TREATMENT OF INDUSTRIAL WASTEWATER USING CONSTRUCTED WETLAND: REMOVAL OF ORTHOPHOSPHATE AND AMMONIA NITROGEN

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Chemical Engineering (Biotechnology)

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I declare that this project report entitled "*Treatment of Industrial Wastewater Using Constructed Wetland: Removal of Orthophosphate and Ammonia Nitrogen*" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	……………………
Name	:	Anabil Ubil
Date	:	16th May 2008

Dedicated to mom, dad and the whole family

Thank you for everything…

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This is a fulfilling moment when the report has been completed successfully after a few months of hard work.

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ABSTRACT

Industrial wastewater is one of the major concerns of the environment problems. As the wastewater is found to be highly contaminated, it could not be discharged directly into the environment. Therefore, wastewater treatment is essential to minimize the effect of the contaminants to nature. Based on previous studies, constructed wetland system (CWS) was proved to have high efficiency in treating industrial wastewater with low operating and maintenance cost. The industrial wastewater studied was Palm Oil Mill Effluent (POME) which was taken from Lepar Hilir Palm Oil Mill. In this research, lab scale of free water surface constructed wetlands was designed with the water lettuce *(Pistia Stratiotes*) as the wetland plant. The parameter studied including ammonia nitrogen (NH_3-N) and orthophosphate (Po_4^{3-}). In order to investigate the effectiveness of the systems, three variables were studied which were the number of plant used (5, 10, 15), the wastewater concentration (87.5%, 75%, 62.5%) and the physical appearance of the plants during the treatment. The results showed that NH_3-N was removed at high removal efficiency meanwhile Po_4^{3-}removal appeared at low removal efficiency. Both NH_3-N and Po_4^{3-} removal showed better results in the CWS with 15 plants. In term of the different POME concentration variable, the CWS with 87.5% showed the highest removal efficiency for NH_3-N and 75% POME concentration showed the highest removal efficiency for Po_4^{3-}. For plant growth observation, at the end of the treatment, many of the water lettuces were wilted. As conclusion, this study showed that constructed wetland can remove contaminant in POME.

ABSTRAK

Sisa buangan industri merupakan salah satu masalah utama kepada alam sekitar. Sisa buangan ini amat tercemar dan tidak boleh dibuang sewenang-wenangnya ke alam sekitar. Oleh yang demikian, rawatan sisa buangan adalah penting untuk meminimumkan kesan pencemaran kepada alam sekitar. Berdasarkan kajian yang dijalankan sebelum ini, sistem tanah bencah buatan menunjukkan kecekapan yang tinggi dalam merawat sisa buangan industri dengan kos operasi dan penyelenggaraan yang murah. Sisa buangan industri yang dikaji ialah sisa cecair daripada pemprosesan kelapa sawit yang diambil daripada kilang kelapa sawit Lepar Hilir. Sistem tanah bencah buatan ini adalah berskala makmal dan menggunakan pokok kiambang (*pistia stratiotes*) sebagai tumbuhan akuatik. Parameter yang telah dikaji ialah ammonia nitrogen (NH_3-N) dan orthophosphate (PO_4^{3-}). Untuk mengkaji keberkesanan sistem ini, eksperimen dijalankan berdasarkan bilangan tumbuhan akuatik yang berlainan (5, 10, 15), kepekatan sisa buangan (87.5%, 75%, 62.5%) dan keadaan fizikal pokok kiambang pada akhir rawatan. Keputusan kajian menunjukkan NH_3-N telah disingkirkan pada peratus keberkesanan yang tinggi manakala peratus keberkesanan penyingkiran PO_4^{3-} adalah rendah. Penyingkiran kedua-dua NH_3-N dan PO_4^{3-}menunjukkan keputusan yang baik di dalam tanah bencah buatan yang mempunyai 15 pokok kiambang. Untuk kepekatan sisa buangan yang berlainan, didapati tanah bencah buatan pada kepekatan 87.5% telah menyingkirkan NH_3-N pada jumlah yang tertinggi berbanding kepekatan yang lain manakala bagi PO_4^{3-} , penyingkiran yang tertinggit dicatatkan pada kepekatan 75%. Pemerhatian kepada keadaan fizikal tumbuhan menunjukkan keadaan daun tumbuhan adalah semakin layu di akhir eksperimen. Secara keseluruhannya, kajian ini menunjukkan bahawa sistem tanah bencah buatan boleh menyingkirkan bahan pencemar di dalam sisa buangan kilang kelapa sawit.

