LANDFILL LEACHATE TREATMENT USING SUBSURFACE FLOW CONSTRUCTED WETLANDS ENHANCED WITH MAGNETIC FIELD

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

Faculty of Civil Engineering
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NOVEMBER, 2006

ABSTRACT

Leachate is a complex and highly polluted wastewater. Constructed wetlands are potentially good, low-cost and appropriate technological treatment systems for treating leachate. Thus, the purpose of this study was to assess the impact of magnetic field towards the performance of vertical and horizontal subsurface flow constructed wetland (SSF) vegetated with *Limnocharis flava* for leachate treatment. The metals uptake by plants also been investigated. The main parameters evaluation are total suspended solid (TSS), turbidity, ammoniacal nitrogen (NH_4^-N), nitrate (NO_3^-N), phosphorus and metals (ferum and manganese). Experiments were run in two systems, which were vertical SSF and horizontal SSF, conducted in duration of 18 days for each. Each of the system consists of control, vegetated and vegetated with magnet tanks. Results show that the capability of emergent plant in the removal of all parameters did show a performance compared to unplanted control. Presence of the vegetation did show there were a substantial removal shown for NH_4^-N>80%, NO_3^-N>70% and heavy metals (Fe>96 and Mn>83%). However, the capability of emergent plant has lower removal efficiency in TSS (<48%). Constructed wetland with magnetic field had a greater ability than vegetated treatment in removal of TSS and metals. For those parameters, highest removal was recorded in both systems compared to other treatment which was >86% for TSS, complete removal for Fe and for Mn, removal was >88%. The effect of different flow format used in this study had shown that vertical flow format do provide a good condition for nitrification but no denitrification. On the other hand, horizontal flow format cannot provide nitrification because of their limited oxygen transfer capacity. The treatability of vertical SSF had showed greater removal in NH_4^-N (>87%) and Mn (>78%) while horizontal flow had showed greater removal of NO_3^-N (>66%). Others parameters did not contribute to substantial differences between vertical and horizontal SSF constructed wetlands. The result for metals uptake by *Limnocharis flava* shows that the plants leaves and roots are capable to absorb Fe and Mn in leachate.

ABSTRAK

Air larut resap adalah sesuatu yang rumit dan merupakan air sisa yang sangat tercemar. Tanah bencah buatan berpotensi bagus, berkos rendah dan merupakan sistem rawatan berteknologi yang sesuai untuk merawat air larut resap. Oleh itu, kajian ini bertujuan untuk menilai kesan medan magnet terhadap tanah bencah buatan jenis vertical dan horizontal aliran sub permukaan (SSF) yang ditanam dengan *Limnhocharis flava* untuk rawatan air larut resap. Keupayaan tumbuhan dalam menyerap logam juga dikaji. Parameter utama untuk dikaji adalah pepejal terampai (TSS), kekeruhan, ammonia nitrogen (NH_4^-N), nitrate (NO_3^-N), phosphorus (P) dan logam (ferum dan manganese). Dua sistem eksperimen telah dijalankan iaitu vertical SSF dan horizontal SSF yang berlangsung selama 18 hari bagi setiap sistem. Setiap sistem mengandungi tangki kawalan, tumbuhan dan tumbuhan dengan magnet. Keputusan menunjukkan keupayaan tumbuhan untuk menyingkirkan semua parameter berbanding kawalan. Kehadiran tumbuhan menunjukkan penyingkiran yang banyak bagi NH_4^-N>80%, NO_3^-N>70% dan logam (Fe>96 dan Mn>83%). Walaubagaimanapun, keupayaan tumbuhan untuk menyingkirkan TSS adalah rendah (<48%). Tanah bencah buatan dengan medan magnet mempunyai kebolehan yang lebih baik berbanding tanpa magnet dalam menyingkirkan TSS dan logam. Bagi parameter tersebut, penyingkiran tertinggi telah dicatatkan bagi kedua-dua sistem berbanding dengan rawatan lain iaitu >86% untuk TSS, penyingkiran semua untuk Fe dan untuk Mn, penyingkiran adalah sebanyak >88%. Kesan terhadap perbezaan format aliran dalam kajian ini menunjukkan format aliran vertical menyediakan keadaan sesuai untuk nitrification dan bukan denitrification. Dengan kata lain, format aliran horizontal tidak boleh untuk nitrification kerana keupayaan pemindahan oksigen yang terhad. Rawatan bagi vertical SSF menunjukkan penyingkiran lebih bagus bagi NH_4^-N (>87%) dan Mn (>78%) manakala aliran horizontal menunjukkan penyingkiran lebih bagus bagi NO_3^-N (>66%). Parameter lain tidak menyumbang kepada perbezaan penyingkiran yang banyak di antara tanah bencah buatan jenis vertical dan horizontal. Keputusan keupayaan penyerapan logam oleh *Limnocharis flava* menunjukkan daun dan akar tumbuhan berkeupayaan untuk menyerap Fe dan Mn dalam air larut resap.

