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Some Plant Extracts Potential in Cleaning Soil Environment Contaminated with Petroleum Hydrocarbon

Ukpaka Chukwuemeka Peter[1,*], Okwu Kingsley[2]

Abstract

This research considered the trend of some agro-based plant extracts obtained from paw paw, mango and aloe-vera leaves for the purpose of treatment of a contaminated soil environment. The potential of each agro-based plant extract was tested with respect to its ability in the area of petroleum hydrocarbon clean-up in soil environment. The impact of the variation on the pH on each of the bioreactor set-up was monitored and the trend illustrates the role of the bio-stimulant in enhancing remediation programs. The soil samples were evaluated for an interval of 5 days in 20 days. The parameters evaluated were pH level and total hydrocarbon content (THC). The analysis of the soil samples throughout the remediation period showed that the rate of reduction of the total hydrocarbon content increased as the amount of the bio-stimulant of the plant extracts increased. The evaluation of the study revealed that the Aloe-Vera has the highest reduction rate in the total hydrocarbon content in 20 days, followed by Mango and Paw-Paw with 18%, 9.3% and 7.94% respectively. Therefore, the Aloe-Vera leave extract is best used for the remediation of a crude oil polluted soil environment compared to Mango and Paw-Paw. However, the significance of the investigation was to check the suitability of these agro-based plant extracts to be use as a bio-simulants or bio-remediants and the obtained results shows that the variation in the pH was observed to have cause the active site of the microbes inhibited and this can influence the remediation process. The depletion in the concentration of the petroleum hydrocarbon revealed the potential benefit of the bio-simulants application in cleaning polluted soil environment.

Keywords: Cleaning, potential, mango, paw-paw, aloe-vera, remediation

INTRODUCTION

Research on the potential of plants in enhancing clean-up program is not new, including the hazard associated in the treatment as well as the impact to the ecosystem [1, 2]. When the soil is contaminated with hazardous substances such as crude oil, its toxic nature influences the soil characteristics in terms of changing the physicochemical properties of the soil [3]. Research has revealed that the unwanted substance identified as crude oil is a threat to the soil and the water environment. Because of the impact in soil and water environment, including the air there is need to handle the way substance is being processed [4, 5]. Investigation into the possible products obtained because of the action of the microorganisms on feeding on the substrate demonstrates the usefulness of the application [6, 7] and the products are not harmful to the environment.

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Indeed, the conceptual utilization of bioremediation application to carry out clean-up of a polluted soil environment is developing rapidly and the application of using indigenous microorganisms is gathering momentum. Also, the research considered the attributes of these microorganisms as identified by other investigators on the role played to enhanced clean-up of a polluted soil environment [8, 9]. The utilization of the available nutrients in the system by microorganisms enhances increase in energy and reproduction, provided the system is not inhibited by the possible parameters associated to the environment [10–12].

MATERIALS AND METHODS

Materials

The underlisted steps were considered during the investigation, such as;

1. *Bioreactor:* This showcases, the different reactors set-up to receive all the materials needed for investigation.
2. *Loamy soil:* The soil was characterized with particle size as very fine
3. *Crude oil:* This substance is hydrocarbon which is made of hydrogen and carbon.
4. *Digital weighing balance:* This is a device used in measuring weight.
5. *Bioremediator:* These are plant extracts which include Aloe-vera, Mango and Paw-Paw leaves

Sample Collection and preparation

The soil sample and plant extracts (Mango, Paw-Paw and Aloe-vera leaves) were collected from Elikpokwuodu community in Obio/Akpor Local government area of Rivers State Nigeria. The mango and paw-paw leaves were both dried at room temperature and sun-dry and then were crushed into fine particles.

Determination of pH

The soil p^H level was determined for each sample using a litmus paper. Here 20g of soil was weighed and transferred into 100ml beaker and then 5ml of distilled water was added and stirred continuously for 10 minutes. The litmus paper was then inserted to give the p^H of the samples.

Determination of Total Hydrocarbon Content (THC)

The method used to determine the total hydrocarbon content (THC) of each sample was gravimetric method and the reagent used in this process was n-hexane.

Experimental Procedures

1. 1kg of soil samples was measured into each of the reactors and then analyzed to determine the initial concentration of the soils before pollution.
2. 50 mills of crude oil were added into each of the reactors containing soil samples and then it was stirred for complete mixing.
3. The soil samples inside each of the reactors were analyzed also after pollution.
4. The plant extracts were measured in 25g, 50g and 75g before added into each of the reactors and allowed for 5 days to blend completely.
5. The samples in each of the reactors were analyzed in a 5 day interval of 20 days to evaluate the performances of the plant extracts and also to properly examine the pH level and Total Hydrocarbon content (THC).

THEORETICAL APPROACH

Microbial Kinetics

From first order reaction

$$\frac{dx}{dt} = R_x = \mathrm{Mx} \tag{1}$$

$$\frac{dx}{dt} = \mathrm{Mx} \tag{2}$$

Rearranging equation (2), we have

$$\frac{dx}{dt} = Mdt \tag{3}$$

Applying Integration on equation (3), we have

$$\int_{xo}^{x} \frac{dx}{x} = \int_{0}^{t} Mdt \tag{4}$$

$$lnX_{xo}^{x} = M[t]_{o}^{t} \tag{5}$$

$$lnX - lnX_o = M[t - o] \tag{6}$$

$$\frac{lnX_t}{Xo} = Mt \tag{7}$$

Taking Logarithm of both sides

$$\frac{X_t}{Xo} = e^{Mt} \tag{8}$$

$$X_t = X_o e^{Mt} \tag{9}$$

Where Xo is the initial concentration at time t_o, X_t Is the concentration at time t, M Is the specific growth of microbes, X Is the biomass.

