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Effect of Capillarity on Diffusion of Crude Oil in Soil Environment

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ABSTRACT

The effect of capillarity on diffusion of crude oil in soil environment in some fifteen measuring cylinders of different capacities, diameters and heights ranging from 10cm^3, 100cm^3, 250cm^3, 500cm^3, and 1000cm^3 volumes, 1.20cm, 2.80cm, 3.90cm, 4.80cm and 6.40cm diameters and 12.80cm, 24.10cm, 29.50cm, 34.0cm and 42.50cm respectively. Three quarters (3/4) of the capacity of the cylinders were filled with soil samples such as clay, loamy and sandy, while one quarter (1/4) filled with crude oil. The level created as a result of diffusion of crude into the soil matrix was measured every two minutes with a ruler to calculate the volume diffused into the soil environment. The heights of crude oil diffused into soil, the quantity of crude oil diffused and rate of crude oil diffused into the soil were monitored. In the three parameters monitored, it was discovered that increase in time of the diffusion of crude oil into the soil environment increase in the heights of crude oil diffused, the quantities of crude oil diffused and the rate of crude oil diffused. The diffusion is fastest in sandy, followed by loamy and least in clay in the parameters. The statistical analyses used were analysis of variance (ANOVA) and regression analysis. The time has effect on the height of crude oil that diffused into the soil environment. $P < 0.05$ significant. There was high positive correlation between the time and height of crude oil that diffused into different soil environment.

Key words: Capillarity, Diffusion, Crude Oil, Soil and Environment.

1. INTRODUCTION

Capillarity is defined as the tendency of liquids to rise or fall in a narrow capillary tube. The narrow, the tube, the greater is the capillarity effect. It was explained this is due to an attraction between the water molecules and the solid sides of the tube (Stone et al., 2001).

If a very narrow glass tube is inserted in a beaker of water, we observe that water rises up the tube and its surface is concave to the air in the tube. If an identical tube is placed is placed in a beaker of mercury, the surface is convex to the air and is depressed below the outside level. This is caused by cohesive and adhesive forces. Water and some liquids which wet glass rise in a capillary tube because the force of adhesion of the liquid molecules for glass is greater than their cohesion to each other. Hence water tends to rise up the glass and is concave upwards.

In the case of mercury the cohesion of its molecules is greater than their adhesion to glass. The mercury thus tends to curve inwards and becomes depressed in the tube. Okeke and Anyakoha, (2000) had made the following observations: that blotting paper has fine pores which act like tiny capillary tubes, ink and other liquids rise through the fine pores and enable the blotting papers to soak up the liquid; some common examples of capillary action are water rising up the stem of a plant, ink held on the nib of a pen, blood spreading through the fine capillary channels in the body, liquid candle wax rising up the wick of a candle.

Idodo-Umeh (1996) research to compare porosity and holding capacity of different soil types conducted an experiment, by plugging the neck of the filter funnels with glass wool. Then he put equal weights of the soil samples into each of them. Equal volume of water was poured onto each soil sample and the volume of water collected by each cylinder carrying the sandy soil. The experiment showed that clay retains more water than the two other samples. While loam retains more water than sandy soil, the clay soil retains more water than the loamy soil. It was concluded that sandy was more porous than loam and loam was more porous than clay. That is the porosity of sandy >porosity of loam > porosity of clay.

Soil contamination by crude oil and its products is widespread due to leaking storage tanks, spills, and improper disposal (Karkush and Abdul Kareem, 2018; Oramadike, 2018, Ukpaka, 2018). Although crude oil and its products are relatively immiscible with water, because water is an inorganic solvent, understanding the behaviour of these liquids in the subsurface is important since solubility may exceed drinking water standards. After release, crude oil migrates as a separate phase downward by gravity with some lateral spreading due to capillary forces. If sufficient crude oil has been spilled, eventually, it may reach the groundwater surface. If it is less dense than water (crude oil and its products) it will accumulate as a liquid lens that floats on the ground surface. If it is denser than water, it displaces groundwater and continues downward migration until it encounters a hydraulic or capillary barrier.

