HEAVY METALS REMOVAL FROM LANDFILL LEACHATE USING

VERTIVERIA ZIZANIOIDES AND ARTIFICIAL ROOTS

MOHAMMAD SAFWAN BIN MOHD YANI

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Special thanks to my beloved parents, Mohammad Yani bin Hj Suramin and Shamsuriah binti Hj Mansor and my family, Mohammad Aiman, Najiah Syahirah, Amirah Afiqah and Amirul Haqkim, Hasbullah bin Abdul Aziz, Azri Johari, Izuan Ismail, Bahiah Binti Mazalan, Ungku Mariam Ungku Omar, Ahmad Sobri, Izamuddin (Condeng), Hafizzuddin (Boter), Syahmi (Crouch), Shahrul (Jidin), Shahrul Azri (Talaha), Elly Norisya, Alif Ridzuan, Akram Bahtiar (Katok), Izzul (Ijol 2), Adilah Mahabob (Deqn), Nur Ikhma (Ima), Anis Amalina, Najiba Ramly, Siti Khadijah, Mamat, Fiq, Ayam, Fatin Sara, Nurul Amrah Mohd Noor and for their support and encouragement.
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ABSTRACT

High concentrations of heavy metals and ammonia in landfill leachate can bring hazard to water bodies if it is not treated properly before discharge. Pure water has become the most precious and valuable resource for today generations as its supply become limited and is easily being polluted by industrial wastewater. Nowadays, methods of treatment have become expensive and certainly uneconomical for smaller communities and small medium industries. Biological treatment plays an important role in processing and treating solid waste disposed in a sanitary landfill. Leachate generation is one of the main issues of concerned in a sanitary landfill, due to the existence of high concentrations of heavy metals and ammonia. A combined wetland system utilizing a free floating plant attached with artificial roots was constructed to treat landfill leachate. The aim of the study was to investigate the effectiveness of leachate treatment using floating island wetland system. A free floating plant (*Vertiveria zizanioides*) and artificial roots were used. The wetland systems were arranged in series and operated until the result obtained was in stable state for 50%, 75% and 100% leachate concentrations, respectively. The performances in these series were evaluated with comparison to Set D (control system). The result demonstrated that the removal efficiency of pollutants in leachate using a wetland combination of Set B (*Vertiveria zizanioides* and artificial roots) was achieved for 50% leachate concentration compared to 75% and 100% leachate concentrations. At 100% leachate concentration removal for ammoniacal nitrogen for Set B was 100% compared to set A and Set C which were 89% and 79%, respectively. Besides that, Set B also achieved high metal removal for Cr, Cu, Mn, Fe, Zn at 50% leachate concentration which are 95%, 88%, 93%, 98% and 96% respectively. Set A (*Vertiveria zizanioides*) had higher capacity of metals uptake (Fe, Zn and Mn) in leachate constituents compared to Set C (artificial roots). From the study, it shows that Fe, Zn and Mn uptake were more significant in roots compared to leaves. This study concluded that combination of free floating plants and artificial roots can increase the performances of nutrients and metal uptake and also enhance treatment of leachate.
ABSTRAK

