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# CONCENTRATION DISTRIBUTION OF SPILLED CRUDE PETROLEUM IN DIFFERENT SOILS 2: EFFECTS OF VOLUME OF OIL ON SPATIAL SPREAD

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## ABSTRACT

**Experiments are carried out to determine simultaneous one-dimensional spatial concentration distribution of spilled petroleum in three soils (sandy, loamy and topsoil) in the horizontal and vertical directions. It is shown that the horizontal spread is very slow and the volume of petroleum spilled has minimal effects on the extent of spread in the horizontal direction. The distance migrated in the vertical (downward) direction increases significantly as the volume of spilled oil increases. The extent of spread of spilled oil in the horizontal and vertical directions is highest in sandy soil, followed by top soil, and least in loamy soil.**

**KEY WORDS**: Volume of Oil, Concentration Distribution, Spatial Spread, Soil, Spillage.

## INTRODUCTION

The Niger Delta Region of Nigeria had had its fair share of crises in recent years. These crises are borne out of deliberate neglect of the area by the relevant authorities in the face of degradation of their land caused by oil exploration activities. All aspects of the petroleum industry, starting from the prospecting stage to the distribution of the final products, degrade the environment in one way or the other (Oghenejoboh and Akpabio, 2002a; Oghenejoboh and Akpabio, 2002b; Oghenejoboh, 2005; Oghenejoboh *et al.*, 2008; Adeyinka *et al.*, 2004). One of the most pronounced and visible source of pollution arising from oil activities in the Niger Delta Area is oil spillage which is next only to gas flaring (Oghenejoboh, *et al.*, 2007; Oghenejoboh, 2005). Petroleum spillage is usually caused by leakages from underground pipes as a result of corrosion (aging), blowout from oil wells due to high pressure (Ifeadi and Nwankwo, 1987; Susu *et al.*, 1997) or deliberate human intervention (sabotage in most cases). Petroleum when spilled on land degrades the environment; destroys plants, farmland, and mangrove environment and presents a significant source of groundwater contamination (Akpofure *et al.*, 2000). As a result of the grave consequences of petroleum spillage on the environment, there is need for quick remediation of areas affected by a spill. Actually, once petroleum enters the soil, its constituents become part of biological cycles that affects all forms of life (Oghenejoboh, *et al.*, 2008). Constituents of petroleum hydrocarbon in soil, move in one or more of the following directions (Glasson *et al.*, 1999): (i) vaporize into the atmosphere without chemical change, (ii) absorbed by the soil, (iii) move downwards through the soil in liquid or solution form and be lost from the soil by leaching, (iv) broken down by soil micro-organisms, (v) washed into streams and rivers in surface run-off, and (vi) taken-up by plants or animals and introduced into the food chain. Knowledge of contaminant transport processes in soils is a fundamental concept in site remediation after oil spillage. The extent to which spilled petroleum is transported in soil medium depends greatly on whether the contaminant is soluble in water, and whether its density is less than or greater than unity (Schwille, 1988; Mercer and Cohen, 1990). Although petroleum is immiscible with water, it does slowly dissolve in water thereby leading to mass transfer across the interface formed by water and oil in soil. The slow dissolution of petroleum in water also causes long-term source of subsurface contamination (Schwille, 1984; Faust *et al*, 1989; Feenstra and cherry, 1988; Mercer and Cohen, 1990; Wilson *et al.*, 2001). The extent to which spilled oil spreads along the soil surface and migrates downward depends on the quantity of oil spilled, the physical properties of the spilled oil (density and viscosity) as well as the physical properties of the soil medium (especially soil porosity).

Small quantity of petroleum discharged into the soil will usually not reach the water table, but will migrate downward and laterally under the influence of gravity and capillary forces until the petroleum hydrocarbon becomes discontinuous and immobile (Ryan and Dhir, 1996). If the quantity of spilled petroleum is large and the water table is shallow, the oil may reach the water table forming lens of oil and water as a result of seasonal fluctuation in water table (Reddi et al., 1998). The spreading rate along the soil surface may not be as high as the downward migration since gravity and capillary effects influence the extent of downward migration of spilled petroleum. In this work experiments are conducted to determine the effects of volume of spilled petroleum on the extent of horizontal and vertical spread of the oil in different soil media.

