# SUBSURFACE FLOW AND FREE WATER SURFACE FLOW CONSTRUCTED WETLAND WITH MAGNETIC FIELD FOR LEACHATE TREATMENT

SITI KAMARIAH BINTI MD SA'AT

UNIVERSITI TEKNOLOGI MALAYSIA

# SUBSURFACE FLOW AND FREE WATER SURFACE FLOW CONSTRUCTED WETLAND WITH MAGNETIC FIELD FOR LEACHATE TREATMENT

SITI KAMARIAH BINTI MD SA'AT

A project report submitted in fulfilment of the
requirement of the award of the degree of
Master of Engineering (Civil-Wastewater)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

NOVEMBER 2006

To my mother, father, my lovely sisters
Angah, Obi, Gina, Ida, Arfah and Adik

# ACKNOWLEDGEMENT

Alhamdulillah, grateful to Allah s.w.t., to give me the opportunity to complete my project report.

Firstly, I would like to express my appreciation to my supervisor, Dr. Johan Sohaili for his guidance and supervision over the period of this project. I really appreciate the effort and time he had spent which eventually enabled me to complete my project report.

Next, I am also thankful to all the technicians of Environmental Engineering Laboratory, Pak Usop, En. Mus, Kak Ros, En. Ramlee Ismail and En. Ramli Aris for their help, guidance and cooperations through all my laboratory startup and difficulties in experimental works.

Finally, my sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions especially to Ain Nihla, Shila and Nadiah. I am also grateful to all my family members. I would like to thank my dearest family, sisters, and my beloved, to whom I dedicated this dissertation. They always have been behind me with love, support and endless patient.

Thank you.

## ABSTRACT

This study conducted using two-stage lab-scale Subsurface Flow (SSF) and Free Water Surface (FWS) constructed wetland under influence of magnetic field to treating the leachate. The leachate samples were pre-treated with magnet circulation with strength 0.55T. The constructed wetlands were planted with *Limnocharis flava* (yellow bur-head) and *Eichhornia crassipes* (water hyacinth). The performance of the system determined by suspended solid, nutrient (ammonia and phosphate), heavy metal (Iron and Manganese) removals and uptake by root and leaves of constructed wetland plants. From the analysis, planted system shows higher removal compared to unplanted system. The result shows great removal efficiency with 98.7% $NH_3$-N, 90.2% $PO_4^{3-}$, 98.7% Fe, 92.5% Mn and 94.3% SS removal. At the end of study, the plants harvested and analyzed for heavy metals uptake by plants. The results showed that Fe uptake on leaves greater than on roots while Mn uptake on roots is greater than in leaves. For Limnocharis flava for example, 54% Fe uptake by leaves while 44% uptake by roots and Mn uptake by roots was 51% while 34% by leaves. This study concludes that SSF-FWS constructed wetland with magnetic field can improve the leachate quality.

**ABSTRAK**

Kajian ini dijalankan menggunakan dua peringkat tanah bencah buatan berskala makmal iaitu tanah bencah aliran subpermukaan dan aliran permukaan bebas di bawah pengaruh medan magnet bagi mengolah air larut resap. Sampel air larut resap diolah dengan aliran pengeliligan magnet berkekuatan 0.55 Tesla. Tanah bencah ditanam dengan (jinjir) dan *Eichhornia crassipes* (keladi bunting). Keberkesanan sistem olahan diperoleh daripada pengurangan kepekatan pepejal terampai, nutrien (ammonia dan fosfat) dan metal (besi dan mangan) serta pengambilan oleh daun dan akar tumbuhan tanah bencah. Daripada analisis, system yang mempunyai tumbuhan menunjukkan peratus penyingkiran yang lebih tinggi berbanding sistem yang tiada tumbuhan (kawalan). Hasil ujikaji menunjukkan peratus penyingkiran mencapai sehingga 98.7% bagi ammonia, 90.2% bagi fosfat, 98.7% bagi besi, 92.5% bagi mangan dan 98.7% bagi pepejal terampai. Di penghujung tempoh ujikaji, tumbuhan-tumbuhan dalam sistem tanah bencah dituai dan dikeluarkan bagi menganalis kandungan logam berat yang diambil oleh tisu tumbuhan. Keputusannya, lebih banyak kandungan besi yang diambil oleh daun tumbuhan manakala kandungan mangan lebih banyak di dalam akar. Sebagai contoh, bagi *Limnocharis flava*, 54% besi yang diambil oleh daun manakala 44% yang diambil oleh akar dan 51% mangan yang diambil oleh akar manakala 34% yang diambil oleh daun. Kajian ini menyimpulkan bahawa gabungan tanah bencah aliran subpermukaan dan aliran permukaan bebas dengan pengaruh medan magnet berpotensi bagi meningkatkan kualiti air larut resap.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF SYMBOLS

