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Curve-Fitting of Bioremediation of Polycyclic Aromatic Hydrocarbons (PAHs) By Co-Composting Using Roost Manure

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Abstract – In this work, ten polluted sites with oil were obtained from Niger Delta, mixed homogenously with compost manure and sent to FUGRO International Laboratory PortHarcourt Nigeria, for bioremediation experiments and analyses. The 4800g sample was divided into twelve (12) equal parts of 400g for bioremediation; 6 parts for the experiments and 6 parts for the control. Particular ringed PAH was isolatedly tested for bioremediation for each of the five ringed PAHs (1 to 5 rings) and the 800g sample was used for respiration test of compost incubation. It was found that the efficiency of bioremediation increased from one to three rings and decreased exponentially for the rest of the rings, showing that bioremediation is not effective for higher ring PAHs. It was also found that bioremediation yields best (optimum) result between two and three ringed PAHs. The respiration of the compost microorganisms improved during incubation by more than two-third i.e 67.7%. The result of this work can be used in bioremediation studies when trying to isolate or choose a particular ringed PAHs for such bioremediation jobs.

Index Terms – Curve-fitting, bioremediation, polycyclic aromatic hydrocarbons, co-composting, roost manure, efficiency.

1. INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds containing only carbon and hydrogen atoms that are composed of multiple aromatic rings (organic rings in which the electrons are delocalized). Formally, the class is further defined as lacking further branching substituent off of these ring structures.

A lot of work has been done on compost bioremediation with the aim of studying its effect in bioremediation of contaminants. Compost bioremediation is carried out by co-composting the contaminated soil with suitable compost materials to effect biodegradation of the contaminants. Previous studies have examined the biodegradation of organic pollutants in composts. According to (Abdusalam, 2012; Kahaly et al, 1999; Harayama, 1997), it has been shown that the microbes present in the windrow compost are capable of mineralizing pentachlorophenol. Although, it has been used in the bioremediation of soil contaminated with a number of organic compounds including polycyclic aromatic hydrocarbons (PAHs), the use of composting as bioremediation technique has been given little attention. Most of the work done on treatment of contaminated soils, has been on the soils with lower concentration of the contaminating substance, than were present in actual soil in spite of the fact that compost have been reported to have good potential for remediation of highly contaminated sites (Yaghmaci, 2003; Chorom et al, 2010).

Fewer or no work has been done using groups of hydrocarbons according to their homologous series or otherwise since the contaminants are not present singularly but in groups in their actions. For instance nobody has given attention to the action of hydrocarbons in groups of Benzene ring i.e. all polycyclic aromatic hydrocarbon having 1 benzene ring, 2 benzene rings, 3 benzene rings and so on. In this study, the soil used is an aggregate of misparform. (FAO: Litho sol) contaminated as PAHs in groups of benzene rings: one-ringed PAH (pyrolle) 95 mg/kg, two-ringed PAH (naphthalene) 195 mg/kg, three-ringed PAH anthracene, phenanthrene, fluorene, mean of 165 mg/kg, four ringed-PAH pyrene, chrysene, flourantene (190 mg/kg), and five-ringed PAH Benzo[a]pyrene (85 mg/kg) (Atagana, 2003, 2004).

According to (Atagana, 2003), these high levels of PAHs, provided a good opportunity to study and further understand the potentials of composting in soil bioremediation. Earlier works of Atagana in 2002 and 2003 showed that reasonable amount of higher-molecular-mass PAHs remained in the soil to the end of 16 weeks and 11 months of pilot scale and full scale land farming respectively. He also showed that studying PAHs action singularly in a co-composting is very effective in bioremediation of sludge on contaminated soil (Ohkouchi, 1999).

The problem to be solved herein is using different groups of polycyclic Aromatic hydrocarbons (PAHs) in bioremediation so as to know which ring or rings will be removed faster than the other, and of course, the trend of removal of these rings with co-compositing method using roost manure. The chemical compounds to be removed i.e. PAHs and others are normally acting in a group and not individually, so that calls for the consideration of removal of the group ringed PAHs instead of single PAHs. This scenario when known will be

mathematically modeled to predict future concentration of ringed PAHs with time.

It is important and significant to study the co-composting of soils contaminated with higher-molecular-mass (HMW) PAHs and of course obtain the mathematical models so that future predictions can be made, this saves the time of starting the experiments all over again anytime. Group ring removal of contaminants is very important since the individual contaminants do not as in isolation.

The scope of this study is to perform the co-compositing of ringed PAHs contaminated soil with roost manure as well as obtaining the mathematical modeling of the scenario and nothing else.

