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EFFECT OF HYDRAULIC RETENTION TIME ON PALM OIL MILL EFFLUENT TREATMENT IN A COCOYAM-BASED CONSTRUCTED WETLAND

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ABSTRACT: *Palm oil mill effluent (POME) poses significant environmental threats to land and nearby water resources. Limited economic resources and a lack of awareness of sustainable wastewater treatment methods exacerbate the issue. Horizontal subsurface flow constructed wetlands (HSSFCWs) offers a proven, environmentally friendly, and cost-effective solution for wastewater treatment. This study investigated a greenhouse-scale HSSFCW using plastic containers as wetland cells filled with gravel (1-4 mm), sandy loam soil, and Xanthosoma spp. as a bioremediation agent. POME (0.9 L) was introduced to a controlled wetland and a research wetland, and effluent samples were analysed after 24, 48, and 72 hours of hydraulic retention time (HRT) using the flow rate monitoring method. In the research wetland, pH increased by 34% (from 5.55 to 7.41), BOD decreased by 75% (3.01 to 0.75 mg/L), COD by 76% (6.32 to 1.54 mg/L), while total nitrogen and phosphorus increased by 52.7% (4.27 to 6.52 mg/L) and 46.9% (2.46 to 3.61 mg/L), respectively. The significant differences in removal efficiencies between the control and research wetlands demonstrated the influence of Xanthosoma nutrient uptake on POME treatment. These results suggest that cocoyam-based HSSFCWs can effectively treat POME to meet environmental discharge standards. Future modelling studies could enhance the understanding of internal mechanisms, broadening the application of cocoyam-based HSSFCWs for sustainable POME management in the palm oil industry.*

KEYWORDS: Hydraulic retention time, constructed wetland, palm oil mill effluent, cocoyam.

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INTRODUCTION

Oil palm production is one of the significant agro-businesses in Nigeria and is recognised for its contribution towards economic growth and rapid development (Izah & Ohimain, 2016). The cultivation of oil palms serves as a means of livelihood for many rural families and, indeed, the farming culture of millions of people in the country Lee **(**2019). The industry has also contributed significantly to environmental pollution due to the production of huge quantities of by-products from oil palm extraction processes (Rupani *et al.*, 2010). In both traditional and modern milling settings, the solid waste products that result from the milling operation, such as empty fruit bunches, palm fibre, and palm kernel, are all put to economically beneficial purposes for fuel and mulch in agriculture. According to Ogunsina and Akintan (2020), the management of agro-industrial effluents such as (POME) has been a major environmental concern in countries producing them.

A few factors support the idea that POME must be treated before discharge from the mills. Palm oil mill effluent contains high organic content (Hashiguchi, 2020) and a high value of BOD and COD (Lee, 2019). Various approaches have been applied for the treatment of palm oil mill effluent in other countries, such as Malaysia (Tan, 2019), including chemical, physical or biological. The most common treatment methods in Malaysia, Indonesia and others, for instance, include aerobic ponding treatment, integrated anaerobic-aerobic bioreactor, coagulation and flocculation, thermochemical vermicomposting technology, membrane filtration, photocatalysis, moving-bed biofilm reactor, zero-discharge, phytoremediation, adsorption, and microbial degradation. These methods are thought to contribute to declining water quality as a result of high operation costs and technical and energy demands. Methods that are practical and affordable are needed to improve the performance of wastewater systems (Udom et al., 2018). Establishing more environmentally sustainable treatment processes to preserve the natural environment is necessary (Dölle & Button, 2023).