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LIST OF SYMBOLS

B	-	Magnetic field
BOD	-	Biochemical Oxygen Demand
$CaCO_3$	-	Calcium carbonate
COD	-	Chemical Oxygen Demand
F	-	Magnetic field force
Fe	-	Ferum
FWS	-	Free Water Surface
HF	-	Horizontal flow
I	-	Current
mg/g	-	milligram per gram
mg/L	-	milligram per liter
mL/s	-	milliliter per second
Mn	-	Manganese
NH_4^-N	-	Ammoniacal Nitrogen
NO_3^-N	-	Nitrate
P	-	Phosphorus
SSF	-	Sub Surface Flow
TSS	-	Total Suspended Solid
TOC	-	Total Organic Carbon
TDS	-	Total Dissolved Solids
TKN	-	Total Kjeldahl-N
TN	-	Total Nitrogen
TP	-	Total Phosphorus
VF	-	Vertical Flow
VFA	-	Volatile Fatty Acids
VSB	-	Vegetated Submerged Bed
XOC	-	Xenobiotic Organic Compound

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The mass of solid waste produced globally is increasing at a rapid pace. Although improvements are being made in reducing, reusing and recycling of waste, protecting the environment and human health continues to be a challenge. One of the major consequences of rapid economic growth, urbanization, industrialization and population growth is the massive generation of solid wastes. As a country that moving forward to achieve the industrialized country status by the year 2020, Malaysia is grappling with solid waste management problems. The solid waste disposal method in Malaysia is solely landfill. Other methods such as incineration and composting are at an imperceptible scale. The municipal solid wastes in Malaysia that have gone for landfilling is approximately 95% and only 5% are recycled. Even though there is a huge amount of municipal solid waste that goes to landfill, the landfilling practice in Malaysia is far from environmentally sounded. According to Ministry of Housing and Local Government Malaysia (1999), out of 177 landfills in Peninsular Malaysia, estimated only 6% are sanitary landfills, 44% are control tipping landfill and 50% are crude dumping sites.

However, leachate production when water is allowed to come in contact with the waste and generation of gases from biodegradation of the waste at landfill sites may cause environmental pollution (Wilson, 1981). Leachate is a liquid consisting of moisture generated from landfill during the waste degradation process. When leachate is produced and moving inside the landfill, it picks up soluble, suspended or miscible materials removed from such waste (Corbitt, 1994). Leachate has high content of iron, chlorides, organic nitrogen, phosphate and sulphate (Preez and Pieterse, 1998). When this highly contaminated leachate leaves landfill and reaches water resources, over time, it will cause surface water and ground water pollution. The contamination of water is affecting with the human body and environment.

The high strength of wastewater characteristics in leachate makes it difficult to treat by itself thus biological wastewater treatment technologies can be adapted for treatment of leachate. The technology for treatment and pretreatment of leachate include wetlands treatment. These systems employ natural or man-made (constructed) wetlands systems that treat wastewater utilizing natural processes of sedimentation, adsorption and organic degradation (Corbitt, 1994).

Application of constructed wetlands is significant because the wetlands have often been assumed to possess a specific capacity to absorb and retain particulate matters, nutrients or other pollutants which enters water bodies through surface runoff, domestic wastewater, and industrial wastewater and also from plantations (Hughes *et al*, 1992). Besides constructed wetlands are used to treat wastewater (Brix, 1994) and leachate from landfills (Wittgren and Maehlum, 1997; Robinson, 1990; Staubitz *et al*., 1989; Surface *et al*., 1993), wetlands are also used in the treatment of industrial waste from textile industries and food processing industries.

1.2 Problem Statement

There is a lack of proper leachate collection and treatment in developing countries including Malaysia. The majority of the landfills in Malaysia are without leachate collection and treatment facilities. A regional survey on 30 local authorities, only 4 out of 69 landfills being surveyed have leachate collection (Nasir *et al*, 1998). There is a lack of leachate and an impermeable liner system in most landfill , leachate will easily leach out and contaminate the nearby water. With respect to the environment, this situation should be changed. Due to the financial situation and to the more stringent standards, leachate treatments are much more developed in industrialized countries (Aslam *et al*., 2004). High technology leachate treatment systems are often avoided because of high cost of construction and operation. An alternative is cost efficient natural treatment systems such as constructed wetlands for secondary or tertiary treatment, due to their characteristic properties including simple construction, simple operation and maintenance, process stability and cost effectiveness (Surface *et al.*, 1993; Lin *et al*., 2002). Hence, the potential to expand the use of constructed wetlands to the treatment of leachate is relevant in today's context.

Constructed wetland technologies have already shown good results in treating wastewater. Wetland treatment of landfill leachates has been successfully tested at several locations. Reed beds are used to treat leachate in United Kingdom (Robinson, 1990) and a facility at Ithaca, New York has utilized SSF wetlands and has been operating since 1989 (Staubitz *et al*., 1989; Surface *et al*., 1993). Although, constructed wetland using magnetic technology is a relatively new idea in Malaysia and the potential of magnets has not yet been discovered. Increasing research and knowledge of wetland have led to the trend to construct wetlands enhanced with magnetic field that obviously duplicate the environmental friendly benefit to the ecosystem. Therefore, this study was carried out to study the effectiveness of a magnetic field to leachate treatment using subsurface flow constructed wetland (SSF) planted with *Limnocharis flava.*

1.3 Objectives of the Study

The aim of this study is to investigate the feasibility of applying subsurface flow constructed wetlands (SSF) treatment process enhanced with magnetic field. The objectives of the study are:

(i) To investigate the capability of an emergent plant (*Limnocharis flava*) with and without magnetic field for the removal of ammonia nitrogen, nitrate nitrogen, phosphate, ferum, manganese, SS and turbidity in treating landfill leachate using constructed wetland*;*

(ii) To evaluate the treatability of vertical subsurface flow (VF) and horizontal subsurface flow (HF) constructed wetland;

(iii) To determine the heavy metal (Fe and Mn) uptake by *Limnocharis flava* in roots and leaves.

