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Research Article

MODELING OF DRY RAFFIA PALM TRUNK ENHANCED BIOREMEDIATION OF OIL-BASED DRILL CUTTINGS

***Bright Nweke and Davidson D. Davis**

Department of Agricultural and Environmental Engineering, Rivers State University Nkpolu Oroworokwo Port Harcourt, Nigeria

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Abstract

This study determines the effect of dry raffia palm for degradation of oil-based drill cuttings bioremediation. The remediation process was effectuated using dry raffia palm. The experiment was carried out at the research Centre located at Agricultural and Environmental Engineering departmental workshop in Rivers State University, Port Harcourt. Samples of oil-based drill cuttings were bulked in eleven reactors with four replications (T1, T2, T3-T11). The following physiochemical properties: Total Petroleum Hydrocarbon TPH, Polycyclic Aromatic Hydrocarbon PAH, Benzene, Toluene, Ethylbenzene and Xylene BTEX of the initial drill cuttings, oil-based drill cuttings of dry substrate were analyzed in the laboratory before and after treatments. TPH, BTEX and PAH were observed to have reduced drastically in all treatment options at the end of 16 weeks of remediation. Results also exhibited high coefficient of determinations of (R^2) between the range of 0.9274 to 0.9992 in all the treatment options. The results as attained using the analysis of variants ANOVA showed a significant difference at 95% and highly significant at 99% confidence level. Similarly, the results were collaborated by coefficient of variation which percentages were quite low. This confirmed that the experimental error was very low and reliable. Models were formulated for the degradation of the TPH, BTEX and PAH. The results of the experimental test were plotted against the period to obtain the constant (β) in the predicted models. The modelsshow good agreement between experimental data and the predicted data. The model adapted was the simple nonlinear regression and it was validated using the root mean square (RMSE) and graphical comparison. Results displayed high coefficient of determination R^2 and low RMSE. This further illustrated the ability of the model (simple nonlinear regression) to predict degradation rate of TPH, PAH and BTEX in oil-based drill cuttings bioremediation treated with dry raffia palm trunk respectively.

Keywords: Biodegradation, Bioremediation, Dry Raffia Palm Trunk, Model and Oil-based drill cuttings.

INTRODUCTION

A significant amount of oil-based drill cuttings is utilized in the exploration and extraction of oil and gas for the purposes of stabilizing well bores, cleaning the bottom of the borehole, balancing the reservoir pressure, and cooling and lubricating drill bits (Nweke *et al.,* 2023). Drill waste, consisting of oil-based cuttings, is continually injected down the well via the hollow drill string and returns through the well annulus (Nweke *et al.,* 2023). A field that produces crude oil typically produces a lot of drilling cuttings. For instance, the US produces more than 6 million m^3 of drill waste annually (DPR, 2018).Drilling waste is a complex mixture that includes numerous components, including mineral, fuel hydrocarbon, and synthetic additives such as viscosities (such as clays, polymers, cellulose, xanthan gum, and guar), weighting agents (such as barytine and carbonate), filtrate reducers (such as starch, carboxy methylcellulose, and resins), and clay swelling inhibitors (such as KCl and glycol) (wang *et al.,* 2020, Bakke *et al.,* 2013). Numerous of these ingredients are poisonous, carcinogenic, and mutagenic. As a result, drilling wastes are categorized as hazardous solid wastes in China as well as priority environmental pollutants by the Department of Petroleum Resources (DPR, 2018). Drilling waste is now a significant environmental problem in the oil and gas sector due to a significant rise in drilling activities.The development of treatment technologies is highly valuable due to the hazardous nature and growing production quantity of drilling waste worldwide. While biological treatments are more economical and environmentally friendly, they are also more expensive than conventional physical chemical technologies, such as incineration, chemical stabilization and solidification confinement, burial pits and landfills, and re-injection below a secure stratum (Nweke 2023, wang *et al.,* 2020, wei *et al.,* 2017). In the industrialized world, petroleum is the most significant fossil energy resource. Exploration and drilling are necessary to gain access to oil-containing reservoirs. Geological and geophysical studies are then necessary to confirm the presence of oil and get ready for extraction (Nweke *et al.,* 2023; Santos *et al.,* 2014). Drilling fluids are used to manage reservoir pressure, convey cuttings to the surface, and lessen drill bit friction in order to make the drilling process easier (Santos et al. 2018; Almeida *et al.,* 20017). The most popular drilling fluids are usually oil-based muds (OBMs) with diesel content because of their affordability, good lubrication, and suitability for drilling wells in certain situations like deep or high temperatures (Hou et al. 2018;Paladino et al. 2016)OBMs are among the petroleum industry's most hazardous wastes after being mixed with drill cuttings. They contain complex hydrocarbons, heavy metals, and brine, which are released into the surrounding terrestrial and aquatic environments and have a negative impact on them (Nweke *et al.,* 2023). Because it is less expensive and more environmentally friendly than physicochemical approaches, bioremediation is a possible substitute for cleaning up drilling pollutants (Rybakov & Pereira 2018). If the native degrading microorganisms are not achieving the full degradation rate, one bioremediation strategy that can be used is bioaugmentation, which involves adding enhanced bacteria that are capable of degrading pollutants (Huang *et al.,* 2018). Due to potential synergistic relationships between consortium members and the diverse range of enzymes produced by individual members that can catalyze distinct removal steps, the microbial consortium is preferred over the pure culture in the case of bioaugmentation

