NUTRIENT REMOVAL IN PIG FARM WASTEWATER USING AQUATIC MACROPHYTES - WATER HYACINTH (Eichhornia crassipes) AND WATER LETTUCE (Pistia stratiotes)

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Wee Boon Hong

A dissertation submitted in partial fulfillment of the requirement for the degree of Bachelor of Science (Hons.)

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2005
DECLARATION

No portion of the work referred to in this dissertation has been submitted in support of an application for another degree of qualification of this or any other university or institution of higher learning.

(Wee Boon Hong)
Matric No : 9290
Date : 26 Mac 2005
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ABSTRACT

The efficiency of the two floating aquatic macrophytes (water hyacinth and water lettuce) to improve the water quality of pig farm wastewater was studied. Experiments were conducted by using pig farm wastewater at different dilution (1:1, 1:5 and 1:9) as well as undiluted wastewater. Water hyacinth (Eichhornia crassipes) and water lettuce (Pistia stratiotes) grew well in the 1:5 dilution and 1:9 dilution wastewater. Hence, wastewater with 1:5 dilution was selected for the subsequent experiments for evaluating the nutrient removal efficiency of the plants in monoculture and polyculture. The water parameters evaluated in this experiment were water temperature, pH, dissolved oxygen, ammonia-N, and total phosphorus. For plant contents, total nitrogen and total phosphorus were studied. Throughout the experiments, solar radiation and surrounding temperature were continuously monitored. The reduction rate for ammonia-N and total phosphorus followed first-order kinetics. In terms of percent reduction of total phosphorus, water hyacinth monoculture has the greatest performance (62.98%), followed by polyculture system (54.45%). Whereas for percent reduction of ammonia-N, all the plant systems have similar efficiency whereby reducing the ammonia-N up to 99%. Moreover, water hyacinth monoculture could also improve the pig farm wastewater quality in terms of the pH (pH 7.33) and dissolved oxygen (DO = 7.94mg/L). Therefore, water hyacinth monoculture would serve to be a better floating aquatic macrophyte-based wastewater treatment system in nutrient reduction followed by polyculture and water lettuce monoculture.

Key words: Water hyacinth, water lettuce, pig farm.

ABSTRAK


Kata kunci: Water hyacinth, water lettuce, ladang khinzir.
1.1 Introduction

Livestock industries especially pig farm has grown drastically from a family-sized farm to a large-scale commercial farming industries (Abdullah, 2003). Statistics of the standing pig population in Samarahan division has reached to 174,399 in the year 2002 followed by Kuching division (111,972). The total pig population in the whole of Sarawak has increased to 461,289 which was approximately half a million (Sarawak Agriculture Department, 2002). Therefore, an increase in livestock resulted in an increase of wastewater production. The daily utilization of water for cleanup purposes is believed to reach approximately 30 to 40 liters per standing pig population (SPP) and being discharged without any treatment (Abdullah, 2003). The Department of Environment (DOE) has reported that the untreated pig farm wastewater actually contained various type of pollutants namely NH$_3$-N (75-950mg/L), organic-N (140-1370mg/L), phosphate (160-1600mg/L), BOD (1900-20000mg/L), COD (4800-39000mg/L), TSS (3690-22300mg/L) and SS (636-15900mg/L) (Department of Environment, 2000).

The deterioration of water quality in Sarawak due to agricultural activities had been identified as an alarming issue by The State Veterinary Authority (2001). The effluent from the pig farm which did not undergo proper treatment system was directly discharged to the nearby streams (State Veterinary Authority 2001) and could severely affect the “health” of aquatic system (Dix, 1981) as well as unsafe for human consumption.

According to Abdullah (2003), simple wastewater treatment such as oxidation pond is ineffective in treating the increasing amount of wastewater from the farm;
however, this kind of treatment technique is still practiced. The oxidation pond could not function very well in treating the effluent and most of the pig farm in Sarawak has unsatisfactory effluent from such treatment system, thus causing serious water pollution upon discharging into streams (Abdullah, 2003).

