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Soil Washing to Eliminate Polycyclic Aromatic Hydrocarbons from Petroleum Contaminated Soil: Temperature Effect

Danjuma Muhammad^{1*}, Bintu Grema Mustafa¹, Abdulhalim Musa Abubakar², Alfitouri Ibrahim Jellah³, Abbas Mohamed Al-Khudafi⁴, E. M. Mansour⁵, Mohammed Abdulrahim¹

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ABSTRACT

This study's goals were to identify the components of polycyclic aromatic hydrocarbons (PAHs) in soil samples polluted with petroleum and to ascertain how temperature affected the removal of PAHs pollutants from petroleum-contaminated soil. The concentration of contaminants in the soil samples decreased from 46.22-12.07 ppm to 77.01-30.06 ppm at a temperature increase of 20–160°C, as shown by the results of this study, which are also supported by the percentage removal efficiencies of 22.22–79.69% and 32.90–73.81% for samples M and S, respectively. It was further discovered that 160°C was the ideal temperature range for soil washing to eliminate the pollutants. High removal efficiency values demonstrated the efficacy of the soil washing approach in removing pollutants with high PAH concentrations. This information can help in the creation of more successful and affordable soil remediation techniques.

INTRODUCTION

Polycyclic Aromatic Hydrocarbons (PAHs) are organic pollutants with two linked benzene rings, and are most likely to persist and accumulate in the environment (He *et al.*, 2022; Scott *et al.*, 2012). Land, water, and air pollution are frequently caused by human activities such as petroleum exploration, refining, and distribution, waste creation, landfilling, and other discharges. Via air deposition, these pollutants may affect ecological, human, and environmental health. Heavy metals and PAHs deposition from industrial plants, petroleum storage facilities, landfills, waste disposals, or from fertilizers and pesticides used in agricultural activities are potential sources of soil contamination that could enter large cities and industry (Assarsson, 2015). Because pollutants (particularly oil) alter soil behavior and can be divided into organic and inorganic components, their presence in the soil poses a risk to the ecosystem; especially fluoranthene (a PAH) classified by the United States Environmental Protection Agency (EPA) as one among the 16 priority pollutants (Gnida & Turek-Szytow, 2023; Sayara & Sanchez, 2020). The management of a contaminated area from threats to human health or the environment is referred to as remediation, and restoring all or part of the land to a useful use is referred to as repurposing (Chen & Zhong, 2019; Gupte *et al.*, 2016). Molecular and phase separation, chemical oxidation, soil cleaning, vapor extraction, electro kinetics, and biodegradation are some of the remediation procedures. While strategies

for PAHs bioremediation are land farming, bio-stimulation, composting, bioreactor, phytoremediation, rhizoremediation and Verm remediation (Patel *et al.*, 2020). Benzo[a]pyrene is an indicator of PAHs present in the ecosystem and bioremediation is recommended as a method for PAH removal from the soil owing to its efficacy and low costs (Abubakar & Alhassan, 2021; Gnida & Turek-Szytow, 2023; Tsibart & Gennadiev, 2013). If the physicochemical characteristics of pollutants and particles of soil are well understood before the selection of any technique, successful application of the remediation techniques will be possible. The choice of choosing the most suitable soil and sediment remediation technique rest on the site properties, concentration, kinds of contaminants to be removed and final use of the concentrated medium (Dike *et al.*, 2013).

Petroleum (Lamoj, 2022) pollution of soil is a persistent environmental problem that poses a significant threat to human health and ecosystems. One of the most common pollutants found in petroleum-contaminated soil is PAHs, which are highly toxic and carcinogenic compounds. Soil washing is a promising remediation technique that has been used to remove PAHs from polluted soil. This technique involves the use of water or other solvents to extract and separate pollutants from the soil (Ekanem *et al.*, 2019). Previous studies have shown that temperature is a critical parameter in the soil washing process (Adekunle *et al.*, 2012). High-temperature conditions can enhance the removal efficiency of PAHs from contaminated

¹ Department of Chemical Engineering, Faculty of Engineering, University of Maiduguri, P.M.B. 1069, Maiduguri, Borno State, Nigeria

² Department of Chemical Engineering, Faculty of Engineering, Modibbo Adama University, P.M.B. 2076, Yola, Adamawa State, Nigeria

³ Oil and Gas Engineering Department, Faculty of Engineering, Bani Waleed University, Libya

⁴ Department of Petroleum Engineering, Hadhramout University, Al-Mukalla, Yemen

⁵ PVT Services Center & PVT Lab, Production Department, Egyptian Petroleum Research Institute, Egypt

* Corresponding author's e-mail: djmarshal2010@yahoo.com

soil, but it can also increase energy consumption and associated costs. Therefore, it is crucial to determine the optimum temperature range that can maximize the removal efficiency of PAHs while minimizing the cost. Hence, the objectives in this study are to determine the components of PAHs in the contaminated soil samples using Gas Chromatography Mass Spectrometry (GC-MS), remediate the contaminated soil samples using soil washing method, determine the effect of temperature on contaminants removal and determine the performance efficiency of the soil washing method. The findings of this study will provide valuable insights into the optimum temperature range for soil washing to remove PAHs from petroleum-contaminated soil. This knowledge can aid in the development of more effective and cost-efficient soil remediation strategies.

