REDUCTION OF HEAVY METALS SLUDGE BY VERMICOMPOSTING TECHNIQUE

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By

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DEDICATION

To …..

My parents…

My husband…

My son: Omar

For their love, patience and sacrifice during my study

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"O my Lord! Grant me that I may be grateful for Thy favour which Thou hast bestowed upon me, and upon both my parents, and that I may work righteousness such as Thou mayest approve; and be gracious to me in my issue. Truly have I turned to Thee and truly do I bow (to Thee) in Islam."

رَبِّ أَوْزِعْنِىٓ أَنْ أَشْكُرَ نِعْمَتَكَ ٱلَّتِىٓ
أَنْعَمْتَ عَلَىَّ وَعَلَىٰ وَٰلِدَىَّ وَأَنْ أَعْمَلَ
صَٰلِحًا تَرْضَىٰهُ وَأَصْلِحْ لِى فِى ذُرِّيَّتِىٓ
إِنِّى تُبْتُ إِلَيْكَ وَإِنِّى مِنَ ٱلْمُسْلِمِينَ ١٥

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectroscopy
Al	Aluminum
ANOVA	Analysis of variance.
APHA	American Public Health Association Standard Methods
As	Arsenic
ATSDR	Agency for Toxic Substance and Disease Registry
CD	Cow Dung
Cd	Cadmium
CH34	Thirty four Hydro Carbon
Cont.	Control
Conc.	Concentrate
COD	Chemical oxygen demand
Cr	Chromium
Cu	Copper
DIW	De-ionized water
DWS	De water sludge
EDTA	Ethylenedi-aminetetraacetic acid
Fe	Iron
HCl	Hydrochloric Acid
$HClO_4$	Perchloric Acid
HM	Heavy Metals
HNO_3	Nitric Acid

IWK	Indah water consortium
K	Potassium
M	Molarities
MAS	Membrane Anaerobic System
N	Nitrogen
$Na_2S_2O_5$	Sodium Metabisulfite
Na_2EDTA	Disodium Salt of ethylenedi-aminetetraacetic acid
Ni	Nickel
N:C	Nitrogen to Carbon
OC	Organic
OECD	Organization for Economic Cooperation and Development
P	Phosphor
Pb	Lead
pH	pH value
PSS	Primary Sewage Sludge
PVCplastics	Polyvinyl chloride plastics
R.	Reactor
STP	Sewage Treatment Plant
SPSS	Software program for static analysis
UF	Ultrafiltration membrane
UK	Environmental quality criteria in the UK: soil quality criteria
US EPA	U.S. Environmental Protection Agency's standard methods
WHO	World Health Organization

Zn	Zinc

LIST OF SYMBOLS

^0C	Degree Celsius
%	Percent
g	Gram
mL	Milliliter
cm	Centimeter
mm	Millimeter
rpm	Unit of frequency
mg	Milligram
kg	Kilogram

PENGURANGAN ENAPCEMAR LOGAM BERAT MENERUSI TEKNIK VERMIKOMPOS

ABSTRAK

Dua jenis rawatan digunakan dalam kagian tesis ini, iaitu rawatan secara biologi dan kimia. Kedua-dua rawatan ini digunakan untuk mengurangkan empat logam berat (Al, Ni, Zn, dan Pb) dalam enapcemar industri elektronik. Dalam rawatan biologi atau yang dikenali juga sebagai teknik vermikomposit, kempat-empat enapcemar dalam nisbah yang berlainan (20, 50, 80, dan 100%) dicampur dengan tahi kambing (goat manure) dan jerami padi (rice straw) sebagai bahan komposit bagi spesies cacing *Eisenia fetida* selama empat minggu. Kepekatan logam menunjukkan pengurangan yang signifikan dengan pertambahan masa. Keputusan terbaik diperoleh pada minggu 4 dalam reaktor 4 (R4) dengan 100% nisbah enapcemar bagi Al, Ni, Zn dan Pb, dan nilai kepekatan setiap logam mencecah 1989.7, 93.5, 347.1 dan 10.77 mg logam/kg enapcemar masing-masing. Akumulasi atau penumpukan logam tersebut dalam badan *Eisenia fetida* bertambah dengan pertambahan masa. Akumulasi terbaik berlaku pada *Eisenia fetida* dalam R4 dengan 100% enapcemar pada minggu 4, iaitu 90.03, 72.2-73, 53, 52 mg/kg bagi Al, Ni, Zn, Pb masing-masing. Kebolehan pengurangan terbaik cacing bagi setiap minggu (W1, W2, W3, dan W4) dalam empat nisbah enapcemar yang berlainan ditunjukkan dalam R4 yang mengandungi 100% enapcemar, iaitu 58.13, 10, 3.2 dan 5 mg logam/kg enapcemar /cacing bagi Al, Ni, Zn dan Pb masing-masing. Pengaruh logam tersebut menunjukkan kesan yang tidak signifikan pada berat kering badan *Eisenia fetida* bagi jarskumasa 8 minggu, dengan berat badan bertambah secara positif dengan masa. Pertambahan yang positif dalam berat, iaitu 58% ditunjukkan dalam R2, R3, dan R4 dengan nisbah enapcemar 50, 80, dan 100% masing-masing. Bagi teknik kimia, enapcemar dibasuh dengan campuran daripada dua reagen (Na_2 EDTA dan $Na_2S_2O_5$) pada isipadu larutan basuhan yang berbeza (2.5, 5, dan 7.5) mL hingga 1g enapcemar. Pengurangan logam berat terbaik ditemui dalam 7.5 mL dengan pengurangan 5, 12, 16, 24 % per gram enapcemar bagi Al, Ni, Zn, Pb masing-masing. Berdasarkan dapatan kajian teknik vermikomposit menunjukkan potensi besar bagi mengurangkan logam berat dalam enapcemar elektronik.

