

**RAINFALL EFFECTS TO THE PERFORMANCE OF SUBSURFACE FLOW
CONSTRUCTED WETLANDS IN LEACHATE TREATMENT**

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ABSTRAK

Tanah bench buatan sudah semakin luas diterima sebagai cara pengolahan air sisa. Kesan hujan perlu diambil kira dalam merekabentuk tanah bench buatan tempatan terutamanya di negara-negara tropikal. Kajian ini dijalankan untuk mengkaji kesan-kesan cuaca tropikal (hujan) terhadap prestasi tanah bench buatan aliran subpermukaan mendatar (HSFCW) yang ditanam dengan tumbuhan tempatan, *Typha angustifolia* untuk pengolahan air larut lesap. Prestasi tanah bench buatan dikaji dengan tujuh parameter iaitu nitrat, fosforus, ammonia nitrogen, kromium, kadmium, permintaan oksigen biokimia (BOD₅) dan permintaan oksigen kimia (COD). Dua reactor HSFCW berskala loji pandu telah digunakan dalam eksperiment. Keberkesanan HSFCW dalam pengolahan air larut lesap telah diselidik dengan membuat perbandingan dengan reaktor “blank” yang berfungsi sebagai kawalan. Eksperiment telah dijalankan di bawah “hujan monsoon buatan” di Malaysia. Keputusan menunjukkan kesan hujan terhadap prestasi tanah bench berbeza daripada satu parameter ke parameter yang lain (-1% ke 41% peningkatan), bergantung kepada sifat-sifat masing-masing. Kesemua parameter kecuali kromium menunjukkan peningkatan dalam keberkesanan pengolahan selepas hujan. Kesan hujan (peningkatan keberkesanan pengolahan) adalah lebih ketara dalam reaktor kawalan berbanding dengan reaktor yang ditanam dengan tumbuhan.

ABSTRACT

Constructed wetlands have gained wide acceptance as a wastewater treatment practice. Rainfall effect needs to be taken into account in designing local constructed wetlands particularly in tropical countries. This study was carried out to evaluate the effects of tropical climate (rainfall) towards the performance of horizontal subsurface flow constructed wetlands (HSFCW) planted with local plant, *Typha angustifolia* for landfill leachate treatment. The performance of the constructed wetlands was evaluated using seven parameters i.e nitrate, phosphorus, ammonical nitrogen, chromium, cadmium, biochemical oxygen demand (BOD₅) and chemical oxygen demand (COD). Two pilot scale constructed wetlands reactors were used in the experiments. Performance of HSFCW in leachate treatment was evaluated with comparison to a blank reactor (without plants) serving as control. Experiments were run under artificial “monsoon rainfall intensity” in Malaysia. Results show that rainfall effects towards the performance of wetlands in leachate treatment vary from parameter to another (-1% to 41% enhancement) depending on the characteristic of each parameter. All parameters except chromium have better performance in leachate treatment after rainfall. Rainfall effects (increasing of removal efficiency) are more critical in control reactor as compared to the vegetated reactors.

TABLE OF CONTENTS

CHAPTER	SUBJECT TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF APPENDIXES	xiii
CHAPTER 1	INTRODUCTION	1
	1.1 Introduction	1
	1.2 Problem Statement	3
	1.3 Objectives	4
	1.4 Scope of Work	5

CHAPTER 2	LITERATURE REVIEW	6
2.1	Leachate Characterization	6
2.1.1	Introduction	6
2.1.2	Factors Affecting Leachate Quality	7
2.1.2.1	Processed Refuse	7
2.1.2.2	Depth of Refuse	7
2.1.2.3	Age of Fills	8
2.2	Constructed Wetlands	11
2.2.1	Introduction	11
2.2.2	Types of Constructed Wetlands	12
2.2.2.1	Free Water Surface Treatment Wetlands	12
2.2.2.2	Subsurface Flow Treatment Wetland	13
2.2.3	Application of Constructed Wetland in Leachate Treatment	15
2.3	Heavy Metals	16
2.3.1	Chromium	17
2.3.1.1	Effect of Chromium to Environment	17
2.3.1.2	Effect of Chromium to Human Health	18
2.3.2	Cadmium	
2.3.2.1	Effect of Chromium to Environment	19
2.3.2.2	Effect of Chromium to Human Health	19
2.3.3	Metal removal	20
2.3.3.1	Adsorption and Cation Exchange	21
2.3.3.2	Microbial Mediated Processes	21
2.3.3.3	Filtration	22
2.3.3.4	Plant Uptake	23
2.4	Nutrients	23
2.4.1	Nitrogen	23
2.4.1.1	Ammonia Volatilization	24

