VERMICOMPOSTING TECHNOLOGY FOR STABILIZING THE SEWAGE SLUDGE FROM RURAL WASTE WATER TREATMENT PLANTS

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Abstract
There are problems associated with sludge management in small treatment plants (<10 L/s) located in rural communities, due to costly conventional technology for sludge stabilization. Many of these plants have only sludge drying beds. Mexican Institute of Water Technology has proposed developing suitable low-cost technologies, one of which is vermicomposting a biodegradation system using earthworms of the species *Eisenia foetida* (earthworm) which stabilize sludge and reduce its pathogenicity. The objective of this work is to present two case studies where vermicomposting technology has been applied in Mexico. The first study corresponds to a plant where 4.8 m^3/month of sludge are produced; for these wastes, a vermicomposting system was built and installed. The second study is a treatment plant where 9 m^3/month of sludge are produced; experimental tests were conducted with sludge and water hyacinth and a vermicomposting system was designed. The vermicomposts were analyzed using parameters defined by Mexican standards. In regards to stabilization, TVS was reduced by 38% and the microbiological quality of the vermicompost was Class A and B, with a reduction in fecal coliforms and Helminth eggs according to NOM-004-SEMARNAT-2002. A CRETI (Corrosivity, Reactivity, Explosivity, Toxicity and Ignitability) analysis (NOM-052-SEMARNAT-2005) was used to show that the process reduced the concentration of releasable sulfides. The agronomic quality of the vermicompost exhibited a high content of organic matter comparable to many organic manures and high content of nutrients such as nitrogen and phosphorus. It is concluded that it is possible to improve the conditions of sewage sludge management in small plants of rural communities with a minimum investment (less than $10,000.00 USD) and with a requirement of a minimum area of 60 to 70 m^2 for a production of less than 9 m^3/month of dehydrated sludge (80% humidity).

Key words: sewage sludge, *Eisenia foetida*, vermicomposting and small plants.

INTRODUCTION

The installation and operation of reactors for the stabilization of sludge in small plants of <10 L/s is not carried out due to expensive investment and operation costs. Many of these plants have only drying beds where sludge is dehydrated after being transferred to a dump or a sanitary landfill. Mexican Institute of Water Technology has proposed developing low-cost technologies for the treatment and use of sludge. One of these proposed technologies is vermicomposting, a biodegradation system using earthworms. This process can be defined as the digestion of organic matter by earthworms and microorganisms. By moving around, earthworms cause aerobic conditions throughout the material, promoting the blooming of aerobic microorganisms. In the earthworm's intestines, processes of breaking up, splitting, synthesis, and enzymatic and microbial enrichment take place. Species used for vermicomposting are: *Eisenia foetida, Eisenia andrei, Perionyx excavatus*, *Eudrilus eugeniae* and *Metaphire californica*. According with Toccalino, P. et al., *E. foetida* (Californian red worm) is a hermaphrodite terrestrial annelid which reproduction begins at 3 months old, and continues all lifetime. Mating happens during the night and usually lasts 30–240 minutes; as consequence, a capsule is generated every 7–10 days. After 14–21 days of incubation, 4–20 worms off springs arise from each capsule. Cardoso L. and Ramirez E., 2002, reported a great reduction in volatile solids in stabilized sludge of high agronomical quality. Vermicomposting products are: 1) Humus can be used for soil remediation due to its humic compounds, macro and microscopic elements, amino acids and beneficial soil-forming microorganisms. 2) Vermicompost tea, which is an aqueous extract used for soil remediation and as foliar fertilizer and 3) Worms, whose can be recycled to the system. Different bacteria have been reported to be associated with earthworm intestines, feces or even the fluid of its cocoons, such as: *Pseudomonas, Alcaligenes, Nocardia, Rhodococcus, Azobacter and Penicilium,* which can degrade organic compounds (Cerniglia, 1993; Johnsen *et al*., 2005). Contreras-Ramos *et al.* (2006), mention that earthworms have a great potential for removing hydrocarbons from the soil, even PAHs which are resistant to degradation of the species *Eisenia foetida*, which, in addition to stabilizing sludge, help reduce its pathogenicity, according to Eastman et al., 2001. The reduction of pathogens is accomplished through different phenomena such as depredation and competition among microorganisms. As confirmed by data obtained by Espinoza et al, 2006**,** the inhibition of Salmonella in biosolids and vermicompost is attributed to high concentrations of microflora (1 x 10^9 CFU/g). In August of 1980, Camp, Dresser and McKee, Inc., Boston, MA, USA, conducted a study to prove the technical and economic feasibility of the process of vermistabilization in several plants. The study included an economic analysis based on the testing of treatment plants and costs of operation in plants that treat the effluent of 50 to 500 thousand people. It was estimated that the cost of vermistabilization was between $24.0 and $32.0 US dollars per ton of processed waste. The objective of this work is to present two case studies where this technology has been used in plants less than 10 L/s , located in rural areas in Mexico.