REDUCTION OF HEAVY METALS SLUDGE BY VERMICOMPOSTING TECHNIQUE

ABSTRACT

Two kinds of treatments were used in the current thesis, namely, biological and chemical treatments, to reduce the concentration of four heavy metals (Al, Ni, Zn, and Pb) in the sludge collected from the electronic industry. A biological treatment called vermicomposting technique was employed to expose four different ratios of sludge (20, 50, 80, and 100%) mixed with goat manure and rice straw as a composting material to the earthworm species *Eisenia fetida* for four weeks. The metal concentration exhibited a significant decrease with an increase in time. The best results were obtained at week 4 in reactor 4 (R4) with 100% sludge ratio for Al, Ni, Zn, and Pb; the value of each metal concentration reached 1989.7, 93.5, 347.1, and 10.77 mg metal/kg sludge, respectively. The accumulation of these metals in the body of *Eisenia fetida* increased with an increase in time, and the best accumulation occurred in R4 with 100% sludge at week 4 was 90.03, 72.2-73, 53, and 52 mg/kg for Al, Ni, Zn, and Pb, respectively. The best reduction capability for the worms for each week (W1, W2, W3, and W4) in four different sludge ratios was exhibited in R4 with 100% sludge was 58.13, 10, 3.2, and 5 mg metal/kg sludge/worm for Al, Ni, Zn, and Pb, respectively. The metals showed insignificant effect on the dry weight of *Eisenia fetida* body for 8 weeks as the body weight increased positively with time. The positive increase in weight of 58% was exhibited in R2, R3, and R4 with sludge ratios of 50, 80, and 100%, respectively. For the chemical technique, the sludge was washed with a mixture of two reagents (Na_2 EDTA and $Na_2S_2O_5$) at different volumes of washing solution (2.5, 5, and 7.5 mL to 1 g of sludge). The best reduction of heavy metals occurred in 7.5 mL with a percentage reduction of 5%, 12%, 16%, and 24% per gram sludge for Al, Ni, Zn, and Pb, respectively. Based on the findings, the vermicomposting technique shows greater potential over the chemical washing technique in reducing heavy metal concentration in electronic sludge.

CHAPTER 1

INTRODUCTION

1.1 Industrial Waste Management

The huge quantity of solid waste generated by industrialized countries and fast-developing economies is another issue of pollution. Sludge resulting from metal fabrication, rubber products, metal plating and finishing, and electroplating industries includes various kinds of heavy metals, which can be converted to ceramics after mixing with clay (Abdullah & Aziz, 2006). This so-called toxic sludge normally undergoes chemical treatment by ethylenediaminetetraaceticacid (EDTA) as a pretreatment to decrease the concentration of heavy metals, followed by vermicomposting; finally, it can be used as a soil improver (Metka & Domen, 2010). Occasionally, the sludge is washed with chemicals, such as acids, reagents, and salts, to leach out the heavy metals of the sludge to an aquatic solution. "Heavy metals" are chemical elements with a specific gravity at least five times greater than that of water (Lide, 1992).

The usual final disposal option by landfill is becoming more and more impractical because of scarcity of site, high cost, and management problems. Many solid waste management methods aim for optimum waste reduction and pollution control (Béla, 1997). Different waste treatment options are currently available with different levels of problem solving and resource recovery facilities. All waste management options have some benefits, as well as some problems, when applied to practical cases. However, there is no single technology that can fully solve the waste management problem.

Therefore, integrating different waste management technologies in strategic ways is important to achieve sustainable waste management objectives. Important as well is determining the different technologies through a comparative study of different options, serving as a guiding tool for decision-making processes (Abdullah & Yosuf, 1989).

1.2 Treatment Technology of Industrial Sludge

According to the Malaysian Environmental Quality Report (2002), heavy metal sludge is the second largest waste generated in Malaysia. About 60,200 tons (17%) were produced in 2002. However, only 3% of the waste was exported for treatment and recovery.

Vermicomposting is a new development in biotechnology; it involves composting with worms. Vermicomposting is a mixed culture that contains one specific culture of soil bacteria mixed with an effective strain of earthworms (NIIR Board, 2000; Glenn, 2009). In vermicomposting, worms are fed with decomposed matter. The organic material, which passes through the earthworm gut, undergoes physical and chemical breakdown in the muscular gizzard, which grinds the material to a particle size of 1 to 2 microns.

A rich end product called worm casting is produced. A worm casting is readily soluble in water for uptake by plants (Atiyeh & Lee, 2002). It is a base product that helps partially solve pollution problems (Sharma *et al.*, 2005; Georgescu & Wbber, 2007). The whole process of decomposition and excretion of organic wastes through the metabolic system of earthworms is referred to as vermicomposting.

1.3 Earthworms as a Biological Treatment Agent

Earthworms are the important component of vermicomposting because they work by composting the waste material and turning it into a different material (NIIR Board, 2000). Earthworms are voracious feeders on organic waste: while utilizing only a small portion for their body synthesis, they excrete a large part of the consumed waste material in a half-digested form. The intestines of earthworms harbor a wide range of microorganisms, enzymes, hormones, and so on; thus, these half-digested substrates decompose rapidly and are transformed into a form of vermicompost within a short time (Lavelle, 1988).

