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Testing of Water Hyacinth Compost as Green Bioabsorbent Material for Oilfield Operations in the Niger Delta, Nigeria

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ABSTRACT

There is an increasing focus on developing sustainable green bioabsorbent materials for use in cost-effective oilfield applications. The purpose of this study is to determine the suitability of water hyacinth compost (WHC) produced under locally controlled laboratory conditions, for use as a green bioabsorbent in oilfield applications in the Niger delta of Nigeria. The properties of the water hyacinth compost tested and their values are: viable total heterotrophic bacterial count 2.3×10^8 CFU/g, viable hydrocarbon utilizing bacterial count 1.12×10^4 CFU/g, bulk density 0.0225g/cc, surface area 6.6m²/g and has a positive buoyancy (floats) in water, it (1g) absorbed about 95% of crude oil in 24h equivalent to approximately 8 times the weight of the WHC, it is hydrophobic by the biphasic partitioning method. This result highlights the suitability of the locally sourced WHC as a green nature-based bioabsorbent useful in a circular economy and well fitted into the United Nations Sustainable Developmental Goals (UNSDG).

1. INTRODUCTION

Oil contamination remains a persistent environmental challenge, particularly in oil-producing regions such as the Niger Delta of Nigeria. Conventional oil removal methods — including use of synthetic sorbents and chemical dispersants — are effective but often pose long-term environmental risks due to their non-

biodegradability and cost [1]. As a result, there is increasing interest in sustainable, locally sourced, and biodegradable materials that can serve as eco-friendly alternatives for oil spill management. Water hyacinth (*Eichhornia crassipes*), an invasive aquatic plant widespread across the Niger Delta, represents both an ecological burden and a potential

biomaterial for resource recovery. Its high cellulose and lignocellulosic content make it suitable for conversion into compost and bio-based sorbents [2]. When composted under controlled conditions, water hyacinth can yield a material with favorable structural, chemical, and microbiological properties—critical for applications in environmental remediation [3].

In addition to its porous structure and low density, compost derived from water hyacinth can also host hydrocarbon-degrading microorganisms, enabling a dual-function mechanism for both absorption and biodegradation of petroleum hydrocarbons. The present study evaluates the suitability of such compost—water hyacinth compost (WHC)—for application as a green bioabsorbent in oilfield operations in the Niger Delta. Emphasis is placed on key properties such as surface area, hydrophobicity, oil absorption capacity, and microbial viability, with the broader aim of contributing to circular economy goals and advancing the United Nations Sustainable Development Goals [4].

2. MATERIALS AND METHOD

2.1 Sample Collection

Water hyacinth compost (WHC) used as green bioabsorbent material was obtained from GOA's Research Group, Department of Microbiology, University of Port Harcourt; crude oil was obtained from Port Harcourt Oil Refinery.

2.2 Microbiological Analysis

2.2.1 Enumeration of Bacterial Population in bioabsorbent material

Viable total heterotrophic bacteria in compost samples were enumerated on Nutrient Agar (NA) plates. Serial dilutions of samples were prepared in phosphate buffered saline; aliquots (0.1 ml) of appropriate dilutions 10^{-3} and 10^{-4} were aseptically spread on NA plates, in duplicate and incubated at 37°C for 24h. At the end of the incubation period,

colonies were counted. The population density of the viable organisms was obtained by multiplying the average number of colonies by the dilution factor used; this is the titre, also expressed as:

Titre (CFU/g) = (average number of colonies) x DF x (volume correction).

Where:

DF (dilution factor) = $1/\text{dilution}$ and

$$\text{Volume correction} = \frac{1}{\text{volume (ml) plated}}$$

By plating aliquots (0.1 ml) of samples diluted 10^{-2} , 10^{-3} , and 10^{-4} on mineral salts agar containing (g/l): NaCl, 10.00; $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 0.42; KCl, 0.29; KH_2PO_4 , 0.83; $\text{Na}_2\text{HPO}_4 \cdot \text{H}_2\text{O}$, 1.25; NaNO_3 , 0.42; Agar, 15.0 and distilled water to the 1000 ml mark (pH, 7.2), mean counts of viable total hydrocarbon using bacteria were determined. The medium was autoclaved for 15 minutes at 121°C and 15 psi of pressure to sterilize it. The culture was supplied with crude petroleum in the vapour phase, which was the only source of energy and carbon. To do this, inoculation plates were inverted over sterile filter paper that had been saturated with the sterile crude oil included in Petri dish covers. Every plate was incubated for 24 to 48 hours at 37°C .

