Pilot Scale Studies for Vermifiltration of $1000m^3$/day of Sewage Wastewater

[1]Musaida Mercy Manyuchi, [2]Luckmore Kadzungura and [3]Sandra Boka

[1]Department of Chemical and Process Systems Engineering,
Harare Institute of Technology, P.O. BOX BE277, Belvedere, Harare, Zimbabwe

[2]Department of Chemical and Process Systems Engineering,
Harare Institute of Technology, P.O. BOX BE277, Belvedere, Harare, Zimbabwe

[3]Department of Chemical and Process Systems Engineering,
Harare Institute of Technology, P.O. BOX BE277, Belvedere, Harare, Zimbabwe

---

ABSTRACT— ***Vermifiltration is a technology in which the combined action of earthworms' activity and the adsorption properties of soil, sand and gravel particles on the organic pollutants are applied for wastewater treatment. Vermifiltration was used in sewage wastewater treatment as a cheaper and enviro-friendly technology. $1000m^3$/day of sewage wastewater was treated in a four layered vermifilter at an Eisenia fetida earthworm density of 8 000 earthworms/m^2 in a $3.6m^2$ soil bed. The vermifilter bed layers comprised of 4-8mm garden soil particles, 8-12mm mixed sand and gravel particles, 30-50mm small aggregates and 70-80mm large aggregates respectively. A vermifilter bed porosity of 0.96 was used. The vermifilter had a hydraulic retention time of 0.082days and a hydraulic loading rate of $0.93m^3/m^2$.day. The vermifilter design effectively resulted in over 90% reduction in BOD, COD, TDSS and turbidity as well as neutralized pH in the sewage wastewater. Proper vermifilter design ensures optimum sewage wastewater treatment for potential use in irrigation.***

Keywords— Earthworms, vermifiltration, vermifilter design, wastewater treatment

---

1. INTRODUCTION

Wastewater treatment involves physical, chemical and biological methods to remove unwanted material in contaminated water so that it can be used for a fit purpose [1-4]. Vermifiltration is increasingly becoming popular as an environmentally friendly and cheap way of treating wastewater [3-14]. Vermifiltration technology uses earthworms as bio-filters in waste water treatment, whereby the earthworms feed on the organic pollutants in the wastewater. This results in reduced biological oxygen demand (BOD), chemical oxygen demand (COD), total soluble solids (TSS), total dissolved suspended solids (TDSS) and turbidity by over 80% [3-8; 11; 12-15]. Additionally, a vermicompost, which is a bio-fertilizer, is produced at the end of the process [4-8; 11; 14; 16]. Furthermore, the earthworm microbial activity removes heavy metals that will be in the wastewater [5; 7-8; 11; 12; 17-18]. The vermifiltration process is facilitated by the earthworm activity whereby they act as bio-filters reducing the unwanted organic waste loading in the wastewater [5; 7-8; 11; 12; 14; 18]. Additionally, the soil and gravel particles employed as part of the vermifilter bed contribute to the filtration and cleaning of the sewage wastewater by adsorption of the organic impurities on their surfaces [5; 7-8; 11; 14-15]. The vermifiltration process is therefore a combined action of the earthworms as well as the soil, sand and gravel particles [13-14]. The vermifiltration technology was proposed as an alternative sewage wastewater treatment method in developing countries that are being faced with wastewater treatment challenges [13-14]. This treated water has been recommended for use in irrigation purposes [10; 14; 17]. This was to provide an alternative wastewater treatment method due to the challenges being faced in operating wastewater treatment plants as well as the replacement of equipment costs that are being faced in developing countries [19]. The vermifilter used in this technology is integral to the development of the new high-value treated water and the replacement of existing chemical-based wastewater treatment processes. The proper selection and design of the vermifilter determines the optimal commercial process and the corresponding capital investment hence the need of a proper vermifilter design.

2. MATERIALS AND METHODS

2.1 Materials

Eisenia fetida earthworms obtained from the Institute vermicomposting project were used for the sewage wastewater treatment. The raw sewage wastewater was obtained from the Warren Park Swamp area and it had the following characteristics: pH 5.9-6.3, BOD 190-405 mg/L (milligrams of dissolved oxygen per liter of sewage wastewater), COD 121-280 mg/L, TDSS 320-370 mg/L and turbidity 336-384mg/L.