Kepekatan logam berat dan ammonia yang tinggi dalam air larut lesap boleh membawa bahaya kepada jasad air jika tidak diolah dengan betul sebelum dialirkan keluar. Air tulen telah menjadi sumber yang paling bernilai dan terhad kepada generasi kini kerana ia mudah dicemari oleh air sisa industri. Perkembangan teknologi di dalam kaedah olahan air sisa telah menjadi mahal dan tidak ekonomik untuk penempatan komuniti yang kecil dan industri kecil dan sederhana. Kaedah olahan biologi memainkan peranan yang penting dalam pemprosesan dan mengolah sisa pepejal yang telah dilupuskan di tapak kambus tanah sanitari. Penjanaan air larut lesap adalah salah satu isu utama di tapak kambus tanah sampah, kerana mengandungi kepekatan logam berat dan ammonia yang tinggi. Kajian ini bertujuan untuk menguji keberkesanan olahan air larut lesap menggunakan sistem tanah bencah pulau terapung. Dalam kajian ini, tumbuhan terapung bebas (Vertiveria zizanioides) dan akar tiruan telah digunakan. Sistem tanah bencah disusun secara bersiri dan dikendalikan sehingga keputusan yang diperolehi adalah dalam keadaan stabil untuk 50%, 75% dan 100% kepekatan air larut lesap. Prestasi siri ini telah dinilai dengan membuat perbandingan kepada Set D (sistem kawalan). Keputusan yang diperolehi menunjukkan bahawa kecekapan penyingkiran bahan cemar dalam air larut lesap menggunakan gabenan tanah bencah set B (Vertiveria zizanioides dan akar tiruan) tercapai untuk kepekatan 50% air larut lesap berbanding dengan kepekatan 75% dan 100% air larut lesap. Untuk 100% kepekatan air larut lesap, kecekapan penyingkiran nitrogen ammonia bagi Set B adalah 100% berbanding dengan Set A dan Set C pada 89% dan 79%. Selain daripada itu, Set B juga mencapai kadar penyingkiran logam yang tinggi untuk Cr, Cu, Mn, Fe, Zn bagi kepekatan air larut lesap 50% pada 95%, 88%, 93%, 98% dan 96%, masing-masing. Set A (Vertiveria zizanioides) mempunyai kapasiti yang lebih tinggi untuk pengambilan logam (Fe, Zn dan Mn) dalam juzuk air larut lesap berbanding dengan Set C (akar tiruan). Berdasarkan pada kajian ini, keputusan menunjukkan bahawa penyingkiran bahan logam berat seperti Fe, Zn dan Mn adalah melalui akar berbanding daun. Kesimpulan kajian ini menunjukkan bahawa gabungan tumbuhan terapung bebas dan akar tiruan boleh meningkatkan prestasi pengambilan nutrien dan logam serta meningkatkan olahan air larut lesap.
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LIST OF ABBREVIATIONS

BOD - Biochemical Oxygen Demand
cm/day - Centimeter per day
CAP - Consumers Association of Penang
Ca²⁺ - Calcium
CaCO₃ - Calcium carbonate
C/C₀ - Present concentration over initial concentration
Cl - Clorine
Cl₂ - Chlorine gas
Cd - Cadmium
Cr - Chromium
COD - Chemical Oxygen Demand
CWs - Constructed wetland
Fe - Ferum
FWS - Free Water Surface
HCO₃⁻ - Bicarbonate
HF-SSF - Horizontal Subsurface Flow
HLR - Hydraulic Loading Rate
HRT - Hydraulic Retention Time
IUCN - International Union for the Conservation of Nature
kg - Kilogram
kg/m³ - Kilogram per meter cube
m - Meter
mm - Millimeter
m/day - Meter per day
mg/g - Milligram per gram
mg/L - Milligram
per liter mL/s - Milliliter per second
Mg^{2+} - Magnesium
MLVSS - Mix liquor Volatile Suspended Solid
Mn - Manganese
N_{2} - Nitrogen
gas N_{2}O - Nitrogen Oxides
NH_{4}^{+} - Ammonia
NH_{4}-N - Ammonia Nitrogen
NO_{2}^{-} - Nitrite
NO_{3}^{-} - Nitrate
NO_{2}^{-}-N - Nitrite Nitrogen NO_{3}^{-}
-N - Nitrate Nitrogen
P - Phosphorus
PO_{4}^{3-} - Orthophosphate
SO_{4}^{2-} - Sulfate
SSF - Subsurface Flow
SSF-FWS - Combine Subsurface Flow and Free Water Surface System
SS - Suspended Solid
TIN - Total Inorganic
Carbon TKN - Total Kjeldahl
Nitrogen TN - Total Nitrogen
TP - Total Phosphorus
TOC - Total Organic Carbon
TSS - Total Suspended Solid
VF - Vertical Flow
VF-SSF - Vertical Subsurface Flow
VFA - Volatile Fatty Acid
VOC - Volatile Organic
Carbon RBC - Rotating Biological
Reactor Zn - Zinc
% - Percent
CHAPTER 1

INTRODUCTION

1.1 Background of study

Malaysia has become one of the greatest countries in the Southeast Asian Nations in engineering field, where rapid development in the industrial nation, the good health care, education and better employment opportunities in Malaysia have led to the increase in the population. The massive physical development and socioeconomic activities has produced a large mass of solid waste globally. In Malaysia, production rate of municipal solid waste (MSW) per capita is 0.5-0.8 kg/person/day and in specific high density population, this statistic has increased to 1.7 kg/person/day (Kalantarifard and Yang, 2011).

