Assessment of the Robustness of Biofil Toilet Technology for the Treatment of Blackwater

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Abstract

Black water management is an important problem in the densely populated urban poor communities due to the limited space and the high generation of excreta without effective technologies for treatment and its reduction;Then the Biofil Toilet Technology (BTT) has been developed in Ghana to solve the problem. Extensive use of bactericidal household chemicals for cleaning of toilet rooms may affect the activity of the earthworms and hence it was necessary to test the resistance of earthworms towards such chemicals for the optimization of the technology.

In this study chloroxylenol (dettol) with concentrations [0.3-5 mg/ml], sodium hypochlorite (parazone) concentrations [0.6-9 mg/ml] and lactic acid (Mr. Muscle) concentrations of [0.7-7 mg/ml] were selected for the test based on the frequent use of these chemicals by the urban and peri urban community householders in Ghana.

The results obtained showed that earthworms were able to survive up to 25% when exposed to chloroxylenol (dettol) without any 100% lethal effect; however, earthworms were not able to resist the effect of sodium hypochlorite (parazone) with 2.5 mg/ml concentration and 7 mg/ml concentration of lactic acid (Mr.Muscle) which caused 100% mortality effect over the 21 days of exposure time.

This study provides that increase in the concentrations of the tested chemicals increased toxicity to earthworms which resulted in some mortality, body weight loss and low removal of contaminants but the survived earthworms after a longer exposure (14 to 21 days) could increase in their body weight as well as efficiency in the removal of contaminants.

Key words; Blackwater, Earthworms, Bactericidal chemicals, Body weight change, Survival rate

1. Introduction

One of the major environmental development challenges that majority of developing countries face is the provision of safe sanitation services in both urban and rural areas (Mulenga 2011; Prasad, 2013). While efforts have been made by some governments to provide basic level of these services to the population, the coverage levels have remained insufficient and only 64 percent of the global population uses improved sanitation facilities and 15 percent defecate in the open (WHO/UNICEF, 2013).

The Biofil Toilet Technology (BTT) as shown in Figure 1 was developed to resolve the peculiar sanitation issues of limited availability of space for sanitation facilities and odour generation with simple treatment mechanisms. This is to ensure effective on-site faecal sludge treatment and also to eliminate frequent desludging of OSSs as observed in the traditional systems such as the KVIPs, Aqua privy and septic tanks. Earthworms, bacteria or other micro-organisms degrade organic solid residue (cleansing paper, faeces and all degradable material) while the effluent is biologically filtered out of the bottom of the digester through a sand media and drained into the sub-surface soil where further polishing occurs.

The population of micro-organisms present inside most OSSs determines the effective functioning of the system (Ip, 2004). However, the activities of such organisms are greatly influenced by the introduction of bactericidal chemical constituents with black water during cleaning of the toilet bowls.

Bactericidal chemicals which are commonly used for cleaning are laundry detergents, liquid chlorine bleaches, high test hypochlorite (HTH) and some other toxic chemicals that can be added to many of the household toilets during flushing(Gross, 1978). Given that the Biofil toilet technology (BTT) is highly dependent on the activities of macro/micro-organisms, the introduction of bactericidal chemicals may impact toxicological effects on such organisms inside the vermibed limiting the full working capacity of the technology.

1.1. Back Ground of the Biofil Toilet Technology

Biofil toilet technology (BTT) is one of the youngest biotechnologies invented with the idea of the vermicomposting process to solve the problems of organic waste accumulation in residential areas of developing countries. The Biofil toilet technology (Figure 1) is a simple compact on-site blackwater treatment system that uniquely combines the benefits of the flush toilet system and those of the dry toilets.

It is an initiative of a local entrepreneur (K. Anno Engineering Ltd) in Accra. The Civil and Mechanical/Agriculture/Marine Technical Divisions of the Ghana Institute of Engineers of Ghana in collaboration with K. A. Anno Engineering Limited on Tuesday June 24, 2008 . The system has for the last 5-6 years been installed for individual home owners in the low, middle and high income areas, some institutions, refugee camps, resettlement communities and mining communities.

Wastewater and fecal matter enter at the top of the Biofil Digester where rapid separation of solids and liquid contents of the waste occurs. The digester is essentially a biological filter consisting of a medium of soil and pervious concrete. Bacteria, other organisms degrade solid fecal matter. All liquids are organically filtered out of the bottom of the digester and drained into the soil where further and final decomposition occurs. Other solids (toilet paper & all degradable anal cleaning material) are decomposed and converted into rich & safe soil.
When the Biofil Digester is used in the flush toilet situation, high nutrient biologically treated water is made available for effective landscaping and beautification of the environment.

Earthworms are used to seed the system once after initial use of the system to initiate the accelerated decomposition process. Blackwater dewatering and accelerated waste stabilisation are the main features of this technology, leading to a bio-solid product which may be recycled as an organic fertiliser or soil conditioner (Biofilcom, 2012).