Constructed wetlands (CWs) are one proven solution that has been successfully used worldwide for many years with high pollutant removal efficiencies both in tropical and temperate countries. A constructed wetland is an artificial shallow basin filled with substrate, usually soil or gravel, and planted with vegetation that is tolerant to saturated conditions. Constructed wetlands have been widely used to handle high organic loads associated with agriculture or domestic wastewater (Abou-Elela, 2017). Constructed wetlands (CWs) are one proven solution that has been successfully used worldwide for many years with high removal efficiencies both in tropical and temperate countries. However, there is no evidence of its application for POME treatment in Nigeria (Udom et al., 2018). Cocoyam grows best in fertile, well-draining, sandy loam soil with a pH between 4.2 and 7.5. It can be grown in a wide variety of conditions, including paddies in wetland areas, using a system similar to that of rice (FAO, 2010). *Xanthosoma* species require temperatures above 21°C (69.8°F) to grow properly. Unlike *Colocasia* spp, they will not tolerate waterlogging and grow best in deep, well-draining loams with a pH between 5.5 and 6.5 in partial shade (FAO, 2010). Horizontal sub-surface flow constructed wetland (HSSFCW) has been successfully applied in this area for the treatment of piggery wastewater (Udom et al., 2023). The objectives of this research are to investigate the effect of wastewater retention time and wetland plants on POME treatment in an HSSFCW.

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METHODOLOGY

Study Area

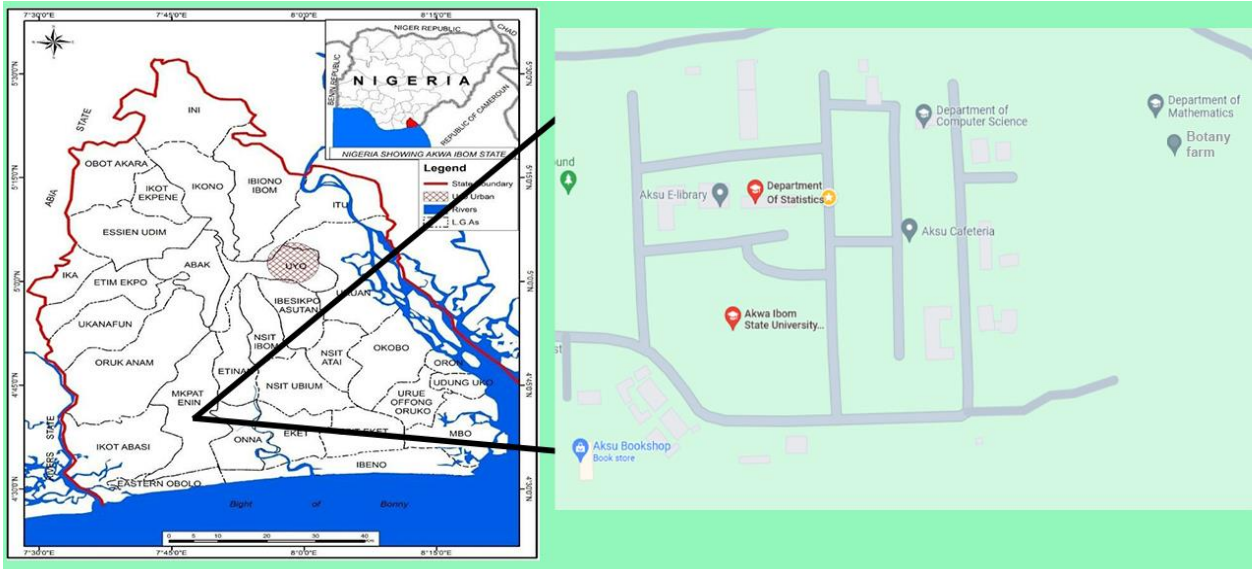

Figure 1: Map of the study area in Akwa Ibom State University.

This study was carried out at the Botany greenhouse located at Akwa Ibom State University, Ikot Akpaden campus. The site was selected based on the prevention of environmental conditions that did not affect the experiment. Akwa Ibom State University is situated in the Mkpat Enin Local Government Area of Akwa Ibom State. Mkpat Enin is located between latitudes 4.614 and 4.628 N and longitudes 7.500 and 7.783 E of the Greenwich Meridian. Mkpat-Enin is located in the South-South region of Nigeria and is a town and a Local Government Area (LGA) of Akwa Ibom State. It sits at an altitude of approximately 185 metres (607 ft) above sea level. Mkpat Enin LGA has an area of 322.352 square kilometres (124.461 sq mi), and it is the second largest local government area in Akwa Ibom State. The LGA is located within the industrial belt extending from Eastern Obolo, Etinan, Oruk Anam, Onna, to Ikot Abasi. The people are traditionally Ibibio speakers. The population was 178,036 based on the 2006 census. The area is rich in oil and natural gas; oil was discovered in Ikot Akpa/Ekop as early as 1953. Forest reserves in the local government area include timber and palm produce.

