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Crude oil Effects on Some Engineering Properties of Sandy Alluvial Soil

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ABSTRACT

Sandy alluvial soils contaminated with crude oil were investigated with a view to understanding the effects of crude oil contamination on their engineering properties. Bulk samples of alluvial soils compacted in layers were admixed thoroughly with 10% by volume of the contaminant and were cured for 63 days under room temperature in the laboratory and outside in the open to simulate field conditions. Mineralogical and chemical compositions of soils were obtained using X-ray diffraction and X-ray fluorescence analyses, and specific gravity, hydraulic conductivity, and compaction tests were conducted on the soils before and after contamination. Results show that the soil is silica-rich with SiO_2 content of 96.24g/g. This is corroborated by the high quartz content (96.62%) observed from the mineralogical composition with minor amounts of kaolinite (6.04%), and trace amounts of haematite (0.02%). The addition of crude oil resulted in an increase in maximum dry density (MDD) with a corresponding decrease in hydraulic conductivity, optimum moisture content (OMC), and specific gravity for both laboratory and outside cured samples. Hence, crude oil contamination can be said to modify the engineering properties of sandy soils, and the environment of samples' emplacement also contributed to the alteration pattern observed.

Keywords : *Alluvial, Compaction, Contamination, Crude oil, Hydraulic conductivity, Specific gravity*

1. Introduction

The recent advancement and industrial growth have impacted the environment adversely. One of the most significant sources of soil contamination is oil spillage. Hydrocarbon pollution of soil can occur in several ways; from natural seepage of hydrocarbons in areas where petroleum is found in shallow reservoirs, to accidental spillage of crude oil on the ground. Nigeria experiences a high frequency of oil spills in different parts of the country [1]. Many of these cases (especially in the Niger Delta region) are caused by sabotage and negligence. The United Nations Development Programme (UNDP) report [2] states that oil spills have devastated the environment of the fertile land of the Niger Delta area of Nigeria, and in the last 30 years, there has been around 6,817 oil spills resulting in more than 1.3 billion liters of oil being spilled into the creeks and soils of southern Nigeria, and some 70% of the crude oil has not been recovered [3]. The Department of Petroleum Resources (DPR) estimated that 1.89 million barrels of petroleum were spilled into the Niger Delta between 1976 and 1999 out of a total of 2.4 million barrels spilled in 4,835 incidents. Sabotage (28 %), pipeline and tanker accidents (50 %), oil production operations (21 %), and inadequate or non-functional production equipment (1 %) account for these spill incidents.

Crude oil contamination is not a particular challenge for environmentalists but also geotechnical engineers. According to [4], crude oil has been implicated as a significant source of contamination resulting in building failure owing to the reduction in some critical geotechnical properties of the contaminated soil. Hydrocarbons influence the quality and physical properties of contaminated soils [5]. In addition to the effects of crude oil spillage on surface and groundwater quality and soil fertility for agricultural practices, the response or behavior of soils, in terms of their geotechnical properties in the presence of crude oil, is also a major problem. [6] observed that the change in the engineering properties and behavior of soils due to crude oil contamination has a far-reaching implication on existing and proposed structures to be supported by such soils. They opined that it can result in structural or functional failure of existing structures, especially when the contamination causes a significant increase in the soil's plasticity, loss of its bearing capacity, increase in its settlement, and/or prevent drainage of water or other fluids. For proposed structures, it can cause an abandonment of the site having the contaminated soil, a reduction in the scope of the project, or an increase in its project cost. [7]Stated that it is unsafe to construct buildings on contaminated sands because any changes in the engineering properties of sand layers may affect the bearing capacity and differential settlement of the foundation.

With recent cases of structural damage to industries and residential buildings resulting from chemical contamination of soils, attention has been drawn towards the importance of modification of engineering properties of such contaminated soils [8]. [9] examined the effects of compactive efforts and spent engine oil (SEO) contamination on the geotechnical properties of lateritic soils by mixing the soil with SEO up to 10% by weight of the soil in a step concentration of 2% before subjecting the soil – oil specimen to geotechnical tests. In their study, they noticed a decrease in the fine content, Liquid Limit (LL), MDD, and Unconfined Compressive Strength (UCS) with up to 10% SEO content. However, with an increase in the compactive effort, the MDD, OMC, and UCS values increased. Furthermore, the regression analysis of the results revealed that the OMC, fine content, and compactive effort significantly influenced the soils' UCS values. [10] Also investigated the effect of crude oil contamination on index properties and engineering properties of clays and sands by performing series of geotechnical laboratory tests on the uncontaminated soils and those contaminated at 3%, 6%, and 9% of crude oil for both soil types. They discovered that the coarse-grained soil (sand), due to its inherent structure and high permeability, allows penetration of crude oil at a higher rate than that

