IMO LATERITIC SOIL AS A SORBENT FOR HEAVY METALS

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ABSTRACT

This paper presents the results of an experimental program to investigate the adsorption capacity of Imo laterite as a sorbent for heavy metals in contaminant barriers. The study reveals that the adsorption capacity of the soil for Pb, Cd, and As increases with increase in sorbate concentration. Based on the obtained results it was established that arsenic has the highest affinity for the lateritic soil, followed by lead, and then by cadmium. The soil may be used as lining material under landfills to absorb the heavy metals so that the ground water resources could be maintained safer.

Keywords: *sorption, contaminant barrier, lateritic soil.*

1. INTRODUCTION

The amount of waste generated in the Niger Delta of Nigeria-the world's third largest wetlands, extending over an area of about 70,000 km^2, comprising mostly mangrove swamps and meandering waterways stretching over 483 km, has been very enormous. Wastes are generated by oil and non-oil industrial establishments, local markets and residences. Throughout the region, waste is most often indiscriminately discarded on the ground, swamps and water bodies around surrounding communities with little or no special treatments given before disposal. It is very common to find waste piles lying directly on an unprotected ground surface, and its particle migrating into the ground. In the case where the waste is soluble in a liquid transport medium, the dissolved constituents leach downward and pollute ground water sources. The high risk of health problem posed by this unrestrained dumping of waste, and the lack of formal waste management practices in the region inform the need for the development of engineered sanitary landfills for special treatment of waste generated by organizations and the people in the Niger delta. This will require sourcing for cheap and readily available barrier materials that would be used for the anticipated landfills, hence the need for this research program to investigate the adsorption capacity of Imo lateritic soil-a soil predominantly available in Imo state-one of the nine states that make up the Niger Delta of Nigeria. A study of the geological and soil maps of Nigeria (Figs. 1 and 2, respectively) after D'Hoore (1964) shows that the lateritic soil found in this area belongs to the group of ferralsols derived from cainozoic (tertiary) sedimentary rocks.

