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Micro-Encapsulation Technique for Effective Remediation of Hydrocarbon Contaminants

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Abstract— the menace of soil contamination from petroleum exploration, production and refining must be checkmated so as to conserve the environment from the prevailing pollution problems. This research investigates the subjection of some contaminated soil samples to the Micro-encapsulation remediation technique. Three soil samples (clay, sandy silt and sandy soil) contaminated with gasoline, diesel, multiple fuels, refinery wastes and weathered crude, each for all soil samples were tested for leaching and toxicity. The technique was found to be most effective in sandy soil and least in clay soil for all pollutants. The efficiency of the entire micro-encapsulation process was observed to depend on the nature of the soil, type of contaminants and also the inherent properties of the soil samples. Soils of granular, porous, permeable and uniform mineralogy promoted the remediation process. Results obtained from this investigation indicated a considerable reduction above 94% in contaminant level after the micro-encapsulation technique was employed for all soil samples. A tolerable level lower than 10mg/l as recommended by environmental agencies was achieved after the remediation process for all contaminated soil samples.

Index Terms— Micro-encapsulation, Remediation, Total Petroleum Hydrocarbon, Leachate, silica, toxicity and Contaminants.

1 Introduction

THE mainstay of the Nigerian economy is crude oil, accounting for about 90% of the country's foreign earnings. The oil industry has indeed brought economic benefits to the people of country and has at the same time left behind trails of complex mix of environmental pollution and degradation [1]. The pollution and degradation of the environment has devastated major and minor areas of the Niger Delta where expiation, exploration and production take place on massive level. The activities in the exploration, production, refining, transportation and marketing industry have caused spillages and deposition of liquid hydrocarbons and products to the environment, resulting to serious environment hazards. Oil spillage and products deposition simply refers to as an unplanned and undesired discharge of liquid hydrocarbons into the environment through undesired course of action, accident or natural incidents. The liquid hydrocarbons in this context include crude oil, refined petroleum products, oil residues, sludge, oily components of effluent water and spent oil [2],[3]. The research conductrd by (Ebele ,1986) reported concentrations of dissolved petroleum hydrocarbon in the environment from refineries and oil terminals in the Niger Delta. The concentration ranged from 11.2mg/l to 53.98mg/l and an average hydrocarbon content of 62.7mg/l in Olomo creek, Niger Delta. According to reports from Nigerian Agip oil company NAOC in 1998, Clean – up cost average is over N50 per barrel including repair of the pipeline. Direct oiling quickly kills subsurface and floating macrophytes. In some cases, spills have contaminated and killed several hectares of mangrove swamps. The more severe cases of mortality have usually been cause by diesel oil, sub-lethal. A wide variety of remediation strategies representing technological development which reduces environmental impact of oil production activities was outlined in [4] the clean-up technologies include biological, physical, chemical and thermal processes. The study indicated chemical treatment of hydrocarbons and petroleum products to include, Alkali metal dechlorination, alkaline chlorination, catalytic dehydrochlornation, electrolytic oxidation, hydrolysis, neutralization ozonation, polymerization, ultraviolet pyrolysis and chemical immobilization (micro – encapsulation). Additionally, chemically treating hazardous waste not only has the potential advantage of converting it to less hazardous form, but can also produce useful by products. Cyanide is converted to less toxic cynate using alkaline chlorination (pH above 10), further chlorination oxidizes the cynate to simple carbon dioxide and Nitrogen gas. Nearly complete destruction of cynate results. According to [5], waste treated via redox reaction includes, benzene, phenols, most organics, cyanide, arsenic, iron and manganese. Those treated using successful reduction include chromium, mercury, lead, silver, chlorinated organics, like unsaturated hydrocarbons.

This study aims at investigating contaminant level and other parameters like total petroleum hydrocarbons (TPH) in crude oil and some of its petroleum products and will involve the demonstration of micro-encapsulation technology using port Harcourt Refining company and Agbala field as case study, laboratory analysis to identity and establish contaminants level of mobility and toxicity, Model analysis to establish the effects of accumulated toxicity in the environment and finally present a relationship to account for the effectiveness of the micro-encapsulation remediation technique.