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of fine-grained soils (clay), which have low permeability, and thus are less liable to get affected due to crude oil contamination. They also noted that increment in the rate of crude oil contamination can be stated for the deterioration of geotechnical properties for both soil types. [4] investigated the impact of crude oil on the permeability of disturbed A-6 (CL) soils obtained from the Ibagwa area of Enugu state. They divided the sample into five portions, each of which was dosed with Bonny light crude oil at 2%, 4%, 6%, and 8% by weight of the sample. The results of their investigation indicated a decrease in permeability as the oil was added. They also mentioned that the reduction in permeability of the studied soil alters the natural groundwater recharge, which can be remedied by enhanced bioremediation through aeration of the soil. [11] performed a series of laboratory tests in order to determine the influence of oil contamination and aging effect on geotechnical properties of Kuwaiti sand. The amounts of oil added to the sand varied, and the parameters of shear strength, compressibility, permeability, and compaction were determined. [12] performed a series of triaxial tests on contaminated and uncontaminated clean sands. The results showed that the oil-saturated samples drastically reduced the friction angle for loose and dense samples. On the other hand, it increased the volumetric strain. These findings also suggested that settlement of footing would increase as a result of oil contamination.

Several remediation methods for oil-contaminated soils have been recommended, including incineration, vitrification, soil washing, and solvent extraction, but none is considered to be cost-effective, especially in developing countries. In order to find an alternative and cost-effective remediation method, the use of oil-contaminated soils in engineering and construction has been considered. However, for any possible application of crude oil contaminated soils, knowledge of geotechnical properties and behavior of the contaminated soils is required [13]. Hence, this paper investigates the compaction, specific gravity, and hydraulic conductivity of sandy alluvial soil contaminated with crude oil.

2. Test Materials, sample preparation, and protocols

Alluvial soil samples were obtained from Ebute Meta, south-western Nigeria. Grain size distribution, natural moisture content, and the specific gravity of the soil were determined in accordance with BS1377 standard test procedures [14](Table 2). Standard proctor compaction tests (ASTM-D698, Method A) were conducted on the samples to determine the compaction characteristics of the soil. Furthermore, constant head permeability tests (ASTM-D2434) were also carried out on the soil samples to determine their hydraulic conductivity values. Mineralogical and chemical compositions of the soil were obtained using X-ray diffraction (Fig. 1) and X-ray fluorescence analyses. The physiochemical properties of the crude oil used in this experiment are presented in Table 1. 10% by volume of crude oil was added to the soils and allowed to cure for 63 days to ensure homogeneity of the mixture. Upon contamination, a set of the samples was placed outside and exposed to adverse weather conditions, typically experienced by in-situ contaminated soils, while the other set was cured in the laboratory under room temperature.

3. Results and discussions

The pre-contamination properties of the soils (Table 2) show well-graded sand (SW) and A-3 soil based on the Unified Soil Classification (USC) and the American Association of State Highway and Transportation Official (AASHTO) soil classification system respectively. Furthermore, the soils possess specific gravity of 2.67, natural moisture content of 8.91%, a permeability value of 1.85×10^{-5} cm/sec., optimum moisture content of 15.3%, and a maximum dry density of 1.67 gm/cc.

In addition, the soil is silica-rich with SiO_2 content of 96.24g/g. This result is corroborated by the high quartz content (96.62%) observed from the mineralogical composition with minor amounts of kaolinite (6.04%) and trace amounts of haematite (0.02%).

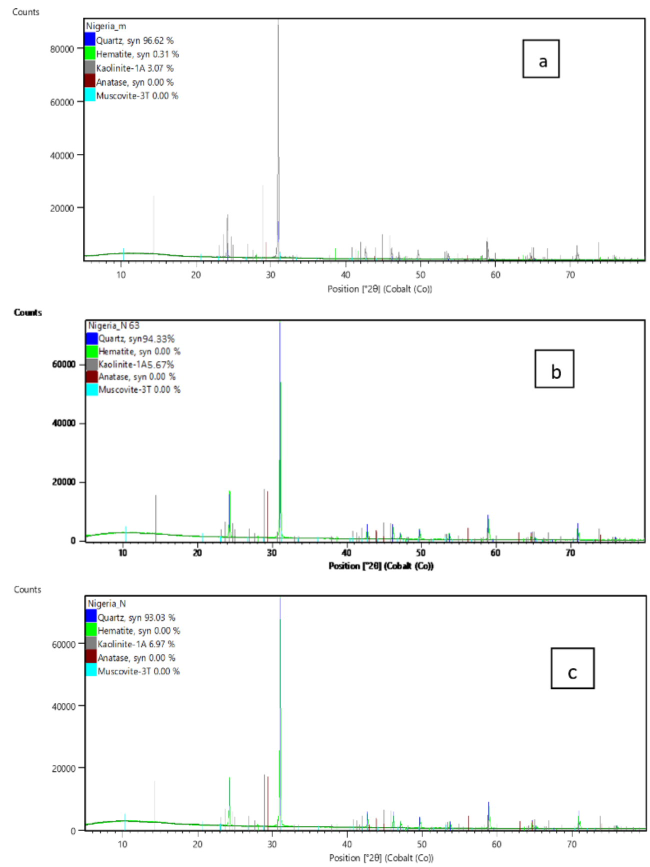

Fig. 1. X-ray diffractograms (a. Uncontaminated, b. Laboratory cured and c. outside cured samples).