2. LITERETURE REVIEW

2.1 POLYCYCLIC AROMATIC HYDROCARBON

Polycyclic Aromatic Hydrocarbon PAHs, also called polynuclear hydrocarbons are hydrocarbons i.e. are organic compounds containing only carbon and hydrogen. They are composed of multiple aromatic rings. However, the class is further defined as lacking further branching substituent off of these ring structures. It is encountered during crude oil refining, cleaning of oil storage vessels and waste treatment (Ohkouchi et al, 1999). Also, it can be found in coal deposits, incomplete combustion of carbon containing matters such as wood, tobacco, incense etc. The chemical composition of PAHs is complex and depends on the source. It has high content of aromatic hydrocarbons compounds in the range of 1- 8 and more. The two major sources of PAHs are oil storage tanks and refinery-wastewater treatment plants (Potter et al, 1999; Atagana, 2004). PAHs found in crude oil storage tanks is typically made up of anthracene, phenanathrene, phenols, heavy metals, aliphatic and polycyclic aromatic hydrocarbons (PAHs) of 4, 5, 6 and more rings, in over 10-20 fold concentration (Sahagun, 2012). Asphaltenes are polycyclic aromatic clusters, substituted with varying alkyl side chain. Aromatics hydrocarbons are unsaturated ring type (complex polycyclic of three or more fused aromatic rings) compounds, which reacts readily because they have carbon atoms that are deficient in hydrogen. All aromatics hydrocarbons have at least one benzene ring as part of their molecular structure. These components are highly recalcitrant under normal conditions. Such characteristics are attributed to their strong molecular bonds, high molecular weights, hydrophobicity and relative low solubility in water. Polycyclic Aromatic Hydrocarbons PAHs has been classified by the United States Environmental Protection Agency (US EPA) as a hazardous organic complex (Renner, 1999; Sahagun, 2014). This contaminant enters the environment as a result of human activities, which includes deliberate dumping, improper treatments and management, storage, transportation and landfill disposal. This calls for concern because many of the PAHs components have been found to be cytotoxic, mutagenic and potentially carcinogenic (Renner, 1999). The environmental impact of PAH contamination includes physical and chemical alteration of natural habitats, lethal and sub-lethal toxic effects on aquatics and terrestrial ecosystem. PAHs contain volatile organic carbons (VOCs) and semi volatile organic carbons (SVOCs) which over the years have been reported as being genotoxic (Abn et al, 1997; Nkeng et al, 2012). They have cumulative effect on the central nervous system (CNS) leading to dizziness, tiredness, loss of memory and headache, and the effect depends on the duration of exposure. In severe cases, PAH metabolism in human body produces epoxide compound with mutagenic and carcinogenic properties that affects the skin, blood, immune system, liver, spleen, kidney, lungs, developing foetus and it also causes weight loss (Juhasz et al, 1997). However, environmental regulations in many parts of the world have stressed on the necessity to decrease emission of volatile organic compounds and polycyclic aromatic hydrocarbon (PAHs), and have placed more restriction on land disposal of PAHs (Lim et al, 1999). The South African petroleum industry association (SAPIA) reported that about 19.5 million tonnes of crude oil are brought into South Africa annually to feed the country's four largest refineries (Atagana, 2004).

2.2 SOME IMPORTANT COMPOUNDS OF PAHS

Some important polycyclic aromatic hydrocarbons (PAHs) of environmental concern include, naphthalene, 1-methyl naphthalene, 2-methyl naphthalene, acenaphthylene, acenaphthene, fluorene, anthracene, phenanthrene, fluoranthene, pyrene, chrysene, benzo[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene and indenol(1,2,3-cd) pyrene.

2.3 NAPHTHALENE

It is an aromatic hydrocarbon, with molecular formula $C_{10}H_8$ and the structure of two fused benzene rings. Biodegradation of naphthalene involves the microbial utilisation of naphthalene (Atagana,2004). The initial reaction in the bacterial oxidation *Compost* of naphthalene involves the formation of dihydrodiol intermediates. Bacteria oxidised naphthalene to D-*trans*-1, 2-dihydroxy-1, 2-dihydronaphthalene (Abn, 1999). Bacteria utilise a dioxygenase reaction to initiate the degradation of naphthalene, a reaction which is further catalysed by dehydrogenase to give 1, 2-dihydroxynaphthalene (Mohan et al, 2011; Atagana, 2003). The bacterial naphthalene dioxygenase system is particularly useful for oxidising bi- and tri- cyclic PAH substrates, such as naphthalene, phenanthrene and anthracene. The naphthalene dioxygenase system is a multicomponent enzyme. Generally, it includes nicotinamide-adenine-dinucleotide hydride (NADH) oxidoreductase, ferredoxin and oxygenase component that contains the active site. The enzymes involved in the conversion of naphthalene to

salicylate can also degrade phenanthrene to naphthalene- 1, 2-diol (Nkeng et al, 2012). Studies (Juhasz et al, 1997; Kanaly et al, 1999; Abdulahi, 2012) have shown that naphthalene can be degraded by fungi. Fungi can oxidise naphthalene to trans-2-dihydroxy-1,2-dihydronaphthalene, 1-naphthol and 2-naphthol.