Floating crude oil can partly be removed by creating a pumping well (Mercer and Cohen, 1990). The less denser crude oil will flow towards the well, facilitated by the ground water table gradient and can be pumped into a recovery tank. Although, removing crude oil is difficult, and pressure gradients must be high, denser crude oil can be pumped out of the subsurface as well. Not all of the crude oil can be removed, since some of it is retained in the capillaries of the porous medium. The remaining crude oil can be contained hydrologically or can be removed by other techniques such as air sparging or bioremediation.

Research conducted by Abriola and Pinder (1985), Kaluarachchi and parker(1989) and White et al.(1995) observed that one of the most notable difference between reservoir models and other models is that in theto reservoir models, it is assumed that air is at atmospheric pressure, and pressure differences in the air phase are negligible. In addition, capillary forces appear to be especially important in Non- Aqueous phase Liquid (NAPL) contaminant transport problems. Capillary forces are due to interfacial tensions between the fluids and the solid in the capillaries (pores) of a porous medium. Since, velocities are small, capillary forces highly control the distribution of the fluids in the porous medium. Furthermore, the aim of contaminated subsurface lead to a relatively important role for capillary forces. Usually, quantification of un-remediated NAPL is needed as well as this NAPL mist retained in the pores due to capillary forces (Wipfler, 2003).

2. MATERIALS AND METHODS

Materials:

Soil sample, cylinders of capacities 10cm^3, 100cm^3, 250cm^3, 500cm^3 and 1000cm^3, a stop watch, crude oil, a beaker and a ruler.

Method:

The three soil samples were air- dried at normal temperature and pressure. A sieve of 2mm was used to filter the soil samples to obtain the required particle size. Some fifteen cylinders of the capacities1000cm^3, 500cm^3, 250cm^3, 100cm^3 and 10cm^3, heights of 42.5cm, 34.0cm, 29.50cm, 24.10cm and 12.80cm with diameters 6.40cm, 4.80cm, 3.90cm, 2.80cm and 1.20cm respectively were used to collect soil samples in the order of clay, loamy and sandy. The three quarters $\left(\frac{3}{4}\right)$ of the capacity of the cylinders were filled with soil samples, and one quarter$\left(\frac{1}{4}\right)$ with crude oil. The empty levels of the cylinders were measured with a ruler every two minutes to enable easy calculation of the volume of the crude oil that was diffused into the soil matrix, using the formula for the volume of cylinder $(V = \pi r^2 h)$The radius was obtained, using the formula, half of the diameter $\left(r = \frac{D}{2}\right)$; and the rate of diffusion of crude oil into the soil was calculated using the formula $\left(R = \frac{V}{t}\right)$.

The quantity of sand in 1000cm^3= $\left(\frac{3}{4}x1000cm^3\right) = 750cm^3$

The volume of crude oil in $1000cm^3 = 1000cm^3 - 750cm^3 = 250cm^3$

The quantity of sand in 500cm^3= $\left(\frac{3}{4}x500cm^3\right) = 375cm^3$

The volume of crude oil in $500cm^3 = 500cm^3 - 375cm^3 = 125cm^3$

The quantity of sand in 250cm^3= $\left(\frac{3}{4}x250cm^3\right) = 187.5cm^3$

The volume of crude oil in $250cm^3 = 250cm^3 - 187.5cm^3 = 62.5cm^3$

The quantity of sand in 100cm^3= $\left(\frac{3}{4}x100cm^3\right) = 75cm^3$

The volume of crude oil in $100cm^3 = 100cm^3 - 75cm^3 = 25cm^3$

The quantity of sand in 10cm^3= $\left(\frac{3}{4}x10cm^3\right) = 7.5cm^3$

The volume of crude oil in $10cm^3 = 10cm^3 - 7.5cm^3 = 2.5cm^3$

Figure 1 Experimental set-up for capillarity diffusion of Crude Oil in Soil Environment

3. RESULTS AND DISCUSSION

The results obtained from the research work are presented in Figures and Tables as described below.

