UNIVERSITI PUTRA MALAYSIA

PHYTOREMEDIATION OF PALM OIL MILL SECONDARY EFFLUENT USING VETIVER SYSTEM

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By

NEGISA DARAJEH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

March 2016

DEDICATION

Lovingly dedicated to all whose hearts beat for the Earth and try to save precious resources of our planet for posterity, I hope I have taken a small step in this regard. This work is also dedicated to my parents as a source of encouragement and inspiration throughout my life, who have always loved me unconditionally.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Doctor of Philosophy

PHYTOREMEDIATION OF PALM OIL MILL SECONDARY EFFLUENT BY THE VETIVER SYSTEM

By

NEGISA DARAJEH

March 2016

Chairman : Professor Azni Idris, PhD
Faculty : Engineering

Malaysia is the second largest exporter of palm oil after Indonesia. It has contributed to environmental pollution due to the production of huge quantities of Palm Oil Mill Effluent (POME). Palm Oil Mill Secondary Effluent (POMSE) the product of secondary treatment of POME, is facing serious environmental issue due to not set compliance of discharge standard. The BOD 20 mg/L level is a difficult target from DOE and many mills have not been able to comply with it. To date chemical treatment methods are the only successful means in getting BOD to be less than 20 mg/L. The biological POME polishing system achieved BOD levels of < 20 mg/L, but it cannot be sustained due to biological failure and poor bacterial growth. A phytoremediation method (floating Vetiver system) was used to treat POMSE. A batch study using 40L treatment tanks was carried out under different conditions and Response Surface Methodology (RSM) and Artificial Neural Network (ANN) were applied to optimize the treatment process. In this study POMSE concentration, Vetiver plant density and time have significant effects on the percentage removal of BOD, COD, TN, Color and TSS. An extraordinary decrease in organic matter as measured by BOD and COD (96% and 94%respectively) was recorded during the experimental duration of 4 weeks using a density of 30 Vetiver plants. The best and lowest final BOD of 2 mg/L was obtained when using 15 Vetiver plants after 13 days for low concentration POMSE (initial BOD= 50 mg/L). The next best result of BOD at 32 mg/L was obtained when using 30 Vetiver plants after 24 days for medium concentration POMSE (initial BOD= 175 mg/L). The study concluded that the Vetiver system is an effective method of polishing and treating POMSE to achieve stringent effluent standard. The comparison between RSM and ANN models by scale of Relative Standard Error (RSE) showed that ANN is more accurate in measuring treatment efficiency with an RSE of less than 0.45%, as opposed to 1.80% RSE with RSM.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

RAWATAN SECARA FITOPEMULIHAN BAGI EFLUEN SAWIT SEKUNDER MENGGUNAKAN SISTEM VETIVER

Oleh

NEGISA DARAJEH

Mac 2016

Pengerusi : Profesor Azni Idris, PhD
Fakulti : Kejuruteraan

Malaysia adalah negara pengeksport kedua terbesar minyak sawit selepas Indonesia. Ia telah menyumbang kepada pencemaran alam sekitar disebabkan oleh pengeluaran kuantiti yang besar sisa sawit, *Palm Oil Mill Effluent (POME)*. *Palm Oil Mill Secondary Effluent (POMSE)* adalah hasil rawatan sekunder POME, menghadapi isu alam sekitar yang serius disebabkan oleh kegagalan pematuhan piawai pelepasan. BOD tahap 20 mg/L adalah sasaran yang sukar dari Jabatan Alam Sekitar dan banyak kilang tidak dapat mematuhinya. Setakat ini kaedah rawatan kimia adalah satu-satunya cara berjaya mendapat BOD kurang daripada 20 mg/L, tetapi rawatan kimia bukanlah mampan. Sistem rawatan biologi mencapai tahap BOD <20 mg/L, tetapi ia tidak boleh dikekalkan kerana kegagalan sistem biologi dan pertumbuhan bakteria yang perlahan. Satu kaedah Fitopemulihan (sistem Vetiver terapung) telah digunakan untuk merawat POMSE. Satu kajian kelompok menggunakan tangki rawatan 40L telah dijalankan di bawah keadaan yang berbeza dan *Response Surface Methodology (RSM)* dan *Artificial Neural Network (ANN)* telah digunakan untuk mengoptimumkan proses rawatan. Dalam kajian ini, kepekatan POMSE, kepadatan pohon Vetiver dan masa mempunyai kesan yang besar ke atas penyingkiran peratusan BOD, COD, TN, Warna dan TSS. Penurunan yang luar biasa bagi bahan organik seperti yang diukur oleh BOD dan COD (96% dan 94%) dicatat sepanjang tempoh eksperimen 4 minggu menggunakan kepadatan 30 pohon Vetiver. Pencapaian yang terbaik dan terendah BOD akhir sebanyak 2 mg/L telah diperolehi apabila menggunakan 15 pohon Vetiver selepas 13 hari untuk POMSE kepekatan yang rendah (BOD awal = 50 mg/L). Hasil terbaik seterusnya ialah BOD pada 32 mg/L telah diperolehi apabila menggunakan 30 pohon Vetiver selepas 24 hari untuk kepekatan sederhana POMSE (BOD awal = 175 mg/L). Kajian ini menyimpulkan bahawa sistem Vetiver adalah kaedah yang berkesan untuk menggilap dan merawat POMSE untuk mencapai piawai efluen yang ketat. Perbandingan antara model RSM dan ANN menggunakan skala Relatif Ralat Piawai atau *Relative Standard Error (RSE)* menunjukkan bahawa ANN adalah lebih tepat dalam mengukur keberkesanan rawatan dengan RSE kurang daripada 0.45%, berbanding dengan RSM yang memperolehi 1.80% RSE.