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BOD	-	Biochemical Oxygen Demand
$CaCO_3$	-	Calcium carbonate
C/C_O	-	Present concentration over initial concentration
COD	-	Chemical Oxygen Demand
CW	-	Constructed wetland
Fe	-	Ferum
FWS	-	Free Water Surface
mg/g	-	milligram per gram
mg/L	-	milligram per liter
mL/s	-	milliliter per second
Mn	-	Manganese
NH_4^+	-	Ammonia
NH_3-N	-	Ammonia Nitrogen
NO_3-N	-	Nitrate Nitrogen
PO_4^{3-}	-	Orthophosphate
POME	-	Palm Oil Mill Effluent
SF	-	Sub Surface Flow
SS	-	Suspended solid
TN	-	Total nitrogen
TP	–	Total phosphorus

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CHAPTER 1

INTRODUCTION

2.1 Background of Study

Over the years, the high growth rate of the industrialization and urbanization has causes several environmental problem all over the world. Until recently, water was viewed by the industry as a nearly-free commodity and was used as a medium for receiving rejected chemicals and rejecting thermal energy from processing plants. The main environmental aspects of wastewater are the impacts on surface water quality and groundwater quality, because some of the wastewater may migrate from the refuse and contaminate the surface waters and groundwater. If not dealt properly its can affecting aquatic ecosystems, human health problems and effect the environment. It is important that wastewater are treated and contained to prevent these occurrences.

Nowadays, wastewater treatment is one of the most important problems that we are facing. Underground disposal of commercial and industrial wastewater can cause serious soil and ground-water contamination if not carefully controlled. On-site sewage treatment systems are designed to treat household wastewater and do not provide adequate treatment for the types of contaminants found in commercial and industrial facilities. Because of the potential for wastewater to contaminate soil and ground water, the policies and regulations regarding underground disposal systems are strict. Increase in production of the industry creates challenges for cost effective treatment methods to process wastewater. Disposal of wastewaters from an industrial plant is a difficult and costly problem.

The increasing of the numbers of wetland all over the world proves that the interest has been growing in treating and recycling wastewater with constructed wetlands. An international survey identified 67 wetlands for wastewater treatment in Canada (Pries 1994). Of these wetlands, 67% are full-scale operating systems. Meanwhile, in southern part of USA, the distribution between FWS and SSF wetlands was almost even. Altogether and including wetlands treating acid, Kadlec and Knight (1996) estimated that there were over 650 natural wetlands in USA and Canada in 1994.

Wetlands for water purification have been used in different parts of the world since 1950 to successfully treat agricultural, municipal or industrial wastewaters (Verhoeven and Meuleman, 1999). These systems effectively integrate wastewater treatment and resource enhancement at a competitive cost, in some cases a reduction of 60 to 95% from the cost of conventional mechanical systems (Wilson *et al*., 1998). In constructed wetland, because chemical treatment of the wastewater is not necessary, the effluent is far less environmentally damaging. In addition to their ecological advantages, constructed wetlands offer open space and visual amenities. The EPA, in reviews of 17 wetland treatment systems from across the country, found that they significantly improve water quality and provide many additional benefits such as wildlife habitats (U.S. EPA, 2000).

As they are depleted and affected by development, the importance of natural wetlands in watershed systems becomes increasingly apparent. Efforts to restore and maintain wetlands have been crucial to water quality in many areas. Therefore, the treatment of wastewater by natural systems seems to be environmentally sustainable for treatment of many constituents. Constructed wetlands have proven very effective technology for the treatment and have great potential as a clean-up technology of variety of wastewaters.

2.2 Problem Statement

Nitrogen is an essential ingredient in the formation of proteins for cell growth. From complex organisms like animals to the simple bacteria, living thing needs some form of nitrogen to survive. Microorganisms require nitrogen to form proteins, cell wall components, and nucleic acids (Maier, 1999). Phosphorus is an essential nutrient required for the development of strong bones and teeth, for metabolism of fats and carbohydrates, for protein synthesis, and for synthesis of ATP (an energy storage molecule) by the body.

Excess nitrogen and phosphorus in the environment can be a bad thing. Excess nitrogen and phosphates discharged into the waterways can contribute to eutrophication, the gradual change of water bodies into marshes, meadows, and forests. It can also contribute to massive algae blooms leading to oxygen depletion in water and its associated problems. Ammonia is toxic to fish, and nitrates at high enough dosages in the drinking water cause methemoglobinemia in infants (Clarke *et al*., 2002). Phosphorus has been described as a major limiting nutrient in freshwater marshes (Klopatek, 1978) and various other wetland types.

