NUTRIENT REMOVAL FROM LEACHATE USING HORIZONTAL SUBSURFACE CONSTRUCTED WETLANDS

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This work is dedicated to my family members who love me and support me during my whole journey of education. Thanks for yours support!

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ABSTRACT

Leachate from sanitary landfill usually contains substantial amount of organic matters and inorganic substances, and has the potential to pollute ground and surface water. Treatability of leachate is dependent upon the composition of the leachate and the nature of the organic matters present. Constructed wetlands are treatment systems that treat the wastewater either above or below the soil surface. In this study, horizontal subsurface flow constructed wetlands had been applied. This study was conducted to investigate the removal of nutrient from landfill leachate by *Typha angustifolia* and to determine the treatability of horizontal subsurface constructed wetlands with different concentration of influent, hydraulic retention time (HRT), and sand to soil ratio comparison between the treatability of horizontal subsurface constructed wetlands with and without vegetation is also carried out. Two laboratory-scale wetlands unit with one of the unit planted with cattails (*Typha angustifolia)* and another as control without any plants, were fed with primary treated landfill leachate and operated at hydraulic retention time of 1 – 5 days. The experiment is design by 2^k factorial design to study the joint effect of the factors on the response. According to the study removal efficiency of nutrient from landfill in the form of ammoniacal nitrogen and nitrate by *Typha angustifolia* ranges from 42.6 – 88.9 %. Removal of BOD_5 and COD by horizontal subsurface constructed wetlands with *Typha angustifoilia* ranges from 62.6 – 72.8 % and 64.5 – 85.7 % respectively. Removal efficiency of nutrient from landfill in the form of ammoniacal nitrogen and nitrate by unplanted reactor ranges from 38.6 – 76.6 %. Removal of BOD_5 and COD by unplanted horizontal subsurface constructed wetlands ranges from 67.2 – 71.5 % and 60.3 – 72.5 % respectively. The HRT was found to affect the results, about 10 to 30% of differences in removal efficiency for longer HRT compare to shorter HRT.

ABSTRAK

Air larut lesap dari kawasan perlupusan sampah mengandungi bahan organik dan tak organik yang banyak dan berpotensi mencemarkan air bumi dan air sungai. Keboleholahan air larut lesap adalah bergantung kepada komposisi air larut lesap dan sifat bahan organik yang hadir. Tanah benceh binaan ialah sejenis sistem olahan yang digunakan untuk mengolah air sisa sama ada melalui lapisan atas atau bawah tanah. Dalam kajian ini, tanah benceh binaan aliran melintang telah digunakan. Kajian ini bertujuan untuk mengenalpasti perpindahan nutrien daripada air larut lesap oleh *Typha angustifolia* dan memperolehi keboleholahan tanah benceh binaan aliran melintang terhadap pelbagai tahap kepekatan influen, masa penahanan hidraulik dan nisbah pasir kepada tanah antara sistem dengan tumbuhan dan tanpa tumbuhan. Dua sistem tanah benceh binaan berskala makmal digunakan. Satu sistem ditanam *Typha angustifolia* dan satu sistem tanpa ditanam *Typha angustifolia* beroperasi pada masa penahanan hidraulik antara 1 – 5 hari. Kajian ini direka berdasarkan 2^k faktorial untuk mengkaji kesan faktor berkongsi terhadap rangsangan. Berdasarkan kajian ini, perpindahan nutrien oleh sistem ditanam *Typha angustifolia* dalam bentuk ammonikal nitrogen dan nitrate adalah dalam lingkungan 42.6 – 88.9 %. Perpindahan BOD_5 dan COD oleh tanah benceh binaan aliran melintang yang ditanam dengan *Typha angustifolia* adalah antara 62.6 – 72.8 % dan 64.5 – 85.7 %. Sementara perpindahan nutrien oleh tanah benceh binaan aliran melintang tanpa *Typha angustifolia* adalah dalam lingkungan 38.6 – 76.6 %. Perpindahan BOD_5 and COD oleh tanah benceh binaan aliran melintang tanpa *Typha angustifolia* adalah antara 67.2 – 71.5 % dan 60.3 – 72.5 %. Masa penahanan hidraulik juga mempengaruhi keputusan perpindahan. Perbezaan antara 10 -30% didapati dengan membandingkan masa penahanan hidraulik yang panjang dengan masa penahanan hidraulik yang pendek.