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My deepest gratitude goes to my parents for their unflagging love and unconditional support throughout my life and my studies. I would like to express my special feeling of gratitude to my lovely grandpa and grandma who have been supporting me all the time.

Last, but not least, I wish to express my love and hoping to bring prosperity to my country (IRAN), with new development and modern education for our people. And I would also express my love and thanks to my second country (MALAYSIA).

I certify that a Thesis Examination Committee has met on 16 March 2016 to conduct the final examination of Negisa Darajeh on her thesis entitled "Phytoremediation of Palm Oil Mill Secondary Effluent using Vetiver System" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AAD	Absolute Average Deviation
ADMI	American Dye Manufacturers Institute
ANOVA	Analysis of Variance
ANN	Artificial Neural Network
BBP	Batch Back-Propagation
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CPO	Crude Palm Oil
DO	Dissolved Oxygen
DOE	Department of Environment
EQA	Environmental Quality Act
FFB	Fresh Fruit Bunches
FTW	Floating Treatment Wetland
FWSCWs	Free Water Surface Constructed Wetlands
g	Gram
GA	Genetic Algorithm
HCP	High Concentrated POME
HF CWs	Horizontal Flow Constructed Wetlands
HLR	Hydraulic Loading Rates
HRT	Hydraulic Retention Time
IBP	Incremental Back-Propagation
kg	Kilogram
LCP	Low Concentrated POMSE
LM	Levenberg Marquardt

MBR	Membrane Bioreactor
MCP	Medium Concentrated POMSE
MF	Microfiltration
Mg	Magnesium
mg/L	Milligrams Per Liter
pH	negative log of Hydrogen concentration
POME	Palm Oil Mill Effluent
POMSE	Palm Oil Mill Secondary Effluent
PPM	Parts Per Million
QP	Quick Propagation
RMSE	Root Mean Squared Error
RSM	Response Surface Methodology
TDS	Total Dissolved Solids
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
UF	Ultra Filtration
VF CWs	Vertical Flow Constructed Wetlands
VS	Vetiver System

CHAPTER 1

INTRODUCTION

1.1 General Background

Malaysia has the second largest number of palm oil mills in the world after Indonesia. This important industry, in addition to producing Palm Oil Mill Effluent (POME), has created other major problems in disposing lingo-cellulose biomass such as oil palm trunks (OPT), oil palm fronds (OPF), empty fruits bunches (EFB) palm pressed fibre (PPF) and palm shells (Abdullah & Sulaiman, 2013). Amongst all wastes produced, researchers have concluded that POME is the most difficult waste to handle due to the high volume generated (Madaki & Seng, 2013) and difficulties in handling its treatment (Rupani et al., 2010). During the processing of POME, more than 70% (by weight) of the processed fresh fruit bunches (FFB) usually remains as oil palm wastes (Prasertsan & Prasertsan, 1996).