	2.4.1.2	Ammonification (Mineralization)	25
	2.4.1.3	Nitrification / Denitrification	25
	2.4.1.4	Plant Uptake	27
	2.4.2	Phosphorus	28
2.5		Organics	28
2.6		Role of Wetlands Vegetation in Wastewater Treatment	29
2.7		Rainfall in Malaysia	31
CHAPTER 3		METHODOLOGY	33
3.1		Leachate Sample Collection	33
3.2		Laboratory Design	34
	3.2.1	Component of Wetlands Design	39
3.3		Plants	40
3.4		Rainfall Design	42
	3.4.1	Summary of Experimental Design	43
3.5		Sampling of Wetlands Effluents	44
3.6		Laboratory Analysis	44
CHAPTER 4		RESULTS AND DISCUSSIONS	45
4.1		Heavy Metal Removal	45
	4.1.1	Contribution of Wetlands Components in Heavy Metal Removals	47
4.2		Nutrient Removal	47
4.3		Organic Removal	50
4.4		Performance of <i>T. angustifolia</i> in Leachate Treatment	52
4.5		Rainfall Effect to the Performance of HSFCW	53
CHAPTER 5		CONCLUSIONS AND RECOMMENDATIONS	59
5.1		Conclusions	59
5.2		Recommendations	60
		REFERENCES	61
		APPENDIX	65

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Typical Data on the Composition of Leachate from New and Mature Landfills	10
2.2	Roles of macrophytes in constructed wetlands	30
3.1	Summary of experimental design	43
3.2	Analytical methods for every parameter	44
4.1	Performance of reactor for heavy metal removal	46
4.2	Heavy metal concentrations in wetlands components	47
4.3	Performance of reactor for nutrient removal	49
4.4	Performance of reactor for organic removal	51
4.5	Comparison between performance of Reactor A and Reactor B	52
4.6	Percentage increase of removal efficiency after rainfall (%)	54

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	FWS wetland containing rooted, floating leaf plants	13
2.2	Typical arrangement of horizontal system SSFCW	14
2.3	Typical arrangement of vertical SFCW system	15
2.4	Processes of metal removal in constructed wetlands	20
3.1	Equipments for leachate collection	34
3.2	New plants were reproduced during the growing period before experiment started	35
3.3	Schematic plan of HSFCW used in experiment	36
3.4	Storage tank and control tank	37
3.5	Arrangement of HSFCW reactors on site	37
3.6	Longitudinal section of HSFCW that used in the experiment	38
3.7	Influent perforated pipe (left) and effluent perforated pipe (right)	38
3.8	Short description of <i>T. angustifolia</i>	41
3.9	Ten-year monthly rainfall pattern in Johore Bahru	42
3.7	Rainfall piping	43
4.1	Average removal efficiency for 7 parameters with and before rainfall	51
4.2	Rainfall effect to the performance of wetlands	53
4.3	Chromium removal	55
4.4	Cadmium removal	55
4.5	Phosphorus removal	56
4.6	Ammonical–nitrogen removal	56

