Asian Journal of Engineering and Technology (ISSN: 2321 – 2462)
Volume 01– Issue 04, October 2013

Application of the Vermifiltration Technology in Sewage Wastewater Treatment

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ABSTRACT— ***Vermifiltration was used for treatment of sewage wastewater using the Eisenia fetida earthworm species. The earthworms' gut acted as a bioreactor whereby there was reduction in the sewage wastewater's solid and liquid organic wastes through ingestion and expelling these as vermicompost. 500 earthworms were used in the vermifilter over a 5 period of days. The treated water pH increased from being acidic to neutral. The sewage wastewater biological oxygen demand (BOD_5), chemical oxygen demand (COD), total dissolved and soluble solids (TDSS) and turbidity decreased by 98%, 70%, 95% and 98% respectively through vermifiltration. Vermifiltration significantly decreased the sewage water's physicochemical parameters compared to an ordinary bio-filter without earthworms' presence. The vermi-treated sewage water compared well with the set standards for irrigation water. Vermifiltration technology can therefore be applied as an environmentally friendly technique for sewage water treatment for irrigation purposes.***

Keywords— Bio-filter, earthworms, *Eisenia fetida*, sewage wastewater treatment, vermifiltration technology

1. INTRODUCTION

WASTEWATER treatment is the removal of contaminants from any form of wastewater and it includes physical, chemical and biological processes so that the water can be re-used [1]-[4]. The most suitable wastewater treatment technique to be applied must meet the recommended microbiological and chemical quality guidelines at low cost, least operational and maintenance requirements [3]; [5]. Adopting a low level of treatment as possible is needed in developing countries, not only from the point of view of cost but also in acknowledgement of the difficulty of operating complex systems reliably [3]; [5]-[9]. Vermifiltration technology which uses epigeic earthworms as a means of treating wastewater is increasingly becoming an environmentally friendly wastewater treatment technique [3]-[4]; [6]-[11]. Vermifiltration is a low cost, odourless and non-labour intensive method of wastewater treatment [6]; [9]. The resulting vermi-filtered water is clean and disinfected enough to be reused for farms irrigation, in parks and gardens [4]; [6]; [10]-[11]. During vermifiltration, there is no sludge formation in the vermireactor which requires additional expenditure on landfill disposal; instead a vermicompost which is a bio-fertilizer is formed [4]; [6]-[8]; [10]-[12]. Vermifiltration also removes heavy metals, solid and liquid organic waste in the wastewater through the action of earthworms [6-9; 11; 13].

Various earthworm species have been used in vermifiltration of municipal wastewater [6]-[8]; [10]-[11]; [13-14]. The earthworms' body work as a bio-filter and earthworms' have been found to reduce biological oxygen demand (BOD_5), chemical oxygen demand (COD), total dissolved solids (TDS), total dissolved and suspended solids (TDSS) and turbidity from wastewater [3]-[4]; [6]-[8]; [9]-[11]; [13]. Earthworms increase the hydraulic conductivity and natural aeration of the organic particles by granulating the organic particles into small particles [10]. In addition, the earthworms grind the silt and sand particles, increasing the total specific surface area which enhances the ability to adsorption of the organic and inorganic particles from the wastewater [4]; [6]; [7]-[8]; [9]-[11]. Increment of soil processes and soil aeration by the earthworms enables the soil stabilization and filtration system to become efficient. Suspended solids are trapped on top of the vermifilter, processed by earthworms' ingestion and fed to the soil microbes immobilized in the vermifilter [6]-[8]. The processes of microbial stimulation, biodegradation as well as the enzymatic degradation of waste solids by earthworms simultaneously work in the vermifiltration system [4]; [6]-[8]; [9]-[11].

Currently, Zimbabwe is faced with the environmental cost of dealing with current and future generations of rising municipal and industrial wastewater [5]. Over 70% of the water supplies used in many developing countries return as wastewater, hence the need to speed up development while meeting the requirements of environment conservation [5]; [10]. Sewage wastewater carries hazardous chemicals and very high loadings of organic matter which must be treated before disposal. Sewage wastewater in Harare, Zimbabwe goes to two large activated sludge plants but still large volumes of inadequately treated wastewater are being discharged into the rivers, Marimba and Mukuvisi which drain into the city's major sources of water i.e. lakes Chivero and Manyame [5]. Treatment of this wastewater for sustainable development with environmental protection can be achieved by the use of earthworm's species which promises to provide cheaper solutions to social, economic, environmental and health problems crippling our nation [5]. This work therefore applied the vermifiltration technology for treatment of Harare Municipal Sewage wastewater using the *Eisenia fetida* earthworm species. *Eisenia fetida* earthworms have been found to be efficient in vermifiltration studies [7]-[8].