Earthworms have three categories (i.e., endogeic, anecic, and epigeic), each of which has different habits. Over 4,400 species have been identified. Six types of epigeic worms have been found useful for composting. The most commonly used is the red worm called *Eisenia fetida*, which is found in every continent (NIIR Board, 2000; Appelhof, 2003). *T*he common names of this worm are red worm, red wiggler, and tiger worm. *E. fetida* is an epigeic worm. This type of worm lives on the soil surface or on the top 10 inches or so of the topsoil under the litter layer. It can handle a wide temperature range (between 0 and 35 ^{o}C) and can actually survive for some time almost completely encased in frozen organic material (NIIR Board, 2000; Elaine *et al.,* 2006; Glenn, 2009). This worm can produce cocoons after 28 days in normal conditions, and its sexual maturity is approximately 55–85 days under ideal conditions (Bing, 2004).

In the present study, the sludge collected from the electronic industry was exposed to *E. fetida* to reduce the heavy metals (i.e., Al, Ni, Zn, and Pb) through the vermicomposting process. This process was adopted because it is easy to use, almost natural, and economical; it also does not require chemicals or instruments, and can produce useful products without the use of extra treatments (Jain & Singh, 2004; Sharma *et al.,* 2005). The possibility of accumulating these metals in the worm's body without influencing it and without any pre-treatment for the sludge is a great challenge for this project. To establish a comparison, the industrial sludge was washed with a mixture of two chemicals (i.e., Na_2EDTA and $Na_2S_2O_5$) to transfer the metals from the sludge to an aqueous solution. The products from both treatments were defrayed to test them in terms of their heavy metal residual concentration to have an idea on the best way to treat the sludge. The present research is important for the treatment of industrial wastes to make them useful products for agriculture, especially in Malaysia where huge industrial zones produce different kinds of wastes.

1.4 Objectives

The objectives of this research are as follows:

1. To determine the reduction concentration of heavy metals Al, Ni, Zn, and Pb in industrial sludge using two kinds of treatments: (a) vermicomposting technique (biological treatment) and (b) sludge washing technique (chemical treatment)
2. To measure the accumulation of Al, Ni, Zn, and Pb in the worm’s body tissues
3. To compare the residual metal concentrations in the sludge after biological treatment with those after the chemical treatment

1.5 Thesis Outline

The present thesis is organized into five chapters as follows:

Chapter 1 introduces environmental pollution caused by heavy metals. This chapter also describes vermicomposting and chemical soil washing, and enumerates the objectives and benefits of the present research.

Chapter 2 discusses the literature on sludge treatments in Malaysia and in the world. The chapter defines and reviews the vermicomposting technique and the chemical method applied to heavy metals.

Chapter 3 illustrates the procedures and materials for chemical and biological treatments, and all the parameters for the sludge and earthworms' bodies.

Chapter 4 presents the research results and discusses the results using chemical and biological techniques as well as statistical analysis for vermicomposting and the chemical method.

Chapter 5 presents the conclusion and contributions of the present research to the literature, with some recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 The Environment and Heavy Metal Contamination

Environmental contamination is one of the most important factors contributing to the destruction of the biosphere. Heavy metals play the main part in this destruction; the total heavy metal amount in soils is distributed over some fractions. The soluble and exchangeable fractions are the primary cause of groundwater pollution that affects plant nutrition. The movement of metals in sludge-amended soils depends on the composition of the sludge (Sastre *et al.,* 2001).

Heavy metals enter the environment through different ways and sources, but the main source of trace elements in soils is parent materials. Anthropogenic sources, including industrial emissions and effluents, bio solids, fertilization, soil ameliorants, and pesticides, can contribute to the increasing amount of metals in soils (Maria *et al.,* 2003). Heavy metal pollution depends on the properties of soil and the economic activities in a particular area. Therefore, knowledge of the influence of heavy metals on soil and of their migration in soil is very important (Darûnas & Antanas, 2004).

Industrial solid wastes create environmental problems because of their demand for disposal space and water pollution effect through leaching. Although numerous investigations have been conducted on heavy metals, adapting the data directly to a specific region is impossible. Thus, investigating the condition of a certain environment before adopting any waste disposal method is necessary (Jain, 1994). The problem of environmental pollution caused by toxic metals has begun to cause great concern in most of the major metropolitan cities. Toxic heavy metals entering the ecosystem may lead to geo-accumulation, bioaccumulation, and bio-magnification. Heavy metals, such as Fe, Cu, Zn, Ni, Pb, and trace elements are important for the proper functioning of biological systems. Their deficiency or excess could lead to a number of disorders or intoxication to humans, animals, and plants. Therefore, a better understanding of heavy metal sources, their accumulation in the soil, and their effect on water and soil in plant systems is particularly important issues of present-day research on risk assessment (Lokeshwari & Chandrappa, 2006).

2.1.1 Hazardous Effect of Heavy Metals on Humanity

There are 35 metals that we should be wary of because of occupational or residential exposure; among these metals, 23 are known as the heavy elements or "heavy metals," namely, antimony, arsenic, bismuth, cadmium, cerium, chromium, cobalt, copper, gallium, gold, iron, lead, manganese, mercury, nickel, platinum, silver, tellurium, thallium, tin, uranium, vanadium, and zinc (Glanze, 1996). Interestingly, small amounts of these elements are common in our environment and diet. The amount of these metals naturally present in food is actually necessary for good health, but large amounts of any of them may cause acute or chronic toxicity (poisoning) (International Occupational Safety & Health Information Centre, 1999).

