LANDFILL LEACHATE TREATMENT PERFORMANCE IN SUBSURFACE FLOW CONSTRUCTED WETLANDS USING SAFETY FLOW SYSTEM

AESLINA ABDUL KADIR

A project report submitted in partial fufilment of the
requirements for the award of the degree of
Master of Engineering (Civil-Environmental Management)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

OCTOBER 2004

Dedicated to my dearest parents mak and abah,

sisters arni, aerin, atin and

my beloved aqeem, aziq, abd

Thanks for your support, encouragement and

for really understand me.........................

aeslina

ACKNOWLEDGEMENT

In the name of Allah the Most Gracious and the Most Merciful, I thank Thee with all my heart for granting Thy Servant immeasurable help during the course of this study and peace be upon him, Muhammad, the last messenger of Allah.

First of all, I would like to express my gratitude to my supervisor, Associate Prof. Dr. Mohd. Razman Salim, for all his guidance and supervision over the period of this research. I really appreciate the effort and time he had spent which eventually enabled me to develop and present my work in its present form. Equally appreciated is dedicated to Prof. Dr. Zaini Ujang, Associate Prof. Dr. Eddy Soedjono, Associate Prof. Dr. Mohd. Ismid Mohd. Said and Associate Prof. Zainuddin Samsudin for their invaluable advice and encouragement. I'm deeply indebted for their constant source of support throughout the study.

Appreciation is also goes to all my colleagues especially my research partner Lee Yun Fook, my friends Salmiati, Rafidah, Fadhil, Ong, Ee Ling, Nava, Ai Ling, Yap, Izan, Hilda, Simran, Liza, and Sha. Without their support, this study would not have been possible. Next, I am also thankful to all the technicians of Environmental Engineering Laboratory, En. Ramlee Ismail, En. Ramli Aris, En. Yusof M. Napi, En. Zulkurnain Md. Khalid and En. Azlan Abd. Aziz, for their guidance and cooperations through all my laboratory difficulties. Finally, and most specially, I would like to thank my dearest family, sisters, and my beloved, to whom I dedicated this dissertation. They have been "my tower of strength", and have always been behind me with love, support and endless patient.

ABSTRACT

The increasing application of constructed wetlands for leachate treatment is an ever-growing incentive for the development of better process design tools. This study was conducted to investigate leachate treatment performance of horizontal subsurface flow constructed wetlands (HSSFCW) installed with water dispersal system, called Safety Flow® to produce a defined subsurface wetting pattern along the line and length of the system. A pilot scale HSSFCW with three parallel reactors was set up with dimensions of 2.45 m length x 0.20 m width x 0.40 m depth. All reactors were dosed using pre-treatment leachate effluent from sanitary landfill, Johor Bahru. Out of the three reactors, Reactors A and C were planted with *Thypha angustifolia*, whilst Reactor B was not planted and used as a control. In addition, Reactor C was installed with water dispersal system. The performance of constructed wetlands system was evaluated from the effluent quality. The main parameters were organics matter (biochemical oxygen demand (BOD) and chemical oxygen demand (COD), nutrients (ammonical nitrogen (NH_4-N), nitrate (NO_3-N), phosphorus (P), and heavy metals (chromium (Cr) and cadmium (Cd). Based on the observation, Reactor C was found better than both Reactors A and B. Reactor C had removed more than 70% of BOD and COD, up to 80% of NH_4-N and P and at least 90% of heavy metals.