1.4 Scope of the Study

Increasing research and knowledge of the role of natural wetlands in controlling water pollution have led to the trend to construct wetlands that duplicate the environmental benefit to the ecosystem. Hence, the following criteria will form the principal for the scope of the study:

(i) There were two systems performing subsurface flow constructed wetlands (SSF) and each system was operated for a period of 18 days. The first system was conducted as vertical flow (VF) while the second system was horizontal flow (HF) constructed wetlands;

(ii) Each system contained 3 tanks. Tank A was not planted for control purposes whilst tanks B and C were planted with 8 clusters of *Limnocharis flava.* In addition, sample discharged from tank C was treated with magnetic field for 6 hours;

(iii) The vegetation species that was used in this study is *Limnocharis flava*;

(iv) Six sets of permanent magnet with 0.55 Tesla was used in the experiment;

(v) The efficiency of leachate treatment for each system was evaluated for ammonia nitrogen, nitrate nitrogen, phosphate, ferum, manganese, SS and turbidity. HACH DR/4000 spectrophotometer equipment was used for analysis of each parameter;

(vi) Heavy metal (Fe, Mn) by plant uptake are two components which were investigated by looking at the concentration in plant leaves and roots;

(vii) All experiments were carried out in Environmental Engineering Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia.

REFERENCES

Agamuthu, P. (2001). *Solid Waste: Principles and Management with Malaysian Case Studies.* Kuala Lumpur: University of Malaya Press.

Aeslina Abdul Kadir. (2005). *Landfill Leachate Treatment Performance in Subsurface Flow Constructed Wetland Using Safety Flow System.* Universiti Teknologi Malaysia: Master Tesis.

Aslam, M.M., Baig, M.A., Malik, M. and Hassan, I. (2004). Constructed Treatment Wetlands: An Option for Wastewater Treatment in Pakistan. *Electronic Journal of Environmental, Agricultural and Food Chemistry.* ISSN: 1579-4377.

American Water Works Association (AWWA). (1998). Non-Chemical Technologies for Scale and Hardness Control. Federal Technology Alerts.

Baker, J.S. and Judd, S.J. (1996) Magnetic Amelioration of Scale Formation. *Water Resources*. 30:247-260.

Bagchi, A. (1990). *Design, Construction and Monitoring of Sanitary Landfill.* New York: John Wiley & Sons.

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.

Bastian, R.K., Shanaghan, P.E. and Thompson, B.P. (1989). Use of Wetlands for Municipal Wastewater Treatment and Disposal – Regulatory Issues and Environmental Protection Agency Policies. In: Hammer, D.A. ed. *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural.* Chelsea: Lewis Publishers. 265-276.

Bays, J., Dernlan, G., Hadjimiry, H., Vaith, K. and Keller, C. (2002). Treatment Wetlands for Multiple Functions: Wakodahatchee Wetlands, Plam Beach County, Florida. In: *Proceedings of the Water Environment Federation's*

Technical Exhibition and Conference (WEFTEC). October 14-18. Anaheim, California.

Barrett, R.A. and Parsons, S.A. (1998). The Influence of Magnetic Fields on Calcium Carbonate Precipitation. *Water Research*. 32: 609-612.

Braskerud. (2000). Measurement and Modeling of Phosphorus Retention in Small Constructed Wetland Treating Agricultural Non-point Source Pollution. In: *Proceedings of the 7th International Conference on Wetland Systems for Water Pollution Control*. November 11-16. Lake Buena Vista, Florida: International Water Association. 75-86.

Breen, P.F. (1990). A Mass Balance Method for Assessing the Potential of Artificial Wetlands for Wastewater Treatment. *Water Research*. 24(6): 689-697.

Bruk, O.B., Klassen, V.I. and Krylov, O.T. (1987). Mechanism of Magnetic Treatment of Disperse Systems. *Soviet Surface Engineering Application and Electrochemical (Elektronmaya Obrabotka Materiolov)*. 6: 45-50.

Bruns, S. A., Klassen, V.I. and Konshina, A.K. (1966). Change in the Extinction of Light by Water after Treatment in a Magnetic Field. *Kolloidn Zh*. 28: 153-155.

Busch, K. W., Busch, M.A., Parker, D.H., Darling, R.E. and McAtee, J.L. (1986). Studies of a Water Treatment Device that uses Magnetic Fields. *Corrosion.* 42(4): 211-221.

Busch, K. W., M. A. Busch, R. E. Darling, S. Maggard. and S. W. Kubala. (1997). Design of a est loop for the evaluation of magnetic water treatment devices. Process Safety and Environmental Protection. *Transactions of the Institution of Chemical Engineers* 75 (Part B): 105-114.

Brix, H. (1994). Use of Constructed Wetlands in Water Pollution Control: Historical Development, Present Status, and Future Perspectives. *Water Science Technology*. 30(11): 209-223.

Carleton, J.N., Grizzard, T.J., Godrej, A.N., Post, H.E., Lampe, L. and Kenel, P.P. (2000). Performance of Constructed Wetlands in Treating Urban Stormwater Runoff. *Water Environment Resources*. 72(3):295-304.

Chechel, P. S. and Annenkova, G.V. (1972). Influence of Magnetic Treatment on Solubility of Calcium Sulphate. *Coke Chemical*. 8: 60-61.