In the 1960's, the easiest and cheapest method for disposal of partially treated or raw POME was to release it into nearby rivers. Excessive amounts of untreated POME deplete oxygen in water bodies and suffocate aquatic life such that many rivers have been environmentally destroyed by these discharges. By the 1970's, with the rapid expansion of the industry, local waterways could no longer handle the pollution load, as the potential oxygen depletion of raw POME is 100 times more than domestic sewage; so palm oil processing became synonymous with POME pollution (Madaki & Seng, 2013).

Although, new techniques and technologies have been developed to find more affordable solutions for POME management, palm oil mills are still trying to meet higher standards for effluent discharge permitted by the Department of Environment (DOE) Malaysia. By 1984, the law on effluent discharge in Malaysia limited the Biological Oxygen Demand (BOD) to 100 parts per million (ppm). However, since 2006, the DOE Malaysia has imposed a stricter requirement of 20 mg/L of BOD in the environmentally sensitive region of Sabah and Sarawak for example on the Kinabatangan River (Madaki & Seng, 2013).

There are more than 430 palm oil mills in Malaysia. The largest crude palm oil (CPO) producers in Malaysia are in Sabah and Sarawak states with 124 and 55 mills respectively (Wu et al., 2010). Based on the new environmental challenges facing palm oil mills, there is an urgent need for the palm oil mills to explore and take advantage of the current options and alternatives to improving their environmental performance. POME is generally biodegradable and treatment is based on anaerobic, aerobic and facultative processes. The processes are basically biochemical in nature and depend on the enhanced growth and activities of microorganisms to breakdown organic matter into simple end-product gases such as methane (CH_4), carbon dioxide (CO_2) and hydrogen sulfide (H_2S) (Thani et al., 1999). Although anaerobic digestion has been accepted as a successful method for POME treatment, this method alone has difficulty in meeting the DOE-mandated levels of limited discharge due to the high organic impacts of POME. The main problems related to anaerobic treatment are long retention time, slow start up (granulating reactors), the production of greenhouse gases and the large area required for conventional digesters (Borja et al., 1996; Metcalf, 2003; Chan et al., 2010).

Today, constructed wetlands (CWs) for wastewater treatment represent innovative and promising solutions for environmental protection, placing them in the overall context of the need for low-cost and sustainable wastewater treatment systems in developing countries (Babatunde et al., 2008; Vymazal, 2010b). CWs are engineered wastewater treatment systems that consist of aquatic plants which act as bio-filters by providing a large filtering surface area (Kadlec & Knight, 1996; Vymazal, 2005; Kumari & Tripathi, 2014). CWs have been successfully used to reduce environmental pollution by removing a wide range of pollutants from wastewater such as organic compounds, suspended solids, pathogens, metals, and nutrients (Haberl et al., 1995; Kadlec & Wallace, 2008; Gikas et al., 2013; Ranieri et al., 2013), as well as pharmaceutical and personal care product chemicals (Matamoros & Bayona, 2006; Ranieri et al., 2011; Zhang et al., 2014a).

In the past several decades, CWs have become a popular choice for wastewater treatment and have been recognized as attractive alternatives to conventional wastewater treatment methods. This is due to their high pollutant removal efficiency, easy operation and maintenance, low energy requirements, high rates of water recycling, and potential for providing significant wildlife habitat rehabilitation (Tanner et al., 2002; Kadlec & Wallace, 2008; Vymazal, 2010b). In terms of performance efficiency, most developing countries have warm tropical and subtropical climates, and it is generally accepted that CWs are more suitable for wastewater treatment in tropical regions than in temperate ones (Denny, 1997; Kivaisi, 2001). Wetlands in the tropics, which are exposed to higher temperatures and more direct sunlight throughout the year, have higher year-round plant productivity and a concomitant decrease in the time necessary for microbial biodegradation. This in turn results in more efficient treatment of pollutants (Zhang et al., 2012). One of the phytoremediation methods for wastewater treatment is Floating Treatment Wetlands (FTWs) which is a novel treatment concept that employs rooted, emergent macrophytes (such as: Vetiver, Water Hyacinth, Typha, etc.) growing on floating platforms rather than rooted in the sediments (Fonder & Headley, 2011; Tanner & Headley, 2011). One of the main advantages of FTWs over conventional sediment-rooted wetlands is their ability to cope with variable water depth (Kerr-Upal et al., 2000). In FTW, the plant roots are not in contact with the benthic sediments or soil and can access nutrients contained within the floating platforms and in the water column (Kadlec & Wallace, 2008). This is in contrast to a sediment-bound wetland, where the plant roots obtain nutrients from the underlying soil. Beneath the floating platforms, a network of roots, rhizomes, and the hanging root biofilm provides a biologically active surface area for the biochemical transformation of contaminants and physical processes such as filtering and entrapment of particulates (Kyambadde et al., 2004; Li et al., 2009).

