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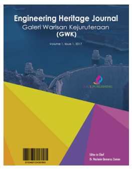

Phytoremediation of suspended solids and turbidity of palm oil mill effluent (POME) by *Ipomea aquatica*

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A B S T R A C T

Malaysia produces 60 million tons palm oil mill effluent per year. Treatment methods are unable to pass discharge standards. Phytoremediation as a co-treatment could be used for anaerobically treated POME. Direct application of plant species in palm oil mill effluent has not been fully addressed. *I. aquatica*, illustrated in 28 pots with one liter capacity in 7 series and 4 concentrations of POME. The results of this study indicate that 80 % of suspended solid and 90.4 % of turbidity in undiluted POME removed with simple one-week phytoremediation process. Water spinach, which naturally grown around the POME polluted area, is a capable nominate for POME phytoremediation.

1. Introduction

Palm oil mill effluent (POME) is well-known as dark brown ship agroindustrial wastewater. High chemical oxygen demand, ammonia nitrogen, suspended solid and turbidity are other specifics of POME which have been treated by anaerobic system [1]. Meanwhile, aerobic treatment method augmented with natural adsorbent is high effective treatment method in short time [2]. Based on the results of [3,4], suspended solids are the main critical pollutant which are the source of other pollutant in POME. Suspended solids usually include the larger floating particles and consist of sand, grit, clay, fecal solids, paper, pieces of wood, particles of food and garbage, and similar materials [5]. SS in POME usually contain 70 % organic solids and 30 % inorganic solids. Furthermore, particle analyzing system (PAS) by [6] indicate that most particle sizes in POME are in range 100-700 µm. Elevated SS can affect the water quality due to the decrease in dissolved oxygen (from heat absorption) consequently, affecting the fisheries resource, and ecology of aquatic environments. Turbidity is an important water-quality indicator as it not only indicates the presence of suspended solids but also shows the possible presence of algae, microorganisms, organic matter, and microparticulates. Generally, SS and turbidity are removed through two very important steps in a typical water treatment process: coagulation and flocculation [7].

Phytoremediation is a common treatment method for runoff, ground water and municipal wastewater [8] or post-treatment of pre-treated strength wastewater such as landfill leachate [9]. Phytoremediation of palm oil mill effluent is a new opportunity for decontamination of this highly polluted colloidal wastewater. High concentration of suspended solids and organic pollutants are limitation factor in phytoremediation [10] and it should be diluted for plant species living [11]. Nevertheless, non-toxic content of POME [12] may contribute capability of aquatic plants in phytoremediation of anaerobically treated POME. Water spinach have been investigated for treating several types of phytoremediation and pollutants such as nitrogen [13], metallic element [14], nutrients [15]. Table1 illustrate current researches of POME phytoremediation by microalgae and macrophytes. Ability of *Ipomea aquatica* as native and naturally grown macrophyte around the ponds of palm oil mill effluent treatment system hasn't been assessed on POME phytoremediation yet.

This study was carried out with aim of assessing ability of *Ipomoea aquatic* as an aquatic macrophyte in the decontamination of high strength wastewater, especially total suspended solids (TSS) and turbidity. The findings from this study would be most suitable for developing countries where budget for sophisticated wastewater treatment are most limited.

Table 1: Summary of current researches on POME phytoremediation.

Plant species	POME	Treatment Length (day)	Results Removal percent %	Reference
Eichhornia crassipes *Nymphaea sp.*	Anaerobically treated POME directly used	3-8	COD: 50, TN: 88, TP: 64	[16]
Spirulina platensis		15	COD: 50, TN: 79, TP: 96.5	
Chrysopogon zizanioides L.	High & low diluted POME	15	Low: BOD: 90, COD: 94	[17]
			High: BOD: 60, COD: 39	
Chlamydomonas incerta	Sediment & filtered & diluted POME	28	COD: 67	[18]
Botryococcus sp. *Scenedesmus* sp. *Chlorella* sp.	Dilution 1:1 Filtered (SS) pH adjusted	35	COD: 58-65 TN: 71-99 TP: 42-64 For *Chlorella* sp.	[11]

	Sterilization			
Chlamydomonas sp UKM 6	Diluted POME	9	COD:8.6-29.1, TN: 43.5-73 Ammonia: 58.6-100 TP: 38.1-63.5	[19]
Ipomea aquatica	Undiluted	7	SS: 80, turbidity : 90.4%	Current study

2. Materials and method

2.1. POME sampling

Sampling of POME carried out from anaerobically treated POME with ponding system by high density polyethylene (HDPE) in United Oil Palm mill (UOPM) located at 5° 9' 13.63" N and 100° 30' 27.90" E (pond number 8) and immediately transferred to cool room with 4 °C temperature for minimizing microbial activities. Characteristic of collected POME and Malaysia discharge limits are showed in Table 2.