2.4 PHENANTHRENE

Phenanthrene is a polycyclic aromatic hydrocarbon composed of three fused benzene rings. Many species of bacteria found in soil are capable of utilisingphenanthrene as a growth substrate. The degradation of this compound by bacteria follows an oxidative pathway (Charmichael and Pfaender, 1997; Coates et al, 1997). Bacteria can oxidize phenanthrene to cis-1, 2-dihydroxy-1,2-dihydrophenanthrene, which forms 1,2-dihydrophenanthrene when it undergoes enzymatic dehydrogenation. The compounds can be oxidised further to 1-hydroxy-2-naphthoic acid, 2-carboxybenzaldehyde, o-phthalic acid, protocatechuic acid (Ling and Isa, 2006).

2.5 PYRENE

Pyrene is a polycyclic aromatic hydrocarbon (PAH) consisting of four fused benzene rings. It is the smallest peri-fused PAH (the rings are fused through more than one face). Many microorganisms have shown the capability of utilising four ringed aromatic hydrocarbons such as pyrene (Ortmann et al, 2013). Bacteria such as *Rhodococcus*sp. strain UW1 are capable of growing on pyrene as sole carbon source (Lim et al, 1999). This organism was found to mineralise up to 72% of pyrene to CO_2 within two weeks (Yaghmaci, 2002). Three percent of the carbon was found in the organic phase and 25% was present as water-soluble metabolites in the aqueous phase. Pyrene-4, 5-dihydrodiol was identified as the initial ring oxidation product and 4-phenanthroic acid as the major metabolite of the degradation of pyrene by a *Mycobacterium sp*. Also, a proposed catabolic pathway of pyrene by aerobic bacteria has been suggested (Holman et al, 1999; Makhadia et al, 2011).

2.6 FLUORENE

Fluorene is a polycyclic aromatic hydrocarbon. It has been found to be susceptible to microbial degradation to varying extents (Dave et al, 2011; Makhadia et al, 2011). The initial attack on fluorene is catalysed by dioxygenase to yield 9-fluorenol and 1, 1a-dihydroxy-1-hydro-9-fluorenone.

2.7 FLUORANTHENE

This is a four fused benzene ring polycyclic aromatic hydrocarbon consisting of naphthalene. Many microorganisms showed the capability of utilisingfluoranthene (Chorom et al, 2010). The catabolic pathway describing the biodegradation of fluoranthene by *M. Vanbaalenii*PYR-1, initiated by mono-and deoxygenated reactions was discovered recently (Bhattacharya et al, 2015).

2.8 BENZO[A]PYRENE

This is a five ring polycyclic aromatic hydrocarbon whose metabolites are mutagenic and highly carcinogenic (Harayama, 1997). Benzo[a]pyrene can be oxidised to various metabolites by different microorganisms, which include; *trans*-7, 8-dihydroxy-7, 8-dihydrobenzo[a]pyrene, 3-hydroxybenzo[a]pyrene and 9-hydroxybenzo[a]pyrene, *trans*-9,10-dihydroxy-9,10-dihydrobenzo[a]pyrene, benzo[a]pyrene-1,6-quinone and benzo[a]pyrene-3,6-quinone (Maletic et al, 2013).

2.9 ANTHRACENE

This is a solid polycyclic aromatic hydrocarbon consisting of three fused benzene rings. It is also component of coal tar (Maletic et al, 2013).

3. EXPERIMENTATION AND ADOPTION OF MODEL

3.1 EXPERIMENTATION

A total of 4800g of PAH contaminated soil was excavated from ten different sites in Niger-Delta area of Nigeria, and was transported in clean polyethylene bags to an independent laboratory: FUGRO International laboratories Ltd, Port Harcourt, where it was stored at 4^0C following Atagana (2003) experimental methods.

Five out of the ten different soil samples were mixed and air-dried before being homogenized by hand, to make the soil easy to mix with compost material.

The five 400g bags of homogenized soil was placed for bioremediation, while the other five bags are for control experiment, plus one 800g bag for respiration experiment for 11 months. The lab technologists at FUGRO fixed the machine to selectively determine 1, 2, 3, 4 and 5 ringed PAHs using each of the five bioremediation bags in turn.

The same is done with the 5 bags for control samples (see tables 1-5).

FUGRO also characterized such parameters as soil type, organic carbon content, total nitrogen content, total phosphorus content, soil pH, and water holding capacity.