| | | |
|---|---|---|
| BOD | - | Biochemical Oxygen Demand |
| COD | - | Chemical Oxygen Demand |
| C/Co | - | Present concentration over initial concentration |
| Fe | - | Iron |
| FWS | - | Free water surface flow |
| k | - | Removal rate constant |
| mg/L | - | milligram per liter |
| Mn | - | Manganese |
| $NH_3$-N | - | Ammonia Nitrogen |
| $NO_3$-N | - | Nitrate Nitrogen |
| $PO_4^{3-}$ | - | Orthophosphate |
| Q | - | Flowrate |
| $r^2$ | - | Correlation coefficient |
| SS | - | Suspended Solid |
| SSF | - | Subsurface flow |
| t | - | time |
| T | - | Tesla |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Over the years, industrialization and urbanization with the high growth rate has causes several environmental problem all over the world. Nowadays, solid waste management and wastewater treatment are most important problems that we are facing. Malaysia, like most of the developing countries, is facing an increase of the generation of waste and of accompanying problems with the disposal of this waste. The amount of solid wastes produced around the world is increasing at high rates. Landfill is one of the most widely employed methods for the disposal of municipal solid waste (MSW). Up to 95% total MSW collected worldwide is disposed of in landfills (El-Fadil *et al*, 1997). However the landfill causes generation of leachate. Landfill leachates will cause environmental problems without proper handling. Increase in landfill leachate creates challenges for cost effective treatment methods to process wastewater.

In recent years, natural treatment systems, including wetlands have grown in popularity for wastewater treatment since the early 1980s (Reed *et al.*, 1995). Constructed wetland is a most promising method to treating landfill leahate. The potential to expand the use of constructed wetlands to the treatment of landfill leachates is relevant to today context because it seem to be environmental sustainable for the treatments of many constituent and cost savings. At present, there are several constructed wetland facilities in operation around the world. Constructed wetlands are preferred because they have more engineered systems and they are easier to control.

Magnetic treatment attracts a special attention due to its safety, purity, simplicity and low operating costs. There are only few studies that use magnetic field for wastewater treatment processes, and in most of them, magnetic field is used only for separation of solids or attached microorganisms from effluent. The magnetic field tended to increase the bacterial activity and able to detoxify toxic compounds (Yavus and Celebi, 2000). It also tended to increase sedimentation of suspended solid in wastewater (Johan, 2003). Since lack of studies of magnetic field potential in wastewater treatment, this study will investigate the performance of magnetic field in leachate treatment with combination of constructed wetlands system Subsurface Flow (SSF) and Free Water Surface (FWS).

## 1.2 Problem Background

Landfill leachate is wastewater emanated from sanitary landfills treating a variety of municipal and industrial solid wastes. Due to anaerobic conditions and long retention time prevailing in sanitary landfills, landfill leachate normally contains high concentrations of organic matters, nutrients, pathogens and heavy metals which, if not properly collected and treated, can cause serious pollution to nearby surface and groundwater sources. Organic matter in leachate can cause decomposition by microorganisms and can cause oxygen depletion in surface water bodies. The presence of heavy metals such as mercury, iron, manganese and copper at high concentrations in landfill leachate usually causes toxic effects to microbes, making it difficult to be treated biologically. Landfill leachate may contaminate not only surface water and groundwater supplies (Tatsi and Zouboulis, 2002) but may also cause marine water pollution and trans-boundary contamination (Al-Muzaini *et al.*, 1995).

Leachate treatment has become an important issue due to the contamination of water resources. There are various options to treat landfill leachates. The identification of the preferred option in specific circumstance is a function of the cost; both operating and capital cost and the limitation impose on the quality and quantity of discharge. The potential methods for the management of landfill leachates are mainly recirculation of leachate through the landfill, physical-chemical treatment, membrane filtration and reverse osmosis, anaerobic and aerobic biological treatment and constructed wetlands (Kappelmeyer, 2005).

Locally, many studies have been conducted for leachate treatment using constructed wetlands (Aeslina, 2003, Lee, 2003, Thien, 2006). Nevertheless, this technology is less utilized in Malaysia. Field and laboratory studies that have been conducting using wetland systems to treat leachate show variable results (Surface *et al.*, 1993; Mulamoottil *et al.*, 1998, Liehr *et al.*, 2000 and Cossu *et al*, 2001). Inconsistent results can be attributed to the variable nature of the leachate and the lack of universally accepted design standards for wetland treatment systems.

## 1.3 Objective

In this study, the application of constructed wetland to treating landfill leachate is applying under influence of magnetic field effect. The objectives of this study are:

(i) To investigate a performance of SSF-FWS constructed wetland under influence of magnetic field;

(ii) To examine the effect of SSF and FWS plant on leachate quality for suspended solid (SS), nutrient ($NH_3$-N, $NO_3$-N and $PO_4^{3-}$) and heavy metal (Fe and Mn) removal and;

(iii) To examine the amount of heavy metal uptake by root and leaves of the SSF and FWS plant.

## 1.4 Scopes of Study

The scopes of this study are includes: set-up two stage constructed wetland (SSF-FWS) to treating landfill leachate under influence of magnetic field. The experiments are carried out in the Environmental Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia. Leachate sample is taken from Pasir Gudang Sanitary Landfill. The plants use in this study are *Eichhornia crassipes* (water hyacinth) as floating plant for FWS wetland and *Limnocharis flava* (yellow bur-head) as plant for SSF wetland. Six set of permanent magnet used in this study with magnetic strength of 0.55 T. The performance of magnetic field in constructed wetland evaluates using water quality parameter suspended solid (SS), ammonia nitrogen ($NH_3$-N), nitrate nitrogen ($NO_3$-N) and orthophosphate ($PO_4^{3-}$) and heavy metals (iron, Fe and manganese, Mn) removal. The heavy metal uptake by plants also investigate by analyze the plant roots and leaves.