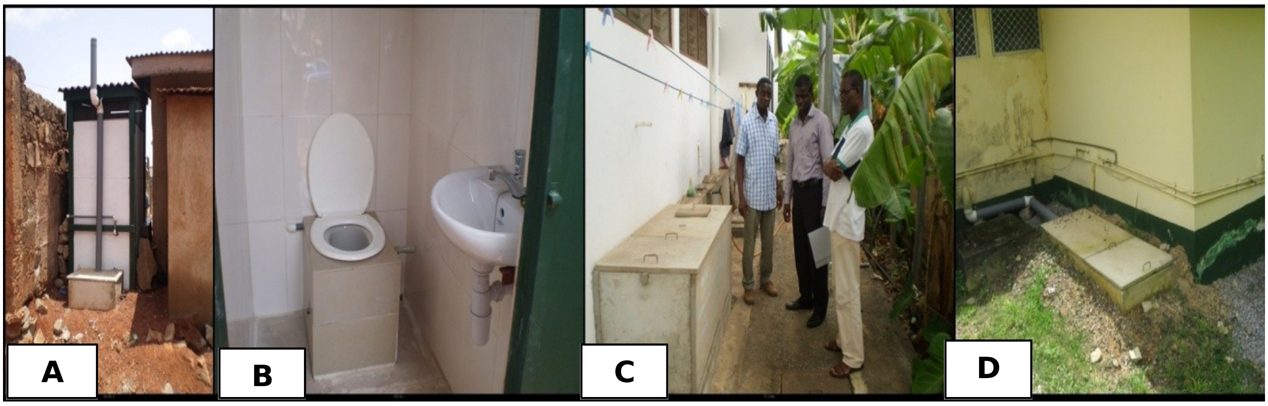

Figure 1: The Biofil Toilet Technology

(A) = standalone micro-flush Biofil toilet technology; (B) = standalone micro-flush seat connected to hand washing facility; (C) = Biofil toilet technology retrofitted to a WC installed on subsurface soil; and (D) = flush retrofit Biofil toilet technology installed in the ground)

The digester (i.e. concrete box panel) in Figure 2 is 0.61m high, 0.61m wide and 1.83m long. It can be installed buried in the ground or on the subsurface soil depending on the level of the water table or presence of rock beds which may prevent excavation. It can be connected to a water closet as a retrofit to the septic tank or pour flush system (called the flush system) or installed as a stand-alone connected to a hand washing facility (called the micro-flush). In this case, wastewater from the hand washing facility serves as a water seal and also flush water for the next user. The micro-flush is ideally designed for areas with unreliable water supply.

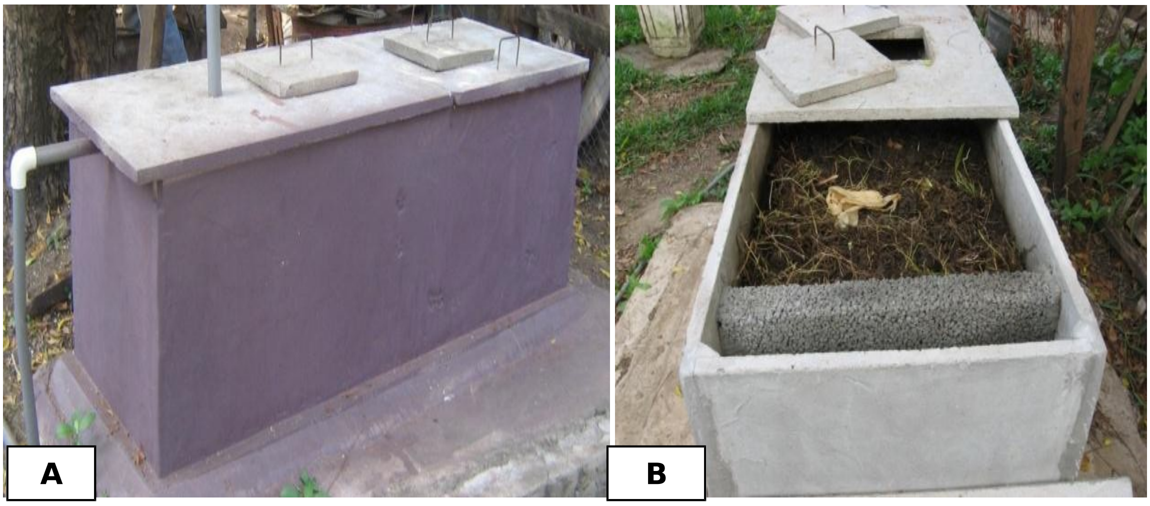

Figure 2: The Biofil Toilet Separate Digester (A), the Internal View of the Digester (B)

Within the concrete box panel in Figure 2, there is a pervious filter membrane made of grade of gravel and supported on pavement blocks from the bottom platform. On top of the filter membrane are bulking materials made of shredded coconut fibre and grass. A fine mesh is used to line the filter membrane to prevent fines from the bulking materials clogging it.

A filtering media of sand or coarse gravel is placed beneath the filtering membrane for further polishing of the effluent before entering the sub-surface soil. Between the top cover and bulking material and the filter membrane and the bottom concrete box panel are air spaces. A vent is provided on top cover for aeration as shown figure 3.