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2. MATERIALS AND METHODS

2.1 Materials

A vermifiltration bed which was made up of gravel of different sizes, sand, garden soil, a sprinkler, a fibrous plastic filter was used. 500 *Eisenia fetida* earthworms were used on the earthworm type based on a 5000-10000 worms/m^2 calculation [6-8]. The *Eisenia fetida* worms were obtained from the Institute vermicomposting project [12].

2.1.1 Description of the vermifiltration bed

The vermifiltration bed constituted of a layer of the fibrous plastic filter to cover the base of the bed. The bottom most layers were made up of aggregates of sizes 7.0-8.0 cm and filled up to the depth of 0.2 m. On top, was a layer of aggregates 3.0-5.0 cm and filled up to another depth of 0.2 m. Another 10cm layer of small gravel mixed with sand was introduced with a depth of about 0.25 cm. The top most layer was then made up of 15 cm of garden soil and was the one in which worms were introduced into. The worms were given one week settling time in the soil bed to acclimatize in the new environment. As the earthworms played the critical role in wastewater purification, their number and population density increased [6]-[8]; [11]; [13]. The untreated sewage water was evenly distributed in the vermifiltration bed by turning spurt water device.

2.1.2 Raw Sewage wastewater characteristics and the acceptable values

The raw sewage wastewater was obtained from the Warren Park, Harare's swamp area. Sewage is the cloudy fluid of human fecal matter and urine, rich in minerals, organic substances and rich in turbidity. Sewage wastewater contains 99.9% water and 0.1% solids, of which 70% of the solids are organic material. The sewage water characteristics are indicated in Table 1. The Environmental standards for treated wastewater to be used for irrigational purposes were obtained from Alberta Environment. [15]. The BOD, COD, TDSS and turbidity were measured in milligrams of dissolved oxygen per liter (mg/L).

TABLE I
SEWAGE WASTEWATER PHYSICOCHEMICAL PROPERTIES

Water parameter	Sewage Wastewater	Environmental standard for irrigation water
pH	5.9-6.3	6.5-8.5
BOD (mg/L)	190-405	10-20
COD (mg/L)	121-280	25-50
TDSS (mg/L)	320-370	10-20
Turbidity (mg/L)	336-384	Not provided

2.2 Methods

2.2.1 Wastewater physicochemical properties analysis

The untreated sewage wastewater was fed to the vermifilter bed as well as the control bio-filter bed and allowed to move through the bed. The treated sewage water was then collected at the bottom of the vermifilter bed and was analyzed for pH, BOD_5, COD, TDSS and turbidity. The pH was measured by the Hanna Instrument which was allowed to settle for 10 minutes before measurement. The BOD_5 was determined by the standard oxidation procedure after 5 days at 20◦C whilst the COD and turbidity were also determined by a Shimadzu *uv-vis* spectrophotometer according to procedures clearly explained in detail by Sinha *et al*., [6] The TDSS was determined by filtration and the amount of solids removed was determined by drying at 100°C.

2.2.2 The vermifiltration experimental procedure

5L of sewage wastewater was kept in calibrated 8L poly vinyl chloride (PVC) drum. The drum was kept on an elevated platform just near the vermifilter bed. The PVC drum had a tap at the bottom to which an irrigation system was attached. The irrigation system consisted of a 1.3 cm polypropylene pipe with 2mm holes for trickling water that allowed uniform the distribution of wastewater on the soil surface of the vermifilter bed. Wastewater from the drum flowed through the irrigation pipe by gravity at a rate of 0.003 m^3/hr. The wastewater percolated down through various layers in the vermifilter bed passing through the soil layer inhabited by earthworms, the sandy layer, the gravel, and at the end was collected in a chamber at the bottom of the vermifilter bed. The hydraulic retention time (HRT) in the vermifilter bed was kept uniformly at 2 hours in all experiments and each experimental run was allowed to go through 2 cycles. All experiments for both the vermifilter and the control bio-filter were replicated 3 times.