2.2.2. Identification of isolates

Isolates were identified by examining their morphological properties and taxonomic characteristics using the methods in Bergey's Manual of Determinative Bacteriology [5].

2.3. Physicochemical analysis of bioabsorbent material

Water-holding capacity, pH, amount of moisture, and biological material content were the physicochemical properties that were examined. Every analysis was performed twice, and the Margesin et al. [6] method was followed for presenting the average findings. After a half-hour of combining one part compost with 3 parts 9ml CaCl_2 , each specimen's pH was determined. The Mettler Toledo MP220 pH meter was used to test

the pH of the experiment's solution as well as the control (C) solution. The reduction in weight of oven-dried compost after 6 hours at 250°C was used to determine loss on ignition, a measure of organic matter content [6]. Constant weight loss of oven-dried compost for three hours at 105°C was used to measure the amount of moisture [7]. The Jones et al [8], method was used to determine the water holding capacity (WHC) by placing 9g of 1 day oven-dried compost in a plastic funnel lined with filter paper and covering the mouth of a glass measuring cylinder. The similar configuration was created for the second scheduling, but the compost was not included. The funnels were covered with aluminum foil to prevent the water from evaporating after adding an equivalent volume (10 ml) of distilled water to the sets. The funnels were then left to drain naturally for two hours at an ambient temperature (25°C). Each setup's water retention and drainage capacities were recorded and this information was utilized to calculate the compost's water-holding capacity as follows:

Volume of water drained = x

Water (volume) held by filter paper = (weight of wet filter paper) - (weight of dry filter paper) = y

Water held by the compost = z = 10 - (y + x)

Water holding capacity (ml/100 g) = $z \times 10 \%$

2.3.1 Absorption analysis

The absorbent, water hyacinth compost particles (10g) were put into a 250-mL beaker containing crude oil (i.e., with volumes of 100, 80, 60, 40, and 20 ml). The suspension was mixed at room temperature with a constant pH (about 7) for 120 minutes at 500 rpm. A nylon membrane syringe with pores measuring 0.22 µm was used to filter an aliquot of the mixture. A UV-Vis spectrophotometer (Model 7205; JENWAY; Cole-Parmer; U.S.; between 250 and 500 nm) was used to evaluate the filtrate. The Beer-Lambert Law was used to standardize and extract the findings of the UV-Vis spectrometry:

$A = acl$,

where:

A = Absorbance

a= Absorption coefficient

c= concentration of solute

l= optical path length of the instrument (usually 1cm), to get the actual concentration [9]

2.3.2 Oil sorption efficiency of WHC-biomass

Buoyancy test:

Typically, absorbing materials employed in water spills undergo the buoyancy test. The buoyancy test was conducted using the stationary system technique [10] In a 500 ml beaker, 250 ml of crude oil was covered with one gram of WHC (the sorbent) and left for 15 minutes. The buoyancy percentage was then determined by measuring the floated sorbent mass.

Hydrophobicity test: Testing the partitioning of the WHC between aqueous and hexane phases revealed the water hyacinth compost's propensity to be extracted from the water phase into a non-polar phase [11]. A sample of about 1.0g of WHC was added to a beaker with distilled water and hexane (1:1), and the mixture was swirled for three minutes. After that, the mixture was left to stand for five minutes, which is how long it takes for the phases to separate. Filtration, drying, and weighing were used to determine the amount of material that was transported to the organic phase. The percentage of material that is held at the interface or transported to the organic phase is how the results are expressed. This value is an estimation of the degree of hydrophobicity of the WHC.

2.3.3 Sorption capacities of the oils onto the WHC in the absence of water

The procedure was to determine the oils' sorption ability onto the biomass when there was no water present [9;10]. Every test was run at 27°C. About 1.0 g of water hyacinth sorbent was added to 100 ml of oil in a glass beaker to test the sorbent's

ability to sorb oil in water-free oil. The oil was drained for two minutes following the 60-minute sorption period, and the wet sorbent was weighed. The oil sorption capacity [11] of the sorbent was determined by the following equation

$$q = [mf - (mo + mw)] / mo$$

where, q is the sorption capacity (g/g), mf is the weight of the sorbent after 2 min of drainage (g), mo is the initial weight of the sorbent (g), and mw is the weight of the water (g). It is found that oil without any water is a medium where mw is equal to zero.