3.1.1 COMPOST MATERIALS

The compost materials used are cow dung and roost droppings. The cow dung was collected from the cattle farm of the Federal University of Technology, Owerri, (FUTO) while the roost dropping was collected from Rumuosi-Akpor village in Rivers State of Nigeria. The bulking agent used was wood chips and dried grass. It was collected from timber site where timber logs of wood were industrially sawn at Naze, Owerri West Local Government Area of Imo State. The wooden chips needed no

further size reduction as it is already reduced to the smallest size needed for the compost during the sawing process.

3.1.2 SOIL, COMPOST MATERIAL, AND BULKING AGENT MIXING

The cow dung was mixed with the contaminated soil in the ratio of 3:1, the mixture of cow dung and contaminated soil were mixed with roost manure in the ratio of 2:1. These mixtures were made with the bulking agents in the ratio of 1:1. These compost materials and bulking agents provides the necessary nutrients for microorganisms that will decompose the PAHs in the contaminated soil.

3.1.3 RESPIRATION OF COMPOST ORGANISMS DURING COMPOSITING

Another 800g PAH contaminated soil in two bags of 400g each were made available for respiration test. A bag was homogenized with roost manure ready for bioremediation and the other for control. The two bags were monitored with respiratory equipment simultaneously in FUGRO International Laboratory for respiration for 11 months. The result is as shown in table 6. This respiration determined by closed jar methods (Forster, 1995) involved taking soil samples from four different levels (15cm, 25cm, 35cm and 50cm) in the composting pile were done on nutrient agar and represented as colony forming unit per gram (cfu/g). The reduction in respiration indicates reduction in microbial population by succession of mesophilic to thermorphilic and the availability of the target contaminants in the compositing pile system. This also indicates that the metabolic activities of the microorganism contribute so much to enhance the reduction of the concentration of polycyclic aromatic hydrocarbon (PAHs) in the compost pile mixture.

However, the control setup which has no roost manure showed mild increase in the respiration. This may be due to fungi growth observed in the control compost pile system.

The study also found that even very low concentrations of PAHs can slow fish heartbeats and disrupt the development of fish larvae. The work may have implications for mammals and other forms of vertebrate life (Sahagun L. 2014).

PAHs are also found in cooked foods. Studies have shown that high levels of PAHs are found, for example, in meat cooked at high temperatures such as grilling or barbecuing and in smoked fish.

3.2 ADOPTION OF MODELS

For this work, two models were adopted: Exponential model $(a\ exp(bx) + c\ \exp(dx) + e$ and Gaussian model $a_1\exp(-((a_1-b_1)/c_1)^2)+a_2\exp\ (-c(a_2-b_2)/c_2)^2$, based on the ability of the models to sweep a good area under it as will be seen in the coefficient of correlation (R_2). The percentage area bio-remediated determines the efficiency of such bioremediation on the polluted soil.

The efficiency will be plotted against number of rings of PAHs that gave rise to it (fig 6) to see the range of ring of PAHs that are well bio-remediated. Such ringed PAHs will determine the optimum for such operation in the future.

3.3 ANALYSIS OF THE MODEL

The models adopted will be superimposed on both the control and the experimentally bioremediated profiles to ascertain the fitness of the model on the experimented (bioremediated) data. The actual area bioremediated is the difference between control (A_c) and the bioremediated (A_e) areas. The bioremediated efficiency of modeling the composting activity can then be calculated as:

$$\%\,\eta = \frac{\mathrm{Ac} - \mathrm{Ae}}{\mathrm{Ac}}\ x\ \ 100\%$$

Plot of percentage efficiency against number of ringed PAH is then carried out to reveal the optimum number of ringed PAH that yields the optimum efficiency (best bioremediated).

4. RESULT PRESENTATION AND DISCUSSION

4.1 RESULT PRESENTATION

The results obtained from the FUGRO International Laboratory tests are as presented below in tables 1 to 6 and figures 1 to 7, with corresponding graphs of tables 7 to 12.

Table 1: Concentration variation of 1 ringed pah (pyrolle) during composting

Time (months)	0	1	2	3	4	5	6	7	8	9	10	11
Concentration mg/kg (control)	73	62	59	57	57	55	53	48	45	44	43	43
Concentration mg/kg (Pyrrole)	73	35	15	10	4	0	0	0	0	0	0	0

Table 2: Concentration variation of 2 ringed pahs (naphthalene) during composting

Time (months)	0	1	2	3	4	5	6	7	8	9	10	11
Concentration mg/kg (control)	140	122	118	110	90	85	80	74	64	61	60	59
Concentration mg/kg (Naphthalene)	140	40	20	2	0	0	0	0	0	0	0	0

Table 3: Concentration variation of 3 ringed pahs (anthracene and fluorene) during composting

Time (months)	0	1	2	3	4	5	6	7	8	9	10	11
Concentration mg/kg (control) A+F	70	63	59	57	54.5	53.5	50	47	45	43.5	42.5	40
Concentration mg/kg (A + F)	70	25	12	3	1	0	0	0	0	0	0	0

Table 4: Concentration variation of 4 ringed pahs (pyrene, chrysene, and fluoranthene) during composting.

