PALM OIL MILLS EFFLUENT TREATMENT THROUGH VERMIFILTRATION EMPLOYING *Eudrilus eugeniae*

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by

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LIST ABBREVIATIONS AND SYMBOLS

APHA	American Public Health Association
ANOVA	Analysis of Variance
BOD	Biochemical Oxygen Demand
CF	Control Filter
COD	Chemical Oxygen Demand
EC	Electro Conductivity
ECOPRO	Eco process Technology Research
EPA	Environmental Protection Agency
NTU	Nephelometric Turbidity Units
POME	Palm Oil Mill Effluent
RGR	Relative Growth Rate
S.D.	Standard Deviation
SGR	Specific Growth Rate
TSS	Total Suspended Solids
VF	Vermifilter

RAWATAN SISA KILANG MINYAK KELAPA SAWIT MELALUI PROSES PENURASAN VERMI DENGAN MENGGUNAKAN *Eudrilus eugeniae*

ABSTRAK

Prestasi sistem penurasan vermi atau cacing dibantu sistem penapisan menggunakan *Eudrilus eugeniae* dalam merawat efluen kilang minyak kelapa sawit (POME) telah dikaji. Efluen kilang minyak kelapa sawit (POME) dianggap sisa yang paling berbahaya untuk alam sekitar jika dilepaskan dengan tidak dirawat. Efluen minyak kelapa sawit mentah (POME) adalah berasid yang tidak bertoksik dan cecair berwarna coklat pekat yang mengandungi sisa pepejal yang tinggi, nilai BOD dan nilai COD yang tinggi. Di Malaysia, penghasilan tinggi POME daripada pengeluaran minyak sawit mentah kini dirawat menggunakan kaedah konvensional yang dikenali sebagai sistem takungan, di mana mempunyai masalah ruang yang tidak cekap. Sebagai usaha untuk menyelesaikan dilema kaedah lama, kaedah baru dan alternatif seperti penurasan vermi sedang dikaji dan diperkenalkan kepada rawatan air sisa. Penurasan vermi adalah satu proses penapisan di mana pepejal dipisahkan daripada cecair dibantu oleh cacing tanah. Dalam kajian ini, empat eksperimen telah dijalankan untuk memilih keadaan yang terbaik untuk sistem penurasan vermi. Eksperimen pertama adalah untuk membandingkan prestasi penapis menggunakan medium penapis yang berbeza (100% serat kelapa sawit, 100% pasir pembinaan dan 100% tanah tanaman) di dalam 0.0009 m^3 isipadu medium penapis. Eksperimen kedua adalah untuk membandingkan prestasi penapis dengan ketinggian vermibed yang berbeza (ketinggian vermibed; 5 cm, 10 cm dan 15 cm). Eksperimen ketiga adalah untuk membandingkan prestasi penapis dengan kepadatan cacing yang berbeza (10 cacing/L, 20 cacing/L, 30 cacing/L, 40 cacing/L dan 50 cacing/L) di dalam 0.0009 m^3 isipadu medium penapis. Eksperimen terakhir, sistem penurasan vermi skala yang lebih besar dengan 0.0045m^3 isipadu medium penapis dibina dan prestasi penapis vermi (VF) yang mengandungi cacing tanah, *Eudrilus eugeniae* dan penapis kawalan (CF), tanpa cacing tanah dibandingkan dengan menggunakan campuran pasir dan tanah tanaman sebagai medium penapis. Vermibed dengan ketinggian 15 cm dan kepadatan cacing 40 cacing/L telah dipilih masing – masing sebagai kedalaman vermibed dan kepadatan cacing terbaik untuk sistem penapis vermin dengan bacaan menunjukkan penurunan tertinggi dalam COD (89.9 %), TSS (92 %) dan kekeruhan (84%). Kajian ini telah dijalankan di skala makmal. Semua jenis penapis telah ditetapkan secara tiga replikasi. pH POME meningkat daripada berasid kepada neutral. Ia diperhatikan bahawa penapis vermi dalam fasa skala besar menunjukkan kadar tertinggi pengurangan BOD, COD, TSS dan kekeruhan sebanyak 92%, 90%, 95% dan 86%, masing-masing berbanding penapis kawalan dalam fasa skala besar masing-masing sebanyak 55%, 45%, 65% dan 52%. Di samping itu, analisis percambahan untuk POME yang ditapis melalui penapis vermi dalam sistem penurasan vermi dilakukan. Hasil peratusan percambahan menunjukkan ujian percambahan yang lebih tinggi daripada 50% hanya untuk kepekatan 1% dan 3% daripada POME yang ditapis, jadi cairan ini menunjukkan kematangan kompos dan selamat untuk digunakan sebagai larutan nutrien dalam kultur tanpa tanah pada tumbuh-tumbuhan. Teknologi penurasan vermi dengan itu boleh digunakan sebagai teknik yang mesra alam, mempunyai potensi untuk merawat POME dan mempamerkan potensi dalam tujuan penanaman.