Generally, in Malaysia, sanitary landfill is the main option in solid waste management compare to incineration. On the other hand, due to the scarcity or limited land reserved, land space for MSW is now becoming critical, when the wastes produced are much higher as compare to the degrade mechanism production. Thus, land space for MSW becomes hard and costly to achieve. Installation of incineration system is acceptable but it is expensive and hazardous to human health.

Sanitary landfill is an isolation of municipal solid waste from the environment until the wastes are non hazardous through the chemical, physical and
biological processes of nature. Sanitary landfill involves two basic conditions; 1) compaction of the municipal solid wastes after spreading them into thin layer, and 2) Covering the wastes daily with soil to prevent negative impacts on human health and environment.

Sanitary landfill system causes formation of leachate (Ain Nihla, 2006) by precipitation percolating through waste layer deposited in a landfill. Combination of chemical, physical and microbial process in the residual transfer pollutants from the residual matter to the percolating water (Kjeldsen and Christophersen, 2014).

Highly polluted leachate move downwards into the base or impermeable layer from landfill into groundwater table by gravity force as a production of infiltrated precipitation. Once leachate reaches ground water table, over time, it will cause ground water pollution (Fetter, 2001; Nazaitulshila, 2006). Landfill leachate compositions depend on several factors such as pH, temperature, availability of moisture and oxygen, landfill age and operation system, climate, composition and depth of waste (Aderemi et al., 2011).

When a massive of solid waste is placed on the landfill sites, some reaction will occur due to the activity, such as biological decay of organic materials, chemical oxidation of waste materials or dissolving and leaching of organic and inorganic materials by water through the landfill. Those reactions produce gases, such as ammonia, carbon dioxide, hydrogen sulfide, oxygen, nitrogen, and methane

Organic matters are decomposed by microorganism and causes oxygen on surface water to deplete (Vymazal et al., 2008). In conjunction, the process brings harm to aquatic life. Therefore, leachate can be toxic and acidic which contain high concentration of heavy metal such iron, manganese and copper. Heavy metals are dangerous because they tend to bioaccumulation. Bioaccumulation is the uptake of organic compounds from water or food containing the chemical amd process by which chemical is taken up by an organism (Mark, 2008). Highly contaminated leachate can affect flora and fauna ecosystem, human health and environment, so
Landfills leachate treatment is required as a necessary part of solid waste management before being discharged into receiving water to prevent these occurrences (Chew, 2005).

Generally, wastewater in landfill leachate is difficult to be treated by itself due to the high strength of concentration. Thus, a biological treatment technology such as constructed wetlands can be adapted for this treatment. Constructed wetland treatment systems are engineered system that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils to assist in treating wastewater.

Usually, leachate treatment systems are made from steel and concrete construction (man-made) wetland treatment or employ naturally where it relies on intensive inputs of chemicals, that treat wastewater utilizing natural processes of sedimentation, precipitation, and adsorption, assimilation by plant tissue, microbial transformation and organic degradation (Alkassabeh et al., 2009).

In addition, wetlands have a higher rate of biological activity in ecosystem where they can transform many of the common pollutants that occur in conventional wastewater into harmless by product or essential nutrients that can be used for additional biological productivity. These transformations are accomplished by virtue of the wetland’s land area, with its inherit natural environmental energies of sun, wind, soil, plants and animals. These pollutant transformations can be obtained for relatively low cost of earthwork, piping, pumping, and few structures. Wetlands can be categorized as one of the least expensive treatment systems to operate and maintain, because of the natural environment energies at work in the wetland treatment system, with minimal fuel energy and chemical.
1.2 Problem Statement

Landfill leachate produced by MSW landfill sites contains highly contaminated heavy metals and complex wastewater that are very hard to deal with (Daud et al., 2009; Foul et al., 2009; Palaniandy et al., 2009; Mohajeri et al., 2010). Leachate contain high concentration of organic matters (biodegradable and non-biodegradable), ammonia nitrogen, chlorinated organics, inorganic salt, high concentration of Chemical Oxygen Demand (COD), and heavy metals (Aeslina, 2004; Renou et al., 2008). Leachate concentration may range over several orders of magnitude (Deng and Englehardt, 2007).