2.3.4 Sorption capacities of the oils onto the biomass in the presence of water:

In a succession of 250 ml glass beakers, varying amounts of oil (diesel, castor oil, and lubricating oil) were poured onto 100 ml of sea water in order to determine the relationships between oil/water selectivity and oil thickness in the water surface. The measured oil thicknesses were 0.5, 1.3, 1.5, 2.6, and 2.8 cm, in that order. Once a steady state was reached, the beakers were filled with 1.0 g of water hyacinth compost. The wet sorbent was taken out after 60 minutes of sorption, drained for two minutes, and weighed. The soaked sorbent was squeezed. Next, using the usual procedure D4007-8I, the liquids that were recovered from the sorbent were centrifuged. The oil capacity of the sorbent was determined using equation above.

3. RESULTS AND DISCUSSION

3.1. Microbiological Properties of bioabsorbent material

The Total Viable Heterotrophic Bacterial Count (TVHBC) of the water hyacinth compost samples is shown in Table 3.1. The counts range from 1.01×10^8 CFU/g to 1.16×10^8 CFU/g for the stem parts after and before absorption with crude oil respectively,

representing 87.1% drop after absorption and 1.23×10^8 to 1.67×10^8 CFU/g for the root parts, after and before absorption with oil respectively, representing 73.7% drop after absorption. The viable hydrocarbon utilizing bacterial (VHUB) counts range from 3.3×10^3 CFU/g to 6.51×10^4 CFU/g for the stem parts after and before absorption with crude oil respectively, representing 5.1% drop in HUB after adsorption and 4.78×10^3 CFU/g to 8.62×10^4 CFU/g for the root, after and before adsorption with crude oil respectively, representing 5.5% drop in HUB after absorption with crude oil.

Table 1. Microbial population on water hyacinth compost (stem and root) before and after oilfield absorption for 30 days

Sample- type	TVHBC (CFU/g)	VHUBC (CFU/g)
Stem	1.16×10^8	6.51×10^4
Root	1.67×10^8	8.62×10^4
After absorption		
Stem	1.01×10^8	3.30×10^3
Root	1.23×10^8	4.78×10^3

Key: TVHBC-Total Viable Heterotrophic Bacterial Count; VHUBC-Hydrocarbon Utilizing Bacterial Count

The isolates identified from biochemical analysis (Table 3.1) include *Acinetobacter* sp., *Klebsiella* sp., *Bacillus* sp and *Pseudomonas* sp.

3.2 Proximate quality of bioabsorbent material

The results presented in Table 3.3 show the proximate composition of water hyacinth samples used in the study. The moisture content of water hyacinth was 42.5 %, others are: %crude protein 3.5 ± 0.40 , %ash content 3.5 ± 0.42 , %crude fat 0.2 ± 0.02 , % carbohydrate 35.2 ± 1.03 and %crude fibre 15.1 ± 0.10 . Water hyacinth compost is almost hygroscopic and is rich in carbohydrate and crude fibre.

Table 2. Proximate composition of Water hyacinth

Parameters	Bulk (Stem, Root and Leaves)
Moisture Content (wt %)	42.5 ± 0.40
Crude Protein (%)	3.5 ± 0.040
Ash Content (wt %)	3.5 ± 0.42
Crude Fat (wt %)	0.2 ± 0.02
Carbohydrate (%)	35.2 ± 1.03
Crude Fibre (%)	15.1 ± 0.10

Values are mean ± S.D of triplicate determinations (n=3)

3.3. The Geo-technical properties of water hyacinth compost samples

The Table 3.3 contains the values of the geo-technical properties of water hyacinth compost from the stems and roots of the plant. The bulk density of the compost from stems was 0.0139 g/cc while that from the roots was 0.031 g/cc. The value for the roots is almost three times that of the stems. The particle density of the stems compost was 0.0078 g/cc while the particle density of compost from roots was 0.021g/cc. Similarly the particle density for the roots is higher than that for the stems. The pore space volume of the compost from stems was 3.2 ml while the pore space volume of the compost from roots was 2.2 ml. The value for the pore space volume is higher, about one and a half times for the stems than for the roots. The surface area of the compost from stems was 5.4 m²/g while the one from roots was 7.788 m²/g. The surface area value for the roots was almost one and a half times more for the roots than for the stems. The value of the buoyancy of the compost from roots was 37.9% while the one from stems was 40.1%, both are floatable; hydrophobicity of the compost from the roots was 15.1% while the one from the stems was

22%, both are hydrophobic.