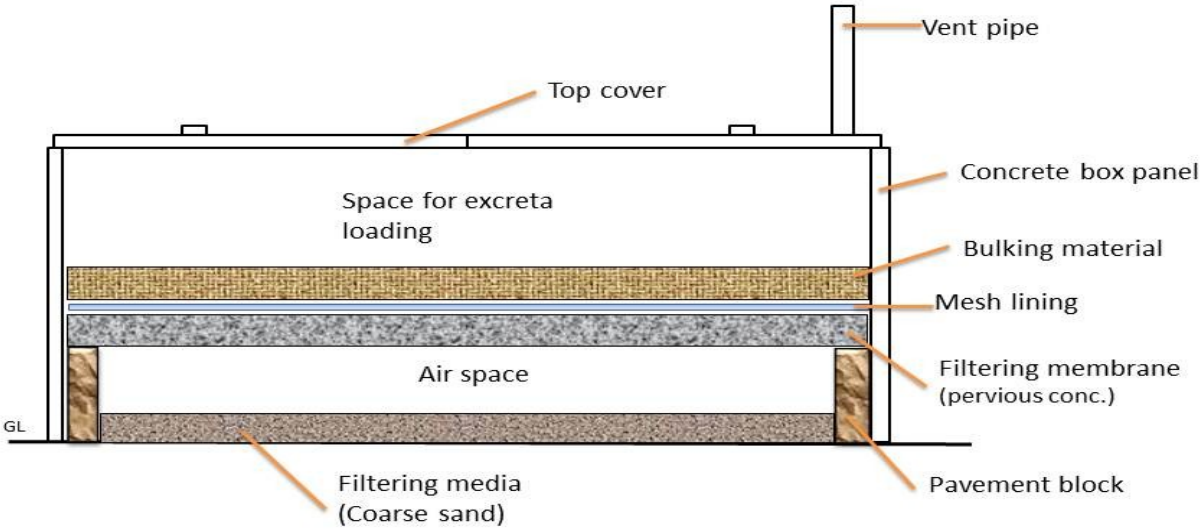

Figure 3: Schematic Design of the Biofil Toilet Technology

The design of the digester is simple, replicable and operates on very low maintenance needs. The system eliminates the possibility of costly site remediation and clean-up (as in the case of failed septic tank system/ KVIPs).

Since its development and installation, there has not been any detailed research conducted on it, though a sample of the effluent from the system was once tested by the Centre for Scientific and Industrial Research in Accra on June 2010 (Biofilcom, 2012).

2. Research Aim and Objectives

The main focus of the research is to assess the robustness of the Biofil Toilet Technology to bactericidal chemical constituents in blackwater.

The specific objectives of the research are:

1. To determine the survival rate of the waste digester (i.e. earthworm) in the Biofil toilet technology when exposed to bactericidal chemicals in flush water.
2. To determine the lethal concentration of bactericidal chemical constituents that will render the biofil toilet technology ineffective for organic contaminant removal in black water.
3. To determine the recovery rates of the earthworms after the application of bactericidal chemical constituents in flush water.

3. Materials and methods

3.1. Collection and Identification of Earthworms

For the aim of toxicity test, African species of earthworms (Eudrilus eugeniae) were collected and cultured with organic waste. At the beginning, eudrilus eugeniae were collected carefully from Accra, (the capital of Ghana) composting digester manually and transported to Kumasi (where the study were conducted) for further culturing and growth. Due to their high potential in organic waste degradation and rapid reproduction rate, Eudrilus eugeniae were selected for the study.

The experimental earthworms (eudrilus eugeniae) were cultured (Figure 4) in 18 litre plastic containers with holes drilled at the bottom to prevent water stagnation and maintain a moisture content conducive for the growth of earthworms. To make sure the earthworms could not escape from the culturing plastic container through the bottom drilled holes; a rubber mesh was fixed at the bottom of the container. The plastic container was left uncovered with a net meshing to allow air circulation within the vermibed. Earthworms (eudrilus eugeniae) were monitored under a moisture content of 55-70% and pH range of 6.5-7.Blackwater was added as a feed for the growth of earthworms (eudrilus eugeniae) every 7 days. Water was periodically sprinkled on the plastic box to moisten the blackwater (culturing media). Earthworms were kept under such conditions inside the plastic container for 3 months before the main laboratory test was carried out.

Figure 4: Culturing of Earthworms (*Eudrilus eugenaie*)

3.2. Description of Test chemicals

The following three most common bactericidal test chemicals were selected for the toxicity test of earthworms (*eudrilus eugeniae*).

1. Chloroxylenol (dettol); 2 .Sodium hypochlorite (parazone) and 3. Lactic acid (Mr.Muscle)

The test chemicals were selected because of their wide application in urban poor areas of Africa, including Ghana. Most households in Ghana use the chemicals mentioned earlier to clean their sanitation facilities due to their accessibility in low cost and good ant-microbial potential.

All the test chemicals were purchased from supermarkets and diluted to prepare the concentrations.