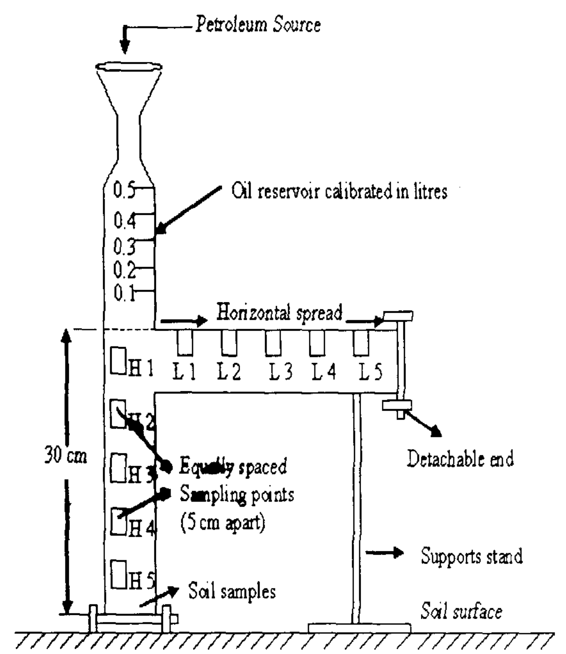



**Fig. 1.** Experimental set-up for the determination of spreading rate of crude petroleum in soil medium.

## MATERIALS AND METHODS

### Materials

The apparatus shown in Fig. 1 for the experiments carried out in this study was designed to promote a uniform and simultaneous one-dimensional flow regime vertically downwards and horizontally along the soil surface from the source of spill. The apparatus was fabricated using galvanized stainless steel sheet coated inside with ant-rust oil-resistant paint to prevent reaction between the steel and active chemical components of petroleum. The laboratory apparatus consists of a graduated reservoir capable of holding 500 $cm^3$ of petroleum. Five equally spaced sampling points placed 5cm apart were provided both vertically and horizontally and labeled H1 – H5 and L1 – L5 respectively. Loading of soil sample into the apparatus is done through the detachable ends of the apparatus. Three soil types – sandy, loamy and top soils obtained for Uyo in Akwa Ibom State of Nigeria, and crude petroleum obtained from Shell Petroleum Development Company's Afiesere field in Ughelli-North Local Government of Nigeria, were used for the experiments.

### Experimental Methods

#### 2.2.1 Soil Samples

The three types of soil were tested for the following physical properties: total porosity, soil texture, bulk density, particle density, pH, effective cation-exchange capacity (ECEC), organic matter, hydraulic conductivity and water content. The soil texture was determined using the hydrometer method (Day, 1965). The soil bulk and particle densities were measured using the pycnometer methods of Blake and Hartge (1986a; 1986b). Soil pH was measured using a pye Unicam Model MK2 pH meter from a 1 – 5 soil/water weight solution. The ECEC are determined using the ammonium acetate method (McKeague, 1978). The soil total porosity was determined from the measured bulk and particle densities (i.e. $\text{ç} = 1-(\tilde{n}_b / \tilde{n}_p)$ where ç is the porosity, $\tilde{n}_b$ is the bulk density and $\tilde{n}_p$ is the particle density). The organic matter content of the soils was determined using the Walkley-Blake method (Nelson and Summers, 1982; Juo, 1979) after first determining the organic carbon by using a conversion factor of 1.724 (corresponding to the assumption that total organic carbon represents 58% of organic matter). The hydraulic conductivity was determined using gravimetric method of Evans et al., (1982). The water content of soil sample was determined by placing the saturated soil sample in a forced air oven at 105°C until a constant weight of the dried soil was obtained. The water content of the soil was then calculated as the difference between the weights of the saturated and dried soils.