Table 3. Geo-technical characteristics of the bioabsorbent material (root and stem)

Parameter	Stem	Root
Bulk density (g/cc)	0.0139	0.031
Particle density (g/cc)	0.0078	0.023
Pore space volume (ml)	3.20	2.200
Surface area (m ² /g)	5.4	7.788
Pore volume (cm ³)	17.78	13.75
Buoyancy (%)	40.1	37.9
Hydrophobicity (%)	22	15.1

3.4 Results of oilfield absorption studies using water hyacinth compost

The Results of oilfield absorption studies using water hyacinth compost from roots and stems of *Eichornia crassipes* plant are presented in Table 3.4. The values are for experiments conducted in the presence and absence of water. The compost from stems absorbed more crude oil, both in the absence and presence of water. The treatment using the root without water had an efficiency of 4.64% while for the stem it was 8.22%

Table 4. Oil sorption capacity of water hyacinth compost samples from roots and stems used in the study in the absence and presence of water.

Source of water hyacinth compost sample	Oil sorption value (%) in absence of Water(-)	Oil sorption value (%) in presence of Water(+)
Root	4.643	4.434
Stem	8.220	5.920

The WHC absorbed up to 8 times its own weight of crude oil (Table 3.4).

4. CONCLUSION

The findings of this study highlight the efficacy of WHC as a sustainable and environmentally friendly bioabsorbent for oilfield operations. The WHC exhibited high crude oil uptake — absorbing approximately 95% of crude oil relative to its weight within 24 h — demonstrating superior oil affinity and retention. This is in line with previous reports where lignocellulosic materials with high porosity and hydrophobicity have shown to enhance sorption characteristics [13]. The compost's surface area (6.6 m²/g) and low bulk density (0.0225 g/cc) suggest a structurally favorable matrix for hydrocarbon sorption. Its hydrophobic behavior, confirmed via biphasic partitioning, ensures selectivity in oil-water environments — a crucial trait for offshore or aquatic spill scenarios. Positive buoyancy further supports its field applicability by enabling easy recovery from water surfaces, an advantage over denser biochar alternatives [3].

The microbial analysis of WHC revealed a viable total heterotrophic bacterial count of 2.3×10^8 CFU/g and hydrocarbon-utilizing bacterial count of 1.12×10^4 CFU/g. This microbial profile is essential for post-sorption biodegradation of trapped hydrocarbons, providing an added layer of remediation that synthetic absorbents lack [2]. Such a dual-action mechanism — physical absorption and microbial degradation — greatly enhances the ecological value of WHC.

Beyond technical performance, the use of WHC contributes to regional sustainability by repurposing invasive water hyacinth biomass into a value-added product. This approach supports SDG 12 (responsible consumption), SDG 13 (climate action), and SDG 14 (life below water) through waste valorization and reduced dependency on non-biodegradable materials [4]. In resource-constrained oil-producing regions, deploying such local, low-cost bioabsorbents could significantly reduce the cost and ecological impact of oil spill response efforts [1].

This study establishes the suitability of water hyacinth compost (WHC) as an effective green

bioabsorbent for crude oil removal in oilfield environments. Its high absorption efficiency, favorable physicochemical properties, and microbial viability present a robust alternative to conventional synthetic sorbents. The WHC not only offers a sustainable solution to oil pollution but also provides an innovative method for managing invasive aquatic biomass through resource recovery. The use of WHC supports local environmental management efforts, promotes circular economy principles, and aligns with the United Nations Sustainable Development Goals. Further field-scale testing and long-term biodegradation studies are recommended to optimize its implementation in practical oil spill scenarios.

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Conflict of Interest Declaration

The author(s) declare that they have no conflict of interest.

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