Heavy metals become toxic when they are not metabolized by the body and accumulate in the soft tissues. Heavy metals may enter the human body through food, water, air, or absorption through the skin when they come in contact with humans in agriculture and manufacturing, pharmaceutical, industrial, or residential settings. Industrial exposure is the common route of exposure for adults (Roberts, 1999; Dupler, 2001).

Heavy metal toxicity can result in damaged or reduced mental and central nervous functions, lower energy levels, and damage to blood composition, lungs, kidneys, liver, and other vital organs. Long-term exposure may result in slow progress in physical, muscular, and neurological degenerative processes similar to Alzheimer's disease, Parkinson's disease, muscular dystrophy, and multiple sclerosis. Allergies are common, and repeated long-term contact with some metals or their compounds may cause cancer (International Occupational Safety & Health Information Centre, 1999; Zevenhoven & Kilpinen, 2001).

2.1.2 Commonly Encountered Toxic Heavy Metals

Toxic heavy metals are included in the Agency for Toxic Substances and Disease Registry's (ATSDR) "Hazardous Substances" list. The ATSDR in Atlanta, Georgia, USA (part of the US Department of Health and Human Services), was established by a congressional mandate to perform specific functions concerning adverse human health effects and diminished quality of life associated with exposure to hazardous substances.

2.1.2.1 Lead

Lead is second in the ATSDR list. It accounts for most of the cases of pediatric heavy metal poisoning (Roberts, 1999; ATSDR, 2007a). Lead is a very soft metal used in making pipes, drains, and soldering materials for many years. Thus, humans are subjected to chronic exposure from weathering, flaking, chalking, and dust. Every year, the industry produces about 2.5 million tons of lead throughout the world. Most of this lead is used in batteries. The remainder is used in cable covering, plumbing, ammunition, and fuel additives. Other uses of lead are for paint pigments and PVC plastics, X-ray shielding, crystal glass production, and pesticides. The harmful effect of lead targets the bones, brain, blood, kidneys, and thyroid gland (International Occupational Safety & Health Information Centre, 1999; (ATSDR), 1999; (ATSDR), 2007b).

2.1.2.2 Nickel

Nickel, which is number 53 on the ATSDR list, is an abundant natural element. Pure nickel is a hard, silvery-white metal that can be combined with other metals such as iron, copper, chromium, and zinc to form alloys. These alloys are used to make coins, jewelry, and items such as valves and heat exchangers. Most nickel is used to make stainless steel (ATSDR, 2005).

Nickel is found in all types of soil and is emitted by volcanoes. It is also found in meteorites and on the ocean floor. Nickel and its compounds have no characteristic odor or taste (Duffus, 2002).

The most common harmful health effect of nickel in humans is allergic reaction. Some people working in nickel refineries or nickel-processing plants have experienced chronic bronchitis and reduced lung function (OSHA, 2009).

2.1.2.3 Zinc

Zinc, which is number 74 on the ATSDR list, is one of the most common elements in the earth's crust. It is found in air, soil, and water, and is present in all foods. Pure zinc is a bluish-white shiny metal (ATSDR, 2005).

Zinc is an essential element in our diet. Too little zinc can cause health problems, whereas too much zinc is also harmful. The harmful effects of zinc generally begin at levels 10–15 times higher than the amount needed for good health. Large doses taken orally, even for a short time, can cause stomach cramps, nausea, and vomiting. Taken longer, zinc can cause anemia and decrease the levels of the body's good cholesterol. If high levels of zinc can affect reproduction in humans is not yet known. However, rats fed with large amounts of zinc become infertile (Lokeshwari & Chandrappa, 2006).

Inhaling large amounts of zinc (as dust or fumes) can cause a specific short-term disease called metal fume fever. The current literature does not provide information on the long-term effects of breathing high levels of zinc; however, putting low levels of zinc acetate and zinc chloride on the skin of rabbits, guinea pigs, and mice causes skin irritation. Therefore, skin irritation will probably occur in humans as well (ATSDR, 2005).

2.1.2.4 Aluminum

Aluminum is number 187 on the ATSDR list. This element makes up about 8% of the surface of the earth and is the third most abundant element (ATSDR, 1999; ATSDR, 2008).

Aluminum is readily available for human ingestion through using food additives, antacids, buffered aspirin, astringents, nasal sprays, and antiperspirants; drinking water;

inhaling automobile exhaust and tobacco smoke; and using aluminum foil, aluminum cookware, cans, ceramics, and fireworks (WHO, 1998).

Only a very small amount of aluminum, which one may inhale, ingest, or have skin contact with, can enter the bloodstream. Exposure to aluminum is usually not harmful; however, exposure to high levels can affect one’s health. Workers who breathe large amounts of aluminum dust can have lung problems, such as coughing or abnormal chest X-rays. Some workers who breathe aluminum dust or aluminum fumes have decreased performance in some tests that measure functions of the nervous system (Ferner 2001).

Some people with kidney disease store much aluminum in their bodies and sometimes develop bone or brain diseases, which may be caused by the excess aluminum intake. Some studies show that people exposed to high levels of aluminum may develop Alzheimer's disease, whereas other studies have not found this to be true. Thus, if aluminum really causes Alzheimer's disease is not yet certain (Anon. 1993).

