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Physiochemical Properties of Soil in Relation to Varying Rates of Crude Oil Pollution

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ABSTRACT
The behavior of selected physiochemical properties of the soil in relation to varying rates of crude oil pollution has been studied. Stratified random sampling was adopted for soil sample collection from various study sites of the study area, Niger Delta. Crude oil sample was also collected from three selected oil wells of Qua-Ibo, Brass River and Bonny, respectively. Sorption test was carried out by mixing the various characterized soil samples with the hydrocarbon-determined crude oil samples and the mixture was shaken for 5 h to establish adequate mixture and sorption process. Soil samples, crude oil samples and the crude oil-contaminated-soils collected after each sorption process were analyzed in the laboratory using routine and special analytical techniques. The results showed corresponding increase in values of some selected physiochemical properties of the soil (Bulk density and organic matter) with increase in sorption time, hydrocarbon concentrations of various crude oil samples and volumes of the crude oil applied during sorption process while an inverse relationship was observed for porosity values.

Key words: Soil, characterization, sorption, crude oil, pollution, contamination properties

INTRODUCTION
Oil pollution in the environment has been a major source of concern to the people living in the crude oil-rich-areas. Oil pollution due to spill could take place in water or on land. Crude oil pollution on land depends on a number of factors which include; the permeability of the soil, adsorption properties of the soil and the partition coefficient (Nudelman *et al*., 2002). Similar studies carried by Mashalah *et al*. (2006) using sandy loam soil and a specie of crude oil also confirmed pronounced changes on the physiochemical and the microstructure of the oil contaminated soil. The contamination reduced the cation exchange capacity and the double thickness of the soil. Also, the heavy metal values of the soil physiochemical properties increased on contamination with crude oil. Benka-Cooker and Ekundayo (1995) observed significant build-up of lead, iron and zinc in crude oil contaminated Niger Delta soil. In a related study, Chukwuma *et al*. (2010) showed that zinc distribution is more in an oil polluted site than non-oil polluted areas and also observed that its distribution depends on certain soil properties such as clay, organic matter and ph. Leschber *et al*. (1985) revealed zinc positive relationship with ph and effective cation exchange capacity whereas clay and organic matter did not affect zinc distribution in the soil polluted by crude oil. Other parameters including electrical conductivity, available

phosphorus and total nitrogen in crude oil impacted soils were comparatively low while the total organic carbon was high, compared with the reference site (Benka-Cooker and Ekundayo, 1995). In assessing the physiochemical values of a leachet polluted soil, Ogundiran and Afolabi (2008) observed significant reduction in the bulk density with its corresponding increase in porosity and organic matter content. Crude oil contamination of clay studied by Andrade *et al.* (2004) showed a decrease on some of its geotechnical properties. The decrease in strength, stiffness and permeability of the clay was attributed to formation of an open structure occasioned by the crude oil contamination.

Certain mechanisms are involved in the fixation of crude oil by soil. Such mechanisms were studied and presented by Ur-Rehman *et al.* (2007) as adsorption, ion exchange capacity and chemical precipitation. Due to low absorptivity of certain soil types and the inability of the oil to accumulate on such soils, some components of the crude oil such as acryl-amide may migrate through the soil structure to pollute the ground water (Coulin and Deille, 2003). Crude oil equally upset the microbial biomass of the contaminated soil. Investigation of Franco *et al.* (2004) showed a decline of Inceptisols and a slight increase of entisols.

This study will examine the effects of crude oil on the selected physical properties of different soils of Niger-Delta Nigeria which include; the percentage organic matter, porosity and bulk density, using different crude oil samples of different physiochemical properties. The applied volume variation effects of the crude oil samples on those soil properties will also be studied.