4.7	Nitrate removal	57
4.8	BOD removal	57
4.9	COD removal	58

LIST OF APPENDIX

APPENDIX	TITLE	PAGE
A1	Removal efficiency of chromium in Rector A & B before rainfall	66
A2	Removal efficiency of chromium in Rector A & B after rainfall	67
A3	Removal efficiency of cadmium in Rector A & B before rainfall	68
A4	Removal efficiency of cadmium in Rector A & B after rainfall	69
A5	Removal efficiency of phosphorus in Rector A & B before rainfall	70
A6	Removal efficiency of phosphorus in Rector A & B after rainfall	71
A7	Removal efficiency of ammonical-nitrogen in Rector A & B before rainfall	72
A8	Removal efficiency of ammonical-nitrogen in Rector A & B after rainfall	73
A9	Removal efficiency of nitrate in Rector A & B before rainfall	74

A10	Removal efficiency of nitrate in Rector A & B after rainfall	75
A11	Removal efficiency of biochemical oxygen demand (BOD) in Rector A & B before rainfall	76
A12	Removal efficiency of biochemical oxygen demand (BOD) in Rector A & B after rainfall	77
A13	Removal efficiency of chemical oxygen demand (COD) in Rector A & B before rainfall	78
A14	Removal efficiency of chemical oxygen demand (COD) in Rector A & B after rainfall	79
B1	Analysis ANOVA for chromium removal	80
B2	Analysis ANOVA for cadmium removal	81
B3	Analysis ANOVA for phosphorus removal	82
B4	Analysis ANOVA for ammonical-nitrogen removal	83
B5	Analysis ANOVA for nitrate removal	84
B6	Analysis ANOVA for BOD removal	85
B7	Analysis ANOVA for COD removal	86

CHAPTER I

INTRODUCTION

1.1 Background study

In many countries including Malaysia, sanitary landfills have been the most popular method of municipal solid waste disposal. Although attention has been drawn to increased recycling, waste reduction, and incineration, the sanitary landfill will remain its dominant in the solid waste disposal methods for the next decade due to the rapid population growth (Oasim, S.R. and Chiang, W. 1994). In conjunction with the increasing number of sanitary landfills, more leachates are generated. Landfill leachates will cause environmental problems if it is not properly handled. Increase in landfill leachate creates challenges for those seeking cost effective treatment methods to process this wastewater.

Leachate may be defined as liquid that has percolated through waste and has extracted dissolved or suspended materials from it. It arises from the biochemical and physical breakdown of wastes (Lu *et. al.*,1985). The leakage of leachate which contains high organic, inorganic, suspended solids, heavy metals and other pollutants will contaminate ground water and surface water sources.

For the past fifty years, conventional wisdom has mandated the development of extensive waste water collection systems directed to a centralized treatment plant. More attention is now being given to the benefits of a decentralized approach in waste water treatment where on site treatment is applied. In many situations, a decentralized systems of waste water treatment, potentially with constructed wetlands, can provide not only a more economical and energy efficient means of achieving treatment objectives, but also a resource in the form of reclaimed water available for landscape irrigation or creation of wildlife habitats (Campbell C.S., 1999).

The principal development of wetlands systems in Europe begun in the late 60th. The wetlands systems were develop rapidly in Europe in the 70th. Since then a large variety of design lines has been established. Especially in the late 15 years there has been a significant interest in reed bed (Platzer C.2000).

As a developing country, Malaysian government has shown interest in wastewater treatment using constructed wetland. This can be seen in the construction of Putrajaya wetlands which is the largest constructed freshwater wetlands in the world, which cover a total of 650 hectares. Under the concept of sustainable development, Putrajaya Wetlands was created using the latest environmental technology to function as a flood control system and a natural filter system for the Putrajaya Lake and provides flood mitigation measures for the whole area. It contains over 12 million plants from some 70 exclusively indigenous species.

Constructed wetlands system has high efficiency in treating wastewater from unknown sources with low operating and maintenance cost. It can be used in the wastewater treatment by treating the organic content, non-organic content, heavy metals, nutrients, suspended solids and other pollutants from point source and non point source before allowing the wastewater to flow into the natural water body. The characteristic properties of wetlands make them unique ecosystems; they contain

anoxic soil, have varying hydrology, distinct nutrient cycling and are composed of plants tolerant of flooded conditions. Since wetlands are often found as a transitional zone between aquatic and terrestrial ecosystems, they can receive a wide array of dissolved substances through storm water runoff as well as through rivers, streams and water channels. Wetlands are able to transform and reduce these compounds, so they have been utilized for water treatment (Fraser *et. al.*, 2004).