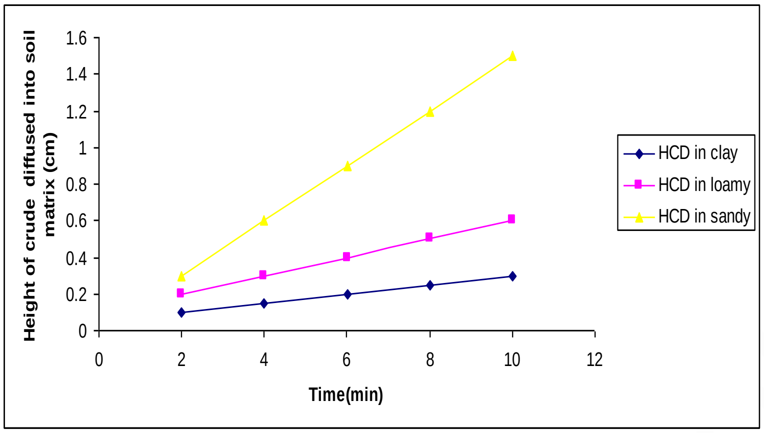

Figure 2 Variation of the Level of Crude Oil Diffused into Soil Matrix with Time in 1.20cm Diameter Cylinder.

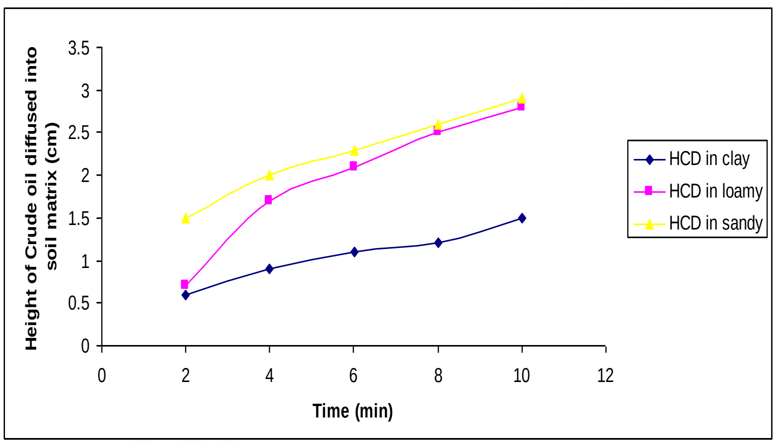

Figure 3 Variation of the Level of Crude Oil Diffused into Soil Matrix with Time in 2.80cm Diameter Cylinder.

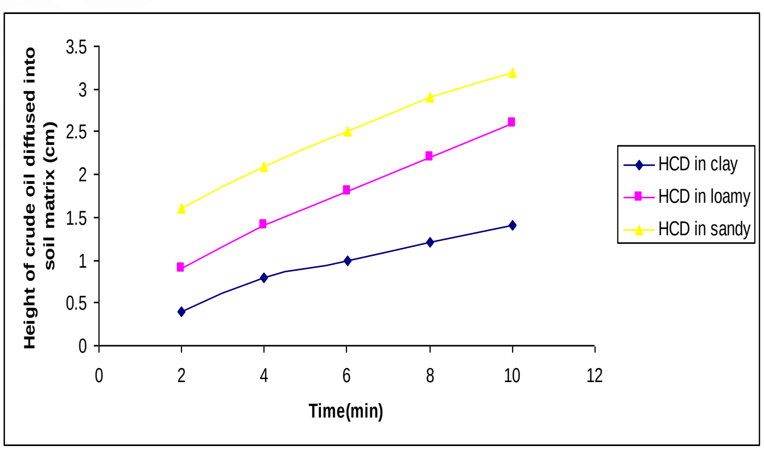

Figure 4 Variation of the Level of Crude Oil Diffused into Soil Matrix with Time in 3.90cm Diameter Cylinder.