High concentration of contaminants in leachate (such as COD, ammonia and inorganic salts) can be hazardous to surface waters and ground water table, thus they need to be treated before being discharged to water resources (Bashir et al., 2010). In addition, lack of safety management in leachate collection and treatment also can contribute to harmful environment for flora and fauna. In Malaysia, 230 landfills have been recognized and most of them are not designed with proper leachate collection mechanism and do not come under sanitary leachate category because there are no facilities for collection and treatment leachate and landfill gas (Alkassabeh et al., 2009)

Operation and maintenance for landfill leachate treatment require high budget due to the sophisticated and advance technology that had ben used to treat all the heavy metals and hazardous component in the leachate before it been discharges to the nearer river. Plus, adequate skill labors are compulsory due to the management of the sophisticated system. An alternative eco-friendly and low cost technology with high sufficient natural treatment is therefore needed, such as constructed wetlands for secondary or tertiary treatment to treat treated leachate.
Constructed wetlands are built with such greater degree of control, thus allowing the establishment of experimental treatment facilities with a well-defined composition of substrate, type of vegetation, and flow pattern. In addition, constructed wetlands offer several additional advantages compared to natural wetlands, which include site selection, flexibility in sizing and most importantly control over the hydraulic pathways and retention time.

1.3 Objectives

The objectives of this research are as follows:

1. To investigate the removal efficiency performances of COD, Ammonia Nitrogen (NH₃-N), and heavy metal (Chromium Hexavalent, Copper, Manganese, Zinc, Iron) for different leachate concentrations (100%, 75%, and 50%) by *Vertiveria zizanioides* (Set A), *Vertiveria zizanioides* with artificial roots (Set B), Artificial roots (Set C) and Control system (Set D)

2. To evaluate the heavy metals uptake by *Vertiveria zizanioides* in roots, shoots with or without the combination of artificial roots.

3. To investigate the effect of leachate concentration in the capability growth of the *Vertiveria zizanioides*.

1.4 Significance of Study

Sophisticated leachate treatment technology usually is expensive in operation and maintenance and requires constant supervision, typical purification system consist of mechanical and chemical process which are required adequate skill staff, large amount of energy (non-renewable) resources.

Meanwhile, *Vertiveria zizanioides* is a biological purifier and renewable resources which can be used in others applications when no longer needed for
phytoremediation purpose. New potential plants species with good climate condition in Malaysia can bring new ideas for natural environment as introduced in constructed wetlands to treat leachate. Thus, in this context, variation of expanding new ideas generate large concept beyond the common treatment of wastewaters.

This research is to evaluate the efficiency of the floating island system to treat the leachate from the landfills. Floating island plants will remove the pollutants from the leachate naturally without harming other flora and fauna lives before being discharged into the mainstream water base. Due to the eco-friendly characteristic, this method is potential to be used in landfill site to improve the quality of water. Floating islands are innovative variant of constructed wetland and pond technologies that can treat wastewater. Floating island employ rooted, emergent macrophytes on a mat floating on the surface of the water rather than a rooted in the sediments. Floating islands are hybrid between a pond and a wetland, which behave similarly to detention pond. The plant roots hang beneath the floating amt and provide a large surface area for biofilm growth which forms an important part of the treatment.

The research study can determine the suitable leachate concentration for optimum removal of pollutants through analysis of the parameters and criteria. Leachate concentration plays the vital role to ensure that the leachate concentration is neither too high nor too low to influence the effectiveness of treatment in constructed wetlands. In addition, the research also provides the information carried by the floating island system such as the heavy metal removals.

1.5 **Scope of Study**

The research was carried out in lab-scaled wetland system to treat leachate. Leachate will be collected from landfill and initial characteristics of the leachate were analyzed. Then, experiments were conducted separately in constructed wetlands, where leachate is only used as control, 100% leachate, 75% leachate and
50% leachate. All the experiments in the constructed wetlands were aerated and the total amount of leachate in each pair of tanks is 247.5 liters.

Evaluation of treatment efficiency for different leachate concentrations is determined for the following parameters (Temperature, DO percentage, DO, Conductivity, Total Dissolved Solid, pH, NH$_4$-N, NO$_3$–N, COD) and heavy metals such as Chromium Hexavalent, Copper, Manganese, Zinc and Iron. The heavy metal removals evaluation will be determined on the leaves, rhizomes and roots of the floating plants (*Vetiveria Zizanioides*) and identify the function of artificial roots. The effects of leachate concentration are determined based on the length and physical appearance of the leaves throughout the experiment conducted.
REFERENCE


Thian Siaw Hui, 2005. Leachate Treatment by Floating Plants in Constructed Wetland, Master of Civil Engineering, University Technology Malaysia, Skudai.