2 Research Methodology

2.1 Field Investigation

Two locations were selected for investigation in study. Shell Petroleum Development Company (East) fields located in Agbada, about 25km from port Harcourt, in Ikwerre local government area of Rivers state and the Port Harcourt Refinery Company located in Alesa-Eleme about 30km from port Harcourt city. These two areas of investigation lie in the same climate zone with a mean daily temperature of 280C and

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a daily rainfall of 180mm. Soils around these environments were found to be are slightly acidic (pH: 4.4-6.1) With high conductivity values (40 -15.99mS/cm), the soils generally are high in aquatic matters, average porosity (23.38-40)%, sulfate (103-190)mg/l, mean value of clay (26.5%).silt (10.5%), sand (26.5%). The states of the contaminants, the soil matrix within these zones and bacterial metabolism/growth rates are found to be affected by the inherent temperature ranges. The recorded temperature ranges between 26 – 36^{0}C. Also, inherent properties of the soil affect the rate of degradation of contaminants. Soils of granular, porous permeable and of uniform mineralogy promote breakdown as compared to soils of fractured rock, complex mineralogy, low permeability and water logged.

2.2 Methodology

. Comprehensive treatability and performance Analysis developed in this study sets out complete analytical and site process on hydrocarbon and products contaminants.

Analytical data carried out in this study include long-term degradation analysis involving: Diesel fuel, Gasoline (PMS), Oil/waste oil, Sludge, Refinery waste, Crude oil

Comprehensive site remediation profiles involving all laboratory data for:

- Gasoline contaminated soils
- Diesel fuel contaminated soils
- Waste oil contaminated soils
- Refinery wastes
- Crude contaminated soils.

The micro-encapsulation process was designed to significantly reduce or eliminate the mobility and toxicity of contaminants and in turn reduce the impact of these contaminants on the environment and human health.

Four essential guidelines must be satisfied in order for the soil to be considered as acceptably remediated. These are: Protection for groundwater, Protection for life, Protection of fish and wild life, Protection from odor and permeability [7]

The toxicity and mobility reduction is a function of:

- The efficiency of the treatment process.
- The rate of leaching of any untreated material
- The life span of encapsulated silica cell

When these factors are optimized, an informed deduction to the safety and confidence of encapsulation /immobilization can be made.

The following life expectancy evaluation program was carried out using the under listed procedures in order to provide the quantitative degree of encapsulation and non-leachability (immobilization) under varieties of environment and soil conditions.

2.3 Experimental Proceedure for Micro-encapsulation

- First stage: Emulsification

Emulsifiers were applied to hydrocarbon contaminated soil and treatment was allowed to stay for few hours.

The oil was emulsified into microscopic droplets

- Second stage: Encapsulation

A Reactive silicate was applied to the emulsified hydrocarbon and this produced an instantaneous chemical reaction with the hydrocarbon droplets to form pure silica which is amorphous and insoluble.

- Third stage: Sampling

Bulk samples of the contaminated soil were collected using a shovel to a depth of about 1ft. The samples were in insulating barrels and transported to the laboratory.

2.4 Toxicity Analysis

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The rainbow trout test which is a modified version of freshwater rainbow trout test in [6] was adopted for this study.

Each analysis included three materials;

- Fresh water
- Toxicant
- Reactive silicate

Each of the analysis was run in triplicate. The median lethal concentration (LC50) was established after a 96-hour exposure. Dodecy1 sodium sulphate was used as reference toxicant. Rainbow trout was used as test species (a desirable species typical of sensitive cool-water fish in its reaction to pollutants). A 96-hour lethal concentration for 50% of the individuals (96 hour LC-50).

Emulsifier - 360mg/l

Reactive silicate - 670mg/l

The Procedure included Bioassays conducted on the oil contaminated soils using method of measuring the acute toxicity of effluents to freshwater and marine organisms – at soil loading levels of about 250PPM and 750PPM. Note that all lab analysis was conducted in SGS Inspection Nigeria.

3 RESULTS OBTAINED

The maximum allowable limit for oil/grease, petroleum products and other hydrocarbons discharge into the environment by regulatory agencies for both swamp and land is about 30mg/l or 30PPM. In course of this study, it was discovered that both the Agbada oil field and refinery environment had excessive amount of petroleum products and other hydrocarbon contaminants.