PALM OIL MILLS EFFLUENT TREATMENT THROUGH VERMIFILTRATION EMPLOYING *Eudrilus eugeniae*

ABSTRACT

The performance of vermifiltration or worm aided filtration systems employing *Eudrilus eugeniae* in treating palm oil mill effluents (POME) was studied. Palm oil mill effluent (POME) is considered the most harmful waste for the environment if discharged untreated. The raw palm oil mill effluent (POME) is an acidic non toxic and thick brownish liquid that contains high solids, high BOD and COD values. In Malaysia, high generation of POME from crude palm oil production is currently treated using conventional method known as ponding system, which is space inefficient. As an attempt to resolve the long-standing dilemma, recent and alternative method such as vermifiltration is being studied and introduced to wastewater treatment. Vermifiltration is a filtration process where solids are separated from liquid aided by earthworms. In this research, four experiments were conducted to select the best conditions for vermifiltration system. The first experiment was to compare performance of filter using different filter medium (100% of palm pressed fibre, 100% of construction sand and 100% of garden soil) in 0.0009 m^3 volume of filter medium. The second experiment was to compare performance of filter with different height of vermibed (vermibed height; 5 cm, 10 cm and 15 cm) in 0.0009 m^3 volume of filter medium. The third experiment was to compare performance of filter using different worm loadings (10 worms/L, 20 worms/L, 30 worms/L, 40 worms/L and 50 worms/L) in 0.0009 m^3 volume of filter medium. The final experiment, larger scale of vermifilter system with 0.0045 m^3

volume of filter medium was setup and the performance of a vermifilter (VF) containing the earthworms, *Eudrilus eugeniae* and a control filter (CF), without earthworms were compared using the mixture of sand and garden soil as filter medium. Vermibed with height 15 cm and worms loading 40 worms/L were selected respectively as the best depth of vermibed and worm loadings for vermifilter system with readings showed the highest reduction in COD (89.9 %), TSS (92 %) and turbidity (84%). The research was conducted at laboratory scale. All type of filters was set as triplicates. The POME pH increased from acidic to neutral. It was observed that vermifilter in larger scale phase shows the highest reduction rate of BOD, COD, TSS and turbidity by 92%, 90%, 95% and 86% respectively compared to control filter in larger scale phase by 55%, 45%, 65% and 52% respectively. In addition, the germination analysis for vermifiltered POME in vermifiltration system was done. The result of germination test showed germination percentage higher than 50% only for 1% and 3% concentration of vermifiltered POME, so these dilutions indicates the maturity of the compost and are safe to be used as nutrient solutions in soil-less culture on plants. Vermifiltration technology can therefore be applied as an environmentally friendly technique, has potential to treat POME and exhibit potential in cultivation purposes.

CHAPTER 1

INTRODUCTION

1.1 Research background

The discharge of sewage is the primary source of pollution in water. According to Arora et al. (2014), untreated sewage covers a large portion of biodegradable organic matter and many disease caused by pathogenic organisms which gave harmful effects on human health. Numerous on-site treatment technologies are seen to be functioning and effective in removing the pollutants such as septic tanks, aerobic biological treatment units, fixed activated sludge treatment, trickling filters and constructed wetlands (Xing et al., 2011). Currently, these technologies are restricted to use due to prone to failure because of high capital, high operations costs and high maintenance costs which are expensive for developing countries (Muga and Mihelcic, 2008). Thus, it is required to look for an alternative onsite wastewater treatment process that is economically, environmental sustainable and socially acceptable (Wu et al., 2013; Arora et al., 2014).

Agro industrial effluents management such as Palm Oil Mill Effluent (POME) from oil palm industry has been a major environmental concern in countries discharging them like Malaysia and Indonesia. Normally, POME has low pH value because of the organic acids released in the fermentation process, ranging around 4 to 5. It is a voluminous, high biochemical oxygen demand (BOD) liquid waste and usually released at 75–85 °C. It is also a colloidal diffusion of biological origin and with an unpleasant odour. POME is a land and aquatic pollutants when discharged untreated, due to existence of high organic load and their phytotoxic properties. According to Vairappan and Yen (2008), Malaysia is pointed out as the country that discharges the largest POME in the river. Due to this, the palm oil industry needs to ensure environmental preservation, while retaining its economic viability with sustainable development.

The current treatment technology of POME ordinarily includes biological aerobic and anaerobic digestion or facultative digestion. Biological treatment systems require proper maintenance and monitoring as the processes only depend on microorganisms to decompose the pollutants. The microorganisms are very sensitive to the changes in the environment and the proper care must be taken to assure that favourable environment is retained for the microorganisms to thrive in. It needs expert observation, commitment and long retention time (Ma, 2000). Furthermore, it generates a huge amount of biogas. This biogas includes methane, carbon dioxide and trace amounts of hydrogen sulphide. Some of these gases are smelly. The treated water released also cannot be recycled back to the plant (Bhatia et al, 2007).

Vermifiltration is a new technology to process organically polluted water using earthworms (Lu et al., 2009). It was found to have extraordinary potential to stabilize and reduce the sludge (RohitPathania et al., 2012). It is a process that modifies traditional vermicomposting into a passive wastewater treatment process contains high organic content (Ghatnekar et al., 2010). In the vermifiltration system, the suspended solids are trapped on top of the vermifilter and are fed to the soil microbes immobilized in the vermifilter after being processed by the earthworms (Kharwade and Khedikar, 2011). It does not need high operational cost and large land area compared to the conventional wastewater treatment system (Zhao et al., 2010). It is one of the effective and economical wastewater treatment systems to treat organic polluted water such as wastewater from industrial, agricultural and household sectors.