LITERATURE REVIEW

Thermal desorption of soil pollutants or thermal remediation, removes pollutants from soil through phase changes and is one of the most widely applied techniques (Bonten, 2001). Liu *et al.* (2022) arrived at a temperature of 400°C, which they concluded as enough to meet thermal remediation objectives of their work. Using contaminated soil sample collected from a petrochemical complex in South Iran, as reported by Madadian *et al.* (2014), Brij 35 surfactants (5 g/L) at 80°C after washing for 1 hour, presents the highest removal efficiency (81.66%) of PAHs. Actually, the experiments/washing was carried out under temperatures of 20°C, 40°C and 80°C using Triton X and Brij 35 surfactants for 30 and 60 minutes, where it was observed that the higher the temperature, the highest would be the removal efficiency due to increase in molecular movements of the solution. Also, at different treatment times of 15, 30, 45 and 60 minutes, thermal desorption at 200, 400 and 600°C to remove PAH, alkylated PAHs, unresolved complex mixtures (UCM), and total petroleum hydrocarbons (TPH), were studied by Choi *et al.* (2020). In the study, after 15 minutes, almost complete removal of TPH, UCM, PAHs and Alk-PAHs at

400°C (98% removal) and 600°C (99% removal) occurred. In the literature, methods of removing PAHs are namely, chemical oxidation, solidification/stabilization, solvent extraction/soil washing, supercritical fluid extraction, ozone, thermal desorption, electrokinetic remediation, soil vapor extraction, Fenton method, volatilization, dissolution, diffusion, ion exchange, adsorption, hydrolysis, photolysis, neutralization, aerodynamic, hydrodynamic and electrochemical bleaching (Ahmad *et al.*, 2020; Darajeh *et al.*, 2020; Stepanova *et al.*, 2022). According to Darajeh *et al.* (2020), combining all these methods can be a feasible choice for better cleanup of PAH from contaminated environment. Apart from the well known soil clean up methods, Funada *et al.* (2018) came up with a novel magnetic separation technology, in which 96% removal efficiency of PAHs was obtained. As further deduced from the same authors, the new (Fe-AC-alg powder) technique is very economical, simple and environmentally friendly. Aouf & Dounit (2022) demonstrates the use of a laboratory-scale fluidization technique (column) to remediate 1 year old crude oil contaminated soil, which indicates a low process efficiency even after 120 minutes of operation. A cleaner approach, consisting of utilizing eucalyptus oil as solvent in the removal of PAHs at varying concentrations from the soil, as obtained by Kariyawasam *et al.* (2022), is very efficient during soil cleaning than the removal of PAHs from sediments. Simple use of microorganisms (e.g., *Micrococcus inteus*, *Pseudomonas sp.*, & *Pennisetum purpureum* etc.) through a technique called bio-remediation is another friendly clean up strategy; however, taking longer period of time (Ambust *et al.*, 2021; Bonten, 2001; Kinyua *et al.*, 2022; Riskuwa-Shehu *et al.*, 2022).

METHODOLOGY

Materials and Equipment

Equipment and apparatus used in the course of the investigation are shown in Table 1.

Reagents used are 200 mL deionized water supplied by SHESTCO LAB and 10g detergent.

Table 1: Apparatus and Equipment Manufacturers Information

Name	Manufacturer	Range
Equipment		
GC-MS	Thermo Scientific Trace	0.1–50 ppm
Hot Plate Magnetic Stirrer	HPS-340PII	5–340°C & 0–1500 rpm
Suction Pump	U7J	0–1×10 ³ Pa
Weighing Balance	Dawood	300 g
Stop Watch	16 Jewel	3600 seconds
Hand Auger		
Apparatus		
Cylinder	Pyrex Glass	
Beaker	Pyrex Glass	
Measuring Cylinder	Pyrex Glass	
Table Spoon		

Study Area Description

This research was carried out on Maiduguri and Suleja polluted soil samples collected, both in Northern Nigeria. Maiduguri is a medium sized city in North Eastern Nigeria with the population of about 2,607,497, which is located at 11°50'N 13°09'E (Abubakar, 2017). This dynamic population of Maiduguri suggest its demand for petroleum product for transportation and fueling of electricity generating sets for both domestic and industrial needs by the residents. The Nigeria National Petroleum Corporation (NNPC) depot is located at Maiduguri Metropolitan Council (MMC), Maisandari Damboa Road, Maiduguri, Borno State. It is responsible for storage and distribution of petroleum products such as Premium Motor Spirit (PMS), Automotive Gasoline Oil (AGO), and Dual-Purpose Kerosene (DPK) within and outside Maiduguri environs owned by the Pipeline

and Product Marketing Company (PPMC) limited, a subsidiary of NNPC (Eke & Enibe, 2007).

On the other hand, Suleja, is a major satellite town near the Federal Capital Territory (FCT) Abuja, characterized by high and low-income earners with major occupation such as farming, business, and civil servants. The area is densely populated with about 368,900 people, mostly indigenes of Gbagyis and other settlers from all part of Nigeria (Brinkhoff, 2022). It is bounded by Gurara and Tafa Local Government areas in Niger state and Gwagwalada Area Council (Zuba) in FCT. The specific study area is the NNPC tank farm popularly known as Suleja Depot, located in Maje- Suleja, Niger State, North Central Nigeria. It lies between Latitude 9° 15' 15.80"N and Longitude 7° 10' 18.84"E (Birmah *et al.*, 2021). Respective maps of the described locations are shown in Figures 1 and 2.