Substrate Kinetics

Considering when the rates of degradation of the contaminants (substrates) is directly proportional to the functional coefficient that influence the system or process.
Mathematically,

$$\frac{ds}{dt} = BS \tag{10}$$

B is the functional coefficient and S is the Substrate

$$\frac{dS}{S} = Bdt \tag{11}$$

Applying Integration on equation (11), we have

$$\int_{so}^{s} \frac{ds}{s} = \int_{o}^{t} Bdt \tag{12}$$

$$[lnS]_{so}^{s} = B[t]_{o}^{t} \tag{13}$$

$$lnS - lnS_o = B[t - o] \tag{14}$$

$$\frac{lnS}{So} = Bt \tag{15}$$

Determining the coefficient B, equation (15) becomes;

$$B = \frac{1}{t}\, ln\frac{S}{So} \tag{16}$$

Also, from equation (15), taking logarithm of both sides, we have

$$\frac{S}{So} = e^{Bt} \tag{17}$$

$$S = S_o e^{Bt} \tag{18}$$

Where,
S = substrate,
B = functional coefficient
Note that for negative substrate, the solution was negative.

Decay rate Kinetics

$$R_d = k_d x \quad (19)$$

Recall from first order reaction

$$\frac{dx}{dt} = Rx = Mx \quad (20)$$

$$M = \frac{Mmax\,[s]}{k+[s]} \quad (21)$$

$$\frac{dx}{dt} = Rx = \frac{Mmax[s]x}{k+[s]} \quad (22)$$

$$M = \frac{1}{x}\frac{ds}{dt} = \frac{Mmax[s]x}{k+[s]} = MS \quad (23)$$

$$MS = \frac{ds}{dt} \quad (24)$$

$$\frac{dx}{dt} = \frac{Mmax[s]x}{k+[s]} - k_d x \quad (25)$$

Where, $\frac{dx}{dt}$ is the net rate of microbial growth

Micheal's-Menten Model

$$V = \frac{Vmax\,[s]}{k+[s]} \quad (26)$$

Where, s = initial concentration of plant extracts, k = specific rate constant of the bioremediation reaction, Vmax = maximum specific rate of reaction.

In a situation where the pH is an activator, that is the increment in pH favors the bioremediation reaction, the inhibitor is represented as:

I = pH (27)

Therefore, the equation will now become

$$V = \frac{Vmax\,[s]}{k+[s]} \times \text{pH}$$

This only holds if an increase in the pH favors the bioremediation reaction.

Monod Model

$$M = \frac{Mmax\,[s]}{K+[s]} \quad (28)$$

$$Mt = \ln\frac{X_t}{X_o} \quad (29)$$

Rearranging equation (28) we have

$$M = \frac{1}{z}\ln\frac{X_t}{X_o} \quad (30)$$

$$\frac{1}{t}\ln\frac{X_t}{X_o} = \frac{(\frac{1}{z}\ln\frac{X_t}{X_o})_{max}\cdot\,[s]}{K+[s]} \quad (31)$$

We can also relate the Monod's model into LineWaver Burk Plot.

Lineweaver Burk Plot Model

From equation (26), we have

$$V = \frac{Vmax\,[s]}{k+[s]}$$

Taking the inverse of the above equation

$$\frac{1}{V} = \frac{k+[s]}{Vmax\,[s]} \tag{32}$$

$$\frac{1}{V} = \frac{k}{Vmax\,[s]} + \frac{[S]}{Vmax\,[s]} \tag{33}$$

$$\frac{1}{V} = \frac{k}{Vmax\,[s]} + \frac{1}{Vmax} \tag{34}$$

Equation (34) is the Lineweaver Burk plot model.

To obtain values of K and –Vmax, a graph of $\frac{1}{V}$ will be plotted against $\frac{1}{[s]}$ with slope = $\frac{K}{Vmax}$ and intercept $\frac{1}{Vmax}$

RESULTS AND DISCUSSION

The data obtained from the research are presented in Tables and Figures as demonstrated below:

From Table 1 it was seen that among the following components for pH value of Aloe-Vera sample containing 25g (A_{S25}), 50g (A_{S50}), 75g (A_{S75}), Mango sample containing 25g (M_{S25}), 50g (M_{S50}) and 75g (M_{S75}) and Paw-Paw sample containing 25g (P_{S25}), 50g (P_{S50}) and 75g (P_{S75}). Increase in pH value was observed with increase in time.

Determination of Total Hydrocarbon Content (THC) Using the Gravimetric Method.

For soil sample containing 25g of Aloe-Vera extract i.e. A_{S25}
Weight of empty beaker = 100g
Weight of beaker + extract containing hexane before heating = 173.2g
Weight of beaker + oil extract after heating = 102.68g

Using the formula $\frac{W2-W1}{W3} \times 100\%$

Where, W1 is the weight of empty beaker, W2 is the weight of beaker + extract containing hexane before heating, W3 is the weight of oil extract after heating.

$\frac{173.2-100}{102.68} \times 100 = 71.28\%$

Converting to ppm, we have: $\frac{71.28}{1000} = 0.071$ppm

We do same for A_{S50} and $A_{S75.}$
For soil sample containing 25g of Mango extract i.e. M_{S25}
Weight of empty beaker = 100g
Weight of beaker + extract containing hexane before heating = 181.12g
Weight of beaker + oil extract after heating = 102.37g

Using the formula $\frac{W2-W1}{W3} \times 100\%$

Where, W1 is the weight of empty beaker.
W2 is the weight of beaker + extract containing hexane before heating.
W3 is the weight of oil extract after heating.

$\frac{181.12-100}{102.37} \times 100 = 79.24\%$

Converting to ppm we have: $\frac{79.24}{1000} = 0.079$ppm

We do same for M_{S50} and M_{S75}.
For soil sample containing 25g of Paw-Paw extract i.e. P_{S25}
Weight of empty beaker = 100g
Weight of beaker + extract containing hexane before heating = 167.83g
Weight of beaker + oil extract after heating = 102.68g

Using the formula $\frac{W2-W1}{W3} \times 100\%$

Where W1 is the weight of empty beaker, W2 is the weight of beaker + extract containing hexane before heating, W3 is the weight of oil extract after heating.

$\frac{167.83-100}{102.68} \times 100\%$

$= 66.05\%$

Converting to ppm, we have: $\frac{66.05}{1000} = 0.066$ppm

We do same for P_{S50} and P_{S75}.