Chilukuri, S. (2000). *Metal Removal using Constructed Wetlands.* Civil Engineering Departments. University of Missouri-Rolla: Master Thesis.

Christensen, J.B., Jensen, D.L., Gron, C., Filip, Z. and Christensen, T.H. (1997). Characterization of the Dissolved Organic Carbon in Leachate-Polluted Groundwater. *Water Research*. 32:25-135.

Comin, F.A., Romero, J.A., Astorga, V. and Garcia, G. (1997). Nitrogen Removal and Cycling in Restored Wetlands used as Filters of Nutrients for Agricultural Runoff. *Water Science and Technology*. 35(5): 255-261.

Cooke, J.G. (2000). Phosphorus Removal Process in a Wetland after a Decade of Receiving a Sewage Effluent. *Journal of Environmental Quality*. 21: 733-739.

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

Corbitt, R.A. and Bowen, P.T. (1994). Constructed Wetlands for Wastewater Treatment. In: Kent, D.M. *Applied Wetlands Science and Technology*. U.S.: Lewis Publisher.

Coey, J.M.D. and Cass, S. (2000). Magnetic Water Treatment. *Journal of Magnetism and Magnetic Materials.* 209:71-74.

Cowardin, L.M., Carter, V., Golet, F.C. and LaRoe, E.T. (1979). *Classification of Wetlands and Deepwater Habitats of the United States*. U.S. Department of the Interior. Fish and Wildlife Service. Washington.

Crolla, A.M. and Kensley, C.B. (2002). Use of Kinetic Models to Evaluate the Performance of a Free Water Surface Constructed Wetland Treating Farmstead Runoff. In: *Proceedings of the 8th International Conference on Wetland Systems for Water Pollution Control*. September 16-19. Arusha, Tanzania. International Water Association. 774-787.

David, C.W. (1981). *Waste Management; Planning, Evaluation and Technologies.* New York: Oxford University.

Davis, T.H. and Cottingham, P.D. (1993). Phosphorus Removal from Wastewater in a Constructed Wetland. In: Moshiri, G.A. ed. *Constructed Wetland for Water Quality Improvement*. Boca Raton, Fluorida: Lewis Publishers. 315-320.

Donaldson, J. D. (1988). Magnetic treatment of fluids-preventing scale. *Finishing*. 12: 22-32.

Drizo, A., Frost, C.A., Smith, K.A. and Grace, J. (1997). Phosphate and Ammonium Removal by Constructed Wetlands with Horizontal Subsurface Flow using Shale at a Substrate. *Water Science and Technology*. 35(5):95-102.

Duffy, E.A. (1977). *Investigation of Magnetic Water Treatment Devices*. Clemson University, South Carolina: Ph.D. Thesis.

Ernest, C. and Andrew, H. (2002) Responses of Wetland Plants to Ammonia and Water Level. *Ecological* Engineering. 18(3): 257-264.

Faulkner, S.P. and Richardson, C.J. (1989). Physical and Chemical Characteristics of Freshwater Wetland Soils. In: Hammer, D.A. ed. *Constructed Wetlands for Wastewater Treatment*. Chelsea, Michigan: Lewis Publishers. 41-72.

Fennesy, M.S. (1989). Treating Coal Mine Drainage with an Artificial Wetland. *Journal of Water Pollution Control Federation*. 61:11-12.

Florestano, E.J., Marchello, J.M. and Bhat, S.M. (1996). Magnetic Water Treatment in Lieu of Chemicals. *Chemical Engineering World*. 31(10): 133-136.

Forsburg, J.C. (1996). *Evaluation of Subsurface Flow Constructed Wetlands for the Treatment of Heavy Metals in Municipal Solid Waste Landfill Leachate.* State University of New York: Master. Thesis.

Galbrand, C.C. (2003). *Naturalized Treatment Wetlands for Contaminant Removal: A Case Study of the Burnside Engineered Wetland for Treatment of Landfill Leachate.* Dalhousie University, Halifax, Nova Scotia: Master Thesis.

Gehr, R., Zhai, Z.A., Finch, J.A. and Rao, S.R. (1995). Reduction of Soluble Mineral Concentrations in $CaSO_4$ Saturated Water Using a Magnetic Field. *Water Research*. 29(3): 933-940.

Gersberg, R.M., Elkins, B.V., Lyon, S.R. and Goldman, C.R. (1986). Role of Aquatic Plants in Wastewater Treatment by Artificial Wetlands. *Water Research*. 20(3):363-368.

Greenway, M. and Wolley, A. (2000). Changes in Plant Biomass and Nutrient Removal over 3 years in Constructed Free Water Surface Flow Wetland in Cairns, Australia. In: *Proceedings of the 7th International Conference on Wetland Systems for Water Pollution Control*. November 11-16. Lake Buena Vista, Florida: International Water Association, 707-718.

Gruber, C.E. and Carda, D.D. (1981). Performance Analysis of Permanent Magnet Type Water Treatment Devices. *Research and Education in Water Quality Report*. South Dakota School of Mines and Technology, Rapid City, South Dakota, USA.

Hammer, D.A. (1989). *Constructed Weyland for Wastewater Treatment: Municipal, Industrial and Agricultural*. ed. Chelsea, Michigan: Lewis publishers, Inc.