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LIST OF ABBREVIATIONS

KLIA	Kuala Lumpur International Airport
MSC	Multimedia Super Corridor
TNB	Tenaga National Berhad
DID	Drainage and Irrigation Department
BOD_5	Biochemical Oxygen Demand-5 days
COD	Chemical Oxygen Demand
HRT	Hydraulic Retention Time
SF	Surface Flow
FWS	Free Water Surface
SSF	Subsurface Flow
VF	Vertical Flow
HF	Horizontal Flow
SS	Suspended Solids
FAP	Floating Aquatic Plant
cBOD	Carbonaceous Biochemical Oxygen Demand
TN	Total Nitrogen
TP	Total Phosphorus
HSSFCW	Horizontal Subsurface Flow Constructed Wetlands
PVC	Polyvinylchloride

LIST OF SYMBOLS

ha	Hectare
NH_3-N	Ammonia Nitrogen
Fe	Ferum
Al	Aluminum
Ca	Calcium
N	Nitrogen
P	Phosphorus
N_2	Dinitrogen gas
N_2O	Nitrous Oxide
NH_3	Ammonia
H_2O	Water
NH_4^+	Ammonium
OH^-	Hydroxide ion
NO_2^-	Nitrite
NO_3^-	Nitrate
mV	milliVolt
°C	degree celcius
kg	kilogram
yr	year
L	Liter
M	meter
d	day
mg	milligram

CHAPTER 1

INTRODUCTION

Leachate is defined as "any contaminated liquid that is generated from water percolating through a solid waste disposal site, accumulating contaminants and moving into subsurface areas. As these wastes are compacted or chemically react, bound water is released as leachate" (Pankratz, 2001). In unlined landfills, leachates frequently discharge to groundwater or appear as a surface drainage around the base of the landfill. In modern lined landfills, leachates are collected from lined cells and routes to treatment units. Due to recent stringent environmental regulations and a high potential for soil, surface and groundwater pollution, disposal of landfill leachate has become a problem in handling solids waste from municipalities. Therefore, landfills leachate treatment is required as an essential part of solid waste management (El-Gendy, 2003).

1.1 Constructed Wetlands and Landfill

Constructed wetlands, which is considered one of the natural treatment systems, is currently gaining considerable attention as it has been used successfully in secondary or tertiary treatment of effluent from aerated lagoons (Mæhlum, 1995). Reed bed treatment system have been used successfully to provide polishing of biologically treated leachate effluent and achieve very high effluent standards (Robinson *et. al*., 1999). The many functions and values of wetlands are widely recognized, particularly with regard to their abilities to improve water quality. It has recently been proven to be one of the cost effective means of leachate and wastewater management (Mæhlum, 1995, Gearheart, 1999, Kadlec, 1999 and El-Gendy, 2003).

While wetlands treatment is defined as “A wastewater treatment system using the aquatic root system of cattails, reeds, and similar plants to treat wastewater applied either above or below the soil surface” (Pankratz, 2001).

The role of wetlands in water resource management is fast gaining ground resulting in the construction wetlands in most developed countries. Constructed wetlands are man-made system that involves altering the existing terrain to simulate wetlands conditions. They primarily attempt to replicate the treatment that has been observed to occur when polluted water enters the natural wetlands.

These wetlands have been seen to purify water by removing organic compounds and oxidizing ammonia, reducing nitrates and removing phosphorus. The mechanisms are complex and involve bacterial oxidation, filtration, sedimentation and chemical precipitation (Lim *et. al.,* 2001).

Most constructed wetlands attempt to imitate the ecosystem's biochemical function as filtration and cleansing agents, followed closely by the hydrological function that is centered on flood mitigation.

The use of constructed wetlands to treat urban surface runoff (Revitt *et. al.,* 2004) and remove nutrients from diverse sources in rural catchments has received much attention lately. Thus, wetlands are essentially the filtering area, the 'kidneys' of the catchments, intercepting water flow, trapping sediment and pollutants, removing toxic substances (pesticides, herbicides, metals) and assimilating nutrients and energy derived from the upstream catchments area.

Wetlands have the ability to filter nutrients from inflowing waters which represent the base of many food chains that not only start and finish within the wetlands but extend beyond the wetlands complex itself. Where there is food there is life, and hence wetlands act as breeding grounds, nurseries and homes to numerous plants, invertebrates, frogs, reptiles, fish and waterbirds. In fact, wetlands are best known as habitats for fish and waterbirds.

Wetlands are becoming increasingly popular as ecotourist destinations. Their biodiversity, open space, aesthetics and the development of public amenities make them attractive propositions for passive recreational activities and social pursuit (Diederik *et. al.,* 2004).