Time (months)	0	1	2	3	4	5	6	7	8	9	10	11
Control (P + C+ F)	155	134	125	118	113	103	96	91	88	85	82	79
Concentration mg/kg (P + C + F)	155	130	115	90	45	12	4	1	0	0	0	0

Table 5: Concentration variation of 5 ringed pahs (pentacene and benzo[a]pyrene) during compositing

Time (months)	0	1	2	3	4	5	6	7	8	9	10	11
Concentrationmg/kg Control (P + B)	70	64	59	55	52	48	46	45	42	38	37	37
Concentration mg/kg(P + B)	70	60	47	38	25	12	4	2	0	0	0	0

Table 6: Profile of respiration of compost inhabiting microrganisms during incubation

Time (months)	0	1	2	3	4	5	6	7	8	9	10	11
Control	700	1250	2000	2800	3250	3500	4000	3800	4000	3800	3800	4000
CO_2µm dwt/day	125	500	650	750	1100	1125	1080	1250	1265	1275	1350	1360

FIGURES OBTAINED FROM THE READINGS ABOVE

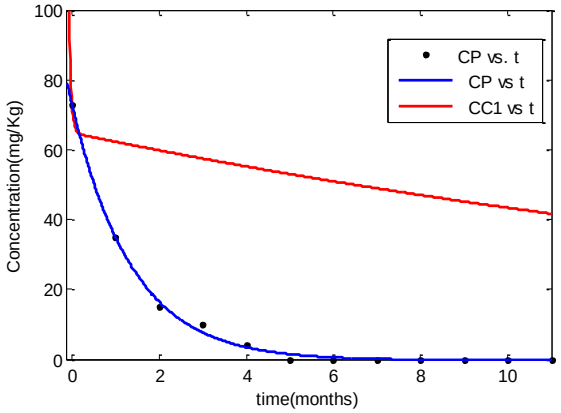

Fig 1: Concentration versus Time for 1-ring PAH (A_c=576.898,A_e=96.1298,η=83.34)

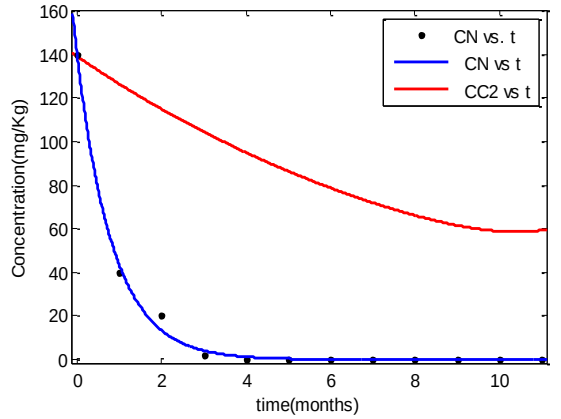

Fig 2: Concentration versus Time for 2-ring PAH(A_c=962.493, A_e=119.197,η=87.62)

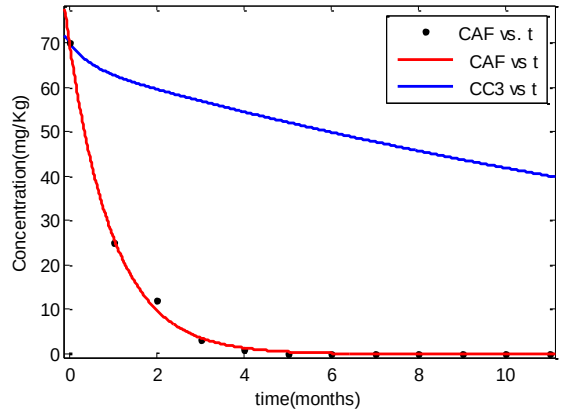

Fig 3: Concentration versus Time for 3-ring PAH (A_c=569.089, A_e=70.5433,η=87.60)