The agricultural waste, for instance, effluent from the livestock farming activities, contains high concentration of nitrogen and phosphorus as well as other pollutants. According to Abdullah (2003), pig industry was identified to cause chronic water pollution among other industries. Therefore, high concentration of pollutants posed a threat to living organism upon consumption for any purposes. Moreover, literature survey indicates that without a proper waste treatment process, discharging of the effluent will highly fertilize the receiving body and cause increment in the BOD (Mosse and Chagas, 1984). The discharging of untreated wastewater containing high concentration of nitrogen and phosphorus (mostly exist as $\text{PO}_4^{3-}$ form) accelerates the occurrence of eutrophication resulting in objectionable tastes and odors to the water column. Thus the excessive amount of nitrogen and phosphorus (0.005 to 0.05 mg P/L) (McGhee, 1991) in the receiving water bodies will cause algae bloom and excessive aquatic plants population. In 1984, the National Agricultural Policy of Malaysia proclaimed that livestock farming predominately pig farming should be located in suitable areas incorporated with waste treatment facilities. Data below indicates some of the areas in Sarawak that have been identified for effluent contamination of water bodies (Abdullah, 2003):

a) Kuching Division - Stampin, Semaba Road, Bau, Landeh and Matang area.

b) Kota Samarahan Division - Tarat, Engsengai, Panchor, Baki and Serian.
c) Sibu Division - Oya Road, Merah River, and Maaw River.

d) Miri Division - Riam Road and Tukau.

By virtue of the hazardous effect mentioned, the research in finding appropriate wastewater treatment technology should be done in a faster pace. The notion of using aquatic plants for wastewater treatment has gained the attention of local and states agencies in various parts of the USA such as California, Florida, Mississippi, Louisiana, and Texas (Reddy and DeBusk, 1985). In developing country such as Malaysia, state-of-the-art wastewater treatment methods of agriculture waste treatment may be exorbitant. Thus, an alternative wastewater treatment using aquatic plants should be practiced due to its low cost on installation, operation and maintenance (Mosse and Chagas, 1984). This floating aquatic macrophyte-based treatment system is no doubt important for nutrient removal, further more; the aquatic macrophytes can provide other beneficial purposes for instance harvested aquatic macrophytes can be processed into green fodder for livestock thus reducing feeding expenses. For example, the purification system in Beijing Zoo applied the usage of aquatic macrophyte which was able to produce 130 tons of green fodder to fish, waterfowl, and herbivorous animals every year; this could save 20000 Yuan (RMB) per year or approximately RM10000 for feed fee (Zhu and Zhu, 1998). In Malaysia, these two plants (water hyacinth and water lettuce) are often found growing in shallow ponds for pig-food (Polunin, 1987). Apart from that, the biomass could be used for the production of gaseous fuel (Reddy and DeBusk, 1985; Shiralipour and Smith, 1984), fiber (Reddy and DeBusk, 1985; Nolan and Kirmse, 1974), and compost and organic soil amendment (Reddy and DeBusk, 1985; Parra and Hortenstein, 1974).
Water hyacinth and water lettuce are chosen for this experiment because these large-leaved floating species have a faster rate in removing N and P than the small-leaved floating species for instance the duckweeds (DeBusk and Reddy, 1991), cattails and elodea (Reddy, 1983). Furthermore, this study will emphasize on the comparison of these two macrophytes as well as identify the efficiency of polyculture system in nutrient removal.

_Eichhornia crassipes_ or commonly known as water hyacinth belongs to the Pontederiaceae Family. It is also well known to the local dwellers as “Keladi Bunting” in Malaysia. Water hyacinth is a large leaf floating plant. Its smooth round leaves have stalks that are swollen at the base, appearing inflated but actually filled with spongy tissue (Smith, 1989). The flowers are grown as crowded spike and with a lavender yellowish color (Smith, 1989).