3.3. Test Chemical Concentrations

Five different concentrations of each toxic test chemical namely; Chloroxylenol (dettol solution), sodium hypochlorite (parazone solution) and lactic acid (Mr. Muscle solution) were applied for toxicity resistant test of earthworms (*eudrilus Eugenie)*. The concentrations were diluted and prepared based upon the usage instructions prescribed by the manufacturing companies. A range of concentrations were also prepared outside the stipulated, based on household user practices in low income areas of Ghana (i.e. concentrations below and above the recommended values by the manufacturing companies) (Table 1)

Table 1: List of Applied Concentrations

Type of test chemicals	Applied concentration	
	mg/ml	ml/ml
Chloroxylenol(Dettol)	0.3	20/3000
	0.6	40/3000
	1.2	80/3000
	2.4	160/3000
	5	320/3000
Sodium hypochlorite(Parazone)	0.6	40/3000
	1.3	80/3000
	2.5	160/3000
	5	320/3000
	9	640/3000
Lactic acid(Mr.Muscle)	0.7	100/3000
	1.3	200/3000
	2.4	400/3000
	4	800/3000
	7	1600/3000

4. Results and Discussion

The survival rates were determined based on the standard recommendation by the Organization for Economic Co-operation Development (OECD), which stipulates less than 10% mortality(OECD, 1984). Earthworms (*eudrilus eugeniae*) treated in the control responded to gentle mechanical stimulus to their front end throughout the whole experiment and thus were considered as alive (OECD, 1984)

4.1. Effect of Chloroxylenol (dettol) on Eudrilus eugeniae

During the first 7 days after application of chloroxylenol: 8(100%), 7(87.5%), 4(50%), 3(37.5%) and 2(25%) of the worms out of 8 survived when exposed to the various concentrations of 0.3, 0.6, 1.2, 2.4 and 5mg/ml chloroxylenol respectively. Only the concentration at 0.3mg/ml did not record any mortality within the 7 days exposure alongside the control (Figure 5).

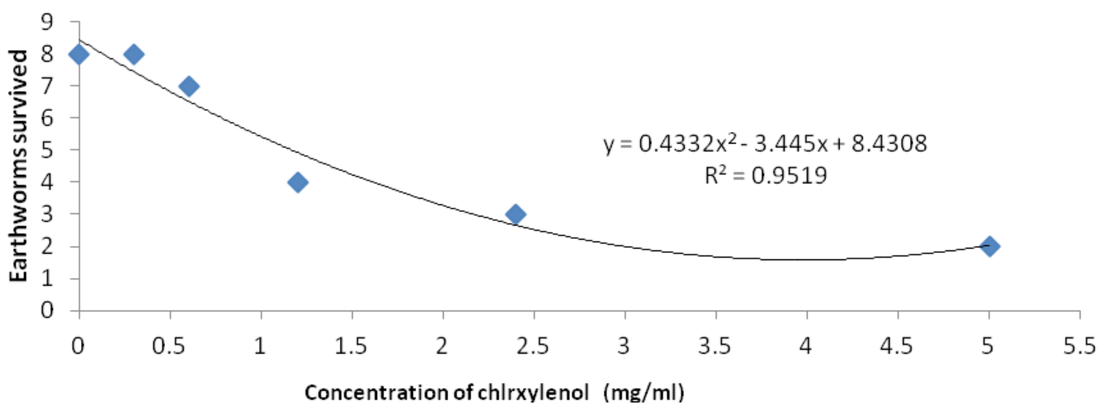

Figure 5: Effect Chloroxylenol on the survival of *Eudrilus eugeniae* after 7 days

Similarly, after 14 days of the application of chloroxylenol concentrations; 6(75%), 5(62.5%), 3(37.5%), 2(25%) and 2(25%) of earthworms were able to survive with 0.3, 0.6, 1.2, 2.4 and 5 mg/ml concentrations respectively (Figure 6).

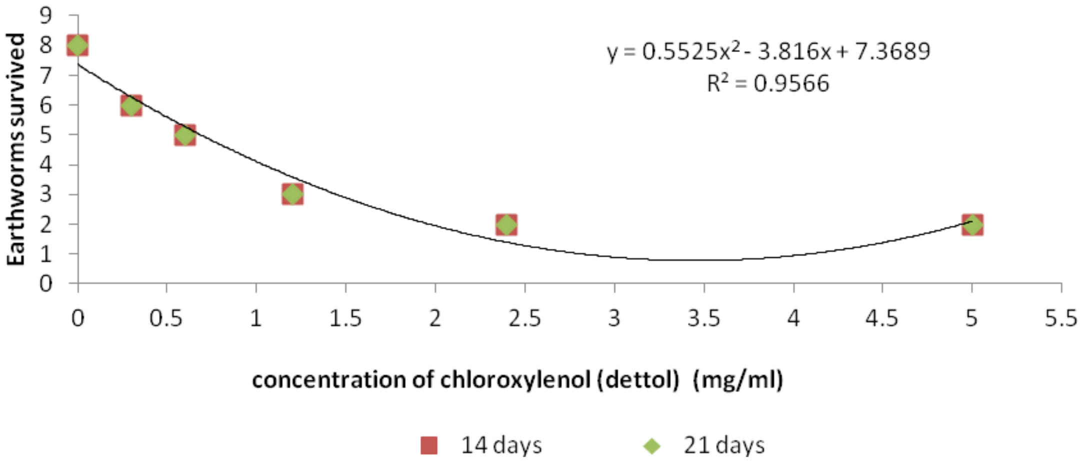

Figure 6: Effect of Chloroxylenol on *Eudrilus eugeniae* Survival after 14 and 21 Days

After 21 days of exposure, the concentrations of chloroxylenol did not cause any lethal effect on the earthworms. The number of earthworms that survived were 6(75%), 5(62.5%), 3(37.5%), 2(25%) and 2(25%) at concentrations of 0.3, 0.6, 1.2, 2.4 and 5mg/ml respectively, same as recorded during the 14 days exposure.