Mkpat Enin is known for palm oil and palm kernel production. Although the state government gets its significant revenue from federal allocations from crude oil sales, palm fruit processing is the primary source of income for the locals in the area. The people are primarily subsistence farmers who grow palms, vegetables, cassava, and tap raffia palms. “In a month, over 20 drums of palm oil is processed in the area, a drum capacity is about 300 litres of palm oil, as reported by Saviour (2024)

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Wetland System Design

Horizontal subsurface flow constructed wetland (HSSCW) was in 0.4m×0.2m and height of 0.275m plastic containers. The gravel (size) was washed with tap water and sun-dried before being layered in the base of the wetland tank. The size of granite gravel used was between 1 and 4 cm diameters. The soil used in this experiment was collected from the Department of Agricultural Engineering demonstration farm, Akwa Ibom State University, Ikot Akpaden. The soil was collected between a depth of 0 – 90 cm using a soil auger. Miroslav and Vladimir (1998) reported that analysis of the upper layers is relevant in understanding soil interactions with other environmental compartments and the pathways of pollutants between them. Soil samples were collected at 6 points on the farm and mixed thoroughly to create a representative sample. The soil collected was analysed to know the type of soil used in the wetland. The soil test result, calculation and reading from the textural triangle chart show that the soil was sandy loam. After the test was concluded, the particle size distribution of the soil was 57% sand, 29% silt and 14% clay. The constructed wetland system was placed in 0.4×0.2m and a height of 0.275m plastic containers, as shown in Figure 2.

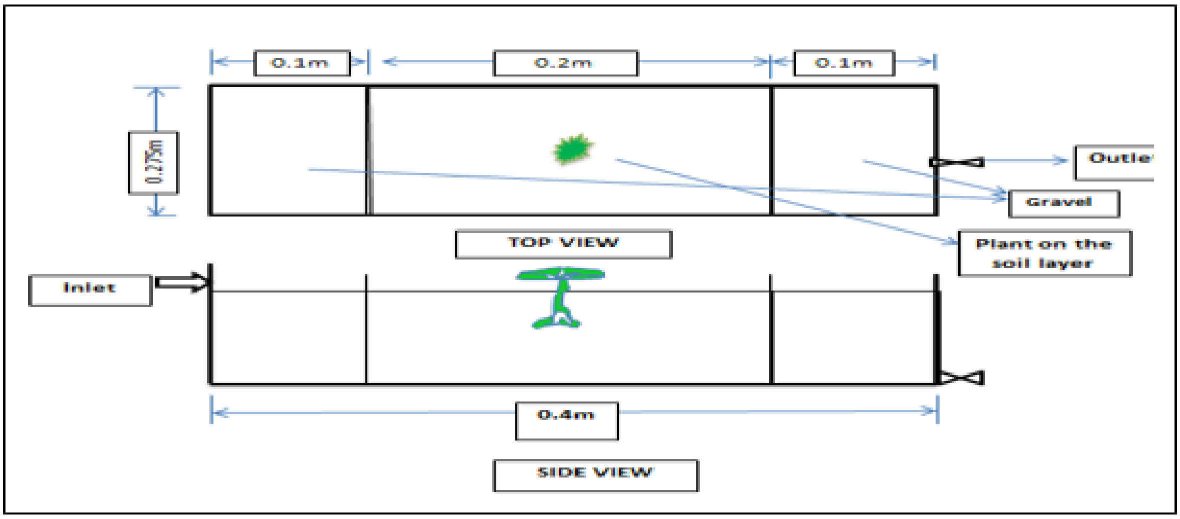

Figure 2: Constructed Wetland system setup

The wetland cells were demarcated into three (3) compartments (Udom et al., 2018) of 0.3m gravel media served as the influent inlet, 0.6m soil media which had the plant on it, and 0.3m gravel media with tap position at the outlet end and tilted to a slope of 0.1% to aid drainage and collection of the effluent at the outlet. The cocoyam plant was experimented with as the macrophytes (*Xanthosoma esculenta*) due to its proliferation in waterlogged areas in the study area. The plants were propagated and allowed to be established before establishment in the wetland to avoid being stressed.