From Table 2 it was seen that among the following components for total hydrocarbon content of Aloe-vera sample containing 25g (A_{S25}), 50g (A_{S50}), 75g (A_{S75}), Mango sample containing 25g (M_{S25}), 50g (M_{S50}) and 75g (M_{S75}) and Paw-Paw sample containing 25g (P_{S25}), 50g (P_{S50}) and 75g (P_{S75}). Decrease in THC value was observed with increase in time.

Table 3 illustrates that among the following components for the control sample for pH value of Aloe-Vera sample containing 25g (A_{S25}), 50g (A_{S50}), 75g (A_{S75}), Mango sample containing 25g (M_{S25}), 50g (M_{S50}) and 75g (M_{S75}) and Paw-Paw sample containing 25g (P_{S25}), 50g (P_{S50}) and 75g (P_{S75}). Significant increase of pH value was observed with increase in time.

Table 4 shows that among the following components for the control sample for total hydrocarbon content of Aloe-Vera sample containing 25g (A_{S25}), 50g (A_{S50}), 75g (A_{S75}), Mango sample containing 25g (M_{S25}), 50g (M_{S50}) and 75g (M_{S75}) and Paw-Paw sample containing 25g (P_{S25}), 50g (P_{S50}) and 75g (P_{S75}). Significant reduction of THC value was observed with increase in time.

Table 1. The pH of the samples as recorded on a 5 days interval for 20 days.

Reactor time (days)	A_{S25}	A_{S50}	A_{S75}	M_{S25}	M_{S50}	M_{S75}	P_{S25}	P_{S50}	P_{S75}
0	5	6	7	5	5	6	4	5	6
5	5	6	7	6	7	8	6	6	7
10	6	7	8	6	6	7	5	6	7
15	7	7	8	7	7	7	6	7	7
20	7	8	8	7	8	8	6	7	8

Table 2. Concentration of THC of the samples as recorded on a 5 days interval for 20 days.

Reactor Time(days)	A_{S25} (ppm)	A_{S50} (ppm)	A_{S75} (ppm)	M_{S25} (ppm)	M_{S50} (ppm)	M_{S75} (ppm)	P_{S25} (ppm)	P_{S50} (ppm)	P_{S75} (ppm)
0	0.071	0.067	0.061	0.079	0.067	0.064	0.066	0.066	0.063
5	0.070	0.065	0.057	0.078	0.065	0.063	0.066	0.064	0.061
10	0.070	0.064	0.055	0.076	0.064	0.062	0.064	0.064	0.059
15	0.069	0.064	0.052	0.075	0.062	0.060	0.063	0.063	0.058
20	0.068	0.062	0.050	0.072	0.061	0.058	0.062	0.061	0.058

Table 3. Control of pH of the samples as recorded on a 5 days interval for 20 days.

Reactor Time(days)	A_{S25}	A_{S50}	A_{S75}	M_{S25}	M_{S50}	M_{S75}	P_{S25}	P_{S50}	P_{S75}
0	5	6	6	6	7	7	5	5	5
5	6	7	7	7	8	8	6	6	6
10	8	7	7	7	7	6	8	8	8
15	6	8	8	8	7	7	7	6	7
20	7	8	8	7	7	8	7	8	8

Table 4. Concentration of THC of the control samples as recorded on a 5 days interval for 20 days.

Reactor Time (days)	A_{S25} (ppm)	A_{S50} (ppm)	A_{S75} (ppm)	M_{S25} (ppm)	M_{S50} (ppm)	M_{S75} (ppm)	P_{S25} (ppm)	P_{S50} (ppm)	P_{S75} (ppm)
0	0.039	0.034	0.032	0.030	0.029	0.024	0.039	0.038	0.034
5	0.037	0.028	0.026	0.029	0.026	0.022	0.038	0.036	0.029
10	0.035	0.014	0.010	0.028	0.024	0.020	0.036	0.029	0.027
15	0.031	0.026	0.024	0.026	0.023	0.019	0.034	0.026	0.025
20	0.025	0.025	0.023	0.024	0.021	0.019	0.032	0.024	0.020

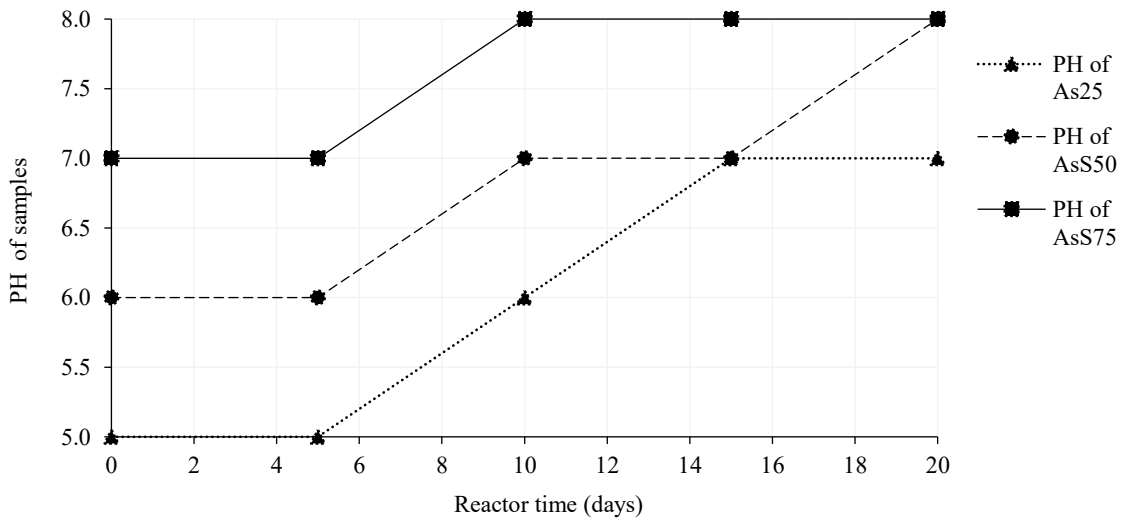

Figure 1. pH versus time for reactors (A_{S25}, A_{S50}, A_{S75}).