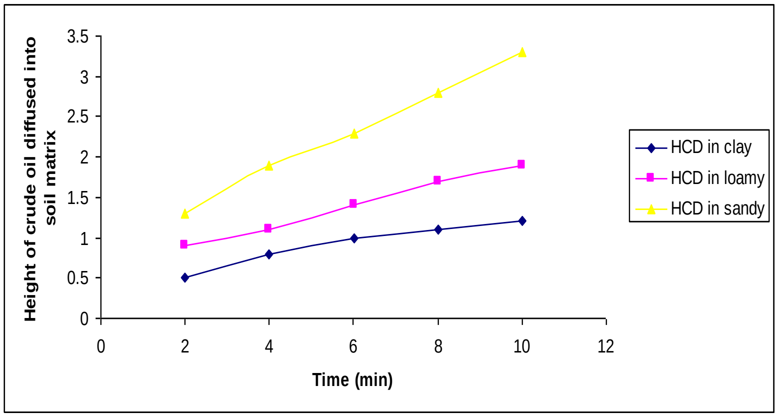

Figure 5 Variation of the Level of Crude Oil Diffused into Soil Matrix with Time in 4.80cm Diameter Cylinder.

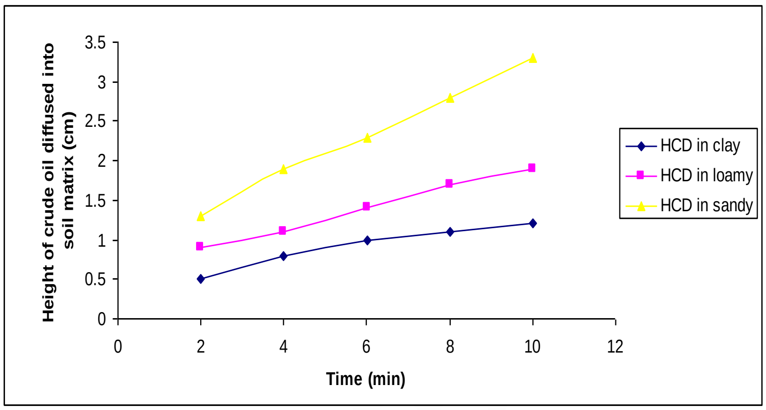

Figure 6 Variation of the Level of Crude Oil Diffused into Soil Matrix with Time in 6.40cm Diameter Cylinder.

Figure 2 to 6 demonstrates the relationship between heights of Crude diffused into soil matrix and time 1.20cm diameter cylinder. The degree of the crude oil diffusion of soil matrix is classified in the order of magnitude as HCD in sandy soil > HCD in loamy soil > HCD in clay soil as presented in Figure 2. The variation in the degree of diffusion of the crude oil can be attributed to the variation in time as well as the characteristics of the soil sample. From Figure 3 to 6 the same trend of behavior was experienced by the system as explained in Figure 2.Figure.2-6 shows the effect of the diameter of cylinders on the rate of diffusion of crude oil into the soil matrix. Generally, the diffusion of crude oil into the soil matrix increases as the diameter of the cylinders increases. It was observed that the porosity of the soil matrix played a vital role in the diffusion of crude oil in the soil environment. The soil with high porosity diffuses faster than the ones with low porosity. For instance, in the diffusion of crude oil in sandy soil in all the diameter of the cylinder it was higher than loamy and clay, because, sandy has highest porosity, followed by loamy and finally clay. The bulk density of clay and its plasticity will inhibit the flow of crude oil into the soil.

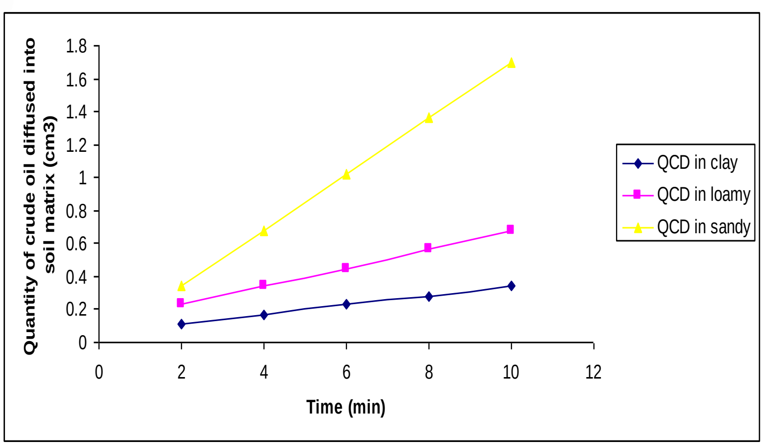

Figure 7 Variation of the Quantity of Crude Oil Diffused into Soil Matrix with Time in 1.20cm Diameter Cylinder.