Hammer, D.A., Pullin, B.P., McCaskey, T.A., Eason, J. and Payne, V.W.E. (1993). Treating Livestock Wastewaters with Constructed Wetlands. In: Moshiri, G.A. ed. *Constructed Wetlands for Water Quality Improvement*. Boca Raton: CRC Press LCC. 343-348.

Harrison, J. (1993). *WQA Glossary of Terms. Water Quality Association*. Lisle, Ill.

Harish Badrinarayanan. (2001). *Effect of Mesohaline Constructed Wetland on Water Chemistry Discharged From a Shrimp Aquaculture Facility in South Texas.* Kingsville University: Master Thesis.

Haslam, S.M. (2003). *Understanding Wetlands: Fen, Bog and Marsh.* USA and Canada: Taylor and Francis Group.

Hasson, D. and Bramson, D. (1985). Effectiveness of Magnetic Water Treatment in Suppressing $CaCO_3$ Scale Deposition. *Industrial Engineering Chemical* Process. 24: 588-592.

Higashitani, K. and Oshitani, J. (1997). Measurements of Magnetic Effects on Electrolyte Solutions by Atomic Force Microscope. Process Safety and Environmental Protection. *Transactions of the Institution of Chemical Engineers*. 75 (Part B): 115-119.

Hirschbein, B.L. Brown, D.W. and Whitesides, G.M. (1982). Magnetic Separations in Chemistry and Biochemistry. *Chemtech Magazine* Mac 1982.

Holford, I.C.R. and Patrick Jr, W.H. (1979). Effect of Reduction and pH Changes on Phosphate Sorption and Mobility in Acid Soil. *Soil Science Society of America Journal*. 43:292-296.

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

Hunt, P.G. and Poach, M.E. (2000). State of the Art for Animal Wastewater Treatment in Constructed Wetlands. In*: Proceedings of the 7th International Conference on Wetland Systems for Water Pollution Control*. November 11-16. Lake Buena Vista, Florida: International Water Association, 707-718.

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

Jiles, D. (1991). *Introduction to Magnetism and Magnetic Materials.* United States: Chapman and Hall.

Johan Sohaili. (2003). *Kesan Medan Magnet Terhadap Pengenapan Zarah Terampai Dalam Kumbahan*. Universiti Teknologi Malaysia: Tesis Ph.D.

Johan Sohaili, Fadil Othman and Zularisam Ab Wahid. (2001). Effect of Magnetic Field for Wastewater Treatment. *Proceedings of the Brunei International Conference on Engineering and Technology* (BICET 2001). Developments in Engineering and Technology. October 9 – 11, 2001. Bandar Seri Begawan, Brunei Darussalam. 233 – 241.

Johan Sohaili, Zularisam Ab Wahid, Fadil Othman and Zaki Faisal Khamisan. (2001). Enhancement of Sewage Sedimentation with Magnetic Field. *IWA 2nd World Water Congress*. October 15-19. Berlin, Germany.

Joshi, K. M. and Kamat, P.V. (1966). Effect of Magnetic Field on the Physical Properties of Water. *Journal of Industial Chemical*. 43: 620-622.

Kadlec, R.H. and Kadlec, J.A. (1978). *Wetlands and Water Quality*. American Water Resources Association.

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

Kent, D.M. (1994). *Applied Wetlands Science and Technology*. U.S.: Lewis Publisher, Inc.

Kern, J. and Idler, C. (1999). Treatment of Domestic Wastewater and Agricultural Wastewater by Reed Bed Systems. *Ecological Engineering*.12:13-25.

Kim, S. and Geary, P.M. (2000). The Impact of Biomass Harvesting on Phosphorus Uptake by Wetland Plants. In*: Proceedings of the 7th International Conference on Wetland Systems for Water Pollution Control*. November 11-16. Lake Buena Vista, Florida: International Water Association, 105-112.

King, B.R., Long, G.M. and Sheldon, J.K. (1992). *Practical Environmental Bioremediation.* Boca Raton, Florida: Lewis Publisher.

Kjeldsen, P., Barlaz, M.A., Rooker, A.P., Baun, A., Ledin, A. and Christensen, T.H. (2002). *Critical Reviews in Environmental Science and Technology*. Pg 297-336.

Klassen, V.I. (1981). Magnetic Treatment of Water in Mineral Processing. In: *Developments in Mineral Processing, Part B, Mineral Processing*. New York: Elsevier. 1077-1097.

Knight, R. L. (1997). Wildlife Habitat and Public Use Benefits of Treatment Wetlands. *Water Science Technology*. 35(5): 35-43.

Kouezeli-Katsiri, A., Bosdogianni, A. and Christoulas, D. (1999). Prediction of Leachate Quality from Sanitary Landfills. *Journal of Environmental Engineering*. 125(10): 950-958.

Kronenberg, K.J. (1985). Experimental Evidence for Effects of Magnetic Fields on Moving Water. *Institute of Electric and Electronic Engineers (IEEE) Trans. on Magnetics*. 5(21): 2059-2061.

Krylov, O. T., Vikulova, I.K., Eletskii, V.V, Rozno, N.A. and Klassen, V.I. (1985). Influence of Magnetic Treatment on the Electro-kinetic Potential of a Suspension of $CaCO_3$. *Colloid Journal*. 47: 820-824.

Kuusemets, V., Lohmus, K. and Mander, U. (2002). Nitrogen and Phosphorus Assimilation and Biomass Production by Scirpus Sylvaticusand Phragmites australis in a Horizontal Subsurface Flow Constructed Wetland. In: *Proceedings of the 8th International Conference on Wetland Systems for Water Pollution Control*. September 16-19. Arusha, Tanzania: International Water Association, 930-937.