MATERIALS AND METHODS

For the first case study a treatment plant located in Nicolas de Ibarra was chosen, in the edge of Lake Chapala, Jalisco, 7 km northeast of the town of Chapala, between 20° 19' 38 and 20° 19' 32" parallels of north latitude and between 103° 07' and 103° 08' meridians of west longitude. The annual temperature ranges between 16 and 29° C, the approximate mean value is 25°C. The treatment plant has a volume of less than 10 L/s, with a production of 4.8 m^3/month of sludge (80% humidity) and drying bed. The proposed vermicomposting system was designed for the treatment of 1.2 m^3 /week of dehydrated sludge. The system's total area is 11.96 m x 4.96 m=59.4 m^2 and includes two earthworm beds and three working lanes along the system and two lanes at the heads, each 1 m wide. The total useful volume of each bed is 9.96 m x 0.64 m x 0.72 m = 4.6 m^3. The roofed surface is 69.0 m^2 (12.30 m long x 5.60 m wide and 2.0 m minimum height and 2.60 m maximum height). The beds have a drainage system that consists of a small slope that conducts the excess humidity to orifices distributed every meter along the bed. The orifices are connected to PVC pipes 1.5 inches in diameter, linked to a common collector to facilitate the collection of leachates in a container. There is sufficient space in the bed for keeping working tools and packed vermicompost. The roof was built to provide the system and operator with shade and to protect against rainfall, Figure 1. The installation, Figure 2, consisted of the following procedure: a) In bed 1, a 5 cm layer of dry sewage sludge that was dampened was placed; b) Over the layer of sludge, 246 kg of vermicompost were placed, containing a high density of cocoons (900 cocoons/kg) and 12 kg of adult earthworms.

Figure 1. Vermicomposting treatment in the small plant of Chapala

It was decided to begin with a low density of earthworms, on the one hand with the purpose of adapting the earthworms to the sewage sludge, and on the other, because when starting with a low density the frequency of coupling is high and the increase of population if quicker; c) After this layer, another 5 cm layer of sludge from the drying beds was placed. Every week the system was fed with the weekly production of sludge. The sludge was distributed in 15 to 20-cm thick layers on one of the beds, which was fed for four consecutive weeks. Worm harvest was conducted through the last feeding. The last layer of sludge was placed, and because the earthworms are epigeous, they moved up to the new layer of sludge to feed. This layer was removed and served as a base for the second bed. The processes began in the second bed where the sludge layer with earthworms was emptied and feeding took place as described for the first bed, beginning a new cycle. The vermicompost was left to lie in the first bed for one month in order to reach the necessary degradation and maturity, and so the residence time of the sludge in each of the beds was two months, a month of intensive degradation and another month of maturing or additional stabilization. Light irrigation was applied every day to dampen the surface. No leachates were detected during the system operation time. The second case study was developed in the treatment plant of the island of Janitzio, located in the center of Lake Patzcuaro, Michoacan, Mexico. The plant responds to the treatment needs of an indigenous population of Purepecha origins of less than 100,000 inhabitants; it is located 2,150 meters above sea level; it has cold-temperate climate, with a mean annual temperature of 16 degrees centigrade. It is located in Michoacan, 19º 30’ N latitude parallel and to the west of meridian 101º 30’. The waste water treatment plant was designed to treat a volume of 9 L/s, under a process of activated sludge through extended aeration. The amount of sludge produced is 300 kg/day, 9 m^3/month of dehydrated sludge (80% humidity).