2.2 Methods

The pH was measured by a Hanna Instrument. The sewage wastewater was allowed to settle for 10 minutes before pH measurement. The BOD_5 was determined by the standard oxidation procedure after 5 days at 20◦C whilst the COD and turbidity were determined by a *uv-vis* spectrophotometer according to procedures used by Sinha *et al.*, [5]. The TDSS was determined by filtration and the amount of solids removed was determined by drying at 100°C. The soil, sand and aggregates mean diameters were obtained by using stainless steel sieves of various sizes.

2.2.1 Vermifilter Design Method

The purpose of an effective vermifilter design is to control, contain and positively influence both the earthworm activity and the effect of the soil, sand and gravel particles on the rate of organic pollutants removal. To accomplish this, several factors were taken into consideration which include hydraulic residence time (HRT), hydraulic loading rate (HLR), volumetric flow rate of the sewage wastewater (Q_w), volume of the sewage wastewater (V_w), volume of the soil bed where the earthworms reside (V_s) and the physicochemical characteristics of the sewage wastewater i.e. pH, BOD, COD, TDSS and turbidity.

3. RESULTS AND DISCUSSION

3.1 Sewage Wastewater Treatment by Vermifiltration Process Design

The vermifiltration process for the sewage wastewater treatment is indicated in Figure 1and the process stream numbers are clearly defined in Table 1. The sewage wastewater must first undergo primary treatment which includes screening, grit removal, and flow monitoring from the storage tank (S1). The process generally does not have primary settling tanks; therefore there is need for effective removal of grit and scum. The solid waste at this stage can be sent off to vermicomposting plants where the material is decomposed into a bio-fertilizer reducing sludge disposal costs [4-8; 11; 14; 17]. A peristaltic pump can be used to pump the sewage wastewater to the sieved effluent tank (S2). The sewage wastewater was then pumped to the vermifilter bed where the vermifiltration process was allowed to take place as a secondary treatment stage (S3). Vermicompost was formed from the vermifiltration process was removed together with the *Eisenia fetida* earthworms. The vermifiltered water was then transferred to a settling tank (S4) where minute vermicompost particles that would have escaped from the vermifilter were recaptured whilst the treated water was transferred to a storage tank (S5). The tertiary treatment stage is not essential as this water will be diverted to irrigation ponds. Furthermore, the vermifiltration process reduced the bacterial load in the sewage wastewater to such an extent that it can be safely utilized in irrigation [10; 14]