Studies on animals show that the nervous system is a sensitive target of aluminum toxicity. Obvious signs of damage were not seen in animals after high oral doses of aluminum. However, the animals did not perform as well in the tests that measure the strength of their grip or how much they moved around (ATSDR, 2008).

2.2 Electronic Industrial Sludge

This kind of sludge is a toxic industrial waste that has a concentration of heavy metals higher than the acceptable limit for industrial sludge in the world. According to the US Environmental Protection Agency (US EPA), the UK, and Environmental Quality

Criteria of Canada as regards the standard limit of sludge, electronic industrial sludge is considered toxic to human beings (CCME, 1991; Alloway, 1995).

2.3 Sludge Treatment

Sludge is generated by industrial downstream activities. It is an end product of waste water treatment plants from industries, such as chemical manufacturing, metal fabrication, rubber products, metal plating and finishing, and electroplating. Sludge is dried solid waste produced by the precipitation of metal ions in wastewater with metal hydroxides. According to Netpradit *et al.* (2003), sludge usually contains insoluble metal hydroxides, $M(OH)_n$, and other salts, such as $CaSO_4$, $CaCO_3$, NaCl, and $NaHCO_3$. Therefore, sludge has many disposal treatments, which change according to the different sludge contents. Many kinds of sludge treatment of industrial wastes are used in Malaysia and currently in the world. Among these treatments is thermal treatment, physical treatment, and chemical treatment. Another kind of sludge treatment is the biological treatment, which involves composting the wastes with the micro organisms, solidification, recovery, and recycling (Abdullah & Yosuf, 1989).

2.4 Industrial Waste Treatment Technology

Different waste treatment options with different levels of problem solving and resource recovery facilities are currently available. All waste management options have some benefits, as well as problems, when applied in actual cases (Al-Salem, 2009). Treatment technologies can be classified as thermal treatment, e.g., incineration, through which waste materials are converted into gas, heat, steam, and ash. This type of treatment is considered a practical method of disposing certain hazardous waste materials (e.g., biological medical waste). Incineration is a controversial method of waste disposal because of such issues as emission of gaseous pollutants (Isabelle & Myrope, 1997).

The other option involves chemical treatment, e.g., extraction of some chemicals from waste or converting waste into useful products (Abdullah & Yosuf, 1989). An example of biological treatment is composting. This treatment is an aerobic bacterial decomposition process that stabilizes organic wastes and produces humus (compost) (UNEP, 2010). Sludge composting aims to stabilize sludge biologically by exploiting its nutrient or organic value to develop agricultural or other end-use outlets. Sludge composting can be applied to either non-digested sludge (e.g., in Italy and France) or digested sludge (e.g., in the Netherlands). Composting involves aerobic degradation of organic matter as well as a potential decrease in the sludge water content whose efficiency depends on the composting process applied (Isabelle & Myrope, 1997). Vermicomposting is a new biological method for treating wastes using earthworms. The worms eat the wastes and convert them to fertilizer (Fauziah & Agamuthu, 2009).

Other approaches, such as recovery and recycling, suggest reusing the waste after cleaning and transforming it into a useful product (Banar *et al.*, 2009). The most common consumer products that can be recycled include aluminum beverage cans, steel, food and aerosol cans, HDPE and PET bottles, glass bottles and jars, paperboard cartons, newspapers, magazines, and corrugated fiberboard boxes. PVC, LDPE, PP, and PS are also recyclable, although these are not commonly collected. These items are usually composed of a single type of material, making them relatively easy to recycle into new products. The recycling of complex products (e.g., computers and electronic equipment) is more difficult because of the additional dismantling and separation required (Zaman, 2009).

Land filling, also known as a dump or rubbish dump, is a common method for the disposal of waste materials by burial. This method is the oldest form of waste treatment. Historically, land filling is the most common method of organized waste disposal and is applied in many places around the world (Béla, 1997).

2.5 Industrial Waste Treatments in Malaysia

Booming industrial activities in Malaysia for the past few decades have not only enhanced economic growth but also raised concerns on industrial hazardous waste treatment and disposal. Improper handling of hazardous waste can result in air, water, and soil pollution. Generally, industrial hazardous wastes can be classified into three large groups: by-products generated from production processes, sludge resulting from waste water treatment plant, and expired toxic items.

Sludge is generated by industrial downstream activities; it is an end product of waste water treatment plants from industries such as chemical manufacturing, metal fabrication, rubber products, metal plating and finishing, and electroplating (Abdullah & Aziz, 2006). Jamal *et al.* (2005) worked on Sewage Treatment Plant sludge collected from the Indah water consortium in Kuala Lumpur. The researchers isolated filamentous fungi, especially *Aspergillus*, from the sludge to produce citric acid through the fermentation method. The reason is that *Aspergillus* naturally produces citric acid.

Other researchers treated sludge by vermicomposting. Zularisam *et al.* (2010) recovered the municipal sewage sludge collected from selected sewage treatment plants in Malaysia and converted it to bio fertilizer by composting the sludge with *E. fetida.*

Abdurahman *et al.* (2010) treated sewage sludge through aerobic digestion using scaled membrane anaerobic system (MAS). The MAS was found to be a successful biological treatment system to achieve high COD removal efficiency in a short period of time. The system was able to operate at a very high solid retention time (day), making it tolerant to variations of influent COD loading. MAS seems to be a good alternative for treating high-strength wastewater and for the recovery of energy with methane as a value-added product in the process.