To illustrate the practicability of micro-encapsulation, the Agbada flow station and Port Harcourt refinery depot filled with oil wastes and Total Petroleum Hydrocarbons were used as case study. For both locations, inventory of post impact assessment (PIAS) was taken through visual aid scientific assessment to determine the potential for soil and groundwater contamination.

Table 1-5 gives detailed results of analysis carried out on the samples drawn before and after en-capsulation in which LT1 = clay soil, LT2= sandy silt soil and LT3 =sandy soil

For all three samples collected, analysis showed the presence of heavy metals and cations before micro encapsulation show that the intervention levels were not exceeded. Howev-

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er, this was not the case of total petroleum hydrocarbon (TPH) results that were above the intervention levels.

TABLE 1:
LEACHATE ANALYSIS ON GASOLINE CONTAMINATED SOIL BEFORE AND AFTER MICROENCAPSULATION

	BEFORE ENCAPSULATION					AFTER ENCAPSULATION				
Sample Location /Parameters mg/l	LT_1	LT_2	LT_3	Target value	Intervention value	LT_1	LT_2	LT_3	Target Value	Intervention Value
NO_3	3.37	3.24	3.82			0.083	0.168	0.298		
SO_4	1.50	1.66	1.73			0.088	1.547	1.813		
PO_4	1.83	1.51	1.79			0.180	0.539	1.665		
Zn	1.34	1.35	1.41	140	720	0.184	1.657	0.154	140	720
Cr	1.12	1.18	1.09	100	380	0.001	0.012	0.015	100	380
Cd	1.03	1.14	1.19	0.8	12	0.050	0.040	0.030	0.8	12
Ni	0.99	0.98	1.04	35	210	0.027	0.020	0.007	35	210
Cu	0.66	0.10	0.21	36	190	<0.001	<0.001	<0.001	36	190
Pb	1.55	1.22	1.01	85	530	<0.001	<0.001	<0.001	85	530
TPH	166.9	1144.7	675.1	50	100	1.178	2.200	0.090	50	100

TABLE2:
LEACHATE ANALYSIS REPORT ON DIESEL CONTAMINATED SOIL BEFORE AND AFTER MICRO ENCAPSULATION

	BEFORE ENCAPSULATION					AFTER ENCAPSULATION				
Sample Location /Parameters mg/I	LT_1	LT_2	LT_3	Target Value	Intervention Value	LT_1	LT_2	LT_3	Target value	Intervention value
NO_3	4.50	4.32	5.11			0.587	0.367	0.304		
SO_4	1.89	1.66	1.73			0.648	0.424	0.327		
PO_4	3.01	3.34	3.47			0.010	0.039	0.024		
Zn	1.22	1.25	2.61	140	720	0.01	0.049	0.177	140	720
Cr	1.49	1.45	1.26	100	380	0.002	0.001	0.019	100	380
Cd	0.21	0.25	0.19	0.8	12	0.001	0.001	0.001	0.8	12
Ni	0.57	0.49	0.51	35	210	0.001	0.014	0.028	35	210
Cu	0.01	0.03	0.01	36	190	0.001	0.024	0.074	36	190
Pb	1.86	1.46	1.22	85	530	0.074	0.024	0.070	85	530
TPH	257.5	426.3	922.5	50	100	6.257	0.141	3.120	50	100

TABLE 3

LEACHATE ANALYSIS ON MULTIPLE FUEL CONTAMINATED SOIL BEFORE AND AFTER MICRO-ENCAPSULATION

	BEFORE ENCAPSULATION					AFTER ENCAPSULATION				
Sample location /parameters mg/1	LT_1	LT_2	LT_3	Target value	Intervention value	LT_1	LT_2	LT_3	Target value	Intervention value
NO_3	22.50	21.60	25.56			0.104	0.140	0.133		
SO_4	37.87	44.86	40.88			4.208	6.409	6.101		
PO_4	30.17	33.36	34.75			0.001	0.001	0.001		
Zn	2.45	2.46	2.51	140	720	0.027	0.030	0.025	140	720
Cr	9.96	9.90	9.01	100	380	0.004	0.001	0.002	100	380
Cd	2.59	2.55	2.59	0.8	12	<0.001	<0.001	0.003	0.8	12
N1	2.85	2.81	2.89	35	210	0.012	0.008	<0.001	35	210
Cu	0.03	0.06	0.04	36	190	<0.001	<0.010	<0.001	36	190
Pb	6.21	4.89	4.07	85	530	0.073	0.059	0.049	85	530
TPH	420.9	530.5	306.7	50	100	3.133	1.225	0.161	50	100

