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# Mix Model Formulation for TPH Prediction during Bioremediation of Hydrocarbon Contaminated Soils

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***ABSTRACT:*** *Since bioremediation of polluted soil involves several input parameters required to achieve a satisfactory objective, this study developed a mix design model to predict the amount of Total Petroleum Hydrocarbon (TPH) removed from a given soil polluted by crude oil during bioremediation process. Thus, the percentage of TPH removed was expressed as a function of treatment time, treatment dosage, crude oil volume and soil weight. The leaves and barks of mango (Magnifera indica) were used as amendment agents. The leaves and bark of mango were separately crushed to fine particle sizes and sieved to 2.0mm. Sandy, silt loam and clay soils were used for this study. The TPH content was analyzed every 7 days for a total period of 28 days. The results obtained showed that increase in time and treatment weights also increases the percentage of TPH removed from the soils. However, sample with treatments recorded highest amount of TPH degradation than the control samples, and it was highest with 50g treatment weight. For instance, at the 28$^{th}$ day of analysis for 50g treatment weight, the TPH percentage removed from sandy, silt loam and clay soils with mango leave particles were obtained as 93.84%, 91.87% and 96.93% respectively, while with mango bark, the TPH percentage removed were 94.49%, 92.37% and 97.13% for sandy, silt loam and clay soils respectively. Thus, the results implied that mango bark treatment slightly outperformed mango leaves in reducing TPH content in the soils, while the highest degradation of TPH was recorded in clay soil, followed by sandy soil and least in silt loam soil. Finally, it is shown that the correlation coefficient between the measured and the predicted percentages of TPH removed from sandy, silt loam and clay soils treated with mango leaves and bark ranged from 0.9225 to 0.9613, which indicated that over 90% of the measured TPH was explained by the mix design model. Hence, the mix model can be applied to estimate the optimum treatment weight and time required to remediate a given weight of soil polluted with a known volume of crude oil.*

***KEYWORDS:*** *Mix design Model, Bioremediation, TPH, Mango Treatment, Polluted Soil*

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## I. INTRODUCTION

The discussion about crude oil pollution is an age long history that is as old as oil discovery itself. Crude oil or petroleum hydrocarbon can be harmful to organisms including man, and it is also not readily degradable under normal circumstances [1] [2]. Although this study focuses on soil pollution, many studies on crude oil pollution on water environment, such as oil slick quantification and spreading have been reported [3] [4] [5]. Also, numerous studies on the pattern of oil transport, or migration on water after discharge have equally been investigated through mathematical models [6] [7] [8].

The diffusion or penetration of petroleum and its fractions into soil has equally been studied [9]. In a study carried out by Khalilova [10] to ascertain the diffusion rate of different hydrocarbon compounds in soil. He found that there was high content of total petroleum and polyaromatic hydrocarbons, asphaltenes and heavy metals in soil samples collected from various oil fields, up to 1.5m depth. Khalilova further reported that the effect of hydrocarbon pollution has significantly impacted on the soil biological properties due to long-term anthropogenic activities, which reduced the self-purification capacity of the soil.

Oil contamination did not only affect soil properties, it also reduces soil ability to support plants' growth, and increase the tendency of groundwater contamination [11]. Because of natural properties of soil, most hydrocarbon pollutants may naturally degrade due to self-purification capacity of soil, whereas, others may not [10]. The migration of pollutant into soil was made possible due to its porosity. Soil also has the ability to trap some contaminant, preventing them from seeping through to groundwater aquifer. Heydataemeh *et al*. [12]

demonstrated the ability of soil nano-particles used as adsorbent for removal of green malachite dye from aqueous solutions, which removed about 80% of the green malachite dye from wastewaters.

However, based on numerous studies, information regarding soil contamination with petroleum and its products, measurement techniques as well as remedial methods has been widely documented [13]. Thus, there are many scenarios in which degradation of petroleum hydrocarbon can occur.

In a review by Bandura *et al*. [14], the use of adsorbents as suitable technology for the removal of petroleum substances was highlighted, while Nnaji [15] recommended the use of nano-materials for oil pollution clean-up as appraisal of nanotechnology in Nigeria. However, in earlier work by Elloit [16], it was reported that nano-particles in bioremediation of petroleum and heavy metals was faster and offered better penetration of contaminated matrices.

Another technique that had been applied to treat petroleum polluted soil is the use of solvent or surfactant to wash off contaminant in polluted environment [17] [18]. Again, an effective technique for environmental remediation of crude oil and its fraction is the use of microorganism [19] [20]. This technology (bioremediation) is a promising treatment method for oil contaminated sites owing to its cost effectiveness and tendency to achieve complete mineralization of organic contaminants into carbon dioxide, water, inorganic compounds, or cell protein [1]. Studies had shown that many indigenous microorganisms in water or soil has the capacity to degrade hydrocarbon contaminants [1] [21] [22]. According to Adams *et al*. [23], bioremediation uses microbial metabolism in favourable environmental conditions and sufficient nutrients to breakdown contaminants like petroleum hydrocarbons.