2.6 Heavy Metal Removal from Sludge and Contaminated Soil

The risk of accumulation of heavy metals in the environment as a result of industrial activity has led to a growing need to find solutions to clean up the environment and remove the poisonous effects from all life forms on the ground (Darunas & Antanas, 2004).

Diels *et al.* (1999) extracted heavy metals from contaminated soil using the microorganism *Alcaligenes eutrophus.* The bacterium had the ability to solubilize the metals (or increase their bioavailability) through the production of siderophores. It can also adsorb the metals in the biomass through metal-induced outer membrane proteins and bioprecipitation. After the addition of thirty four Hydro Carbon (CH34) to soil slurry, the metals moved toward the biomass.

Shiro and Tahei (2000) found that heavy metals in sewage sludge could be removed easily by treating a sludge filter cake with phosphoric acid containing hydrogen peroxide for an hour at room temperature. Phosphoric acid of 8% concentration with hydrogen peroxide showed good removal rates of heavy metals comparable with that with 1 N hydrochloric acid. Sewage sludge with low heavy metal content can be recycled as a useful resource.

Naoum *et al.* (2001) removed the heavy metals from sludge by acid treatment using hydrochloric, sulfuric, nitric, or phosphoric acid with 5 mL acid to 1 g sludge to leach the metals from the sludge within 15–60 min.

Słomkiewicz and Zdenkowski (2003) extracted heavy metals from sludge by immobilizing them using the hygienization process of wastewater sludge to environment utilization. Municipal wastewater sludge was treated by dust from the electro filters of cement mills with the addition of roasted raw detrital basalt to leach the heavy metals from the sludge. The treated sludge showed potential for use as fertilizer.

Naghipoor *et al.* (2006) and Abumaizar and Smith (1999) washed the contaminated soil from heavy metals through the exposure of the soil to a chemical reagent (Na_2 EDTA). This reagent can extract heavy metals from contaminated soil and can be used as a fertilizer or soil amendment after treatment.

Bayat and Sari (2009) used the bioleaching technique to remove heavy metals from dewatered metal plating sludge through *Acidithiobacillus ferrooxidans.* The authors compared the results of this technique with those of a chemical leaching technique using commercial inorganic acids (i.e., sulfuric acid and ferric chloride).

2.7 Vermicomposting Technique

2.7.1 Introduction to Vermicomposting

The system of decomposition and excretion of organic wastes through the metabolic system of earthworms is called vermicomposting. The environmentally acceptable vermicomposting technology using earthworms can be adopted for converting waste into wealth. Considerable work has been carried out on vermicomposting of various organic materials. Epigeic forms of earthworms has been considered to hasten the composting process extensively, resulting in a better quality of composts than those prepared through traditional methods (Sharma *et al.*, 2005).

In vermicomposting, worms are fed with decomposed matter, and the organic material passes through the earthworm gut. A rich end product called worm casting is produced. A worm casting consists of organic matter that has undergone physical and chemical breakdown through the muscular gizzard, which grinds the material to a particle size of 1 to 2 microns. Nutrients present in worm castings are readily soluble in water for uptake by plants (Atiyeh & Lee, 2002; Lazcano *et al.*, 2008).

Vermicomposting is considered a simple and low-cost technique of removing toxic metals and breaking down complex chemicals into non-toxic forms (Hand *et al.,* 1988; Jain & Singh, 2004). Earthworm casting is the final product used for farming as fertilizer (Gunadi *et al.,* 2002).

The secretions in the intestinal tracts of earthworms, along with some soil passing through the earthworms, make nutrients more concentrated and immediately available for plant uptake. The nutrients from earthworms include micronutrients because the worms in vermicompost break down food wastes and other organic residues into nutrient-rich compost (Ndegwa & Thompson, 2001).

Vermicompost contains not only worm castings but also bedding materials and organic wastes at various stages of decomposition. It also contains worms at various stages of development and other microorganisms associated with the process of composting (Insam *et al.,* 2002)**.**

Earthworms, especially *E. fetida*, have the capability to accumulate heavy metals in sewage sludge vermicompost (Saxena & Chauhan, 1998). The viability of using earthworms as a treatment or management technique for numerous organic waste streams has been investigated by a number of researchers (Hand *et al.,* 1988; Madan *et al.,* 1988; Logsdon, 1994; Singh & Sharma, 2002). Similarly, a number of industrial wastes have been vermicomposted and turned into nutrient-rich manure (Sundaravadivel & Ismail, 1995). The characteristics of vermicomposting are summarized in Table 2.1.

Table 2.1 Chemical characteristics of vermicompost.

Parameter*	Vermicompost
pH	6.80
EC (mmhos/cm)**	11.70
Total Kjeldahl nitrogen (%) ***	1.94
Nitrate nitrogen (ppm) ****	902.20
Phosphorous (%)	0.47
Potassium (%)	0.70
Calcium (%)	4.40
Sodium (%)	0.02
Magnesium (%)	0.46
Iron (ppm)	7563.00
Zinc (ppm)	278.00
Manganese (ppm)	475.00
Copper (ppm)	27.00
Boron (ppm)	34.00
Aluminium (ppm)	7012.00

Notes:

*Units- **ppm**=parts per million, **mmhos/cm**=millimhos per centimeter.