## 1.5 Significant of the study

The study is conducted to evaluate the performance of magnetic field in combined constructed wetland to treating landfill leachate. It also an environmental friendly approach. Leachate poses a number of environmental problems. This is due to variable types of waste and its composition. Leachate can contain high concentration of organic matters, nutrients and heavy metals. In the recent years the interest is more on natural system treatment. In this way, constructed wetlands represent a viable choice, offering extremely positive characteristics for treatment of the landfill leachate, as a good removal of heavy metals; great capacity of nitrifying-denitrifying, with consequent lowering of high concentrations of ammonia typical of landfill leachate; sensible reduction of the volume of the leachate, due to high evapotranspiration bring by plants, and consequently sensible reduction of the costs of an eventual further treatment of the leachate. According to Eckhardt *et al.*, (1999), combination of constructed wetland (FWS and SSF) has potential to increase removal of pollutant from landfill leachate. It is shows high removal of BOD, phosphorus and heavy metals. Thus, the study of combined constructed wetland investigated because it has not been discovered yet in Malaysia.

Magnetic field proven has potential in wastewater treatment. Although, magnetic technology uses is still new in Malaysia. According studied by Johan, (2003) higher magnetic strength will enhance the settling of suspended particles and reduction of SS, $BOD_5$, $NH_3$-N and COD concentration in wastewater. Magnetic field can affect the equilibrium and stabilization of suspended particles to settle after aggregation process. Therefore, the carry out study on combination of constructed wetland and magnetic field will be the promising method to treat the leachate with proper treatment and low cost.

# REFERENCES


Aeslina Abdul Kadir (2004). *Landfill Leachate Treatment Performance in Subsurface Flow Constructed Wetlands Using Safety Flow System*, Universiti Teknologi Malaysia: Master thesis

Ain Nihla Kamarudzaman (2006). *Leachate Treatment using SSF-FWS Constructed Wetland*. Universiti Teknologi Malaysia: Master Thesis.

Al-Muzaini, S., Beg, M.U. and Muslmani, K. (1995). Characterization of Landfill Leachates at a Waste Disposal Site in Kuwait. *Environment Intemational*. 21: 399 – 405.

Alimi, F., Tlili, M., Claude, G., Maurin, G., and Ben Amor, M. (2006). Effect of a magnetic water treatment on homogeneous and heterogeneous precipitation of calcium carbonate. *Water Research*. 40:1941 – 1950

APHA (2002). *Standard Methods for the Examination of Water and Wastewater,* American Public Health Association, AWWA, and WPCF, Washington DC.

Ayaz, S.A. and Acka, L. (2001). Treatment of wastewater by natural systems. *Environment International*.26: 189-195

Baker, J. S., and Judd, S.J. (1996). Magnetic amelioration of scale formation. *Water Research*. 30(2): 247-260

Barlaz, M. A. (1996) Microbiology of solid waste landfills. In: *Microbiology of Solid Waste*. A.C. Palmisano and M.A. Barlaz (eds). CRC Press. Boca Raton. Florida.

Barlaz, M. A. and Gabr, M. A. (2001). Closing the Gaps in the Regulation of Municipal Solid Waste Landfills: Defining the End of the Post-Closure Monitoring Period and Future Stability of Leachate Recirculation Landfills. In Catherine C. Galbrand (2003). *Naturalized Treatment Wetland for Contaminant Removal: A Case Study of the Burnside Engineerd Wetland for Treatment of Landfill Leachate*. Dalhousie University Master Thesis, Halifax, Nova Scotia.

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

Belova, V. (1972). Magnetic Treatment of Water. *Society Science Revolution Scientist Development U.S.S.R.* 3:150-156

Beruto, D.T., and Giordani, M. (1995) Effects of low frequency electromagnetic fields on crystal growth from solution. In: Compton, R.G. and Hancock, G.(1995) *Research in Chemical Kinetics, Elsevier Science*. Volume 3: pg 175

Bernardin, J.D. and Chan, S.H (1991). Magnetic effect on simulated brine properties pertaining to magnetic water treatment. *Journal of Crystal Growth*. 108: 792

Bethan, P. (1996). *Ammonium and Nitrate Removal from Belle Isle Landfill Leachate in Constructed Wetland Cells*. College of Environmental Science and Forestry, New York: Master Thesis.

Bogatin, J., Bondarenko, N.P, Gak, E.Z, Rokhinson, E.E, and Ananyev, I.P. (1999). Magnetic treatment of irrigation water: experimental results and application conditions. *Environmental Science*. 33: 1280.

Bolto, B.A. (1990). Magnetic particle technology for wastewater treatment, *Waste Management*. 10 (1): 11.

Bruns, S.A., Klassen, V.I. and Konshina, A.K. (1966). Change in the extinction of light by water after treatment in magnetic field. *Analytical Chemistry*. 23: 214.

Brix, H. (1993). Wastewater Treatment in Constructed Wetlands: System Design, Removal Processes and Treatment Performance. In: G.A. Moshiri (ed).*Constructed Wetlands for Water Quality Improvement*. Lewis Publishers: Boca Raton. p.9-22.

Brix, H., (1994). Functions of macrophytes in constructed wetlands. *Water Science Technology*. 29: 71–78.

Brix, H., (1997). Do macrophytes play a role in constructed treatment wetlands? *Water Science Technology*. 35:11–17.