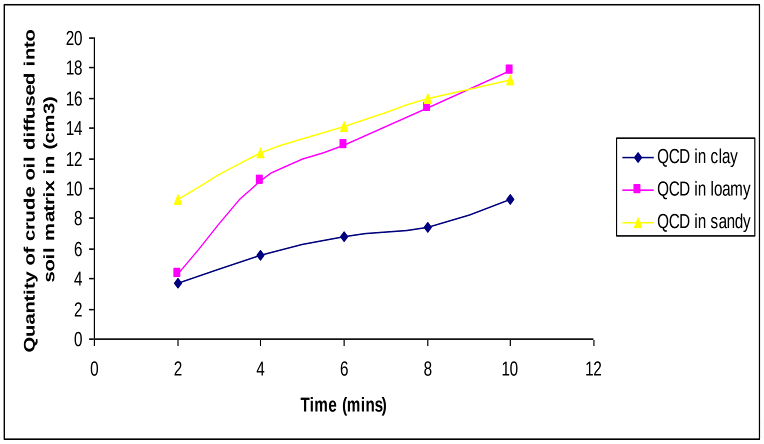

Figure 8 Variation of the Quantity of Crude Oil Diffused into Soil Matrix with Time in 2.80cm Diameter Cylinder.

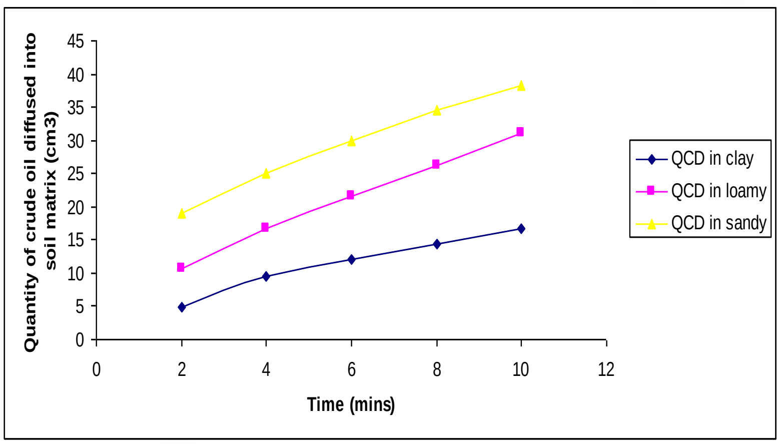

Figure 9 Variation of the Quantity of Crude Oil Diffused into Soil Matrix with Time in 3.90cm Diameter Cylinder.

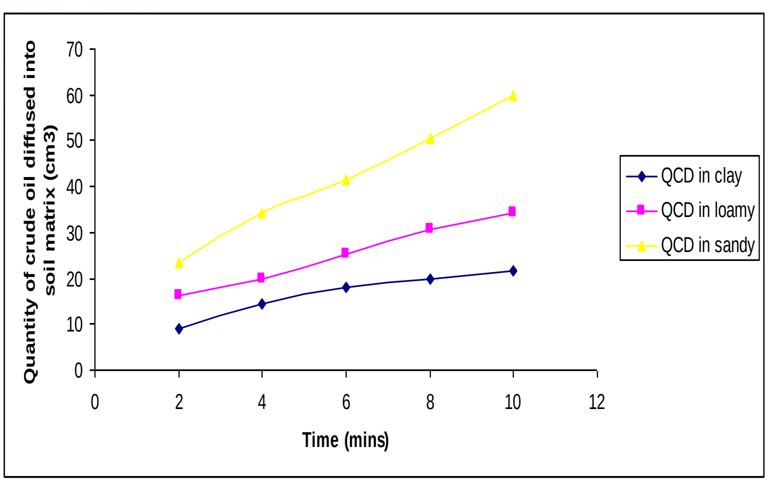

Figure 10 Variation of the Quantity of Crude Oil Diffused into Soil Matrix with Time in 4.80cm Diameter Cylinder.