TABLE 4
: LEACHATE ANALYSIS ON SOIL CONTAMINATED WITH REFINERY WASTE BEFORE AND AFTER MICRO-ENCAPSULATION

	BEFORE ENCAPSULATION					AFTER ENCAPSULATION				
Sample location /parameters mg/1	LT_1	LT_2	LT_3	Target value	Interven-tion value	LT_1	LT_2	LT_3	Target value	Interven-tion value
NO_3	18.00	17.28	20.41			0.037	0.032	0.035		
SO_4	27.87	35.02	36.06			7.329	12.875	12.027		
PO_4	26.24	29.82	27.80			2.656	1.072	1.782		
Zn	1.22	1.64	1.25	140	720	<0.001	<0.001	<0.001	140	720
Cr	2.98	2.97	3.15	100	380	0.014	0.004	<0.001	100	380
Cd	0.518	0.892	0.90	0.8	12	<0.001	0.005	0.011	0.8	12
N1	1.28	1.31	1.22	35	210	0.003	<0.001	<0.001	35	210
Cu	1.66	1.26	1.16	36	190	<0.001	<0.001	<0.001	36	190
Pb	3.47	2.73	2.27	85	530	<0.001	<0.001	<0.001	85	530
TPH	425.9	137.7	591.7	50	100	10.349	0.046	0.385	50	100

TABLE 5:
LEACHATE ANALYSIS ON SOIL CONTAMINATED WITH CRUDE OIL BEFORE MICRO-ENCAPSULATION

	BEFORE ENCAPSULATION					AFTER ENCAPSULATION				
Sample location /parameters mg/1	LT_1	LT_2	LT_3	Target value	Intervention value	LT_1	LT_2	LT_3	Target value	Inter-ven-tion value
NO_3	25.54	23.51	26.38			8.04	4.74	3.42		
SO_4	15.02	16.12	19.56			7.20	3.11	1.30		
PO_4	33.14	30.27	31.16			3.14	4.27	1.12		
Zn	2.45	2.43	2.61	140	720	1.66	1.43	1.30	140	720
Cr	9.81	8.92	10.32	100	380	0.34	0.32	0.31	100	380
Cd	2.50	2.62	2.69	0.8	12	0.35	0.32	0.30	0.8	12

ISSN 2229-5518

N1	2.84	1.65	1.94	35	210	0.84	0.75	0.64	35	210
Cu	2.01	2.11	1.88	36	190	0.01	0.01	0.06	36	190
Pb	0.02	0.14	0.43	85	530	0.02	0.04	0.03	85	530
TPH	1194.933	1058.133	1068.767	50	100	23.899	2.115	2.138	50	100

4 DISCUSSION

From the table 1 presented above, it is deduced from results obtained that there were records of considerable reduction in the value of anions such as; SO_4, NO_3 and PO_4. It was also observed that there was high reduction in the values of metals (Zn, Cr, Ni, Cd, Cu and Pb) after encapsulation, the level of reduction obtained for the metals varies from metal to metal. The highest level of reduction was recorded for chromium. These reductions also occurred in all the locations.

Table 2 shows the same trend of results that was obtained for the anions, (SO_4, NO_3, and PO_4) When diesel was used in place of gasoline. However, the degree of reduction in the value of the anions was less in diesel contaminated case than that of gasoline. This could be ascribed to the different locations. Metals such as Zn, Cr, Ni, Cd, Cu and Pb were found to be substantially reduced when the diesel was used in place of gasoline. Though the levels of metals recorded in diesel contaminated were lower than what they were in the gasoline case. For TPH the same pattern of reductions were observed.