The idea of employing earthworms in filtration system was advocated by Jose Toha (Zhao et al., 2010). Several studies have been done to evaluate the performance of vermifiltration system in treating domestic wastewater (Sinha et al., 2008), municipal wastewater (Yang et al., 2010), domestic greywater (Kharwade and Khedikar, 2011), swine wastewater (Li et al., 2008) and pilot scale of sewage wastewater (Manyuchi et al., 2013).

Earthworms are widely used by researchers because earthworms are essential as a common assay organism for soil fertility tests particularly since it constitutes a huge group in the terrestrial environments (Weeks and Svendsen, 1996). Earthworms are known to contribute to soil processes through faecal excretion in the form of casts, burrowing, digestion and feeding (Tian et al., 2000; Oboh et al, 2007). Earthworms are also known to assist in plant decay (Tian et al., 1995) and convert plant residue into soil organic matter (Lavelle, 1988).

1.2 Problem statement

The most significant pollutant from palm oil mills is POME (Poh and Chong, 2009). The production of highly polluting palm oil mill effluent (POME) has caused serious environmental hazards. Although anaerobic digestion is broadly accepted as an effective method for the treatment of POME, it also has difficulty in meeting discharge limits due to the high organic strength of POME. Besides, the conventional anaerobic aerobic treatment systems regularly face difficulty related to their large space needed, long hydraulic retention time (HRT), low organic loading rate (OLR) and increased production of effluents by mills (Yi et al., 2010). If there is no proper waste management applied in palm oil mills, POME can cause water and air pollution through biomethane emission (Wu et al., 2010). This problem has become more challenging as the number of palm oil mills in Malaysia has increased enormously in the past few years. Hence, immediate actions should be taken to overcome this problem.

In recent years, vermifiltration has been utilized as one of effective technology for municipal and industrial wastewater treatment, due to its simple system which provides high efficiency in reduction of BOD and SS, as well as its flexibility in operation costs without sacrificing effluent quality (Sinha et al., 2008; Kharwade and Khedikar, 2011). However, very few vermifiltration studies have been conducted in relation to POME.

Previous work from Malek (2013) has proposed vermifiltration of pH treated palm oil mill effluent (POME). The pH of the POME was adjusted to pH 5-7. The final removal efficiencies for vermifiltration system were more than 90% for both parameters, COD and TSS. The work by Malek (2013) can be helpful and useful for this research to extend to new ways of handling POME for agricultural purposes.

There is still no study done for vermifiltration of untreated POME. Untreated raw POME is acidic, with pH value 4.5 - 5. POME is an organic waste and non toxic effluent therefore it could be a source of food to the earthworms. According to Sinha et al. (2007), any non toxic wastewater from industries can effectively be treated by earthworms and the vermifiltration system can be designed to suit that particular wastewater. For this research, *Eudrilus eugeniae* is used as the earthworms for vermifiltration system. Most researchers have classified that the earthworms from epigeic group such as *Eudrilus eugeniae* is best suited for vermifiltration treatment under all climatic conditions (Sinha et al., 2008; Malek, 2013). *Eudrilus eugeniae* were chosen because it is proven to be effective to treat wastewater based on previous study by Amare et al. (2014), Kharwade and Khedikar (2011) and Sinha et al. (2008). According to Amare et al. (2014), *Eudrilus eugeniae* also were able to tolerate temperatures above 40 °C and avoided odor and clogging problems inside the filter system.

Studies on the types of filter medium used in vermifiltration treatment are also limited. In this study, three types of filter medium (palm pressed fibre, construction sand and garden soil) will be used and compared in treating POME through vermifiltration treatment. Comparisons between different height of vermibed is also important in this study since Wridge et al. (1996) stated that filter height can also influence total suspended solids removal.

Worm loadings also play an important role in determining the treatment efficiency (Sinha et al., 2007). Therefore, a study to determine the suitable worm loadings was conducted during vermifiltration of POME.

There is also no study done yet for agriculture purposes on vermifiltered POME. Other researches such as by Xing et al. (2010), Sinha et al. (2008) and Malek (2013) treat wastewater using vermifiltration just for discharge purposes. In this study, POME will be assessed for its potential on seed germination. POME contains substantial amounts of Ca, K, Mg, N and P (Habib et al., 1997; Muhrizal et al., 2006), which are important nutrients elements for plant growth. POME can possibly be used in agriculture due to the non toxic nature and fertilizing properties. According to Ho (2014), seed germination with *Lactuca sativa* (lettuce) seeds can be used to evaluate the quality, toxicity and effectiveness of a treatment system. This study will be platform for further scientific study in oil palm growing countries and to suggest that the vermifiltered POME can be used safely for agricultural purposes on seed.

1.3 Objectives of the study

This study was carried out toward the purpose of achieving the following specific objectives.

1.3.1 To evaluate the filtration efficiency of vermifilter employing *Eudrilus eugeniae* in treating POME in relation to type of filter medium, vermibed height and worm loadings.