2.2.3 The control bio-filter bed experiment

The control bio-filter bed, without earthworms was set as a comparison to evaluate the effect of earthworms as bio-filters in wastewater treatment. The control bio-filter bed was an exact replica of the vermifiltration bed but had no earthworms added to it. The soil, sand particles and the gravels in the control bio-filter bed are reported to also contribute in the filtration and cleaning of wastewater by adsorption of the impurities on their surface [6]-[8]; [11]. Soil, sand and gravel particles provide ideal sites for colonization by decomposer microbes which work to reduce BOD, COD, TDSS and the turbidity from the wastewater [6]-[8]; [10]-[11]. When the wastewater passed through the beds, a layer of microbial film was produced around them and together they constituted the geological and the microbial system of wastewater filtration [6]-[8]; [11]. Increase of the volume of wastewater passing through the soil filter also increases formation of biofilms of decomposer microbes [6]-[8]; [10]-[11]. Hence it is critical to have a control bio-filter bed to determine the effect of earthworms on pH, BOD_5, COD, TSS and turbidity on the sewage wastewater.

3. RESULTS AND DISCUSSION

3.1 Critical observations made during experimentation

The vermifiltration bed and control bio-filter bed were constantly observed for foul odor, percolation of wastewater through the soil bed, and appearance of the upper layer of soil bed. The vermifilter bed was also observed and monitored for the activity and movement of the earthworms. Any form of toxicity in the wastewater seriously affects the earthworms' activity in the soil bed. The earthworms in the vermifilter bed were active, healthy and achieved good growth throughout the period of study. The earthworms appeared to be increasing in number, size and weight. The same observations were made by Sinha *et al*., [6]. Several earthworms were seen wriggling down into the sand and gravels and inhabiting in the voids. There was no problem of any foul odor with the vermifilter bed throughout the experimental study. However, foul odor was observed from the control bio-filter bed. Wastewater percolated smoothly into the soil bed in the vermifilter bed throughout the experimental study while in the control bio-filter bed it was constantly clogging after few smooth run down of wastewater. The same observations were made by Azuar and Ibrahim. [11].

3.2 Change in pH value of treated sewage

pH measures the hydrogen ion concentration in a liquid. The average pH value (6.45) of the raw sewage water was neutralized by the earthworms in the vermifilter bed to a pH of around 7.0 (see Fig. 1). However, pH value of treated sewage wastewater without earthworms also improved to 6.6 but not as high as those in the vermifilter (see Fig. 1). Azuar and Ibrahim. [11] noted the same trend when they applied the vermifiltration technology in treating the palm oil mill effluent. Earthworm activity causes an in-built pH buffering ability by increasing the pH, hence neutralizing the sewage wastewater pH [12]. The pH values obtained in the vermifiltration and control bed were acceptable for use of the treated sewage water for irrigation purposes i.e. pH range of 6.5-8.5 [15]. Furthermore, this pH is ideal for optimum earthworm activity [12].