The results before and after micro-encapsulation in Table 3 recoerds, a commendable reduction though the target values of these contaminants were not exceeded except that of the TPH result that was above the target point. E.g. Nitrate (NO_3), Cadmium (Cd) and total petroleum hydrocarbon (TPH) have 4.50 mg/1; 0.21 mg/1 and 257.5 mg/1 as results before treatment and the results reduced after treatment was applied thus 0.587 mg/1, 0.001 mg/1 and 6.257mg/1 in clay soil respectively. The above table compares the total petroleum hydrocarbon (TPH) results obtained from the different contaminated soil sample analyzed before and after micro-encapsulation.

As presented in Table 4, the trend of reduction in the values of the anions ranged between that of gasoline and the diesel contaminants. The same thing was repeated for metals and TPH. This is probably an indication of the effects of the physical properties of the multi-fuel used. The level of reduction in both the anions and cations was remarkable and followed the general trend. It gives an indication that the micro encapsulation of refinery waste was quite effective. The specifics on percentage reduction are shown in subsequent tables below.

Leachate analysis of crude oil contaminated soil before and after micro-encapsulation in Table 5 indicates a reduction in the values obtained for the various heavy metals, cations and total petroleum hydrocarbon (TPH) tested in the samples.

4.1 TPH Level

Although the method achieved reduction of contaminants below the allowable limits for all contaminant types, the reduction level of the total petroleum hydrocarbons was least for clay soils. This is however due to the properties of the clay soil since it is less porous and permeable. The best level of reduction was reported for sandy soil type while sandy silt soil followed closely. For clay soil the degree of reduction of the anions though very substantial (almost complete elimination in some cases) varies from contaminant types.

The highest nitrate (NO_3) removal of about 99.79% was achieved in refinery waste contaminants followed by multi-fuel, gasoline and diesel in that order. 68.51% removal of was achieved for diesel contaminant. Again, this is attributed to the physic-chemical properties of the contaminants. For sulphate (SO_4) highest removal of 94.17% was achieved with gasoline contaminant while crude oil recorded the lowest degree (51.44%) of removal. Also total removal of phosphate (PO_4) was achieved for multi-fuel contaminant while the other contaminants recorded between 99.67% - 60.35% removal.

4.2 Anions

For sandy silt soil, highest level of removal of nitrate (NO_3) was achieved using multiple fuel contaminants which recorded 99.35% removal. Refinery waste (98.15%), Gasoline (94.81%) and diesel (91.50%) followed in that order. The least removal (79.83%) was recorded for crude oil. Multiple fuel contaminated sandy silt soil had the highest removal sulphate (SO_4) With 85.71% achieved. This was followed by diesel, refinery waste, crude oil and surprisingly gasoline recorded the lowest removal. It was discovered that phosphate (PO_4) was more readily removed from the sandy silt soil. 100% removal was achieved in case of multiple fuel contaminants, while 98.8%, 91.41, 64.3% and 85.99% removal were achieved for Diesel, refinery waste, gasoline and crude oil respectively. For sandy soil, remarkable nitrate (NO_3) removal across the whole contaminants used was recorded. This further confirms that micro-encapsulation is very effective in removing nitrates.

For all contaminants types the sulphate (SO_4) removal was found quite satisfactory with multiple fuel contaminants leading in the order of level reduced. Diesel, refinery waste, gasoline and crude oil followed in this order. Again phosphate (PO_4) was completely eliminated when multiple fuel was used as contaminant 99.31% removal was achieved using diesel while the refinery waste, crude oil and gasoline recorded 93.59%, 44.80% and 6.98% respectively.

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4.3 Heavy Metals

In clay soil, highest level (99.18%) of removal of zinc (Zn) was achieved for diesel and refinery waste contaminants, while multiple fuel, gasoline and crude oil has 98.90%, 86.27% and 32.25.

Note, complete removal of (Cr) was achieved for multiple fuel type while near total removal was equally reported for gasoline. Diesel, crude oil and refinery waste recorded 99.87%, 96.53 and 99.53 respectively.

In multiple fuels, it recorded (Cd) of about 99.96%, 99.80% for refinery waste. Removal of nickel (Ni) was very high for all types of contaminants, ranging from 99.82% (diesel) and 70.42% (crude oil). In clay contaminant soil, almost complete removal of lead (Pb) was obsesrved in all the contaminant types. In sandy silt soil, the level of removal of Zinc (Zn) was high for diesel, multiple fuel, crude oil and refinery waste but low for gasoline. In all cases the values were below the target limit. Quite satisfactory level of removal (Cr) was achieved for all types of contaminants. (Cd) was almost nonexistent in the sample after encapsulation for all types of contaminants. An average of 90% removal of Nickel (Ni) was achieved for all types of contaminants. Apart from diesel that has a very low level of removal of cupper (Cu) other contaminants recorded near total removal.

