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Adsorption of Crude Oil in Aqueous Medium Using Dried Plantain (*Musa Paradisiaca*) Leaves and Peels

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ABSTRACT
Adsorption of crude oil in aqueous media using dried plantain (Musa paradisiaca) peels (PP) and plantain leaves (PL) was studied. Effect of particle size, dosage, contact time, initial crude oil concentration in terms of Total Organic Carbon (TOC) and effect of microbial count were investigated. The Langmuir, Freundlich and Temkin isotherm models were employed to analyse the experimental data. The results showed that the higher the particle size for both adsorbents PP and PL the higher the adsorption in a reverse adsorption phenomenon and particle size of 800µm (0.8mm), *gave optimal result. Adsorption increased with dosage until equilibrium saturation was achieved. 2.0g was the optimum dosage obtained at equilibrium for both PP and PL. Adsorption increased with reduction in crude oil concentration, PP and PL recorded 98.84% and 99.07% respectively for initial crude oil concentration of 5207.74mg/L, TOC. Crude oil adsorption increased sharply within 10 minutes contact time, equilibrium was achieved in 120 minutes for both PP and PL with an optimum result of 99% crude oil adsorbed. Result showed an increment in microbial count in the aqueous medium of PL and crude oil after 24 hours incubation process. The Temkin adsorption model with a regression coefficient of 0.9919 provided the best fit to the experimental data compared to the Langmuir and Freundlich models. Therefore, based on the results obtained, these adsorbents have the potential of being an efficient tool for remediation in attempting to resolve the age long challenge of crude oil spillage/pollution in aqueous medium.*

KEYWORDS: Adsorption, Isotherm, Aqueous Medium, Crude Oil, Plantain Leaves, Peels.

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1. INTRODUCTION

The unending need for non-renewable energy sources like crude oil by advanced countries and nations like Nigeria has prompted the increase for the search of the fluid, its refining and other related modern and industrial application of the fluid. For most part of the world, including the Niger Delta area of Nigeria, the underlying effect associated with these quests for non-renewable sources of energy and its related products is that our marine environment and farmlands are left with undesirably far-reaching pollution in the process. (Odokuma & Okpokwasili, 1993; Adebusoye *et al.*, 2010). The willful activities of criminals in vandalizing petroleum product pipelines as is usually the case in the oil rich Niger Delta area of Nigeria has in no small measure exacerbated the contamination and pollution incidents.

There are also incidences of disputes between these oil and gas companies and the indigenes of the impacted communities who believe that their environment and sources of livelihood have been polluted and destroyed by the activities of these companies. Moreover, our marine environment is under an incredible pressure, and contamination by crude oil poses a great risk to the continual existence of earth. About one million three hundred thousand tons of petroleum fluid spills into the oceans and seas every year (NRC, 2003). Severe cases of pollution attract lots of condemnation from the general public, an example is the six hundred thousand tons of crude that spilled into the Gulf of Mexico succeeding the Deep-water Horizon explosion disaster in 2010 was reported by Crone and Tolstoy (2010).

The ocean and sea are highly prone to crude oil and its associated products spillage and pollution incidences because these products are mainly transported to various location of interest through the oceans and seas. As of 2005, over two billion tons of these product had been shipped by tankers, accounting for 62% of all crude oil produced (Rodriques, 2012). Oil spill incidences constitutes a major environmental challenge, and if left untreated, the toxic and persistent chemicals within crude oil and its associated products can cause long term adverse effects in the surrounding marine environment. Therefore, conscious and concerted effort should be made at deploying natural adsorbents for a more effective remediation with an added advantage of no further harm to the environment since they are biodegradable. Therefore, in a bid to attempt to solve this environmental pollution challenge, this study leveraged on the abundance of plantain plant (*Musa paradisiaca*) in the Niger Delta communities of Nigeria that is mainly affected by this crude oil pollution, for use as a natural adsorbent for crude oil pollution remediation.

Based on the review of previous research there is no published work to date on the use of plantain peels and leaves, comparatively, as adsorbents, for crude oil adsorption in aqueous medium. The objectives of this study are to investigate the effect of different particle sizes of plantain peels and leaves, their dosages, contact time, initial crude oil concentration in terms of TOC, mg/l and effect of microbial count on crude oil remediation. The equilibrium isotherm model study of these adsorbents was also determined.

2.0 MATERIALS AND METHODS

2.1 MATERIALS

The following materials and apparatus were used for this work: Nigerian plantain (*Musa paradisiaca*) leaves and peels, Crude Oil sample, Open Air Oven, High Temperature Furnace, Desiccators, Crucibles, Tongs, Funnels, Filter papers, pH Meter, 4510 Conductivity Meter (JENWAY), Redwood Viscometer, Pycnometer, Two electronic weighing balances, Ohaus top loading balance (0.01) and a more sensitive electronic analytical weighing balance (0.001, Adams AFP 360L), Retort stand, UV Spectrophotometer, Thermocouple with temperature sensor, Centrifuge Tube, Spatula, Crusher, Thermometer, Sieves, Measuring cylinders, 500ml Beaker, 250ml conical flask, Mortal Pestle, 10ml Pipette, HCL, Concentrated H_2SO_4, Syringe (5ml), filter paper, etc.