MATERIALS AND METHODS

Study area: The soil samples were collected from four different points of Niger-Delta South Eastern Nigeria between May 2004-September 2008. The soils of the area are from coastal plain sands (benin formation) of the Oligocene-Miocene geological era. The area has a low land geomorphology and is of humid tropical climate with an average annual rainfall of about 2500 mm and mean annual temperature range of between 26-29. It is situated within the highly depleted rainforest vegetation, characterized by varieties of vegetal forms although dominated by tree and shrubs. Frequent oil spillages are reported in the study area due to oil pipe rupture occasioned by pressure, aging and sabotage. Residents cultivate on the soils of the area for arable crops and also harvest their ground water form the same area.

Field sampling: Field sampling was carried out by adopting a free survey technique of stratified random unpolluted soil sampling of four different sites of the study area that is soil unaffected by crude oil spill. Each site was designated as A, B, C and D. On each site, soil samples were randomly taken at ten points making a total soil sample collected to forty. These soil samples were air-dried in readiness for various laboratory analysis. Crude oil samples were also collected form three different oil wells which included; Brass oil, Qua Iboe and Bonny light. The crude oil samples were designated as A, B and C, respectively.

Characterization of soil: Textural characteristics of the soil samples were determined by analysis of the particle size distribution and the uniform coefficient which categorized the soil samples based on the percentage mixture of clay, silt and sand particles using SB sieve. Also, analyzed were the porosity, bulk density and the percentage organic matter using standard methods.

Crude oil characterization: The three crude oil samples were subjected to total hydrocarbon analysis using Gas Chromatographic (GC) method to determine total hydrocarbon contents of each crud e oil sample. Density, API^0 and viscosity of the crude oil samples were also determined using ASTM methods.

Sorption test: The materials used as adsorbent media were soils of different textural characteristics and the three types of crude oil of known concentrations were used as liquid substances. The predetermined textural characteristics of the four types of soil were sun dried and 50 g of soil sample A was put into a 800 mL conical flask with 100 mL of a particular crude oil sample, say sample (A) of a known initial total hydrocarbon concentrations. These were shaken in a mechanical shaker for 5 h. After which, a sample of the adsorbent (soil) was collected for analysis of bulk density, porosity and organic carbon at regular intervals of 1 month for five months. The effects of varying the volume of crude oil at 400, 500 and 600 mL with contact time of 1, 2, 3, 4 and 5 months were studied. The experiment was repeated with the two other oil samples B and C and the three other types of soil samples B, C and D.

RESULTS AND DISCUSSION

Soil characterization: The soil types used for this work were classified according to their particle size distribution, bulk density, percentages of organic matter and porosity. Soil sample C has the highest percentage of sand while sample D has the least percentage of sand. In terms of percentage of clay, sample D has the highest value with sample C having the lowest. Soil sample B has the highest percentage of silt while sample C has the lowest silt percentage. The soil characterization is normal to a typical Oligocene-Miocene geological era as equally observed by Ogundiran and Afolabi (2007). Bulk density and percentages of organic matter of various soil samples showed direct relationship with the percentage of clay of the corresponding soil samples. Porosity showed the inverse trend. These pattern of relationships seem to be in agreement with the study of Favis-Mortlock *et al.* (2000).

Crude oil classification: The crude oil characterization was carried out based on the hydrocarbon fractions of the n-alkanes of various crude oil types, viscosity, API, gravity and density. The values for the total hydrocarbon fractions of the three crude oil types are 1248.5109, 1109.0751 and 1007.9991 ppm, respectively. The variations observed on the total hydrocarbon of the three crude oil samples could be attributed to the concentration levels of their hydrocarbon constituents. For instance, the concentrations of the high molecular weight hydrocarbon of Brass crude oil were observed to be higher than that of Qua Iboe crude oil and Bonny light. This pattern of variation was evident on their viscosity, and density values. The viscosity and density values of Brass river crude were higher than that of qua iboe crude with bonny light having the lowest values. There were slight variations in the hydrocarbon content of the Bonny light crude oil of this work with facados and escravos light observed by Ogboghodo *et al.* (2004). The reason for this variation was buttressed by the work of Mashalah *et al.* (2006) where, the variations in hydrocarbon content of various crude oil samples were attributed to difference in geological era.