The result presented in Figure 1 demonstrates the relationship among the following components for pH of Aloe-vera sample containing 25g (A_{S25}), 50g (A_{S50}) and 75g (A_{S75}) upon the influence of reactor time. The variation in Aloe-Vera sample containing 25g (A_{S25}), 50g (A_{S50}) and 75g (A_{S75}) can be attributed to the variation in reactor time. Increased in pH value was observed with increase in time for Aloe-Vera sample containing 25g (A_{S25}) from time 5 to 20 days when optimum pH value was attained. Comparison of the Aloe-Vera sample containing 25g (A_{S25}), 50g (A_{S50}) and 75g (A_{S75}) shows that pH value of A_{S25} is greater than.

Figure 2 demonstrates the relationship among the following components for pH of Mango sample containing 25g (M_{S25}), 50g (M_{S50}) and 75g (M_{S75}) upon the influence of reactor time. The variation in Mango sample containing 25g (M_{S25}), 50g (M_{S50}) and 75g (M_{S75}) can be attributed to the variation in reactor time. Increased in pH value was observed with increase in time for Aloe-Vera sample containing 25g (M_{S25}) from time 0 to 6 days when optimum pH value was attained before sudden decrease in pH value within the range of > 6 days < 10 days and the pH value remained constant. Comparison of the Mango sample containing 25g (M_{S25}), 50g (M_{S50}) and 75g (M_{S75}) shows that pH value of Mango sample containing 25g (M_{S25}) is greater than.

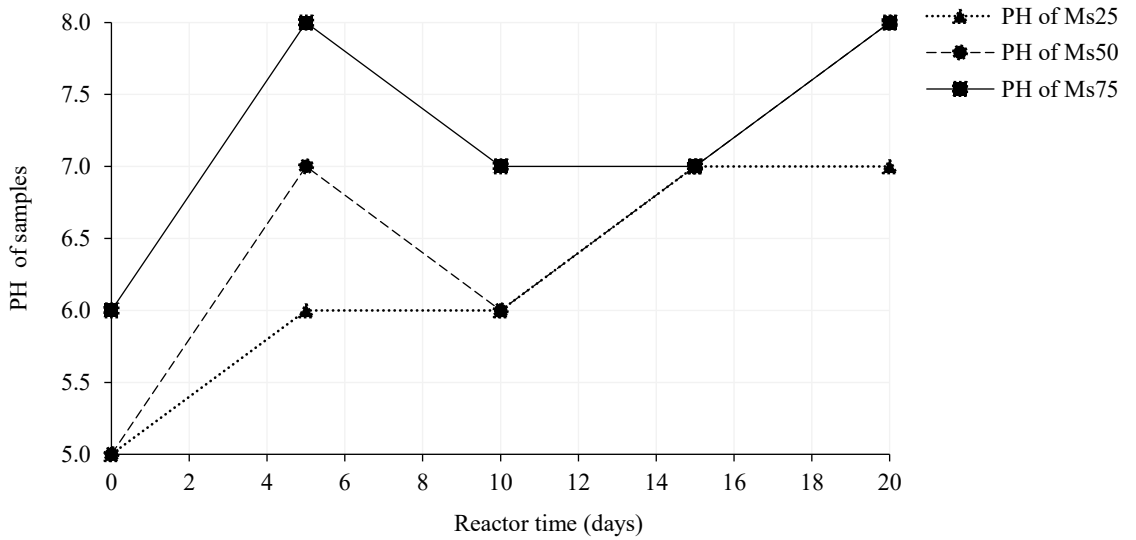

Figure 2. pH versus time for reactors (M_{S25}, M_{S50}, M_{S75}).

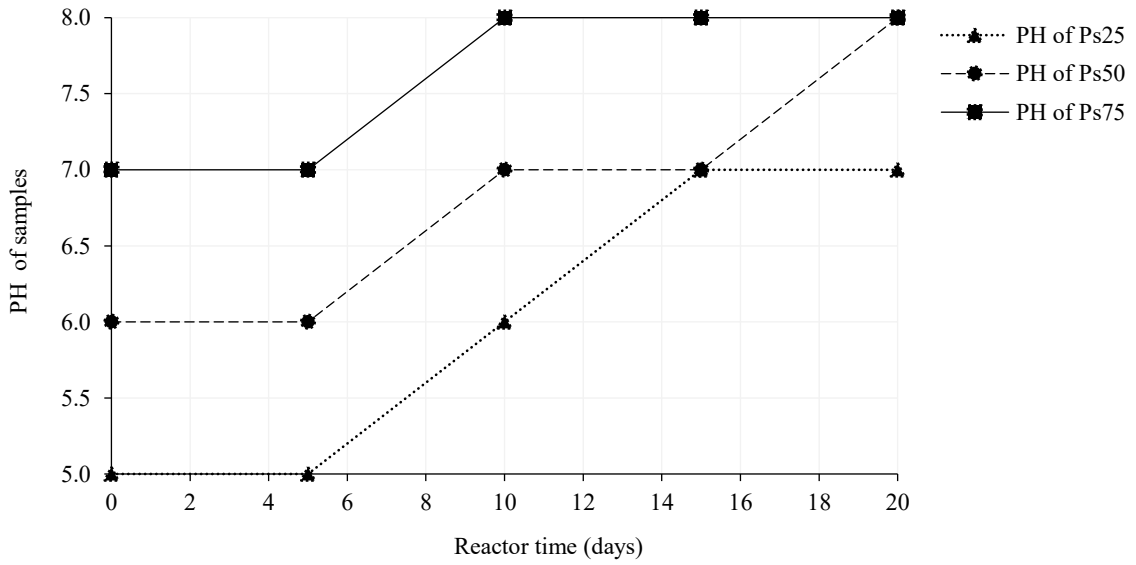

Figure 3. pH versus time for reactors (P_{S25}, P_{S50}, P_{S75}).

From Figure 3 it is seen that the relationship among the following components for pH of Paw-Paw sample containing 25g (P_{S25}), 50g (P_{S50}) and 75g (P_{S75}) upon the influence of reactor time. The variation in Paw-Paw sample containing 25g (P_{S25}), 50g (P_{S50}) and 75g (P_{S75}) can be attributed to the variation in reactor time. Increased in pH value was observed with increase in time for Paw-Paw sample containing 25g (P_{S25}) from time 5 to 15 days before the pH value experiences a stationary phase. Comparison of the Paw-Paw sample containing 25g (P_{S25}), 50g (P_{S50}) and 75g (P_{S75}) shows that pH value of Paw-Paw sample containing 25g (P_{S25}) is greater than.