Corresponding Author:** ***Bright Nweke,
Department of Agricultural and Environmental Engineering, Rivers State University Nkpolu Oroworokwo Port Harcourt, Nigeria.

(Junior *et al.,* 2017; Priecel and Sanchez 2019). The carbon, nitrogen, and phosphorus ratio in soil is unbalanced due to the high quantities of petroleum hydrocarbons added; this imbalance should be corrected and adjusted by adding organic or inorganic compounds prior to the bioaugmentation process (Nweke *et al.,* 2023). Microorganisms employed for bioaugmentation should be able to tolerate and proliferate in high salinities because drill cuttings are frequently connected with high concentrations of salt (Nweke *et al.,* 2023).Extremophiles that can thrive at high concentrations of NaCl, from 0.2 to 5.5 M, are known as halophilic microorganisms (Wang et al. 2017, Chinwendu *et al.,* 2021). Therefore, the growth of phosphate and nitrate is necessary for the microorganisms that break down hydrocarbons; the amount and pace of degradation of bioremediation using oil-based drill cutting in the environment is impacted by the limitation of these substrates.

The solid waste particles from the trunk that are mostly formed during the taping or cutting down of the trunk into separate logs used to prepare palm wine are known as dry raffia palm. The process of obtaining dry raffia palm involves mechanically grinding the solid material (trunk) using a machine or an axe, splitting the log intohalophilic bacteria,which are type of extremophiles that can grow in high concentrations of NaCl. They can also break down into tiny pieces by repeatedly hammering the log with a very forceful hammer on top of a metal rod according to Nweke et al. (2023),The dry trunk of the raffia palm, heated continuously, created a large amount of powder, which was then spread out to dry further in the sun.

The dry raffia palm is an alkaline plant that includes organic matter, phosphorus, nitrogen, and magnesium along with potassium, calcium, and potassium. Because of its rich concentration in potassium, phosphorus, magnesium, calcium, and nitrogen, Raffia palm ash refuses are employed by (Nweke *et al.,* 2023) as an excellent fertilizer and liming material that aid in boosting soil fertility, nutrient uptake, and pH.Adding dry raffia palm as an organic supplement is one of the practical and affordable ways to recover contaminated environment from oil-based drill cuttings. To implement cleanup, an understanding of the petroleum and environmental variables is required. Additionally, Phaseolus L vulgaris cultivated in diesel oil-contaminated soil was studied by Onyelucheya et al. (2013) to determine the growth performance and mineral nutrients composition of the plant, which improved the soil fertility during bioremediation.