Application of Vetiver grass (*Chrysopogon zizanioides* L.), which belongs to the Gramineae family, for wastewater treatment is a new and innovative phytoremedial method. It is at the heart of a green and environmental friendly wastewater treatment system as well as being used in a natural recycling method. Vetiver can be used to treat industrial and domestic wastewater due to its exceptional absorption ability and its capacity to tolerate excessive levels of nutrients (Wagner et al., 2003; Truong, 2008). In the treatment process, the Vetiver plant absorbs essential plant nutrients such as nitrogen (N), phosphorus (P) and cationic elements, and converts them to biomass that has other uses. The biomass provides high quality and nutritious animal feed, mulching material for gardens, roof thatching material, handicraft fibres (to make ropes, mats, hats, baskets), raw material for making pulp, paper and organic matter amendments used in organic farming (Smeal et al., 2003). Recently its use has been extended to include biofuel production and carbon sequestration (Pinners, 2014). Due to its extraordinary and unique morphological and physiological attributes, Vetiver grass has been used as a phytoremediation method to treat both liquid and solid wastes globally. One of the most prominent and outstanding Vetiver grass applications is the treatment of contaminated wastewater that has gained international recognition and received awards such as the American Academy of Environmental Engineering Award in 2012.

Conventional optimization methods are "one-factor-at-a-time" techniques. This approach often fails to identify the variables that give rise to the optimum response because the effects of factor interactions are not taken into account in such procedures (Deepak et al., 2008). Response surface methodology (RSM) is an analytical tool used to establish the optimum conditions for a multi-variable structure and has been useful for optimizing wastewater treatment protocols. In last two decades, artificial neural network (ANN) techniques have been applied as one of the appropriate methods for empirical modeling and optimization in wastewater treatment optimization studies. Use of advanced statistical methods such as RSM and ANN provide an alternative methodology for optimizing a particular process by considering the interactions among the factors to give an estimate of the combined effect of these factors on a response.

1.2 Problem Statement

There are currently about 430 palm oil mills in Malaysia that produce about 18.9 million tonnes of crude palm oil (CPO) obtained from 92.9 million tonnes of fresh fruit bunches (FFB), with the assumption that the ratio of FFB processed to POME generated is 1:1.5 the total POME generated was about 139.35 million tonnes (Noorshamsiana et al., 2013). POME has been identified as one of the main sources of water pollution in Malaysia due to the resulting high biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Palm oil mill secondary effluent (POMSE), the product of secondary treatment of POME, is facing serious environmental issue due to not set compliance of discharge standard. POMSE is characterized by its thick, brownish color, higher pH (7 to 9 pH), but has a lower BOD and COD effluent as compared to POME. Although the industry claims that POMSE is properly treated with the pond system, open tank digesters and extended aeration systems, this conventional system has often been found to exceed the standard discharge limit set by Department of Environment (DOE) Malaysia as defined in the 1974 Environment Quality Act (EQA). Although the law regulating discharge limits has been implemented by government, some studies such as those done by Shahrifun et al. (2014), Fadzil et al. (2013) and Siew (2006) have showed that COD and BOD of POMSE is higher than the permitted legal levels.

Today phytoremediation as a green method is one of the main environmentally friendly methods that scientists currently use in research on wastewater treatment methods. Phytoremediation directly uses green plants to clean up contaminated water, soils, or sediments. Phytoremediation especially using Vetiver plant is an emerging, cost effective, aesthetically pleasing, low cost and suitable solution for many environmental problems across the world (Macek et al., 2004; Truong et al., 2010; Paz-Alberto & Sigua, 2013). The World Bank first used Vetiver grass for soil and water conservation purposes in India in the 1980s. But since that time, Vetiver's role has been successfully extended to waste water treatment and environmental protection, due to its unique morphological and physiological characteristics and tolerance to adverse conditions (Truong, 2003a).