1.3.2 To determine the growth and survival of earthworm with different worm loadings in vermifilter system.

1.3.3 To evaluate the filtration efficiency of larger scale *Eudrilus eugeniae* assisted filter system.

1.3.4 To determine the germination effect of vermifiltered POME on selected seed through seed germination test.

1.4 Scope of study

This study focuses in determining a suitable system for vermifiltration of untreated POME. This research was done only at laboratory scale and using the earthworms, *Eudrilus eugeniae*. The parameters measured are percolation rate, water quality of wastewater (parameters study: pH, turbidity, EC, COD, BOD and TSS), nutrients and trace elements (C, N, K, Ca, Mg, Fe, Na, Mn, Zn and Cu) as well as growth (by weight) and survival of earthworms. Besides, the germination effect of vermifiltered POME on lettuce seed through seed germination test was determined for further agricultural purposes. The scope of study is illustrated in Figure 1.1.

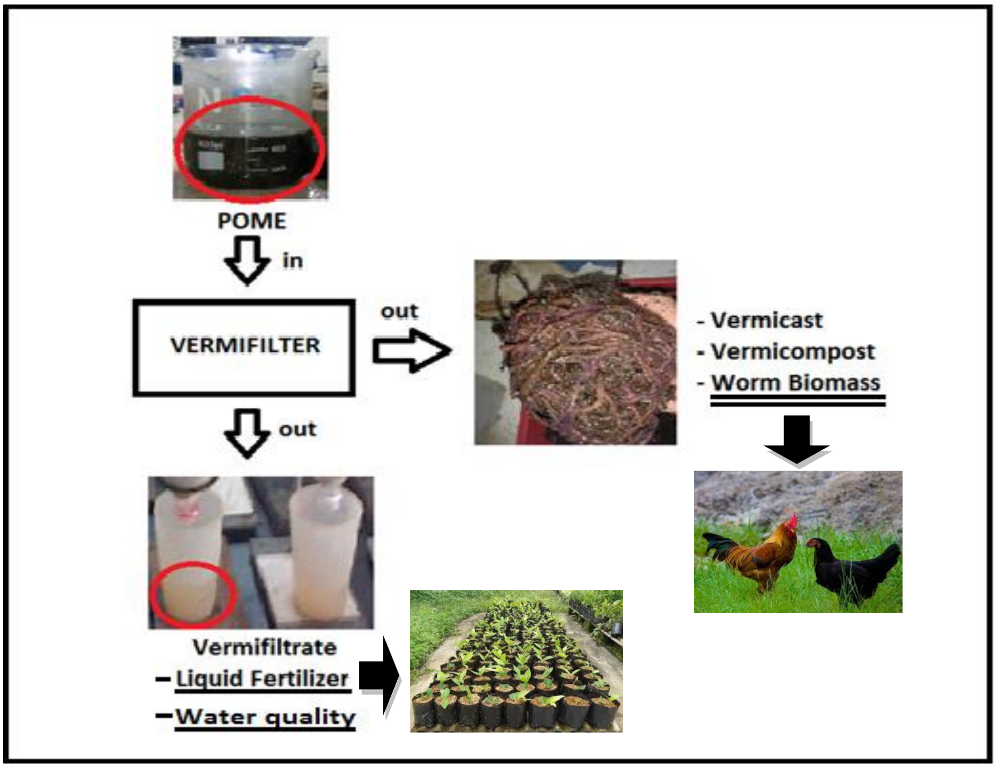


Figure 1.1 Scope of study

CHAPTER 2

LITERATURE REVIEW

2.1 Filtration

Filtration may be defined as the separation of solids from liquids by passing a suspension through a permeable medium which retains the particles (Svarovsky, 2001). This broadly used technique in wastewater treatment is based on some simultaneously occurring phenomena, for instance adsorption of colloidal matter, flocculation, mechanical straining of undissolved suspended particles and bacteriological-biological processes and removal of pollutants such as particles, microorganisms, organic and inorganic compounds (Zaman et al., 2014). Figure 2.1 shows schematic diagram of a filtration system. A pressure drop, ΔP has to be applied across the medium to obtain fluid flow through the filter medium. There are four types of driving force involved in filtration process i.e. gravity, vacuum, pressure and centrifugal.

Basically, there are two types of filtration, which are based on surface filter and depth filter. Surface filters are used for cake filtration in which the solids are stored in the form of a cake on the up-stream side of a relatively thin filter medium. The filter medium in a surface filter has a low initial pressure drop as can be seen in Figure 2.2, where particles of the same size or larger than openings wedge into the openings and create smaller passages which remove even smaller particles from the fluid (Svarovsky, 2001). On the other hand, depth filters are used for deep bed filtration in which particle deposition takes place inside the medium and cake deposition on the surface is undesirable. In a depth filter, the particles are smaller than the medium openings and thus they proceed through relatively long tortuous pores where they are collected by a number of mechanisms such as gravity, diffusion and inertia and attached to the medium by molecular and electrostatic forces as shown in Figure 2.3. Generally, the initial pressure drop across the depth filter is higher than across a surface filter (Svarovsky, 2001).