ABSTRAK

Aplikasi penggunaan tanah bencah buatan yang semakin meningkat merupakan satu pencapaian yang baik kerana teknologi tanah bencah buatan memainkan peranan yang penting di dalam pengolahan air larut resap. Kajian ini dijalankan adalah bertujuan untuk mengkaji kebolehan sistem tanah bencah buatan jenis aliran sub-permukaan di dalam pengolahan air larut resap dengan penambahan sistem pengairan yang dinamakan Safety Flow®. Ia boleh menghasilkan corak pembasahan di permukaan dan di sepanjang sistem. Tiga buah unit (A, B dan C) tanah bencah buatan jenis horizontal aliran sub-permukaan berskala telah dibina dengan dimensi 2.45 m panjang x 0.20 m lebar x 0.40 m kedalamannya. Ketiga-tiga unit ini dialirkan dengan air larut resap yang telah menjalani pra-rawatan di tapak pelupusan sampah, Johor Bahru. Unit A dan C ditanam dengan *Thypha angustifolia* manakala unit B bertindak sebagai unit kawalan. Sebagai tambahan, unit C dilengkapi dengan sistem Safety Flow®. Kualiti efluen daripada setiap unit diuji untuk mengetahui unit yang memberikan rawatan air larut resap yang terbaik. Parameter yang diuji di dalam kajian ini ialah kandungan organik (keperluan oksigen biokimia dan keperluan oksigen kimia), kandungan nutrien (ammonia nitrogen, nitrat, dan fosforus) dan logam berat (kromium dan kadmium). Secara keseluruhannya, hasil kajian menunjukkan unit bencah buatan C (dilengkapi dengan Safety Flow®) memberikan rawatan yang lebih baik dalam pengolahan air larut resap berbanding unit bencah buatan A dan B. Unit C telah menyingkirkan lebih daripada 70% kandungan BOD dan COD, lebih daripada 80% kandungan NH_4-N dan P manakala kadar penyingkiran bagi logam berat pula adalah melebihi 90%.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	-	d*W, cross-sectional area of wetland bed, perpendicular to the direction of flow, m^2
cm	-	centimeter
^0C	-	celcius
d	-	depth of wetlands media, m
hr/h	-	hour
k	-	hydraulic conductivity of the medium, m^3/m^2-d
^0K	-	Kelvin
L	-	length of wetlands media, m
L	-	liter
m	-	meter
MHz	-	MegaHertz
mg	-	milligram
ml	-	mililiter
mm	-	millimeter
µg	-	microgram
n	-	porosity of media, $n = V_v/V$ where (V_v and V are volume of voids and total volume).
Q	-	average flow rate through the system, m^3/d
S	-	slope of the bed, or hydraulic gradient (as a fraction or decimal)
t	-	hydraulic retention time
W	-	width of wetlands media, m

LIST OF ABBREVIATIONS

Ag	-	Argentum
Al	-	Aluminium
APHA	-	American Public Health Association
Ba	-	Barium
BOD	-	Biological Oxygen Demand
BOD_5	-	5-day Biochemical Oxygen Demand
Ca	-	Calcium
$CaCO_3$	-	Calcium Carbonat
Cd	-	Cadmium
COD	-	Chemical Oxygen Demand
CO_2	-	Carbon dioxide
Cr	-	Chromium
Cu	-	Cuprum
EPA	-	*Environmental Protection Agency*
Fe	-	Iron
H_2	-	Hydrogen
HF	-	Horizontal Flow
Hg	-	Mercury
HSSFCW	-	Horizontal Subsurface Flow Constructed Wetlands
ICP	-	Inductively Coupled Plasma
IWA	-	International Water Association
MBAS	-	Methylene Blue Active Substances
Mn	-	Manganese

N_2	-	Nitrogen
NH_4-N	-	Ammonical Nitrogen
Ni	-	Nikel
NO_3-N	-	Nitrate
P	-	Phosphorus
Pb	-	Plumbum
SF	-	Surface Flow
SS	-	Suspended solids
SSF	-	Subsurface Flow
TDS	-	Total Dissolved Solids
TOC	-	Total Organic Carbon
VDS	-	Volatile dissolved solids
VF	-	Vertical Flow
VSS	-	Volatile suspended solids
Zn	-	Zink