It is generally accepted that wetlands have the potential to attenuate flooding. Wetlands provide retention storage for storm water by spreading the water over a wide flat area. Wetlands vegetation retards surface water flow to varying extents depending on the type, density and water depth (Revitt *et. al.,* 2004).

Wetlands are a fertile ground for scientific study and research. In fact, there is also a growing interest in wetlands among school children who are beginning to embark on a voyage of discovery of their environment by being introduced to this dynamic ecosystem. This may well be the first step in public education of wetlands, which are the collective responsibilities of all users.

1.2 Application of Constructed Wetlands in Malaysia

Constructed wetlands in the Malaysian context are gaining popularity for treatment of stormwater, urban runoffs and agriculture effluents.

1.2.1 Putrajaya Constructed Wetlands

Putrajaya is the new Federal Government Administrative Centre in Malaysia, located south of Kuala Lumpur, north of the new International Airport (KLIA) and along the Multimedia Super Corridor (MSC). It consist of government departments, commercial offices, residential premises and recreational parks as well as water bodies. Green space will occupy 30% of the land area of the city.

In balancing the ecosystem and the future population of Putrajaya, one of the most distinctive features is the development of the lake that covers a total of 650 ha and has been created by the construction of a dam at the lower reaches of the River Chuau. An important component of the lake is the creation of 23 constructed wetlands (Fig. 1.1). The wetlands act as a natural treatment system that filters most of the pollutants in the river water before it enters the lake.

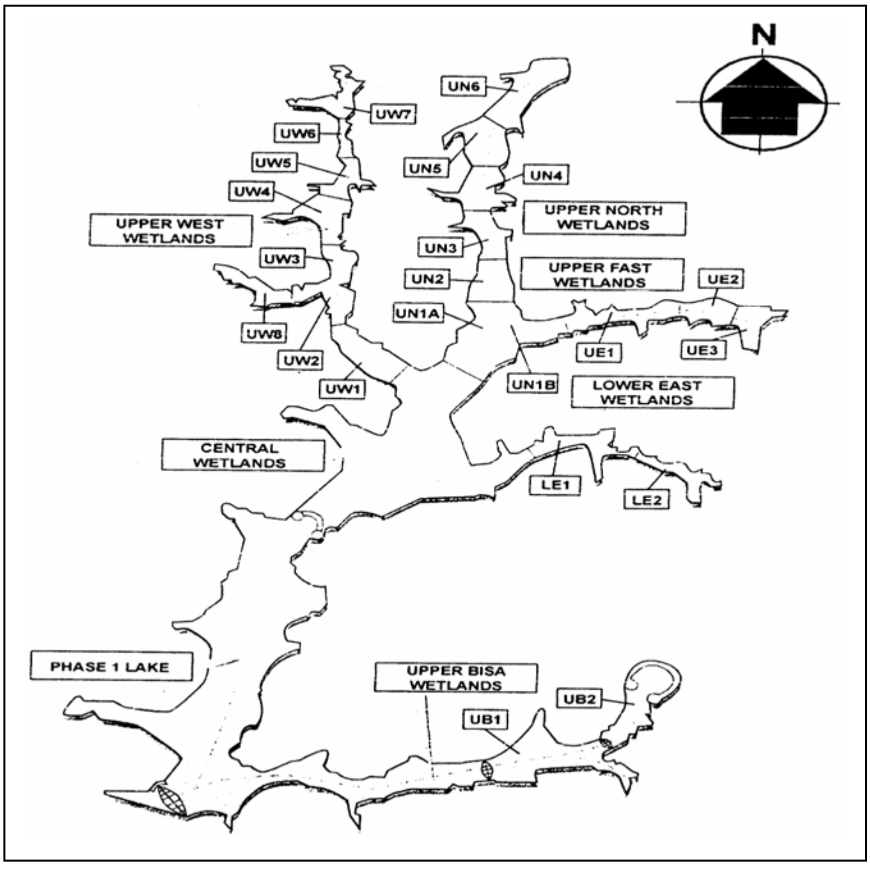

Figure 1.1 Putrajaya Lake and Wetlands system, Malaysia (Shutes, 2001).

Located in the middle of Putrajaya, the lake provides a landscape feature and varied recreational activities for the population as well as creating wildlife habitats. An interpretation centre describes the design and operation of the lake and wetlands system and their role in the developing ecology. The ultimate goal of the development is a self-sustaining and balanced lake ecosystem set in the Garden City of Putrajaya.