Figure 1: Map of Maiduguri Showing Damboa Road

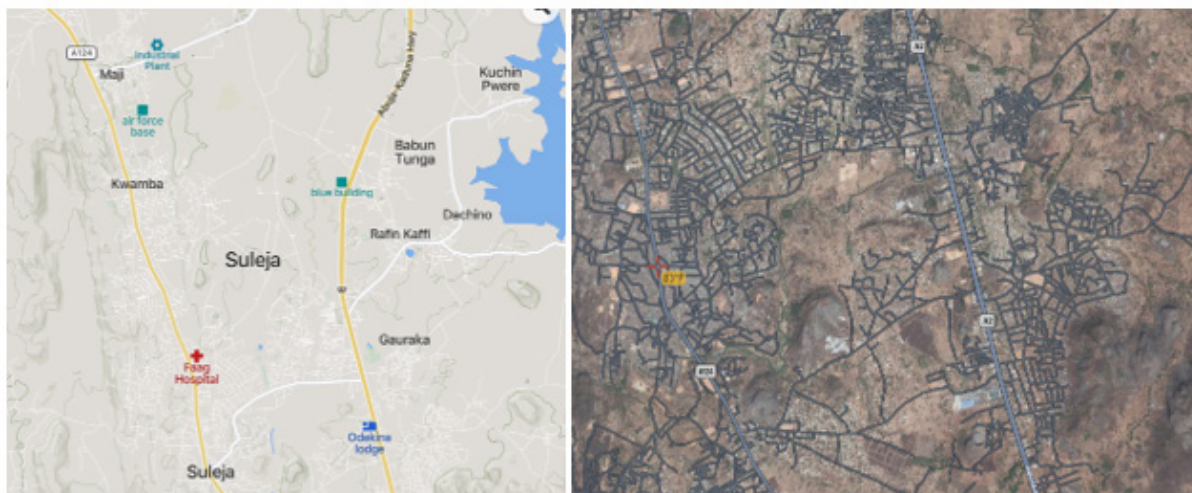


Figure 2: Map of Suleja

Soil Sampling Collection

Contaminated soil was collected from Maiduguri and Suleja Tank Farm, and uncontaminated soil was also collected away from the Tank Farm as control using

an operated auger from a depth of about 10 cm from ground surface according to British Standard (BS) 10176 2022 and taken to the laboratory for analysis. The contaminated samples taken from Maiduguri and Suleja

Tank Farm were labelled Sample M and Sample S, and the uncontaminated samples were labelled Sample MC and Sample SC, respectively. A total of 4 samples of 1000g each, were taken at different locations of the Tank Farms. The samples were analyzed to know the kinds and concentration of the PAHs contaminant present.

Solid-Liquid Extraction of Contaminants and Concentration Determination using GC-MS

101g each of the contaminated soil for 4 samples were weighed and 300 mL volume of acetone–ethyl acetate–water mixture (containing 50 mL ethyl acetate, 40 mL of acetone and 10 mL of water) was added to each of the contaminated soil sample in order to promote an efficient contact between the solid and liquid. Magnetic agitation at 200 rpm was used to promote contact between the phases. An optimized contact time of 15 minutes and a solid-liquid ratio of 1:8 (v/v) was used. The solvents containing the extracted contaminants was separated from the soil samples by vacuum filtration. After the separation, the soil samples and the samples of the extract mixture were analyzed with GC-MS to characterize and determine the contaminants concentration. After this, the sample with the highest concentration of contaminants from each location was then divided into 8 samples each for remediation. This work adopts collectively, the

extraction technique described in Lau *et al.* (2010) and Wloka & Smol (2014).

Preparation of Wash Solution

A common household laundry detergent (Brand name: Viva) containing Linear Alkyl Benzene Sulfonate (LABS) solution was used to prepare the wash solution. This was carried out by dissolving 100g of the detergent in 2 litres (2000 mL) of deionized water to form the wash agent, based on the detergent-water ratio of 1:20.

Remediation Procedure

The sample with the highest contaminants concentration in sample M was divided into 8 samples of 101 g each and placed into 8 different beakers. Then, 150 mL of the wash solution was added to each beaker containing the samples based on the optimized soil-water ratio of 1:2 (v/v). The content was allowed to stay for 1 hour to ensure soaking of the soil and weakening of the adhesive force between the contaminants and the soil. After soaking is achieved, the content in each beaker was heated at different temperatures of 20°C, 40°C, 60°C, 80°C, 100°C, 120°C, 140°C and 160°C, and stirred at the same time for 15 minutes in other to achieve the effect of washing, as shown in Figure 3.

Temperature above 160°C may affect some of the soil

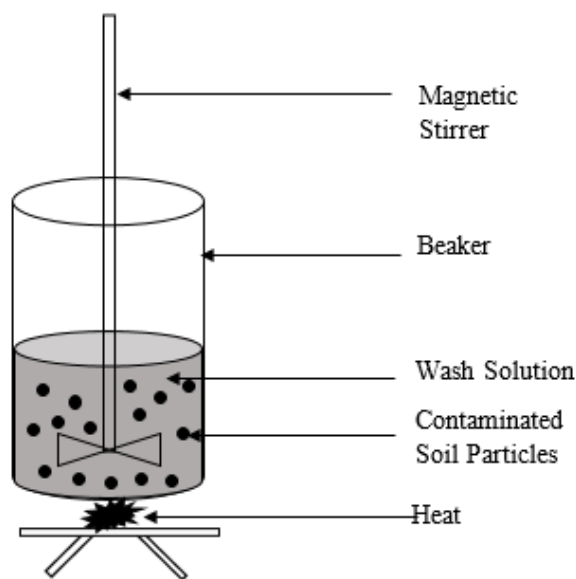


Figure 3: Laboratory Experimental Setup

properties as explained by Abdullahi *et al.* (2020). After 15 minutes of heating and stirring, the soil-detergent solution mixtures in the beakers was allowed to stand for 24 hours. The wash solution was then drained out using suction pump at 6×10^{-2} Pa. Now, 150 mL of deionized water was added to the washed samples to further remove the residual wash solution in the samples. The deionized water was then drained out through pipe by suctioning. After the washing was completed, the residual contaminants in the washed soil samples were extracted

using solid-liquid extraction method and then analyzed using GC-MS. Percentage removal of the contaminants will be calculated using Equation 1.

$$R(\%) = \frac{(C_i - C_f)}{C_i} \times 100 \quad (1)$$

Where C_i is the contaminant concentration before (or pre-) remediation (CBR), C_f is contaminant concentration after (or post-) remediation (CAR) and $R(\%)$ is the percentage removal of contaminant after remediation (Dike *et al.*, 2013). Same procedure was then repeated for sample S.