Environmental quality regulations beginning in 1997 as enforced by the DOE regarding the discharge of effluent from the palm oil industry require all palm oil by-products be effectively managed in order to treat and dispose of these by-products thus enhancing environmental conservation and increasing the quality of river water. In particular since 2006 in the environmentally sensitive regions of Sabah and Sarawak, the DOE has imposed a stricter requirement of BOD < 20 mg/L. The BOD 20 mg/L level is a difficult target and many mills have not been able to comply with it. To date chemical treatment methods are the only successful means in getting BOD to be less than 20 mg/L. The biological POME polishing system achieved BOD levels of < 20 mg/L, but it cannot be sustained due to biological failure and poor bacterial growth.

COD fractionation has been widely used to show high levels of biodegradable and non-biodegradable content in wastewater and making tertiary treatment very difficult. A recent study was conducted by Mohed (2015) on COD fractionation to determine the biodegradable and non-biodegradable fractions in POME taken from the effluent of facultative pond 1 (FP1) and facultative pond 3 (FP3) (last pond) and the results are shown in Table 1.1.

Table 1.1 COD Fractionation of FP1 and FP3 POME
Source: (Mohed, 2015)

Influent	COD total (mg/L)	COD Fractionation (mg/L)			
		Ss (%)	Xs (%)	S_I (%)	X_I (%)
FP1 POME	3930	668 (17)	472 (12)	943 (24)	1847 (47)
FP3 POME	2350	75 (3.2)	536 (22.8)	917 (39)	822 (35)

Readily biodegradable (Ss); Slowly biodegradable (Xs); Soluble non biodegradable (Si); Particulate non biodegradable (Xi).

The results show that FP1 contains a high concentration of readily biodegradable material (Ss) at 17% of the total COD, contrary to FP3 (last pond) which contains a low concentration of Ss at 3.2% of total COD. Meanwhile, the concentration of slowly biodegradable material (Xs) in FP3 is estimated at 22.8% of the total COD, which is higher than FP1 at 12% of the total COD. However, some of the Xs may actually be soluble in Ss (Guisasola, 2005). On the other hand, the non-biodegradable fraction (Si plus Xi) contained in FP1 and FP3 is almost the same with 71% and 74% from total COD, respectively. The biodegradable fraction in FP1 and FP3 (Ss plus Xs) were recorded below 50% of total COD, contrary to study by Salmiati et al. (2010) which reported more than 50% of total COD. This difference could be due to type of POME used in their studies. While COD fractionation in the Mohed (2015) study was done on POME from the final facultative pond, Salmiati et al. (2010) used fermented POME collected from the anaerobic tank. Both FP1 and FP3 contain a high concentration of particulate non-biodegradable material (Xi) with 47% and 35%, respectively. According to these results more than 70% of POME in pond 3 is non-biodegradable and 33 % is slowly biodegradable. This means that POME after pond 3 cannot be treated by stimulating bacterial activity alone, as this requires a much too long retention time. Consequently, there is an important need for a low cost and environmentally green solution for the final pond POMSE treatment. The central hypothesis of this research is that the use of the innovative Vetiver System, a green and environmentally friendly treatment method provides a suitable solution for POME treatment and polishing.

1.3 Limitations of the current POMSE treatment methods

The above data shows that POMSE generated from palm oil mills contains high concentration of organic pollutants, which must be reduced to an acceptable level before being discharged to the surrounding environment. Studies by Zinatizadeh et al. (2006), Poh and Chong (2009) and Choi et al. (2013) demonstrated the success of an anaerobic process to treat POME, therefore, most mills employ this treatment method to treat their wastewater at the primary stage. However for the tertiary or polishing stage, the mills as well as wastewater technology providers are still looking for the best treatment for POME and POMSE. Some of the approaches that have been studied for tertiary treatment of POME are ultra-filtration (Wu et al., 2007), using biological aerated filters (BAF) (Cheng et al., 2010), adsorption (Shavandi et al., 2012) and a membrane bioreactor process (MBR) (Damayanti et al., 2011). Although all these methods show positive results for POME treatment, they still have drawbacks that need to be addressed. Membrane fouling/scaling, frequent filter back washing, and high capital cost are the main problems with the membrane filtration process (Cartwright, 1991). For BAF and MBR, the long hydraulic retention time is the major problem for these treatment processes.