2.2 Preparation of Adsorbents

The plantain (*Musa paradisiaca*) peels and leaves Figure 1 and 2 respectively, collected from the Department of Crop/Soil Science Demonstration Farm, Faculty of Agriculture, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, Nigeria, were thoroughly washed, first with running tap water then distilled water and appropriately dried under the sun light for three days. The materials were oven-dried at 105°C for 24hrs after which they were crushed using laboratory mortar and pestle. They were later grounded with a manual grinding machine and sieved to get particle sizes of 75µm, 150µm, 300µm, 600µm and 800µm.Mass ranges between 0.25 - 2.5g of the different particle sizes were also taken. The various particle sizes & mass were packaged ready for use.

2.3 Characterization of Crude Oil

The Niger Delta heavy crude oil used for this study and was characterized on the basis of its Viscosity, Density, Specific Gravity, pH, Conductivity, Total Organic Carbon (TOC).

Figure 1: (a) Plantain Peels, (b) Dried Plantain Peels, (c) Grounded and Sieved Plantain Peels

Figure 2: (a) Plantain Leaves (b) Dried Plantain Leaves and (d) Grounded and Sieved Plantain Leaves

2.3.1 Determination of Total Organic Carbon (TOC)

0.2ml of sample was measured into a 500ml flask.10ml of 0.5M potassium dichromate solution ($K_2Cr_2O_7$) was added and swirled gently. 20ml of H_2SO_4 was added rapidly and swirl gently to mix the reagents while avoiding splash. Flask was allowed to stand for 30minutes. 200ml of Distilled water was added, then 10ml 0f Ortho Phosphoric Acid (H_3PO_4). 3 drops of Ferroin Indicator were added. The solution was titrated against FAS (Ferroin Ammonium Sulphate) Solution.

Total Organic Carbon (TOC) was determined from this given formula;

$$\% \text{ TOC} = \frac{(Vb - Vs) \, X \, M \, X \, 1.38}{Volume \ of \ Sample} \quad (1)$$

Where,
Vb = ml of FAS used for blank
Vs = ml of FAS used for sample
M = Molarity of FAS (0.25M)
Volume of sample = 0.2ml
FAS = Ferroin Ammonium Sulphate (FAS)

2.4 Characterization of Adsorbent

The waste Nigerian plantain leaves and peels were characterized on the basis of moisture content, density, fixed carbon, ash content and volatile matter(proximate analysis) and iodine number using the ASTM methods as described in the work of Ademiluyi and David-West (2012).

2.5 Adsorption Analysis of Crude Oil using Dried Plantain Leaves and Peels

2.5.1 Effect of Particle Sizes of Dried Plantain Leaves and Peels

2 grams of PP sample of particle sizes, 75µm, 150µm, 300µm, 600µm and 800µm were added into each of five 500 ml conical flasks. 250ml of distilled water and 0.5 ml of the heavy crude oil sample was added into each of the flasks. Stirred and shaken, then allowed to settle for two hours at room temperature. The solution in each flask were filtered using a filter paper, the Total Organic Carbon (TOC) of the filtrate in each of the flasks were measured respectively. The same process was repeated for the PL samples.

2.5.2 Effect of Dosage of Plantain Leaves and Peels on Adsorption of Crude Oil

Crude oil concentration of 18131 mg/L was prepared and added into each conical flask containing dosages of 0.25g, 0.5g, 0.75g, 1g, 1.5g, 2g and 2.5g of 800µm PP and 250ml of distilled water. The solution was stirred and allowed to settle for two hours at room temperature. The TOC of the filtrates were measured. This was also repeated for the PL sample.

2.5.3 Effect of Initial Crude Oil Concentration on Adsorption using Dried Plantain Peels and Leaves

The initial concentration of the crude oil (TOC) in solution was varied from 5208mg/L, 6911mg/L, 10417mg/L, 15,526mg/L to 18131mg/L and added into each of five conical flasks respectively. PP of 800µm and 2 grams were added into each of the crude oil concentrations in the flask. The mixture was stirred, then allowed to settle for 2 hours at room temperature. Each of the solutions in the flask was filtered and the TOC of the filtrates were measured to determine the effect of initial crude oil concentration on adsorption. The same process was repeated for PL.

2.5.4 Effect of Contact Time on Adsorption of Crude Oil using Plantain Leaves and Peels

The packaged 800µm PP of 2 grams were added into each of the flask with the crude oil varied concentrations. The mixture was stirred, then allowed to settle for 2 hours at room temperature. The mixture in each of the flasks were withdrawn at various contact times; 10mins, 30mins, 60mins, 120mins and 24hrs. Then filtered and the TOC of the filtrate were measured to determine the effect of contact time on crude oil adsorption. This process was also repeated for the PL sample.

2.5.5 Determination of the amount of Crude Oil adsorbed by the Adsorbents

The amount of crude oil adsorbed at equilibrium, Q_e (mg/g) was determined using equation

$$Q_e = \frac{(C_o - C_e)V}{m} \quad (2)$$

And the percentage adsorption (%) of crude oil adsorbed was computed as follows

$$\text{Percent adsorption (\%)} = \frac{C_o - C}{C_o} * 100 \quad (3)$$

Where C_o and C_e are the initial and equilibrium concentration (mg/l), V, volume of solution (l), m the mass of the dried Plantain leave (sample) and C the solution concentration at the end of adsorption.