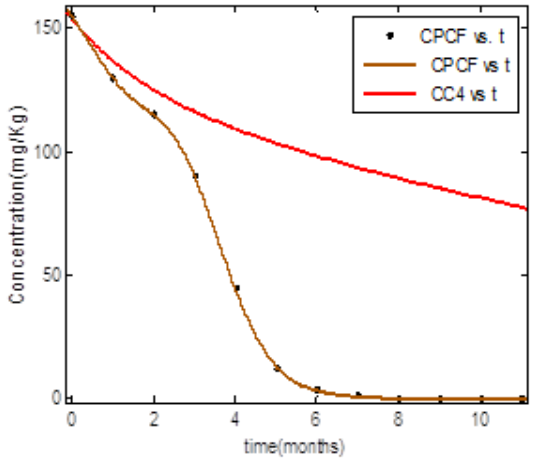

Fig 4: Concentration versus Time for 4-ring PAH(A_c=1151.82,A_e=472.175,η=59.01)

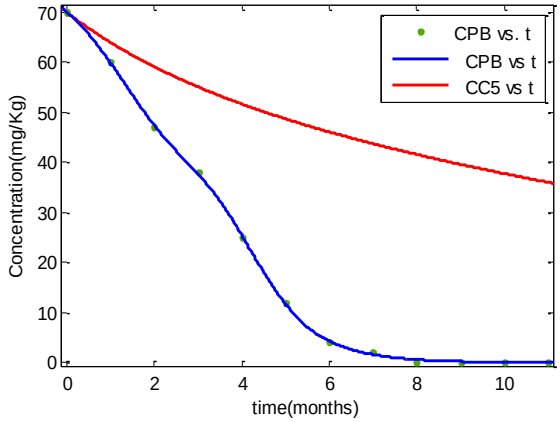

Fig 5: Concentration versus Time for 5-ring PAH (A_c=539.594,A_e=222.795,η=58.71)

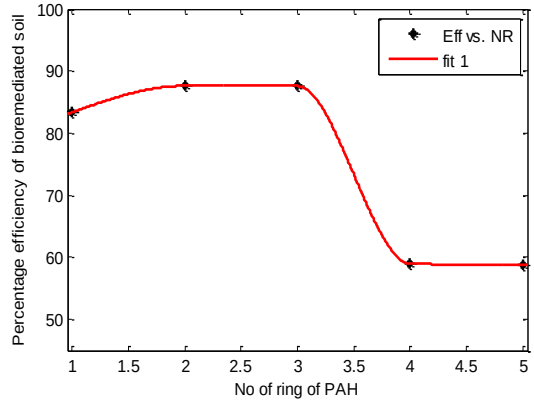

Fig 6: Percentage efficiency of bio-remediated soil samples versusNumber of rings of PAH

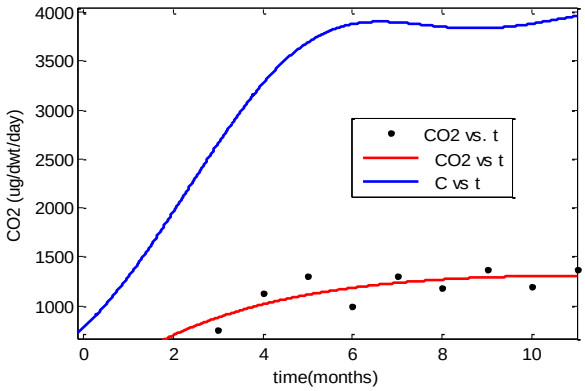

Fig 7: CO_2 versus Time of respiration of Compost Micro-organisms during incubation (A_c=34603.5, A_e=11191.8, η=67.66)

Table 7: Control and bioremediated model characteristic of goodness of fit

Coefficients with 95% confidence bound (control)	**Goodness of fit**
A=8.152	SSE=17.88
B=-21.72	R Squared=0.9805
C=64.85	Adjusted R Squared=0.9732
D=-0.04019	RMSE=1.495
Coefficients with 95% confidence bound (bioremediation)	**Goodness of fit**
A=-0.9498	SSE=10.44
B=-0.1337	R Squared=0.998
C=73.89	Adjusted R Squared=0.9973
D=-727	RMSE=1.142

Table 8: Control and bioremediated model characteristic of goodness of fit

Coefficients with 95% confidence bound (control)	**Goodness of fit**
A=139.1	SSE=99.53
B=0.09552	R Squared=0.9882
C=0.005044	Advanced R Squared=0.9838
D=0.696	RMSE=3.527
Coefficients with 95% confidence bound (bioremediation)	**Goodness of fit**
A=1.364	SSE=60.74
B=3.033	R Squared=0.9967
C=139.5	Adjusted R Squared=0.9954
D=1.171	RMSE=2.756

Table 9: Control and bioremediated model characteristic of goodness of fit

Coefficients with 95% confidence bound (control)	**Goodness of fit**
A=5.007	SSE=3753
B=-2.047	R Squared=0.9959
C=65	Adjusted R Squared=0.5543
D=0.04407	RMSE=0.68849
Coefficients with 95% confidence bound (bioremediation)	**Goodness of fit**
A=69.94	SSE=7.036
B=-2.047	R Squared=0.9985
C=65	Adjusted R Squared=0.9979
D=0.05457	RMSE=0.9378