Figure 4 shows the relationship among the following components for total hydrocarbon content of Aloe-vera sample containing 25g (A_{S25}), 50g (A_{S50}) and 75g (A_{S75}) upon the influence of reactor time. The variation in Aloe-Vera sample containing 25g (A_{S25}), 50g (A_{S50}) and 75g (A_{S75}) can be attributed to the variation in reactor time. Decrease in THC value was observed with increase in time for Aloe-Vera sample containing 75g (A_{S75}) from time 0 to 20 days. Comparison of the Aloe-Vera sample containing 25g (A_{S25}), 50g (A_{S50}) and 75g (A_{S75}) shows that THC value of A_{S75} decreases more with time.

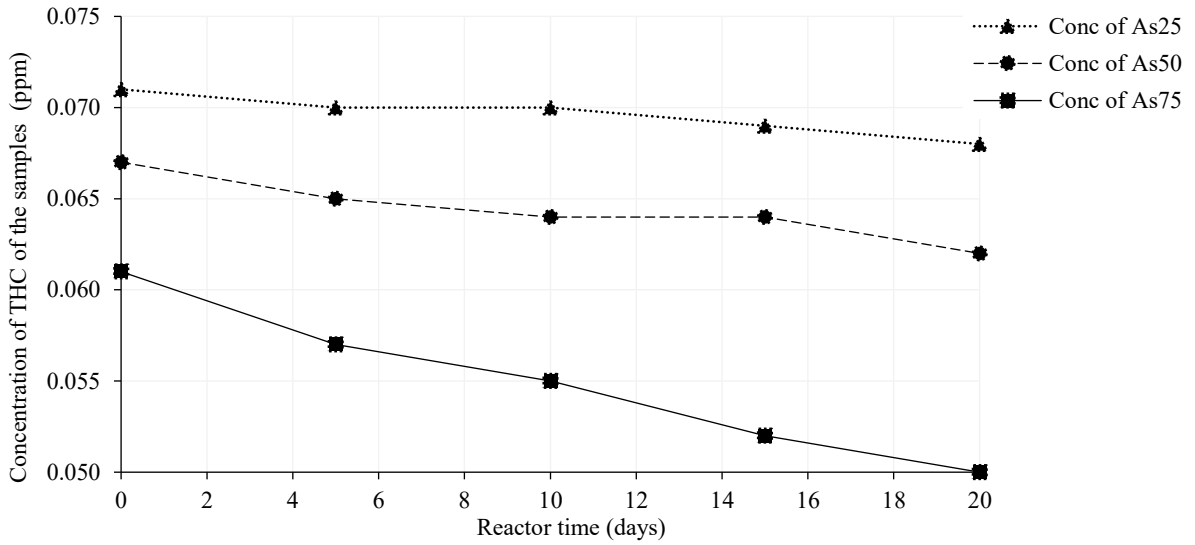

Figure 4. THC versus Reactor Time of the ratio of 25:50:75 (A_{S25}, A_{S50}, A_{S75}).

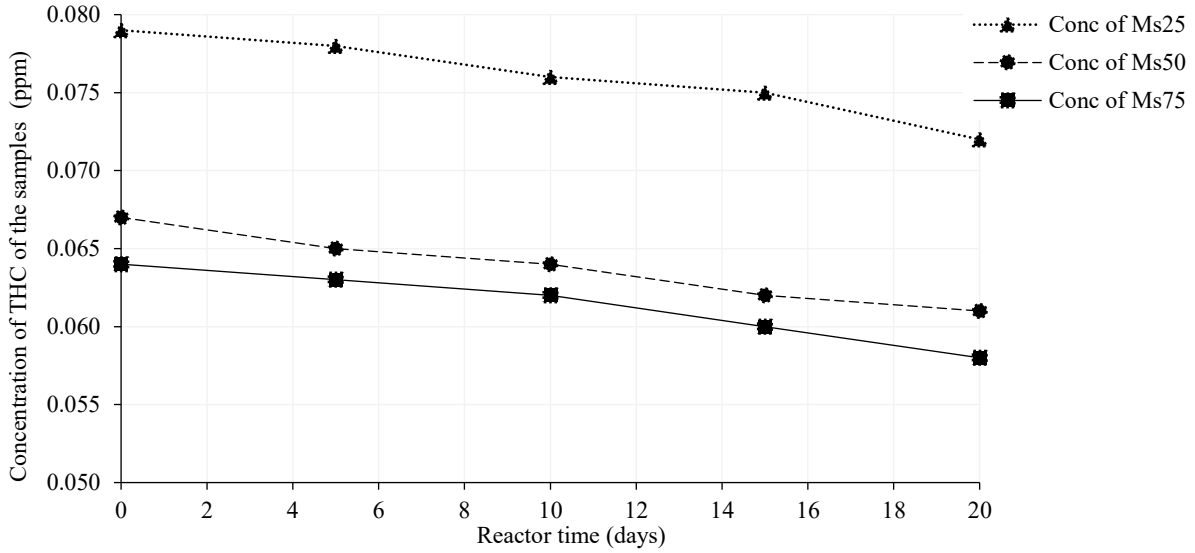

Figure 5. THC versus reactor of the ratio of 25:50:75 (M_{S25}, M_{S50}, M_{S75}).

From Figure 5 it is seen that the relationship among the following components for total hydrocarbon content of Mango sample containing 25g (M_{S25}), 50g (M_{S50}) and 75g (M_{S75}) upon the influence of reactor time. The variation in Mango sample containing 25g (M_{S25}), 50g (M_{S50}) and 75g (M_{S75}) can be attributed to the variation in reactor time. Slight decrease in THC value was observed with increase in time for Mango sample containing 75g (M_{S75}) from time 0 to 15 days before rapid decrease was attained from time 15 to 20 days. Comparison of the Mango sample containing 25g (M_{S25}), 50g (M_{S50}) and 75g (M_{S75}) shows that THC value of M_{S75} decreases more with time.