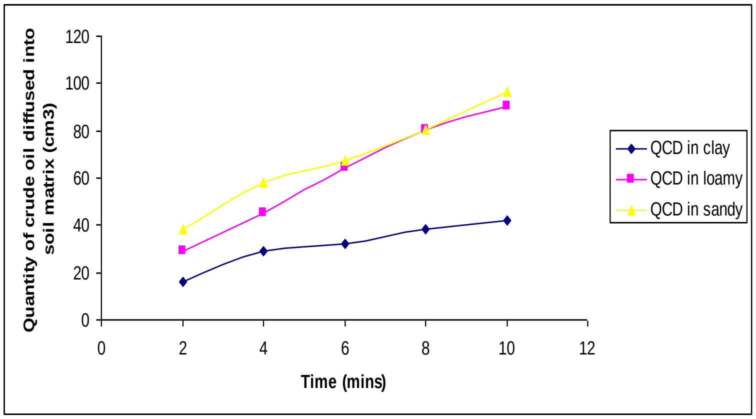

Figure 11 Variation of the Quantity of Crude Oil Diffused into Soil Matrix against Time in 6.40cm diameter cylinder.

Figure 7 to 11 illustrates the relationship between the quality of Crude oil diffused into matrix and time in various diameter of cylinder. Increase in diffusion was observed with increase in time upon the influence of varies in diameter of cylinder used for this investigation. The variation in the degree of the quality of crude oil diffusion in the soil matrix can be attributed to the variation in time as well as the changes in diameter of cylinder subjected into the research work. The degree of diffusion in order of magnitude is stated as QCD in sand soil> QCD in loamy soil > QCD in clay soil. This variation can be attributed to the characteristics of the soil structure, soil texture and other environmental factors. Figure 7-11 show the quantity of crude oil diffused into the soil environment with given time. It was observed that as the time increases, the quantity of crude oil diffused also increases in all the diameters of the cylinders. The quantity diffused into sandy in all the diameter of the cylinders recorded highest followed by the loamy and finally clay.

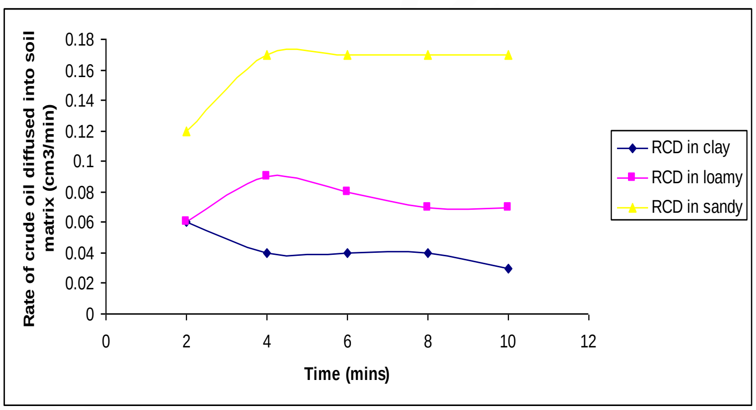

Figure 12 Variation of the Rate of Crude Oil Diffused into Soil Matrix aganist Time in 1.20cm Diameter Cylinder.

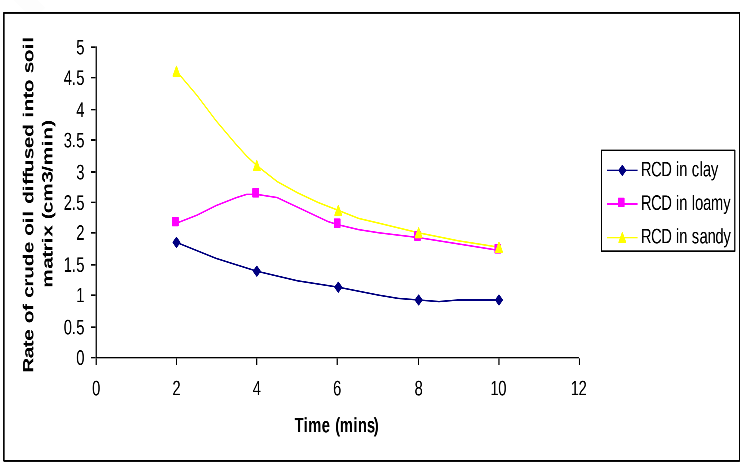

Figure 13 Variation of the Rate of Crude Oil Diffused into Soil Matrix aganist Time in 2.80cm Diameter Cylinder.