_Pistia stratiotes_ (water lettuce) is a tropic plant from Araceae/Arum family which originated from Africa or South America. Water lettuce is also a large leaf floating plants. It has light, green and thick leaves, rosettes occurring singly or connected to others by short stolons (Smith, 1989). Flowers of water lettuce are inconspicuous and are group together on small fleshy stalk which nearly hidden in leaf axils (Smith, 1989).
1.2 Objective

The main objective of this project was to investigate the efficiency of aquatic macrophytes in removing nutrient (NH$_3$-N and total phosphorus) from pig farm wastewater. Water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) as well as the polyculture of the two macrophytes were selected in this study.
2.1 Literature review

In dairy industry, primary and secondary treatment systems were very common. Unfortunately, the efficiency of nutrient removal in dairy effluent was somehow not very satisfactory (Tripathi and Upadhyay, 2003). Tripathi and Upadhyay (2003) had done some experiments to determine the nutrient removal capacity of *Eichhornia crassipes*, *Lemna minor*, and *Azolla pinnata*. The data on the percentage of nitrogen removal by *Eichhornia crassipes*, *Lemna minor*, and *Azolla pinnata* which were tested individually were 71.8%, 62.5%, and 60.1%. As for phosphorus removal, the percentage was 63.2%, 58.8%, and 56.3%. Polyculture of two type of macrophytes maximized the nutrient removal capacity, such as combination of *Eichhornia crassipes* and *Lemna minor* (78.8% N and 69.4% P), combination of *Eichhornia crassipes* and *Azolla pinnata* (74.1% N and 68.7% P), finally the combination of *Lemna minor* and *Azolla pinnata* (70.0% N and 66.7% P).

According to researchers, industrialization in Bangladesh had developed very fast and occurrence of some problems of pollution of river and canal were inevitable (Haider *et al.*, 1983). Therefore, an inexpensive wastewater treatment system had been developed by using water hyacinth grown in tanks and lagoons for removing the toxic substances. In the experiment, wastewaters treated by this system were collected from different factory namely, Sylhet Pulp and Paper Mills (SPPM), Dacca Tannery and from Fertilizer Factory (Haider *et al.*, 1983). The research showed that the concentration of impurities (BOD and phosphate) from the waste effluent treated by water hyacinth has reduced.
In the past two decades, scientists had done thorough research on the efficiency of reservoir systems stocked with aquatic macrophytes for treating agricultural drainage water. In the experiment done by Reddy et al. (1982), a few reservoirs had been set up and individually planted with water hyacinth, followed by elodea, and cattails. The nutrient removal capacity of these 3 aquatic macrophytes were compared with submerged plant namely *Chara* spp planted in another separate reservoir where the drainage water was pumped into it. It was proven that the reservoirs with aquatic floating macrophytes were more effective than reservoir containing *Chara* spp. The nitrate and ammonium removal rates were in the range of 1 – 14 kg N/ha per day and 0.1 – 2 kg P/ha per day, respectively, meanwhile the soluble P removal were in the range of 0.05 – 1.3 kg/ ha per day.

According to literature, one maturation pond covered with water hyacinth was used to perform the tertiary treatment from oxidation pond effluent from domestic sewage and resulted in the reduction of Total Kjeldahl Nitrogen (TKN) (33.8%) and Total phosphorus (33.2%), organic matter, solids, coliforms and algae (Mosse and Chagas, 1984). According to Mosse and Chagas (1984), the mechanism of nutrient removal was just simply the absorption of the nutrients and their utilization for development and biomass increase. In India, the dairy effluent was primarily treated using *Eichhornia crassipes* and the percentage for nitrogen removal was 71.8%, meanwhile the corresponding figure for phosphorus removal was 63.2% (DeBusk and Reddy, 1991). According to the research done by Sooknah and Wilkie (2004), water hyacinth was able to improve the water quality of anaerobically digested flushed dairy
manure wastewater in terms of reduction of TKN (91.7%), ammonium (99.6%), total phosphorus (98.5%), and soluble reactive phosphorus (96.5%) in a 31 days batch growth.

Water hyacinth was considered as the most productive photosynthetic aquatic macrophyte in the world with the growth rate of 60-110 t/ha/yr (Reddy and DeBusk, 1987). Based on Bich et al. (1999), the nitrogen removal from the raw rubber wastewater was more efficient if water hyacinth was stocked into a high rate algal pond. Besides that, comparison of water hyacinth ponds, facultative ponds and anaerobic ponds was studied in arid climate of Marrakesh and has proven that macrophytic ponds were more efficient in organic load removal whereas microphytic ponds were efficient in removing nutrients namely TKN (71%), NH₄ (60%), total phosphorus (80%) and PO₄ (62%) (Quazzani et al., 1995).