Table 10: Control and bioremediated model characteristic of goodness of fit

Coefficients with 95% confidence bound (control)	**Goodness of fit**
A=26.11	SSE=41.58
B=0.5703	R Squared=0.9932
C=127.8	Adjusted R Squared=0.9999
D=0.0455	RMSE=0.6345
Coefficients with 95% confidence bound (bioremediation)	**Goodness of fit**
A_1=170	SSE=2.416
B_1=-1.123	R Squared=0.9999
C_1=3.489	Adjusted R Squared=0.9999
A_2=49.58	RMSE=0.6345
B_2=2.751	
C_2=1.495	

Table 11: Control and bioremediated model characteristic of goodness of fit

Coefficients with 95% confidence bound (control)	**Goodness of fit**
A=11.56	SSE=6.489
B=0.3568	R Squared=0.995
C=58.43	Adjusted R Squared=0.9931
D=-0.04465	RMSE=0.9006
Coefficients with 95% confidence bound (bioremediation)	**Goodness of fit**

A_1=72.99	SSE=1.168
B_1=-0.8072	R Squared=0.9998
C_1=3.978	Adjusted R Squared=0.997
A_2=9.593	RMSE=0.4411
B_2=3.494	
C_2=1.389	

Table 12: Control and bioremediated model characteristic of goodness of fit

Coefficients with 95% confidence bound (control)	**Goodness of fit**
A=1579	SSE=1.366E5
B=-0.012	R Squared=0.9219
C=-1452	Adjusted R Squared=0.8926
D=0.2711	RMSE=130.7
Coefficients with 95% confidence bound (bioremediation)	**Goodness of fit**
A_1=3925	SSE=1.211E5
B_1=12.63	R Squared=0.9917
C_1=6.44	Adjusted R Squared=0.9847
A_2=2603	RMSE=142.1
B_2=4.766	
C_2=4.081	

4.2 RESULT DISCUSSION

The experimental tables from FUGRO were obtained after observing the necessary condition and rituals in the previous section. The plots show that different degrees of contamination exist and require different degrees of bioremediation depending on the ringed PAH (figs 1 to 5). The effective area swept under the curve slightly increase from one ring to two ring PAHs and almost constant between two and three ring PAHs, and, then decreased exponentially (fig 6). This shows that as the number of rings increased, the bioremediation decreased as expected from literature and optimum bioremediation occurs in a contaminated soil that contains two and three ring PAH. As the ring of PAH increases, efficiency decreases and perhaps bioremediation will no longer do the job (fig 6). Figure 7 shows the level of improvement in the respiration of compost microorganisms during incubation (67.7%).

5. CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

In this work, ten polluted sites with oil were obtained from Niger Delta, mixed homogenously with compost manure and sent to FUGRO International Laboratory PortHarcourtNigeria, for bioremediation experiments and analyses. The 4800g sample was divided into twelve (12) equal parts of 400g for bioremediation; 6 parts for the experiments and 6 parts for the control. Particular ringed PAH was isolatedly tested for bioremediation for each of the five ringed PAHs (1 to 5 rings) and the 800g sample was used for respiration test of compost incubation. It was found that the efficiency of bioremediation increased from one to three rings and decreased exponentially for the rest of the rings, showing that bioremediation is not effective for higher ring PAHs.

It was also found that bioremediation yields best (optimum) result between two and three ringed PAHs. The respiration of the compost microorganisms improved during incubation by more than two-third i.e 67.7%.

The result of this work can be used in bioremediation studies when trying to isolate or choose a particular ringed PAHs for such bioremediation jobs.

5.2 RECOMMENDATIONS

From the results of the experiments, we strongly recommend a synergy between chemical engineers and biotechnologists, in developing effective microorganisms that can decontaminate soils contaminated with High Molecular Weight, Polycyclic Aromatic Hydrocarbons. It clear now that ordinary bioremediation cannot remove oil contamination involving high number of ring PAH e.g rings >4 and above. If this is successful, the decomposition of polyethylene materials by microorganisms will as well be possible.

REFERENCES

[1] Abdulsalam S. (2012). Mathematical Modeling of Bioremediation of soil contaminated with spent motor oil, Journal of Emerging Trends in Engg and Applied Sciences (JETEAS) 3(4) p 654-659.

[2] Ahn Y., Sanseverino J., Sayler G.S. (1999). Analyses of polycyclic aromatic hydrocarbon-degrading bacteria isolated from contaminated soils Biodegradation.