2.5.6 Determination of the Total Microbial Count in the Crude Oil Sample

Petri dish and test tube **were** sterilized first in an auto clave for some time and removed from it. 2g of crude oil polluted water was measured into a beaker and nutrient agar into a conical flask and mixed with 75ml of distilled water. The sample was poured into a Petri dish and 9ml of nutrient agar also into them respectively. Filter paper soaked with crude oil was placed inside the Petri dish containing the sample respectively. It was covered with foil paper and incubated for 24 hours in an incubator. After 24 hours, the sample was brought out and counted to know the number of hydrocarbons utilizing bacteria. The count was obtained by multiplying with a dilution factor.

$$\text{Total count} = \frac{\text{Colony count}}{\text{Volume inoculated}} \; x \; Dillution\ factor \quad (4)$$

2.6 Adsorption Characteristics Study

The most commonly used adsorption isotherms in adsorption studies to fit the experimental adsorption data **were** used, namely: Langmuir, Freundlich and Temkin.

a. Langmuir isotherms was used to determine the isothermal behaviour of the adsorption processes. The process in this model entails three different steps: the process by which ions residue was diffused to the external surface of the sorbent; the process of diffusion into the pores of the sorbent; and the sorption of the residue on the internal surface of the sorbent (Nasehir-Khan *et al.*, 2011).

The Langmuir isotherm is expressed as

$$\frac{C_e}{Q_e} = \frac{1}{K_L} + \frac{a_L c_e}{K_L} \quad (5)$$

where:

Q_e = the amount of crude oil adsorbed per unit mass of adsorbent (mg/g) at equilibrium.

C_e = the equilibrium concentration of the adsorbate (mg/l).

K_L = a constant related to the affinity between the adsorbent and the adsorbate.

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$\frac{K_L}{a_L}$ = theoretical monolayer saturation capacity Q_o.

The values of Q_o and K_L were determined by plotting C_e/Q_e versus C_e. One of the most important parameters of the Langmuir isotherm model was the separation factor R_L which is a dimensionless factor defined by (Ademiluyi & Ujile, 2013).

$$R_L = \frac{1}{1 + a_L c_O} \quad (4)$$

where:
C_o = the initial adsorbate concentration and a_L is the Langmuir constant related to the energy of adsorption. The values of R_L shows the shape of the isotherm to be either unfavorable ($R_L > 1$), favorable ($0 < R_L < 1$), linear ($R_L = 1$), or irreversible ($R_L = 0$).

b. The linear form of the Freundlich isotherm **was** the earliest known relationship describing the adsorption equation and is often expressed as

$$\text{Log } Q_e = \text{Log}K_f + \frac{1}{n}\text{Log}C_e \quad (5)$$

K_f = The Freundlich constant related to the adsorption capacity.
$1/n$ = The Freundlich constant related to the adsorption intensity.
When employing this model in adsorption study, the assumption that should be taken into cognizance is that the removal of crude takes place on a heterogeneous sorbent surface and can also be applied to multilayer sorption (Bhairavi *et al.*, 2018 ; Ju *et al.*, 2016).

c. The Temkin isotherm is also often used to represent the equilibrium adsorptive behavior between two phase-
es composing the adsorption system. The Temkin isotherm is expressed as;

$$Q_e = a + b + \ln C_e \quad (6)$$

where:
a, b = Constant related to energy and capacity of adsorption..

3.0 RESULTS AND DISCUSSION

3.1 Characteristics of the Crude Oil

The experimental analysis result based on the characteristics of the crude oil used for this study are presented in Table 1. The specific gravity values of petroleum products are close to density values and ranges from about 0.80 – 0.88 for light crude oils to about 0.94 - 0.98 for heavy oils (Speight, 2001).The analysis result of the crude oil used for this study gave a specific gravity of 0.9601 and API gravity of 16.0 which falls under the group of heavy oils.
This crude oil is heavy because it does not flow easily and its density/specific gravity are higher than that of light crude oil. Heavy oil is asphaltic (contains Asphaltenes and Resins). The Specific gravity, API gravity and kinematic viscosity results of the crude oil used for this work compared favorably with the work of Ofodili *et al.* (2018), where they obtained 0.9450, 18.0° and 80.4cSt respectively. The pH value of 3.64 suggest a strongly acidic crude oil. Results on various study on the characteristics of Niger Delta crude oil done by other researchers corroborated this work

3.2 Characterization of the Dried Plantain Peels and Leaves

The characterization results of dried plantain peels (PP) and leaves (PL) used for the adsorption of the crude oil in aqueous solution is presented in Table 2. The bulk density, proximate analysis, iodine value (a measure of activity level and the micro pore content of the adsorbents; higher number indicates higher adsorption) and when comparing the iodine numbers of the two adsorbents, plantain peel (PP) and leaves (PL) used for
the study, the PL showed a higher iodine number of 1,339.605 which was an indication of more micro pore (3.7) and implied higher sorption capacity based on iodine value evaluation.
The ash content recorded in this study for both PP and PL (*Musa paradisiaca*) were 8.5% and 12% respectively which is similar to the work by Babayemi *et al.* (2010), where they reported that a range of 6.3 to 12.0% ash content was observed in some varieties of *Musa* species

3.3 Effect of Particle Size of Dried Plantain Peels and Leaves on the Adsorption of Crude Oil in Aqueous Solution

The effect of particle sizes of dried PL and PP on the adsorption of crude oil in aqueous medium is presented in Figure 3 and 4. Based on the results obtained, the adsorption of crude oil increased with increment in particle size and decreased with the smaller particle size. Though, adsorption is a surface phenomenon which is dependent on surface area, which implied that, by increasing the surface area of a particular adsorbent the adsorption tendencies should increase and smaller particle sizes have higher surface area compared to bigger particle sizes. However, in this study, the crude oil adsorption in aqueous solution decreased with the smaller particle sizes with supposedly larger surface area and increased with the larger particle sizes with smaller surface area in a reverse phenomenon. This reverse adsorption phenomenon suggest that the smaller particle sizes must have plugged off their pores or interstices by particles accumulation on each other or a process that have resulted to the rupture of the natural capillaries of the smaller particle sizes which must have distorted their natural adsorption tendencies.