According to published results, Vetiver appears to be a more effective, environmentally friendly method of polishing and treating POMSE for pollutants with moderate to low BOD, COD and Total Nitrogen (TN) than other methods currently being used. In addition varying Vetiver planting density may have a significant impact on nutrient removal efficiency and aeration that improves the removal efficiency of pollutants in POMSE.

1.4 Objectives of Research

The overall goal of this study is to evaluate the removal of organic and inorganic components of Palm Oil Mill Secondary Effluent using Vetiver grass in order to permit compliance with the latest DOE regulation for POME discharge that has BOD levels lower than 20 mg/L.

The specific objectives are to:

1- To evaluate Vetiver grass with respect to its ability to reduce Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Nitrogen (TN), Total suspended solids (TSS) and Color from Palm Oil Mill Secondary Effluent; in aerobic condition.

2- To study the effects of POMSE concentration, Vetiver plant density and retention time on the treatment of Palm Oil Mill Secondary Effluent; and

3- To apply and compare two advanced statistical models (RSM and ANN) used to study the variables that could optimize treatment conditions for Palm Oil Mill Secondary Effluent.

1.5 Scope of Research

The research presented in this study focus on Vetiver grass (*Chrysopogon zizanioides*) due to the fact Vetiver is a non-invasive plant species. Invasiveness of plants such as: cattails *(Typha latifolia)* and common reeds *(Phragmites spp.)* is aggressive and quickly permits these species to inhabit disturbed areas, ultimately reducing diversity and productivity of wetland systems.

One of the main advantages of using floating wetlands as a phytoremediation method is the simplicity of its implementation. No highly delineated design is needed for these wetlands. The floating plants facilitate the uptake of nutrients and pollutants irrespective of the water depth or area shape, implying that existing ponds at palm oil mills can be used directly without the need to build costly new wetlands.

Previous studies such as those done by Zhang et al. (2010), Dong et al. (2012), Kumari and Tripathi (2014), Jones Jr (2014) and Wu et al. (2014) reported that the poor oxygen transfer rates in constructed wetlands often restrict treatment efficiency. They also suggest that the use of artificial aeration can overcome oxygen limitations to meet advanced treatment standards. This research therefore studies the effect of aeration on Vetiver grass pollutant removal ability for treatment of POMSE. Based on previous research results and recommendations, different POMSE concentrations, plant densities and retention times were investigated.

Preliminary treatment studied the survival of Vetiver when grown on the POMSE. Once proven that Vetiver does indeed survive when grown on POMSE, the Vetiver growth potential under various aerobic conditions and its pollutant removal capacity were tested using different concentrations of POMSE and different Vetiver densities and treatment times.

Statistical procedures were used in this research to provide an alternative methodology to optimize a particular process by considering mutual interactions among the variables and give an estimate of the combined effect of these variables on final results. Response surface methodology (RSM) is one such statistical technique, based on the fundamental principles of statistics, randomization, replication and duplication, which simplifies the optimization process by studying the mutual interactions among the variables over a range of values in a statistically valid manner. The use of artificial neural networks (ANNs) in the modeling of complex systems that have nonlinear characteristics is a popular tool for modeling of biological processes. Up till now, no attempt has ever been made to test models of Vetiver grass on floating wetlands treatment of POMSE.

In this research, Vetiver grass was chosen for POMSE treatment because of its exceptional high absorption and tolerance characteristics with respect to excessive levels of pollutants. The pollutant removal capability of Vetiver was tested for COD, BOD, TN, TSS and color. The RSM results were then compared with those produced using ANN modeling methodology. The principle output of the present study is to scientifically demonstrate the positive value of using Vetiver as a phytoremediation method for POMSE treatment.

1.6 Thesis Layout

This thesis includes 5 chapters as listed below.

i. Introduction to the subject matter, problems, importance, validity of this work and the research objectives are indicated.
ii. Review of the literature related to POME treatment, phytoremediation,

treatment of various types of wastewater using wetland methodology, and Vetiver grass history. Recent articles published in related fields are reviewed for comparison purposes.

iii. The methodology used for compound detection and a description of all analytic materials used is provided.

iv. Results obtained in the study are presented and discussed with respect to aeration effects, Vetiver plant densities, and POMSE concentrations as they relate to pollutant removal.

v. Research conclusions and recommendations for further research are provided.

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