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Wetland System Monitoring

Constructed horizontal flow wetland technology is based on the treatment power of micro-organisms present in the soil, the physical and chemical properties of the wetland system and the macrophytes (cocoyam). The present system was monitored for three months in order to ensure greater plant coverage and stable performance for pollutant removal Lin *et al.,* (2002) since it provides microorganisms with the opportunity to grow and adhere to the surface roots of the planted species and the solid-porous substrate María *et al.*, (2015).

DATA COLLECTION

Raw, undiluted POME samples were collected for physicochemical analysis from a local palm oil processing mill at Ikot Akpaden, Mkpat Enin Local Government Area, Akwa Ibom State, Nigeria. The POME was collected using a 20-litre container to be sufficient for the experiment. Samples for physicochemical analyses were collected at three points within the wetland for three months: August, September and October 2024. The samples were collected under aseptic conditions using 200ml labelled sterile bottles, corked and properly labelled and then transported to the laboratory for analyses of pH, BOD, COD, Total nitrogen and Total phosphorus. Thereafter, a POME volume of 0.9 litres was delivered to flood the wetland.

Plate 1: Introduction of influent to the cell

Plate 2: Collection of the effluent

The collection tap was opened at different hydraulic retention times, 24 hrs., 48 hrs., and 72 hrs., for samples to be taken to the lab for analysis. The laboratory calibration of the setting was based on hydraulic retention time.

Chemical Parameters Determination

The samples collected were analysed following quality control protocols for water quality analysis as recommended by APHA (2005). All laboratory determination was done according to standard methods for the examination of samples collected. The following parameters were analysed: pH, COD, BOD5, Total nitrogen and Total Phosphorus. pH and COD were determined in the field using a multi-parameter, Hach Sension 156, instrument. The instrument probe was placed in the wastewater sample, and the values of the parameters were read and recorded in the field notebook. BOD was measured based on the accurate measurement of DO

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at the beginning and at the end of the five-day period in which the sample was held in a dark incubated condition. BOD was computed from the difference between the initial and final DO. COD was determined by the closed reflux titrimetric method. Total nitrogen was determined by the Persulfate method, and total phosphorus was determined by the Vanadomolybdophosphoric Acid Colorimetric Method.

Statistical Analysis of POME

Data collected were analysed using the Analyses of Variance (ANOVA) method. The removal efficiency of palm oil mill effluent was calculated according to Siti *et al.* (2019):

$$\%\ Removal = \frac{(Ci - Ce)}{Ci} \times 100$$

Where,

Ci: is the initial concentration of the influent ('Raw' Sample); Ce: is the final concentration of the effluent.

The hydraulic retention time of the wetland was calculated;

$$\text{HRT} = \frac{V}{Q}\ (\text{l/h})$$

Where V =the volume of the wetland cell, Q = the flow rate of the influent (Tom, 2022).

RESULTS

Composition of Palm Oil Mill Effluent

The analysis of the results of the initial composition of POME before a treatment based on the selected physiochemical properties, which include pH, BOD, COD, Total Nitrogen and Total Phosphorus, are presented in Table 1

Table 1: Composition of Palm Oil Mill Effluent

Parameters	Composition
Ph	5.55
BOD	3.56
COD	7.12
Total Nitrogen	6.211
Total Phosphorus	3.411

The initial pH of palm oil mill effluent was acidic at 5.55. Nta et al. (2020) had earlier reported the pH of POME from the area to be 5.56. The pH indicates the acidity and the alkalinity of the palm oil mill effluent. The acidic nature of the palm oil mill effluent may be a result of the organic acids found in the fresh fruit. The BOD and COD were recorded as 3.56 and 7.12 mg/l. Total nitrogen and total phosphorus were 6.21 and 3.41 mg/l, respectively.