Earthworm survival rate recorded at 14 days experimentation was statistically different from that recorded during 7 days exposure time (T-test, p=0.118) at 95% of confidence interval. The applied concentrations had different effects on survival of earthworms after the 14 days exposure compared to the 7 days of exposure.

The earthworms that survived over the 14 days exposure stayed alive without any lethal effect after 21 days of experiment. This might be either that the applied concentrations of chloroxylenol lost its toxicity strength or earthworms adapted to the concentrations and started digesting the feed (blackwater). The number of earthworms that survived during the 14 days of exposure were statistically different (p=0.05) with increase in applied chloroxylenol concentrations at 95% confidence interval. This shows that the effect of various applied concentrations on earthworms were different on earthworms' survival potential.

The test chloroxylenol did not cause 100% lethality/mortality effect on the earthworms over the 21 days of exposure with the different concentrations. The maximum concentration of 5mg/ml only caused 75% mortality at the end of the experimental period. A similar trend in earthworm mortality test was observed by VanGestel et al., (1988) who observed the depreciation in the toxicity effect of the chemical with time.Neuhauser and Callahan, (1990) also recorded a reduced effect of toxicity with increase in exposure time.

4.2. Effect of Sodium Hypochlorite (parazone) on Eudrilus eugeniae

After the first 7 days of experiment: 7(87.5%) and 6(75%) of the earthworms survived at 0.6 and 1.3 mg/ml concentration of sodium hypochlorite respectively. However, no survival of earthworms was recorded at concentrations 2.5,5 and 9 mg/ml. Hence 2.5mg/ml concentration could be considered as the lethal concentration that was able to kill 100% of earthworms *(eudrilus eugeniae).*

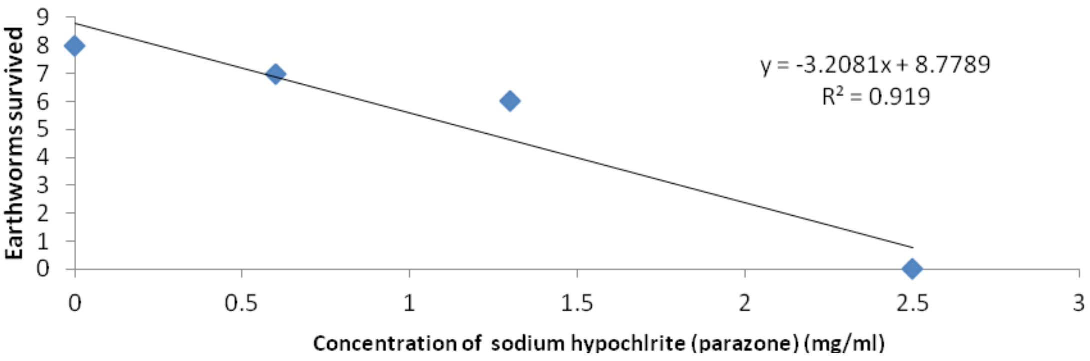

Figure 7: Effect of Sodium Hypochlorite on *Eudrilus eugeniae* survival after 7 Days

The Analysis of variance (ANOVA) single factor test suggested that, the survival rate of earthworms during the first 7 days of exposure was statistically similar (p=0.02) with gradual increase in the applied concentrations at 95% of confidence interval. This implies that increasing the chloroxylenol concentration could not cause different effect on survival of earthworms. However, the correlation test shows that the survival of earthworms is inversely correlated (-0.885) with the gradual increase of applied concentrations. This shows that increasing of the applied concentrations resulted in mortality and reduction of earthworm population over the 7 days of exposure.

After 14 days of exposure, 5(62.5%) and 4(50%) of earthworm survival was recorded at 0.6 and 1.3 mg/ml concentrations of sodium hypochlorite respectively.

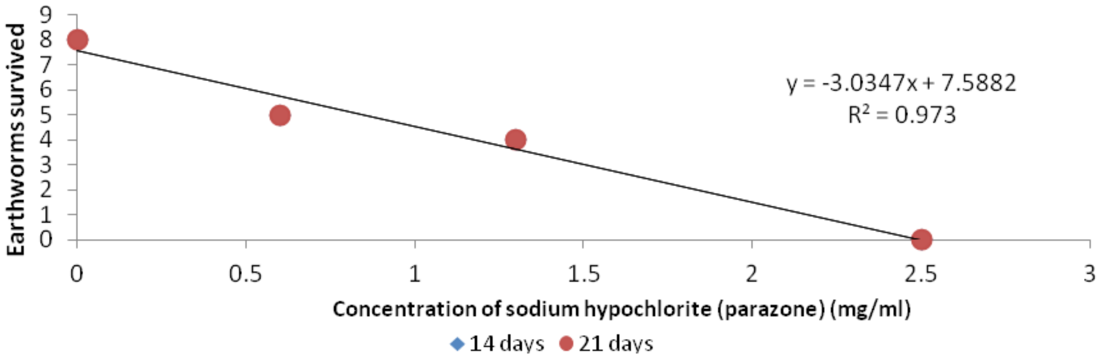

Figure 8: Effect of Sodium Hypochlorite on *Eudrilus eugeniae* Survival after 14 and 21 Days

Earthworms that survived after the 14 days of experiment stayed alive without any lethal effect by any of the applied concentrations. In effect, 62.5% and 50% of earthworms were able to survive after 21 days of exposure at 0.6 and 1.3 mg/ml of sodium hypochlorite respectively.