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These results are similar to the work by Hamid and Zahra (2017), Abdelwahab *et al.* (2017), and Husseien *et al.* (2009). In addition, the research work carried out by Husseien *et al.* (2009) and Kim *et al.* (2008) where they studied the adsorption of oil by natural adsorbents established that the oleophilic compounds in the oil tends to be adsorbed more into the available large pores of the adsorbents. Figure 3 and 4, show that the biggest particle sizes, 800µm, adsorbed the higher amount of crude oil within 2 hours of adsorption. Therefore, based on the result of this study for effective adsorption of crude oil in aqueous solution using dried PP and PL, for optimal crude oil adsorption, the particle size of the adsorbent should be (≥ 800µm). But, when comparing PP and PL based on the results obtained as shown in Figure 5, PL gave a better sorption for equivalent particle sizes. At 800µm, PL gave a value of 53.3% while PP value was 49.8%.

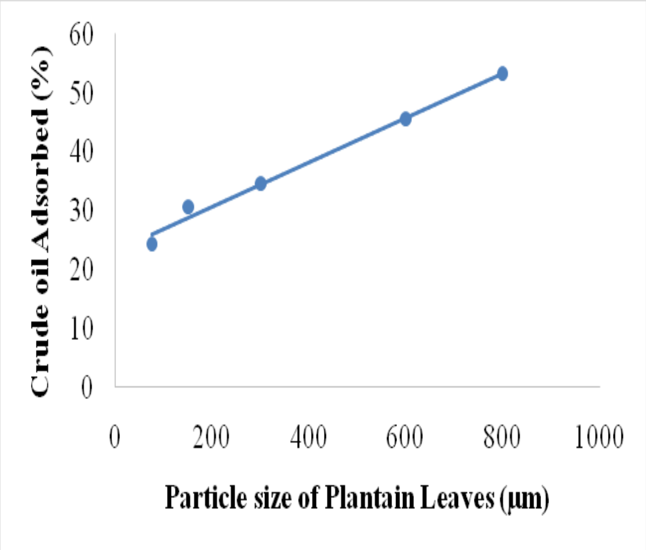

Figure 3: Effect of Particle Size of Dried Plantain Leaves on the Adsorption of Crude Oil in Aqueous medium

3.4 Effect of Dosage of Dried Plantain Peels and Leaves on the Adsorption of Crude Oil in Aqueous Solution

Crude oil in aqueous medium was adsorbed using PP and PL dosages ranging from 0.25 – 2.5g.

The effect of dosage of dried PP and PL on the adsorption of crude oil of known concentration in aqueous solution is presented in **Figure** 6 and 7 respectively. Based on the results obtained from this study, the adsorption of crude oil increased with increase in adsorbent dosage until an equilibrium or optimal adsorption is achieved in this case at a dosage values of 2.0g as shown in **Figure** 6 and 7. The initial increment in adsorption of crude oil with increase in dosage was due to the availability of active sorption sites and easier penetration of the crude oil molecules into those active sites. Similar result was obtained by Abdul *et al.* (2016). In this study the adsorption observed with the PP, as shown in Figure 8, was more compared to that of the PL, considering the adsorption values obtained for any particular dosage, as PL and PP recorded 98.8% and 99.1% respectively in crude oil adsorbed. This result suggest that PP gives a better adsorption of crude oil in aqueous solution based on dosage consideration.

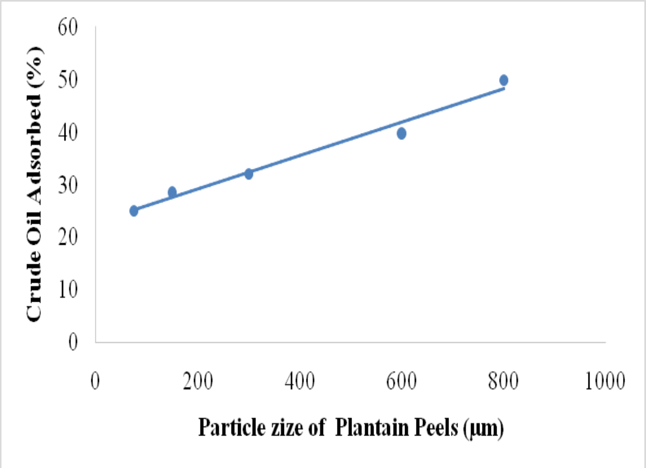

Figure 4: Effect of Particle Size of Dry Plantain Peels on the Adsorption of Crude Oil in Aqueous Solution