Figure 6 shows the relationship among the following components for total hydrocarbon content of Paw-Paw sample containing 25g (P_{S25}), 50g (P_{S50}) and 75g (P_{S75}) upon the influence of reactor time. The variation in Paw-Paw sample containing 25g (P_{S25}), 50g (P_{S50}) and 75g (P_{S75}) can be attributed to the variation in reactor time. Slight decrease in THC value was observed with increase in time for Paw-Paw sample containing 25g (P_{S25}) from time 5 to 10 days before rapid decrease was attained from time 10 to 20 days. Comparison of the Paw-Paw sample containing 25g (P_{S25}), 50g (P_{S50}) and 75g (P_{S75}) shows that THC value of P_{S25} decreases more with time.

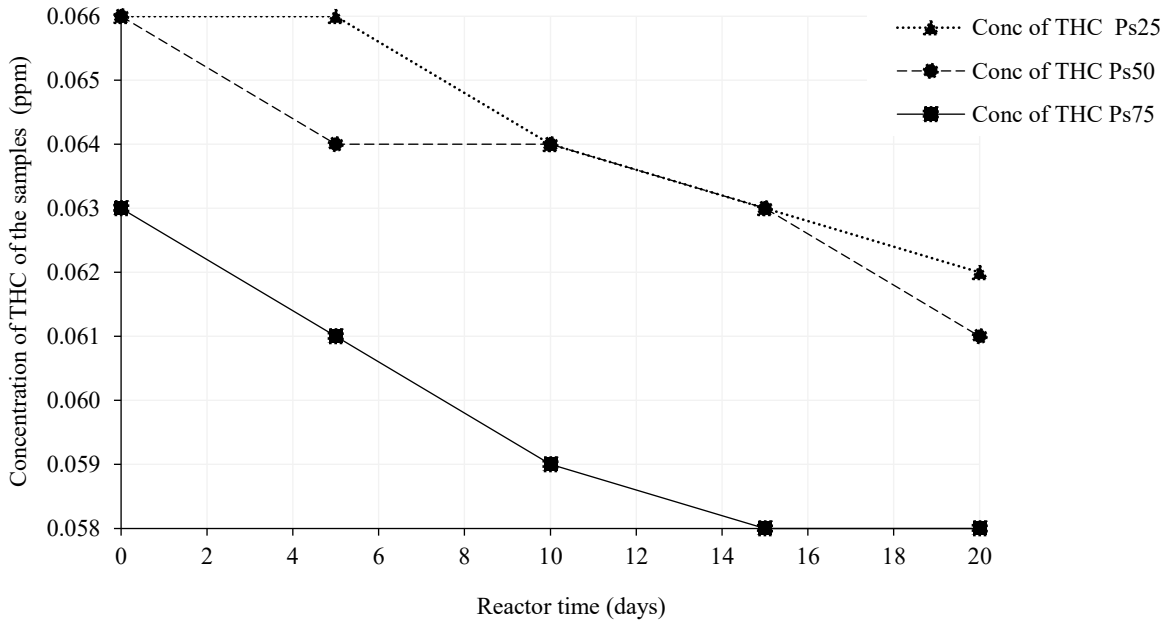

Figure 6. THC versus reactor time of the ratio of 25:50:75 (P_{S25}, P_{S50}, P_{S75}).

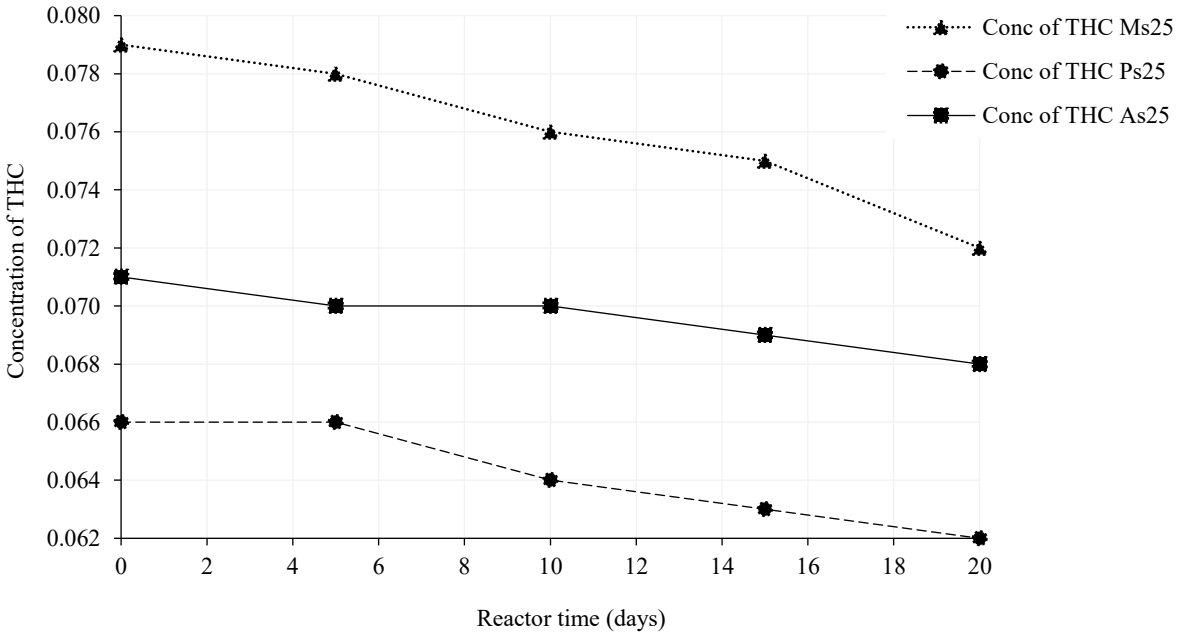

Figure 7. THC $M_{S25,}$ P_{S25} and A_{S25} versus reactor time (days).