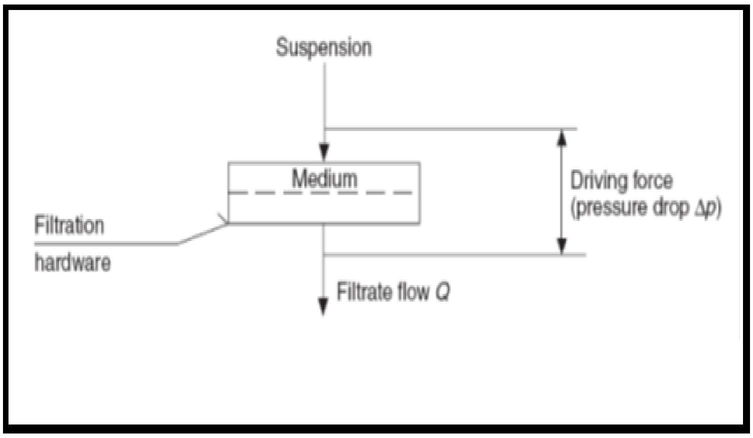
Darcy's basic filtration equation, Eqs (2.1) and (2.2) relating the flow rate, Q of a filtrate of viscosity, μ through a bed of thickness, L and face area, A to the driving pressure, Δp is;

$$Q = \frac{KA\Delta p}{\mu L} \qquad (2.1)$$

K is a constant referred to as the permeability of the bed. Equation 2.1 often written in the form;

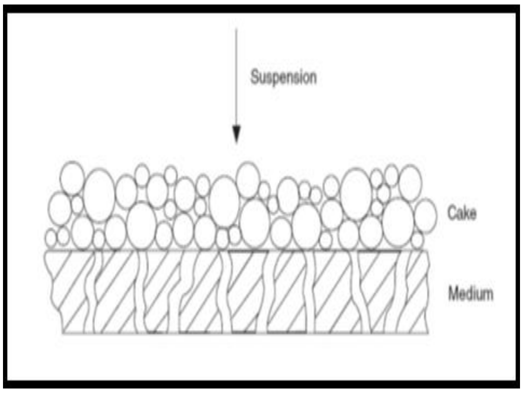
$$Q = \frac{A\Delta p}{\mu R} \qquad (2.2)$$

R is called the medium resistance and is equal to L/K, the medium thickness divided by the permeability of the bed.



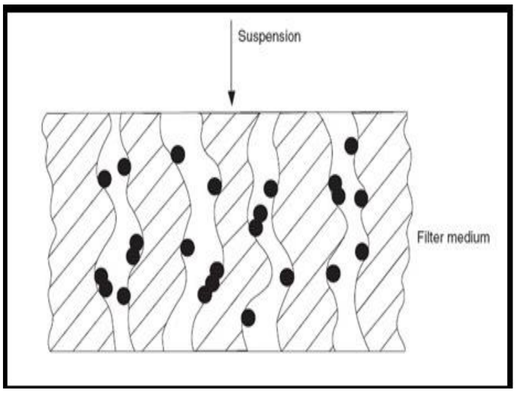
Source : Svarovsky, 2001.

Figure 2.1 Schematic diagram of a filtration system



Source : Svarovsky, 2001.

Figure 2.2 Cake filtration



Source : Svarovsky, 2001.

Figure 2.3 Deep bed filtration

2.1.1 Filtration and Resistance

Resistance is one of the factors which influence the filtration process. There are two types of resistances, the medium resistance, R_m and the cake resistance, R_c (Svarovsky, 2001).

Normally, the medium resistance, R_m is constant but it may vary with time because of some penetration of solids into medium and it may also change with applied pressure into medium (Earle and Earle, 2004). On the other hand, the cake resistance, R_c, can be constant for incompressible cakes but it may change with time. However, most of cakes are compressible and their specific resistance change with the pressure drop across the cake (Svarovsky, 2001).

Flow rate through filter medium is inversely proportional to the filter resistance (Svarovsky, 2001). An increase in filter resistance will decrease the flow rate through filter medium. The increase in filter resistance will cause filter system to clog in a dead end filtration.

2.1.2 Biofiltration

Biofiltration is a relatively emerging new technology applied to wastewater treatment and other toxic compounds (Kumar et al., 2013). Any type of filter with attached biomass on the filter media can be described as a biofilter also known as geofilter or control filter.

The main purpose of the biofilter is to biodegrade pollutants by the microorganisms attached onto the filter media (Chaudhary et al., 2003). The parameters that can influence the performance of a biofilter are the characteristics of filter media, hydraulic and organic loading rate and filter backwash techniques.

There are several disadvantages in biofiltration system (Kumar et al., 2013). Biofiltration system is not suitable for compounds, which have low adsorption and degradation rates. Large biofilters units or large areas are needed to treat contaminated sources with high chemical emissions. In addition, biofilters need long period of adaption for microbial population such as weeks or even months.

Even though, biofiltration has been used for many years, it is still hard to clarify theoretically all the biological processes that happened in a biofilter. The biofilters may be operated at different filtration rates and influent characteristics can have varied efficiency for different target pollutants (Chaudhary et al., 2003).

Incorporating worms in biofiltration led to the term bio-vermifiltration or in short vermifiltration. It has the advantages of low energy consumption (Sinha et al., 2008) and easy maintenance (Wang et al., 2011).