Table 2: POME characteristics and Malaysian discharge standards

Parameters	Anaerobically treated POME Undiluted	Malaysian Discharge standard
Suspended solid (mg/l)	500	400
Turbidity (NTU)	400	-
COD (mg/l)	1100	400
NH_3-N (mg/l)	120	150
Colour (Pt.Co)	10700	-

2.2. Plant selection

Preliminary experiences showed that Water hyacinth (*Eichhornia crassipes*), Water lettuce (*Pistia stratiotes*) and Umbrella plant (*Cyperus alternifolius*) couldn't resist and live in undiluted POME which are in line with previous researches [11,17,18] which diluted anaerobically treated POME. This study concentrated on direct application of local plant species on POME treatment. For this purpose, naturally grown Water spinach (*Ipomoea aquatic*) around POME treatment ponds (Fig 1) selected for this study. Water spinach (*Ipomoea aquatica*) weighing 15 ± 1 gr was purchased from polluted ponding area as naturally grown local plant species [20] in palm mill and after rooting (one week) in tap water, placed in the hydroponic phytoremediation system as the macrophyte (Fig 2). Biomass to wastewater concentration ratio in this study was 0.015, 0.03, 0.05 and 0.075 for undiluted, 50%, 30% and 20 % diluted POME respectively. The ratio of biomass to polluted media followed previous study on terrestrial spinach (*Spinacia oleracea* L) [21].

2.3. Experimental design and data collection

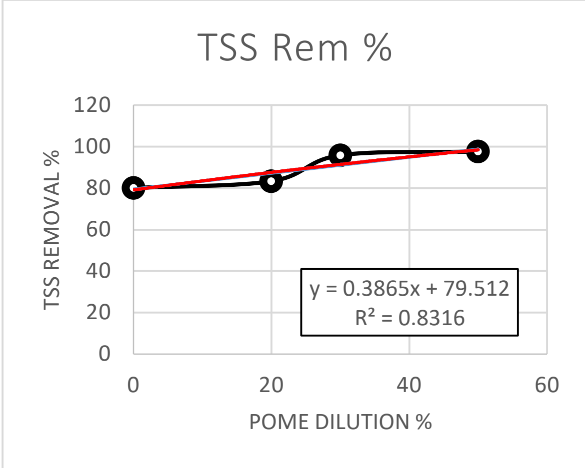
A batch phytoremediation system without any other control mechanisms (e.g. agitation, recirculation, artificial aeration, etc.) was set-up. 28 (7 series in 4 concentration rate) high density polyethylene pots with total volume of 1100 mL, filled with 1000 mL anaerobically treated and diluted POME. The batch Pot experiment were placed in a greenhouse outside of the Environmental Laboratory 2, School of Civil Engineering, Universiti Sains Malaysia (USM). POME as the high strength wastewater was sourced from a nearby mill and used in four treatment contain 50 %, 30 % and 20 % mixed with distilled water and undiluted POME. The characteristics of sourced POME and Malaysian discharge standards presented in Table 2. Experimental work was carried out for one week during which regular growth of *I. aquatica* as well as the quality of the POME (colour, COD, turbidity, ammonia nitrogen, nutrient and TSS levels) was observed [22]. Efficiency of removal collected by following equation:

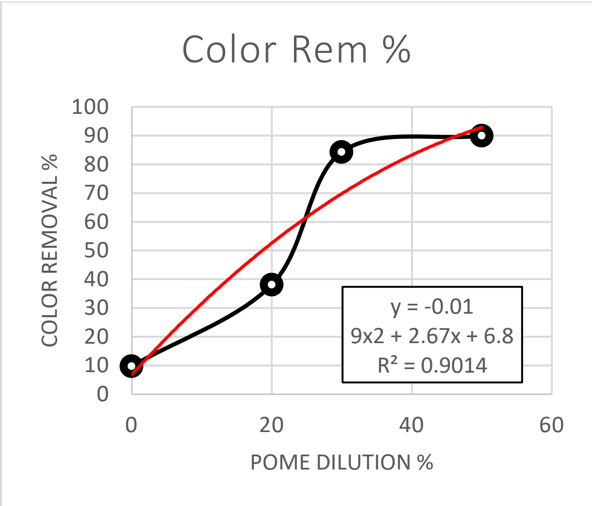
$$Removal\ (\%) = \frac{Ci - Cf}{Ci} * 100 \qquad (1)$$