Effects of sorption on the soil properties: Sorption seems to have profound effects on the soil properties analyzed for this study. Soil properties such as the bulk density, organic matter and porosity were appreciably influenced. This observation is in line with that of Ogundiran and Afolabi (2008) in their study of soil physiochemical properties polluted with leachet from the municipal waste. The apparent effects on the mentioned physiochemical properties of various soil samples

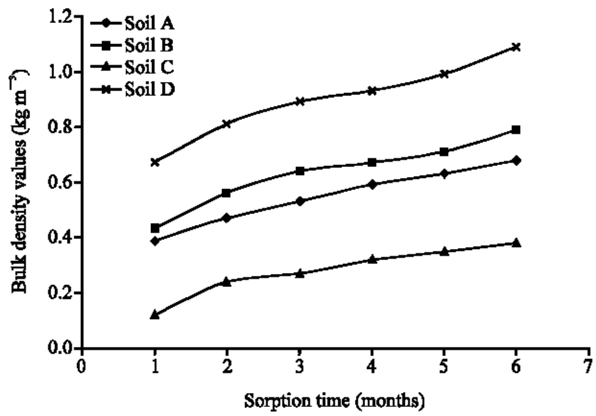

Fig. 1: Bulk density variation with sorption time on application crude oil samples

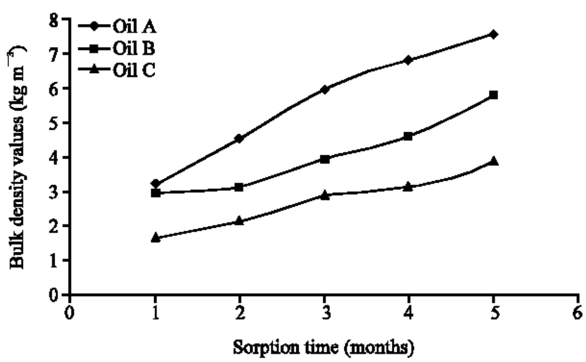

Fig. 2: Bulk density variation with sorption time at different crude oil samples for soil sample A

could be attributed to three basic reasons; the crude oil samples, applied volume of various crude oil samples and the constitution of various soil used in this study.

Figure 1 presents the relationship between bulk density of the soil samples with sorption time on application of crude oil samples.

The bulk density of the soil increased linearly with time of sorption. As the time of sorption increased more of the hydrocarbons adsorbed and distributed on the soil matrix thereby adding to its mass and consequently to density values. The bulk density of the various soils varied with different crude oil samples and various crude oil volumes used for the sorption process. Figure 2-5 show the bulk density values of soil samples A, B, C and D on treating with various crude oil samples (A, B and C). Form all the figures, sorption processes with light crude oil samples that is, crude oil samples with a large amount of low hydrocarbon molecules, impacted lower density values on the soil samples than the heavy crude oil samples. Sorption of crude oil sample A which is heavier than samples B and C, on various soil samples, produced more soil bulk density values after the process than that of crude oil samples B and C. The variations of soil bulk density observed after the sorption process with various crude oil samples were attributed to different values of the total hydrocarbon content of various crude oil samples and the soil bulk density impaction by the crude oil samples was done according to the values of the Total Hydrocarbon Content (THC) inherent in each crude oil, similar observations were made by Ogboghodo *et al.* (2004).

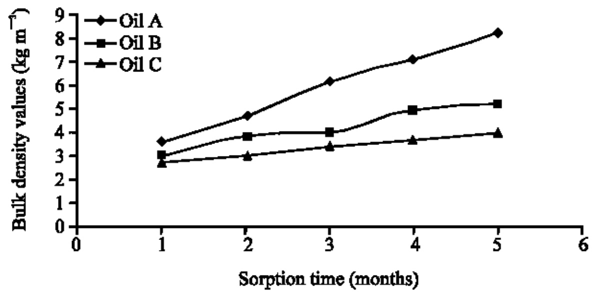

Fig. 3: Bulk density variation with sorption at different crude oil samples for soil sample B