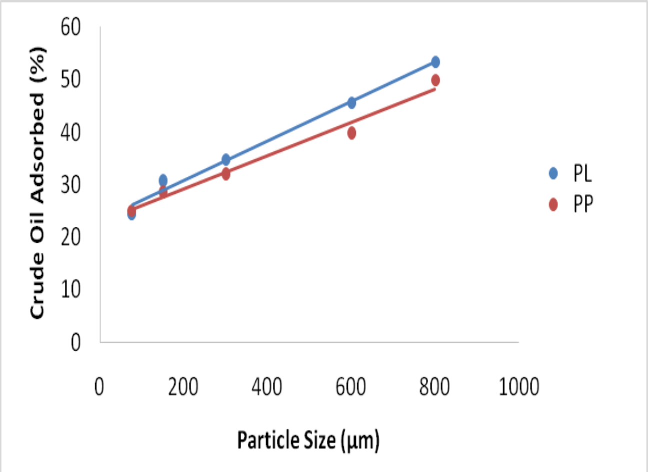

Figure 5: Comparison of the Effect of Particle Size of PP and PL

Table 1: Characteristics of the Niger Delta Crude Oil

S/NO.	Parameter	Unit	Result
1	Appearance/colour	-	Dark brownish liquid
2	Density @15°C	g/cm^3	0.9592
3	Specific gravity@60F	-	0.9601
4	API gravity	-	16.0°
5	Kinematic viscosity	cSt	91.8
6	Dynamic viscosity	cP	88.05
7	pH @ 27.2^0C	-	3.64
8	Electrical Conductivity	µs	1.58
9	Total Coliform	cfu/ml	**$21x10^5$**
10	Moisture Content	%	0.029
11	TOC	mg/l	3.04570×10^6

Table 2: Characterization of Dry Plantain Peels and Leaves

S/NO.	Parameter	Plantain Peels (PP)	Plantain Leaves (PL)
1	Bulk density (g/cm^3)	0.424	0.137
2	Moisture content (%)	3.51	2.72
3	Iodine value (mg/g)	1,186.842	1,339.605
4	Volatile matter (%)	22	23
5	Ash content (%)	8.5	12
6	Fixed carbon (%)	65.99	62.28

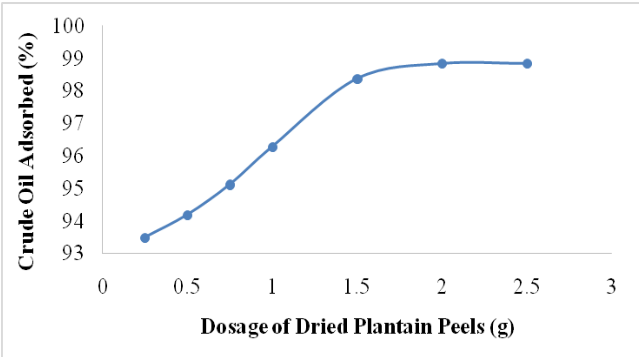

Figure 6: Effect of Dosage of Dried Plantain Peels on the Adsorption of Crude Oil in Aqueous Solution

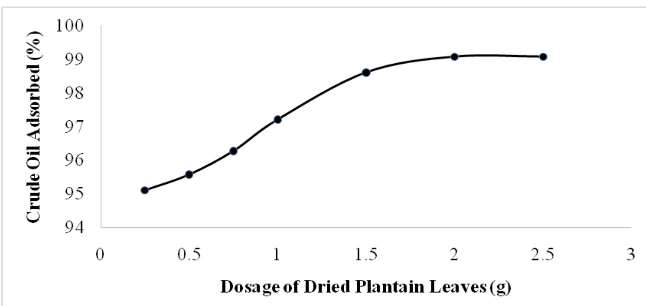

Figure 7: Effect of Dosage of Dried Plantain Leaves on the Adsorption of Crude Oil in Aqueous Solution

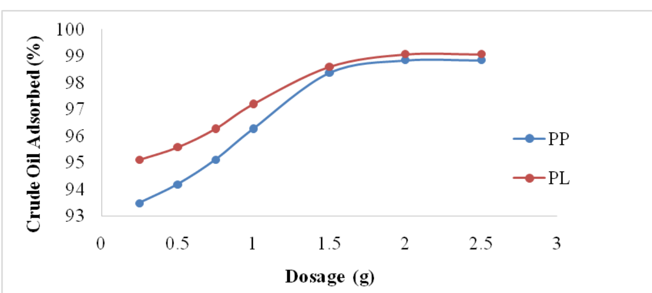

Figure 8: Comparison of the Effect of Dosage of PP and PL

3.5 Effect of Initial Crude Oil Concentration on Adsorption using Dried Plantain Peels and Leaves

The effect of initial crude oil concentration on adsorption using dried PP and PL is presented in **Figure** 9 and 10 respectively. Based on the result of this study, the adsorption of crude oil in aqueous solution increases with reduction in the initial concentration of crude oil in solution. Adsorption increased from 93% to 99% and 94% to 98% as the concentration of crude oil decreased from 18131mg/L to 5208mg/L within 120mins of adsorption for the PL and PP respectively. This result is similar to the work reported by Babatope and Funmilayo (2017). Comparing PP and PL as shown in Fig. 11, both adsorbent's effect on initial concentration of the adsorbate was found to be somewhat same considering the closeness of the experimental data but the PL adsorbed 1% more than the PP at adsorbate concentration of 5208mg/L.