MATERIALS AND METHODS

Description of the Study Area

The experimental site was located at the Rivers State University, Port Harcourt, Nigeria. The oil-based drill cuttings were obtained from the Boskel Nigeria Limited, in Rivers State, Niger Delta region of Nigeria. The experiment was carried out between the months of August 2020 to December 2020. The experimental area is made up of flat plains with soil characterized as coasta l plain sand. The vegetative cover is the tropical rain forest with longitude and latitude of (5°19'N, 6°28'E).

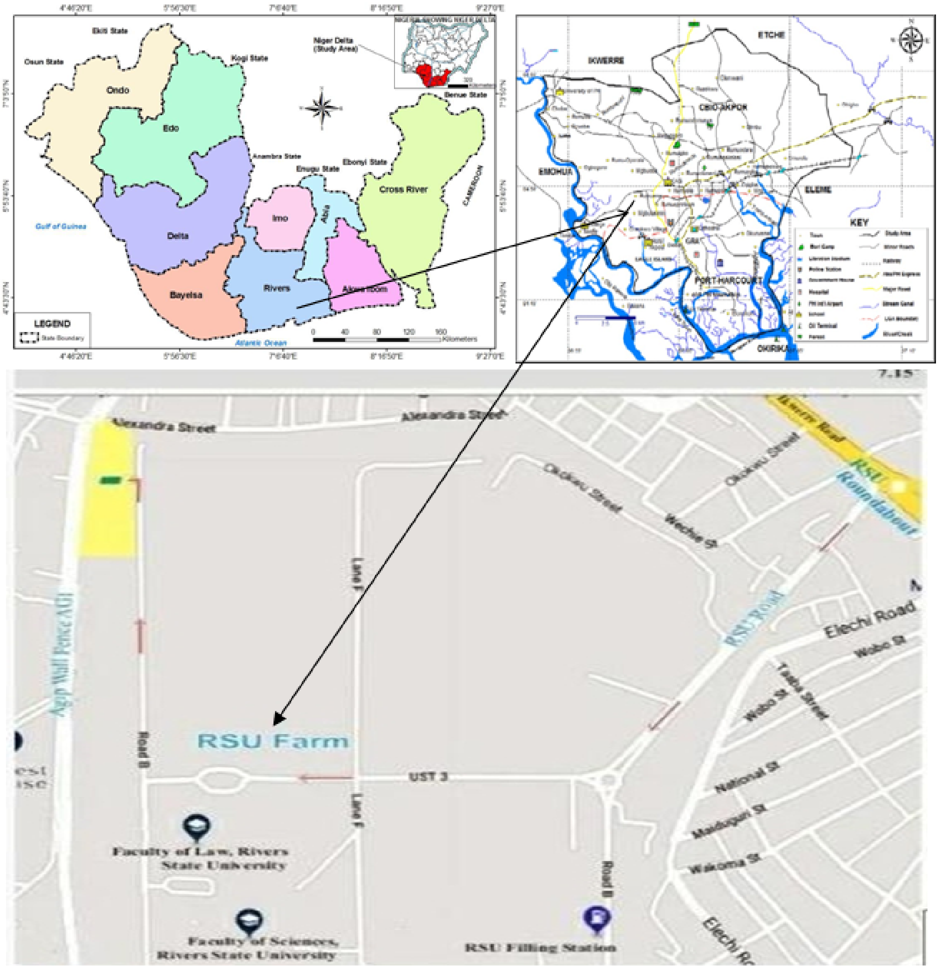

Figure 1. Map of Niger delta, Port Harcourt metropolis and river state university

