinary pit latrines [17]. The highest pH measured in this study was 8.96, which was not too high to inhibit the anaerobic process.



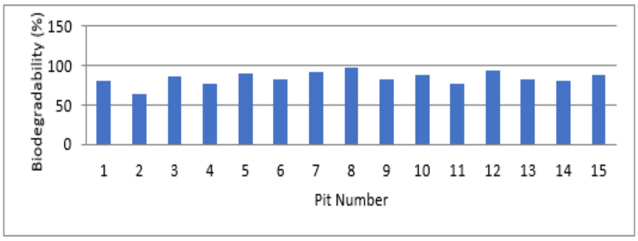
[Fig.1: Variation of pH in Pit Sludge]

ii. Variation of Biodegradability of Pit Sludge in Terms of BOD

Figure 2 showed the variation of biodegradability of pit sludge in terms of BOD. In the Figure, 12 pits (Pits 1, 3, 5, 6, 7, 8, 9, 10, 12, 13, 14 and 15) have biodegradability level of 80% and above. Pit 8 had the highest value of biodegradability of 97% at temperature range of 24°C - 65°C. The maximum moisture content in same pit was 87.73% with pH ranging from 7.76 to 8.10 and microbial density of 50mg/g. These conditions favoured biodegradation of the sewage in pit latrines (Ugwu, 2015). Pits 3, 7, 8, 10, 12 and 15 had biodegradability above 85% and were considered to perform maximally due to favourable temperature, pH, moisture content and microbial density in the pits.

BOD is aerobic and as the pit depth increased, the amount of oxygen available for microorganisms decreased resulting in decreased aerobic activity. Thus, the readily biodegradable components in the faeces have already been consumed on the surface.

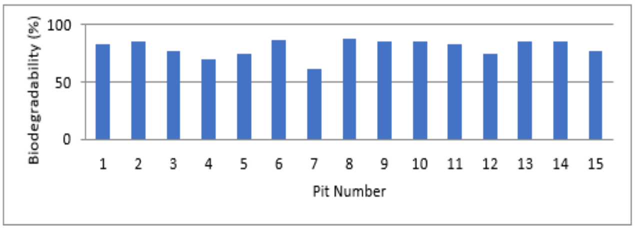
The time the newly deposited faeces spends on the surface under aerobic conditions depends on the rate of addition of new material to the pit and the pit dimensions (Buckley et al., 2008). Once the organic material has been covered over by new pit contents, the material became anaerobic through lack of oxygen and the rate of degradation dropped dramatically as seen in this research work.



[Fig.2: Variation of Biodegradability Level with Pit Number in Terms of BOD]

iii. Variation of Biodegradability of Pit Sludge in Terms of COD

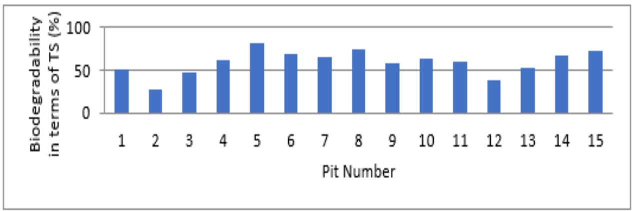
Figure 3 showed the variation of biodegradability of pit sludge in terms of COD. In the Figure, 9 pits had biodegradability above 80%. The highest was in Pit 8 with biodegradability of 87.9% at pH range from 7.76 – 8.10 with maximum moisture content of 87.73% and temperature range of 29.67°C - 65°C. The microbial density was 50mg/g which was favourable to faecal decomposition in the pits. The variation in the biodegradability in the various pit sludges was attributed to the conditions that prevailed in the pits during faecal decomposition. The pits with high level of biodegradability showed favourable conditions of temperature, moisture content, soil conditions, pH and presence of high microorganisms in the system. Consequently, a substantial amount of biodegradable material in faecal sludge was biodegraded during the process.