Microorganism use for bioremediation can be cultured from plants and animal sources and then introduced directly into the polluted system or, the microorganism source is introduce into the polluted system as nutrient stimulant, thereby energizing the microorganisms in the system to grow or populate as the plant or animal source decays over time. The various techniques for microbial culture and application in bioremediation processes of soil contamination has been outlined [24]. Thus, there are varieties of nutrient stimulant or amendment agents previously applied for soil remediation.

Ferreira *et al*. [25] used aerobic yeast called *Yarrowia lipolytica* to degrade crude oil in soil, and observed that *Yarrowia lipolytica* was effective for crude oil degradation in soil, which the highest removal was recorded at temperature 28°C and 250 rpm agitation speed. Also, the use of fertilizer such as NPK has equally been reported as a promising stimulant for microorganism during bioremediation of crude oil polluted soils [26] [27] [28] [29].

However, in Obiakalaije *et al*. [21], goat manure, poultry droppings and cow dung were investigated for bioremediation of crude oil contaminated soil, where 87.1%, 76.6% and 70.7% of TPH were removed by goat manure, poultry droppings and cow dung respectively.

Other amendments like organic waste compost [30] [31] [32], cassava peels [33] [34], moringa leave extract [35], dried poultry manure, goat dung and fine sawdust [36], bitter leaf [37] and spent mushroom [38] [39] have also been reported as good treatment for crude oil polluted soils.

Another area of bioremediation study is the description of TPH degradation kinetics in soil using different amendment agents [28] [31] [40] [41]. However, since several input parameters are involved in attaining an appreciable level of remediation, a mix model was developed to study the right proportion of input parameters required to obtain the desired removal of crude oil in soils, especially during contingency planning, and this was studied using mango leaves and bark.

## II. MATERIALS AND METHODS

### 2.1 Collection of Soil and Treatment of Samples

The leaves and bark of mango were used as amendments for remediation of crude oil polluted soil. The collected leaves and bark of the mango were sun dried for about two weeks to remove moisture content, and thereafter, transported to Chemical/Petrochemical Engineering laboratory, Rivers State University for further preparations. The dried mango leaves and bark were crushed and sieved to 2.0 mm uniform fine particle size.
Three soil types were used in this study namely sandy, silt loam and clay soils. These soils are peculiar to the Niger Delta areas of Nigeria where crude oil pollution is persistent. However, investigation was carried out to determine which of the soils the amendment agents was more efficient in degrading crude oil content. Meanwhile, the soils were collected between 10cm and 30cm depth using hand trowel, and bagged before being transported to Chemical/Petrochemical laboratory, Rivers State University, Port Harcourt. The soils, mango leaves and bark were collected from Wakama Town, Ogu/Bolo Local Government Area of Rivers State, Nigeria.

### 2.2 Experimental Procedure

300g of each sandy soil, silt loam soil and clay soil samples were weighed into plastic vessels with labels. Thereafter, all the samples were contaminated with 50ml of Bonny light crude oil. Each of the mixture

was properly mixed to ensure uniform concentration of the crude oil in the soil samples. It was left for three days to settle without any disturbance before commencement of treatment. The prepared mango treatments were measured and weighed to 10, 20, 30, 40 and 50g weights of mango leaves and bark, and then separately added to each of the vessels containing the polluted soil samples. Also, three different vessels containing only sandy, silt loam and clay soils were used as control (without treatment) samples. Every two days, the content of the vessels was stirred to ensure uniform distribution of the treatment concentration in the vessel, while every seven (7) days the soil samples were collected for laboratory analysis to determine the residual Total Petroleum Hydrocarbon (TPH) content for a period of 28 days. This was determined using ASTM method D3921 [42].
Thus, Hydrocarbon content was extracted with dichloromethane in an extractor and treated with 2ml of activated silica gel. The TPH of the representative samples were then determined with the aid Gas Chromatography – Flame Ionization Detector (GCFID) Model, HP 5890 Series II, U.S.A.

### 2.3 TPH Removal Efficiency

The percentage of TPH removed at any given time was determined according to the following expression:

$$TPH_R(\%) = \frac{TPH_i - TPH_f}{TPH_i} \times 100\% \quad (1)$$

Where: $TPH_R$ is the percentage of *TPH* removed with time, $TPH_i$ and $TPH_f$ are the initial and final measured concentrations of TPH.

**Plate 1:** Set-up of treatment samples

### 2.4 Mix Model for TPH Degradation Prediction

The formulated mix model for prediction of TPH removal efficiency at any given treatment dosage, soil weight, treatment time and crude oil volume in the soil was developed through the application of multiple linear regression method. Thus, the percentage TPH removed was expressed as a function of treatment time *t*, treatment dosage $w_t$, crude oil volume *v* and soil weight $w_s$. This is mathematically expressed as:

$$TPH(\%) = f(t, w_t, v, w_s) \quad (2)$$

Using multiple linear regression method, the TPH degradation can be expressed as:

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + e \quad (3)$$

Where: y = the percentage of TPH removed (%)

$x_1$ = Treatment time (day)

$x_2$ = Treatment dosage (g)

$x_3$ = Crude oil volume (ml)

$x_4$ = Soil weight (g)

$e$ = error

$a_0, a_1, a_2, a_3$ and $a_4$ = Constant coefficients of the mix variables

The error can be evaluated by rearranging equation (3) as follows:

$$e = y - (a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4) \quad (4)$$

Again, the sum of squares of the residual error is expressed as:

$$S_r = \sum e^2 \quad (5)$$

Thus, combining equations (3.8) and (3.9) gives:

$$S_r = \sum e^2 = \sum \left(y - a_o - a_1 x_1 - a_2 x_2 - a_3 x_3 - a_4 x_4\right)^2 \quad (6)$$

Differentiating equation (6), partially with respect to the constant coefficients, gives as follows.