Experimental design

The Randomized Complete Block Design (RCBD) were used to conduct the investigation. Eleven options (consisting of seven treatment options involving (fresh) *extracts* from the *raffia* palmand compost tea from raffia palm all were used as treatment materials while the controlwas left uncontaminated. compost raffia palm cast which serves as tea for irrigation that enhanced tilling for aeration. All these bio-stimulants or derivatives were tested and filled in 20 Liters of bucket at very low thermal conductivities containing fixed masses of the oil-based drill cuttings according to their fixed ratios. The content was mixed thoroughly to get a composite mixturethereafter they were safeguard and kept at room temperature except for control. Samples were taken every 4weeks and analyzed for reduction in total petroleum hydrocarbon (TPH), Benzene Toluene Ethylbenzene and Xylene (BTEX) and Polycyclic Aromatic Hydrocarbon (PAH), biodegradation from oil-based drill cuttings.

Preparation of specimens

i. Oil based drill cuttings: 180 liters of untreated oil-based drill cuttings were used for the research with high TPH, TPAH and BTEX content as shown in Appendix H. Thereafter, the untreated oil-based drilling cuttings samples were treated with the different raffia palm substrates at different treatment levels using a mix ratio of 2:1 according to Nweke *et al.,* (2023).

ii. Dry raffia palm trunk: Dry used in the study was obtained from raffia palm trunk locally, by cutting down the trunk into different log. The log was crushed into pieces with the use of axe, thereafter, was transferred and placed on a strong metal iron where it was grinded into fine size by the use of hammer. The grinded substrate was air dried daily at an interval of 30 days to obtain oven drying. The substrate was passed through a sieve analysis to obtain fine aggregate using US Sieve no. 60.

Modeling of dry raffia palm trunk

Simple nonlinear regression graph was plotted for oil-based drill cuttings contaminant concentration (C_0, mg/kg) against period (t, weeks) and the values for the constants (β) were established for different treatment.

$$C_{o_1} = C_{o_0} e^{-\beta t} \qquad (1)$$

Where
C_{o_1} = Oil-based drill cutting contaminant at any time, mg/Kg,
C_{o_0} = Intercept on the line C_o axis,
β = oil-based drill cuttings contaminant degradation constant (slope of the line)
t = Time (weeks), the applied simple non-linear regression model.

Modeling the Effect of Dry Raffia Palm on TPH, PAH and BTEX of Oil-Based Drill Cuttings Bioremediation

Statistical analysis

The single factor experimental analysis of variance (ANOVA) were used to performed on the various replications of the experimental cells in order to determine the percentage reduction of TPH, simplenon-linear regression model analysis were employed to evaluate the relationship between time (in weeks) and some measured oil based drill cutting characteristics since bioremediation is a time dependent process while simulation cum root mean square were used for comparison on the classification of the difference between two treatment means as significance and non-significance at 5% level of probability. This analysis followed the procedure described by Nweke *et al.,* (2023).

RESULTS AND DISCUSSION

TPH, PAH and BTEX model calibration

The TPH degradation models at constant treatment of dry raffia palm trunk at different remediation periods of 0, 4, 8, 12 and 16 weeks was established for predicting the degradation of TPH in oil-based drill cutting treated with dry raffia palm. The TPH concentrations are shown in Table 1, 2 and 3 (Figure 2, 3 and 4).

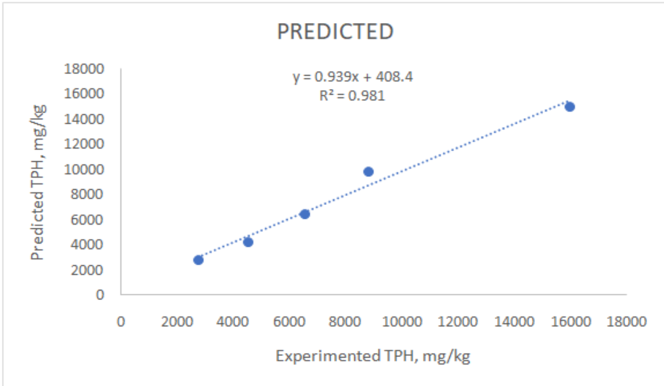

Figure 2. Comparison of predicted and experimented effect of dry raffia palm on tph concentration on oil based drill cuttings