Lasat, M. (2000). The Use of Plants for the Removal of Toxic Metals: A Review of Biological Mechanisms *Journal of Environmental Quality*. 31:109-120.

Liburkin, V. G., Kondratev, B.S. and Pavlyukova, T.S. (1986). *Action of Magnetic Treatment of Water on the Structure Formation of Gypsum, Glass and Ceramics*. (English translation of Steklo I Keramika) 1: 101-105.

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, P.E. and Polprasert, C. (1998). Constructed Wetland for Wastewater Treatment and Resource Recovery. *Environmental System Reviews.* No. 41, 1996.

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

Lin, I. and Yotvat, Y. (1989). Electro-magnetic Treatment of Drinking and Irrigation Water. *Water and Irrigation Reviews*. 8:16-18.

Lin, Y.F., Jing, S.R., Lee, D.R. and Wang, T.W. (2002). "Nutrient Removal from Aquaculture Wastawater Using Constructed Wtlands System". *Aquaculture*. 209: 169 – 184.

Lipus, L., Krope, J. and Garbai, L. (1994). Magnetic Water Treatment for Scale Prevention. *Hungarian Journal of Industrial Chemical*. 22: 239-242.

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.

Maehlum, T. (1999). Wetlands for Treatment of Landfill Leachates in Cold Climates. In : Edited by Mulamoottil, G., McBean, E.A. and Rovers, F. *Constructed Wetlands for the Treatment of Landfill Leachates*. United States of America: Lewis Publisher.

Marshall, S.V. and Skitek, G.G. (1978). *Electromagnetic Concepts and Applications*. Englewood Cliffs, N.J: Prentice-Hall.

Martynova, O. I., Tebenekhin, E.F. and Gusev, B.T. (1967). Conditions and Mechanism of Deposition of the Dolid Calcium Carbonate Phase from Aqeuous [sic] Solutions under the Influence of a Magnetic Field. *Colloid Journal*. 29: 512-514.

Mays, P.A. and Edward, G.S. (2001). Comparison of Heavy Metal Accumulation in a Natural Wetland and Constructed Wetlands Receiving Acid Mine Drainage. *Ecological Engineering*. 16:487-500.

McBean, E.A. and Rovers, F. (1999). Landfill Leachate Characteristics as Inputs for the Design of Wetlands Used as Treatment Systems. In: Mulamoottil, G., McBean, E.A., and Rovers, F. ed. *Constructed Wetlands for the Treatment of Landfill Leachates.* United States: Lewis Publishers. 1:1-16.

Moore, J.A., Skarda, S.M. and Sherwood, R. (1994). Wetland Treatment of Pulp Mill Wastewater. *Water Science and Technology.* 29(4): 241-247.

Mistch, W.J. and Gosselink, J.G. (2000). *Wetland.* 3rd ed. New York: John Wiley & sons.

Moore, J.A., Skarda, S.M. and Sherwood, R. (1994). Wetland Treatment of Pulp Mill Wastewater. *Water Science and Technology*. 29(4): 241-247.

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.

Mulamoottil, G., McBean, E.A. and Rovers, F. (1999). *Constructed Wetlands for the Treatment of Landfill Leachates.* United States: Lewis Publishers.

Nasir, M.H., Yusoff, M.K., Sulaiman, W.N. and Rahman.R.A. (1998). Issues and Problems of Solid Waste Management in Malaysia. In M.N.H. Hassan, L.A. Abudullah, I. Komoo, *National Review on Environmental Quality Management in Malaysia: Towards the Next Two Decades*. Kuala Lumpur: Institute for Environment and Development. 179-225.

Navanitha Krishnan. (2005). *Leachate Treatment Using Horizontal Subsurface Flow Constructed Wetland.* Universiti Teknologi Malaysia: Undergraduate Thesis.

Noor Ida Amalina Ahamad Noordin. (2006). *Leachate Treatment Using Constructed Wetland with Magnetic Field.* Universiti Teknologi Malaysia: Master Thesis.

Nurnberg, G., Hartley, K.R. and Davis, E. (1987). Hypolimnetic Withdrawal in Two North American Lakes with Anoxic Phosphorus Release from the Sediments. *Water Research*. 21(8):923-928.

Osmond, D.L, Line, D.E., Gale, J.A., Cannon, R.W., Knott, C.B., Bartenhagen, K.A., Turner, M.H., Coffey, S.W., Spooner, J., Wells, J., Walker, J.C., Hargrove, L.L., Foster, M.A., Robillard, P.D. and Lehning, D.W. (1995). *Mining Acid Mine Drainage*, WATERSHEDS: Water, Soil and Hydro-Environmental Decision Support System.

Panswad, T. and Chavalparit, O. (1997). Water Quality and Occurance of Protozoa and Metazoa in Two Constructed Wetlands Treating Different Wastewaters in Thailand. *Water Science Technology*. 36(12):183-8.

Paredes, D. (2003). *Landfill Leachate Treatment in Constructed Wetlands: Removal of High Nitrogen Loads.* Center of Environment Research, Germany. Unpublished.

Parsons, S.A., Judd, S.J., Stephenson, T., Udol, S. and Wang, B.L. (1997). Magnetically Augmented water treatment. Process Safety and Environmental Protection. *Transactions of the Institution of Chemical Engineers* 75 (Part B): 98-104.