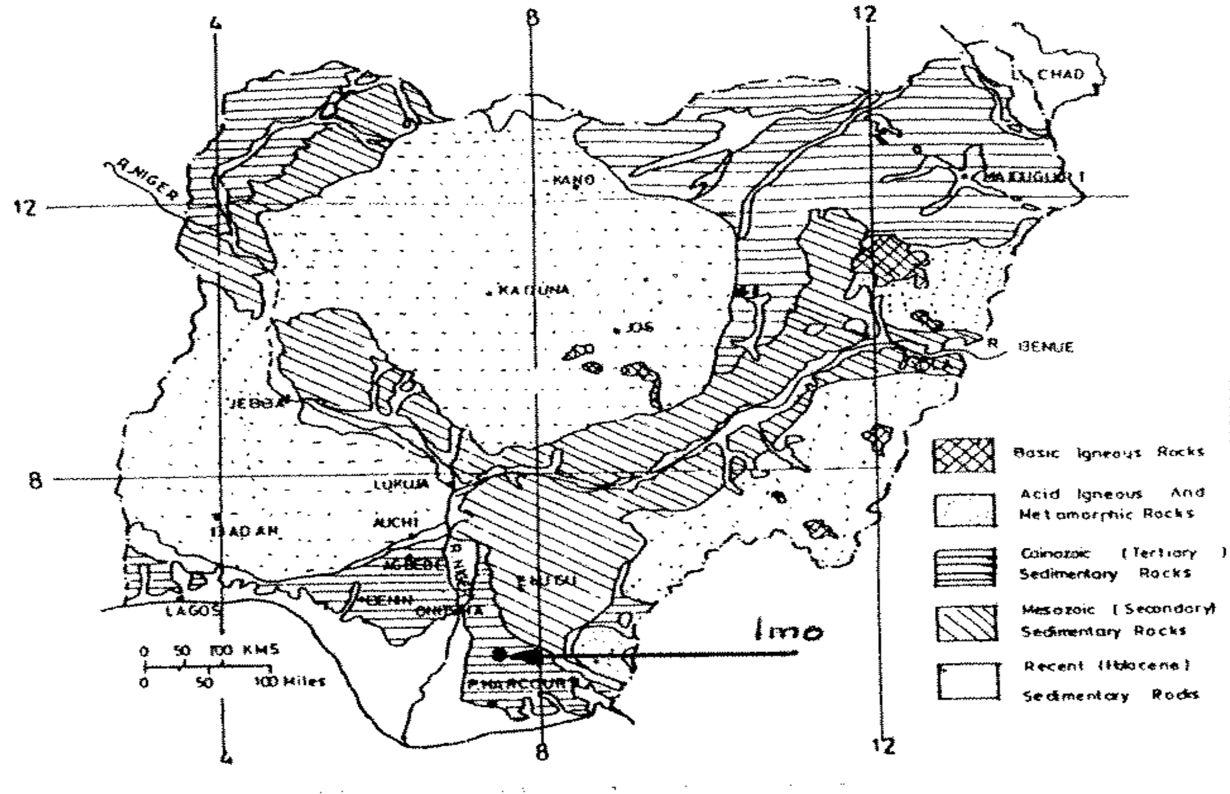

Fig. 1. Geological Map of Nigeria

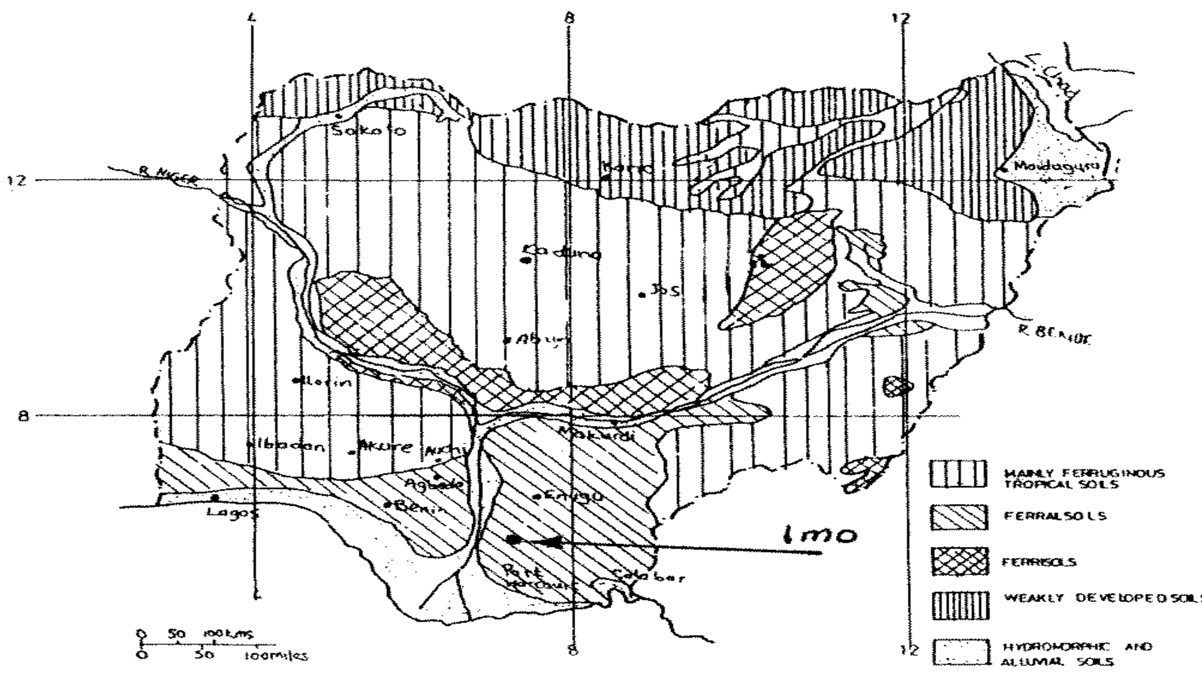

Fig. 2. Soil Map of Nigeria

Anderson and Hee (2000) and Osinubi (1998) in their work recommend the use of lateritic soil for landfill liner due to its low hydraulic conductivity. Maji et al (2006) in their investigation on the adsorption characteristics of arsenic on lateritic soil collected from Gopali area in West Midnapore of India observed that the soil could remove up to 98 % of total arsenic. Chalermyanont et al (2009) noted in their findings on the potential use of lateritic and marine clay soils as landfill liners to retain heavy metals that marine clay had better adsorption capacity than lateritic soil from Thailand, and that its hydraulic conductivity was lower. In addition, they observed that the hydraulic conductivities of both soils when permeated with low concentration heavy metal solutions were below 1 x 10^{-7} cm^2/s.