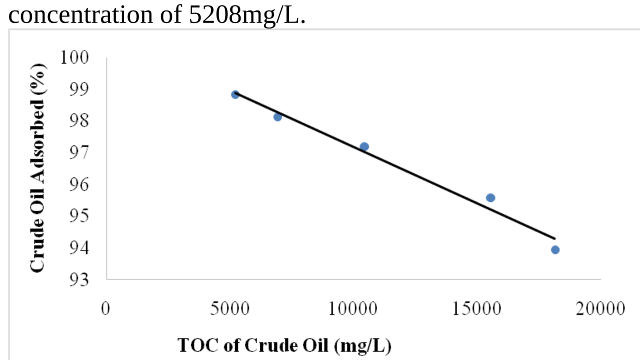

Figure 9: Effect of Initial Concentration on the Adsorption of Crude Oil Using Dried Plantain Peels

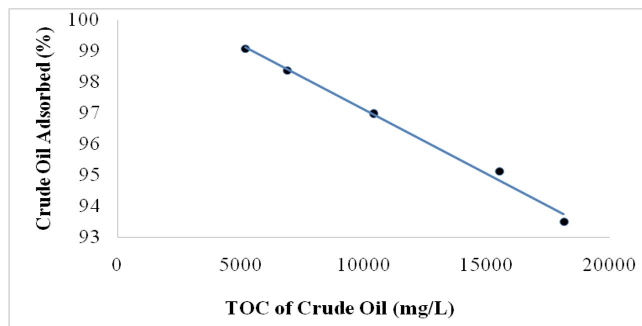

Figure 10: Effect of Initial Concentration on the Adsorption of Crude Oil Using Dried Plantain Leaves

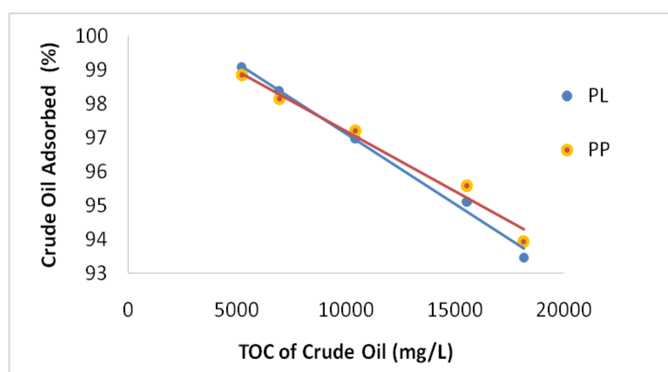

Figure 11: Comparison of the Effect of Initial Concentration of PP and PL

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3.6 Effect of Contact Time on Adsorption of Crude Oil in Aqueous Solution

Figure 12 & 13 shows the effect of contact time on the adsorption of crude oil in aqueous medium using dried PP and PL. The results showed that the optimum percentage of crude oil adsorbed was achieved in 10mins. From Figure 12 and 13, the sharp increase of adsorption in the first 10mins contact time can be attributed to the initial adsorption onto the surface of the sorption materials and subsequent penetration into the inner microscopic pores. But beyond 10mins, the extent of an increase in adsorption with time was lower up until 120 minutes when equilibrium was achieved after which there was no noticeable increase or change in crude oil adsorption. It also shows that at lower crude oil concentration ranges the percent adsorption is high because of the availability of more reactive sites. At higher concentration of crude oil in solution more and more surface sites are covered, the capacity of the adsorbent gets exhausted due to non-availability of active sites.

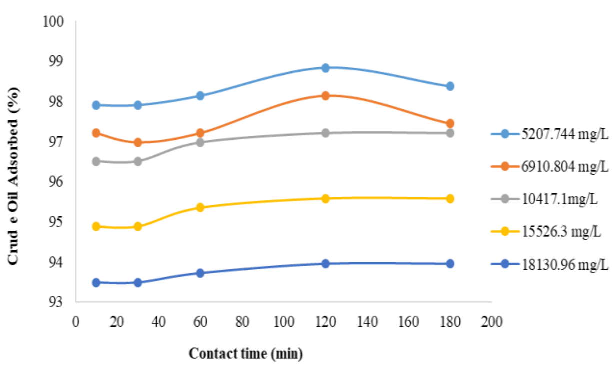

Figure 12: Effect of Contact Time on the Adsorption of Crude Oil in Aqueous Solution Using Dried Plantain Peels

This leads to a lower percentage of crude oil adsorbed at higher concentration. Similar results were obtained by Nwadiogbu *et al.* (2015). Also, from the result obtained it was observed that the percentage adsorption of crude oil reached an equilibrium in 120 minutes contact time, which gave an appreciable optimal.

3.8 Adsorption Isotherm Equilibrium

3.8.1 Langmuir Adsorption Isotherm for Crude Oil

The Langmuir adsorption isotherm for the adsorption of crude oil on PL and PP at 26°C is presented in Figure 14 and 15. The ratio of the equilibrium concentration (C_e) to the amount of crude oil adsorbed, (C_e/Q_e), was plotted against the equilibrium concentration of crude oil (C_e). The linearity of the plot shows that the Langmuir isotherm model can be used to predict the sorption of crude oil on PL and PP. The Langmuir plots from this study shows that there is increase in the rate of adsorption at different concentrations. This implies that the lesser the concentration of the crude oil, the higher the adsorption by the adsorbents.

The separation factor (R_L) was determined from equation 3.6, the values for PL were between 0.0383 - 0.1217 and for PP between 0.0229 - 0.0754 for adsorbate concentrations between 18130.96mg/L - 5207.74mg/L. Therefore, since R_L is less than 1 for all the concentrations it implies that adsorption process is favorable, similar R_L result of 0.014 – 0.065 were obtained by Nurul *et al.* (2011) after their work on the adsorption of crude oil on banana pseudo stem fibers for adsorbate initial concentration range of 20% - 100% v/v. Comparing the adsorption capacity (Q_o) of this study to other research work with reference adsorbents as shown in Table 4, PL and PP has a higher affinity for crude oil.