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Prior to modern developments in sanitary engineering, people disposed off wastewater to natural aquatic ecosystems, including natural wetlands (Kadlec and Knight, 1996). However, natural wetlands are important resources in natural ecology and are legitimately protected in most countries. Wetlands are among the most important links in the natural ecosystem. The major functions of wetlands, include holding and recycling nutrients, providing wildlife habitats, stabilizing shorelands, controlling and buffering natural floods, recharging ground water, providing treatment for pollutants and so on (Hughes *et al.*, 1992). Constructed wetlands provide an effective method for treating wastewater by simulating the processes that occur in natural wetlands. Such artificial ecological system has also been found to be useful in improving the quality of river water (Kadlec and Hey, 1994 and Jing *et al.*, 2001).

Constructed wetlands are now used to improve the quality of point or nonpoint sources of water pollution including stormwater runoff, domestic wastewater, agricultural wastewater and coal mine drainage. It is also being used to treat petroleum refinery wastes, compost and landfill leachates, fishpond discharges and pretreated industrial wastewaters (Moshiri, 1993).

Constructed wetlands systems are characterized by the advantages of moderate capital cost, low energy consumption and maintenance requirements and benefits of increased wildlife habitat (International Water Association (IWA), 2000). As a result of both extensive research and practical application, insight is being gained into the design performance, operation and maintenance of constructed wetlands for water quality improvement. Constructed wetlands can be sturdy and effective systems. However, to be effective, they must be carefully designed, constructed, operated and maintained (Moshiri, 1993).

Putrajaya wetlands is another milestone in the development of Malaysia as an independent and sovereign nation. Putrajaya wetlands trace the development of Malaysia's first constructed wetlands and it is built to demonstrate the benefits of incorporating this unique ecosystem in urban areas. It is also a tribute to the nation's commitment and government interest to sustainable development, by selecting the environmental-friendly solution of constructing wetlands to treat catchment water before it enters Putrajaya Lake.

Constructed wetlands can be used to treat leachate from sanitary landfills (Rash and Lier, 1999). In this study, a new water dispersal system called Safety Flow® was used in designing horizontal subsurface flow constructed wetlands to see its performance in treating landfill leachate.

1.2 Problem Statement

Landfilling represents the least desirable means of dealing with society's wastes involving the controlled disposal of wastes on or in the earth's mantle, and it is by far the most common method of ultimate disposal for waste generated. The major environmental concern associated with landfills is related to discharge of leachate into the environment and the current landfill technology is primarily determined by the need to prevent and control leachate problems. Landfill leachate management has been given significant attention in recent years (Ding *et al.*, 2001).

Currently, a number of options exist for the containment and treatment of this type of wastewater. Constructed wetlands as tool in the treatment of polluted water is increasing in popularity as an ecological engineering alternative to conventional, chemical based methods. Wetlands ecosystems have the advantages of being self-perpetuating, aesthetically pleasing, low-maintenance and cost-effective treatment system. Constructed wetlands have been investigated and found to be capable of removing organics matter, nutrients, heavy metals and other pollutants simultaneously (Lim *et al.*, 2003). In these facilities, high levels of pollutant removal are due to a good combination of chemical, biological and physical processes (Brix, 1997).

Generally, constructed wetlands can be divided into two categories, which are surface flow constructed wetlands and subsurface flow constructed wetlands. Subsurface flow systems are more effective than surface flow systems at removing pollutants at high application rates. Though, subsurface irrigation always has the problem of tunneling where the soil moisture uptake rate cannot keep to the water applied. This leads to water draining up and down, causing pooling at the surface and rapid release to the water table. With all the subsurface systems to date, the water-releasing rate is faster than the soil and plant uptake. In this study, Safety Flow® system has been introduced to overcome these problems. Safety Flow® was initially applied for subsurface irrigation system, which requires precision irrigation, and provides more benefits especially in managing gravitational water loss, saline soil conditions, and root zone wetting pattern, evaporative losses and plant requirements and minimizing water losses. With all the features and advantages of Safety Flow®, it was applied in this study to enhance the removal efficiency of constructed wetlands for leachate treatment.