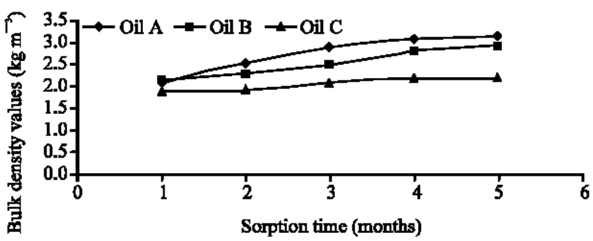

Fig. 4: Bulk density variation with time of sorption at different crude oil samples for soil C

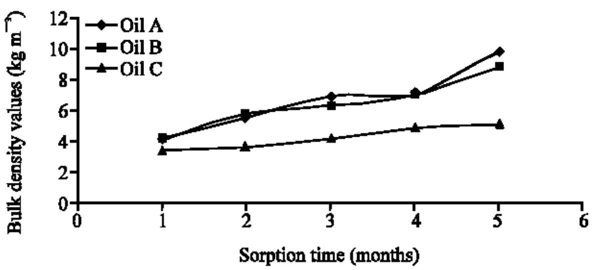

Fig. 5: Bulk density variation with time of sorption at different crude oil samples for soil sample D

In addition to the foregoing, constitution of various soil samples has pronounced contribution to the bulk density variation of the soil samples after sorption process.

Soil sample D with appreciable quantity of clay and organic matter content exhibited the highest adsorption powers which are evident on its increased bulk density values with sorption time of the crude oil samples. This is so because clay is negatively charged and has the tendency to attract any positively charged component of the crude oil samples. Similarly, Owneremadu, 2008 reported appreciable attraction of heavy metals to clay soils due to their (clay soils) negatively charged status. The bulk density variations of various soil samples took place according to the quantity of clay content in the soils and it is shown in this manner; soil sample D>soil sample B> soil sample A >soil sample C. the linear relationships is clearly shown on Fig. 1.

The crude oil volume variations on the sorption process were also studied and effects of varying crude oil volumes were displayed on Fig. 6-10. Figure 6-10 show the effects of crude oil volume variation of samples A, B and C on the bulk density values of soil samples A,B,C and D, respectively. From all the figures, the soil bulk density values related linearly with the volumes of crude oil applied on the sorption process. Crude oil volume of 600 mL impacted higher bulk density

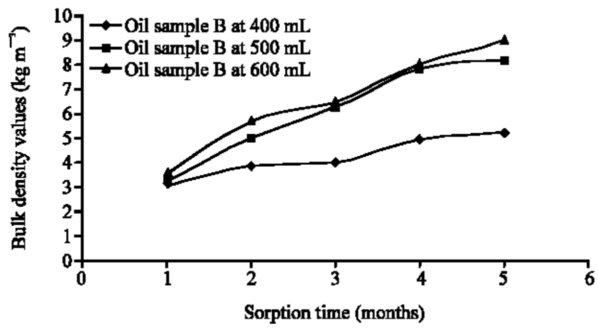

Fig. 6: Bulk density variation with sorption time for soil sample Bwith oil sample B at various volumes

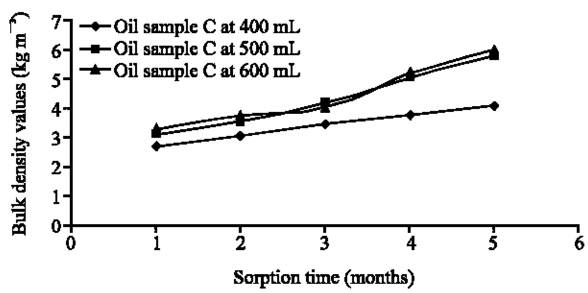

Fig. 7: Bulk Density variation and sorption time for soil sample B with oil sample C ay various volumes