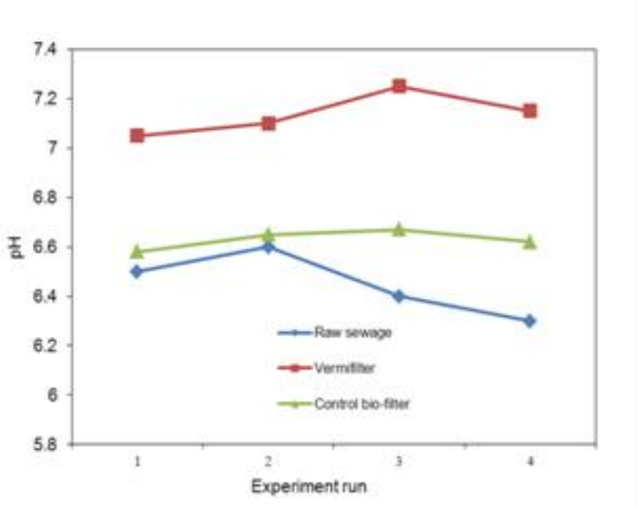

Fig 1: pH changes during sewage water vermifiltration

3.3 Removal of BOD_5

BOD refers to the amount of dissolved oxygen that is required by aerobic bacteria to breakdown organic contaminants in wastewater. The earthworms in the vermifilter removed BOD_5 loads by about 98% whilst the control bio-filter bed indicated a BOD removal of around 75% (see Fig. 2). Earthworms significantly degraded the wastewater organics by enzymatic actions whereby the earthworms worked as biological catalysts resulting in faster biochemical reactions hence high BOD removal in the vermifilter [4]; [6]-[8]; [10]-[11]; [13]. This has been indicated as the major difference between microbial degradation and vermi-degradation [11]. Furthermore, the reduction by the control bio-filter which was due to the microbial degradation was also significant (see Figure 2.0) The BOD values remaining after vermifiltration of the sewage water were acceptable for use of the treated sewage water for irrigation purposes i.e. BOD range of 10-20 mg/L [15]. However, BOD values below 100 mg/L were also obtained in the control bio-filter (65-75 mg/L) and these are still acceptable for water to use in irrigation purposes [15].

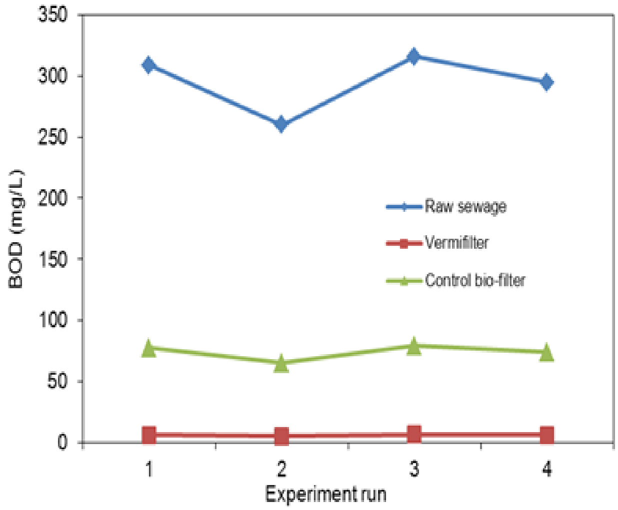

Fig 2: BOD removal during sewage water vermifiltration

3.4 Removal of COD

COD refers to the chemical decomposition of organic and inorganic contaminants in wastewater which cannot be biologically removed. The average COD removed from the sewage water by earthworms in the vermifilter was around 70% while that without earthworms was about 20% (see Fig. 3). COD removal by earthworms was not as significant as the BOD removal; however, the COD amount removed was still much higher than that removed by the microbial system. This was possibly because the enzymes in the gut of earthworms helped in the degradation of several of those chemicals which could not be decomposed by microbes [4]; [6]; [9]-[11]. The COD values remaining after vermifiltration of the sewage water were acceptable for use of the treated sewage water for irrigation purposes i.e. COD range of 25-50 mg/L [15]. However, COD values below 150 mg/L are still acceptable but those in the control bio-filter bed were slightly higher than 150 mg/L which is required for irrigation water [15].

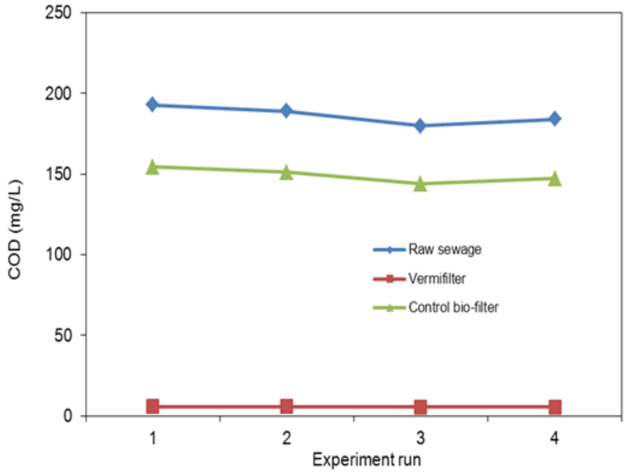

Fig. 3: COD removal during sewage water vermifiltration

3.5 Removal of TDSS

Total dissolved and suspended solids refer to the organic and inorganic contaminants which are either suspended or dissolved in the wastewater. The earthworms in the vermifilter significantly removed the TDSS from the sewage water by about 95% while the control bio-filter bed indicated a 60% decrease (see Fig. 4). These solids which were removed accumulate over time as sludge in a normal bio-filter and choke the system which then ceases to work properly [6]-[8]; [9]-[11]. However, in the vermifilter bed these bio-solids were constantly ingested by the earthworms and expelled as vermicompost [6]-[8]; [10]. This explains why there was no choking and interrupted functioning of the vermifilter bed. The TDSS values (14-15 mg/L) remaining after vermifiltration of the sewage water were also acceptable for use of the treated sewage water for irrigation purposes i.e. TDSS range of 10-20 mg/L [15]. However, values below 100 mg/L are still acceptable but the TDSS values (145-178 mg/L) in the control bio-filter were unacceptable in water to be used for irrigation water purposes [15].