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Effect of Hydraulic Retention Time on POME Concentration in Wetland Cell without plant

Table 2 presents the effect of **hydraulic retention time** on POME treatment of 0.91 l/hr and influent volume of 22 litres after 24hrs, 48hrs and 72hrs hydraulic retention time. Q = 0.9l/hr, V = 22liters.

Table 2: Effect of Hydraulic Retention Time on POME Concentration in wetland cell without plant

HRT (Hours)	Parameters				
	pH	BOD (mg/l)	COD (mg/l)	Total Nitrogen(mg/l)	Total Phosphorus (mg/l)
Influent	5.55	3.010	6.32	4.272	2.459
24	7.75	3.414	6.829	6.721	4.714
48	7.23	1.395	2.790	6.514	4.502
72	7.08	2.532	5.064	6.393	3.816

Hydraulic Retention time is the amount of time it takes for the molecules of palm oil mill effluent to travel a certain distance from the inlet to the outlet. Hydraulic Retention allows for contact between the water and the chemicals or other treatments being used. POME pH concentration of 5.55 (acidic) was reduced to 7.75, 7.23 and 7.08 after 24, 28 and 72 hours of retention, respectively. At 24hrs HRT, BOD moved from 3.01 to 3.414; at 48hrs HRT, it was 1.395 and at 72hrs, it was 2.532. POME COD concentration of 6.32 fluctuated from 6.829, 2.790 and 5.064 after 24, 28 and 72 hours of retention, respectively. The increased COD level indicates the existence of aerobic conditions in the root zone bed, Vinita *et al.*, (2008). POME total nitrogen concentration of 4.272 was increased to 6.721, 6.514 and 6.393 after 24, 28 and 72 hours of retention, respectively. POME total phosphorus concentration of 2.459 was unstable, with 4.714, 4.502, and 3.816, respectively, after 24, 28, and 72 hours of retention.

Effect of Hydraulic Retention Time and Cocoyam on POME Concentration

Table 4 presents the effect of **hydraulic retention time and cocoyam** on POME treatment of 0.91 l/hr and influent volume of 22 litres after 24hrs, 48hrs and 72hrs hydraulic retention time. Q = 0.9l l/hr, V = 22liters.

Table 3: Effect of Hydraulic Retention Time and Cocoyam on POME Concentration

HRT (Hours)	Parameters				
	pH	BOD (mg/l)	COD (mg/l)	Total Nitrogen(mg/l)	Total Phosphorus (mg/l)
Influent	5.55	3.01	6.32	4.272	2.314
24	7.14	2.05	4.03	6.302	3.503
48	7.32	1.86	3.14	6.219	3.421
72	7.41	0.752	1.54	6.52	3.613

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POME pH concentration of 5.55 (acidic) was reduced to 7.14, 7.32 and 7.41 after 24, 28 and 72 hours of retention, respectively. POME BOD concentration of 3.01 was reduced to 2.05, 1.86 and 0.752 after 24, 28 and 72 hours of retention, respectively. POME COD concentration of 6.32 was reduced to 4.03, 3.14 and 1.54 after 24, 28 and 72 hours of retention, respectively. The increased COD level indicates the existence of aerobic conditions in the root zone bed, Vinita *et al.*, (2008). POME total nitrogen concentration of 4.272 was increased to 6.302, 6.219 and 6.52 after 24, 28 and 72 hours of retention, respectively. According to Ewemoje *et al.* (2015), phosphorus is partially removed by sedimentation and by reacting with porous media minerals.

POME phosphorus concentration of 2.459 was unstable from 3.503, 3.421 and 3.613 after 24, 28 and 72 hours of retention, respectively.

Percentage Reduction Efficiency of POME Concentration

Tables 4 and Table 5 show the variations in the composition of POME at different Hydraulic Retention times and the removal efficiency (%) of palm oil mill effluent.