**Spreading experiment**

The vertical and horizontal wings of the apparatus were loaded with sandy soil through the detachable ends by means of a heavy square iron bar of almost the same diameter as the dimension of the apparatus. The compaction was done in a way that there is minimal loses in the soil physical properties as determined from the soil particle density. After replacing the detachable ends, 100 cm$^3$ (0.1 litres) of crude petroleum of known properties was introduced into the oil reservoir. The experimental set-up was then left in the laboratory of the Department of Chemical and Petrochemical Engineering, Rivers State University of Science and Technology, Port-Harcourt, Nigeria. Two sets of samples were collected from the sampling points L1 – L5 and H1 – H5 in plastic sample-bottles using a 5ml open-end syringe (plunger type) according to standard procedures (Beneski, 2000) every 10 days for a period of 50 days. Samples were analysed immediately using a speectron 70 UV Spectrophotometer to measure the absorbance of the contaminated soil. The measured absorbance was the converted to total petroleum hydrocarbon (TPH) concentration by means of a calibration curve. Similar experiments were conducted with loamy soil and topsoil using the same crude petroleum. The experiment for each soil was replicated with crude petroleum volumes of 200. 300, 400, and 500 cm$^3$

## RESULTS AND DISCUSSION

The results of the physical properties of the petroleum used in the experiments, and soil analyses, are presented in Tables 1 and 2 respectively.

**Table1.** Physical Properties of Afiesere Crude Oil

| | |
|---|---|
| Density (g/cm$^3$) | 0.95634 |
| Viscosity (Nsm$^{-2}$) | 2.43 x $10^{-3}$ |
| Water Content (%) | 0.0 |
| Initial TPH Concentration (g/l) | 39.199 |

Figures 2 – 4 show the results of the experiment on the extent of spread of spilled petroleum in each soil, while Figs. 5 and 6 compares the extent of spread of a known volume of petroleum in the three types of soils.

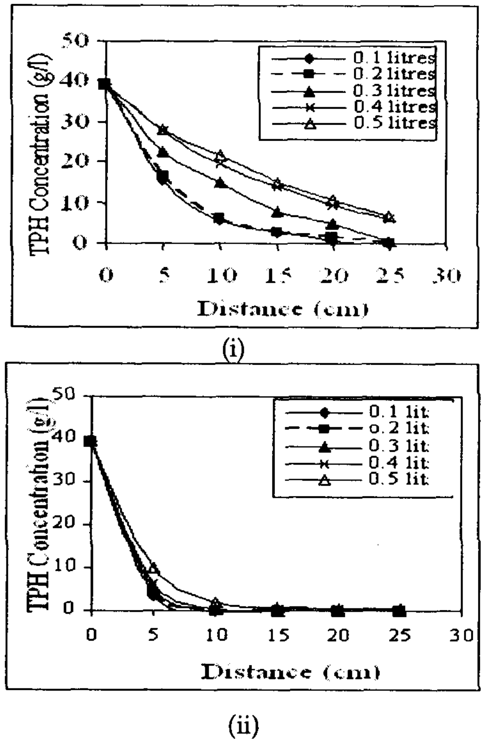
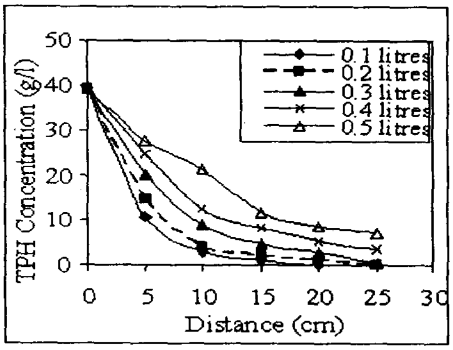


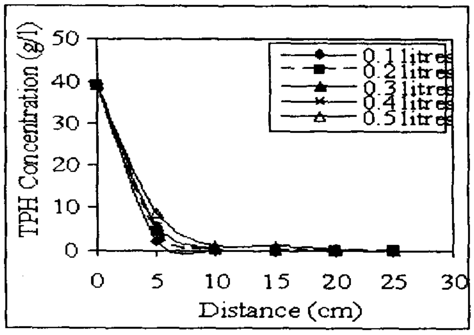

**Fig. 2.** Spatial concentration distribution of crude petroleum spilled in loamy soil.
(i) Verticle (y-direction) spead (ii) Horizontal (x-direction) spread