The result presented in Figure 7 demonstrates the relationship among the following components for total hydrocarbon content of Mango sample containing 25g (M_{S25}), Paw-Paw sample containing 25g (P_{S25}) and Aloe-Vera sample containing 25g (A_{S25}), upon the influence of reactor time. The variation in Mango sample containing 25g (M_{S25}), Paw-Paw sample containing 25g (P_{S25}) and Aloe-vera sample containing 25g (A_{S25}) can be attributed to the variation in reactor time. There is constant change in THC value observed with increase in time from 0 to 5 days for Aloe-vera sample containing 25g (A_{S25}) before rapid decrease was attained from time 5 to 20 days. Comparison of the Mango sample containing 25g (M_{S25}), Paw-Paw sample containing 25g (P_{S25}) and Aloe-Vera sample containing 25g (A_{S25}) shows that THC value of Aloe-Vera sample containing 25g (A_{S25}) decreases more with time.

The result presented in Figure 8 shows the relationship among the following components for total hydrocarbon content of Mango sample containing 50g (M_{S50}), Paw-Paw sample containing 50g (P_{S50}) and Aloe-Vera sample containing 50g (A_{S50}), upon the influence of reactor time. The variation in Mango sample containing 50g (M_{S50}), Paw-Paw sample containing 50g (P_{S50}) and Aloe-vera sample containing 50g (A_{S50}) can be attributed to the variation in reactor time. Decrease in THC value was observed with increase in time from 0 to 5 days for Paw-Paw sample containing 50g (P_{S50}) before experiencing a constant change in time from 5 to 10 days and decrease of THC value was attained from time 10 to 20 days. Comparison of the Mango sample containing 50g (M_{S50}), Paw-Paw sample containing 50g (P_{S50}) and Aloe-vera sample containing 50g (A_{S50}) shows that THC value of Paw-Paw sample containing 50g (P_{S50}) decreases more with time.

From Figure 9 it is seen that the relationship among the following components for total hydrocarbon content of Mango sample containing 75g (M_{S75}), Paw-Paw sample containing 75g (P_{S75}) and Aloe-Vera sample containing 75g (A_{S75}), upon the influence of reactor time.

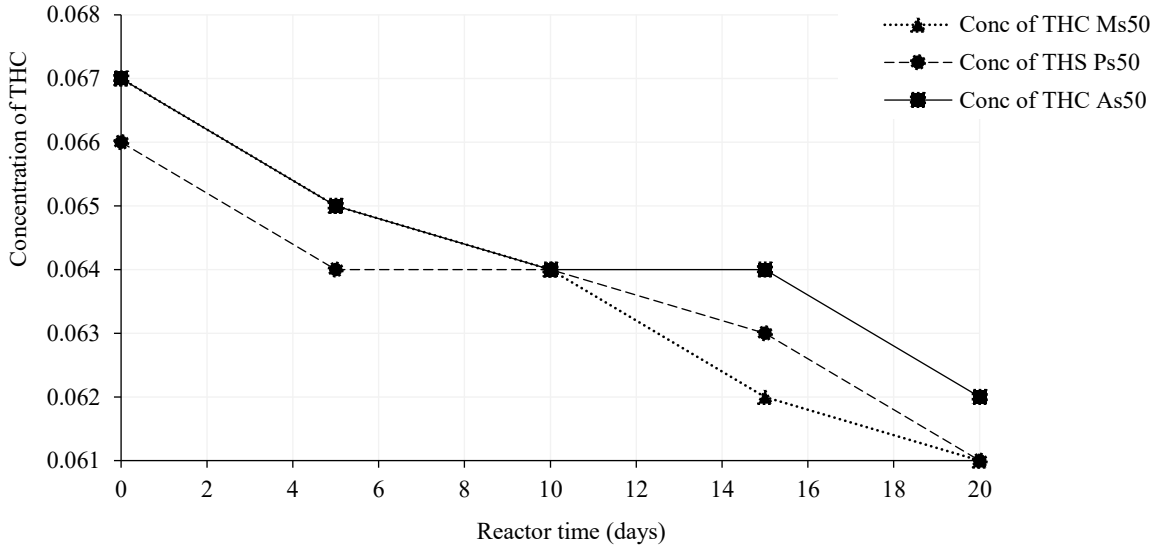

Figure 8. THC $M_{S50,}$ P_{S50} and A_{S50} versus Reactor Time (days).

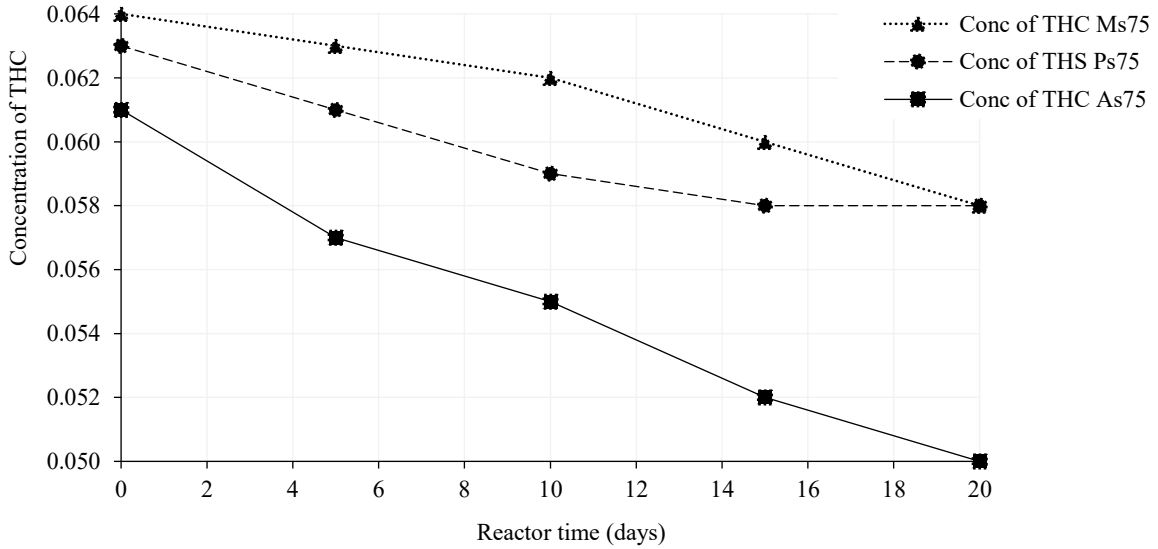

Figure 9. Graph of THC $M_{S75,}$ P_{S75} and A_{S75} versus reactor time (days).