Generally, it was found that water hyacinth was in fact more efficient in nutrient removal than other aquatic macrophytes. The high uptake of nutrients by water hyacinth was also proven by Reddy and DeBusk (1985) which showed that nitrogen removal was more efficient by water hyacinth followed by water lettuce (Pistia stratiotes), pennywort (Hydrocotyle umbellate), Lemna (Lemna minor), Salvinia (Salvinia rotundifolia), Spirodela (Spirodela polyrhiza), and egeria (Egeria densa). The research was done during summer season. On contrary, during winter season, pennywort ranked first, then water hyacinth, Lemna, water lettuce, Spirodela, Salvinia, and eventually egeria (Reddy and DeBusk, 1985). Again water hyacinth and egeria systems has higher efficiency in removing phosphorus (Reddy and DeBusk, 1985) than other macrophytes. Unfortunately, according to Reddy and DeBusk (1985), water hyacinth could not withstand freezing temperature during the winter season due to the chilling cold weather which severely
impaired the growth rate of the plant thus decreased the nutrient removal rate. Therefore, this project was emphasized predominately on water hyacinth and water lettuce because these macrophytes could survive very well in subtropical and tropical climate. According to Reddy and DeBusk (1987), a few criteria should be taken into account upon selection of aquatic macrophytes for inclusion in water treatment systems. They were:

a) Adaptability to local climate  
b) High photosynthetic rates  
c) High oxygen transport capacity  
d) Tolerance to adverse concentration of pollutants  
e) Pollutant assimilative capacity  
f) Tolerance to adverse climatic condition  
g) Resistance to pests and diseases  
h) Ease of management

In literature, most researches were conducted on domestic sewage, dairy effluent, tannery and other industrial effluent however not much study was done on polyculture of water hyacinth and water lettuce in treating wastewater from pig farm. A research done by Costa et al. (2000) in treating pig farm wastewater by utilization of water hyacinth pond and found that the pond system was efficient in removing approximately 50% of the organic loads namely COD, BOD, total nitrogen and total phosphorus. In the experiment, 20 days of hydraulic retention period was proven to be adequate for the pig farm wastewater treatment (Costa et al., 2000). Apart from that, Costa et al. (2003) has studied on the optimization of the pig waste treatment in water hyacinth monoculture through the application of the mathematical calculation in order to formulate an optimal water
hyacinth harvesting strategy. The study proven that the water hyacinth pond showed better efficiency if 50% of the pond surface area was covered by water hyacinth (Costa et al., 2003). Thorough research was not conducted to compare between different plants and the integration of plant in polyculture. Thus, this experiment played a significant role in proposing a wastewater management practice by using aquatic macrophytes-based treatment system to treat pig farm wastewater.

2.2 Mechanism involved in nutrients removal

Wastewater treatment by aquatic macrophytes occurs by several mechanisms, which include solids settling, plant uptake of nutrients, biotransformation, and physico-chemical reactions (Sooknah and Wilkie, 2004). For nitrogen removal, there are five main mechanisms which cause the reduction of TKN: plant uptake of NH₄-N, volatilization of NH₃, nitrification by nitrifying bacteria or known as chemoautotrophic bacteria (Nitrosomonas and Nitrobacter) (McGhee, 1991), entrapment of particulate matter (organic nitrogen) by the extensive root system, and settling. The aquatic root system provides an ideal support for the nitrifiers bacteria (convert NH₃ to nitrate or nitrite which are essential for plant growth) due to the large surface area as well as transport of sufficient oxygen to the root system thus pivotal for bacterial nitrification process. The plant and microorganism established a symbiotic relationship with each other, resulting in the reduction of nitrogen concentration.