The number of earthworms that survived during the 7 days exposure were statistically different (P=0.07) with increasing concentrations of sodium hypochlorite. The gradual increase of applied concentrations resulted in different mortality/survival of earthworms. In addition, the correlation test showed that earthworm survival under 7 days of experiment was inversely correlated (-0.959) to the gradual increase of concentrations. The study suggested that 2.5 mg/ml caused 100% mortality effect on earthworms representing a lethal concentration for earthworms under the test condition.

The earthworm population inside the biofil digester was highly affected with the concentrations of sodium hypochlorite over the 7 and 14 days of exposure time.

4.3. Effect of Lactic acid (Mr Muscle) on Eudrilus eugeniae

After 7 days of chemical application, 7(87.5%), 7(87.5%), 6(75%) and 3(37.5%) of earthworms (*eudriluseugeniae*) were able to survive at 0.7, 1.3, 2.4 and 4mg/ml respectively. At 7 mg/ml, earthworms were not able to resist the toxicity effect resulting in 100% mortality after the 7 days of exposure.

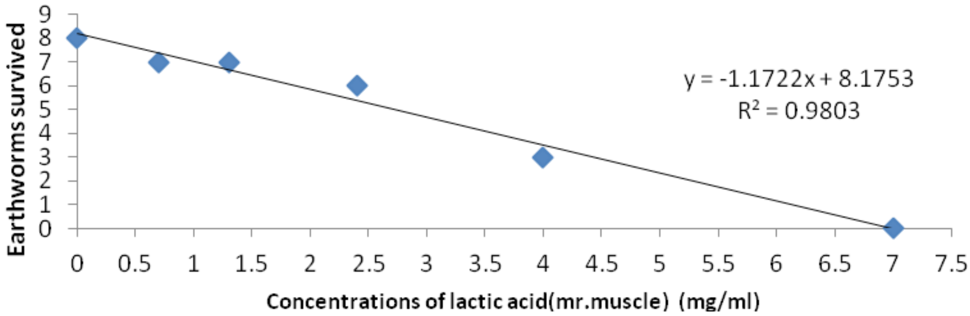

Figure 9: Effect of Lactic acid on *Eudrilus eugeniae* Survival after 7 Days

Earthworms were able to survive at 7(87.5%), 6(75%), 5(62.5%) and 2(25%) treated with concentrations of 0.7, 1.3, 2.4 and 4 mg/ml respectively after 14 days of exposure. However, the concentrations did not cause 100% mortality effect on earthworms during this time.

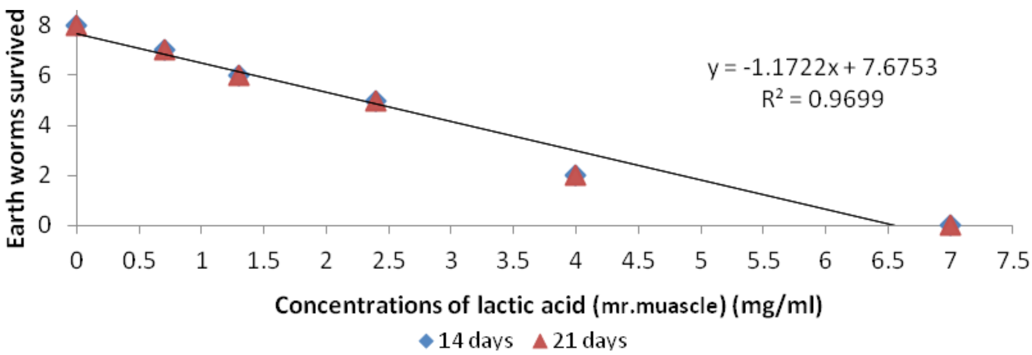

Figure 10: Effect of Lactic acid on *Eudrilus eugeniae* survival after 14 and 21 Days

After 21 days of exposure, no mortality was recorded on earthworms and earthworms that survived after 14 days of exposure were able to survive after 21 days without experiencing any adverse effect by each of the concentrations.

Furthermore, earthworms survival recorded during the 14 days exposure was statistically different (p=0.61) with gradual increase of applied concentrationsl.This shows that the respective test concentrations were able to cause earthworm mortality as the exposure time was increasing from 7 to 14 days.

4.4. Recovery Potential of Earthworms (Eudrilus eugeniae)

To determine the recovery of earthworms (*eudrilus eugeniae*), the body weight change recorded over the 21 days of exposure and contaminant removal potential were used. After the application of the test chemicals, the survived earthworms may have adapted to the toxicity effect and digested the feed (blackwater) to show body weight change which is an indication of recovery potential of the survived earthworms (Otitoloju, 2005).