Figure 2. Installation of vermicomposting system in Chapala

The current train of sludge treatment consists of an aerobic digester that is not operating because of its high operation costs, and some drying beds. After dehydration, the sludge is disposed in the land inside and around the plant, with great risk to public health due to the high content of parasites and microorganisms of fecal nature. Faced with this problem, the need to further stabilize the sludge was raised, as well as to reduce its infectious biological characteristics through a vermicomposting system. A vermicomposting test was conducted in a plastic recipient 0.60 m x 0.32 m wide x 0.30 m deep, with drainage; placing a mixture of 5 parts sewage sludge and 1 part water hyacinth, an hydrophytes plant that is abundant in the lake. A population of 1.5 kg earthworms was placed and fed with this mixture. For the Janitzio treatment plant, a vermicomposting system was designed, with two beds distributed in an area of 70 m^2, Figure 3. An evaluation of the vermicomposts obtained in the two case studies to determine microbiological and physicochemical characteristics was conducted with the parameters enlisted in Table 1.

RESULTS AND DISCUSIÓN

An evaluation was conducted of the biosolids produced in the vermicomposting system installed in the Chapala plant and in vermicomposting test in Janitzio with the following results: During the vermistabilization process, around 38% reduction in the relation TVS/TS was obtained in both cases (Chapala and Janitzio) which means that it is a stable waste according to requirements of Mexican standards (NOM-004-SEMARNAT-2002). It was established a weekly feeding program to permit the contact between sludge-worms, Figure 4.

Vermistabilization benefits sewage sludge with the transformation of the sludge appearance from a sticky solid with fetid odor to granular soil that smells moist and which, at the moment of application, will not cause problems of smells and vectors.

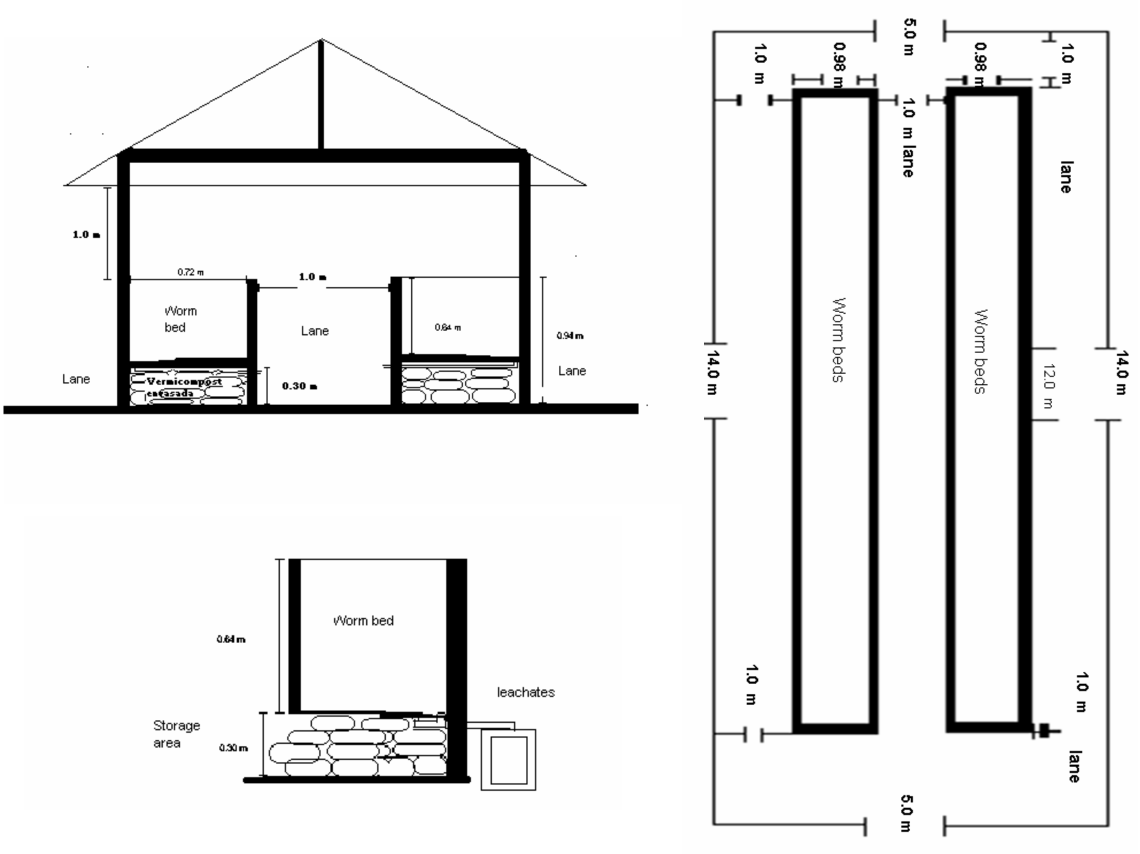

Figure 3. Design sludge system treatment in the small plant of Janitzio

Table 1. Analytical methods to determine characteristics in sludge and vermicomposting