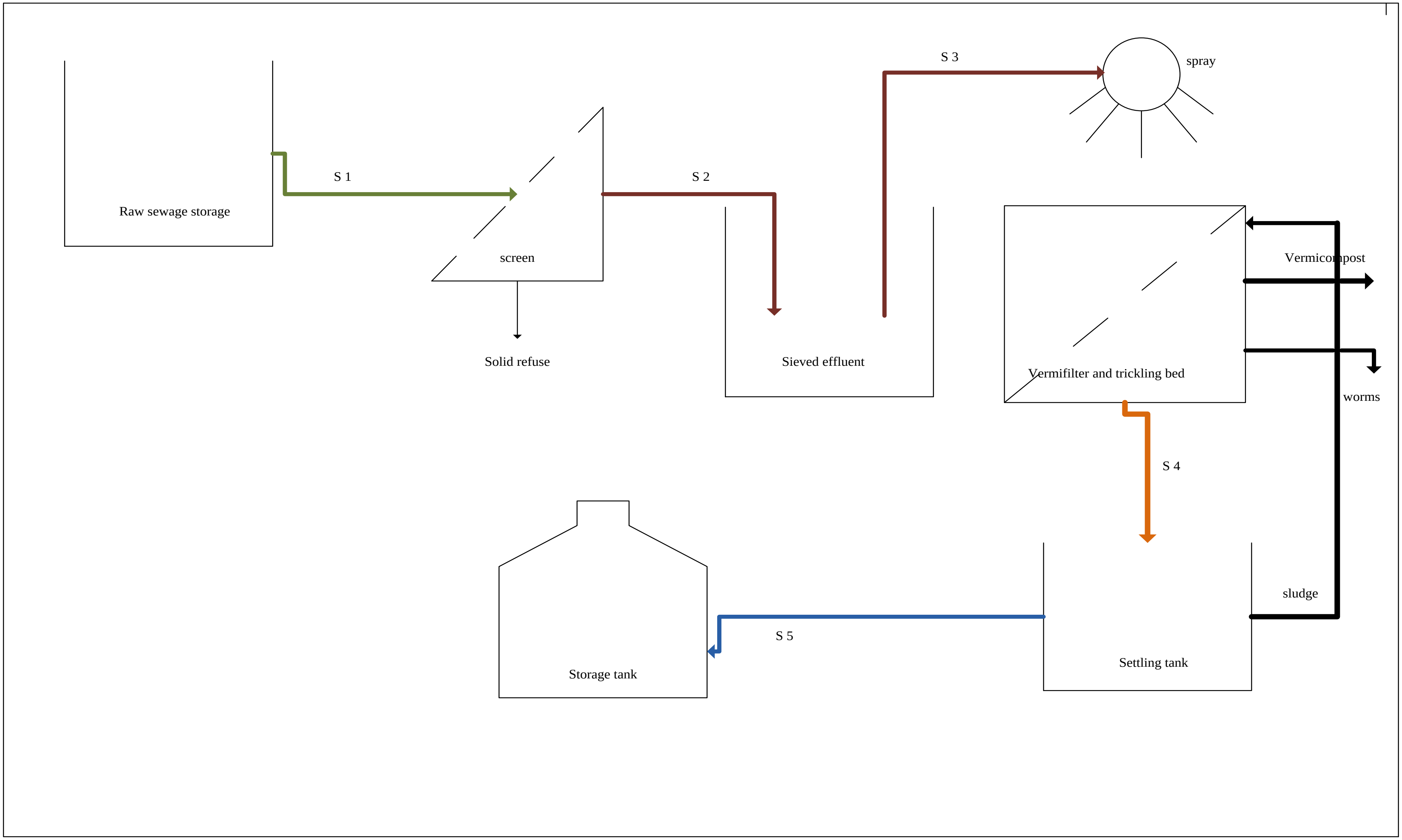

Figure 1: Proposed sewage wastewater vermifiltration process

Table 1: Process streams showing the sewage wastewater flow during vermifiltration

Stream number	Material
S1	Raw sewage waste water
S2	Sieved effluent
S3	Sieved effluent
S4	Vermifiltered water with sludge
S5	Clarified vermifiltered wastewater

3.2 Sewage Wastewater Feed Rate

The sewage wastewater was introduced at a volumetric flow rate (Q_w) of 1000m^3/day. The volumetric flow rate has significance on the vermifiltration process. The higher the volumetric flow rate, the lower the rate at which the organic pollutants will be removed from the sewage wastewater since the earthworms will not have enough time to consume the organic waste. Furthermore, the adsorption of the impurities in the sewage wastewater will not fully adsorb on the sand and gravel particles if the volumetric flow rate is too high, instead they will be washed away. Hence an optimum volumetric flow rate must be maintained.

3.3 Earthworms Density

Earthworm density refers to the number of live adult earthworms per unit area in the soil bed. An average of 8 000 *Eisenia fetida* earthworms were used per square meter of the 3.6m^2 soil bed. This is the recommended optimum earthworm density in vermifiltration processes [7-8; 11; 17]. The higher the earthworm density in the vermifilter, the higher the rate of vermifiltration since higher quantities of organic pollutants will be consumed by the earthworms.