Generally, constructed wetlands can be divided into two major types which are free water surface (FWS) constructed wetlands and subsurface flow (SF) constructed wetlands. There are two types of subsurface flow constructed wetlands, which are horizontal systems and vertical systems. In this study, horizontal subsurface flow constructed wetlands (HSFCW) is being used to treat landfill leachate collected from one of the sanitary landfill in Johore Bahru.

1.2 Problem Statement

Malaysian government has introduces recycling campaign to reduce the solid waste generation due to the population growth in the country. However, the recycling programme is not able to balance the increased solid waste generation due to the rapid population growth. As a result, more sanitary landfills need to be prepared for solid waste disposal. In conjunction with the increasing number of landfills, leachate treatment has become an important issue.

Many studies have been conducted for leachate treatment in wastewater treatment using constructed wetlands (Rash and Liehr, 1999). Nevertheless, this technology is not utilised in Malaysia. Thus, study is required to develop leachate treatment facilities using constructed wetlands by incorporating local components and expertise. It had been proven that local tropical plants such as *Scirpus*

globulosus, *Ericaulon sexangulare*, *Scleria Sumatrensis* Retz and *T. angustifolia* are suitable to be used in constructed wetlands for various applications which including heavy metals, nutrients, organics and solids removal. However, the effect of local tropical climate to the performance of the constructed wetlands has not been emphasised. Therefore this study was carried out to study the tropical rainfall effect to leachate treatment using HSFCW planted with *T. angustifolia*.

1.3 Objective

Hypothetically, the performance of subsurface flow constructed wetlands in leachate treatment will be enhanced after rainfall. Two objectives were set in this study as listed below.

- i. To study the performance of HSFCW planted with *T. angustifolia* in leachate treatment.
- ii. To study the tropical rainfall effect to the performance of the HSFCW system

1.4 Scopes of Work

The scopes of the study are:

- i. To study the efficiency of leachate treatment in the HSFCW by checking 7 parameters: BOD, COD, chromium, cadmium, phosphorus, ammonical - nitrogen and nitrate.

- ii. To evaluate the removal efficiency of the HSFCW system under an artificial monsoon rainfall

REFERENCES

- Badkoubi, A., Ganjidoust, H., Ghaderi, A. And Rajabi, A. (1998). Performance of a subsurface constructed wetland in Iran. *Wat. Sci.Tech* 38(1):345-350.
- Baker, L.A. (1998). Design Considerations and Applications for Wetland Treatment of High-Nitrate Waters. *Wat. Sci.Tech*, 38(1):389-395.
- Brix, H. (1994). Function of Macrophytes in Constructed Wetlands. *Wat. Sci.Tech* 29:71-78.
- Boyle, W.C. and Ham, R.K. (1974). Biological Treatability of Landfill Leachate. *Journal Water Pollution Control Federation*, 46(5):860-872.
- Calmona, W., Hong, J. and Forstner, U. (1993). Binding and Mobilization of Heavy Metal in Contaminated Sediment Affected by pH and Redox Potential. *Wat.Sci.Tech*, 8(9): 223-235.
- Campbell, C.S. and Ogden, M. (1999). *Constructed Wetlands In The Sustainable Landscape*. New York : John Wiley & Sons, Inc.
- 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.
- DeBusk, T.A., Langston, M.A., Burgoon, P.S., and Reddy, K.R. (1990). A Performance Comparison of Vegetated Submerged Beds and Floating Macrophytes for Domestic Wastewater Treatment. In: Cooper, P.F. and