** EC = electrical conductivity is a measure (millimhos per centimeter) of the relative salinity of soil or the amount of soluble salts it contains.

*** Kjeldahl nitrogen = is a measure of the total percentage of nitrogen in the sample including that in the organic matter.

**** Nitrate nitrogen = that nitrogen in the sample that is immediately available for plant uptake by the roots.

Source: (Dickerson, 2001).

2.7.2 Types of Earthworms

Earthworms are natural invertebrates of the agro ecosystem belonging to the family Lumbricidae, which are dominant in temperate and tropical soils. The most common types of earthworms used for vermicomposting are brandling worms (*Lumbricus* *rubellus*) and red worms or red wigglers (*E. fetida*). These earthworms are often found in aged manure piles. They generally have alternating red and buff-colored stripes. These earthworms should not be confused with the common garden or field earthworms (*Allolobophora caliginosa* and other species). Although garden earthworms occasionally feed on the bottom of a compost pile, they prefer ordinary soil. An acre of land can have as many as 500,000 earthworms, which can recycle as much as 5 tons of soil or more per year. However, red worms and brandling worms prefer the compost or manure environment. Passing through the gut of the earthworm, recycled organic wastes are excreted as castings or worm manure, an organic material rich in nutrients that looks like fine-textured soil (NIIR, 2000).

2.7.3 Biology of Earthworms

The earthworm has a long, rounded body with a pointed head and slightly flattened posterior. Rings that surround the earthworm's moist, soft body enable the earthworm to twist and turn, considering that it has no backbone and no true legs (Edwards & Lofty, 1972).

Food is ingested through the mouth into the stomach (crop). Afterwards, the food passes through the gizzard, where it is ground up by ingested stones after passing through the intestine for digestion (Edwards *et al.,* 1995).

Cocoon production starts at the age of 6 weeks and continues until the end of 6 months. Under favorable conditions, one pair of earthworms can produce 100 cocoons in 6 weeks to 6 months (Ismail, 1997).

The incubation period of a cocoon is roughly about 3–5 weeks. In temperate worms, incubation ranges from 3–30 weeks and 1–8 weeks in tropical worms. Red worms take 4–6 weeks to become sexually mature (Edwards *et al.,* 2005).

Under optimum conditions, red worms can eat food scraps and bedding in one day as much as their own weight. However, on average, approximately 2 lbs. of earthworms (approximately 2,000 breeders) is required to recycle a pound of food waste in 24 h (Lee & Keneth, 1985). Earthworms eat all kinds of food and yard wastes, including coffee grounds, tea bags, vegetable and fruit waste, pulverized egg shells, grass clippings, manure, and sewage sludge.

2.7.4 Construction of Worm Bin

A vermicomposting bin is a box containing a decomposition system for organic matter. It is easy to set up and requires only a few tools to construct. Bins can be made of wood, plastic, or recycled containers such as old bathtub barrels, or trunks; redwood or other highly aromatic woods that may kill the worms should be avoided; and the containers must be cleaned well and should not have contained pesticides or other chemicals (Dickerson, 2001).

Drilling air/drainage holes (1/4 to 1/2 inch diameter) in the bottom and sides of the bin will ensure good water drainage and air circulation. Place the bin on bricks or wooden blocks in a tray to catch excess water that drains from the bin. The bins can also be located inside or outside, depending on the owner’s preference and governing circumstances (NIIR Board, 2000).

Each bin should have a cover to conserve moisture and block out light because worms prefer darkness. Bins can be covered with a straw mulch or moist burlap to ensure darkness while providing good air ventilation (Sharma *et al.*, 2005).

Red wigglers tend to be surface feeders; thus, bins should be no more than 8–12 inches deep (Edwards, 1998). The vermicomposting system is illustrated in Figure 2.1