Thus, differentiating partially with respect to $a_o$:

$$\frac{\partial S_r}{\partial a_0} = -2\sum \left(y - a_o - a_1 x_1 - a_2 x_2 - a_3 x_3 - a_4 x_4\right) \quad (7)$$

Differentiating with respect to $a_1$:

$$\frac{\partial S_r}{\partial a_1} = -2\sum \left(y - a_o - a_1 x_1 - a_2 x_2 - a_3 x_3 - a_4 x_4\right)x_1 \quad (8)$$

Differentiating with respect to $a_2$:

$$\frac{\partial S_r}{\partial a_2} = -2\sum \left(y - a_o - a_1 x_1 - a_2 x_2 - a_3 x_3 - a_4 x_4\right)x_2 \quad (9)$$

Differentiating with respect to $a_3$:

$$\frac{\partial S_r}{\partial a_3} = -2\sum \left(y - a_o - a_1 x_1 - a_2 x_2 - a_3 x_3 - a_4 x_4\right)x_3 \quad (10)$$

Differentiating with respect to $a_4$:

$$\frac{\partial S_r}{\partial a_4} = -2\sum \left(y - a_o - a_1 x_1 - a_2 x_2 - a_3 x_3 - a_4 x_4\right)x_4 \quad (11)$$

To minimizing error, the partial differential terms at the left hand side of equation (7) through equation (11) will reduce to zero. Thus, re-writing the equations gives as follows:

$$0 = -2\sum \left(y - a_o - a_1 x_1 - a_2 x_2 - a_3 x_3 - a_4 x_4\right) \quad (12)$$

$$0 = -2\sum \left(y - a_o - a_1 x_1 - a_2 x_2 - a_3 x_3 - a_4 x_4\right)x_1 \quad (13)$$

$$0 = -2\sum \left(y - a_o - a_1 x_1 - a_2 x_2 - a_3 x_3 - a_4 x_4\right)x_2 \quad (14)$$

$$0 = -2\sum \left(y - a_o - a_1 x_1 - a_2 x_2 - a_3 x_3 - a_4 x_4\right)x_3 \quad (15)$$

$$0 = -2\sum \left(y - a_o - a_1 x_1 - a_2 x_2 - a_3 x_3 - a_4 x_4\right)x_4 \quad (16)$$

Further simplification and arrangement of equation (12) through equation (16) gives:

$$\sum a_o + a_1 \sum x_1 + a_2 \sum x_2 + a_3 \sum x_3 + a_4 \sum x_4 = \sum y \quad (17)$$

But $\sum a_0$ is equivalent to the number of samples (mix parameters), which is here represented by $n$ (i.e. $\sum a_o = n$). Thus, equation (17) becomes

$$n + a_1 \sum x_1 + a_2 \sum x_2 + a_3 \sum x_3 + a_4 \sum x_4 = \sum y \quad (18)$$

From equation (13), we have:

$$a_o \sum x_1 + a_1 \sum x_1^2 + a_2 \sum x_1 x_2 + a_3 \sum x_1 x_3 + a_4 \sum x_1 x_4 = \sum x_1 y \quad (19)$$

From equation (14), we have:

$$a_o \sum x_2 + a_1 \sum x_1 x_2 + a_2 \sum x_2^2 + a_3 \sum x_2 x_3 + a_4 \sum x_2 x_4 = \sum x_2 y \quad (20)$$

From equation (15), we have:

$$a_o \sum x_3 + a_1 \sum x_1 x_3 + a_2 \sum x_2 x_3 + a_3 \sum x_3^2 + a_4 \sum x_3 x_4 = \sum x_3 y \quad (21)$$

From equation (16), we have:

$$a_o \sum x_4 + a_1 \sum x_1 x_4 + a_2 \sum x_2 x_4 + a_3 \sum x_3 x_4 + a_4 \sum x_4^2 = \sum x_4 y \quad (22)$$

Arranging equation (18) through equation (22) in matrix format gives as follows.