Increasing input of nitrogen and phosphorus compounds in the lakes and artificial reservoirs lead to increase of primary production of water born organisms and finally its consequence is disappearance of oxygen in waters (Kirby, 2002). Therefore, constructed wetland was developed as an alternative method to treat the industrial wastewater since it has low cost of construction and maintenance (Verhoeven J.T.A and A.F.M Meuleman, 1999). Constructed wetlands have great potential as a clean-up technology for a variety of wastewaters. Constructed wetlands have proven to be a very effective method for the treatment of municipal and industrial wastewater. Due to its high rate of the biological activities, the wetland can transform common pollutants into harmless byproducts and essential nutrients (Kadlec and Knight, 1996).

2.3 Scope of Research Work

In each experiment, Lab-scaled constructed wetland was set-up for the wastewater treatment. The wastewater was taken from Lepar Hilir Palm Oil Mill, Gambang. The same plant species (*Pistia Stratiotes.*) was used and the amount of wastewater for each container was 15 liters. The scopes of study include:

- The efficiency of wastewater treatment was evaluated in terms of orthophosphate and ammonia nitrogen water quality parameters analysis.
- There were 2 types of wetland system being set up based on the variables. The condition of the wetland systems including different number of plant and different wastewater concentration.
- The effects of wastewater on wetland plant growth were determined in terms of the physical appearance of the leaves throughout the experiment.
- One control experiment was set-up for comparison with the variables, with no addition or subtraction to the wastewater sample.
- Approximately, 60 wetland plants and 7 containers were used in the experiment. The treatment was carried out for duration of 12 days.

The equipment used for the analysis was DR 2800 portable spectrophotometer (HACH). All experiment was conducted in open environment condition with day light source. The experiment was carried out at the Basic Science Laboratory, Chemical Engineering Laboratory, Universiti Malaysia Pahang.

2.4 Objective of the Project

The purpose of the study is to investigate the efficiency of the constructed wetland system using Water lettuce (*Pistia Stratiotes L*) to remove the nutrient (orthophosphate and ammonia nitrogen) from Palm Oil Mill Effluent (POME).

CHAPTER 2

LITERATURE REVIEW

5.3 Wetland

Wetlands are the areas where the soil is saturated with water or where shallow standing water results in the absence of plant species which depend on aerobic soil condition (Kadlec and Knight, 1996). The aquatic plants that grow in wetland are unique since microorganisms in the soil consume most of the oxygen in the soil, making it unfit for most of the common plant species (Paquiz, 2004). Wetlands are composed of an underlying impervious layer, overlying hydric soil, detritus and hydrophilic vegetation. They receive water from precipitation, groundwater, runoff and from surrounding lacustrine systems (streams, rivers, and lakes) and absorbing water during wet periods and releasing water during dry periods of the year. As a result wetlands can help reduce flooding, ease periods of droughts and recharge groundwater (Kadlec and Knight, 1996). In addition, wetlands can be considered as the kidneys of the planet since they have the ability to filter out pollutants, transform nutrients and serve as sinks for many compounds (Jordan *et al*., 1999). Generally, there are two types of wetland, which are natural wetland and constructed wetland.

5.3.1 Natural Wetland

Natural wetlands are transitional areas located between terrestrial ecosystems and a more permanent water body such as lakes. Natural wetlands perform many functions that are beneficial to both humans and wildlife (Kadlec and Knight, 1996). One of their most important functions is water filtration. As water flows through a wetland, it slows down and many of the suspended solids become trapped by vegetation and settle out. Generally, natural wetlands include swamps, marshes, fens, and bogs. Two types of natural wetlands which are frequently used are swamp and marsh.

Swamp wetland is rich in nutrient which offers excellent habitat for mammals, frog, salamanders and songbirds (DNR, 1998). Swamp is the only type of wetland that is dominated by water-tolerated woody plants such as black spruce and alder. On the other side, marsh is the type of wetland which is frequently inundated with inflowing water (Moore, 1993). The marsh plants are usually dominated by non-woody, emergent aquatic macrophytes with extensive root and rhizome systems that are morphologically adapted to saturated soil condition (Galbrand, 2003). Marsh is important to support abundant plants and provides critical habitat for wildlife such as reptiles, aquatic mammals, amphibians and aquatic insects (DNR, 1998).