Peter, R.S. (1983). Commercial Landfill Management. In: John, R.H. *Practical Waste Management.* New York: John Wiley & Sons Ltd. 345-358.

Petruska J.A. and Perumpral J.V. (1978). *High Gradient Magnetic Separation : A Potential Treatment for Food Processing Wastewater*. Cranfield University. 21: 993-996.

Peverly, J.H., Surface, J.M. and Wang, T. (1995). Growth and Trace Metal Adsorption by *Phragmites australis* in Wetlands Constructed for Landfill Leachate Treatment. *Ecological Engineering*. 5:21-35.

Polprasert, C. (1989). *Organic Waste Recycling.* New York: John Wiley & Sons.

Preez, L., Pieterse, T. (1998). Case Study on Leachate Management at the Weltevreden Solid Waste Disposal Site. In Sardinia 1997. *6th International Landfill Symposium.* October 1997, S. Margherita di Pula, Italy.

Reed, S.C., Middlebrooks, E.J. and Crites, R.W. (1988). *Natural System for Waste Management and Treatment*. New York: McGraw-Hill, Inc.

Reed, S., Crites, R.W. and Middlebrooks, E.J. (1995). *Natural System for Waste Management and Treatment*. 2nd ed. New York: McGraw-Hill, Inc.

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.

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.

Ridhuan, M.I. (1995). Sanitary Landfill Development in Malaysia. Paper presented at a short course on "*Practical of landfill design*". School of Civil Engineering, University Science of Malaysia.

Robert, A.C. (1999). *Standard Handbook of Environmental Engineering*. 2nd ed. New York: McGraw-Hill.

Robinson, H. (1990). Leachate Treatment to Surface Water Standards Using Reed Bed Polishing. In: *The Use of Macrophytes in Water Pollution Control Report*. International Association on Water Pollution Research Conference (IAWPRC) Newsletter. London. 3:32.

Rogers, K.H., Breen, P.F. and Chick, A.J. (1991). Nitrogen Removal in Experimental Wetland Treatment Systems: Evidence for the Role of Aquatic Plants. *Research Journal of Pollution Control Federation*. 63: 934-941.

Roser, D.J., McKersie, S.A., Fisher, P.J., Breen, P.F. and Bavor, H.J. (1987). Sewage Treatment Using Aquatic Plants and Artificial Wetlands. *Water*. 14(3): 20-24.

Rosolen, S. (2000). *An Evaluation of Adsorptive Media for Improving Phosphorus Removal in Constructed Wetlands.* Queen's University, Kingston, Ontario, Canada: Master Thesis.

Rylander, H. (1998). Global waste management. In: *14th Waste Congress*. October 12-15. Gauteng, South Africa.

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.

Shaw, S.P. and Fredine, C.G. (1956). *Wetland of the United States, Their Extent and their Value for Waterfowl and Other Wildlife.* U.S. Department of Interior, Fish and Wildlife Service, Circular 39, Washington, D.C. 67.

Sherwood, R., Tchobanoglous, G., Colt, J. and Knight, A. (1979). *The Use of Aquatic Plants and Animals for the Treatment of Wastewater*. Department of Civil Engineering and Land, Air and Water Resources, University of California, Davis, California.

Skousen, J.A., Sexstone, J., Garbutt, J. and Sencidiver, J. (1994). Acid Mine Drainage Treatment with Wetlands and Anoxic Limestone Drains. In: Kent, D.M. ed. *Applied Wetland Science and Technology*.Boca Raton, Fluorida: Lewis Publisher. 263-281.

Spiegel, M.S. (1998). "Method and Apparatus for Applying Magnetic Fields to Fluids." (US Patent No. 035826).

Stark, L.R., Williams, F.M., Steven, S.E., Eddy, D.P. (1994). *Metal removal in wetland treatment system.* Proc. Int. Land Reclamation and Drainage Conf.24-29 April 1994. Vol2. Bureau of Mines SP063-94. U.S. Dept. of Interior, Pittsburgh, P.A. Pp 89-98.

Staubitz, W.W., Surface, J. M., Steenhuis, T. S., Peverly, J. H., Lavine, M. L., Weeks, N. C., Sanford W. E., and. Kopka, R. J. (1989). Potential Use of Constructed Wetlands to Treat Landfill Leachate. In: Hammer, D. A. ed. *Constructed Wetlands for Wastewater Treatment*. Chelsea: Lewis Publishers. 735-742.

Stowell, R., Ludwig, R., Colt, J. and Tchobanoglous, G. (1981). Concepts in Aquatic Treatment System Design. *Journal of Environment Engineering, Proceedings of ASCE.* 107(5): 919-940.

Surface, J.M., Peverly, J.H., Steenhuis, T.S., and Sanford, W.E. (1993). Effect of Season, Substrate Composition, and Plant Growth on Landfill Leachate Treatment in Constructed Wetlands. In Moshiri, G.A. ed. *Constructed Wetlands for Water Quality Improvement*. Boca Raton: Lewis Publishers. 461-472.

Tanner, C.C. (1994). Treatment of Dairy Farm Wastewaters in Horizontal and Up-flow Gravel Bed Constructed Wetlands. *Water Science and Technology*. 29(4): 85-93.