That is,

$$[A]\{X\}=\{B\} \tag{23}$$

Where: $[A]$ is coefficient matrix, $\{X\}$ is the input variable and $\{B\}$ is the output variable. Hence, we have on arrangement:

$$\begin{bmatrix} n & \sum x_1 & \sum x_2 & \sum x_3 & \sum x_4 \\ \sum x_1 & \sum x_1^2 & \sum x_1x_2 & \sum x_1x_3 & \sum x_1x_4 \\ \sum x_2 & \sum x_1x_2 & \sum x_2^2 & \sum x_2x_3 & \sum x_2x_4 \\ \sum x_3 & \sum x_1x_3 & \sum x_2x_3 & \sum x_3^2 & \sum x_3x_4 \\ \sum x_4 & \sum x_1x_4 & \sum x_2x_4 & \sum x_3x_4 & \sum x_4^2 \end{bmatrix} \begin{Bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \end{Bmatrix} = \begin{Bmatrix} \sum y \\ \sum x_1y \\ \sum x_2y \\ \sum x_3y \\ \sum x_4y \end{Bmatrix} \tag{24}$$

Equation (24) is a system of simultaneous equation. So to effectively use the model, the constant coefficients must first be determined. Thus, to facilitate the computation for the determination of the constants, equation (24) was implemented in MATLAB.

## III. RESULTS AND DISCUSSION

### 3.1 Effect of treatment weight on TPH removal

The effect of weight of mango leaves and bark particles on TPH degradation in the soils over the investigation period is shown in Figures 1 through 6.