3.4 Vermifilter Hydraulic Retention Time (HRT)

The vermifilter hydraulic retention time (HRT) is the time taken by the wastewater to flow through the soil bed in which the earthworms are habitant [5; 17]. The sewage wastewater must remain in the soil bed and be in contact with the earthworms for a certain period of time for optimum removal of the organic pollutants. HRT therefore depends on the sewage wastewater flow rate to the vermifiltration unit, volume of the soil profile, and the diameter of the soil used [17]. HRT is very important, because this is the actual time spent by earthworms in the wastewater utilizing organic matter from it as their source of food. During this period, the earthworms activity involve the physical and biochemical process to remove nutrients, thereby reducing the sewage wastewater BOD, COD, TDSS and the turbidity [4-8; 11; 13-14]. The longer the sewage wastewater remains in the soil bed, the higher will be the efficiency of vermifiltration process. Therefore, the sewage wastewater flow rate in the vermifilter is an important consideration as it determines the retention of suspended organic matter and solids. Maximum HRT can results from slower rate of wastewater discharge on the soil bed profile and hence slower percolation into the bed. Increasing the volume of soil profile can also increase the HRT. The number of live earthworms functioning per unit area in the soil bed also influences HRT. HRT in a vermifiltration process can be calculated as indicated in Equation 1. The HRT used in this pilot study was 0.082 hours (4.92 minutes) in accordance to Equation 1. The vermifilter bed porosity used for the design was 96% in accordance to the work of Yang *et al*., [20]. An HRT of 4-5 minutes was also used by Ghatnekar *et al*., [6] in the vermifiltration of liquid effluents from the gelatin industry.

$$HRT = (\rho \times V_s) / Q_w \quad \text{(Equation 1)}$$

Where:

HRT = hydraulic retention time (hrs)

V_s = volume of the soil bed (m^3)

ρ = Porosity of the vermifilter bed through which the sewage wastewater flows

Q_w = Flow rate of sewage wastewater through the soil bed (m^3/hr)

3.5 Vermifilter Hydraulic Loading Rate (HLR)

The vermifilter hydraulic loading rate (HLR) is the volume of sewage wastewater applied per unit area of the soil bed per unit time [5; 17]. HLR also depends on the earthworm density with respect to the organic pollutants load reduction. HLR of vermifilter can be calculated by Equation 2. High hydraulic loading rate leads to reduced HRT in the vermifilter thereby reducing the treatment efficiency of the vermifilter [5; 17]. The HLR used in this pilot study was 0.93 m^3/m^2.day in accordance to Equation 2. An HLR of 2.0-3.0 m^3/m^2.day was reported in literature over an HRT of 6-8 hours [7-8; 11; 17]. This was about double the HLR found in this work possibly because the HRT used in this work was low.

$HLR=V_w / (A \times t)$ (Equation 2)

Where:

HLR = Hydraulic loading rate (m^3/m^2.day)

V_w = Volumetric flow rate of wastewater (m^3)

A = Soil bed area exposed (m^2)

t = Time taken by the wastewater to flow through the soil bed (hrs)

3.6 The Vermifilter Design

The vermifilter was designed in such a way that there was maximum removal of organic pollutants in the sewage wastewater. The vermifilter had four layers with different packing of different sizes and characteristics. The details on the layers and the packing are given in Table 2. A free space of 0.3m was left in the vermifilter to allow proper distribution of the sewage wastewater from the sieved effluent tank as well as to cater for the vermicompost that may accumulate and the increase in weight, number and length of the earthworms. The first vermifilter layer was made up of 4-8mm soil particles and Eisenia fetida earthworms, followed by a second layer with 8-12mm small gravel and sand particles, the third layer comprised of 30-50mm small aggregates and finally a fourth layer with 70-80mm big aggregates (see Table 2). The purpose of the four layers was to ensure optimum organic waste removal from the sewage wastewater by the combined effect of both the earthworm activity and the soil, sand and gravel particles [4-8; 11; 13-14].