For sandy soil, zinc (Zn) was satisfactorily removed from all contaminant types achieving over 95% removal on the average. Almost complete removal of chromium (Cr) was achieved averaging over 95% totals removal. No cadmium (Cd) was detected for the crude oil contaminated soil while the other types achieved across all sample. For cupper (Cu) the only exception to a high removal was diesel that strangely had 30% removal while others achieved above 90.0%. lead (Pb) was almost completely removed in all the contaminants types.

TABLE 6:
PERCENTAGE REDUCTION OF IONS AND TPH CONTAMINANTS IN CLAY SOIL AFTER MICRO-ENCAPSULATION

Sample location Parameters mg/1	GASOLINE	DIESEL	MULTIPLE FUEL	REFINERY WASTE	CRUDE OIL
NO_3	97.54	86.96	99.54	99.79	68.51
SO_4	94.13	65.71	88.89	73.70	51.44
PO_4	90.16	99.67	100	89.88	90.52
Zn	86.27	99.18	98.90	99.18	32.24
Cr	99.91	99.87	100	99.53	96.53
Cd	95.15	99.52	99.96	99.80	86.00
N1	97.27	99.82	99.59	99.77	70.42
Cu	99.85	90.00	96.25	99.94	99.50
Pb	99.94	96.02	98.82	99.97	0
TPH	99.29	97.57	99.26	97.57	97.93

TABLE 7:
PERCENTAGE REDUCTION OF IONS AND TPH CONTAMINANTS IN SAND SILT SOIL AFTER MICRO-ENCAPSULATION

Sample location Parameters mg/1	GASOLINE	DIESEL	MULTIPLE FUEL	REFINERY WASTE	CRUDE OIL
NO_3	94.81	91.50	99.35	98.15	79.83
SO_4	6.81	74.46	85.71	63.24	80.70
PO_4	64.30	98.83	100	96.41	85.89
Zn	22.74	96.08	98.78	99.84	41.15
Cr	98.98	99.93	99.99	99.87	96.41
Cd	96.49	99.60	99.96	99.44	87.78
N1	97.96	97.14	99.72	99.92	54.54
Cu	99.00	20.00	83.33	99.92	99.52

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Pb	99.92	98.36	98.79	99.96	71.42
TPH	99.81	99.97	99.77	99.97	99.80

TABLE 8
PERCENTAGE REDUCTION OF IONS AND TPH CONTAMINANTS IN SANDY SOIL AFTER MICRO-ENCAPSULATION

Sample location Parameters mg/1	**GASOLINE**	**DIESEL**	**MULTIPLE FUEL**	**REFINERY WASTE**	**CRUDE OIL**
NO_3	92.20	94.05	99.48	99.82	87.03
SO_4	4.80	81.10	85.08	66.65	93.35
PO_4	6.98	99.31	100	93.59	96.00
Zn	89.07	93.22	99.00	99.92	50.19
Cr	98.62	98.49	99.98	99.97	96.99
Cd	97.48	99.47	99.88	98.78	88.84
N1	99.33	94.51	99.97	99.92	67.01
Cu	99.52	30.00	97.50	99.91	96.80
Pb	99.90	94.26	98.80	99.96	93.02
TPH	99.99	99.93	99.95	99.93	99.79

The table below shows the percentage reduction of contaminants in the three soil samples.