Table 3: Microbial Count Analysis of Different Concentration of Crude Oil in the Presence of PL in Aqueous Medium

Crude Oil Concentration (mg/L)	TBC cfu/mL Initial Value	TBC cfu/mL After 24hrs	% Microbes Growth Value
5207.744	3.2×10^6	3.3×10^7	90.3
6910.804	2.2×10^7	8.1×10^7	72.8
10417.100	2.3×10^7	3.0×10^7	23.3
15526.000	2.7×10^6	1.8×10^7	85.0
18130.960	2.1×10^6	1.5×10^7	86.0

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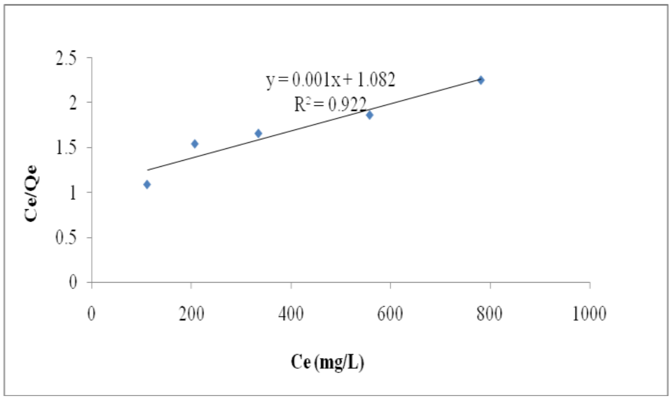

Figure 14: Langmuir Adsorption Isotherm for Batch Adsorption of Crude Oil on Plantain Leaves at 26°C

3.8.2 Temkin Adsorption Isotherm for Crude Oil

The Temkin adsorption isotherm for the adsorption of crude oil on PP and PL at 28°C is presented in Figure 16 and 17. A linear relationship was also exhibited from the plot of amount of crude oil adsorbed (Q_e) at equilibrium against the natural logarithm of equilibrium concentration of crude oil (lnC_e). Similarly, the correlation coefficient R^2 of 0.9919 and R^2 of 0.9789 obtained for the PP and PL respectively shows that the Temkin adsorption model can also be used to predict the sorption of crude oil onto PP and PL

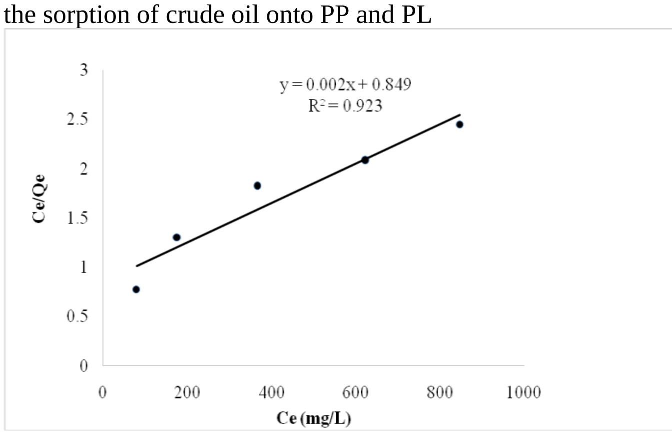

Figure 15: Langmuir Adsorption Isotherm for Batch Adsorption of Crude Oil on Plantain Peels at 26°C

. 3.8.3 Freundlich Adsorption Isotherm for Crude Oil

Figure 18 and 19 shows the batch adsorption isotherm of crude oil on PP and PL at 30°C. Q_e, amount of crude adsorbed at equilibrium was plotted against the equilibrium concentration C_e of the crude oil adsorbed. The adsorption capacity K_f and the adsorption intensity 1/n are obtained directly from the slopes and intercepts of the linear plot. The values of the adsorption intensity for PP (n = 1.9) and PL (n = 1.5) are greater than 1 indicating the adsorption of crude oil using PP and PL is more of chemisorption than physical adsorption

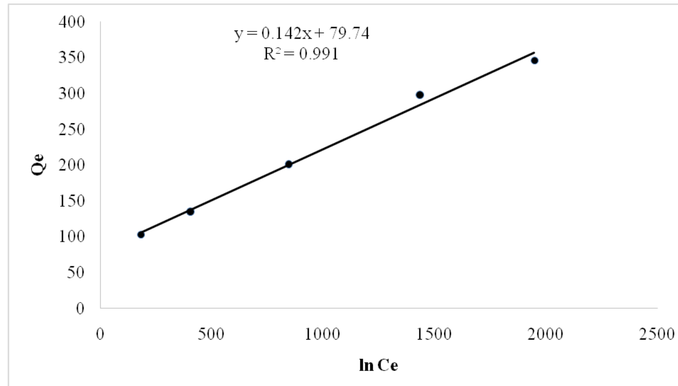

Figure 16: Temkin Adsorption Isotherm for Batch Adsorption of Crude Oil on Plantain Peels at 28°C.