The variation in Mango sample containing 75g (M_{S75}), Paw-Paw sample containing 75g (P_{S75}) and Aloe-Vera sample containing 75g (A_{S75}) can be attributed to the variation in reactor time. Decrease in THC value was observed with increase in time from 0 to 20 days for Aloe-Vera sample containing 75g (A_{S75}). Comparison of the Mango sample containing 75g (M_{S75}), Paw-Paw sample containing 75g (P_{S75}) and Aloe-Vera sample containing 75g (A_{S75}) shows that THC value of Aloe-Vera sample containing 75g (A_{S75}) decreases more with time.

Figure 11 shows the variation of pH of A_{S25}, A_{S50} and A_{S75} varying upon the influence of time (days). Increase in pH value was observed with increase in time.

From the THC table, it was seen that the extract that is more active as a stimulant in the bioremediation process is the Aloe-Vera which produced 18% decrease in the total hydrocarbon content in 20 days, followed by mango with 9.3% decrease and paw-paw as the least with 7.94% decrease.

Figure 10 shows the variation of THC of A_{S25}, A_{S50} and A_{S75} varying upon the influence of reactor time (days). Decrease in THC value was observed with increase in time.

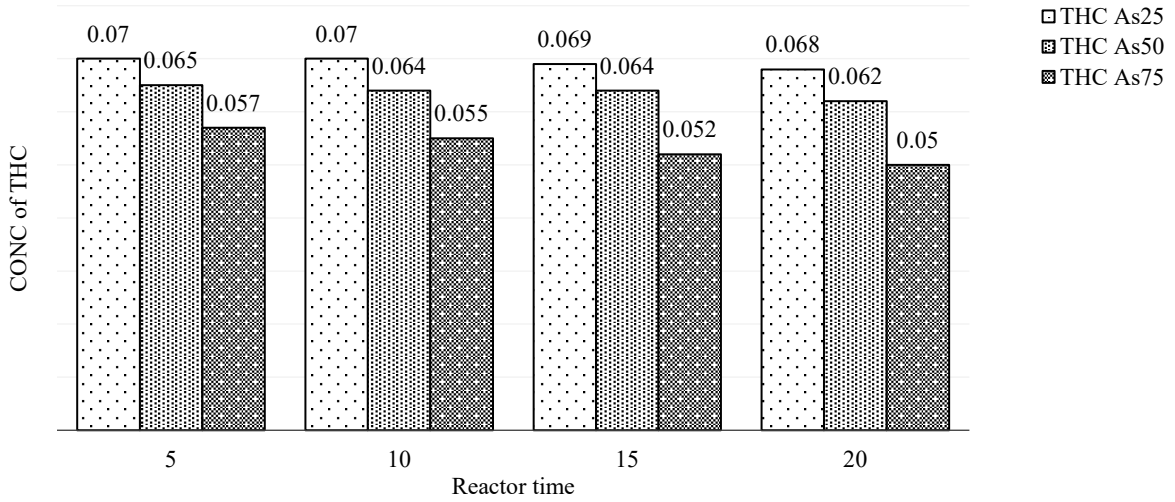

Figure 10. A bar chart showing the relationship between THC A_{S25}, A_{S50} and A_{S75} against reactor time.

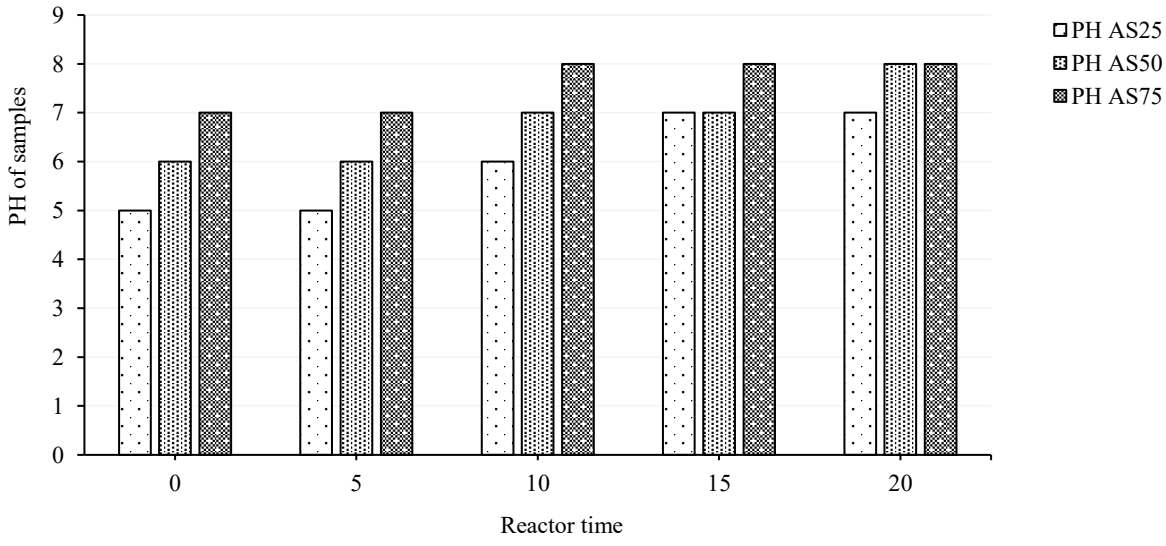

Figure 11. A bar chart showing the relationship between pH of A_{S25}, A_{S50} and A_{S75} against reactor time.

CONCLUSION

The study demonstrates that Aloe-vera, mango, and paw-paw leaf extracts can enhance petroleum hydrocarbon loss in contaminated loamy soil under the experimental conditions. Changes in pH were associated with variations in total petroleum hydrocarbon (TPH) decline, indicating that pH influences the remediation process. Among the extracts tested, Aloe-vera produced the largest TPH reduction over 20 days. Observed increases in microbial activity (as measured during the experiment) are consistent with bio-stimulation by the plant extracts, but further microbial characterization is needed to confirm mechanisms. Overall, these agro-based extracts show promise as low-cost biostimulants for petroleum-contaminated soils; however, larger-scale trials, improved analytical controls (calibrated pH measurement, validated THC quantification), and statistical analysis are required to confirm efficacy and optimize application rates.

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