The NH₃ in the water system was produced through a process known as ammonification (Champbell, 1973; Lawson, 1995). Apart from that, ammonia could also
be generated through the decomposition of the urea and the existence of NH$_3$ is shown in the following equilibrium.

$$\text{NH}_3 + \text{H}_2\text{O} \leftrightarrow \text{NH}_4\text{OH} \leftrightarrow \text{NH}_4^+ + \text{OH}^-$$

According to Reddy (1983), all the macrophytes preferred NH$_4^+$ over NO$_3^-$. Most of the inorganic N was removed through plant uptake, whilst 45 – 52% of N lost was due to NH$_3$ volatilization and nitrification-denitrification processes by microorganism. The reservoirs with the pH more than 8.0 (pH 9 - 9.5) activated the NH$_3$ volatilization and pH 6.7 – 7.0 indicating less favorable conditions for this process to occur. Denitrification also played a significant role in reducing NO$_3^-$ concentration, which primarily occurs in the underlying sediments and most probably in the root systems of the aquatic macrophytes. During the experiment (Sooknah and Wilkie, 2004), the water surface was fully covered by the floating macrophytes and resulted in the depletion of DO to less than 1 $\mu$g/mL. The low DO concentration in the aquatic macrophytes based systems could be explained by the reduction of oxygen diffusion from the atmosphere into the water column due to the plant cover, higher root respiration rates as well as oxygen uptake by microorganism attached to the root systems (Sooknah and Wilkie, 2004). Inadequate dissolved oxygen supply would definitely inhibit the nitrification process. Besides that, reservoir with pH 9.0 also deactivates the nitrification process. Reddy (1983) also concluded that 25 to 29 days of retention period were sufficient to remove 50% of wastewater P. Plant uptake of P was in the range of 3 – 65%, while precipitation with Ca compound at high pH level and adsorption reaction also contribute to 7 - 87% of P lost (Reddy, 1983).
 Whereas for the phosphorus removal, Sooknah and Wilkie (2004), have successfully identified that the reduction in total phosphorus would have been predominantly caused by uptake of soluble P, filtration of particulate matter through the roots, and settling. On the other hand, Reddy and DeBusk (1985) discovered that P removal in summer was the highest for the polyculture systems (water hyacinth and egeria systems), however in winter season, polyculture of pennywort and Lemna removal P showed much better efficiency. Research also showed that 16 to 75% of Total N removal and 12 to 73% TP removal were due to plant uptake, hence the experiment had proven that other mechanism also involved in the nutrient removal besides plant assimilation (Reddy and DeBusk, 1985).

2.3 Interim National Water Quality Standards for Malaysia

Based on the Interim Water Quality Standards (INWQS) proposed by the Department of Environment (1994), the water quality could be subdivided into 5 classes based on selected parameters:

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>Conservation of natural environment;</td>
</tr>
<tr>
<td></td>
<td>Water supply I – practically no treatment necessary</td>
</tr>
<tr>
<td></td>
<td>(Except by disinfection or boiling only);</td>
</tr>
<tr>
<td></td>
<td>Fishery I – very sensitive aquatic species</td>
</tr>
<tr>
<td>Class IIA</td>
<td>Water supply II – conventional treatment required;</td>
</tr>
<tr>
<td></td>
<td>Fishery II – sensitive aquatic species</td>
</tr>
<tr>
<td>Class IIB</td>
<td>Recreational use with body contact</td>
</tr>
<tr>
<td>Class III</td>
<td>Water supply III – extensive treatment required;</td>
</tr>
</tbody>
</table>
Fishery III – common, of economic value and moderately tolerant species;

Livestock drinking

Class IV - Irrigation

Class V - Water unsuitable for specified beneficial uses

The water quality parameters selected for classification were pH, DO, and NH₃-N and tabulated as follow:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Class I</th>
<th>Class IIA</th>
<th>Class IIB</th>
<th>Class III</th>
<th>Class IV</th>
<th>Class V</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (pH unit)</td>
<td>6.5-8.5</td>
<td>6-9</td>
<td>6-9</td>
<td>5-9</td>
<td>5-9</td>
<td>-</td>
</tr>
<tr>
<td>DO (mg/L)</td>
<td>7</td>
<td>5-7</td>
<td>5-7</td>
<td>3-5</td>
<td>&lt;3</td>
<td>&lt;1</td>
</tr>
<tr>
<td>NH₃-N (mg/L)</td>
<td>0.1</td>
<td>0.3</td>
<td>0.3</td>
<td>0.9</td>
<td>2.7</td>
<td>&gt;2.7</td>
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