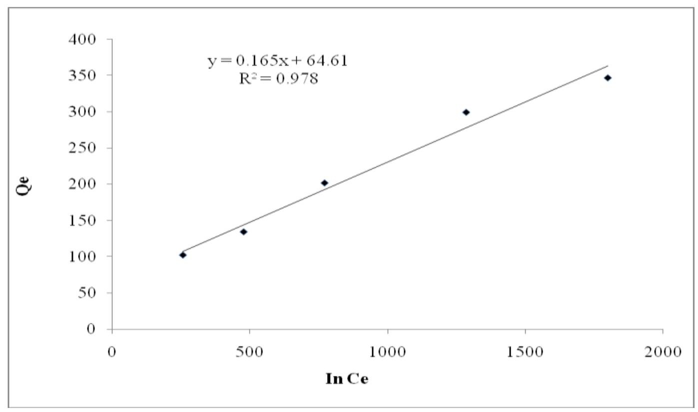

Figure 17: Temkin Adsorption Isotherm for Batch Adsorption of Crude Oil on Plantain Leaves at 28°C

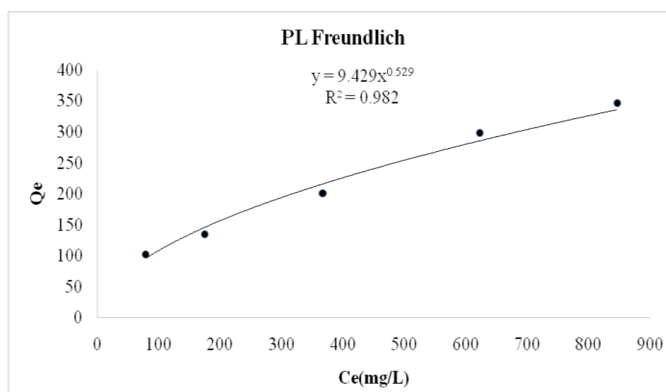

Figure 18: Freundlich Adsorption Isotherm for Batch Adsorption of Crude Oil on Plantain Peels at 30°C

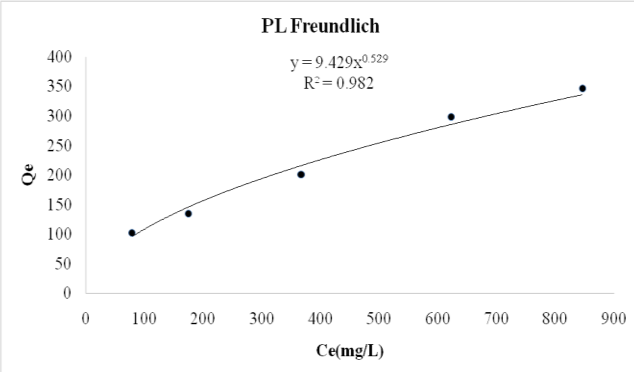

Figure 19: Freundlich Adsorption Isotherm for Batch Adsorption of Crude Oil on Plantain Leaves at 30°C

4. CONCLUSION

The adsorption of crude oil in aqueous medium using waste dry plantain (*Musa paradisiaca*) leaves and peels in a controlled laboratory environment was investigated. Effect of particle size, dosage, initial crude oil concentration, contact time and microbial count were the parameters considered for this analysis. The outcome of this analysis showed that the parameters considered had a significant effect on the adsorption and remediation of the crude oil in the aqueous medium. The result showed that crude oil adsorption increased with increase in particle size. Adsorption was observed to increase with dosage until equilibrium was attained. Varying the crude oil concentration in a solution for a known adsorbent dosage influenced the crude oil adsorption as it was observed that lower concentration favoured adsorption. PP and PL showed similar crude oil adsorption capabilities with remarkable oil sorption capacity of 500mg/g and 667mg/g respectively. In terms of all the parameters investigated the PL exhibited a better adsorbent material. An optimal crude oil adsorption was obtained in 120mins contact time, with both adsorbents, which implies an appreciable adsorption process time. In terms of microbial count, the resultant growth of microbes' colony after just 24hrs incubation time in an aqueous solution of the plantain leaves and crude oil suggest that the crude oil was significantly used up as a remediation process. The adsorption equilibrium isotherm of the experimental data showed that the adsorption of crude oil onto PP and PL is a favorable process and the adsorption process is best fitted to the Temkin Isotherm model with 0.9919 correlation coefficient.

The high sorption capacities and appreciable adsorption time of these adsorbents based on the results from this study can indeed be a very useful application in remediating crude oil polluted marine environment. Furthermore, the practical deployment of PP and PL to crude oil polluted sites to be used as crude oil adsorbents are easily achievable because they are readily available as agricultural waste materials, relative cost advantage, eco-friendly and biodegradable.

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Table 4: Isotherm Models and their Constant Values for Adsorption of Crude Oil from Aqueous Solution using Adsorbents

Isotherms/Constants	Adsorbent from Present Study PP	Adsorbent from Present Study PL	Reference Adsorbent: Kenaf Shive (Salizu *et al.*, 2019)	Banana Pseudo stem Fibers (Nurul *et al.*, 2011)	Coconut Shell (Olufemi & Otuoze, 2018)
Langmuir					
q_{max} (mg/g)	500.00	666.7388	10.4743	169.000	1.9440
K_L	1.1770	0.9241	0.0804	0.00721	3.6795
R^2	0.9239	0.9224	0.9003	0.9260	0.9359
Freundlich					
n	1.8875	1.5067	0.4812	2.8800	1.8241
K_f	0.9745	0.6285	0.1943	38.290	1.2274
R^2	0.9825	0.9871	0.8224	0.9760	0.9695
Temkin			n/a	n/a	
a	79.742	64.610	-	-	168.37
b	0.1420	0.1658	-	-	0.2505
R^2	0.9919	0.9789	-	-	0.9522