Table 2: Vermifilter bed design parameters

Parameter	Property
Vermifilter free space (m)	0.3
Sewage wastewater flow rate into soil bed (Q_w) (m^3/day)	1000
Sewage wastewater volumetric flow rate (V_w) (m^3)	24000
Soil bed with earthworms area (m^2)	3.6 (24 x 1.5)
Soil bed height (m)	1.0
Hydraulic retention time (HRT) (hrs)	0.082
Hydraulic loading rate (HLR) (m^3/m^2.day)	0.93
First layer media	Garden soil with earthworms
Garden soil diameter (mm)	4.0 – 8.0
Soil bed height (m)	1.0
Second layer media	Small gravel mixed with sand
Small gravels mixed with sand diameter(mm)	8 – 12
Small gravel mixed with sand bed height (m)	1.0
Third layer media	Small gravel aggregates
Small gravel aggregates diameter(mm)	30 – 50
Small gravel aggregates bed height (m)	1.0
Fourth layer media	Big gravel aggregates
Big gravel aggregates diameter (mm)	70 – 80
Big gravel aggregates bed height (m)	1.2
Total vermifilter height (m)	4.5
Vermifilter bed porosity (ρ)	0.96
Pump type	submersible

3.6 Vermifilter Pump Selection

A submersible pump was used to extract the water to the surface from the vermifilter side channels in each vermifilter due to its capability to prevent pump cavitation.

3.7 Physicochemical Characteristics of the Sewage Wastewater before and after Vermifiltration

A sample of sewage wastewater that was run through the vermifilter clearly indicated a more than 90% decrease in the BOD, COD, TDSS and turbidity of the wastewater (see Table 3). Furthermore, the increased from being acidic to neutral (see Table 3). This neutral pH is ideal for water to be used for irrigation purposes as well as optimum earthworm activity [14].

Table 3: Raw and treated sewage wastewater characteristics

Water parameter	Raw sewage wastewater	Treatment sewage water
pH	5.6-6.3±0.12	7.05-7.25±0.09
BOD (mg/L)	190-405±24.0	5.2-6.32±0.50
COD (mg/L)	121-280±5.69	5.4-5.79±0.17
TDSS (mg/L)	320-370±6.73	14.5-20.72±2.82
Turbidity (NTU)	336-384±21.6	6.72-13.68±3.16

4. CONCLUSION

Vermifiltration is an alternative, sustainable technology for sewage wastewater treatment. The design of the vermifilter must ensure optimum removal of organic pollutants in the sewage wastewater with respect to the wastewater flow rate, earthworm density, hydraulic retention time and hydraulic loading rate. Vermifiltration successfully lowers the sewage wastewater BOD, COD, TDSS and turbidity as well neutralizing the pH. The treated sewage wastewater can be used for irrigation purposes.

5. ACKNOWLEDGMENT

The Harare Institute of Technology is thanked for funding this work.

6. REFERENCES

[1] M. N. Pons, H. Spanjers, D. Baetens, O. Nowak, S. Gillot, J. Nouwen and N. Schuttinga, “Wastewater characteristics in Europe-A survey”, European Water Management Online, pp. 1-10, 2004.

[2] M. Zielinska and I. Wojnowska-Baryla, “Removal of organic compounds from municipal wastewater by immobilized biomass”, Polish Journal of Environmental Studies, 13(5), pp. 573-577, 2004.

[3] R. K. Trivedy, “Low cost and energy saving technologies for water and wastewater treatment”, Journal of Industrial Pollution Control, 23 (2), pp. 403-411, 2007.

[4] A. M. Kharwade and I. P. Khedikar, “Laboratory scale studies on domestic grey water through vermifilter and non-vermifilter”, Journal of Engineering Research and Studies, 2 (4), pp. 35-39, 2011.

[5] R. K. Sinha, G. Bharambe and P. Bapat, “Removal of high BOD and COD loadings of primary liquid waste products from dairy industry by vermifiltration technology using earthworms”, Indian Journal of Environmental Protection, 27(6), pp. 486-501, 2007.

[6] S. D. Ghatnekar, M. F. Kavian, S. M. Sharma, S. S. Ghatnekar, G. S. Ghatnekar and A. V. Ghatnekar, “Application of vermi-filter-based effluent treatments from the gelatine industry”, Dynamic Soil, Dynamic Plant, pp. 83-88, 2010.

[7] R. K. Sinha, S. Agarwal, K. Chauhan, V. Chandran and B. K. Soni, “Vermiculture technology: Reviving the dreams of Sir Charles Darwin for Scientific Use of Earthworms in Sustainable Development Programs,” Technology and Investment, 1, pp. 155-172, 2010.