Determination of Optimum Temperature

A multiple linear regression was performed using POLYMATH 6.10 Educational Release for the 2 sample values of CBR and dT – and was used to develop a model equation that was used to determine the optimum temperature at which effective remediation was achieved, as explained in Abubakar *et al.* (2022).

RESULTS AND DISCUSSION

Properties of Soil Samples Taken as Control

Soil samples MC and SC were taken to serve as control. The analysis of these samples showed that PAHs were found to be present in quantities of less than 0.01 ppm, as depicted in Table 2.

Table 2: Soil Properties of Samples from Maiduguri and Suleja Without PAHs Contamination

Properties	Sample MC	Sample SC
Initial Water Content (%)	2.0	2.5
pH	7.5	6.0
TOC (%)	0.5	0.3
CEC (Cmol kg ⁻¹)	7.5	9.0
Particle Size Distribution (%)		
< 50µm	12	14
50-75 µm	21	29
75-125 µm	19	24
125-250 µm	9	14
250-500 µm	6	10
500-2000 µm	1	2
Polycyclic Aromatic Hydrocarbons (PAHs) (ppm)		
Phenanthrene	< 0.01	< 0.01
Anthracene	< 0.01	< 0.01
Fluoranthene	< 0.01	< 0.01
Pyrene	< 0.01	< 0.01
Benzo[c]phenanthrene	< 0.01	< 0.01
Benz[a]anthracene	< 0.01	< 0.01
Chrysene	< 0.01	< 0.01
Benzo[e]pyrene	< 0.01	< 0.01
Benzo[k]fluoranthene	< 0.01	< 0.01
3-Methylcholanthrene	< 0.01	< 0.01
Indeno[1,2,3-cd] pyrene	< 0.01	< 0.01
Dibenz[a,h]anthracene	< 0.01	< 0.01
Benzo[a]pyrene	< 0.01	< 0.01

Sample MC = Soil sample from Maiduguri as control, Sample SC = Soil sample from Suleja as control

Percentage Removal of PAHs

PAHs as shown in Table 3, were observed to decrease in concentration after remediation and increase in percentage removal rate in both samples M and S. This reduction was observed from the decrease in the concentrations and increase in percentage removal rate of PAHs in both samples M and S respectively. From Table 3, sample M showed a decreasing concentration and percentage removal rate of 46.22-12.07 ppm and 22.22-79.69% respectively while sample S showed a decreasing concentration and percentage removal rate of 77.01-30.06 ppm and 32.90-73.81% respectively.

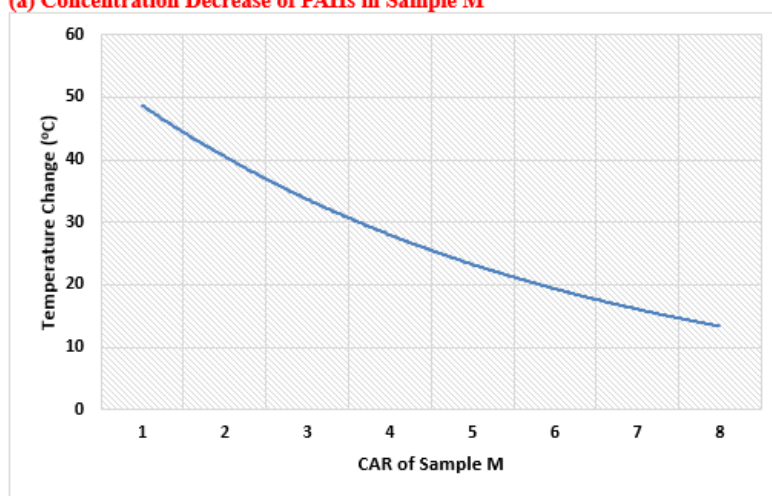
Even with PAHs having low solubility in water and strong adherence to soil particles (Onos *et al.*, 2015; Patel *et al.*, 2020), dissociation and removal of the PAHs was

made possible with detergent as solubilizer (Abdullahi *et al.*, 2020), and at the application of temperature for bond breaking. Table 5 showed that, PAHs were removed individually at different degree ranging from 2-100%. This occurred because individual PAHs gather differently in soil due to their low aqueous solubility, low vapor pressure and high hydrophobicity in accordance with Eldos *et al.* (2022). The adherence of PAHs to soil particles is attributable to the number of benzene-rings present (Mehdi *et al.*, 2015). The same authors, as well as Adeniji *et al.* (2018) also indicated in their study that, PAH solubility in water decreases with increase in molecular weight (number of benzene-rings). This indicates that PAHs with lower molecular weight will be removed faster than those with high molecular weight which explains