1.3 Overview of Constructed Wetlands with Safety Flow® System

Over 1000 treatment wetlands systems are in operation worldwide (Kadlec and Hey, 1994), encompassing a wide variety of designs and objectives. Constructed wetlands designs include horizontal surface and subsurface flow, vertical flow and floating raft systems. More than 95% of constructed wetlands in Europe are subsurface flow wetlands (Platzer, 2000). In horizontal subsurface flow wetlands, wastewater flows horizontally through the substrate, which is composed of soil, sand, rock or artificial media. The purification process occurs during contact with the surface of the media and plant rhizospheres. In this study, the focus was on the performance of horizontal subsurface flow constructed wetlands installed with Safety Flow® system for landfill leachate treatment. There are two types of Safety Flow® configurations, Safety Flow® Flat and Safety Flow® Wrap. Safety Flow® Flat is suitable for this study because it is great for areas where the slope is less than three percent. Safety Flow® is a subsurface system that uses geotextile to spread the water in both horizontal and lateral wetting pattern. It also uses an impermeable layer of polyethylene to minimize the movement of water downwards by gravity allowing the soil to make full use of the water in capillary action. This system has a drip tape delivering the water to the geotextile, and the base polyethylene layer, at a consistent and predetermined rate. The flow rates and emitter spacing can be adjusted to soil conditions and length of run. It also creates an elliptical wetting pattern along the whole length of the material.

Safety Flow® is unique and different from other subsurface systems because it can produce a defined subsurface wetting pattern along the line and length of the system. The combination of drip tape technology; permeable membranes provides thousands of emission points along the system making water available to the soil capillaries to take up the water at the soil absorption rate while impermeable layer is to minimize the movement of water downwards by gravity.

1.4 Aim and Objectives

The main aim and objectives of this study were to evaluate the applications of Safety Flow® system in horizontal subsurface flow constructed wetlands (HSSFCW) planted with *Typha Angustifolia* in treating landfill leachate. The performance of HSSFCW planted with *T. angustifolia* would increase with the installation of Safety Flow® system in landfill leachate treatment. To achieve this aim, the study was carried out with the following objectives;

i) To evaluate the performance of Safety Flow® system in HSSFCW for landfill leachate treatment.

ii) To determine the capability of the HSSFCW for removal of organics (biochemical oxygen demand (BOD) and chemical oxygen demand (COD),

REFERENCES

APHA. (2004). American Public Health Association (APHA*), Standard Methods for the Examination of Water and Wastewater*, APHA, AWWA and WPCF, Washington, DC.

Bagchi, A. (1994). *Design, Construction and Monitoring of Landfills.* 2nd Edition. Wisconsin, Department of Natural Resources, John Wiley & Sons, Inc.

Baig, S., Coulomb, I., Courant, P. and Liechti, P. (1999). Treatment of Landfill Leachates: Lapeyrouse and Satrod Case Studies. *Ozone Science Engineering*. 21: 1-22.

Bulc, T. A., Danijel, V. E. and Kukanja, V. (1997). The use of constructed wetland for landfill leachate treatment. *Water Science Technology.* 35(5): 301-306.

Britz, T. J. (1995). *Landfil Leachate Treatment*. Senior Eric. Microbiology of Landfill Sites. CRC Press. 131-164.

Brix, H. (1997). Do macrophytes play a role in constructed wetlands?. *Water Science and Technology,* IWA Publishing. 35(5): 11-17.

Brix, H. (1998). *In constructed wetlands for wastewater treatment in Europe* (ed. Vymazal, J., Brix, H., Cooper P. F., Green, M. B. and Haberl, R.), 123, Backbuys Publisher.

Brown, D. S. and Reed, S. C. (1994). Inventory of constructed wetlands in the United States. *Water Science Technology.* 29: 309-318.