**Table 2.** Physical Properties of Soils

| Parameters | Sandy Soil | Top Soil | Loamy Soil |
|---|---|---|---|
| Soil Texture: Sand (%) | 96.40 | 92.80 | 60.0 |
| Silt (%) | 2.60 | 5.20 | 29.20 |
| Clay (%) | 1.00 | 2.00 | 10.80 |
| Bulk density (g.cm$^3$) | 0.53 | 1.04 | 1.39 |
| Particle density (g/cm$^3$) | 2.65 | 2.65 | 2.65 |
| Total porosity | 0.80 | 0.60 | 0.54 |
| pH | 5.02 | 5.60 | 5.00 |
| Organic matter content (%) | 2.04 | 2.47 | 2.69 |
| Total hydrocarbon content (%) | 0.00 | 0.00 | 0.00 |
| Hydraulic conductivity (cm/s) | 0.040 | 0.046 | 0.060 |
| Effective cation exchange capacity (kmol/kg) | 4.24 | 6.04 | 7.07 |
| Water content (%) | 57.08 | 58.11 | 64.92 |

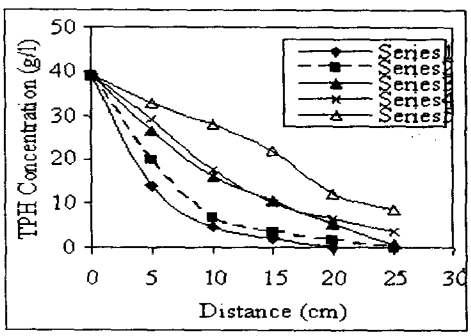



(i)




(ii)

**Fig. 3.** Spatial concentration distribution of crude petroleum spilled in Sandy soil.
(i) Verticle (y-direction) spead (ii) Horizontal (x-direction) spread

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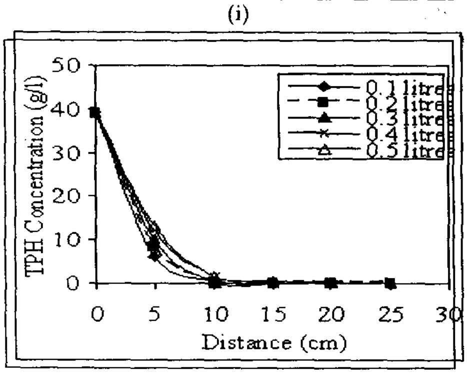
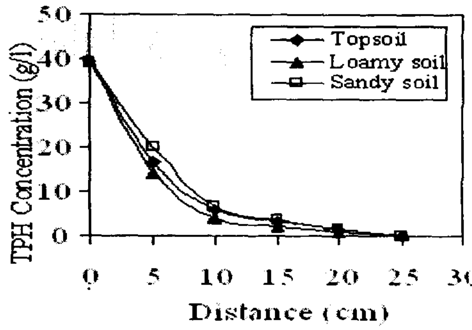
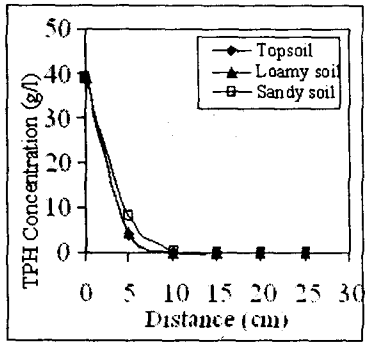



(ii)

**Fig. 4.** Spatial concentration distribution of crude petroleum spilled in top soil.
(i) Verticle (y-direction) spead (ii) Horizontal (x-direction) spread

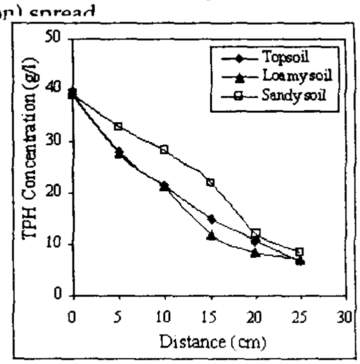



(i)