Previous studies on the bio-vermifilter have been focused on theoretical research of the mechanisms for pollutant removal such as COD and nitrogen (Nie et al., 2015). The bio-vermifiltration or vermifiltration system is a versatile system that can work effectively under a variety of natural and socioeconomic conditions at a reasonable cost.

2. 2 Vermifiltration

Vermifiltration or worms aided filtration is a technology for wastewater treatment, which receives modern concept of ecological design and prolongs the existing chain of microbial metabolism by introducing earthworms (Yang et al., 2013; Arora et al., 2014).

The inoculation of earthworms in a filter without worms or control filter (CF), turn it into vermifilter (VF) has been broadly used to treat municipal and industrial sewage (Wang et al., 2013; Xing et al., 2011) and sludge reduction and stabilization (Zhao et al., 2010; Liu et al., 2012; Yang et al., 2013). Almost all the earlier experiments involving vermifiltration process showed efficiency on sewage treatment with high removal rates of chemical oxygen demand (COD), biochemical oxygen demand (BOD) and suspended solid (SS) (Li et al., 2009).

Vermifiltration of wastewater consume low energy. It also has advantage over all the conventional wastewater treatment systems such as activated sludge process which are using highly energy, pricey to install and operate and do not return any income (Sinha et al., 2010). In the vermifiltration process, it will produce organic materials and there is high value added end products. As an example, vermifiltrate "nutrient rich" water with potency for farm irrigation and vermicompost taken from the vermifilter beds (Daven and Klein, 2008).

The greatest advantage of vermifiltration system is that there is no formation of sewage sludge (Hughes et al., 2005). The earthworms decompose the organics in the wastewater and also guzzle the solid which forms the sludge synchronously (Sinha et al., 2010). The worms in vermifilter also have the capacity to bioaccumulate high concentrations of toxic chemicals in their tissues and release wastewater that is almost free of chemicals (Daven and Klein, 2008). Therefore, the vermifiltrate (wastewater effluent) is also suitable for reuse as water for farm irrigation and other non-potable uses.

2.2.1 Vermifiltration of palm oil mill effluent

Malek (2013) recently did a laboratory scale study for vermifiltration of palm oil mill effluent. The pH of POME was adjusted to pH 5-7 before the wastewater was introduced into the vermifiltration system. From this study, it was shown that vermifiltration (VF) system has a potential to treat POME and reduce the TSS and COD concentrations more than 90%.

The control filter (CF) system in the study done by Malek (2013) started to clog at week 14 because there were no earthworms in CF system to facilitate and increase the efficiency of the drainage system. The solids from POME also will accumulate over time as sludge and choke the system. According to Sinha et al.

(2008), the CF system was constantly choked after few smooth runs while in the VF system, wastewater percolated smoothly into the VF system throughout their experimental study.

In this research, both surface filter and depth filter are involved in the vermifiltration system. If only the filtration process (control filter, CF) is used to treat POME, it will cause the system to clog more quickly because POME is very sludgy and greasy (Malik, 2013). The worms can help a filter system to work longer and delay the clogging process.

2.2.2 Vermifiltration of toxic wastewater from petroleum industry

A finding by Sinha et al. (2012) indicates that some species of earthworms can biodegrade toxic chemicals including heavy metals. Worm vermicasts also can help in adsorption of heavy metals and chemical pollutants in wastewater. The earthworm's body and their vermicast work as a biofilter removing BOD_5 by over 90 %, COD by 60–80 %, TDSS by 90–95 % and toxic chemicals and pathogens from wastewater. The study was a pilot study conducted on highly toxic wastewater from the petroleum industry. The earthworms not only endure and survive in the toxic petroleum environment but also bio-filtered and bio-remediated the dark-brown petroleum wastewater with a pungent smell into pale-yellow and odourless water indicating disappearance of all toxic hydrocarbons.

2.2.3 Vermifiltration of domestic wastewater treatment

Arora et al. (2014) investigated microbial community diversity and antibacterial and enzymatic properties of microorganisms in a pilot-scale vermifiltration during domestic wastewater treatment. The research included identification of diverse microbial community by culture dependent method in a vermifilter (VF) with earthworms and a geofilter (GF) or also known as a control filter (CF) without earthworms. The results showed that the presence of earthworms in VF could efficiently remove biochemical oxygen demand (BOD) and chemical oxygen demand (COD. However, the GF system in this study failed to work for longer time as it is frequently choked due to the formation of sludge and colonies of bacteria and fungi (Li et al., 2009).

2.2.4 Role of earthworms in vermifiltration system

The ability of earthworms to manage sludge was first suggested over ten years ago by Elvira et al. (1998). According to Kwon et al. (2009), earthworms have the ability to breakdown a wide range of organic materials. Earthworm body acts as a 'biofilter'. The earthworm body can reduce the biological oxygen demand (BOD5) by over 90%, chemical oxygen demand (COD) by 80–90%, total dissolved solids (TDS) by 90–92% and the total suspended solids (TSS) by 90–95% from wastewater. Earthworms ingest the solids and also devour on the pathogens in the wastewater (Sinha et al., 2008). Suspended solids are trapped on top of the vermifilter and processed by earthworms and fed to the soil microbes immobilized in the vermifilter (Sinha et al., 2010). Besides, earthworms also can remove chemical contents including heavy metals and pathogens from treated wastewater (Bajsa et al., 2003). Hence, the treated water can be reused in non-potable purposes.