Calmano, W., Hong, J. and Frostner, U. (1993). Binding and mobilization of heavy metal in contaminated sediment affected by pH and redox potential. *Water Science Technology.* 8-9: 223-235.

Carter, V., Bedinger, M. S., Novitzki, R. P. and Wilen, W. O. (1979). *Water Resources and Wetlands.* American Water Resources Association, Minneapolis. 344-376.

Cooper, P. F. and Findlater, B. C. (1990). *Constructed Wetlands in Water Pollution Control.* USA: Pergamon Press, New York.

Cooper, P. F., Job, G. D., Green, M. B. and Shutes, R. B. E. (1996). *Reed Beds and Constructed Wetlands for Wastewater Treatment.* WRC Publications, Medmenham, Marlow, UK.

Christensen, T. H., Cossu, R. and Stegmann, R. (1992). *Landfilling of Waste Leachates.* Elseveir Science Publishers LTD. 70-71.

Chow, V. T. (1964). *Handbook of Applied Hydrology.* McGraw Hill Book Co., New York.

Czinki, L. (1986). *Nitrat-und phosphateliminierung mit "Eustrotop",* Korrespondenz Abwasser. 33: 440.

Dass, P., Tamke, G. R. and Stoffel, C. M. (1977). Leachate Production at Sanitary Landfill Sites. *Journal Environmental Engineering Division*. Proceedings of ASCE, 103: 981-988.

D'Avanzo, C. (1989). *Long term evaluation of wetland creation projects.* U.S Environmental Protection Agency, Corvallis, OR. 75-84.

Ding, A., Zhang, Z., Fu, J. and Cheng, L. (2001). *Biological control of leachate from municipal landfills.* Chemosphere. 44: 1-8.

Fenn, D., Cocozza, E., Isbister, Braids, O., Yare, B., and Roux, P. (1977). *Procedure Manual for Ground Water Monitoring at Solid Waste Disposal Facilities.* U.S. Environmental Protection Agency, Cincinnati, Ohio. 269.

Finlayson, M. and Moser, M. (1991). *Wetlands.* Facts on File, Oxford, UK. 224.

Focht, D. D. and Verstraete, W. (1977). Biochemical ecology of nitrification and denitrification. *Advance Microb Ecology.* 1: 135-214

Folke, C. (1991). *The societal value of wetland life support.* Kluwer Academic Publishers, Dordrecht. 305.

Fungaroli, A. A. and Steiner, R. L. (1979). *Investigation of Sanitary Landfilll Behaviour.* U.S. Environmental Protection Agency, Cincinnati, Ohio. 313.

Gerheart, R. A., Klopp, F., and Allen, G. (1989). *Constructed free surface wetlands to treat and receive wastewater.* Lewis Publishers, Chelsea, MI. 121-137.

Gersberg, R. M., Elkins, B. V. and Goldman, C. R. (1983). Nitrogen Removal In Artificial Wetlands. *Water Resource.* 17: 1009-1014.

Gilliam, J. W. (1994). Riparian wetlands and water quality. *Journal Environmental Quality.* 23(4): 896-900.

Grace, J. B. and Harrison, J. S. (1986). The biology of Canadian weeds: *Typha Latifolia L., Typha Angustifolia L.,* and *Typha Lauca. Journal Plant Science.* 66: 369-379.

Greenway, M. and Wolley, A. (1999). Constructed wetlands in Queensland: Performance efficiency and nutrient bioaccumulation. *Ecological Engineering*. 12: 39-56.

Ham, R. K. (1975). *The Generation, Movement, and Atenuation of Leachate from Solid Waste Land Disposal Sites.* Waste Age. 50-112.

Ham, R. K., Anderson, M. A., Stegmann, R. and Stanforth, R. (1979). *Background Study on the Development of a Standard Leaching Test.* U.S. Environmental Protection Agency, Cincinnati, Ohio.