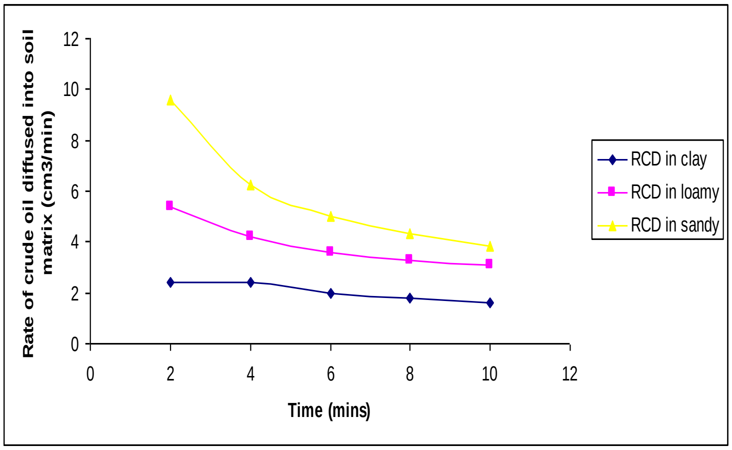

Figure 14 Variation of the Rate of Crude Oil Diffused into Soil Matrix aganist Time in 3.90cm Diameter Cylinder.

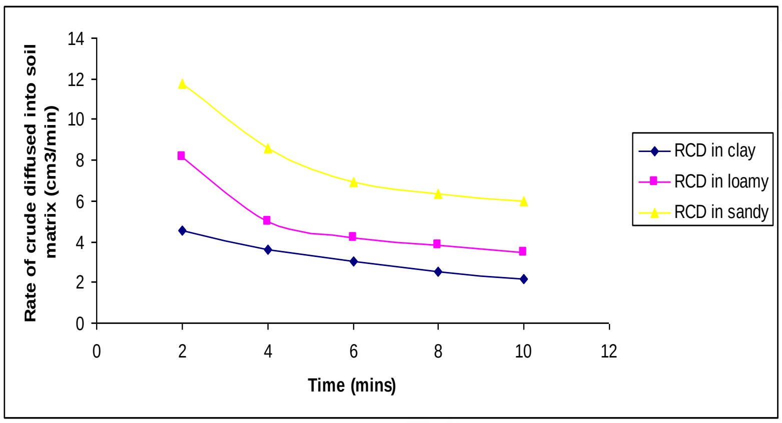

Figure 15 Variation of the Rate of Crude Oil Diffused into Soil Matrix aganist Time in 4.80cm Diameter Cylinder.

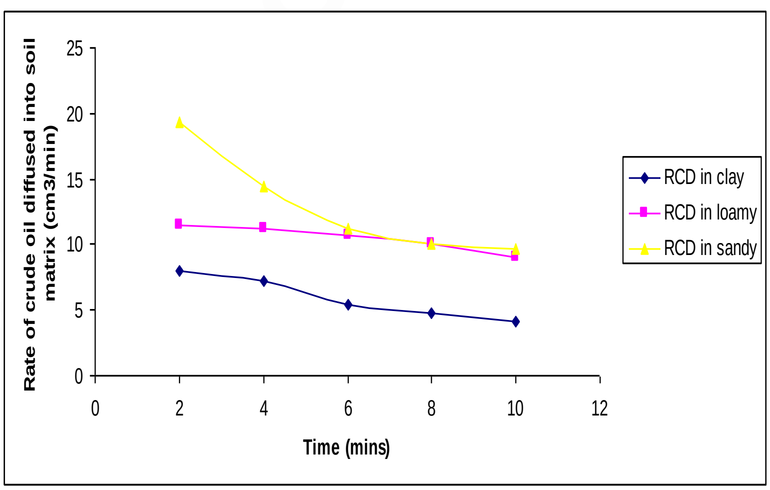

Figure 16 Variation of the Rate of Crude Oil Diffused into Soil Matrix aganist Time in 6.40cm Diameter Cylinder.