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

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

Bulc, T.G. (2006). Long term performance of a constructed wetland for landfill leachate treatment. *Ecological Engineering.* 26: 365–374.

Busch, K.W., Busch, M.A., McAtee, J.L., Darling, R.E., and Parker, D.H. (1985). *Evaluation of the Principles of Magnetic Water Treatment*. API Report 960, Report by American Petroleum Institute, Washington DC.

Busch, K. W., Busch, M.A., Parker, D.H., Darling, R.E., and McAtee Jr., J.L. (1986). Studies of a water treatment device that uses magnetic fields. *Corrosion*. 42(4): 211-221.

Chiba, A., Kawazu, K., Nakanu, O., Tamura, T., Yoshihara, S. and Sato, E. (1994). The Effects of Magnetic Fields on the Corrosion of Aluminium Foil in the Sodium Chloride Solutions. *Corrosion Science*. 36 (3): 539-543.

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

Cameron, K., Madramootoo, C., Crolla, A. and Kinsley, C. (2003). Pollutant Removal from Municipal Sewage Lagoon Effluents with a Free-Surface Wetland. *Water Research*. 37: 2803–2812.

Chen, T.Y., Kao, C.M., Yeh, T.Y., Chien, H.Y. and Chao, A.C. (2006). Application of a Constructed Wetland for Industrial Wastewater Treatment: A Pilot-scale Study. *Chemosphere*. In press.

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.

Cossu, R., Haarstad, K., Lavagnolo, M.C. and Littaru, P. (2001). Removal of municipal solid waste COD and NH4-N by phyto-reduction: A laboratory-scale comparison of terrestrial and aquatic species at different organic loads. *Chemosphere*. 16: 459-470.

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

Crolla, A (2004) *Constructed Wetland In Canada*, ATAU Course Notes. Collège d'Alfred – University of Guelph.

Cronk, J.K. and Fennessy, M.S. (2001). *Wetland Plants : Biology and Ecology*. Lewis Publishers, United States of America.

DeBusk, T.A., Burgoon, P.S., and Reddy, K.R., (1989). Performance of a pilot scale water hyacinth-based secondary treatment system. *Journal Water Pollution Control Federation*. 61: 1217–1224.

Donaldson, J. D., (1988). HDL Symposia at the Universities of York and Aston, January 1988, *New Scientist*, 117

Donaldson, J.D. (1990). *Magnetic Treatment of Fluids*. Brewer's Guardian. July 20-24.

Duffy, E.A. (1977). *Investigation of Magnetic Water Treatment Devices*. Clemson University, Clemson, S.C. Thesis PhD.

Duffy, E.A. (1997). Investigation of Magnetic Water Treatment Devices. Clemson University, Clemson, S.C.: Thesis PhD.

Eckhardt, David A.V., Surface, J.M. and Peverly J.H. (1998). A constructed wetland system for leachate treatment of Landfill Leachate, Monroe Country, New York. In: *Constructed Wetland for the treatment of landfill leachate*, G. Mulamootil, E. A. McBean and F. Rovers, eds., CRC Press, Boca Raton, Florida, 205-222.

El-Fadel, M., Findikakis, A.N. and Leckie, J.O.(1997). Environmental impacts of solid waste landfilling, *Journal of Environmental Management*. 50: 1–25.

El-Fadil, M, E., Bou-Zeid, W., Chahine, B., and Alayli (2002). Temporal variation of leachate quality from pre-sorted and baled municipal solid waste with high organic and moisture content. *Journal of Waste Management*. 22: 269–282.

Ellingsen F.T dan Kristiansen. H. (1979). Does magnetic treatment influence precipation of calcium carbonate from supersaturated solutions. *Bioeletromagnetic*. 6: 169 – 175

Emberton, J.R. (1986). The biological and chemical characterization of landfills. In: Emberton JR, Emberton RF, editors. *Energy from landfill gas*, p. 150–63.

Fadil, O., Johan, S., and Zulfa, F. (2004). Sedimentation of suspended solid under influence of magnetic field, *2nd Bangi World Conference on Environmental Management*, Sept 13 – 14, UKM & EMS Malaysia, 35 – 40

Faseur, A. Dooren, Juan, Vanbrabant, R. and Goossens, W.R.A. (1988). Electromegnetic Treatment of Wastewater. *Filtration and Separation*. 25(5): 344-347.

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

Gamayunov, N. I. (1983). Coagulation of Suspension After Magnetic Treatment. *Journal of Applied Chemistry of the USSR (Zhurnal Prikladnoi Khimii)*. 56(5): 975-982.

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 Dakato Scholl of Mines and Technology, Rapid City, South Dakato, USA.

Gearheart, R. A. (2006) *Constructed Wetland for Natural Wastewater*, Southwest Hydrology, Humboldt State University

Gersberg, R.M., Elkins, B.V., and Goldman, C.R., 1983. Nitrogen removal in artificial wetlands. *Water Resources*. 17: 1009–1014.

Gonet, B. (1985). Influence of Constant Magnetic Fields on Certain Physicochemical Properties of Water. *Bioelectromagnetics.* 6: 169 – 175.

Greenway, M., (1997). Nutrient content of wetland plants in constructed wetlands receiving municipal effluent in tropical Australia. *Water Science Technology*. 35: 135–142.