Hammer, D. A. (1989). *Constructed Wetlands for Wastewater Treatment.* Lewis Publishers, Chelsea, MI. 831.

Hammer, D. A. (1992). *Creating Freshwater Wetlands.* Lewis Publishers, Chelsea, MI. 298.

Hammer, D. A. and Bastian, R. K. (1989). *Wetland ecosystems natural water purifier?.* Lewis Publishers, Inc, Michigan. 6-20.

Hammer, D. A. and Knight, R. L. (1994). Designing constructed wetlands for nitrogen removal. *Water Science Technology.* 29: 309-318.

Hughes, R. H. and Hughes, J. S. (1992). *A Directory of African Wetlands.* IUCN, Gland, Switzerland and UNEP, Nairobi, Kenya. 820.

Hupp, C. R., Woodside, M. D. and Yanosky, T. M. (1993). *Sediment and trace element trapping in a forested wetland.* Wetlands. 13(2): 95-104.

IWA (International Water Association), (2000). *Constructed Wetlands for Pollutant Control Scientific and Technical Report No 8.* IWA Publishing London, England.

IWA Specialist Group on Use of Macrophytes in Water Pollution Control (2000). *Constructed Wetlands for Pollution Control: process, performance, design and operation.* London: IWA Publishing.

Jacobson, M. A. (1994). *Prairie Wetland Restoration and Water Quality Concerns.* Master's thesis, University of Minnesota, MN. 101.

Jing, S. R., Lin, Y. F., Wang, T. W. and Lee, D. Y. (2001). Microcosm wetlands for wastewater treatment with different hydraulic loading rates and macrophtes. *Journal Environmental Quality.* 31: 690-696.

Johnston, C. A. (1991). Sediment and nutrient retention by freshwater wetlands: Effect on surface water quality. *Critical reviews in Environmental Control*. 21(5): 491-565.

Kadlec, R. H. (1999). *Constructed Wetlands for treating landfill leachate*. Lewis Publishers, Boca Raton, FL. 17-31.

Kadlec, R. H., and Hey, D. L. (1994). Constructed Wetlands for River Water Quality Improvement. *Water Science and Technology*. 29: 159-168.

Kadlec, R. H. and Knight, R. L. (1996). *Treatment Wetlands*. CRC Press/Lewis Publishers, Boca Raton, FL. 893.

Karanthanasis, A. D., Potter, C. L. and Coyne, M. S. (2003). Vegetation effects on fecal bacteria, BOD, and suspended solid removal in constructed wetlands. *Ecological Engineering*. 20: 157-169.

Koottatep, T. and Polprasert, C. (1997). Role of plant uptake on nitrogen removal in constructed wetlands located in the tropics. *Water Science Technology*. 36(12): 1-8.

Kuenzler, E. J. and Craig, N. J. (1986). *Land use and nutrient yields of Chowan River Watershed*. In D. L. Correll, ed. Watershed Research Perspectives. Smithsonian Institurion Press, Washington, D.C. 57-76.

Klapper, H. (1992). *Eutrophication*. G. Fischer Verlag Jena.

Lim, P. E., Tay, M. G., Mak, K. Y. and Mohamed, N. (2003). The Effect of Heavy Metals on Nitrogen and Oxygen Demand Removal in Constructed Wetlands. *The Science of The Total Environment*. 301: 13-21.

Lim, W. H., Kho, B. L., Tay, T. H., and Low, W. L. (1998). *Plants of Putrajaya Wetlands*. Selangor: Putrajaya Holdings Sdn. Bhd. Putrajaya.

Lu, J. C. S., Stearns, R. J., Eichenberger, B. and Morrison, R. D. (1980). *A Critical Review of Wastewater Treatment Plant Sludge Disposal by Landfilling*. U.S. Environmental Protection Agency, Cincinnati, Ohio. 273.