2.3 Earthworms

Earthworms are classified into three main categories which are epigeic, endogeics and anecic (Norbu, 2002). Epigeic are surface dwellers working as efficient agent in fragmentation of organic matter on the soil surface and are non-burrowing in nature. While, endogoic earthworms live deep in the soil and derive their nutrients from the original rich soil that they ingest. The anecics feed on the organic matter mixed with soil on soil surface and some is pulled into burrows.

Water contributes 75-90% of the body weight of earthworms (Edwards and Lofty, 1972; Ansari and Ismail, 2012). Hence, the prevention of water loss is important to improve earthworm survival. Earthworms prefer moist but not saturated conditions (William et al., 2006). However, earthworms have ability to survive adverse moisture conditions by moving to a suitable area (Edwards and Lofty, 1972).

2.3.1 *Eudrilus eugeniae*

The African nightcrawler, *E. eugeniae* has useful potential in breaking down organic wastes (Edwards et al., 2011). It is one of the most common earthworm species in West African regions (Edwards and Lofty, 1972; Segun, 1998) and also can be found in other parts of the world. It has rapid growth and prolific. *E. eugeniae* belongs to Eudrilidae families (Segun, 1998). It has been used in monoculture or polyculture with other species of earthworms to produce vermicomposts, vermicast, vermiwash and others. *E. eugeniae* develops well at a temperature of more than 25°C but best at 30°C and reaching maximum weight and length in about 15 to 20 weeks (Rodriguez and Lapiere, 1992). Its size may depend on habitat. The total number of segments in *Eudrilus eugeniae* varies from 80 to over 100 (Oboh et al., 2007).

Reinecke et al. (1992) reported the percentage hatching success by *E. eugeniae* is 78% and the number of hatchlings per cocoon was usually more than two. The matured *E. eugeniae* take 47 days to produce cocoons (Dominguez et al., 2001). Among the researchers who have studied this earthworm are Rodriquez et al. (1986) and Viljoen and Reinecke (1988) providing data on the number, size and growth of hatchlings of *E. eugeniae*.

E. eugeniae worked perfectly as a possible waste decomposer and as a protein source (Katheem et al., 2014). Many fundamental researches about general biology of *E. eugeniae* have been done in order to clearly understand the role of this species as a waste decomposer. According to Bouche (1977), *E. eugeniae* classified as epigiec worm, feeds on litter on or near soil surface. It ingests large amount of litter and most of their activities are at the upper soil surface.

2.3.2 Digestion

Earthworms are physically aerators, crushers and mixers in the decomposer system. It has special chemoreceptors or sense organs (taste reseptor) which react to chemical stimuli and located on the anterior part of earthworms (Katheem et al., 2014). It can also consume food up to one third of own body weight in one day (Daven and Klein, 2008). It obtains their nutrition from organic matter.

The digestive system of earthworms consist a buccal chamber, pharynx, oesophagus, crop, gizzard and intestine (Edwards and Lofty, 1972). The digestive enzymes such as amylase, cellulose, acid phosphatase, alkaline phosphatase and nitrate reductase were secreted in the gut of the earthworms because of the increased existence of microorganisms in it (Katheem et al., 2014).

Earthworm's gut is a powerful tubular reactor, which retains a suitable temperature, thereby speeding up the rates of the bioprocesses and preventing enzyme inactivation caused by high temperatures (Indira and Lakshmi, 2007).

According to Edwards and Bohlen (1996), the earthworm gut is a straight tube which prolongs from mouth to anus. The food will enter through the mouth and sucked in by the pharynx. Food particles move to crop part which acts as temporary storage and is mixed together. After departing from crop section, partially mixed food particles go into gizzard where the actual digestive process begins. The potent muscles of the gizzard stir and mix the mass of food and dirt. The mixture is minimized to a thick paste once the stirring and mixture is complete and then sent to the intestine. Glands in the walls of the gizzard add enzymes, which assist in the chemical breakdown of the organic matter. The intestine has amiable bacteria that act on the food mixture. The mixture that is being consumed will release various vitamins, minerals, carbohydrates, and proteins from the organic matter needed by the worms to be absorbed into the body. Most of the worm’s body length is intestine. It is filled with thousands small blood vessels which assist to absorb liquefied food. Finally, the soil particles and undigested organic matter are removed from the worm's body through the anus at the end of the intestine. The waste produced is known as worm cast or vermicast. The vermicast is rich in microbial activity, plant growth regulators and pest repellents (Katheem et al., 2014).

2.3.3 Burrowing and casting

Earthworms form burrows by literally eating their way through the soil. Not all species or earthworms have burrows. The examples of species that can penetrate deep into the soil are *Eudrilus eugeniae* and *Lumbricus terrestris* (Edwards and Lofty, 1972).