Table 3: Concentration and Percentage Removal of PAHs in All Samples

S/No	Temperature Change (°C)	Sample M				Sample S			
		CBR M	Samples	CAR	%R	CBR S	Samples	CAR	%R
1	20	59.44	M1	46.22	22.22	114.77	S1	77.01	32.90
2	40	59.44	M2	38.48	35.26	114.77	S2	75.00	34.65
3	60	59.44	M3	34.55	41.87	114.77	S3	68.43	40.38
4	80	59.44	M4	29.04	51.14	114.77	S4	60.14	47.60
5	100	59.44	M5	25.51	57.08	114.77	S5	53.05	53.78
6	120	59.44	M6	20.46	65.58	114.77	S6	44.45	61.27
7	140	59.44	M7	15.96	73.14	114.77	S7	37.45	67.37
8	160	59.44	M8	12.07	79.69	114.77	S8	30.06	73.81

(a) Concentration Decrease of PAHs in Sample M



(b) Concentration Decrease of PAHs in Sample S

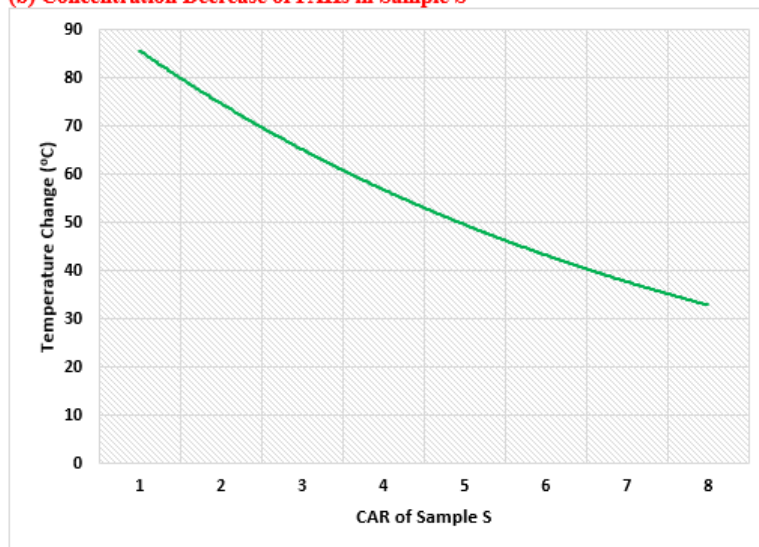


Figure 4: Downward Trends of Concentrations of PAHs in Sample M and S

the decrease of PAHs concentration for both sample M (Figure 4a) and sample S (Figure 4b), respectively. However, the removal rate was not in consistent with the number of benzene-rings in the PAHs compounds shown in Table 5. This may result according to Mehdi *et al.* (2015), from the presence of one PAH lowering the

removal rate of other PAHs. Mehdi *et al.* (2015) further explained in their work that, the concurrent presence of phenanthrene, acenaphthene, fluorine, anthracene, pyrene, and benzo[a]pyrene affects the removal rate of phenanthrene and acenaphthene by reduction while the removal rate of fluorine, anthracene and pyrene was

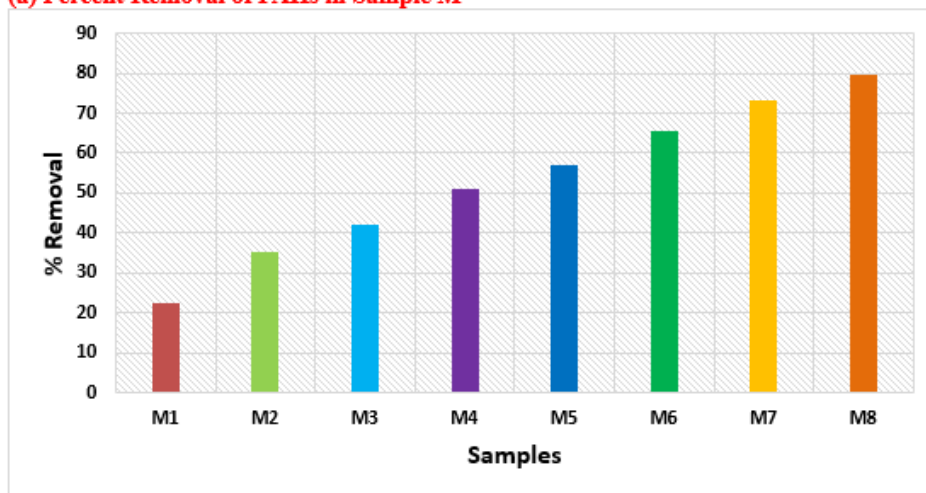
enhanced. The detergent used was for the purpose of increasing the solubility rate by lowering the interfacial tension existing between the PAHs and the soil particles (Abdullahi *et al.*, 2020) and the temperature affected the bond breaking enhancing solubility and exciting the molecules of PAHs for evaporation.

Effect of Temperature on PAHs Removal

Results obtained from this study showed that, temperature decreased the concentration of PAHs from the contaminated soil samples. However, the level to which the disappearance occurred varied due to the variation in temperature used and strength of bond existing between the molecules of the PAHs and the binding sites on the soil. Hydrocarbon substance cannot be easily dissolved by water simply because, water contain in it, hydrogen bond which is stronger than the London dispersion force (induced dipole-induced dipole attraction) existing in hydrocarbons. By implication, for a hydrocarbon to dissolve in water the London dispersion force holding its molecules together must be broken as well as the hydrogen bond binding the molecules of water together,

to create space for the hydrocarbons (PAHs) to fit between the water molecules (Abozenadah *et al.*, 2017). For this reason, detergent containing LABS was used to enhance solubility. Temperature was observed to have affected the presence of PAHs in the contaminated soil samples. This effect has led to the decrease in PAHs and has increase the percentage removal rate of the contaminants in the soil samples M and S (Figure 4). An increase in temperature leads to the decrease in the presence of PAHs and an increase in the percentage removal efficiency. This was again observed in Figures 4a and 4b in which, an increase in temperature between 20-160°C leads to decrease in the concentration of PAHs from 46.22-15.96 ppm and 77.01-37.45 ppm for both samples M and S respectively. This is in comparison with Hiller *et al.* (2008) study, where an increase in temperature from 4-27°C leads to decrease of three components of PAHs (naphthalene, pyrene and phenanthrene) from the soil samples worked on. Thus, the percentage removal efficiency was observed to increase from 22.22-79.69% and 32.90-73.81% for both sample M and S respectively at increased temperature, as shown in Figure 5.