[3] Atagana H.I. (1999). Co-composting of PAH-contaminated soil with poultry manure, School of Earth Sciences, MangosuthuTechnikon, PO Box 12363, Jacobs, Durban 4026 S.Africa.

[4] Atagana H.I. (2003). Bioremediation of creosote contaminated soil: A pilot scale land farming evaluation. World J. Microbial and Biotechnol.19, p571-581.

[5] Bhattacharya M., Biswas D., Sana S., Datta S. (2015).Biodegradation of waste lubricants by a newly isolated ochrobactrum sp. Ci, Indian J. Biotechnol.Springer.

[6] Carmichael L.M., Pfaender F.K. (1997).Polynuclear aromatic hydrocarbon metabolism in soils: relationship to soil characteristics and preexposure. Environ. Toxicol.Chem.

[7] Chorom M., Sharifi H.S., Motamedi H. (1999). Bioremediation of a crude oil-polluted soil by application of fertilizers, Iran J. Environ.Health. Sc. Engg. Vol. 7, No. 4 p 319-326.

[8] Coates J.D., Woodward J., Allen J., Philp P., Lovley D.R. (1997). Anaerobic degradation of polycyclic aromatic hydrocarbons and alkanes in petroleum-contaminated marine harbor sediments. Appl. Environ.

[9] Dave D., Alharathi R., Ghaly A. (2011). Sequential Remediation Process for Effective Removal of oil from contaminated soils, American Journal of Environmental Sciences, 7(5). P 477-491.

[10] Harayama S. (1997). Polycyclic aromatic hydrocarbon bioremediation design.Curr.Opin.Biotechnol
[11] Holman H.Y. N., Tsang Y.W., Holman W.R. (1999). Mineralization of sparsely water-soluble polycyclic aromatic hydrocarbons in a water table fluctuation zone. Environ. Sci. Techno.
[12] Juhasz A.L., Britz M.L., Stanley G.A. (1997). Degradation of fluoranthene, pyrene, benz[a]anthracene and dibenz[a,h]anthracene by Burkholderiacepacia. J. Appl. Microbiology.
[13] Kanaly R.A., Bartha R. (1999).Cometabolic mineralization of benzo[a]pyrene caused by hydrocarbon additions to soil. Environ. Toxicol.Chem.
[14] Lim L.H., Harrison R.M., Harrad S. (1999).The contribution of traffic to atmospheric concentrations of polycyclic aromatic hydrocarbons. Environ. Sci. Technol.
[15] Ling C.C., Isa M.H. (2006). Bioremediation of oil sludge contaminated soil by co-composting with sewage sludge, Journal of Scientific and Industrial Research, Vol. 65, p 364-369.
[16] Makadia T.H., Adetutu E.M., Simons K.L., Jardine D., Sheppard P.J., Ball A.S. (2011). Re-use of remediation soils for the bioremediation of waste oil sludge, Journal of Environmental Management 92 p 866-871.
[17] Maletic S., Dalmacija B., Roncevic S. (2013). Petroleum Hydrocarbon Biodegradability in soil-implications for Bioremediation, INTECH.
[18] Mohan S.R.V., Devi M.P., Reddy M.V., Chandrasekhar K., Juwarkar A., Sarm P.N. (2011). Bioremediation of Petroleum Sludge under anaerobic micro-environment: influence of biostimulation and bioaugmentation, Environmental Engineering and Management Journal.
[19] Nkeng G.E., Nkwelang G., Matthew O. (2012). Bioremediation of Petroleum Refinery Oily Sludge in Tropical Soil, Open Access Scientific Reports, ENSTP BP 510 Yaounde, Cameroon, Vol. 1, Issue 2.
[20] Ohkouchi N., Kawamura K., Kawahata H. (1999). Distributions of three- to seven-ring polynuclear aromatic hydrocarbons on the deep sea floor in the central Pacific. Environ. Sci. Technology.
[21] Ortmann, A.C., Anders J., Shelton N., Gong L. (2012). "Dispersed Oil Disrupts Microbial pathways in Pelagic Food Webs".
[22] Potter C.L., Glaser J.A., Chang L.W., Meier J.R., Dosani M.A., Herrmann R.F.(1999). Degradation of polynuclear aromatic hydrocarbons under bench-scale compost conditions. Environ. Sci. Technol.
[23] Renner R. (1999). EPA to strengthen persistent, bioaccumulative, and toxic pollutant controls-mercury first to be targeted. Environ. Sci. Technol.
[24] Sahagun L. (2014). "Toxins released by oil spills send fish hearts into cardiac arrest".
[25] Yaghmaei S. (2002). Mathematical Modeling of Natural insitu Bioremediation to estimate initial contaminant concentration effect, IJE Transactions A: Basics, Vol. 15, No. 2, p 105-112.