(ii)

**Fig. 5.** Spatial concentration distribution of crude petroleum spilled in different soils at spilled volume of 200cm$^3$.
(i) Verticle (y-direction) spead (ii) Horizontal (x-direction) spread

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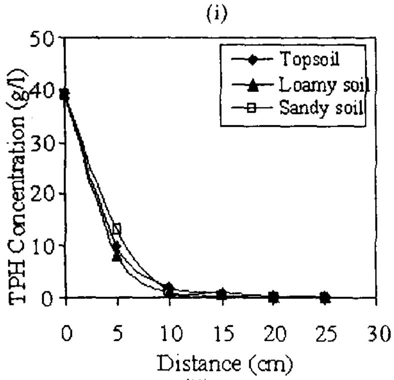


*(ii)*

**Fig. 6.** Comparison Spatial concentration distribution of crude petroleum in different soils at spilled volume of 200cm$^3$.
(i) Verticle (y-direction) spead (ii) Horizontal (x-direction) spread

It may be seen from Figs. 2 – 4 that the spatial concentration distribution of petroleum in soils media both in the horizontal and vertical directions is a function of the quantity of spilled petroleum. The more the volume of spilled petroleum the greater the distance migrated by the oil. This effect is more evident in the vertical downward spread, as the horizontal spread converges within a few centimeters after spill irrespective of the volume of spilled petroleum. Diffusion probably accounts for the concentration distribution of the spilled petroleum in the horizontal direction for all three soils investigated (Alshawabkeh and McGrath, 1999). In the vertical direction, the underlying soil becomes more saturated as the volume of spilled petroleum increases and the leading edge of the spilled petroleum spreads deeper leaving a residual level of immobile petroleum in the soil behind and above the advancing fronts, these results in a sharp decrease in the concentration of the petroleum as the distance migrated by the spilled petroleum increases. At low volume (0.1 and 0.2 litres), the spilled petroleum tends to sorb onto soil particles and the entire petroleum is immobilized within few centimeters after spill; this is due to the fact that volume of petroleum released is small relative to the soil retention capacity.

It can also be seen from Figs. 5 and 6 that the extent of migration of spilled petroleum in the horizontal and vertical directions is highest in sandy soil than in topsoil and least in loamy soil. This is due to the difference in physical properties of the soils. For example, sandy soil has the highest porosity and lower bulk density, followed by topsoil and then loamy soil. Water retention capacity of each soil also plays a significant role in the transport of spilled petroleum in soils. Loamy soil with the highest soil-water retention capacity exhibits high bubbling pressure which retards flow of the spilled petroleum more than topsoil, with the least flow retardation effects exhibited by sandy soil (Ostendorf et al., 1993; Shan, 2003). Baumann et al., (2002) and Finsterle (2004) showed that the shape and size of pores are of utmost importance in quantifying contaminant transport and entrapment in soils. The difference in flow profiles of the spilled petroleum in the three soils is also due to the fractional wettability of the soils (Collis-George and Greene, 1979; Or, 19996; Nemati et al., 2000). Loamy soil with the highest organic matter and water content allow only a portion of the total surface area to be preferentially wetted by the spilled petroleum, hence the low concentration of the petroleum in that soil compared to topsoil and sandy soils.

## CONCLUSION

Experimental investigations on the effects of volume of spilled petroleum on the spatial concentration distribution of the petroleum in different soils have been presented. It is shown that transport of spilled petroleum in the horizontal direction is very slow, and the volume of spilled petroleum does not have significant affect on the extent of spread in this direction. Although the distance migrated in the vertical direction increases as the volume of spilled petroleum increases, it is unlikely that groundwater would be contaminated by vertically migrating spilled petroleum if remediation action is carried out early in the life of a spill. Though, the experiments were designed to measure subsurface concentration distribution of spilled petroleum in the horizontal direction, and not along the soil surface, the results of this work give an insight into the transport behaviour of spilled petroleum on soil surface.

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