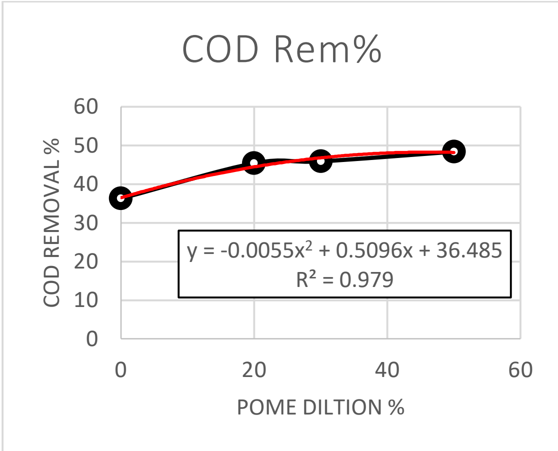
The initial and final concentrations of the collected parameters in this equation are *Ci* and *Cf*, respectively.

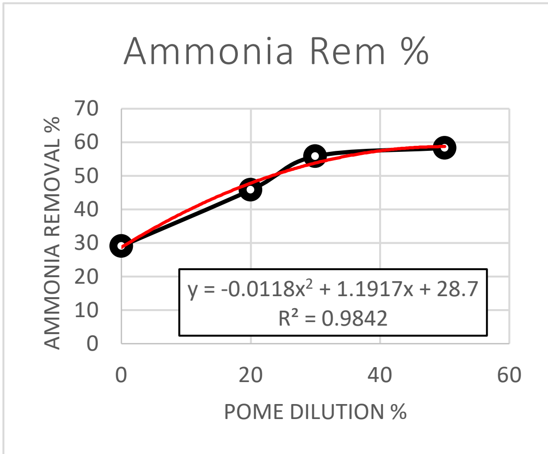
3. Results and discussion

Table 3 shows that the SS and turbidity of the undiluted POME were reduced by 80 % and 90.4 %, respectively after one week of batch treatment (Undiluted POME). Turbidity in water is correlated to suspended solids by the presence of distinct particles contributing to the reduced clarity of water [23]. The removal of TSS and turbidity through use of water spinach in the simple set-up was more efficient compared to a similar application using *Lepironia articulate* where a maximum of 43 % TSS and 42 % turbidity were removed [24]. The use of vegetation helps to reduce the suspended sediments by trapping the materials on stems and leave where the TSS and turbidity removal are significantly influenced by the vegetation density and the length of vegetation [24]. In other words, macrophytes can use organic and inorganic soluble nutrients of wastewater, consequently, pollutants removal by plants cause to improving water quality. Efficiency of colour removal by water spinach in this study was low and it could be for the reason of short time of study or application of any media / absorbent. Growth of water spinach got stress after contacting with undiluted POME by losing some leaves nevertheless after while plant could adapt and produced new leaves and even new branches. Less than 50 % of POME pollution is suspended solids [25]. Suspended solids (2%), and dissolved solids (2%) together are the 80% of the composition of POME pollutant contains, meanwhile the oil content of POME reaches up to (1-2 %) and about 95 % of the remaining is water [26]. Due to that, most part of SS could be adsorbed by plant roots and surface area of *I. aquatica* may contribute for adsorbing a part of dissolved solids. Furthermore, density of big SS particles could be considered as reasonable way of settlement through the treatment period. Fig 3 shows the adsorption diagram for different treatments of this study. As it can clearly see, trend of adsorption are same in collected data and since the all organic and inorganic pollutions in POME originated from suspended solids, so it may ~~could~~ be considered as contribution of high correlation between all collected data.