Many natural wetland plant species are unable to survive in wetlands that receive increased flows (EPA, 1993). Only a selective amount of natural wetland species are adapted to tolerate increases in the natural hydrology. Most natural wetlands (based on the US Army Corps of Engineers definition of a wetland) are not suitable for treatment of wastewater because of the inability of the plant species to sustain in elevated hydrologic conditions. Since the preservation of the natural wetland is essential, natural wetland is not suitable for wastewater treatment. Natural wetlands should be preserved for nature purposes rather than being overburdened deliberately as wastewater treatment systems (Paquiz, 2004)

5.3.2 Constructed Wetland

As well as natural wetlands, there exist constructed wetlands. Constructed wetlands are engineered marshes that duplicate natural processes to cleanse water. Constructed wetlands simulate natural wastewater treatment systems, using flow beds to support water-loving plants. The roots of these plants help provide an aerobic environment to aggressively break down contaminants. Constructed wetlands can offer an affordable solution to wastewater for sites with some of the following characteristics: warm climate, failed conventional absorption field, narrow or oddly-shaped lot, high water table, low soil percolation, high organic matter/suspended solids in wastewater and enough unshaded area. These wetlands are mainly constructed with the purpose of treating wastewater. Constructed wetlands, in contrast to natural wetlands, are man-made systems or engineered wetlands that are designed, built and operated to emulate functions of natural wetlands for human desires and needs. It is created from a non-wetland ecosystem or a former terrestrial environment, mainly for the purpose of contaminant or pollutant removal from wastewater.

5.3.3 Types of Constructed Wetland

There are two main types of constructed wetlands which are surface-flow (SF) constructed wetlands, and subsurface-flow (SSF) constructed wetlands (Tchobanoglous, 1997; Kirby, 2002).

a) Surface Flow (SF) Systems

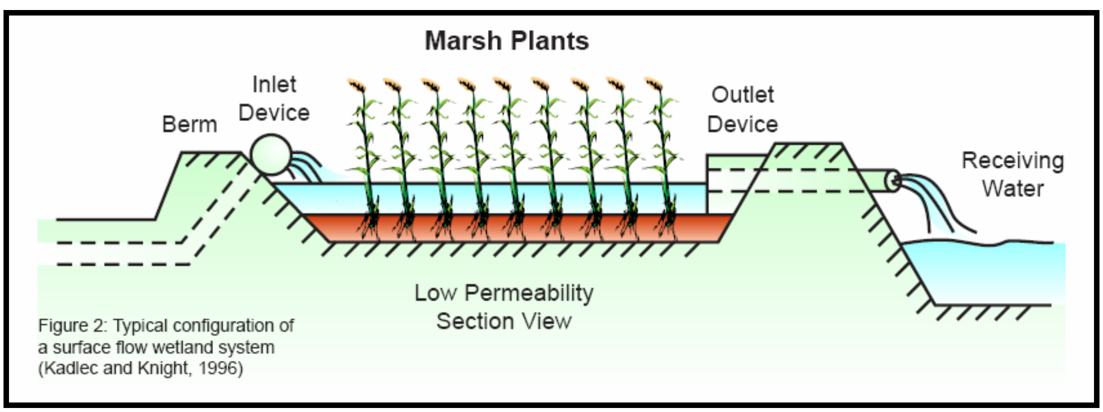

Figure 2.1 Typical configuration of a surface flow wetland system (Kadlec and Knight, 1996)

The majority of constructed wetland treatment systems are Surface-Flow or Free-Water surface (FWS) systems. Figure 2.1 showed the typical configuration of a surface flow wetland system. These types utilize influent waters that flow across a basin or a channel that supports a variety of vegetation, and water is visible at a relatively shallow depth above the surface of the substrate materials. Substrates are generally native soils and clay or impervious geotechnical materials that prevent seepage (Reed, *et al*., 1995). The report in EPA (1993), verifies that SF constructed wetlands can be a reliable and cost effective treatment method for a variety of wastewaters. These included domestic, municipal, and industrial wastewaters.

b) Sub-surface Flow (SSF) System

In a Sub-surface Flow (SSF) system, water flows from one end to the other end through permeable substrates which is made of mixture of soil and gravel or crusher rock. The substrate will support the growth of rooted emergent vegetation. It is also called “Root-Zone Method” or “Rock-Reed-Filter” or “Emergent Vegetation Bed System” (Paquiz, 2004). Figure 2.2 showed the typical configuration of a sub-surface flow system.