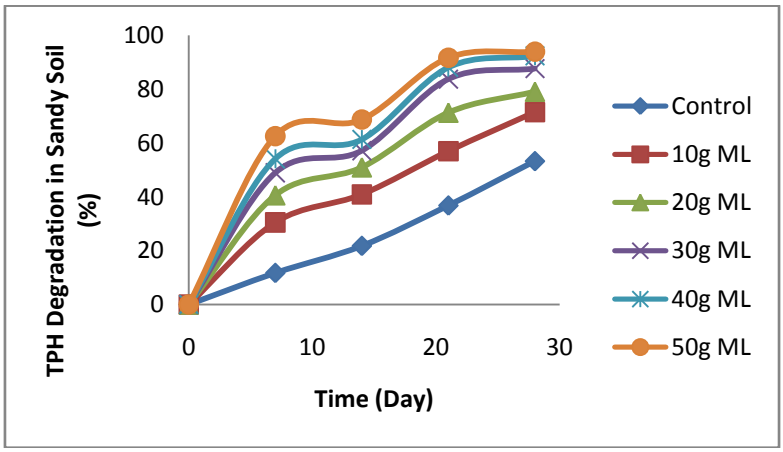


**Fig. 1: Percentage TPH removed from sandy soil treated with mango leaves**

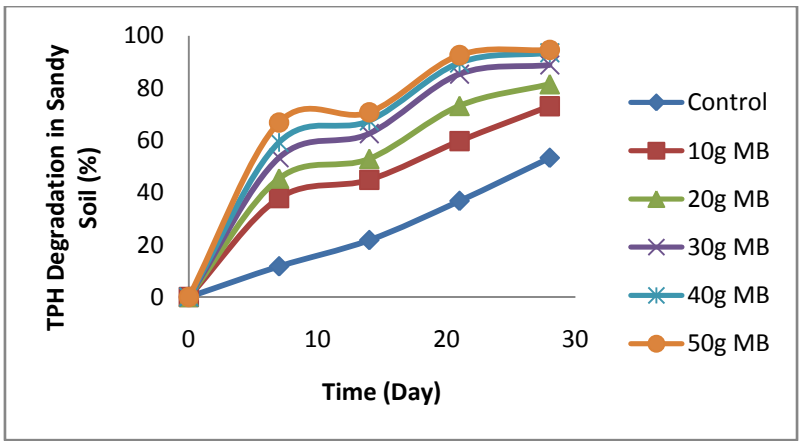


**Fig. 2: Percentage TPH removed from sandy soil treated with mango bark**

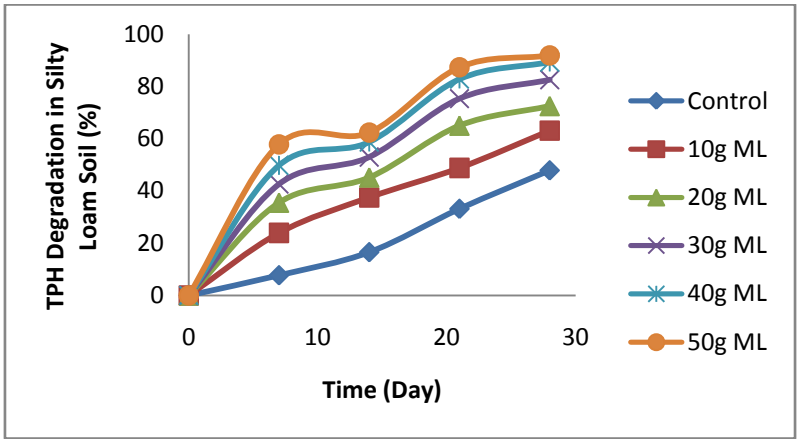


**Fig. 3: Percentage TPH removed from silt loam soil treated with mango leaves**

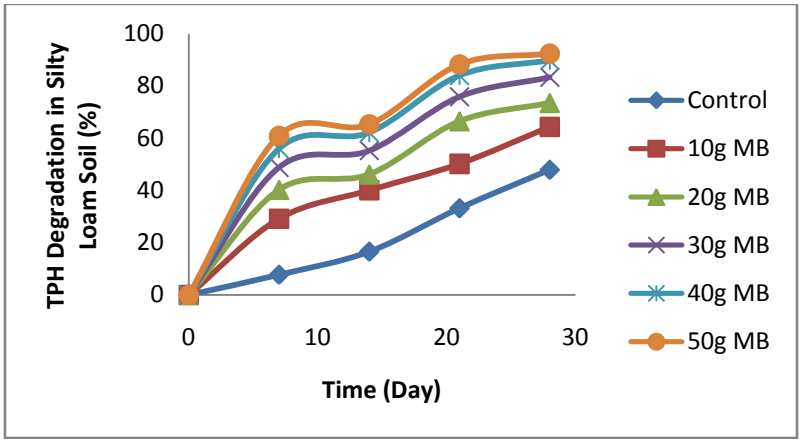


**Fig. 4: Percentage TPH removed from silt loam soil treated with mango bark**

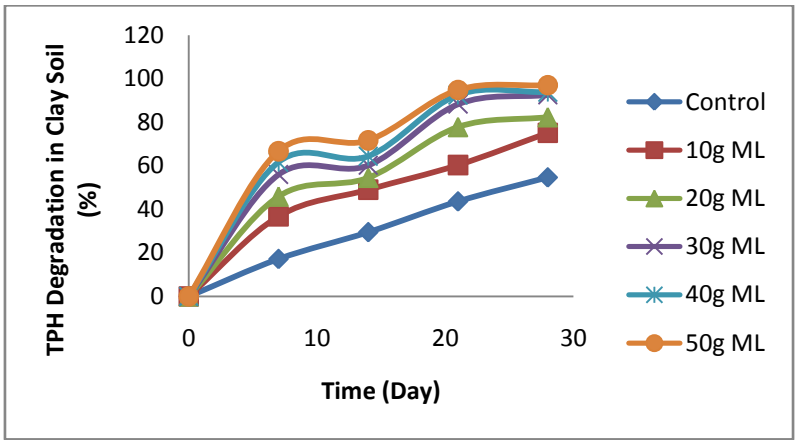


**Fig.5: Percentage TPH removed from clay soil treated with mango leaves**

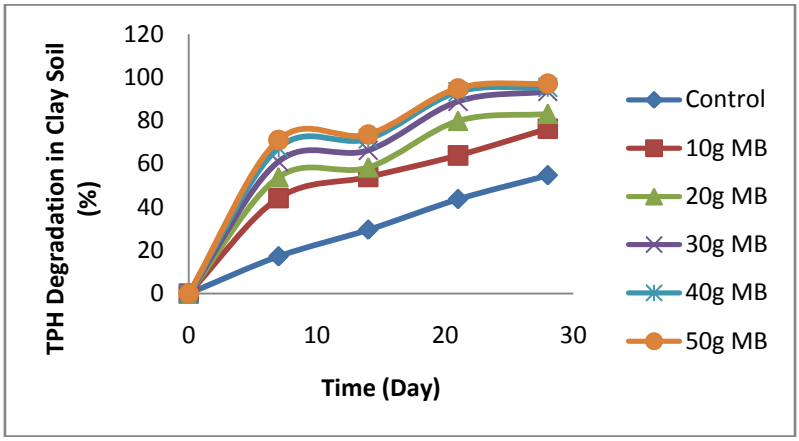


**Fig. 6: Percentage TPH removed from clay soil treated with mango bark**

Figures 1 to 6 show the percentage degradation of TPH with time in sandy, silt loam and clay soils treated with mango leaves and bark particles at different weights. In both treatments, the percentage degradation of TPH increased as time and treatment weight were increased. Meanwhile, there was high increase in degradation of TPH in the first 7 days after pollution, but became slow thereafter, until the 28$^{th}$ day. Conversely, in the control sample, the percentage of TPH removed increased almost linearly over the period. However, the analysis of TPH degradation showed that there was great improvement in TPH reduction when mango leave or mango bark particles were added to the crude oil polluted soils. Thus, percentage TPH degradation in sandy soil with mango leave particles obtained over the period are 11.70%, 21.75%, 36.73% and 53.21% at 7, 14, 21 and 28 days respectively, for 0g (control) sample; 30.48%, 40.90%, 56.96% and 71.45% at 7, 14, 21 and 28 days respectively, for 10g sample; 40.53%, 50.89%, 71.20% and 78.98% at 7, 14, 21 and 28 days respectively, for 20g sample; 48.89%, 57.11%, 83.67% and 87.59% at 7, 14, 21 and 28 days respectively, for 30g sample; 54.10%, 61.30%, 88.05% and 92.29% at 7, 14, 21 and 28 days respectively, for 40g sample; and 62.52%, 68.63%, 91.58% and 93.84% at 7, 14, 21 and 28 days respectively, for 50g sample. With mango bark, the percentage TPH degradation are 37.82%, 44.82%, 59.67% and 73.00% at 7, 14, 21 and 28 days respectively, for 10g sample; 45.34%, 52.88%, 73.16% and 81.45% at 7, 14, 21 and 28 days respectively, for 20g sample; 53.26%, 62.49%, 85.24% and 88.74% at 7, 14, 21 and 28 days respectively, for 30g sample; 59.14%, 67.40%, 89.58% and 93.40% at 7, 14, 21 and 28 days respectively, for 40g sample; and 66.74%, 70.60%, 92.50% and 94.49% at 7, 14, 21 and 28 days respectively, for 50g sample.