Greenway, M. and Woolley, A. (1999). Constructed Wetlands in Queensland: Performance Efficiency and Nutrient Bioaccumulation. *Ecological Engineering.* 12: 39 – 55.

Halvadakis, C. P. (1983). *Methanogenesis in solid-waste landfill bioreactors*. PhD Dissertation, Stanford University, Stanford CA.

Hammer, D.A., (1989). Constructed wetlands for wastewater treatment. Municipal, industrial and agricultural. In: *Proceedings from the First International Conference on Constructed Wetlands for Wastewater Treatment*, held in Chattanooga, TN, June 13–17. Lewis, Chelsea, MI.

Hammer, D.A., Knight, R.L., (1994). Designing constructed wetlands for nitrogen removal. *Water Science Technology*. 29: 15–27.

Hasson, D. and Bramson, D. (1981). The Performance of a Magnetic Water Conditioner Under Accelerated Scaling Conditions. *Proceedings of Progress in the Prevention of Fouling of Industrial Plant*, 217 – 223. April 1981, Nottingham, UK. Institute of Corrosion Science and Technology.

Herzorg, R.E., Shi, Q.H., Patil, J.N. and Katz, J.L. (1989). Magnetic Water Treatment: The Effect of Iron on Calcium Carbonate Nucleation and Growth. *Langmuir*. 5(3): 861-866.

Higashitani, K., Okuhara, K. and Hatade S. (1992). Effects of Magnetic Fields on Stability of Nonmagnetic Ultrafine Colloidal Particles. *Journal of colloid and interface science*. 152: 125 – 131.

Higashitani K., Kage A., Katamura S., Imai K. and Hatade S. (1993). Effects of a Magnetic Field on the Formation of $CaCO_3$ Particles. *Journal of colloid and interface science*. 1: 90 – 95.

Higashitani, K., Iseri, H., Okuhara, K., Kage, A. and Hatade, S. (1995). Magnetic Effects on Zeta Potential and Diffusivity of Nonmagnetic Colloidal Particles. *Journal of Colloid and Interface Science*. 172(1): 383-388.

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

Holysz, L., Chibowski, E. and Szczes, A. (2003). Influence of Impurity Ions and Magnetic Field on the Properties of Freshly Precipitated Calcium Carbonate. *Water Research*, In press.

Huett, D.O., Morris, S.G., Smith, G. and Hunt, N. (2005). Nitrogen and Phosphorus Removal from Plant Nursery Runoff in Vegetated and Unvegetated Subsurface Flow Wetlands. *Water Research.* 39: 3259–3272.

Ifill, A.S., Baker, J.S., and Judd, S.J. (1996). Magnetically-Enhanced Chemical Disinfection. *Transaction of the Institution of Chemical Engineering (Part B).* 74(2): 120-124.

Ingersoll, T.L. and Baker, L.A. (1998) Nitrate Removal in wetland microcosms. *Water Resource*. 32: 677-684.

IWA (2000). *Constructed wetlands for Pollution Control. Processes, Performance, Design and Operation*. International Water Association  Publishing, London.

Jenkins, R. L. and Pettus, J.A.(1985) The use of in-vitro anaerobic landfill samples for estimating gas generation rates. In: *Biotechnology advances in processing municipal wastes for fuels and chemicals*, Antonopoulos, A.A. (ed.), (Argonne National Laboratory Report ANL/CNVS-TM-167), 419.

Johan Sohaili (2003). *Kesan Medan Magnet Terhadap Pengenapan Zarah Terampai Dalam Kumbahan*. Univesiti Teknologi Malaysia: PhD thesis.

Johan, S., Fadil, O., and Zularisam, A.W., (2004). Effect of magnetic fields on suspended particles in sewage, *Malaysian Journal of Science.* 23: 141 – 148

Johnson, K.D., Martin, C.D., Moshiri, G.A. and McCrory, W.C. (1999). Performance of a Constructed Wetlands Leachate Treatment System at the Chunchula Landfill, Mobile County, Alabama, In : edited by Mulamoottil, G., McBean, E.A. and Rovers, F. *Constructed Wetlands for the Treatment of Landfill Leachates.* Lewis Publishers, United States of America.

Jung, J., Sanji, B., Godbole, S., and Sofer, S. (1993). Biodegradation of phenol. A comparative study with and without applying magnetic fields. *Journal of Chemical Technology Biotechnology*. 556: 73– 6.

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

Kadlec, R.H (2000). The inadequacy of first-order treatment wetland models. *Ecological Engineering*. 15: 105–119

Kadlec, R. H and Knight, R.L. (1996). *Treatment Wetlands*. CRC Press LCC: Boca Raton, Florida.

Kamal, M., Ghaly, A.E., Mahmoud, N. and Côté, R. (2004). Phytoaccumulation of Heavy Metals by Aquatic Plants. *Environmantal International.* 29: 1029 – 1039.

Kappelmeyer, U. (2005*) Landfill Leachate Treatment in Constructed Wetlands: Removal of High Nitrogen Loads*, Eng. M.Sc. Diego Paredes.

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

Klassen, V. I., (1981). Develop Miner. Proces. Part B Miner. *Proces*: 1077–1097

Knez, S. and Pohar, C., (2005). The magnetic field influence on the polymorph composition of CaCO3 precipitation from carbonized aqueous solutions. *Journal Colloid Interface Science*. 281: 377–388.