Table 1. Physicochemical Properties of the contaminant.

Contaminant	Specific Gravity	Viscosity at 40°c (cst)	Sulphur Content (%wt)	API Gravity (gm/ml)	Pour Point (°c)
Crude oil	0.8359	2.5	0.139	37.78	0.91

3.1. Crude oil effects on Specific gravity

The specific gravity of the soil upon contamination with crude oil reduced by 1.5% and 8.9% for the laboratory and outside samples, respectively (Fig. 2). The decrease in the specific gravity of the soil samples is attributed to the lower specific gravity of the crude oil [6]. Furthermore, a soil's specific gravity largely depends on the density of the minerals making up the individual soil particles. Sand particles composed of quartz have a specific gravity ranging from 2.65 – 2.67 [15]. The specific gravity of the contaminated soils decreased from an initial value of 2.67 to 2.63 and 2.43 respectively for the laboratory cured and outside cured samples with a corresponding decrease in the percentage of quartz from 96.62% to 94.3% and 93.03%, respectively. Hence, the reduction in the specific gravity (G_s) may also be due to the decrease in the percentage compositions of the soil minerals. The soil is composed mainly of silica with SiO_2 content of 96.24g/g and quartz content of 96.62% (Table 2). Its specific gravity depends largely on the density of the constituting minerals. Results show a decrease in the SiO_2 and quartz contents resulting in a decrease of the specific gravity of the samples. However, the outside cured samples suffered greater loss or decrease in the SiO_2 and quartz contents of the soil caused by the adverse weather conditions under which the samples were cured. This explains why the outside cured samples show lower specific gravity values.

3.2. Crude oil effects on hydraulic conductivity

Contamination of the soil samples with crude oil resulted in noticeable effects in the hydraulic conductivity. The hydraulic conductivity reduced by 73.6% and 30.8% respectively for the laboratory cured and outside cured soil samples (Fig. 3). [16] indicated a decrease in hydraulic conductivity of contaminated soil due to pore clogging and high viscosity of the oil. In addition, the continuous interaction between the soil samples and crude oil may have brought about shifts in pore shapes and size distributions due to dynamic kneading resulting in reduced connected voids. [17] suggested that the formation of a new swelling type of compounds may also be responsible for the reduced coefficient of permeability in the studied soils. Furthermore, it was noticed that the hydraulic conductivity value of the unexposed sample was lower than that of the exposed sample. [18] attributed this variation to a process called bioremediation, in which micro-organisms assisted by the air in the curing environment decomposed the contaminant present in the soil to less complex substances such as water and carbon dioxide. Moreover, the sun's energy also aided evaporation of crude oil, which accounts for the variations noticed between laboratory cured and outside cured soils.

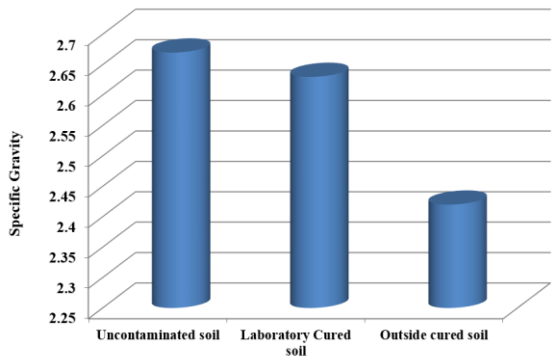

Fig. 2. Specific gravity of uncontaminated and contaminated soil samples.

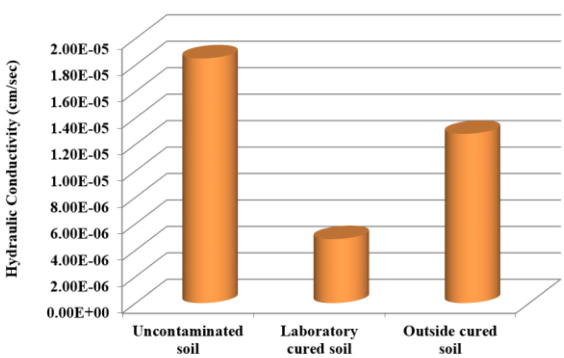

Fig. 3. Hydraulic conductivity of uncontaminated and contaminated soil samples.