2. MATERIALS AND METHODS

The lateritic soil sample used for this sorption study was obtained from within the premises of the Federal University of Technology, Owerri, Imo State of Nigeria. The grain size distribution and the bulk chemical composition of the soil have been reported elsewhere (Udoeyo et al, 2006). Sorption of heavy metals on Imo lateritic soil was determined using batch equilibrium technique. The batch experiments were conducted by adding 40 ml of different concentrations of Cd, Pb and As solutions to pre-calculated weight of lateritic soil (4g for Cd, 1g for Pb and 0.2g for As solutions) based on the computed L/S ratio to produce between 10 % and 30 % adsorption as recommended in the EPA Technical Reference Document (1991). ASTM D4646 specifies that adsorption test be performed using a 1:20 soil to solution ratio, but as stated in the EPA document, a single ratio cannot be used satisfactorily in all cases. Two grain size classification of lateritic soil were considered in this study-the complete soil (soil consisting of all the grain size distributions of the soil, CS) and the sieved soil (soil passing No. 200 US sieve, SS). The soil-suspension samples were equilibrated in 50 ml polystyrene centrifuge tubes by shaking at 250 rpm for 24 hours at 25°C using an incubator shaker (C24 incubator-New Brunswick Scientific City), and then centrifuged at 7,000 rpm for 20 minutes using a Fisher Scientific Centrifuge. The concentrations of heavy metals in the supernatant were analyzed using an Atomic Absorption Spectrometer (Thermo Elemental, Cambridge, UK).

3. RESULTS AND DISCUSSION

Sorption of Heavy Metals

- **Determination of soil-solution ratio**

To construct an adsorption isotherm, soil-solution ratios must be determined that will permit enough solute to be adsorbed to result in measurable, statistically significant differences in solution concentration. A value of 10 % to 30 % adsorption for the highest solute concentration used has been suggested as a useful criterion for selecting a soil-solution ratio (U.S. EPA, 1991). Figs 3, 4, and 5 show the percentage adsorption of each of the investigated metal on lateritic soil as a function of L/S ratio.