Knight, R. L. (1997). Wildlife habitat and public use benefits of treatment wetlands. *Water Science Technology*. 35 (5): 35-43.

Kurniawan, T.A., Lo, W.H. and Chan, G.Y.S. (2006). Physico-chemical treatments for removal of recalcitrant contaminants from landfill leachate. *Journal of Hazardous Materials.* B129: 80–100.

Lee, Y. F. (2004). *Rainfall effects to the performance of SSF constructed wetlands in leachate treatment*. Universiti Teknologi Malaysia: Master Thesis

Lee, G.F. and Lee, J. (2001). Assessing the Water Quality Impacts of Phosphorus in Runoff from Agricultural Land. *Proceedings of American Chemical Society Agro Division Symposium*: Environmental Impacts of Fertilizer Products in Soil, Air and Water. American Chemical Society. Chicago.

Liburkin, V.G., Kondrater, B.S. and Pavlyukova, T.S. (1986). Action of Magnetic Treatment of Water on the Structure Formation of Gypsum. *Glass and Ceramics (Steklo I Keramika)*. 43 (3-4): 116-119.

Liehr, S., Kozub, D., Rash, J., Sloop, M., Doll, B., Rubin, R., House, H., Haws, S. and Burks, D. (2000) Constructed Wetlands Treatment of High Nitrogen Landfill Leachate. *Water Environment Research Foundation*: Alexandria, Virginia.

Lim, W.H., Tay, T.H. and Kho, B.L. (2002). Plants Used in the Putrajaya Wetland System and Problems Associated with Their Establishment and Maintenance. In : Editors : Mansor, M., Eng, L.P. and Shutes, R.B.E. *Constructed Wetlands : Design, Management and Education*. Universiti Sains Malaysia Publisher, Malaysia.

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, Y.F., Jing, S.R., Lee, D.Y., Wang, T.W. (2002) Nutrient removal from polluted aquaculture wastewater using constructed wetlands system. *Aquaculture.* 209: 169–184.

Lin, Y.F., Jing, S.R., Lee, D.Y., Chang, Y.F., Chen, Y.M., and Shih, K.C. (2005) Performance of a constructed wetland treating intensive shrimp aquaculture wastewater under high hydraulic loading rate, *Environmental Pollution*. 134: 411-421

Lipus, L.C., Krope, J. and Crepinsek, L. (2001). Dispersion Destabilization in Magnetic Water Treatment. *Journal of Colloid and Interface Science*. 236: 60-66

Liu, J., Qiu, C., Xiao, B., Cheng, Z., (2000). The role of plants in channel-dyke and field irrigation systems for domestic wastewater treatment in an integrated eco-engineering system. *Ecological Engineering*. 16: 235-241.

Maine, M.A., Sun˜ e, N., Hadad, H., Sa´nchez, G., Bonetto, C., (2005). Phosphate and metal retention in a small-scale constructed wetland for waste-water treatment. In: Golterman, H.L., Serrano, L. (Eds.), *Phosphate in Sediments*. Backhuys Publishers, Leiden, pp. 21–31.

Mantovi, P., Marmiroli, M., Maestri, E., Tagliavini, S., Piccinini, S. and Marmiroli, N. (2003). Application of a Horizontal Subsurface Flow Constructed Wetland on Treatment of Dairy Parlor Wastewater. *Bioresource Technology*. 88: 85 – 94.

Martin, J., Hofherr, E., Quigley, M.F., (2003). Effects of *Typha latifolia* transpiration and harvesting on nitrate concentrations in surface water of wetland microcosms. *Wetland* 23 (4): 835-844

Masbough, A., Frankowski, K., Hall, K.J. and Duff, S.J.B. (2005). The Effectiveness of Constructed Wetland for Treatment of Woodwaste Leachate. *Ecological Engineering*. 25: 552 – 566.

Maschinski, J., Southam, G., Hines, J., Strohmeyer, S., (1999). Efficiency of a subsurface constructed wetland system using native southwestern US plants. *Journal of Environmental Quality*. 28 (1): 1665–1673.

Mashhor, M., Sofiman, O. and Asyraf, M. (2002). Management of Wetland Weeds in Aquatic Systems. In : Editors : Mansor, M., Eng, L.P. and Shutes, R.B.E. *Constructed Wetlands : Design, Management and Education*. Universiti Sains Malaysia Publisher, Malaysia.

Mason, C. H. (1998). *Biology of freshwater pollution Third Edition*. Addison Wesley Longman Limited. England.

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

McBean, E. and Rovers, F. (1999) Landfill Leachate Characteristics as input for the design of wetlands used as treatment system. In: Mulamoottil, G., McBean, E.A. and Rovers, F., (1999) *Constructed Wetlands for the Treatment of Landfill Leachates*, Lewis Publisher, Boca Raton, Florida

Mitsch, W.J. and Gosselink, J.G. (1986). *Wetlands*. New York, Van Nostrand Reinhold Company Inc.

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

Muna Muhammad (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.

Navratil, J.D. (2002). *Adsorption and Nanoscale Magnetic Separation of Heavy Metals from Water*. Environmental Protection Act (EPA).