Similarly, percentage TPH degradation in silt loam soil with mango leave particles are 7.72%, 16.57%, 33.18% and 47.92% at 7, 14, 21 and 28 days respectively, for 0g (control) sample; 23.91%, 37.48%, 48.79% and 63.03% at 7, 14, 21 and 28 days respectively, for 10g sample; 35.47%, 45.12%, 64.95% and 72.44% at 7, 14, 21 and 28 days respectively, for 20g sample; 42.57%, 52.94%, 75.28% and 82.49% at 7, 14, 21 and 28 days respectively, for 30g sample; 49.79%, 58.73%, 82.80% and 89.30% at 7, 14, 21 and 28 days respectively, for 40g sample; and 57.82%, 62.35%, 87.36% and 91.87% at 7, 14, 21 and 28 days respectively, for 50g sample. And with mango bark, the percentage TPH degradation in silt loam soil are 29.15%, 40.02%, 50.14% and 64.27% at 7, 14, 21 and 28 days respectively, for 10g sample; 40.27%, 46.17%, 66.51% and 73.51% at 7, 14, 21 and 28 days respectively, for 20g sample; 48.82%, 55.24%, 75.86% and 83.32% at 7, 14, 21 and 28 days respectively, for 30g sample; 55.95%, 62.16%, 84.00% and 89.79% at 7, 14, 21 and 28 days respectively, for 40g sample; and 60.92%, 65.27%, 88.21% and 92.37% at 7, 14, 21 and 28 days respectively, for 50g sample.

Again, percentage TPH degradation in clay soil with mango leave particles are 17.18%, 29.49%, 43.61% and 54.65% at 7, 14, 21 and 28 days respectively, for 0g (control) sample; 36.78%, 49.04%, 60.36% and 75.14% at 7, 14, 21 and 28 days respectively, for 10g sample; 45.85%, 54.47%, 77.78% and 82.29% at 7, 14, 21 and 28 days respectively, for 20g sample; 55.92%, 60.18%, 88.25% and 92.52% at 7, 14, 21 and 28 days respectively, for 30g sample; 61.63%, 64.37%, 92.48% and 93.74% at 7, 14, 21 and 28 days respectively, for 40g sample; and 66.63%, 71.61%, 94.77% and 96.93% at 7, 14, 21 and 28 days respectively, for 50g sample. And with mango bark treatment, the percentage TPH degradation in silt loam soil are 44.08%, 53.87%, 63.84% and 76.17% at 7, 14, 21 and 28 days respectively, for 10g sample; 53.79%, 58.33%, 79.83% and 83.10% at 7, 14, 21 and 28 days respectively, for 20g sample; 61.05%, 66.29%, 88.87% and 93.44% at 7, 14, 21 and 28 days respectively, for 30g sample; 67.33%, 71.53%, 93.31% and 95.28% at 7, 14, 21 and 28 days respectively, for 40g sample; and 71.02%, 73.62%, 94.98% and 97.13% at 7, 14, 21 and 28 days respectively, for 50g sample.

The highest TPH degradation was recorded at the 28$^{th}$ day, while the 50g treatment weight was the most effective. The control sample with no treatment has the least reduction in TPH. This was due to the fact

that no source of nutrient was added, which would have boosted the energy of the hydrocarbon degrading bacteria to effectively feed on the hydrocarbon substrate [2] [28].

### 3.2 Evaluation of the mix model

In order to accurately formulate an effective mix for better performance of treatment suitable for site applications, we have developed a mathematical relationship between bio-remediating mix parameters. Hence, the utilization of the developed mathematical model for crude oil remediation using mango treatments showed good promise as it was able to predict the TPH values obtained from the experiment at any given design mix. Figures 7 to 12 show the comparison of measured and predicted TPH percentage removed for a given mix.

**Table 1: TPH mix model for soils amended with mango leaves and bark**

| | |
|---|---|
| | **Sandy** |
| **Mango Leaves** | $TPH(\%) = -23.015 + 1.93t + 0.7192\,w_t + 0.2749\,v - 0.965\,w_s$ |
| **Mango Bark** | $TPH(\%) = -21.979 + 1.7379\,t + 0.6868\,w_t + 0.6133\,v - 2.869\,w_s$ |
| | **Silt Loam** |
| **Mango Leaves** | $TPH(\%) = 38.7962 + 1.918\,t + 0.7876\,w_t + 0.3773\,v - 2.959\,w_s$ |
| **Mango Bark** | $TPH(\%) = -24.946 + 1.7152\,t + 0.7796\,w_t + 0.5934\,v - 2.8576\,w_s$ |
| | **Clay** |
| **Mango Leaves** | $TPH(\%) = 106.475 + 1.8154\,t + 0.6726\,w_t - 0.14v - 0.9077\,w_s$ |
| **Mango Bark** | $TPH(\%) = -19.998 + 1.545\,t + 0.625\,w_t - 0.0427\,v + 1.2275\,w_s$ |