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., Clayton, J.S. and Upsdell, M.P. (1995a). Effect of Loading Rate and Planting on Treatment of Dairy Farm Wastewater in Constructed Wetlands-I. Removal of Oxygen Demand, Suspended Solids and Faecal coliforms. *Water Resources*. 29(1):17-26.

Tanner, C.C., Clayton, J.S. and Upsdell, M.P. (1995b). Effect of Loading Rate and Planting on Treatment of Dairy Farm Wastewater in Constructed Wetlands-II. Removal of Nitrogen and Phosphorus. *Water Resources*. 29(1):27-34.

Tanner, C.C., Adams, D.D., Downes, M.T. (1997). Methane emissions from constructed wetlands treating agricultural wastewaters. *J. Environ. Qual*. 26, 1056–1062.

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

Tsouris, C. and Scott, T.C. (1995). Flocculation of Paramagnetic Particles in a Magnetic Field. *Journal of Colloid and Interface Science*. 171: 319-330.

Tombaez, E., Ma, C., Basch, K.W. and Basch, M.A. (1991). Effect of Weak Magnetic Field on Hematite Soil in Stationary and Flowing Systems. *Colloid and Polymer Science*. 269(3): 278-289.

United States Environmental Protection Agency (USEPA). (1983). *Freshwater wetlands for Wastewater Management, Environmental Impact Statement,* phase 1 report. EPA 904/9-83-107, Region 4, Atlanta, Georgia.

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

Uygur, A. and Kargi, F. (2004). Biological Nutrient Removal from Pre-treated Landfill Leachate in a Sequencing Batch Reactor. *Journal of Environmental Management*. 71(1): 9-14.

Vermeiran, T. (1958). Magnetic Treatment of Liquid for Scale and Corrosion Prevention. *Corrosion Technology (Belgium)*. July. 215-219

Vickl, W.S. (1991). Magnetic Fluid Conditioning. *Proceeding of the 1991 Speciality Conference on Environment, American Society Chemical Engineering*. July 8-10. New York, Reno, USA.

Vymazal, J. (2005a). Constructed Wetlands for Wastewater Treatment. *Ecological Engineering.* 25: 475-477.

Vymazal, J. (2005b). Horizontal Subsurface Flow and Hybrid Constructed Wetlands System for Wastewater Treatment. *Ecological Engineering.* 25: 478-490.

Vymazal J., Brix H., Cooper P. F., Haberl R., Perfler R. And Laber, J. (1998). *Removal* Mechanisms *and Type of Constructed Wetland: Constructed Wetlands for Wastewater* T*reatment in Europe.* Leiden: Backhuys Publishers. 366.

Wan Salida Wan Mansor. (2006). *Effect of Magnetic Fields on heavy Metal and Nutrient Removal in Leachate.* Universiti Teknologi Malaysia: Master Thesis.

Wang, F. (2004). *Advanced Oxidation Treatment of Aged Raw and Biologically Treated Landfill.* University of Alberta: Ph.D. Thesis.

Welder, B.Q. and Partridge, E.P. (1954). Practical Performance of Water-Conditioning Gadgets. *Industrial Engineering Chemical*. 46: 954-960.

Wilderman, T.R. and Laudon, L.S. (1989). Use of Wetlands for Treatment of Environmental Problems in Mining: Non-coal-mining Applications. In: Hammer, D.A. ed. *Constructed Wetlands for Wastewater Treatment*. Chelsea, Michigan: Lewis Publishers, Inc. 221-231.

William, J.M. and James, G.G. (1993). *Wetlands.* 2nd ed. New York: International Thomson Publishing.

Williams, P.T. (2005). *Waste Treatment and Disposal.* 2nd ed. United Kingdom: John Wiley & Sons, Ltd. 171-244.

Wilson, D.C. (1981). *Waste Management; Planning, Evaluation and Technologies.* New York: Oxford University.

Wittgren, B. H. and Maehlum, T. (1997). Wastewater Treatment Wetlands in Cold Climates.*Water Science Technology*. 35(5):45-53.

Wong, T.H.F. and Somes, N.L.G. (1995). A Stochastic Approach to Designing Wetlands for Stormwater Pollution Control. *Water Science Technology*. 32(1):145-151.

Ydstebo, L., Kommendal, R. and Bakke, R. (2000). Seasonal Variations in Nutrient Removal in Cold Climate Constructed Wetland. In: *Proceedings of the 7th International Conference on Wetland Systems for Water Pollution Control*. November 11-16. Lake Buena Vista, Florida: International Water Association, 129-134.

Ying, S. (2003). *Mechanisms of Lead and Zinc Removal from Lead Mine Drainage in Constructed Wetland*. University of Missouri-Rolla: Ph.D. Thesis.

Ying T.Y., Yiacoumi S. and Tsouris C. (1999) High Gradient Magnetically Seeded Filtration. *Chemical Engineering Science*. 1101-1113.

Zhu, T., Jenssen, P.D., Maehlum, T. and Krogstat, T. (1997). Phosphorus Sorption and Chemical Characteristics of Lightweights Aggragates (LWA)-Potential Filter Media in Treatment Wetlands. *Water Science and Technology*. 35(56):103-108.

Zulfa Fauzia, Fadil Othman, Johan Sohaili and M. Faiqun (2005). Reduction of Organic Concentration Under Magnetic Fields up to 5500 Gauss. Proceeding in: *Seminar Kebangsaan Pengurusan Persekitaran 2005*. 4-5 Julai. Universiti Kebangsaan Malaysia, Bangi.