Navratil, J.D. (2003). Potential of Magnetic Adsorption/Filtration for Hydrometallurgical Wastewater Treatment. *Fifth International Conference in Honor of Professor Ian Ritchie –Volume 1: Leaching and Solution Purification.* Edited by Young, C.A., Alfantazi, A.M., C.G. Anderson, Dreisinger, D.B., Harris, B.and James, A. TMS (The Minerals, Metals & Materials Society)

Nazaitul Shila Rasit (2006). *Landfill Leachate Treatment Using Subsurface Flow Constructed Wetland Enhanced With Magnetic Field*. Universiti Teknologi Malaysia: Master Thesis.

Nelson,E. A. Specht, W.L. and Knox, A.S. (2004) *Metal Removal From process and stormwater discharges by constructed treatment wetland* WSRC-MS-2004-00763, Department of Energy, Office of Scientific and Technical Information, US.

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

Oshitani, J., Yamada, D., Miyahara, M and., Higashitani, K., (1999) Magnetic effects on Ion Exchange Kinetics. *Journal Colloid Interface Science*. 210: 1-7

Ozeki, S., Wakai, C. and Ono, S. (1991). Is a Magnetic Effect on Water Adsorption Possible?. *Journal of Physical Chemistry*. 95(26): 10557-10559.

Pant, H.K., Reddy, K.R., Lemon, E., (2001). Phosphorus retention capacity of root bed media of sub-surface flow constructed wetlands. *Ecological Engineering*. 17: 345–355.

Parson, S.A. (2000). Advances in Magnetic Treatment Research. *Proceedings of the 3rd International Symposium on New Magneto-Science.* Tokyo, Japan.

Parsons, S., Judd, S.J., Stephenson, T., Udol, S., Wang, B.L., (1997) Magnetically augmented water treatment. *Transaction of the Institution of Chemical Engineering* 75(B): 98–104.

Partidas, H (1995). Magnetic Fluid Conditioning Tools: Removal and Inhibition of Production Reports. *Petromin Nov*. 66-72.

Pempkowiak, H.O. and Klimkowska, K. (1999). Distribution of Nutrients and Heavy Metals in a Constructed Wetland System. *Chemosphere, Elsevier Science Ltd*. 39: 303 – 312.

Qasim, S. R., and Chiang, W. (1994). *Sanitary landfill leachate: generation, control, and treatment*. Technomic Publishing, Lancaster.

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

Reed, S.C., Crites, R.W., and Middlebrooks, E.J. (1995). *Natural Systems for Waste Management and Treatment*, McGraw-Hill, New York, 433 pp.

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., Sutton, D.L., and Bowes, G., (1983). Freshwater aquatic plant biomass production in Florida. *Soil Crop Science Soc. Fla. Process*. 42: 28–40.

Reddy, K.R., and Debusk, W.F. (1985) Nutrient Removal potential of selected aquatic macrophytes. *Journal of Environmental Quality*. 14: 459-462

Reddy, K.R., and D'Angelo, E.M., (1990). Biomass yield and nutrient removal by water hyacinth (*Eichhornia Crassipes*) as influenced by harvesting frequency. *Biomass*. 21: 27–42.

Reddy, K.R., and Smith, W.H. (Eds.). (1987). *Aquatic Plants for Water Treatment and Resource Recovery*. Magnolia Publishing, Orlando, FL, USA.

Reinhart, D.R. (1995). Why wet landfills with leachate recirculation are effective. In: Dunn JR, Singh UP, editors. *Landfill closures: environmental protection and land recovery*. San Diego, CA: Geotechnical Special Publication. 53: 93–99.

Reinhart, D.R. (1996). Full-scale experiences with leachate recirculating landfill: case studies. *Waste Management Research*. 14: 347–365.

Reinhart, D.R. and Al-Yousfi, B. (1996). The impact of leachate recirculation on municipal solid waste landfill operating characteristics. *Waste Management and Research*. 14: 337-346.

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

Sawaittayothin, V. and Polprasert, C. (2006). Nitrogen mass balance and microbial analysis of constructed wetlands treating municipal landfill leachate. *Bioresource Technology*, In Press.

Schwartz, M.F., and Boyd, C.E., (1995). Constructed wetlands for treatment of channel catfish pond effluents. *Program Fish-Culture*. 57: 255– 267.

Shaikh, A. M. N. and Dixit, S.G. (1992). Removal of phosphate from waters by Precipitation and High Gradient Magnetic Separation. *Water Research*. 26(6): 845-852.

Sheoran, A.S. and Sheoran, V. (2006). Heavy Metal Removal Mechanism of Acid Mine Drainage in Wetlands: A Critical Review. *Minerals Engineering*. 19: 105–116.

Shepard, D.P. Edling, B. and Reimers, R. (1995). Magnetic Water Treatment. *Golf Course Management*. 63(3): 55-58.

Shutes, R.B.E., Revitt, M., Forshaw, M. and Winter, B. (2002). Constructed Wetland Monitoring and Management for Urban Runoff Management. In : Editors : Mansor, M., Eng, L.P. and Shutes, R.B.E. *Constructed Wetlands : Design, Management and Education*. Universiti Sains Malaysia Publisher, Malaysia.

Silva, A.C., Dezotti, M., and Sant'Anna, G.L. (2003). Treatment and detoxication of a sanitary landfill leachate. *Chemosphere*. 55: 207–214.

Soltan, M.E. and Rashed, M.N. (2003). Laboratory study on the survival of water hyacinth under several conditions of heavy metal concentrations. *Advances in Environmental Research*. 7:321–334

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

Srebrenik, S., Nadiv, S. and Lin, I.J. (1993). *Magnetic Treatment of Water- A theoretical Quantum Model Magnetic and Electrical Separation*. 5(2): 71-91.