[Fig.3: Variation of Biodegradability of Pit Sludge in Terms of COD]

iv. *Variation of Biodegradability of Pit Sludge in Terms of Total Solids*

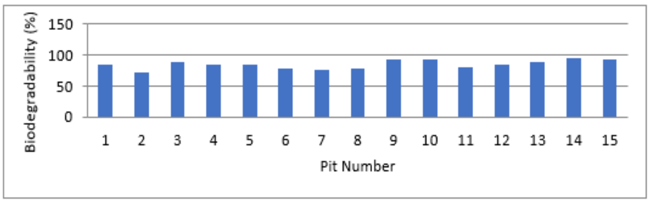
Figure 4 showed the biodegradability of faecal sludge in the pit latrines. The high amount of total solids measured in this study showed poor user-behaviour by the households surveyed, disposing off reasonable amount of solid wastes into the pit latrines, which adversely affected the biodegradation process in the pit latrines. Excessive dumping of solid wastes into the pit latrine led to so much total solids accumulation which could result in the reduction of the amount of moisture that could be available for biodegradation. This invariably impaired the flocking of the microorganisms to digest the faecal sludge adequately. Only 3 pits (5, 8 and 15) exhibited biodegradability of 70% and above as against 80% recorded in Figures 1 and 2 for BOD and COD. Only Pit 5 had biodegradability above 80% showing high level of biodegradation under favourable conditions of temperature, pH, moisture content, microbial density, and good soil conditions.



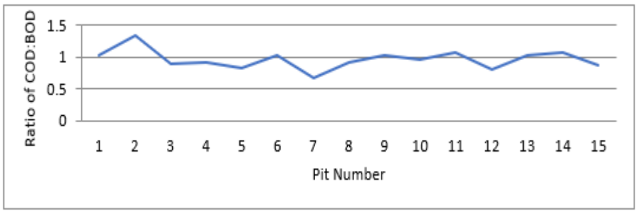
[Fig.4: Variation of Biodegradability of Pit Sludge in Terms of TS]

v. *Variation of Biodegradability of Pit Sludge in terms of Volatile Solids*

Figure 5a showed the biodegradability of pit sludge in 15 pit latrines surveyed in terms of volatile solids. 11 of the pits (pits 1, 3, 4, 5, 9, 10, 11, 13, 12, 14 and 15) had biodegradability above 80%. This means that most of the pits performed reasonably very well. Pit 14 had the highest with biodegradability of 95.8% with pH ranging from 8.01 – 8.95 with temperature ranging from 28.67ºC - 66.67ºC at moisture content of 70.47%. The microbial density was 38 mg/g. Volatile solids indicated the amount of organic content of the faecal sludge and this was higher than the total solids content in this study.



[Fig.5a: Variation of Biodegradability of Pit Sludge in Terms of Volatile Solids]



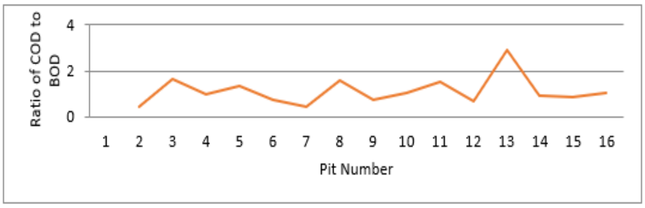
[Fig.5b: Variation of COD: BOD Ratio with Pit Number]

vi. *Variation of the Ratio of Volatile Solids to Total Solids (VS:TS)*

Figure 6 showed the variation of the ratio of volatile solids to total solids (VS:TS) in the various pit latrines. In most of the pits, the value was high which was an indication of high organic content. In pit latrines where the volatile solids concentration was higher than the total solids, there was the likelihood of high biodegradability, taking other factors such as favourable temperature, moisture content, microbial density and pH level into consideration. This could be observed in Pits 2, 3, 4, 7, 9, 10, 12 and 15. Looking at the ratio of volatile solids to total solids as contained in Figure 4b, the amount of organic solids in the faecal sludge samples varied. The ratio was high in most pits indicating high organic content as against low ratios in Pits 1 and 6 indicating low organic content resulting to low biodegradability. Pits with moderate values of the ratio between 0.67 and 0.91 had relatively high organic contents and relatively high biodegradability under favourable condition. Only Pit 12 exhibited very high volatile to total solids ratio which was an indication that the content of faecal sludge in that pit was mostly organic.