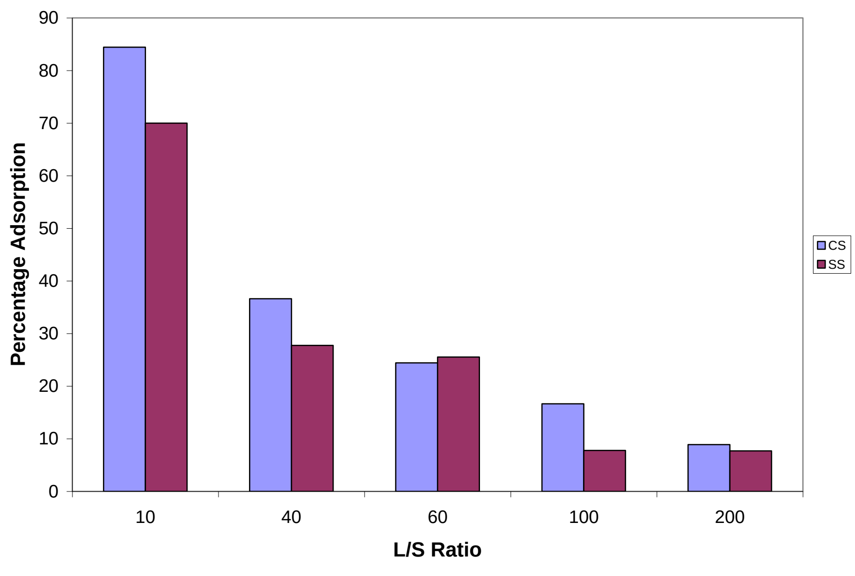

Fig. 3. Percentage adsorption of lead as a function of L/S ratio

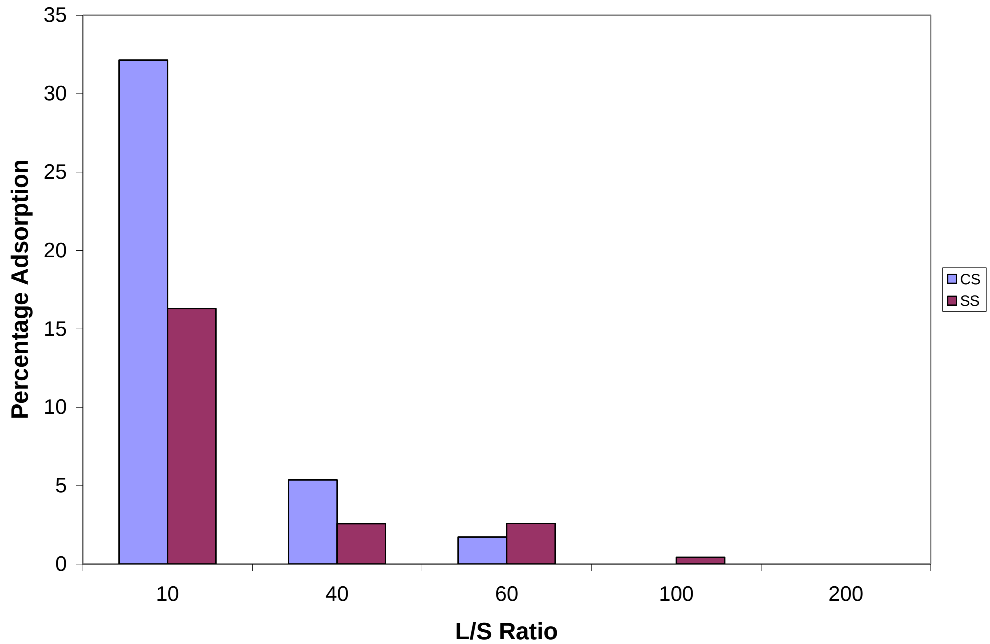

Fig. 4. Percentage adsorption of cadmium as a function of L/S ratio

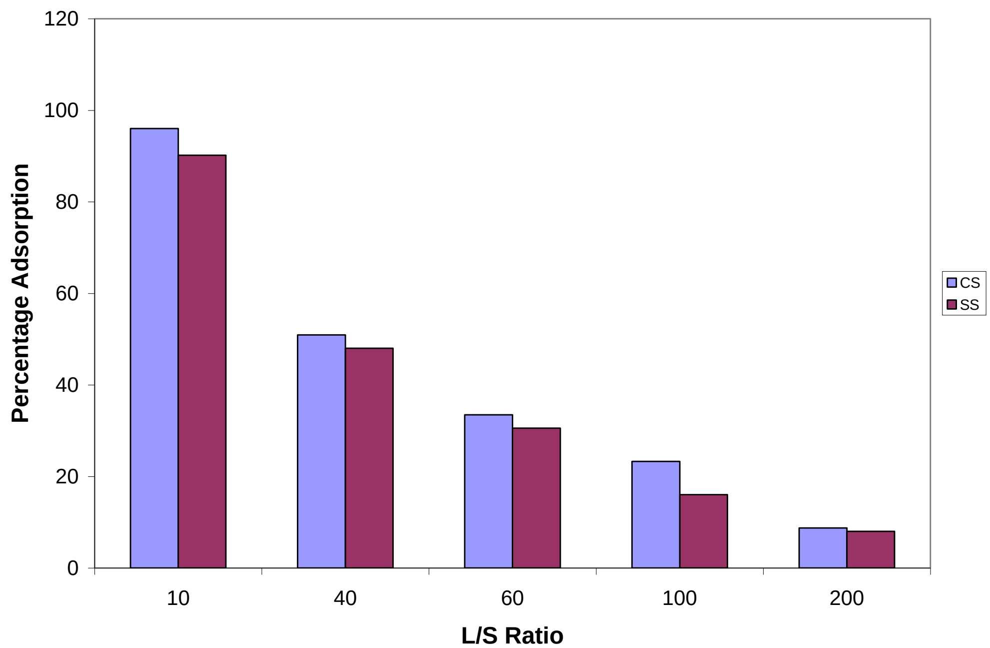

Fig. 5. Percentage adsorption of arsenic as a function of L/S ratio

Based on the afore-stated criterion, an L/S ratio of 1/10, 1/40 and 1/200 were selected for Cd, Pb and As, respectively.

- **Sorption isotherm**

- Table 1. Equilibrium data from sorption experiment at pH = 5 and 25°C

Metal	Initial concentration (mg/L)	Equilibrium concentration (mg/L)		Adsorption capacity (μg/g)		Percentage adsorption	
		SS	CS	SS	CS	SS	CS
Pb	5.46	2.95	1.19	100.49	171.07	45.97	78.21
	11.14	7.74	4.82	136.01	252.81	30.51	56.71
	16.43	12.39	9.01	161.78	296.69	24.62	45.14
	21.48	15.55	11.48	237.21	400.23	27.60	46.58
Cd	4.37	3.59	2.72	7.82	16.49	17.86	37.69
	8.05	7.82	5.31	2.22	27.32	2.76	33.96
	12.17	12.12	8.36	1.00	38.05	0.84	31.27
	15.73	15.84	11.06	0	46.69	0	29.68
As	5.00	4.01	4.07	348.30	627.60	19.80	18.60
	10.00	9.24	8.49	910.60	1503.50	7.60	30.20
	15.00	14.26	13.29	135.60	2296.80	4.93	11.40
	20.00	19.23	17.24	1962.20	3217.17	3.85	13.80