Due to time factor, three representative concentrations out of the five applied concentration listed were used from each test chemicals in order to assess earthworms' recovery potential from toxic effects. For this reason test chemical concentrations: chloroxylenol- 0.3, 1.2 and 5 mg/ml; sodium hypochlorite - 0.6, 1.3 and 2.5 mg/ml and lactic acid - 0.7, 2.4 and 4 mg/ml were used for this experiment. However, for sodium hypochlorite the concentration 2.5 mg/ml caused 100% mortality on earthworms so data were collected from only two concentrations (0.6 and 1.3 mg/ml) over the 21 days of this experiment.

4.4.1.Body Weight Change of Earthworms Exposed to Chloroxylenol

Earthworms tested under the control (C_1) increased their body weight by 22.1% after the 7 days experiment while those treated by chloroxylenol reduced body weight by 0.7% and 25.6% at concentrations of 0.3 mg/ml and 5 mg/ml respectively (Figure 11).

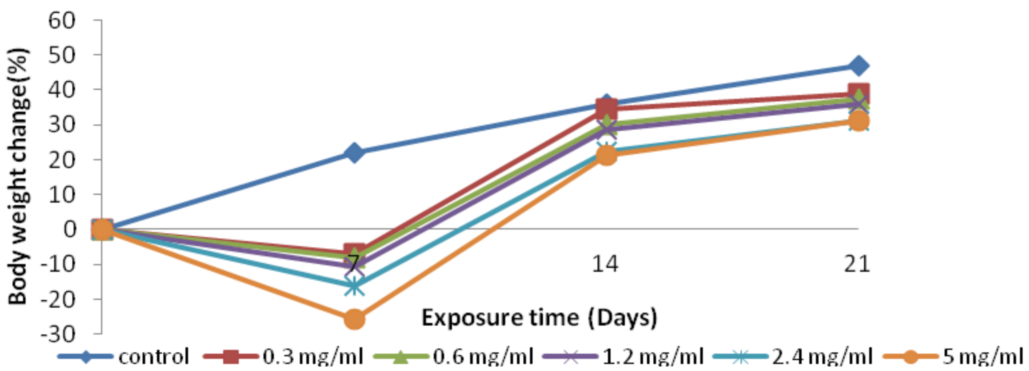

Figure 11: Effect of Chloroxylenol on Body Weight Change of *Eudrilus eugenia*

There was a general increase in body weight after the 7 days exposure. A maximum body weight gain of 35.8% was attained by the earthworms under the control while a 34.4% weight gain was recorded by the earthworms treated by various concentrations of chloroxylenol after 14 days of exposure (Figure 4-8). Earthworms treated at a concentration of 5mg/ml after 21 days of exposure, further increased their body weight by 31.2% and 38.7% at a concentration of 0.3 mg/ml; while in the control earthworms were able to increase by 46.9%.

4.4.2. Body Weigh Change of Earthworms Exposed to Sodium Hypochlorite

The surviving earthworms treated by sodium hypochlorite concentrations after the first 7 days of exposure were not able to either increase or maintain their original body weight. A body weight reduction by 15.7% and 28.5% were observed on the survived earthworms treated with 0.6 and 1.3 mg/ml concentrations respectively as compared to earthworms tested in the control (C1) whose their body weight increased by 22.1% (Figure 12).

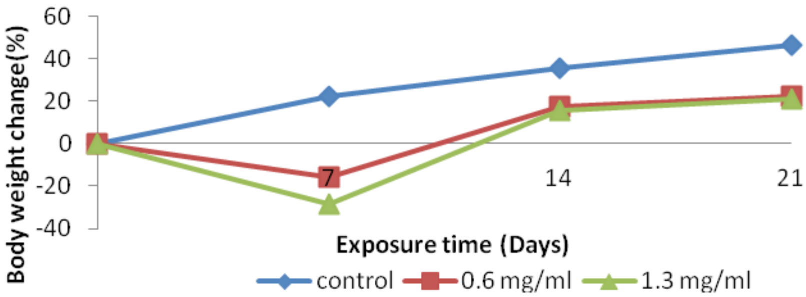

Figure 12: Effect of Sodium Hypochlorite on Body Weigh Change of *Eudrilus eugeniae*

After 14 days of exposure, earthworms started recovering from the toxicity effect by showing a gradual increase of body weight. The earthworms were able to gain body weight by 15.7% and 17.7% treated with concentrations of 1.3 and 0.6 mg/ml respectively as compared with 35.8% attained by earthworms in the control. Furthermore, as the exposure time increased to 21 days, earthworms' body weight increased by 22.2% and 21.1% after treatment with concentrations of 0.6 and1.3 mg/ml respectively (Figure 3-8); while in the control earthworms were able to increase by 46.9%.

4.4.3. Body Weight change of Earthworms Exposed to Lactic acid (Mr. Muscle)

Earthworms after treatment with lactic acid decreased in body weight after 7 days of exposure. A body weight loss (-0.1%) was measured by earthworms tested with lactic acid (Figure 3-9) compared to those exposed to chloroxylenol and sodium hypochlorite. The measured body weight loss by earthworms was statistically significant (p=0.03) with gradual increase of applied concentrations at 95% of confidence interval.

After 14 days of exposure the earthworms recorded a 4.1% and 29.5% weight gain at 0.4 and 0.7 mg/ml respectively.