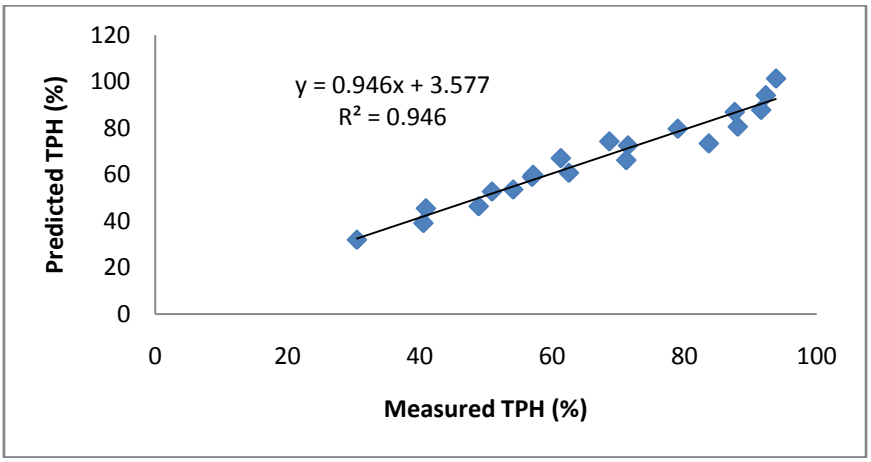


**Fig. 7: Comparison of measured and predicted percentage TPH removed in sandy soil with mango leaves**

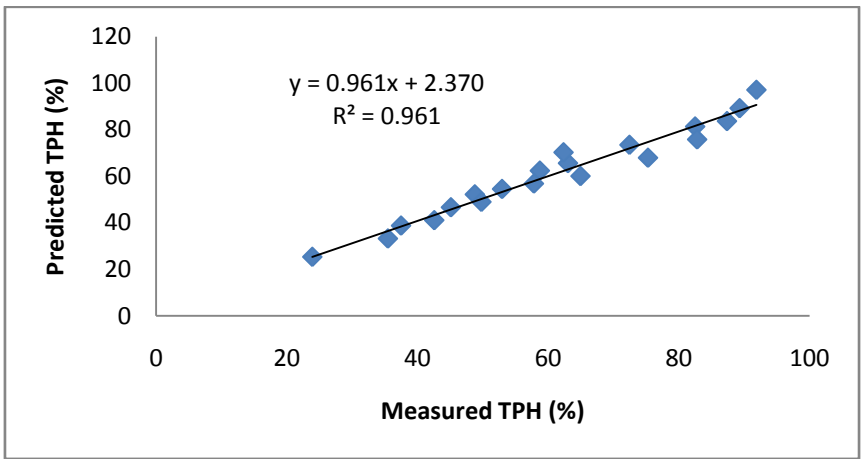


**Fig. 8: Comparison of measured and predicted percentage TPH removed in silt loam soil with mango leaves**

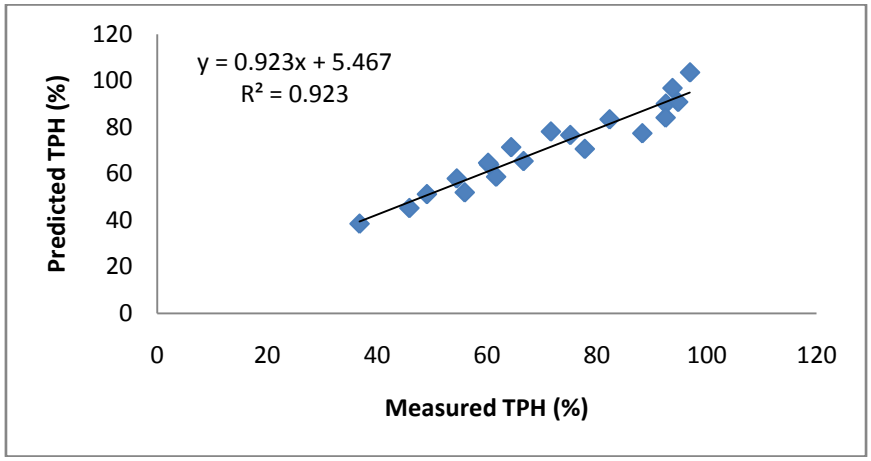


**Fig. 9: Comparison of measured and predicted percentage TPH removed in clay soil with mango leaves**

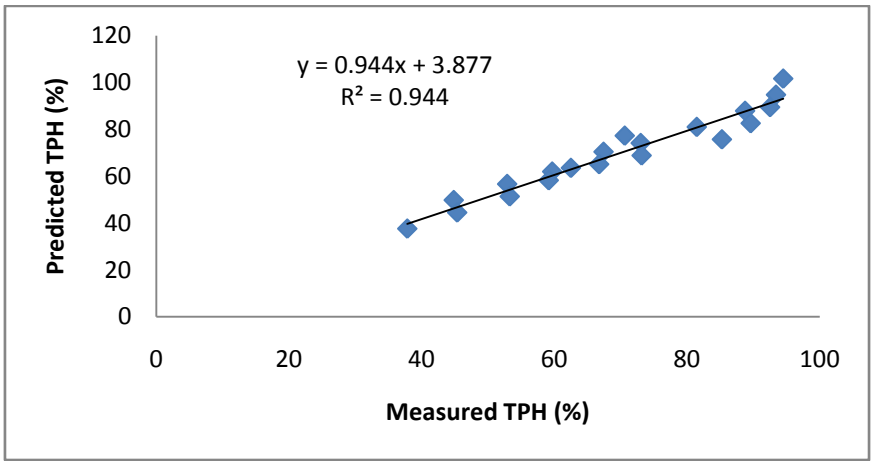


**Fig. 10: Comparison of measured and predicted percentage TPH removed in sandy soil with mango bark**

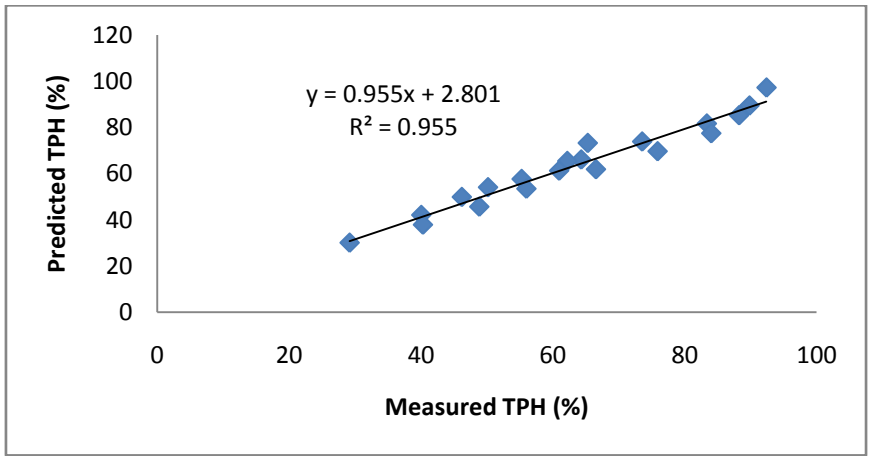


**Fig. 11: comparison of measured and predicted percentage TPH removed in silt loam soil with mango bark**

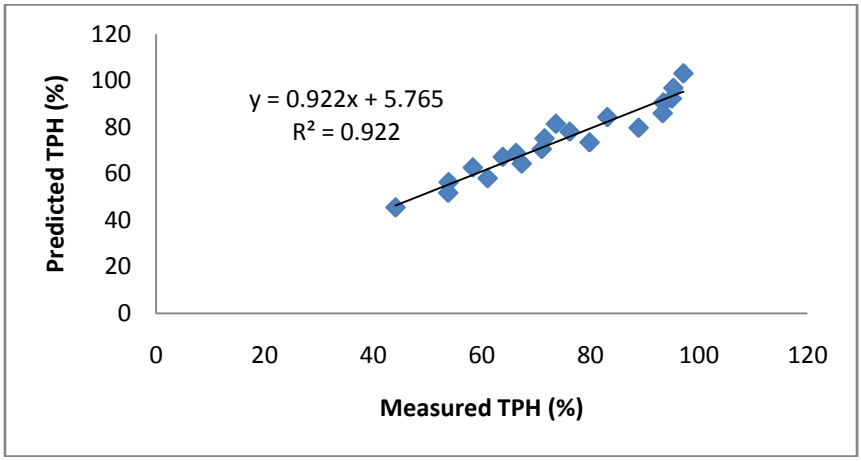


**Fig. 12: Comparison of measured and predicted percentage TPH removed in clay soil with mango bark**

From the Figures, it is shown that the correlation coefficient between the measured and the predicted percentages of TPH removed from sandy, silt loam and clay soils treated with mango leaves and bark ranged from 0.9225 to 0.9613, which indicated that over 90% of the measured TPH was explained by the mix design model. Hence, the model will be useful to determine the appropriate treatment weight and time required to remediate a given volume of crude oil polluted soil.

## IV. CONCLUSION

This study revealed that particles of mango leaves and bark are capable of removing TPH from soil polluted by crude oil via bioremediation. Also, it was revealed that increase in contact time and treatment weight simultaneously increased the percentage of TPH removed from the soils. Again, the highest amount of TPH removed was recorded in samples treated with 50g weight, while control samples with no treatment recorded the least reduction in TPH. It was also noted that mango bark slightly outperformed the mango leaves in all the treatment options, while the highest degradation of TPH was recorded in clay soil, followed by sandy soil and least in silt loam soil.

From the analysis, a ratio of 100g treatment weight to 166.67g/kg soil weight would be appropriate to obtain an effective TPH reduction in soil at limited period of time. However, the mix model can be applied to estimate the optimum treatment weight and time required to remediate a given weight of soil polluted with a known volume of crude oil. This was substantiated by the values of percentage TPH predicted by the mix design, which compared very well with the measured values. Therefore, the accurate prediction of optimum mix parameters would reduce cost and time often associated with bioremediation process.

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