Lutton, R. J. (1980). *Evaluation Cover Systems for Solid and Hazardous Waste*. U.S. Environmental Protection Agency, Cincinnati, Ohio. 57.

Maehlum, T. (1995). Treatment of landfill leachate in on-site lagoons and constructed wetlands. *Water Science Technology*. 32(3): 129-135.

Martin, C. D and Johnson, K. D. (1995). The Use of Extended Aeration and in Series Surface Flow Wetlands for Landfill Leachate Treatment. *Water Science Technology.* 32(3): 119-128.

McBean, E. A., Rovers, F. A. and Farquhar, G. J. (1995). *Solid Waste Landfill Leachate Desalination.* 103.

Mitsch, W. J. and Gosselink, J. G. (2000). *Wetlands.* 3rd Edition, USA: John Wiley & Sons Inc.

Moshiri, G. A. (1993). *Constructed Wetlands for Water Quallity Improvement.* Florida: CRC Press, Boca Raton.

Mulamoottil, G., McBean, E. A. and Rovers, F. (1999). *Constructed Wetlands for the Treatment of Landfill Leachates.* Lewis Publishers, Boca Raton, FL. 281.

Muna, M. (2003). *Pengolahan Air Larut Lesap Melalui Tanah Bencah Buatan Aliran Sub-Permukaan Dengan Scirpus Globulosus Dan Ericaulon Sexangulare Bagi Penyingkiran Logam Berat.* Universiti Teknologi Malaysia: Master Thesis.

Navid, D. (1989). The international Law of Migratory Species: The Ramsar Convention. *Natural Resources Journal.* 29: 1001-1016.

Neralla, S., Weaver, R. W., Lasikar B. J. and Persyn, R. A. (2000). *Improvement of Domestic Wastewater Quality by Subsurface Flow Constructed Wetland.* Bioresource Technology 75: 19-25.

Nor Azmira, H. J. (2003). *Kajian Potensi Spesies Tumbuhan Timbul Tempatan Di Dalam Tanah Bencah Buatan Jenis Aliran Sub-Permukaan Terhadap Penyingkiran Bahan Organik Dan Pepejal Terampai Bagi Pengolahan Air Larut Lesap.* Universiti Teknologi Malaysia: Master Thesis

Nusch, E. A., Poltz, J. and Bucksteeg (1981). *Eutrostop.* Korrespondez Abwasser. 34: 1083.

Ottova, V., Balcarova, J. and Vymazal, J. (1997). Microbial Characteristics of Constructed Wetlands. *Water Science Technology.* 355: 17-123.

Park, S., Choi, K. S., Joe, K. S., Kim, W. H. and Kim, H. S. (2001). Variations of Landfill Leachate Properties in Conjunction with the Treatment Process. *Environmental Technology.* 22: 639-645.

Penman, H. I. (1948). *Natural Evaporation from Open Water, Bare Soil and Grass.* Proceedings of the Royal Society Series A. 193: 120-145.

Pohland, F. G. (1975). *Sanitary Landfill Stabilization with Leachate Recycle and Residual Treatment.* U.S. Environmental Protection Agency, Cincinnati, Ohio. 105.

Platzer, C. (2000). Development Of Reed Bed Systems: A European Perspective. Brazil, 7th Edition. *International Conference: Wetland System for Water Pollution Control.*

Rafidah, H. (2003). *Kajian Pengaruh Konfigurasi Tumbuhan Di Dalam Sistem Tanah Bencah Buatan Jenis Aliran Sub-PermukaanTerhadap Penyinkiran Bahan Organik dan Logam Berat Di dalam Air Larut Resap.* Universiti Teknologi Malaysia: Master Thesis.

Rash, J. K. and Liehr, S. K. (1999). Flow pattern analysis of constructed wetlands treating landill leachate. *Water Science Technology.* 40(3): 309-315.

Reddy, K. R., Kadlec, R. H., Flaig, E. and Gale, P. M. (1999). Phosphorus retention in streams and wetlands: a review. *Critical Review Environmental Science Technology.* 29: 83-146.