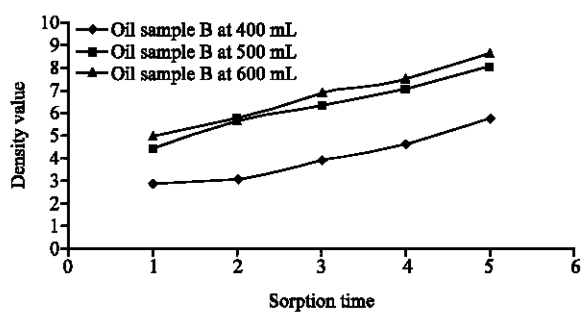

Fig. 8: Density variation with sorption time for soil sample A with oil sample B at various volumes

to the soil samples than the other volumes. Bulk density increased according to the following trend of crude oil volume variation; 400 mL<500 mL<600 mL. This could be attributed to more availability of hydrocarbons present in the said crude oil volume. It is important to note that densification of various soil samples due to the crude oil pollution will give rise to compaction, formation of organic lignands and ponding of surfaces of the study sites which in most cases leads to drainage problems as observed by Uzoije (2008). Similarly, soils of high bulk density may not be good for cropping as Amadi *et al.* (1993) reported poor root ramification and growth of arable crops due to compaction.

The organic matter contents of the soil samples were influenced in the same manner as the bulk density described above. This is because the organic matter has the ability to form a bound with

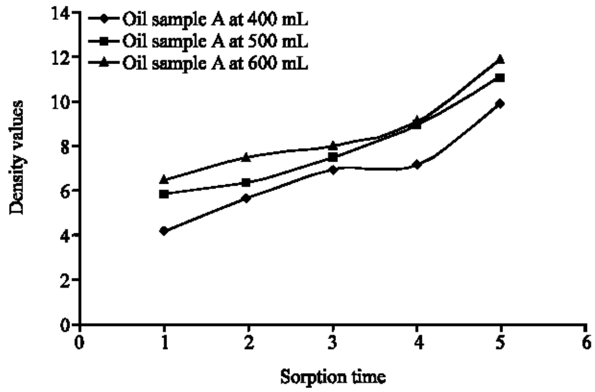

Fig. 9: Density variation with time for soil sample D and oil sample A at various volumes

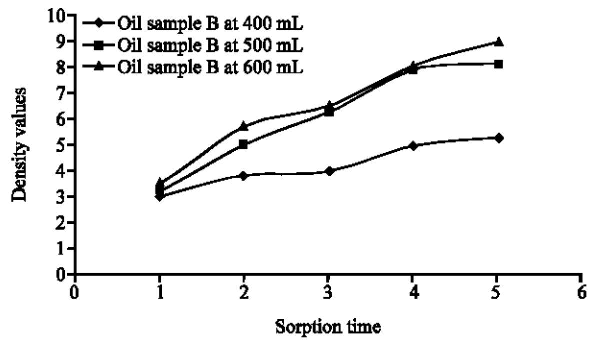

Fig. 10: Density variation with sorption time for soil sample B with oil sample B at various volumes

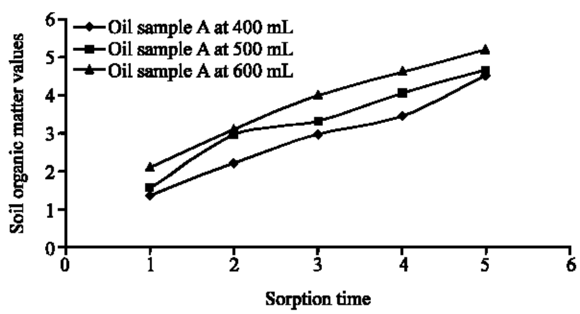

Fig. 11: Soil organic matter content variation with sorption time for soil sample A

the sorbed substances by so doing adding to its values. As the time of sorption progressed, the values of the organic matter also increased. Volumes of the crude oil samples applied in the sorption process also played a role in the increased amount of organic matter present on the soil after the process. Figure 11-13 represent this trend. It was observed from the figures that the % of organic matter present on the soil sample after the sorption process, related directly with the volume of crude oil applied. This could be attributed to the ability of high molecular hydrocarbons of the crude oil samples to distribute on the soil surface after the volatilization and degradation processes of the low and highly degradable HC molecules of the crude oil samples respectively. Also, the presence of crude oil on the soil medium created an anaerobic condition within the medium. This condition