3.3. Crude oil effects on compaction characteristics

The addition of crude oil into the soil increased the maximum dry density (MDD) from an initial value of 1.67gm/cc by 7.7% and 4% for the laboratory and outside cured samples, respectively. However, the optimum moisture content (OMC) reduced by 24.8% and 33.3% for the laboratory and outside cured soils, respectively. (Fig. 4). The increase in MDD is attributed to the lubricating effect of the oil. Crude oil has a higher viscosity than water; therefore, as the pore fluid changes from water to crude oil, it tends to lubricate the soil. During compaction, high viscous fluids provide proper lubrication for the soil particles, which was used to overcome the inter-particle forces, and slide against each other to produce better compaction characteristics [19]. [11] also mentioned that the increase in MDD is due to the lubricating action resulting from the addition of crude oil into the soil, which facilitates compaction and reduces the amount of water needed to reach MDD. According to [6], crude oil is hydrophobic in nature, and as it coats itself around individual particles, it prohibits free water from interacting with the particles of the soil. This may account for the reduction in the amount of water needed by the soil to reach its maximum unit weight.

Table 2. Pre and post- contamination properties of the studied soils.

Soil Properties		Description/Values		
		Pre-contamination	Post-contamination	
			Laboratory samples	Outside samples
Particle Size Distribution	Gravel (%)	0	0	0
	Sand (%)	100	100	100
	Silt (%)	0	0	0
	Clay (%)	0	0	0
	AASHTO Classification	A-3	A-3	A-3
	Unified Soil Classification	SW	SW	SW
Natural Moisture Content	Natural Moisture Content (%)	8.91	7.84	16.34
Specific Gravity	Specific Gravity	2.67	2.63	2.43
Coefficient of permeability	Hydraulic Conductivity (cm/s)	1.85×10^{-5}	4.87×10^{-6}	1.28×10^{-5}
Compaction Parameters	OMC (%)	15.3	11.5	10.2
	MDD ((gm/cc)	1.67	1.80	1.73
Mineral composition (%)	Quartz	96.62	94.3	93.03
	Hematite	0.31	0	0
	Kaolinite	3.07	5.67	6.97
Chemical Composition (g/g)	SiO2	96.24	93.21	92.14
	TiO2	0.24	0.18	0.25
	Al2O3	1.48	1.32	1.32
	Fe2O3	1.42	1.44	1.38
	MnO	<0.01	<0.01	<0.01
	MgO	0.07	<0.01	0.07
	CaO	0.06	0.05	0.06
	Na2O	0.42	0.43	0.32
	K2O	0.22	0.09	0.14
	P2O5	0.03	0.03	0.03
	Cr2O3	0.14	0.12	0.10
	SO3	<0.01	<0.01	<0.01
	LOI	0.68	3.07	O.52

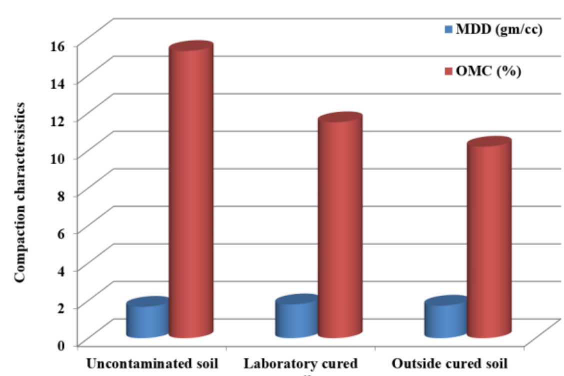

Fig. 4. Compaction characteristics of uncontaminated and contaminated soil samples.

4. Conclusions

Investigation into the effects of crude oil on some engineering properties of sandy alluvial soil shows that the addition of crude oil into the soil increased the maximum dry density and decreased hydraulic conductivity, specific gravity, and optimum moisture content. The observed responses of the soil are attributable to the high viscosity, low specific gravity, hydrophobic nature, and lubricating effect of the crude oil. Furthermore, the environment of the emplacement of the contaminated samples also contributed to the alteration pattern of the samples.

Crude oil has a complex composition and evaporates even under room temperature. However, the evaporation rate is higher in exposed samples. The sun's energy and excessive air aided evaporation of the oil and assisted microorganisms to act on the oil, thereby producing less complex substances that account for the variations noticed between laboratory cured and outside cured soils.

Crude oil can thus be said to have adverse effects on sandy alluvial soils. Therefore, the use of contaminated soils as construction materials without stabilization or remediation is not recommended. These results will be of benefit to the engineers or decision-makers in stabilization or remediation of contaminated soils for possible applications in engineering and construction purposes.

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