Reddy, K. R. and D'Angelo, E. M. (1997). Bigeochemical indicators to evaluate pollutant efficiency in constructed wetlands. *Water Science Technology* 35(5): 1-10.

Richards, Moorehead and Laing Ltd. (1992). *Constructed Wetlands to Ameliorate Metal-rich Mine Waters.* Review of Existing Literature. R&D, National Rivers Authority, Bristol, UK. 1: 102.

Sawidis, T., Chettri, M. K., Papaionnou, A., Zachariadis, G. and Stratis, J. (2001). A study of metal distribution from lignite fuels using trees as biological monitors. *Ecotoxicology Environmental Safety.* 48: 27-35.

Surface, J. M. (1993). *Effect of season, substrate composition and plant growth on landfill leachate treatment in a constructed wetland.* Pensacola, Florida: Lewis Publishers.

Suthersan, S. and Suthan, S. (2001). *Constructed treatment wetland, in natural and enhanced remediation system.* Boca Raton, CRS Press.

SCS (Soil Conversion Service). (1991). *Measurement and Estimation of Permeability of Soils for Animal Waste Storage Facilities.* Technical Note 717, South National Technical Center (SNTC), Ft. Worth, TX. 35.

Shashi Kumaran and Helen O'Conner (1996). *Tasik Bera: Malaysia's Hidden Wetlands.* Kerajaan Negeri Pahang Darul Makmur. 5.

Stuckey, R. L. and Salamon, D. P. (1987). *Typha Angustiolia* in North America: Masquerading As A Native. *American. Journal Botanical.* 74: 757.

Tanner, C. C. (1996). Plants for constructed wetland treatment systems. A comparison of the growth and nutrient uptake of eight emergent. *Ecological Engineering.*7: 59-83.

Tanner, C. C., D'Eugenio, J., Mc Bride, G. B., Sukias, J. P. S. and Thompson, K. (1999). Effect of water level fluctuation on nitrogen removal from constructed wetland mesocosms. *Ecological Engineering.* 12: 67-92.

Tanner, C. C., Sukias, J. P. S. and Upsdell, M. P. (1998). Organic matter accumulation during maturation of gravel bed constructed wetlands treating wastewaters. *Water Resource.* 32: 3046-3054.

Taylor, H. N., Choate, K. D. and Brodie, G. A. (1993). *Storm event effects on constructed wetland discharges.* Constructed Wetlands for Water Quality Improvement. CRC Press, Boca Raton, FL

Tchobanoglous, G., Burton, Theisen, H. and Vigil, S. (1993). *Integrated Solid Waste Management, Engineering Principles and Management Issues.* Mc Graw Hill.

U.S EPA (1983). *Design Manual: Constructed Wetlands and Aquatic Plants Systems for Municipal Wastewater Treatment.* EPA/625/188/022, U.S. EPA, Washington, D.C.

U.S EPA (1993). *Subsurface Flow Constructed Wetlands for Wastewater Treatment, A Technology Assessment.* EPA 832-R-93-001, U.S EPA, Washington D.C.

Verhoeven, T. A. and Meuleman, A. F. M. (1999). Wetlands for wastewater treatment: Opportunities and limitations. *Ecological Engineering.* 12: 5-12.

Vymazal J., Brix H., Cooper P. F., Haberl R., Perfler R., Laber J. (1998). *Removal mechanisms and type of constructed wetland: Constructed wetlands for wastewater treatment in Europe.* Leiden: Backhuys Publishers. 366.

Wiliams, M. (1990). *Wetlands. A Threatened Landscape*. Basil Blackwell, Oxford, UK. 419.

Wolverton, B. C., McDonald, R. C. and Duffer, W. R. (1983). Microorganisms and higher plants for wastewater treatment. *Journal Environmental Quality*. 12: 236-240.