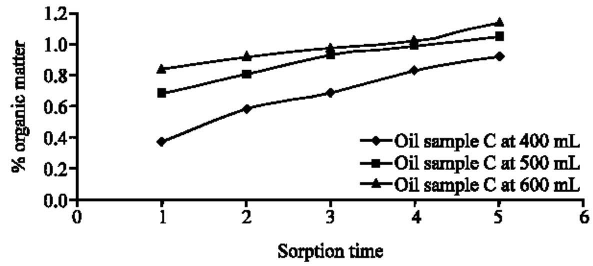

Fig. 12: The soil organic matter variation with sorption time for soil sample C

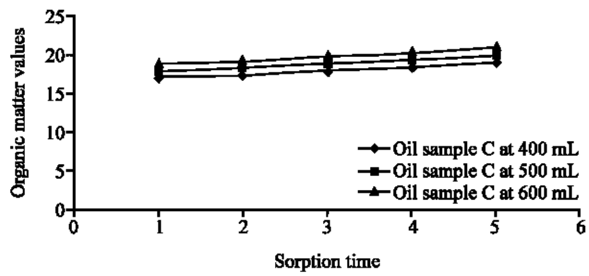

Fig. 13: The soil organic matter variation with sorption time for soil sample D

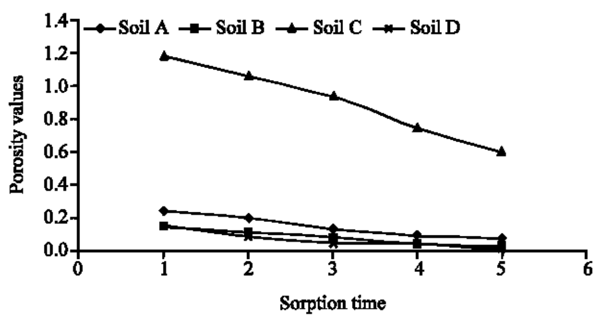

Fig. 14: Porosity variation with sorption time for different soil samples using oil sample A

led to the death of most aerobic micro organisms'. The dead organisms formed part of the organic substance which added to the organic matter content of the soil. This agrees with the observations of Nudelman *et al.* (2002) where, they stated that sorbed decayed substances can distribute and also form covalent bounds with the soil organic matter by oxidative coupling. Owneremadu (2008) also reported that organic matter value was promoted in soils contaminated with waste water in Owerri, Nigeria. These processes imply that the soil containing high % organic substance absorbed most of the crude oil hydrocarbons and therefore most likely to protect the ground water. In line with this observation, Ekundayo and Fagbani (1996) reported that the soil organic matter reduced availability of heavy metal components of the crude oil samples by chalation. This equally implies that the rise in the organic matter values of various soil samples occasioned by oil spill reduces the influence on the ground water of heavy metals of both associated with crude oil and those native to the soils.

Effects of sorption on the porosity of various soil samples took a reverse trend from that of the bulk density and % organic matter. Figure 14-15 show that soil porosity increased with sorption

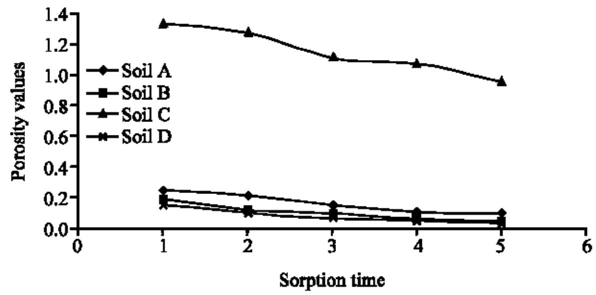

Fig. 15: Porosity variation with sorption time at different soil samples using crude oil sample B