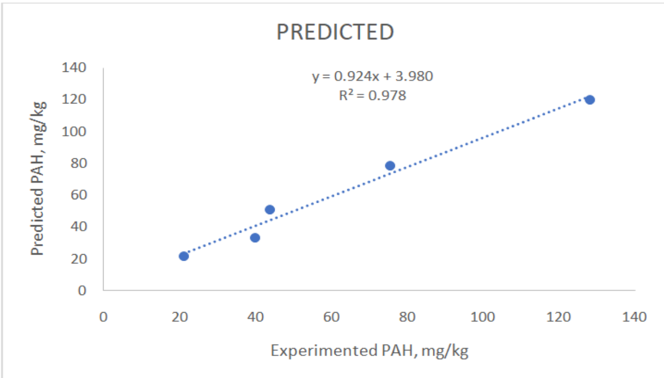

Figure 3. Comparison of predicted and experimented effect of dry raffia palm on pah concentration on oil based drill cuttings

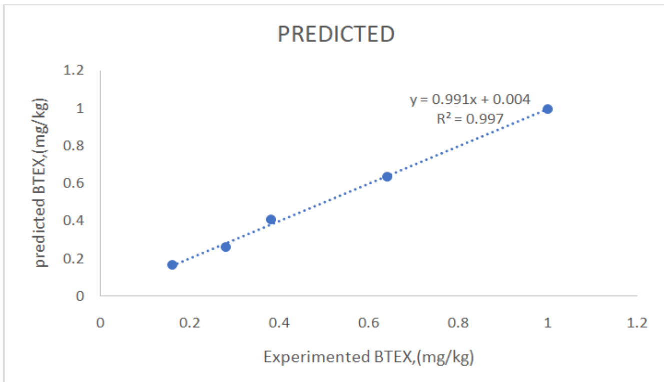

Figure 4. Comparison of predicted and experimented effect of dry raffia palm on btex concentration on oil based drill cuttings

Table 1. Root Mean square error and RPD of TPH computation of dry raffia palm trunk on oil-based drill cuttings bioremediation

Measurd X	X	x - x	(X - x)^2	MSE	SD	Predicted	p – M	(P-M)^2	RMSE	Period, Weeks
15967.9	7717.27	8250.63	68072895.4	21113802	4594.976	14970	-997.9	995804.4	653.6786	0
8804.81	7717.27	1087.54	1182743.252			9835.99	1031.18	1063332		4
6555.46	7717.27	-1161.81	1349802.476			6462.71	-92.75	8602.563		8
4505.77	7717.27	-3211.5	10313732.25			4246.3	-259.47	67324.68		12
2752.41	7717.27	-4964.86	24649834.82			2790.02	37.61	1414.512		16
38586.35			105569008.2			38305.02		2136478		
7717.27								427295.7		
					RPD	7.029412				

Table 2. Root Mean square error and RPD of PAH computation of dry raffia palm trunk on oil-based drill cuttings bioremediation

Measurd: X	x	x - x	(X - x)^2	MSE	SD	Predicted	p - M	(P-M)^2	RMSE	Period, Weeks
128.07	61.75	66.32	4398.3424	1406.065	38.5	118.91	9.16	83.9056	5.354	0
75.64	61.75	13.89	192.9321			76.58	-2.87	8.2369		4
43.79	61.75	-17.96	322.5616			49.32	-6.39	40.8321		8
39.89	61.75	-21.86	477.8596			31.77	3.21	10.3041		12
21.27	61.75	-40.48	1638.6304			20.46	0.15	0.0225		16
308.66			7030.3261			297.04		143.3012		
61.732								28.66024		
					RPD	7.190885				

Table 3. Root Mean square error and RPD of BTEX computation of dry raffia palm trunk on oil-based drill cuttings bioremediation