It is normally the burrowing species which discharge casts on the soil surface near the exits to their burrows (Edwards and Lofty, 1972). The burrowing and casting activities of earthworms contribute to the activity of soil micro organisms and nutrient enriched earthworms casts are good media supporting microbial growth (Vasanthi et al., 2013). Earthworm casts consists of microorganisms, inorganic materials and organic matter in a form usable for plants (Edwards and Lofty, 1972; Indira and Lakshmi, 2007). The existence of casts is a good sign to prove the earthworm activity.

2.3.4 Nitrogen mineralization

Earthworms considerably increase soil fertility. It is due to the increased amounts of mineralized nitrogen that earthworms make obtainable for plant growth (Edwards and Lofty, 1972). The increasing of the amounts of nitrogen in soils in which earthworms were bred may be due to decay of the bodies of dead worms.

Earthworms ingest large amounts of plant organic matter consisting plentiful of quantities of nitrogen and much of this will be returned to the soil through their excretions (Edwards and Lofty, 1972). The exact part of these constituents and the total amount of the nitrogen excreted depends on the species of worms.

2.3.5 Effects of earthworms on soil structure

There are two main activities of earthworms that have most influence on soil structure (Tian et al., 2000). Firstly, it can ingests soil, partial breakdown of organic matter (Edwards and Lofty, 1972). Secondly, it can burrow through soil and bringing subsoil to the surface. Earthworms have ability to move large amounts of soil from deep layers to the surface and discharged as casts.

Earthworms can also improve soil aeration and influence the porosity of soils (Edwards and Lofty, 1972; Edwards and Bohlen, 1996). Earthworms massively increase the aeration and structure of soils. It has been showed that the earthworms aid soil fertility. There have been many tests to add earthworms to poor soil by introducing of organic matter or fertilizers (Edwards and Lofty, 1972; Edwards et al., 2011).

2.4 Sources of wastewater

Wastewater is water that has been used for human activities, by industrial or a manufacturing process, and it contains waste products like sewage. The wastewater can be categorized to many types such as domestic, industrial or washing. Some industrial wastewaters can be treated without difficulty such as domestic grey water (Kharwade and Khedikar, 2011). However, industrial wastewater that contains toxic substances or high percentages of organic materials or solids can make treatment difficult.

2.4.1 Palm oil mill effluent (POME) as a source of wastewater.

The palm oil industry has grown by leaps and bounds to become a very important agriculture based industry in Malaysia over the last few decades. Presently, Malaysia contributes for 51% of world palm oil production and 62% of world exports (MPOB, 2014). Simultaneous to this enormous amount of production, voluminous highly polluting wastewater referred as palm oil mill effluent (POME) is discharged. According to Sethupathi (2004), there are three main processing operations responsible for producing POME, i.e. sterilization of FFB, clarification of the extracted CPO and hydrocyclone separation.

Raw POME is a colloidal suspension consisting 95–96% water, 0.6–0.7% oil and 4–5% total solids (Ahmed, 2009). It is non-toxic since no chemicals are added during a normal oil extraction process but has unpleasant odor (Ahmed, 2009). POME is one of the major sources of water pollution due to its high chemical oxygen demand (COD) and biochemical oxygen demand (BOD) concentrations.

Generally, the characteristics of POME may vary according to different batches, days and factories, depending on the processing techniques and the age or type of fruit as well as the discharge limit of the factory, climate and conditions during palm oil processing (Ahmad et al., 2005 and Ahmad et al., 2006). With the rapid expansion of the palm oil industry and the public's increased awareness of environmental pollution, the industry is obliged to treat its effluent before discharging it. Therefore, the government had enacted Environmental Quality Acts (EQA) in 1978 and the parameter limits for POME discharge into watercourses in Malaysia is summarized in Table 2.1.

Table 2.1 Characteristics of POME and discharge limits in Malaysia.

Parameters	**POME (range)**	**POME (mean)**	**POME (mean) (this study)**	**Discharge standard (1-1-1984 and thereafter)**
pH	3.4 – 5.2	4.2	5.1	5.0–9.0
Biological Oxygen Demand	10 250 – 43 750	25 000	27 500	100
Chemical Oxygen Demand	15 000 – 100 000	51 000	55 500	–
Suspended solid	5000 – 54 000	18 000	22 500	400

*Units in mg/L except pH
Source: Malaysian Palm Oil Board, 2014

Various approaches have been developed to treat POME to reduce pollution caused by the palm oil industry. Anaerobic pond is one of the most common treatments used in Malaysia to treat high concentrated of POME, the effluents produced had difficulty to comply with the DOE discharge limit. One of the main obstructions in anaerobic treatment is the start up process, which is time consuming and unproductive (Alrawi et al., 2011).

Apart from conventional anaerobic treatment systems, membrane treatment systems are also used to treat POME. It has been recognized to discharge consistent and good water quality. However, it has short life and a costly technology (Poh and Chong, 2009).

2.4.2 Pollutant and pollution effect of palm oil industrial wastewater

Insufficient wastewater treatment can cause several environmental and health effects, therefore, scientific actions need to be taken to reduce these effects. These effects may include negative impacts on fish and wildlife populations, oxygen depletion, beach closures and other restrictions on recreational water use, restrictions on fish and shellfish harvesting and consumptions and restrictions on drinking water consumption (World Bank, 1996; Malek, 2013).