vii. *Variation of the Ratio of Volatile Solids to Total Solids (COD:BOD)*

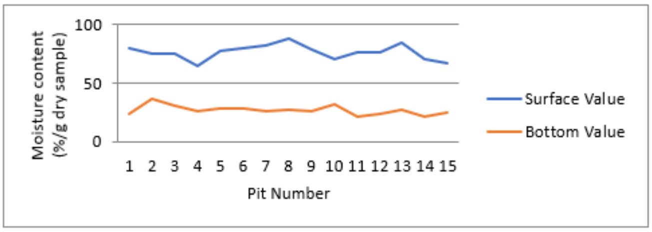
Figure 7 showed the variation of the ratio of COD to BOD in the various pits sludges. The ratio indicated that 11 pits had values ranging from 0.90 – 1.34 and were high in organic content as against 4 pits that had values lower than 0.87. This means that most of the pit latrines studied in the reference community performed very well. However, all the pits performed above average



[Fig.6: Variation of VS:TS Ratio with Pit Number]

viii. *Variation of Biodegradability of Pit Sludge in Terms of Moisture Content (MC)*

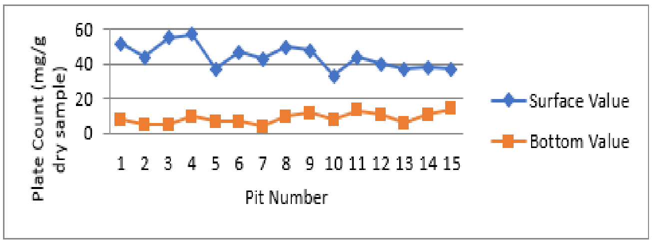
Figure 7 showed the variation of moisture content in the pit latrines studied. Surface moisture content varied from 64.47% – 87.73% while the bottom values varied from 21.43% - 36.20%. The moisture content of Pit 11 was the lowest with 21.83% while Pit 8 had the highest with 87.73%. The moisture content was used to give an approximation of biodegradability characteristics of the material found in the different layers of the pit latrines. Excess moisture content slowed down the rate of faecal decomposition and this affected the flocking of microorganisms that fed on the faecal matter. Lay et al (1997) in their study of the influence of moisture content on the methanogenic activity in the anaerobic digestion of wastewater treatment plant sludge cake showed that methanogenic activity dropped from 100% at a moisture content of 96% to 53% of the maximum activity when the moisture content was reduced to 90% [19].



[Fig.7: Variation of Moisture Content in Pit Latrines]

ix. Variation of Microbial Density in Pit Latrine Sludge

Figure 8 showed the variation of plate count in the 15 pit latrines. The highest microbial density was recorded at the surface since the faeces was fresh and still undergoing aerobic decomposition. As the sludge aged, microbial density decreased. It was possible that the plate count was composed mostly of viruses and helminthes that inhibited microbial decomposition and so, volatile solids were low amidst moderate temperature of 38°C. However, with longer storage time obtained from field survey and increased microbial decomposition, pathogens in faecal sludge died off naturally under temperature higher than ambient, 25°C with the highest recorded in this study being 67°C. At temperatures between 23°C and 67°C observed in this study, most of the pathogens died off due to natural decomposition processes leaving the very few resistant viruses at the bottom of the pits. Overall, it means that when the pits were put out of use after filling up, there was no disruption in faecal sludge composition, thus allowing biodegradation to continue unhindered.

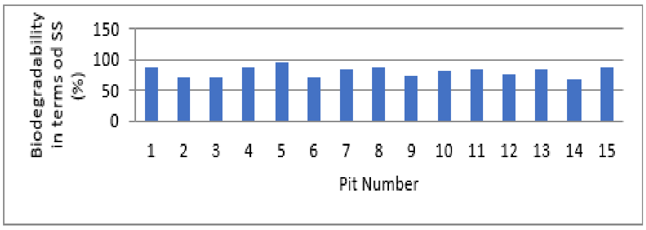


[Fig.8: Variation of Plate Count in Pits Latrines]

x. Variation of Biodegradability of Pit Sludge in Terms of Suspended Solids

Figure 9 showed the level of biodegradability in terms of suspended solids in the pit latrines. Only 9 pits (pits 1, 4, 5, 7, 8, 10, 11, 13 and 15) had biodegradability above 80%. Pit 5 had the highest with 95.3% followed by Pit 1 with 88%, Pit 15 with 86.5% and Pit 8 with 86.1%. The temperature ranged from 51.67°C - 66.67°C while the pH ranged from 6.40 – 8.96 and maximum moisture content was 84.97%. A lot of wastes could have been dumped into most of the pits resulting in changes in its contents which of course, affected faecal decomposition and biodegradability as the pit depth increased.