TABLE:10
SUMMARY OF PERCENTAGE REDUCTION FOR TOTAL PETROLEUM HYDROCARBON (PPM)

PARAMETERS: Total Petroleum Hydrocarbon (TPH) in PPM				
CONTAMINANT		**LT1 (Clay soil)**	**LT2 (Sandy soil)**	**LT3 (Sandy soil)**
	Un-capsulated	166.9	1144.7	675.1
	Capsulated	1.178	2.200	0.090
Gasoline fuel	%change	99.29	99.81	99.99
	Un-capsulated	257.5	426.3	922.5
	Capsulated	6.257	0.141	0.601
Diesel	%change	99.57	99.97	99.93
	Un-capsulated	420.9	530.5	306.7
	Capsulated	3.133	1.225	0.161
Multiple fuel	%change	99.26	99.77	99.95
	Un-capsulated	425.9	137.7	591.7
	Capsulated	10.349	0.046	0.385
Refinery waste	%change	97.57	99.97	99.93
	Un-capsulated	1194.933	1058.133	1068.767
	Capsulated	23.899	2.115	2.138
Crude oil	%change	97.93	99.80	99.80

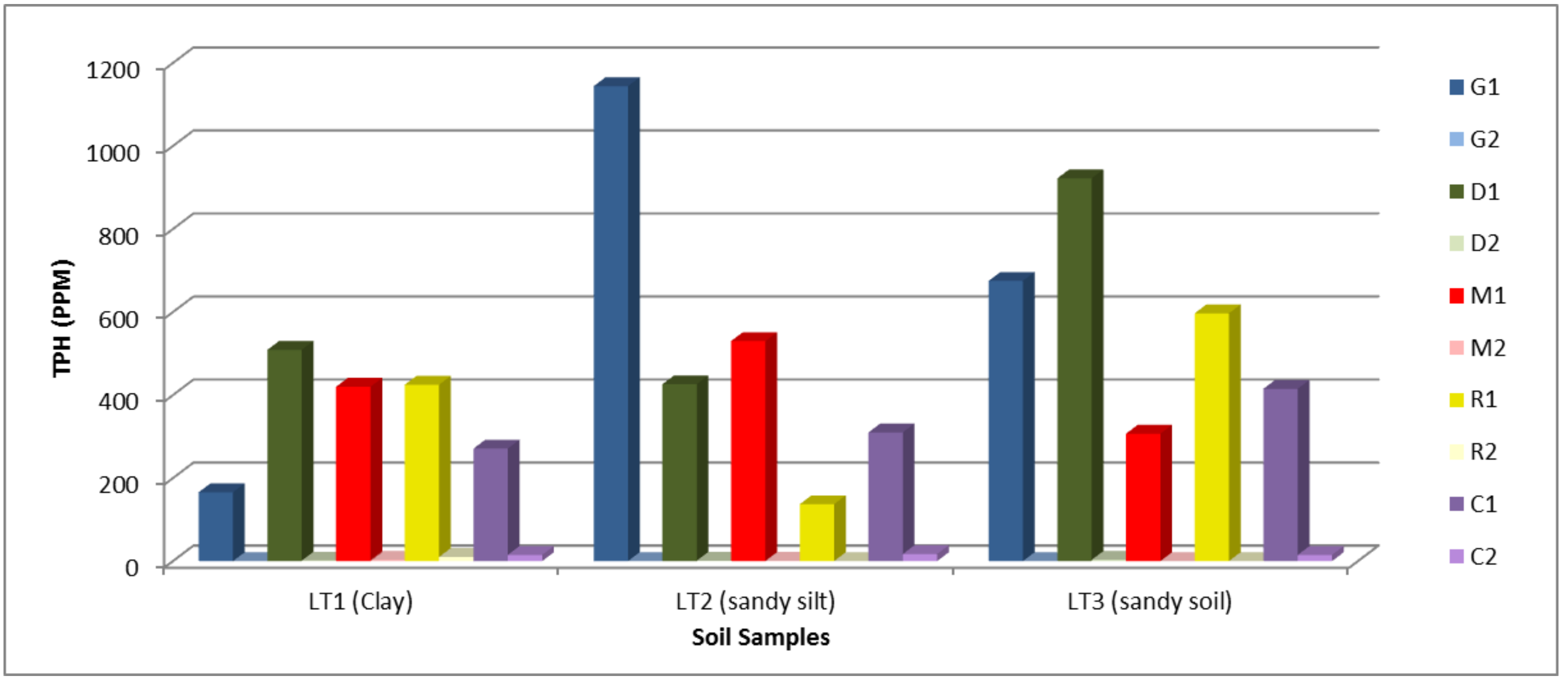

Fig 1: level of reduction of contaminants for all soil types

The figure above shows a summary contaminant reduction level for all sol cases with the notations G1, D1, M1, R1 and C1 respectively representing Gasoline, Diesel, Multiple fuels, Refinery waste and Crude oil contaminants before encapsulation. G2, D2, M2, R2 and C2 on the other hand shows the same contaminants after the encapsulation process.