[8] R. K. Sinha, K. Chauhan, D. Valan, V. Chandran, B. K. Soni and V. Patel, “Earthworms: Charles Darwin’s unheralded soldiers of mankind: Protective and Productive for Man and Environment”, Journal of Environmental Protection, 1, pp. 251-260, 2010.

[9] P. Luth, P. Robin, P. Germain, M. Lecomte, B Landrain, L Yinsheng and D Cluzeau, “Earthworms effects on Gaseous Emissions During Vermifiltration of Pig Fresh Slurry”, Journal of Bioresource Technology, pp. 3679-3686, 2010.

[10] P. Morand, P. Robin, A. Escande, B. Picot, A. M. Pourcher, Q. Jiangping, L. Yinsheng, G. Hamon, C. Amblard, L. S. Fievet, D. Oudart, C. P. L. Quere, D. Cluzeau and B. Landrain, “Biomass Production And Water Purification From Fresh Liquid Manure-Use Of Vermiculture, Macrophytes Ponds And Constructed Wetlands To Recover Nutrients And Recycle Water For Flushing In Pig Housing”, Procedia Environmental Sciences, pp. 130-139, 2011.

[11] S. A. Azuar and M. H. Ibrahim, “Comparison of sand and oil palm fibre vermibeds infiltration of palm oil mill effluent (POME)”, UMT 11th International Annual Symposium on Sustainability Science and Management, 09th-11th July 2012, Terengganu, Malaysia, pp. 1414-1419, 2012.

[12] T. E. U. A Malek, S. A. Ismali and M. H. Ibrahim, “Vermifiltration of palm oil effluent (POME)”, UMT 11th International Annual Symposium on Sustainability Science and Management, 09th-11th July 2012, Terengganu, Malaysia, pp. 1292-1296, 2012.

[13] M. Xing, X. Li, J. Yang, L. Baoyi and Y. Lu, “Performance and Mechanism of Vermifiltration System for Liquid-State Sewage Sludge Treatment Using Molecular and Stable Isotopic Techniques”, Chemical Engineering Journal, pp. 143-150, 2012.

[14] M. M. Manyuchi and S. Boka, “Vermifiltration of sewage wastewater using *Eisenia fetida* earthworms for potential use in irrigation purposes”, World Academy of Science, Engineering and Technology, XXX, pp. XXX-XXX, 2013 (*accepted for publication*).

[15] L. Wang, F. Guo, Z. Zheng, X. Luo, and J. Zhang, “Enhancement of rural domestic sewage treatment performance, and assessment of microbial community diversity and structure using tower vermifiltration”, Journal of Bioresource Technology, pp. 9462-9470, 2010.

[16] M. M. Manyuchi, A. Phiri, N. Chirinda, P. Muredzi, J. Govha and T. Sengudzwa, “Vermicomposting of Waste Corn Pulp Blended with Cow Dung Manure using *Eisenia Fetida*”, World Academy of Science, Engineering and Technology, 68, pp. 1306-1309, 2012.

[17] R. K. Sinha, G. Bharambe and U. Chaudhari, “Sewage Treatment by Vermifiltration with Synchronous Treatment of Sludge by Earthworms: a Low Cost Sustainable Technology over Conventional Systems with Potential for Decentralization”, Environmentalist, pp. 409-420, 2008.

[18] M. Xing, X. Li and J. Yang, “Treatment performance of small-scale vermifilter for domestic wastewater and its relationship to earthworm growth, reproduction and enzymatic activity”, African Journal of Biotechnology, 9 (44), pp. 7513-7520, 2010.

[19] I. Nhapi, “The water situation in Harare, Zimbabwe: a policy and management problem”, Water Policy, 11, pp. 221-235, 2009.

[20] J. Yang, S. Zhang, J. Yang and Z. Lu, "Analysis on the Performance of Vermifilter at Low Temperature in Winter," International Conference on Energy and Environment Technology, ICEET, vol. 3, pp. 193-197, 2009.