The water in the lake must be suitable for recreational activities and aesthetically attractive to the public. It is therefore expected that the lake will be free of floating debris, algae, weed, and objectionable odour as well as safe and healthy for humans and freshwater fauna. In achieving this, the general objectives are:

- the existing environment is sustainable;
- the lake does not become eutrophic;
- the water quality is suitable for body contact recreation;
- the lake creates a natural and pleasant landscape, enhancing ecotourism and attracting wildlife;
- the lake provides a suitable environment for education and scientific research.

Each of the 23 wetlands cells (total area 130 ha) is separated by a weir. An initial settlement forebay is followed by a surface flow wetlands and a final settlement pond. The raised walls at the inlet, outlet and sides of the wetlands allow water storage following storm events. The vegetation types in the wetlands comprise emergent macrophytes (large plants), rheophytes (floating plants) and freshwater swamp species. A total of 70 plant species have been selected for the wetlands and their seeds obtained from locations throughout Malaysia. The 12 million plants have been grown in a nursery that is 5 ha in area.

The wetlands were designed using the multicell, multistage approach, with different water levels at each cell as the water flows across the wetlands. The advantage of the design is that it provides good flow distribution, thus maximizing shallow areas required for the successful growth of macrophytes and facilitates a more cost-effective maintenance including the management of weeds and insects.

A comprehensive water quality monitoring programme will be introduced following the completion of the Putrajaya Lake and Wetlands system in 2000.

1.2.2 Rehabilitation of a drainage System Using a Constructed Wetlands at Kota Kemuning

This is an example of constructed wetlands treatment system in Malaysia which has followed the design of Putrajaya Wetlands. Kota Kemuning Wetlands was created from an existing low-lying water logged area gazetted as reserve land belonging to Tenaga Nasional Berhad (TNB), the Drainage and Irrigation Department (DID) and Kesas Highway. It is a long narrow strip of wetlands, covering an area of 8.8 ha. It is situated near the main entrance of Kota Kemuning Township and Kesas Highway.

The creation of the wetlands was started in June 2002 and it is completed in early September 2003. The main purpose of this man-made wetlands creation is to provide a solution for drainage problems occurring in this low-lying area. The wetlands receive a large volume of stormwater from its catchment area. The wetlands and rooted vegetation function in filtering pollutants, trapping sediment and up take nutrients while dissipating water velocity before it is discharged into Klang River. The wetlands also functions in controlling the occurrence of flash floods due to backflow from the Klang River during heavy downpour.

A total of 157 thousand local indigenous wetlands plants belonging to 15 species have been introduced to the wetlands. These include 13 marsh species and 2 ornamental species. The marsh species are important in nutrient removal and in preventing the wetlands from eutrophication. These plants are hardy and can withstand long periods of waterlogged and eutrophic conditions. A total of 31 species of shrub and woodland species have been planted at the wetlands fringes to create a buffer from human activities and to increase aesthetic values to the area.

1.3 Scopes of Study

According to the introduction, the application of constructed wetlands in Malaysia is less. While almost none of the landfill site in Malaysia applied concept of constructed wetlands for the on-site treatment. So, it is finely to study about the effectiveness of constructed wetlands especially horizontal subsurface constructed wetlands in treating the landfill leachate.

The experiments on the removal of organic matters and nutrients are carried out in the Environmental Laboratory, Faculty of Civil Engineering. Leachate sample is taken from Pasir Gudang landfill. The species of macrophyte, which is used in this study, is called *typha angustifolia.* The model of the sub-surface flow constructed wetlands is set up in the laboratory. The effluent of the leachate is then tested and analyzed in the laboratory to determine the removal of organic matters and nutrients. Parameters, which were considered, are:

i. Biochemical Oxygen Demand (BOD)
ii. Chemical oxygen Demand (COD)
iii. Ammoniacal nitrogen
iv. Nitrate

1.4 Objectives of Study

Constructed wetlands possess attributes of low-cost and low-maintenance and are capable of removing organic matters, nutrients and other pollutants simultaneously (Lin, *et al.*, 2002). The objectives of this study are:

1. To investigate the removal of nutrient from landfill leachate by *Typha angustifola.*
2. To determine the treatability of horizontal subsurface constructed wetlands with different concentration of influent, hydraulic retention time (HRT), and sand to soil ratio.
3. To compare the treatability of horizontal subsurface constructed wetlands with and without vegetation.