- Findlater, B.C. ed. *Constructed Wetlands in Water Pollution Control*. Pergamon Press, Oxford, UK. 301-308.
- Dunbabin, J.S., Pokorny, J. and Bowmer, K.H. (1988). Rhizosphere Oxygenation by *Typha domingensis* in Miniature Artificial Wetland Filters Used for Metal Removal from Wastewaters. *Aquat.Bot.* 29:303-317.
- Fraser, L.H., Carty, S.N. and Steer, D. (2004). A test of four plant species to reduce total nitrogen and total phosphorus from soil leachate in subsurface wetland microcosm. *Bioresource Technology* 94:185-192.
- G. Tchobanoglous, H. Theisen, and S. Vigil (1993). *Integrated Solid Waste Management*. New York: McGrawHill.
- Howard, E.A., Emerick, J.C. and Wilderman, T.R. (1988) Design and Construction of a Research Site for Passive Mine Drainage Treatment in Idaho Springs, Colorado. In: Hammer, D.A. ed. *Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural*, Chelsea, MI, USA: Lewis Publishers.761-764.
- 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.
- Lu, J.C.S., Eichenberger, B. and Stearns, R.J. (1985). *Leachate from municipal landfills: production and management*. Park Ridge, New Jersey: Noyes Publication.
- Maehlum, T., Jenssen, P.D. and Warner, W.S. (1995). Cold-climate Constructed Wetlands. *Wat. Sci. Technol.* 32 (2): 95-102.
- Martin, C.D. and Moshiri, G.A. (1994). The Use of In-Series Surface Flow Wetlands for Landfill Leachate Treatment. *Proceedings of The Fourth IAWQ Conference on Wetland Systems for Water Pollution Control*. November, 6-11. Guangzhou,

P.R. China: Center for International Development and Research, South China Institute for Environmental Sciences. 513-522.

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

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 .

Oasim, S.R. and Chiang, W. (1994). *Sanitary Landfill Leachate-Generation, Control and Treatment*. Texas: Technomic Publishing Co. Inc.

Platzer, C. (2000). Development of Reed Bed Systems – A European Perspective. *Proceedings of the 7th International Conference: Wetland System for Water Pollution Control*. November 12-17. Florida, USA: IWA Publisher.

Rah, J.K. and Liehr, S.K. (1999). Flow Pattern Analysis of Constructed Wetlands Treating Landfill Leachate. *Wat. Sci.Tech*, 40(3):309-315.

Rafidah, H. (2002). *Kajian Pengaruh Konfigurasi Tumbuhan Di Dalam Sistem Tanah Bencah Buatan Jenis Aliran Sub-Permukaan Terhadap Penyingkiran Bahan Organik Dan Logam Berat Di Dalam Air Larut Lesap*. Universiti Teknologi Malaysia: Master Thesis .

Soto, F., Garcia, M., de Luis, E., and Becares, E. (1999). Role of *Scirpus lacustris* in Bacteria and Nutrient Removal for Wastewater. *Wat. Sci.Tech* 40(3):241-247.

Tanner, C.C. (2000). Plants as Ecosystem Engineers in Subsurface-flow Treatment Wetlands. *Proceedings of the 7th International Conference: Wetland System for Water Pollution Control*. November 12-17. Florida, USA: IWA Publisher.

- Tanner, C.C., Clayton, J.S., and Upsdell, M.P. (1995). Effect of Loading Rate and Planting on Treatment Dairy Farm Wastewaters in Constructed Wetlands II. Removal of Nitrogen and Phosphorus. *Wat.Res.*29:27-34
- Ujang, Z., Soedjono, E., Salim, M.R., Shutes, R.B. (2003). Landfill Leachate Treatment by an Experimental Subsurface Flow Constructed Wetland in a Tropical Climate. *Water & Environmental Management Series*.
- Vymazal, J. (1995). *Algae and Element Cycling in Wetlands*. Boca Raton, FL, USA: CRC Press/Lewis Publisher.
- 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. *Constructes wetlands for wastewater treatment: municipal, industrial and agricultural*. Chelsea, MI, USA: Lewis Publishers. 319-351.
- Zulkifli, Y., Chan, C.H., Mohamed, M. and Ujang, Z. (2004). Characteristics of Storm Flow Hydrographs in an Oil Palm Catchment. *Proceedings of International Conference on Water and Wastewater 2004 – Technology and Management in Asia*. March 30-31, KL.