(a) Percent Removal of PAHs in Sample M



(b) Percent Removal of PAHs in Sample S

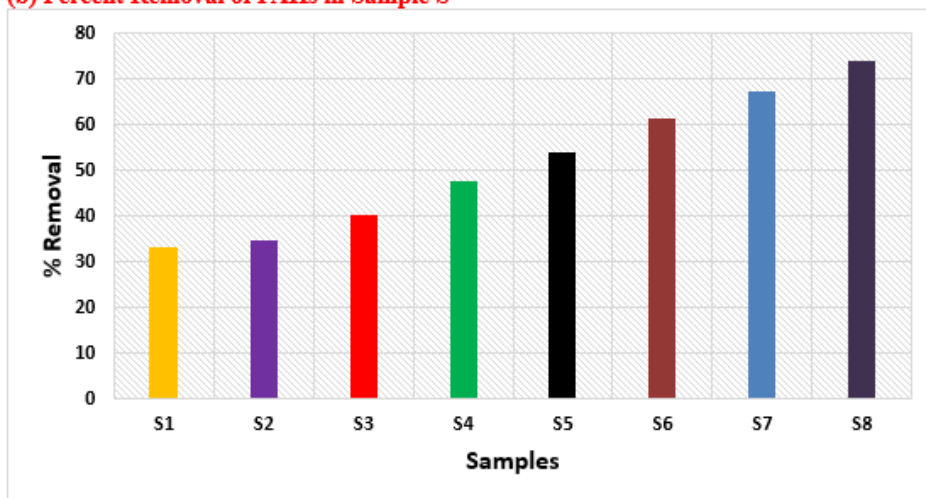


Figure 5: Percentage Removal of PAHs in Sample S and M

Increase in removal efficiency was also indicated in a study by Cora *et al.* (2013) where 81% and about 99% removal efficiency was observed for natural and artificial contaminated soil by PAHs at above 400°C. Edgar *et al.* (2008) in their research also showed similar trend of decrease in PAHs concentration in soil from the result they obtained. Their result indicated that 20.9%, 24.1% and 32.4% decrease was achieved for phenanthrene, naphthalene and pyrene at temperature rise from 4-27°C respectively. He *et al.* (2022) and Hiller *et al.* (2008) also reported 25% decrease in the presence of fluoranthene in soil with temperature increase from 5-15°C. These were made possible because increase in temperature affects the physicochemical properties of PAHs and of the soil according to Zhang *et al.* (2020) and also, increase the solubilities of PAHs in water, which in turn enhance their removal rate as reported by Edgar *et al.* (2008). While Chiou *et al.* (2002) concluded that, the aqueous activity coefficient is a major controlling factor that affect the removal of PAHs (a hydrophobic organic contaminants) in soil with temperature.

Temperature Optimization

In order to correlate CBR and temperature change (dT) with CAR which is the resulting concentration after remediation, multiple linear regression was performed using POLYMATH 6.10 Educational Release for the two sample values of CBR and dT, where the model (or Equation 2) was obtained.

$$CAR = a_1 CBR + a_2 dT \tag{2}$$

By definition, $a_1 = 0.6924443$ and $a_2 = -0.2247164$, are constants obtained from regression. Equation 2 was used to estimate CAR (fitted) in Table 4 and Figure 6a where it was observed that the plots of the two samples data did not closely fit the empirical data. It must be remembered that Equation 2 is only valid for temperature ranging from 20-160°C and CBR between 59.44 and 114.77ppm for samples M and S respectively. Coefficient of correlation, $R^2 = 0.8724457$, adjusted $R^2 = 0.8633346$, Root Mean Square Deviation (RMSD) = 1.757055 and variance = 56.45241, all obtained from the regression software, shows that the newly estimated CAR did not sufficiently fit the empirical results, though proportional to it.

Table 4: Combined Estimates of CAR by Fitting to Two Sample CAR Data Measured

Sample	CBR (ppm)	dT (°C)	CAR (Measured) (ppm)	CAR (Fitted) (ppm)
Sample M	59.44	20	46.22	36.66456119
	59.44	40	38.48	32.17023319
	59.44	60	34.55	27.67590519
	59.44	80	29.04	23.18157719
	59.44	100	25.51	18.68724919
	59.44	120	20.46	14.19292119
	59.44	140	15.96	9.698593192
	59.44	160	12.07	5.204265192
Sample S	114.77	20	77.01	74.97750431
	114.77	40	75.00	70.48317631
	114.77	60	68.43	65.98884831
	114.77	80	60.14	61.49452031
	114.77	100	53.05	57.00019231
	114.77	120	44.45	52.50586431
	114.77	140	37.45	48.01153631
	114.77	160	30.06	43.51720831