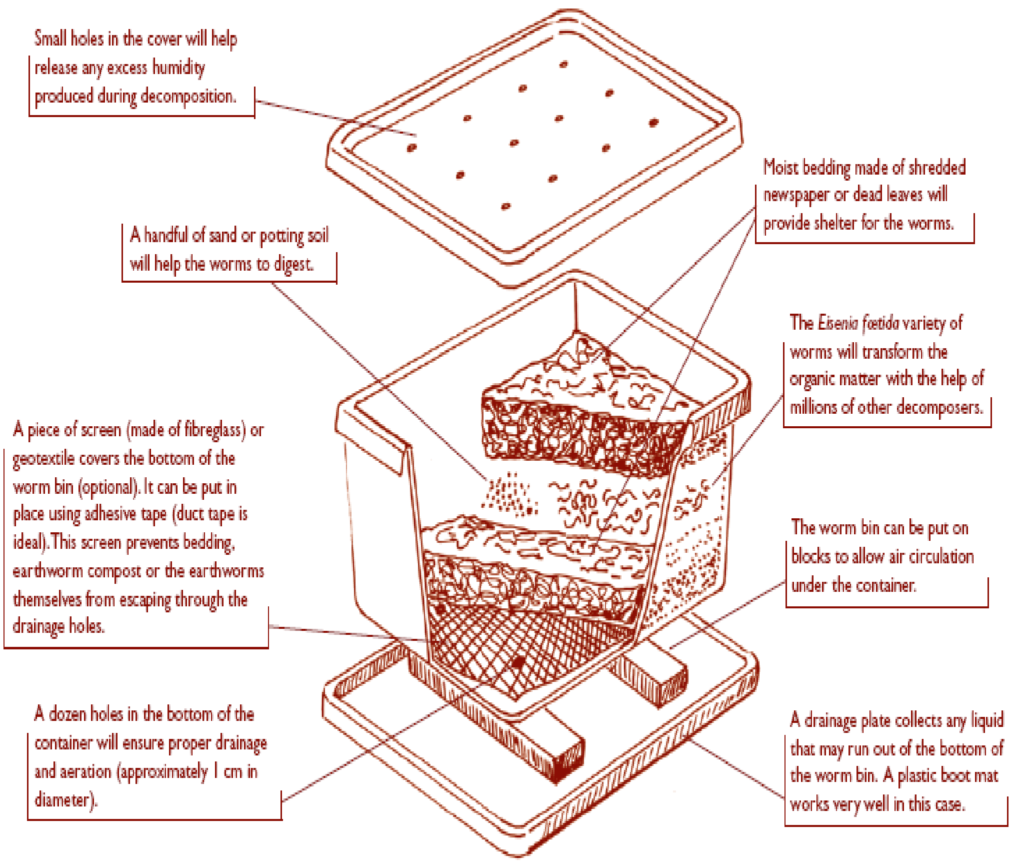

Figure 2.1 The vermicomposting system

Source: (Quartier & McGill, Practical guide)

2.7.5 Bedding Materials

The first step in vermiculture is to select suitable feed materials for the earthworms. These can be nitrogen-rich materials, such as cattle dung, pig manure, and poultry manure, or other organic materials, such as leguminous agro waste. The feed material should not have a C:N ratio of more than 40. Using carbon material with a very high C:N ratio, such as paper and soaked cardboards, may only fatten the worms (Ndegwa & Thompson. 2000).

Bedding for bins can be made from shredded newspapers (non-glossy), computer paper or cardboard, shredded leaves, straw, hay, dead plants, sawdust, peat moss, compost, or manure (Glenn, 2010).

Bedding materials high in cellulose are best because they help aerate the bin, enabling the worms to breathe. Varying the bedding material provides a richer source of nutrients. Some soil or sand can be added to help provide grit for the worms' digestive systems. The bedding material should be allowed to set for several days to make sure it does not heat up; it should also be allowed to cool before adding the worms (Dickerson, 2001).

2.7.6 Important Factors in the Vermicomposting System

Earthworms breathe oxygen, absorbing it through their skin. They can survive low oxygen levels. However, they cannot coexist with anaerobic microorganisms because these give off methane, phenols, and alcohol, which poison the worms. The worms' bodies contain 85% water. An environment with 75%–85% moisture is ideal, but this leaves 15% oxygen, which can become toxic due to anaerobic activity. Therefore, an environment with 60% moisture is practical, and at least 35% moisture is required to keep the earthworms from drying up. A spray bottle may be used to add water during warm weather. System saturation is a potential problem, which may result in a severe odor (Kaviraj & Sharma, 2003).

The tolerance range is between 4 and 29 °C, and the ideal temperature is between 16 and 22 °C. During winter, the worms should not be allowed to freeze. The bin can be kept warm by wrapping it in an old blanket and surrounding it with a 4-inch layer of straw. During summer, when the temperature is in the 90s, ice cubes can be dumped over the top of the bedding layer or frozen water in a 2-liter soda bottle can be placed inside the bin to create adequate worm air-conditioning (Kaviraj & Sharma, 2003).

The bin contents should be kept moist but not soaked. Rainfall should not be allowed to run off from the roof into the bin because it could cause the worms to drown. A straw covering may be required to cover exposed sites to keep the bin from drying out during hot summer weather.

Worms cannot stand light. They become disoriented after 20 minutes of being exposed to sunlight. In 30 minutes, they stop breathing, and in 35 minutes they die. Therefore, worms should be covered up at all times (Garg *et al.*, 2008).

If the system is successful, the bin will become filled with little critters. If fruit flies are a concern and the bin is operated indoors, food scraps may be frozen for 3 days or placed in the microwave for 3 minutes to kill fly larvae (Appelhof, 2003).

2.7.7 Harvesting the Compost and Worms

Worms take 6–8 weeks to produce a noticeable amount of vermicompost. The castings appear as small, dark clumps that easily break apart. There are several methods for removing the finished compost:

1. Every 3–4 months, stop feeding the worms for a few weeks, and rake the compost to one side of the bin. Add fresh bedding to the other side; add food scraps only on the new bedding. Within a few months, worms will move to the new bedding, enabling the harvesting of the finished compost. Refill the empty end of the bin with fresh bedding, and bury more food scraps.
2. Every 3–4 months, dump all the contents of the bin into several piles on a sheet of plastic in a brightly lit room. The worms will dive into the pile bottom. Remove the finished compost from the top and sides of the piles.
3. Every 3–4 months, remove 2/3 of the bin contents for use in the garden. Add new bedding, and slowly build up a worm population.
4. Stop feeding after 4–6 months, and allow the worms to digest all the bedding and food scraps completely. The result will be a fine, homogeneous compost (pure worm castings) with very few red worms (Glenn, 2010).

2.7.8 Vermicomposting and Feed Materials

In the past, various organic wastes were used as feed material for different species of earthworms. Venkatesh and Eevera (2008) used fly ash, which was mixed with cow dung at 1:3, 1:1, and 3:1 ratios and incubated with *Eudrilus eugeniae* for 60 days. This study was conducted to purify the environment from fly ash by composting it with cow