Similarly after 21 days of exposure, earthworms increased their body weight up to 32% compared to the body weight measured over the 14 days of exposure. The effect of each applied concentrations on the body weight gain is illustrated in Figure 13.

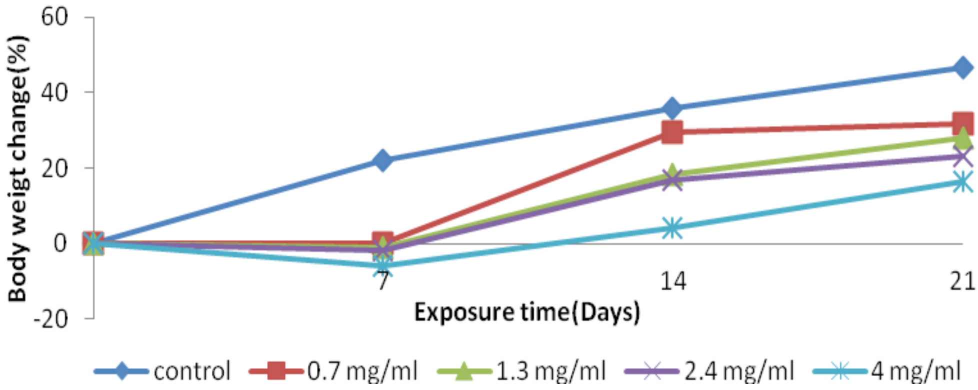

Figure 13: Effect of Lactic acid on Body Weight Change of *Eudrilus eugeniae*

The result obtained suggests that earthworms were able to recover from the toxicity effect of the three chemicals after 14 days of exposure time with significant body weight growth and contaminant removal potential compared to the original body weights. The toxic chemical concentration declines processes like biodegradation and physiological change of earthworms; the earthworms might stay for some time without feeding and this results in body weight loss (VanStraalen and Rijin, 1998).

Earthworm body weight loss after 7 days of experiment may be due to the reduction of feeding as a result of the toxic effect of the feed (Gomez-Eyleset al., 2009).

Body weight gain by earthworms after 14 and 21 days of exposure was statistically significant ($p<0.001$) with gradual increase of applied concentrations at 95% of confidence interval. The correlation test also showed that body weight gain was negatively correlated by (-0.874) with increased in applied concentrations over the 14 days exposure time and by (-0.883) after 21 days of exposure. Hence, as the applied concentration increased gradually, the body weight gain attained by earthworms increased as exposure time increased. This suggests that the effect of chloroxylenol toxicity declined as the exposure duration increased. It has been reported that the pesticide toxicity effect on earthworms decreased through time and the earthworms increased their body weight growth (VanStraalen and Rijin, 1998).

Earthworms exposed to the various concentrations of test chemicals were able to recover from the toxicity effect through time by increasing the quantity of feed they can digest which resulted increase in body weight development and contaminant removal potential (Sinha et al., 2010)

Similarly, Compared to other test chemicals, earthworms experienced body weight loss of -28.5% which shows that the toxicity effect of liquid bleach/sodium hypochlorite/parazone on earthworms was very high over the 7 days of exposure. The correlation test also showed that earthworm body weight reduction had a maximum negative correlation (-1) with increase in concentration of sodium hypochlorite. At 95% of confidence interval, the effect of increased concentration was not statistically significant (p=0.069) on body weight loss of earthworms. Body weight gain by earthworms after 21 days of exposure was statistically significant ($p<0.03$) with increased concentration at 95% of confidence interval. The correlation test also showed that body weight gain after 21 days of exposure was highly correlated (-0.997) with gradual increase in applied concentrations.

5. Conclusion

After 21 days of exposure, this study concludes that chloroxylenol (Dettol) which is the most abundant antiseptic in several households was not able to kill 100% of the test organisms (*eudrilus eugeniae*) for the concentrations tested. The earthworms were not able to resist the toxicity effect of various concentrations of sodium hypochlorite (parazone) tested. More than 50% of the concentrations tested were able to cause 100% mortality effect on earthworms. The concentration, 2.5 mg/ml caused 100% mortality effect on earthworms which means that they were not able to resist toxicity at 2.5 mg/ml. However, 62.5% and 50% of earthworms (*eudrilus eugeniae)* were able to survive at concentrations of 0.6 mg/ml and 1.3 mg/ml respectively.

After testing with lactic acid (Mr.Muscle), 100% mortality was observed on the earthworms by a concentration of 7 mg/ml and up to 87.5% of the earthworms were able to survive with the minimum concentration tested (0.7mg/ml) in the biofil toilet technology blackwater flushing system.

6. Recommendation

For the BTT users employing sodium hypochlorite (parazone) as cleaning chemical can potentially affect the effectiveness of the technology, so it may be advisable to use this chemical with minimum dosages (less than 0.6 mg/ml) for cleaning of the bathrooms in the BTT while using chloroxylenol (dettol) will cause relatively less effect on the activity of earthworms to improve the robustness the biofil toilet technology.

For further study care has to be taken during the collection of blackwater to make sure that it was not already contaminated with other toxic cleaning chemicals before dosing the applied concentration for testing as it may affect the performance of earthworms.

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