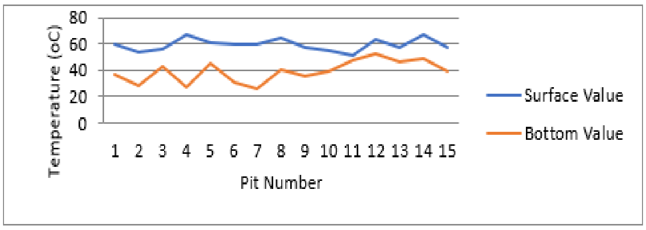
The composition of faecal sludge varied from pit to pit due to the type of food consumed by households. Moreover, a lot of wastes were dumped into some pits as observed during sampling which resulted to changes in pit contents which of course, affected faecal biodegradability in affected pits as the pit depths increased.



[Fig.9: Variation of Biodegradability with Pit Number in Terms of SS]

xi. Variation of Temperature in Pit Sludge

From Figure 10, the highest mean surface temperature recorded was 66.67°C in Pits 4 and 14 while the lowest mean surface temperature was 51.67°C in Pit 11. On the other hand, the highest mean bottom temperature was 52.67°C in Pit 12 while the lowest mean bottom value was 25.67°C in Pit 7. Temperature measured in the pit sludge favoured biodegradability process considering other factors such as moisture content, pH, soil conditions, amount of nutrients in the pit sludge and microbial density. This is within the thermophilic range established by LoK et al. (1985) [12], whose own range was from 55°C – 65°C [13]. Franceys et al. (1992) stated that residence time in the pit had sanitizing effect on pathogens since they were not able to survive during the decomposition processes due to changes in temperature and moisture [14]. Most of the microorganisms exhibited a narrow range of temperature over which they were active [16]. This is in line with the findings of Lopez et al (2004).

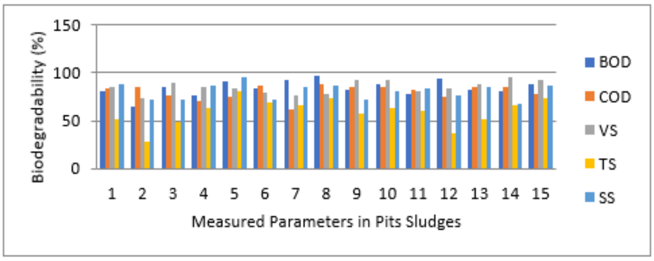


[Fig.10: Variation of Temperature in Pit Latrine Sludge]

C. Comparison of Biodegradability of the Various Faecal Parameters in Pit latrines

Figure 11 showed the comparison of sludge biodegradability in terms of BOD, COD, VS, TS and SS. In Pit 1, four sludge parameters namely the BOD, COD, VS and SS had biodegradability of at least 80%. In terms of TS, the biodegradability was below 60%. In Pit 2, the dominant parameter was COD with biodegradability above 80% while in Pit 3, BOD and VS had biodegradability values above 80%. VS and SS had values above 80% in Pit 4 whereas in Pit 5, four parameters, the BOD, VS, TS and SS had values above 80%. In Pit 6, BOD and COD dominated and in Pit 7, BOD and SS had above 80% biodegradability. In Pit 8, BOD, COD and SS had values above 80% while in Pit 9, BOD, COD, and VS were dominant, In Pit 10, BOD, COD, VS and SS were prominent. In Pit 11, COD, VS and SS dominated whereas in Pit 12, BOD and VS were dominant. In Pit 13, parameters that had biodegradability above 80% were BOD, COD, VS and SS while in Pit 14, BOD, COD and VS had biodegradability above 80%. Three parameters in Pit 15 namely BOD, VS and SS had values above 80%.