Measurd X	X	x - x	(X - x)^2	MSE	SD	Predicted	p - M	(P-M)^2	RMSE	Period, Weeks
1	0.49	0.51	0.2601	0.08954	0.252	0.9945	-0.0055	3.02E-05	0.0344	0
0.64	0.49	0.15	0.0225			0.6354	-0.0046	2.12E-05		4
0.38	0.49	-0.11	0.0121			0.406	0.026	0.000676		8
0.28	0.49	-0.21	0.0441			0.2594	-0.0206	0.000424		12
0.16	0.49	-0.33	0.1089			0.1657	0.0057	3.25E-05		16
2.46			0.4477			2.461		0.001184		
0.492								0.000237		
					RPD	7.325581				

The established model with constant (β) was calculated and fitted into the developed TPH degradation model. These results exhibited the acceptability as well as the agreement with minimum error, demonstrating the acceptability and reliability of the model. This is in-line with the study of Amagbo& Ero (2016) that used kinetic modelling and half-life to study the amount of TPH residual contaminated in the environment thereby showing strong correlation between the experimental and the predicted model which is an indication that can be used to predict the concentration of TPH in the environment amended by biological agent with time which is equivalent to simple nonlinear regression model.

Validation of the model

Prediction and validation upon which problems are solve relied on the authenticity of the established model equation. Figure 2,3 and4 shows the graphical comparison between predicted and experimented TPH concentrations on the oil-based drill cuttings contamination treated with dry raffia palm. The model result has a higher affiliation with experimented results from the remediation process with the coefficient of determination (R^2) as 0.9817, 0.9789 and 0. 9886. Additionally, the predicted model values and experimented results based on the model equations were linked graphically as shown in Figure 2, 3 and 4. The analysis of the graph showed a near alignment of the curves between the model-predicted and experimental TPH concentration of the remediated oil-based drill cuttings with dry raffia palm. Results of the established model for TPH degradation equation for oil-based drill cuttings contamination remediated with dry raffia palm was performed by replacing the results generated from the experimented data as shown in Table 1, 2. and 3.

The root mean square error (RMSE) of predicted and experimented TPH concentrations are summarized as shown in (Table1, 2 and 3). The error analysis which shows the difference between the predicted model results and the measured results ranging from – 37.61 to 997.9 *while the* RMSE was 653.654, 5.35 and 0.0344. The residual prediction deviation (RPD) is the factor that indicates the precision behaviours of the prediction in comparison with the average composition of all the samples. RPD value recorded maximum results at 7.03, 7.19 and 7.33 as shown in Table1, 2 and 3 respectively.This indicate that RPD greater than 3.0 are considered excellent according to Saeys *et al.* (2005) as cited in Jesús *et al.,* (2014). This confirms the reliability and acceptability of the model.

Conclusion

Dry raffia palm influenced the degradation of all parameters (TPH, BTEX, TPAH), in oil-based drill cuttings contamination. It is because of very high content of composition of nutrients (NPK). The dry raffia palm can degrade (TPH, BTEX, TPAH) to about 83, 76 and 84% respectively, and the coefficient of determination (R^2) are 0.9816, 0.9788 and 0.9943 respectively. Similarly, it's also contained coefficient of determination ranges from 0.9785 to 0.9824 with other physiochemical parameters for phosphorus, nitrogen, potassium, organic matter, bacteria count, electrical conductivity, and pH after 16 weeks of bioremediation. The developed model applied for predicting the oil-based drill cuttings biodegradation in the cause of bioremediation was proposed as $C_X = \alpha e^{\beta t}$. The constant (β) for the pollutants degradation with respect to treatment was developed for all the treatments levels from T1 to T11. Model prediction achieved in this study can be considered as good with a high coefficient of determination (R^2) and low RMSE and RPD. The results showed acceptable validity with both experimented and predicted results. These proved the fact that the models can be used to predict the pollutants levels of TPH, TPAH and BTEX on the oil-based drill cuttings at each of the different treatment levels without going through the tedious, rigorous and experiments, thereby reducing the time, cost and energy constraints in obtaining the experiment in the field.

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