Parameter	Analytical method
CRETI (Corrosivity, Reactivity, Explosivity, Toxicity, Ignitability)	According to Mexican standard NOM-052-SEMARNAT-2005. References: USEPA, 1996.
Total volatile solids (TVS);Fecal Coliformes and Heavy metals	Standard Methods for the Examination of Water and Wastewater, 1998.
Helminth eggs	According to Mexican standard NMX-AA-113-SCFI-1999, NOM-004-SEMARNAT-2002. References: Ayres, R. M., 1989.; CETESB, 1989;Satchwell, G. M., 1986
Total nitrogen, Total phosphorus and Organic Matter	Method in Black, 1977.

The Class B raw sludge from the Chapala plant, after the vermicomposting process, passed to A category, for use with no restrictions, Table 2, whereas sludge from Janitzio, due to its high concentration of parasites at the beginning of the process only achieve a reduction of 93% in the concentration of Helminth eggs, and so it only accomplish to obtain a Class B and did not remove adequately the concentration of coliformes. This could be corrected by increasing the density of worms and stabilization time. In the Chapala vermicomposting system, the earthworm population density after a year of operation was 10 kg/m^2. The treatment plants located in rural areas do not exhibit problems in the concentration of metals, as could be confirmed with the concentrations in the vermicompost of the Chapala and Janitzio plants.

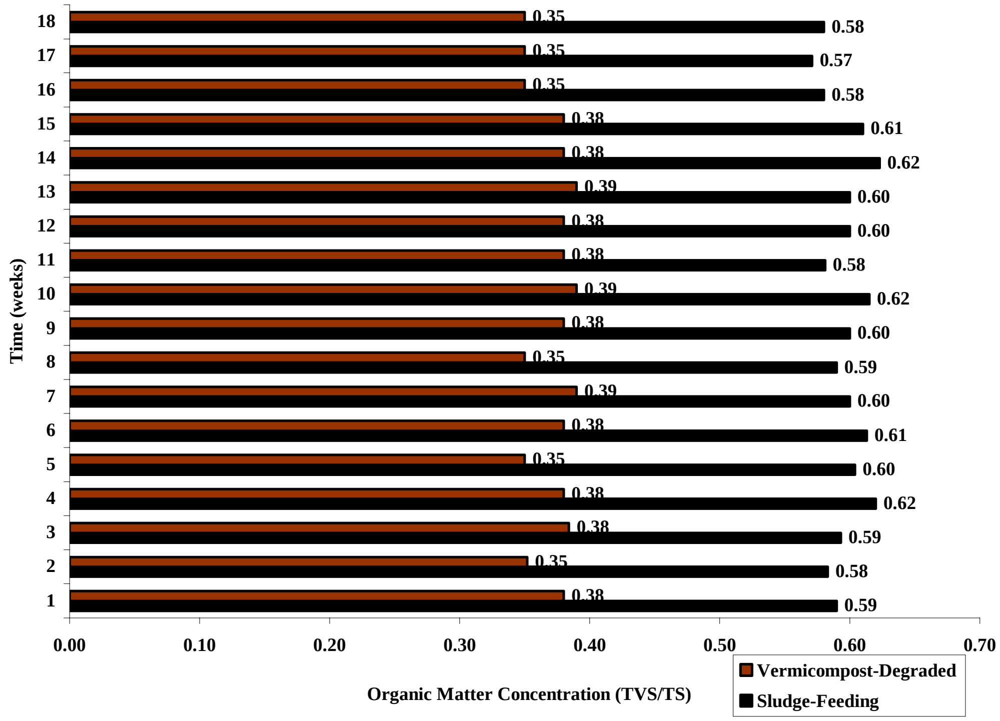

Figure 4. Weekly reduction in the relation TVS/TS

Table 2. Microbiological characteristics of sludge and vermicompost

Pathogens	Sludge Chapala	Vermi-compost Chapala	Sludge Janitzio	Vermi-compost Janitzio	NOM-004-SEMARNAT-2002	
					Class A	Class B
Fecal Coliforms MPN/g dry solids	7,200,000	0	<240,000	230	<1,000	<1,000
Helminth eggs/g dry solids	0.3	0	41.5	3.0	<1	<10
Species of Helminthes	Ascaris, sp. 58% Hymenolepis, sp. 35% Trichiuris, sp. 7%		Ascaris, sp. 60% Hymenolepis, sp. 30% Trichiuris, sp. 10%			