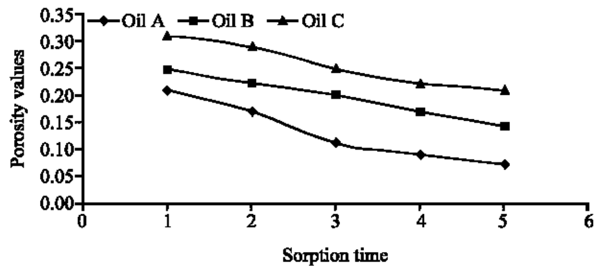

Fig. 16: Porosity variation with sorption time at different oil samples and soil sample B

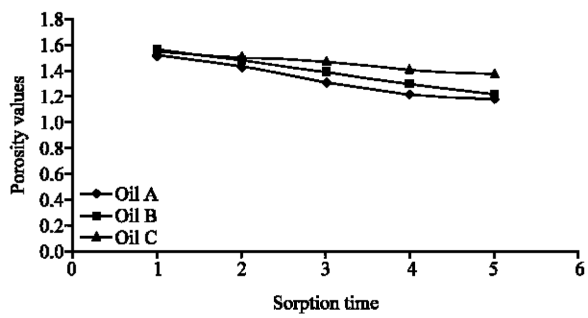

Fig. 17: Porosity variation with sorption time at different oil samples and soil sample C

time. This implied that as the sorption time increased, the said soil porosity decreased. The effects could be attributed to the reduction of pore sizes of the soil by the adsorbed hydrocarbons. It can be deduced from the figures that soil texture and crude oil hydrocarbon contents have major contributions to the observed changes in the soil porosity.

Reductions in soil porosity is more on the soils of high absorption capacity. For instance porosity reduction is more pronounced on soil sample D probably due to its high clay and organic matter content which also have the ability to bind to the crude oil hydrocarbon molecules to reduce its porosity and least porosity reduction was observed on soil sample C with little amount of clay and organic matter substances.

Figure 16-18 show that the constitution of the oil samples could also explain the variation in the soil porosity during the sorption process. Oil sample A which has appreciable amount of high molecular hydrocarbons and tendency to adsorb on the soil matrix resulted to the reduction in soil porosity observed after the sorption process while high soil porosity was observed when oil sample

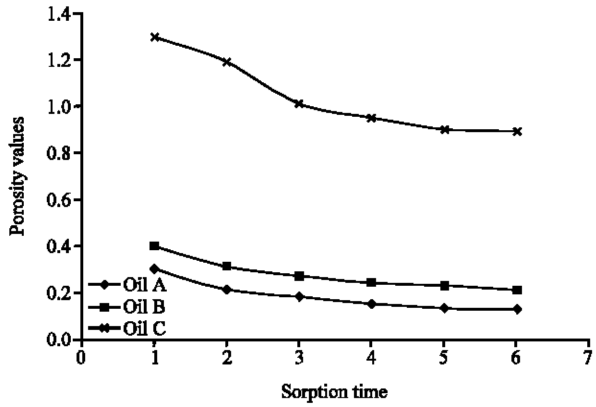

Fig. 18: Variation of porosity with sorption time for different crude oil samples in soil sample D

C was applied due to its low molecular hydrocarbon content. The observation on porosity variations is similar to that made by Andrade *et al.* (2004). Oil pollution altered both chemical and physical soil properties, aggregating soil particles in plaques, lowering porosity and increase resistance to penetration and hydrophobicity. Also, decrease in porosity of the soil samples means that there was constriction of water and air voids as sorption of crude oil on various soil samples progressed. This buttressed the case of massive death of aerobic micro-organisms observed by Nudelman *et al.* (2002) in an oil polluted coastal region.

CONCLUSION

The following conclusions can be drawn from the study.

Values of the bulk density and % organic matter varied linearly with sorption time but porosity values decreased as crude oil sorption process on various soil matrix progressed.

The constitution of various crude oil samples has appreciable influence on the selected soil physiochemical properties after the sorption process. Crude oil samples with low HC made lesser impact on the bulk density, % organic matter and porosity values of the soil samples and vise-verse. Volumes of the crude oil samples applied during the process also have impact on the soil properties. The higher the applied crude oil volume the higher the bulk density and % organic matter values.

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