The choice of 80% biodegradability was to decide clearly high performing pit latrines since this would mean low filling rate and the longer lifespan for the pit latrines. The reduction in total solids content from surface to the bottom was a sign of sufficient microorganisms acting on the substrates.



[Fig.11: Comparison of Biodegradability of Faecal Sludge Parameters in Pit Latrines]

V. CONCLUSION AND RECOMMENDATIONS

A. Conclusions

The biodegradability of faecal sludge in the pit latrines studied has been determined and used to assess the performance of such pits. Biodegradability in terms of BOD could not be used to effectively assess the performance of pit sludge at the lower part of the latrine since aerobic biodegradability prevailed at the surface and minimally down the profile. Thus, biodegradability in terms of COD is a better assessment.

It is inevitable that many Government agencies play a role in the reuse process and, as a result, the effectiveness of the health authorities informulating and enforcing health protection measures is often impeded. Although it is difficult to change cultural habits, experience in Guatemala with excreta use has proved that people may be persuaded to adopt new sanitation and waste reuse customs if they can derive a sustainable benefit from them.

B. Recommendations

- The use of excreta in agriculture and aquaculture has policy relevance in relation to poverty reduction, the protection of public health and the environment, food security and energy reliance. In countries where the scale of current reuse practices is substantial or where a considerable reuse potential exists, there is a need to create a distinct policy framework for excreta use.
- The biodegradability of sewage in pit latrines should be determined before sewage management option is discussed.
- Biodegradability and biodegradation rates are critical factors that should be measured for sewage before separate biological treatment or co-treatment with rural and municipal sewage is decided upon.
- COD should be adopted to assess the biodegradability and performance of any pit latrine.
- Methane production level of sewage should also be used to measure the biodegradability of sewage in pit latrines if the required equipment for such investigation is available.
- Authorities are first encouraged to consider introducing new or expanding existing excreta reuse schemes but only if health protection measures are an integral component of the scheme. Waste reuse in agriculture and aquaculture should be fully integrated into strategic water resources planning. Industrial waste streams should be carefully controlled wherever wastewater or excreta is reused so as to prevent contamination of crops or fish.
- Kind of Reuse Irrigation of alfalfa, maize, cereal crops, tomatoes and beans mostly with untreated wastewater Irrigation of raw-eaten vegetables, cereal cropsand grapes with untreated wastewater Irrigation of rice, wheat, forage and flowers with diluted untreated wastewater Fish growing in ponds receiving untreated wastewater at low loading rates Irrigation of vegetables and non-food cropswith raw wastewater Irrigation of maize and cotton with primary pond effluent Irrigation of maize, alfalfa and fruit trees with effluent from overloaded WSPIrrigation of raw-eaten vegetables withsettled sewageIrrigation of non-vegetable crops and fruittrees with secondary effluentIrrigation of wheat, forage and date palmswith tertiary (filtered and chlorinated) effluentUse of stored faecal material as a fertilizer inagricultureUse of sludge from nightsoiltreatment plants in agricultureUse of excreta for fish pond fertilizationHealth Protection Measures PractisedCrop restriction, some exposure controlfor agricultural workersNone(treatment being planned)NoneCooking of the fishNonePartial wastewater treatment and croprestrictionPartial treatment and crop restrictionPartial treatmentPartial treatment and crop restriction Full treatment and croprestrictionProlonged excreta storage Dewatering and composting of the sludgeCooking of the fish
- All four health protection measures should be examined in assessing new reuse schemes or planned improvements of existing schemes. Flexibility in choosing between individual and combinations of the measures:• wastewater/excreta treatment• crop restriction• appropriate waste application methods, and• human exposure control46is recommended and attention drawn to the need for suitable administrative, legislative and political support systems. It is recommended that every effort should be made to promote the usealso of faecal material, especially in rural and semi-urban sanitation schemes in which the use of double-vault or double-pit latrines proves feasible, and where the handling of

stored excreta is not an absolute taboo. The importance of prolonged communication between the implementing agency and users in this type of scheme is emphasized.Finally, the need for field-level investigations with an epidemiological perspective is re-stated. Study situations should be chosen so as to allow the effectiveness of individual health protection measures or of combinations of measures to be tested in avoiding excess risks from there use practice.

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DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** The authorship of this article is contributed equally to all participating individuals.

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