- SS = sieved soil; CS = complete soil

The values of the total amount of heavy metal adsorbed per unit mass of lateritic soil at equilibrium and the percentage adsorption presented in Table 1 were computed using equations 1 and 2, respectively.

$$q_e = \frac{(C_o - C_e)V}{m} \quad \text{------} \quad (1)$$

$$\% \text{ adsorption} = \frac{C_o - C_e}{C_o} \times 100 \quad \text{------} \quad (2)$$

where q_e is the amount of adsorbate adsorbed per unit mass of lateritic soil at equilibrium in mg/g, C_o and C_e are the initial and equilibrium concentrations, respectively of the adsorbate solutions in mg/l, V is the volume of adsorbate solution in liter, and m is the mass of lateritic soil in grams.

To study the sorption capacity and isotherm, Langmuir and Freundlich equations were fitted to test results. The linearized forms of these equations are given as follows:

Langmuir:

$$\frac{C_e}{q_e} = \frac{C_e}{q_m} + \frac{1}{k_a q_m} \quad \text{------} \quad (3)$$

Freundlich:

$$\ln q_e = \frac{1}{n} \ln C_e + \ln k_F \quad \text{------} \quad (4)$$

where q_m is the maximum sorption capacity corresponding to complete monolayer coverage in mg/g, k_a is the Langmuir constant, and k_F and n are Freundlich constants related to adsorption capacity and adsorption intensity of adsorbent.

Table 2. Isotherm parameters of heavy metals adsorption on Imo lateritic soil

Metal	Langmuir				Freundlich			
	Sieved soil, SS		Complete soil, CS		Sieved soil, SS		Complete soil, CS	
	k_a	q_m	k_a	q_m	k_F	1/n	k_F	1/n
Pb	0.12	0.31	0.36	0.44	-2.82	0.49	-1.86	0.34
Cd	-0.22	4×10^{-4}	0.06	0.12	-1.90	-2.21	-4.86	0.75
As	-0.02	-5.92	0.02	-16.39	-2.30	1.14	-1.02	1.08

The monolayer sorption capacity, q_m and Langmuir binding constant, k_a, were determined from the slope and intercept of the plot between C_e/q_e and C_e, while k_F, and the exponent, n, were obtained from the slope and intercept of the plot between $\ln q_e$ and lnCe. The calculated isotherm parameters for Langmuir and Freundlich equations are presented in Table 2, and the linear regression equations and coefficients of determination generated for the sorption data are shown in Table 3.

Table 3. Linear regression equations and coefficient of determination, R^2, for isotherm models for heavy metals adsorption on Imo lateritic soil

Metal	Langmuir		Freundlich	
	Sieved soil	Complete soil	Sieved soil	Complete soil
Pb	Y = 3.185X + 26.33 R^2 = 0.756	Y = 2.248 X + 6.373 R^2 = 0.901	Y = 0.448X – 2.82 R^2 = 0.865	Y = 0.336X – 1.856 R^2 = 0.928
Cd	Y = 2852X - 12805 R^2 = 0.846	Y = 8.556X + 145.3 R^2 = 0.985	Y = -2.207X – 1.902 R^2 = 0.953	Y = 0.748X – 4.857 R^2 = 0.999
As	Y = -0.169X + 9.16 R^2 = 0.694	Y =-0.061X + 2.791 R^2 = 0.194	Y = 1.136X - 2.309 R^2 = 0.989	Y = 1.078X + 1.022 R^2 = 0.967

As could be observed from the results, many of the obtained values for isotherm constants were negative, implying that the two models considered are not suitable for the explanation of the adsorption process of the studied heavy metals on Imo lateritic soil. However, the adsorption ranking derived from the adsorption capacities obtained in this study shows that the performance of lateritic soil in adsorbing the different metals is in the following order: As>Pb>Cd>. The soil may be used as lining material under landfills to absorb the heavy metals so that the ground water resources could be maintained safer.

4. CONCLUSIONS

A laboratory experimental program to investigate the adsorption of heavy metal onto lateritic soil was studied using batch procedure. The batch sorption isotherm showed that the adsorption capacity of the soil for Pb, Cd, and As increased with increase in the sorbate concentration. Although the determined isotherm parameters showed that neither Langmuir model nor Freundlich model could adequately describe the isotherm of the adsorption of the studied contaminants on Imo lateritic soil, the values of the adsorption capacities obtained in the study are indicative of the affinity of these contaminants to the soil.

5. ACKNOWLEDGMENT

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