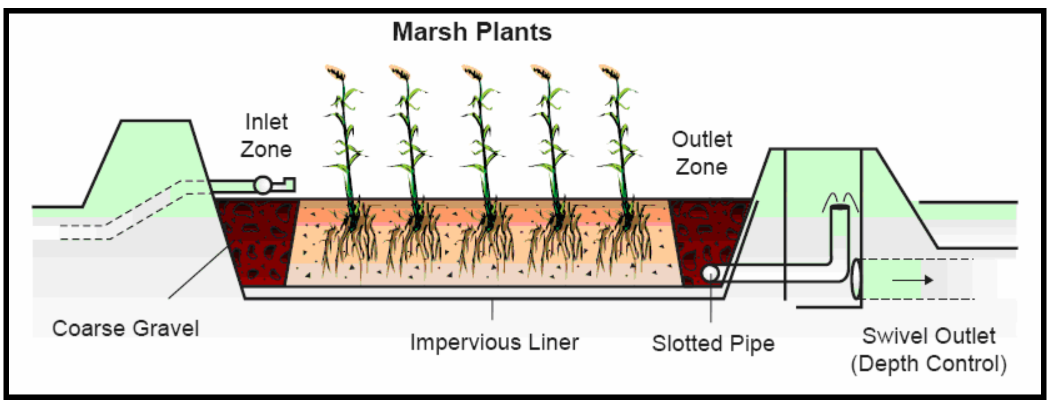

Figure 2.2 Typical configuration of a sub-surface flow system (Kadlec and Knight, 1996)

According to Moore (1993), the substrate supports the growth of vegetation of emergent macrophytes such as reed (*Phragmites spp*.) and Eurasian watermilfoil (*Myriophyllum spicatum*). The media depth is about 0.6 m deep and the bottom is a clay layer to prevent seepage. Media size for most gravel substrate ranged from 5 to 230 mm with 13 to 76 mm being typical. The bottom of the bed is sloped to minimize water that flows overland. Wastewater flows by gravity horizontally through the root zone of the vegetation about 100-150 mm below the gravel surface. When designing this type of system, the specific surface area and porosity of the medium are the most important variables (Hammer 1992; Tchobanoglous, 1997). Typically, SSF systems are smaller than SF systems; however the material for the matrix is more costly (Kirby, 2002). The design criteria for the constructed wetlands are shown in table 2.1. Usually the same species of emergent vegetation are used in both types of systems (Hammer, 1992; Reed *et al*., 1995).

Table 2.1: Design criteria for constructed wetlands (Source: Adapted in part from Kadlec and Knight 1996; Tchobanoglous, 1997; Kirby, 2002)

Design parameter	Unit	Surface wetland	Subsurface wetland
Retention time	d	4 to 14	2 to 7
Water depth / media depth	m, mm	0.1 to 0.8	0.3 to 0.6
Hydroulic loading rate	d^{-1}, m^3	15 to 65	80 to 300
Volume flow rate	d^{-1}	200 to 75000	5 to 13000

5.3.4 Wetland Component

Liu (2002) revealed that there are three components that characterize a wetland. The wetland is characterized by the presence of water, the macrophyte vegetation and substrates. All of these three elements play important roles in wetlands.

Hydrology in wetlands is important in terms of the water flow and storage volume as well as the movement of the water through the wetland system. The water flow and storage determine the length of time the water stays in the wetland and thus, the possible contact between the root zone microorganisms and waterborne substances (Liu, 2002).

Wetland vegetation is the most important components in wetland system because wetland plants effectively facilitate many chemical processes. The vegetative facilitates ideal environment for microbial populations. They do so by providing the surface areas for the microbial attachment (Hammer, 1992). In a study done by Hammer and Knight (1994), they reported the availability of the attachment surface strongly influences denitrification rates within a wetland.

Wetland substrate is important in wetland because most of phosphorus chemical transformation occurs in the substrate form (Liu, 2002). Phosphorus removal is mostly controlled by adsorption and precipitation (Richardson and Clark, 1993). If phosphorus removal is not required, the coarse-textures sand can be used as substrate in wetland (Lim and Polpraset, 1998). However, soils may be chosen as substrate if phosphorus removal is required.

5.3.5 Treatment Process Mechanism

a.) Nitrogen

In wetland, there are three main mechanisms concerning nitrogen removal which are ammonification, followed by nitrification or denitrification, then plant uptake and ammonia volatilization (Campbell and Ogden, 1999).

Ammonification is the process when organic nitrogen is broken down to primarily ammonium by microorganisms in the substrate and water column. Nitrification refers to the biological conversion of ammonium compounds to nitrite and nitrate-nitrogen by bacteria in the presence of oxygen where approximately 4.6 mg/l of dissolved oxygen is required to convert 1 mg/l of nitrogen (USEPA, 1975). Vegetative uptake of nitrogen in wetlands is complex. Klopatek (1978) suggests that aquatic vegetation functions as a "nutrient pump", uptaking nitrogen from the sediment and water column and temporarily immobilizing it within plant tissues. Nitrogen uptake is most effective where water flows slowly and evenly over the wetland surface thus providing an increase in the effective area and detention time available for biological