4.4. Expression For Valuation Of Efficiency Of Microencapsulation

In order to derive an equation that can predict the efficiency of remediation using micro-encapsulation techniques, equation can be recast to have form:

For linear relationship between TPH content in the capsulated and un-capsulated soils as stated as

Y- Total petroleum Hydrocarbon –capsulated

X- Total petroleum Hydrocarbon –un-capsulated

Mathematically:

$$Y = \alpha + \beta X \quad (1)$$

Where

$$\beta = (n(\sum xy) - ((\sum y)(\sum x)))/(n(\sum x^2) - (\sum x)^2)$$

and

$$\alpha = (\sum y)/n - \beta (\sum x)/n$$

(1) now becomes

$$TPH^a = \alpha + \beta TPH^b \quad (2)$$

Where THP^a and TPH^b are TPH after and before encapsulation respectively.

The efficiency ofthe process can be defined as:

$$\eta = (TPH^b - TPH^a) / TPH^b \quad (3)$$

Rearranging (3) the above we have:

$$\eta = 1 - (TPH^a/TPH^b) \quad (4)$$

Also, (4) can be written as

$$TPH^a / TPH^b = 1 - \eta \quad (5)$$

TPH^a and TPH^b are related to through (1)

$$THP^a / TPH^b = \alpha / TPH^b + \beta \quad (6)$$

Substituting (1) and (2):

$$1 - \eta = \alpha / TPH^b + \beta$$

Rearranging above equation we have equation for efficiency of mirco-encapsulation of contaminated soils:

$$\boldsymbol{\eta = 1 - (\alpha + \beta / TPH^b)} \quad (7)$$

(7) is the derived expression for evaluating the efficiency of the encapsulation technique.

5 CONCLUSION AND RECOMMENDATION

Micro-encapsulation shows an excellent performance (far below DPR target value) for all contaminants with reduction efficiency from 85% to 99.97%. It has proved most effective remediation method in gasoline contaminated soil. The technique for diesel contaminated soils was most effective in sandy soil and sandy silt with clay soil being the least with 99.99%, 99.81% and 99.29% respectively. Multiple fuel encapsulation gave a total reduction efficiency of 99.77%, 99.95% and 99.26% in sandy silt, sandy and clay soil respectively. Refinery waste contaminated soils were very impressive in sandy silt soil 99.97% followed by sandy soil and clay with reduction efficiency of 97.93%. The on-site treatment process is virtually instantaneous and treated soil becomes non-hazardous, the process effectively locks (encapsulate) the contaminants (broad range of hydrocarbons and highly mobile contaminants including chlorinated hydrocarbon, anions and metals) within a non-soluble, amorphous silica matrix. Furthermore, the highest percentage reduction for the remediation method was recorded in crude oil contaminated soil, the percentage reduction in sandy silt, sandy and clay soils are 99.80%, 99.79% and 97.93% respectively. The process does not interfere with the soil porosity or permeability which is an important issue for ground water considerations.

Micro-encapsulation is an effective and efficient means of remediation of contaminated soil as shown in the results obtained from this study. However, to optimize the performance of this technique further researcher should investigate effective mixing on-site equipment to ensure speedy reactive silicate process. The most important criteria in the process were adequate mixing of the reagent or surfactant (silica) and soil samples collected, which was done in the lab using a pug mill, ribbon blender and Bomag equipment. Also, since this work is limited to remediation of soil contaminated by the five (5) contaminants, it is recommended that further studies should deal with other ranges of contaminants, particularly aromatic hydrocarbons (benzene, etc)
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NOTATIONS

PIAS - Post Impact Assessment
EDXA - Energy Dispersive X-Ray Analysis
EPA - Environmental Protection Agency
DPR- Department of Petroleum Recourses
PPM – Parts Per Million
Mg/l – Milligram per litre
TPH – Total Petroleum Hydrocarbon
LT1 – clay soil
LT2 – sandy silt
LT3- sandy soil