Some metals present in the Chapala vermicomposts are iron (155 mg/kg) and manganese (87 mg/kg), which can be considered micronutrients that are necessary for the soil and vegetables. In regards to the result of the analysis of metals in the vermicomposts, Table 3, it was found that the addition of water hyacinth from the lake slightly increased the concentration of heavy metals. None of the metals surpassed the maximum permissible limits established in NOM-004-SEMARNAT-2002, and so the vermicomposts obtained the category of Excellent, which allows its use in agriculture with no restrictions. The CRETI analysis showed that, during the process, the concentration of releasable sulfides, a parameter that defines this sludge as hazardous waste due to its reactivity, was reduced from 569.14 mg/kg to a non-detectable concentration, for the Chapala vermicompost, Table 4. In the case of the Janitzio sludge and vermicompost, they did not exhibit any hazardous characteristics.

Table 3. Metal increase in Janitzio vermicompost

	mg/kg			
Metals	Sludge	Vermicompost Janitzio	NOM-004-SEMARNAT-2002	
			Excellent	Good
Cd	0.0	2.36	39.0	85.0
Cr	12.53	55.42	1200.0	3000.0
Cu	65.04	666.82	1500.0	4300.0
Pb	46.68	206.74	300.0	840.0
Ni	8.66	39.24	420.0	420.0
Zn	568.5	1109.43	2800.0	7500.0

Table 4. Results of CRETI analysis

Parameter	Chapala	
	Sludge	Vermicompost
Corrosivity	No	No*
Reactivity	Sulphide > 500 mg/kg	N. D.**
Explosivity	No	No
Toxicity	No	No
Ignitability	No	No

*No present hazardous characteristics.
**No detectable.

The agronomic quality of the vermicomposts, Table 5, presents a high content of organic matter of 30 and 60% comparable to many commercial organic manures and a content of adequate nutrients such as nitrogen 1.35% and 2.5%, and phosphorus 0.88% and 0.96%. The content of organic matter in the Janitzio vermicompost's was greater due to the addition of water hyacinth. The construction costs of the vermicomposting system for the Chapala plant were less than $10,000 USD, including laboratory analyses to determine sludge and vermicompost characteristics.

Table 5. Agronomic characteristics of vermicomposts

Parameter	% Concentration	
	Chapala Vermicompost	Janitzio Vermicompost
Nitrogen	1.35	2.5
Phosphorus	0.88	0.96
Organic Matter	30.0	60.0

The construction costs programmed for the Janitzio vermicomposting system are similarly estimated at $10,000 USD. Operation costs are minimal because some of the additional activities that operators must perform are: daily irrigation, feeding week and loading and emptying of the beds.

CONCLUSIONS AND RECOMMENDATIONS

Vermicomposting is a biodegradation system which stabilizes sludge and reduces its pathogenicity. During the vermicomposting the volatile solid reduction was 38%, which shows a process of stabilization of the organic matter due to the earthworms and microbial populations. Vermicomposting proved to have a good pathogen removal, achieving microbiological quality. In order to obtain 100% removal and to achieve Class A it is necessary to optimize the process, increasing earthworm population density and including an additional curing step. With these case studies it is concluded that vermicomposting is an adequate technology for the treatment of sewage sludge in small plants such as the ones in Chapala and Janitzio (<10 L/s), located in rural areas, because it was possible to transform the sludge of biologically infectious waste into a biosolids that could be used in agriculture. It is possible to improve sewage sludge management conditions in small plants with a minimum investment (less than $10,000.00 USD) and with a minimum required area. It is recommended to conduct a market study to evaluate the possibility of introducing vermicompost as an improver of soils, substrate of nurseries and gardens, to achieve this technology's sustainability.

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