Stefan, E.B., Eriksson, P.G., Graneli, W., Leonardson, L. (1994) Influence of macrophytes on nitrate removal in wetlands. *Ambio*. 23: 363-366

Stowel, R., Ludwig, R., Colt, J., and Tchobanouglous, G. (1981). Concept in Aquatic Treatment Systems Design. *Journal Environmental Engineering Division*. ASCE vol. 107. No EE : 919.

Surface, J.M., Peverly, J.H., Steenhuis, T.S., and Sanford, W.E. (1993). Constructed wetlands for landfill leachate treatment. In: Moshiri, G.A. (Ed.), *Constructed Wetlands for Water Quality Improvement*. Lewis Publishers, Chelsea, MI, pp. 461-472.

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.

Tatsi, A.A. and Zouboulis, A.I. (2002). A field investigation of the quantity and quality of leachate from a municipal solid waste landfill in a Mediterranean climate (Thesaloniki, Greece). *Advanced Environmental Resources*. 6: 207–219.

Tchobanoglous, G., Theisen, H., and Vigil, S.A., (1993). *Integrated Solid Waste Management*. McGraw-Hill. Inc., Singapore, pp. 418–419.

Terashima, Y., Ozaki, H., Sekine, M. (1986). Removal of Dissolved Heavy Metals by Chemical Coagulation, Magnetic Seeding and High Gradient Magnetic Filtration. *Water Research*. 20(5): 537-545.

Thien, S.H. (2005). *Leachate Treatment by Floating Plants in Constructed Wetland*. Master Thesis, Universiti Teknologi Malaysia.

Thullen, J.S., Santoris, J.J., Mark Nelson, S. (2005). Managing vegetation in surface flow wastewater treatment wetlands for optimal treatment performance. *Ecological Engineering*. In Press.

Tsouris, C. and Scott, T.C. (1994). Flocculation of paramagnetic in a Magnetic Field. *Journal of Colloidal and Interface.* 171: 319-330

Van Velsen, A.F.M. van der vos, G. Boersma, R. and de Reuver, J.L. (1990). High Gradient Magnetic Separation Technique for Wastewater Treatment. *Water Science and Technology*. 24(10): 195-203.

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

Vymazal, J., Brix, H., Cooper, P.F., Green, M.B., and Haberl, R. (1998). *Constructed Wetlands for Wastewater Treatment in Europe*. Backhuys Publishers, Leiden, The Netherlands.

Vymazal, J. (2005). Horizontal sub-surface flow and hybrid constructed wetlands systems for wastewater treatment, *Ecological Engineering*. 25: 478–490

Vymazal, J. and Kropfelova, L. (2005). Growth of *Phragmites Australis* and *Phalaris Arundinacea* in Constructed Wetlands for Wastewater Treatment in the Czech Republic. *Ecological Engineering*. 25: 606 – 621.

Wan Salida Wan Mansor (2006). *Effect of Magnetic Fields on Heavy Metals and Nutrient Removal In Leachate*.. Universiti Teknologi Malaysia: Master Thesis

Watson, J.T., Reed, S.C., Kadlec, R.H., Knight, R.L. and Whitehouse, A.E. (1989). Performance expectations and loading rates for constructed wetlands. In: Hammer, D.A. ed. *Constructed wetlands for wastewater treatment: municipal, industrial and agricultural*. Chelsea, MI, USA: Lewis Publishers. 319-351.

Wetzel, R.G. (2000). Fundamental processes within natural and constructed wetland ecosystems: short-tem vs. long-term objectives. In: *Seventh Conference on Wetland Systems for Water Pollution Control Proceedings*, vol. 1, Lake Buena Vista, Florida, November 11-16, pp 3-11

Yang, L., Chang, H.T, and Huang, M.L. (2001). Nutrient removal in gravel- and soil-based wetland microcosms with and without vegetation. *Ecological Engineering*. 18: 91–105

Yang, B., Lan, C.Y., Yang, C.S., Liao, W.B., Chang, H. and Shu, W.S. (2006). Long-Term Efficiency and Stability of Wetlands for Treating Wastewater of a Lead/Zinc Mine and the Concurrent Ecosystem Development. *Environmental Pollution*. In Press.

Yavuz, H. and Celebi, S.S. (2000). Effects of magnetic field on activity of activated sludge in wastewater. *Enzyme and Microbial Technology*. 26: 22-27

Ye, Z.H., Whiting, S.N., Qian, J.H., Lytle, C.M., Lin, Z.Q., and Terry, N., (2001). Trace element removal from coal ash leachate by a 10-year-old constructed wetland. *Journal of Environmental Quality*. 30: 1710–1719.

Ying, T.Y., Yiacoumi, S. and Tsouris, C. (1999). High Gradient Magnetically Seeded Filtration. *Chemical Engineering Science*. 55: 1101 – 1113.

Zulfa Fauzia, Fadil, O., Johan S., M. Faiqun A. (2005). Reduction of Organic Concentration Under Magnetic Fields Up To 5500 Gauss. *Proceeding in Seminar Kebangsaan Pengurusan Persekitaran 2005,* Universiti Kebangsaan Malaysia, Bangi, 4 – 5 Julai.