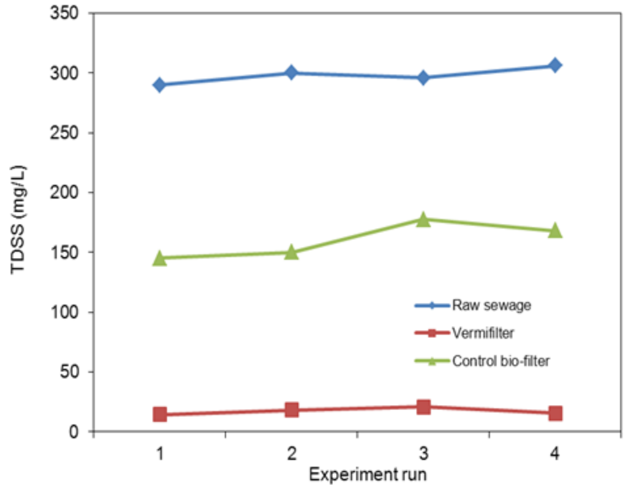

Fig 4: TDSS removal during sewage water vermifiltration

3.6 Removal of turbidity

Turbidity refers to the cloudiness of wastewater due to the presence of both macroscopic and microscopic suspended solids e.g. clay, silt and any organic matter. There was a reduction in the sewage water turbidity by earthworms in the vermifilter by over 98% whilst the sewage water in the control bio-filter bed also showed a significant decrease of about 95% (see Fig. 5). The geological system also played a very important role in turbidity removal by adsorption of suspended particles on the surface of the soil, sand and the gravels in addition to the earthworms' activity. Azuar and Ibrahim. [11] noted the same trend when they applied the vermifiltration technology to treatment of palm oil industry wastewater. The successful reduction of BOD_5, COD and TDSS has a direct link to turbidity reduction as well such that the water can be successfully used for irrigational purposes.

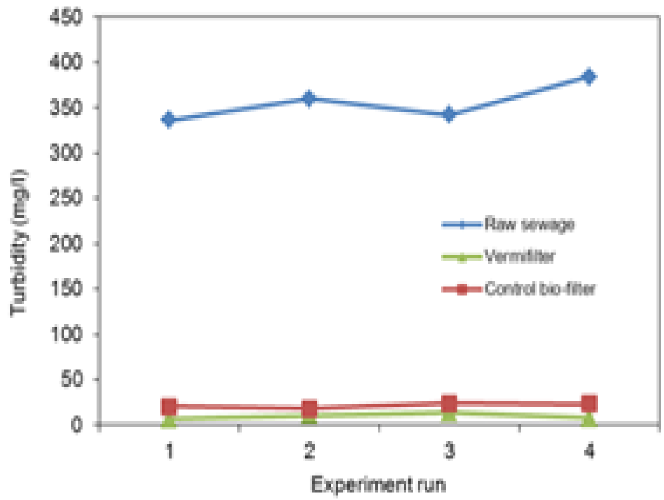

Fig 5: Turbidity removal during sewage water vermifiltration

4. CONCLUSION

Vermifiltration technology is a recommended solution for sewage wastewater treatment in developing countries. Vermifiltration of sewage wastewater results in treated water which can be used for irrigation purposes and a bio-fertilizer, vermicompost instead of unwanted sewage sludge is also obtained. Vermifiltration of sewage wastewater resulted in neutralized water pH, decreased BOD_5, COD, TDSS and turbidity. In addition, the microbial-geological system of the control bio-filter bed without earthworms also helped in the wastewater treatment. The combined effect of the *Eisenia fetida* worms and the microbial-geological system successfully treat sewage wastewater.

5. ACKNOWLDGEMENT

The Harare Institute of Technology is thanked for funding this work
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