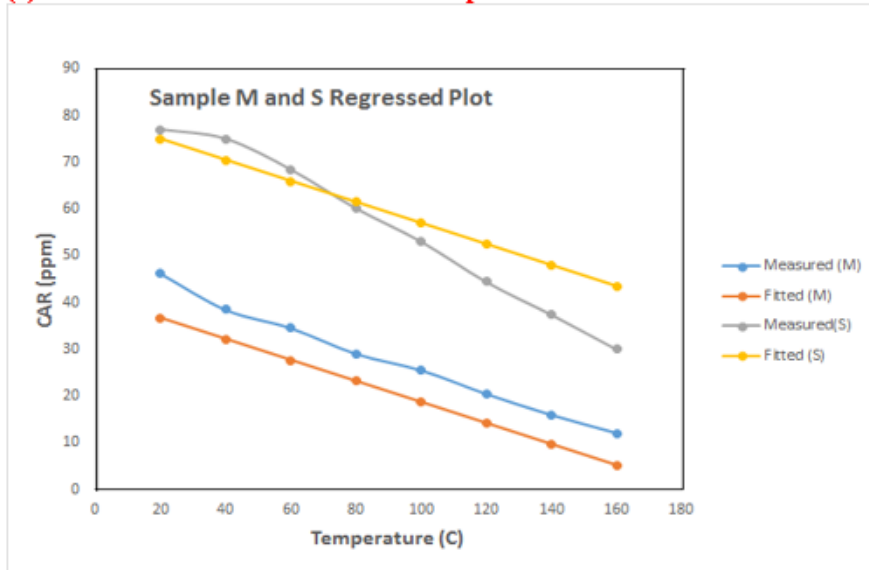
Notwithstanding, the newly obtained model for the work can be used to test for sensitivity of temperature change for a sample of specific concentration before oil removal. It could be seen in Figure 6b that as CAR decreases, the temperature change increases and vice versa – technically CAR is inversely proportional to dT at constant CBR = 59.44ppm.

However, there is no change in behaviour of the linear plot in Figure 6b compared to when CAR is computed at constant CBR = 65 ppm for varying temperature from 20-80°C, as shown in Figure 6c. It could be concluded that, if CBR is high in the contaminated soil sample, CAR (at any temperature) will be proportionally low in

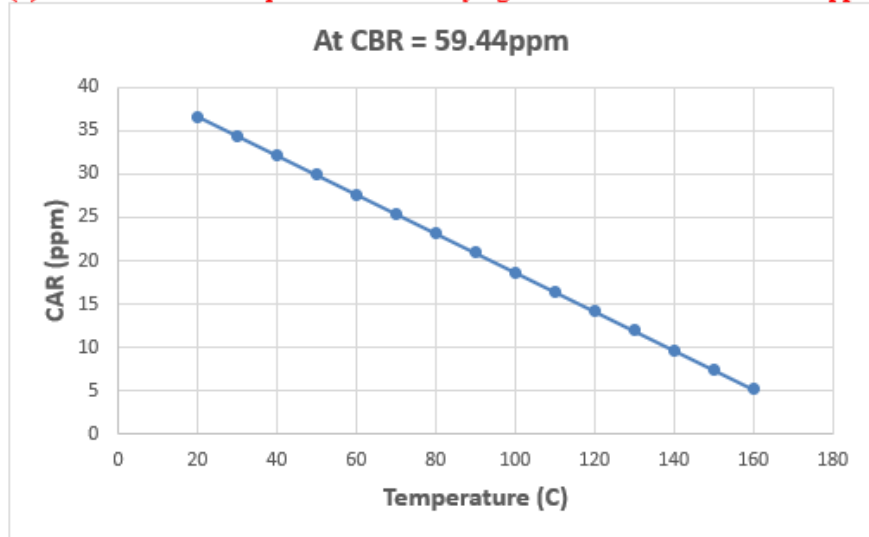
the remediated soil sample and if low, the trend remains the same. So optimum result is where CAR is low and the temperature is high in respective of CBR obtained, either in sample M or sample S.

At constant temperature, as CBR increases, CAR estimated using the model equation also increases and vice versa. This is because removal rate was low as a result of increase in concentration of contaminant at constant temperature. Also, at low constant temperature of 20°C the contaminant concentration in the remediated soil was high due to low removal rate enhanced by the temperature, while at a high constant temperature of 160°C, the contaminant concentration in the remediated

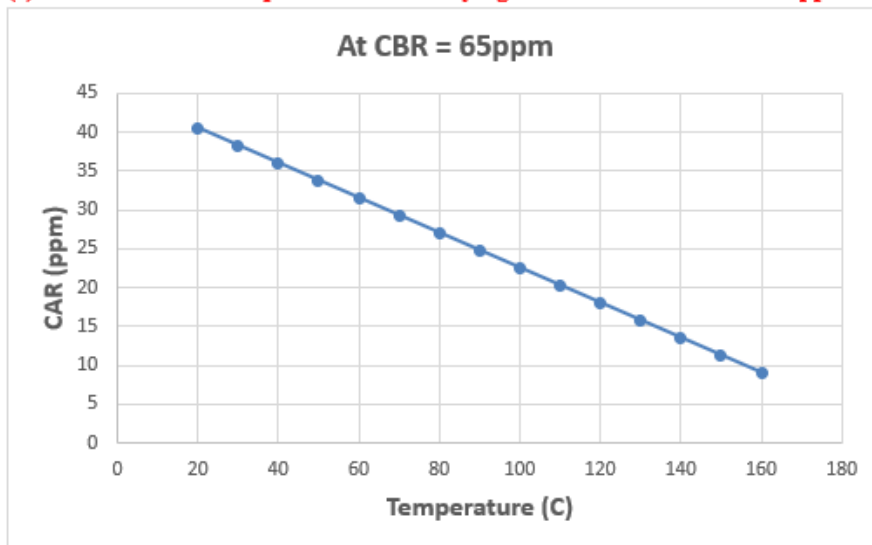
(a) CAR Fitted to Measured Data for Sample M and S