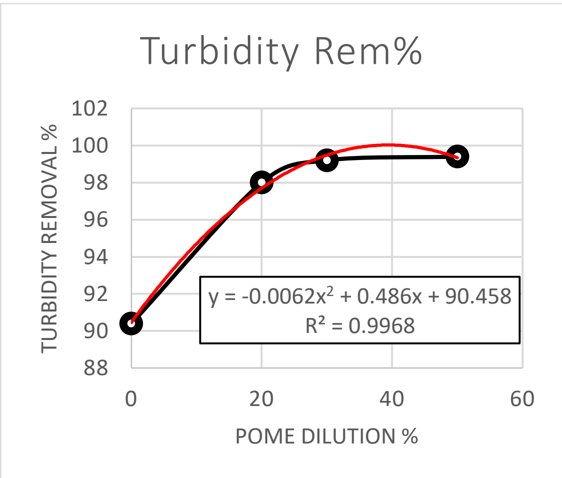


Table 3: Treatments and results of decontamination for diluted and undiluted POME

Dilution %	New branches	Biomass / wastewater	Turbidity removal %	COD removal %	NH_3N removal %	TSS removal %	Colour removal %
0	+	0.015	90.4	36.3	30	80	9.7
20	+	0.030	98	45.4	83	83	38.13

30	+	0.050	99.2	41.9	96.8	96.8	84.3
50	+	0.075	99.4	48.4	97.6	97.5	90
R^2			0.996	0.979	0.984	0.831	0.901

3.1. Dilution strategy

Dilution has been applied as required preparing method in most of the POME phytoremediation (Table 1), nevertheless, [16] could reached to approximately 50% removal with two macrophytes combined with one microalgae in undiluted POME and results of [19] indicate that COD removal efficiency in undiluted POME were more significant than the diluted POME. Preliminary assessment showed that Water hyacinth, Water lettuce and Umbrella plant couldn't resist and live in undiluted POME, thus naturally grown Water spinach around POME treatment ponds selected for this study. Lowest biomass (macrophyte) to contaminants (COD) which was undiluted treatment of this study with value of 0.015 could present fair decontamination in typical pollutants of POME. In other words, with 15 ± 1 gr per one liter undiluted POME, growth of plant (new branches development), 90.4%, 80%, 36.3%, 30%, 9.6% removal collected in turbidity, TSS, COD, NH_3N and colour respectively. It seems properly plant selection and suitable technique of plant application could be contributed as independence of POME treatment to dilution. Results of this study in diluted POME are significantly higher than current researches have been presented in Table 1, even in lower dilution ratio. Findings of this study are in line with [16] and confirms critical effect of plant selection in efficiency of phytoremediation.

3.2. Mechanism of removal

Since this study used only *I. aquatica* as a semi-aquatic tropical macrophyte for pollutant removal in a very short time of treatment (7 days), so all decontamination which have been carried out could be contribute as results of phytoremediation process. Based on the gravitas research study reported in [27], all pollutants in POME have suspended solids source and their particle sizes and concentration are variable. Biosorption as a common nutrient sorption mechanism has been approved for *I. aquatica* [28]. Due to that, plant sorption could be considered as mechanism of POME decontamination. Different range of sorption in colour, NH_3N and other particles among the phytoremediation may depends to particle sizes and plant priority for adsorption. On the other hand, plant parts could play role of surface adsorbent in polluted wastewater even non-living form such as leaf, root herbal shoot [29]. As it can clearly see in Table 3 turbidity and TSS of undiluted POME and different dilution ratios have no same variation such as ammonia and colour so, it may contribute by plant root's surface adsorbent. Effect of gravity in settling of high gravity particles [27], also could be an effective parameter in gradual trend of turbidity and TSS removal among the dilution process.

4. Conclusion

Palm oil mill effluent as a high organically polluted strength colloidal wastewater is an emerging wastewater. Treatment method by plants is a new vision in future environmental cleaning method for this agro-industrial effluent. Application of phytoremediation as co-treatment through the traditional ponding treatment investigated in this study. Naturally grown water spinach in polluted POME site, select as phytoremediator plant species. This aquatic plant could decrease SS as the main organic pollutants and turbidity as the response of fine SS, 80% and 90.4% respectively. Other characteristics of POME such as COD, NH_3N and colour significantly decreased by phytoremediation. The results of this study indicate that direct application of plant species for phytoremediation (without POME dilution) could be possible with suitable plant selection. More studies required with higher concentration of contaminants in undiluted POME phytoremediation and /or other naturally grown plant species to present ability of this green technology as a co-treatment method before river discharge stage.

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