Table 4: Percentage Reduction Efficiency (RE) of POME HRT Concentration

Pollutants	Concentration	24hrs	R E (%)	48hrs	R E (%)	72hrs	R E (%)
pH	5.55	7.14	29	7.32	32	7.41	34
BOD	3.01	2.05	32	1.87	38	0.752	75
COD	6.32	4.03	36	3.14	50	1.54	76
Total Nitrogen	4.272	6.302	48	6.219	46	6.521	53
Phosphorus	2.459	3.503	42	3.421	39	3.613	47

Table 5: Percentage Reduction Efficiency of POME HRT with cocoyam plant Concentration

Pollutants	POME initial Concentration	24hrs	R E (24hrs) %	48hrs	R E(48hrs) %	72hrs	R E(72hrs) %
Ph	5.55	7.75	40	7.23	30	7.08	28
BOD	3.01	3.414	13	1.395	54	2.532	16
COD	6.32	6.829	8	2.790	56	5.064	20
Total Nitrogen	4.272	6.721	57	6.514	52	6.393	50
Total Phosphorus	2.459	4.714	92	4.502	83	3.816	55

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DISCUSSION

Table 4 indicates that wetland cells of POME pH concentration without cocoyam plants have a percentage reduction of 29%, 32%, and 34% after 24, 28, and 72 hours of retention, respectively, in ascending order. Table 5 shows wetland cells with cocoyam plant as phytoremediation to have a percentage reduction in POME pH concentration of 40%, 30%, and 28% after 24, 28 and 72 hours of retention, respectively, in descending order, the presence of plants in the wetland cell has impacted on the treatment process which indicates as the plant grows it increased turns continuous in a reduction in pH moving towards alkalinity in the pH table towards neutral it could be as a result of cocoyam plant having pH possessing some acidic nutrients in the roots zone. POME BOD concentration of wetland cells without plant shows percentage reduction of 32%, 38% and 75% after 24, 28 and 72 hours of retention, respectively, while the concentration in cells with the plant was unstable with 13%, 54%, and 16% this unstable situation indicates the present of aerobic and anaerobic condition in the wetland cell as a result of the plant present in the cell, according to Matamoros, and Bayona (2008), organic matter decomposition is determined by the balance between organic matter load and oxygen transfer rate, which defines the predominant conditions of anaerobic and aerobic systems, The organic matter, expressed as BOD and COD, is decomposed by aerobic and anaerobic microbial processes and also by physical processes, such as sedimentation and filtration (María et al., 2015). POME COD concentration in wetland cells without plants has a percentage reduction of 36%, 50% and 76% in continuously increased order. In comparison, a cell with a plant indicates that the reduction is unstable, with a percentage reduction of 8%, 56%, and 20% after 24, 28, and 72 hours of retention, respectively. Total nitrogen in wetland cells of POME concentration was unstable in percentage reduction as a result of the plant not taking in nitrogen for its growth and has unstable percentage reduction of 48%, 46% and 53%.

In contrast, a cell with a plant shows a continuous increase in the percentage reduction, indicating plant uptake of nitrogen nutrients (Udom, 2023) has a percentage increase of 57%, 52% and 50% after 24, 28 and 72 hours of retention, respectively. According to Ewemoje *et al.* (2015), phosphorus is partially removed by sedimentation and by reacting with porous media minerals. Also, PO_4 is mainly removed by plant uptake and adsorption onto the porous media Shuib *et al.*, (2011). percentage reduction in phosphorus in POME concentration in a wetland without plant was unstable at 42%, 39% and 47%, and wetland cell cocoyam indicates stable percentage reduction in phosphorus concentration and has percentage reduction of 90%, 83% and 55% after 24, 28 and 72 hours of retention respectively as a result of sedimentation and by reacting with porous media minerals.

CONCLUSION

The result showed that horizontal flow constructed wetland treatment varied with hydraulic retention time and has the potential to treat POME. High removal efficiencies were achieved by the pH, Total Nitrogen, Phosphorus, COD and BOD, which is significant in the treatment system by the length of time the wastewater was held in the wetland, which contributed to improving the quality of POME. Improvement in hydraulic retention time could ameliorate the environmental problems of POME in the environment.

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