(b) CAR from Model Equation versus Varying dT at Constant CBR = 59.44 ppm



(c) CAR from Model Equation versus Varying dT at Constant CBR = 65 ppm



(d) Response of CAR at Constant Temperature

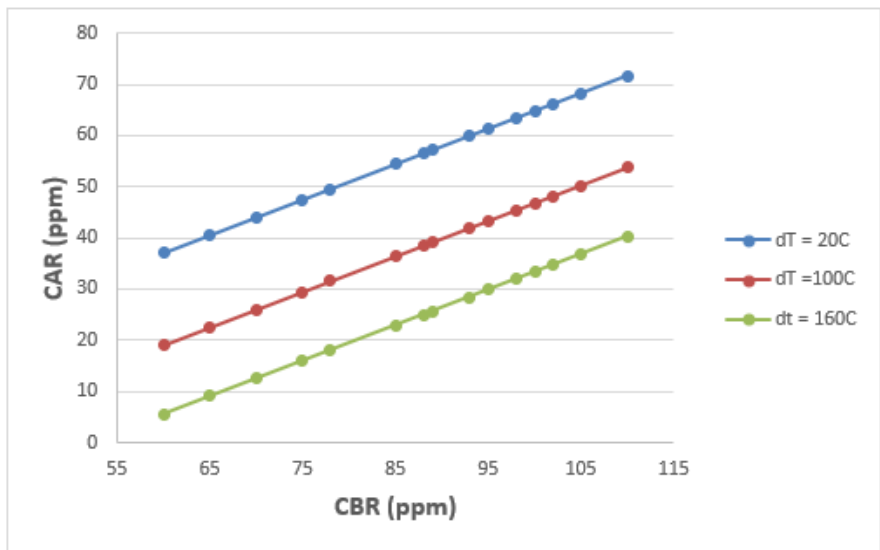


Figure 6: CAR versus Temperature Representation at Different CBR

soil showed a high reduction due to high removal rate enhanced by the temperature as shown in Figure 6d. Though, at different constant temperatures, it was noted that the CAR in the remediated soil decreased as shown in Figure 6d where three different constant dT response for CBR from 60-110ppm were obtained. The optimum temperature obtained is 160°C, because that is the temperature where CAR is expected to be low (notice that ‘dT=160°C line’ is below other lines). The higher

the temperature as seen upward from ‘dT=20°C line’ to ‘dT=100°C line’, the lower the CAR in the remediated soil sample, which by implication means, effective removal.

Performance Efficiency of the Soil Washing

Percentage removal of the contaminants was used to evaluate the efficiency of the soil washing. Table 5 (Sample M) and 6 (Sample S) presents the experimental results showing the performance removal efficiencies of

Table 5: Percentage Removal of PAHs in Sample M

Sample M					
S/No	Temperature (°C)	CBR	Samples	CAR	%R
1	20	59.44	M1	46.22	22.22
2	40	59.44	M2	38.48	35.26
3	60	59.44	M3	34.55	41.87
4	80	59.44	M4	29.04	51.14
5	100	59.44	M5	25.51	57.08
6	120	59.44	M6	20.46	65.58
7	140	59.44	M7	15.96	73.14
8	160	59.44	M8	12.07	79.69

Table 6: Percentage Removal of PAHs in Sample S

Sample S					
S/No	Temperature (oC)	CBR	Samples	CAR	%R
1	20	114.77	S1	77.01	32.90
2	40	114.77	S2	75.00	34.65
3	60	114.77	S3	68.43	40.38
4	80	114.77	S4	60.14	47.60
5	100	114.77	S5	53.05	53.78
6	120	114.77	S6	44.45	61.27
7	140	114.77	S7	37.45	67.37
8	160	114.77	S8	30.06	73.81

PAHs at varying temperature of 20°C, 40°C, 60°C, 80°C, 100°C, 120°C and 160°C. The results show that, for the various temperatures, removal efficiencies between 22.22-79.69% and 32.90-73.81% for both sample M and S were obtained for PAHs respectively looking at Table 5 and Table 6.

These high values of removal efficiencies therefore show the effectiveness of the soil washing method for the removal of PAHs from soil.

CONCLUSION

Data obtained from the experimental work indicated that, the components of PAHs at different concentrations were determined using GC-MS. The PAHs contaminants were removed using soil washing technique at different temperatures. Results obtained showed a decrease in the concentration of PAHs from 46.22-12.07 ppm and 77.01-30.06 ppm at temperature increase from 20-160°C which is also reflected in the percentage removal efficiency from 22.22-79.69% and 32.90-73.81% for both samples M and S respectively. Temperature was shown to have effect on PAHs contaminants in the soil samples by reducing their presence in the contaminated soil. The effect was evident in the percentage removal efficiencies. Highest percentage removal efficiencies of 79.69-73.81% of PAHs contaminants for both samples M and S that were obtained at temperature of 160°C respectively, suggest that temperature can remove high concentration of PAH from petroleum contaminated soil. Thus, the temperature at which the remediation was highly effective is 160°C. The high values of the removal efficiencies showed the effectiveness of the performance of soil washing method for removal of PAHs from petroleum contaminated soil. Soil washing using temperature to determine the reduction of PAHs from petroleum contaminated soil has been successfully developed. However, the following recommendations are areas for further improvement of this work. One, there is need to consider the effect of soil properties (such as, salinity, pH, particle size distribution, initial degree of contamination and soil type) and washing conditions (e.g., solution to soil ratio and concentration of surfactants) in future research. Secondly, there is also the need to compare effect of biosurfactant and synthetic surfactant on the removal of PAHs from contaminated soil.

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