Figure 12 to 16 demonstrate the relationship between the rate of Crude oil diffusion in soil matrix and time at various diameter of Cylinder. In Figure 12 increase in the rate of diffusion of Crude oil in sandy soil was experienced and slight increase in loamy soil whereas the clay soil experienced decrease. In the case of Figure 13 decrease in the rate of diffusion of crude oil was observed in sandy soil and clay soil whereas in the case of loamy soil slight increase was observed before sudden decrease. In Figure 14 decrease in sandy, loamy and clay soil was experienced with increase in time for 3.90cm diameter of cylinder. The research work demonstrates the significance of the cylinder diameter on the rate of diffusion of crude oil. Figure 12-16 show the rate of diffusion of crude oil into the soil environment. It was observed that the rate of diffusion in sandy soil is faster than in loamy and loamy faster than that of clay in all the cylinders. Increase in diameter proliferates the rate of diffusion of crude oil in the soil environment.

The statistical analysis was presented in table 1, 2 and 3. Table 1 (a – e) show the analysis of variance (ANOVA). It was observed that the time has effect on the height of crude oil that diffused into the soil environment, P< 0.05 level of confidence. Table 2 and 3 show the R2 – values of the correction of time and the height of crude that diffuse into different soil environment in different capacities of the cylinders and the regression equations of the correlation of time and height of crude oil that diffuse into different soil matrix of different capacities of cylinders.

Statistical Analysis

H_o: T_1 = 0 Time has no effect on the height of crude oil that diffuse into soil matrix in cylinders.

Table 1(a) Analysis of Variance (ANOVA) of the Height of Crude Oil that Diffuse into Different Soil in 10cm^3 Cylinder

Sources of Variance	df	SS	MS	F_{cal}	F_{tab}
Total	14	2.33			
Treatment	2	4.67	2.34	-11.7	3.74
Error	12	-2.35	-0.20		

F_{tab}>$F_{cal}$$H_o$: Reject

Table 1(b) Analysis of Variance (ANOVA) of the Height of Crude Oil that Diffuse into Different Soil in 100cm^3 Cylinder

Sources of Variance	df	SS	MS	F_{cal}	F_{tab}
Total	14	9.94			
Treatment	2	35.48	17.74	-8.36	3.74
Error	12	-25.54	-2.12		

F_{tab}>$F_{cal}$$H_o$: Reject

Table 1(c) Analysis of Variance (ANOVA) of the Height of Crude Oil that Diffuse into Different Soil in 250cm^3 Cylinder

Sources of Variance	df	SS	MS	F_{cal}	F_{tab}
Total	14	9.61			
Treatment	2	39.44	19.72	-7.92	3.74
Error	12	-29.83	-2.49		

F_{tab}>$F_{cal}$$H_o$: Reject

Table 1(d) Analysis of Variance (ANOVA) of the Height of Crude Oil that Diffuse into Different Soil in 500cm^3 Cylinder

Sources of Variance	df	SS	MS	F_{cal}	F_{tab}
Total	14	8.46			
Treatment	2	32.36	16.18	-8.13	3.74
Error	12	-23.9	-1.99		

F_{tab}>$F_{cal}$$H_o$: Reject

Table 1(e) Analysis of Variance (ANOVA) of the Height of Crude Oil that Diffuse into Different Soil in 1000cm^3 Cylinder

Sources of Variance	df	SS	MS	F_{cal}	F_{tab}
Total	14	8.39			
Treatment	2	34.18	17.09	-15.97	3.74
Error	12	-25.79	-1.07		

F_{tab}>$F_{cal}$$H_o$: Reject

Table 2 R^2 – Values of the Correlation of Time and the Height of Crude Oil that Diffuse into Different Soil Matrix in Different Capacity of Cylinders

Volume of Cylinder(cm^3)	R^2 – value in Clay	R^2 – value in Loamy	R^2 – value in Sandy
10.00	1	1	1
100.00	0.9757	0.9494	0.9734
250.00	0.973	0.9977	0.9926
500.00	0.9383	0.9941	0.9971
1000.00	0.9304	0.9889	0.9898

Table 3 The Regression Equations of the Correlation of Time and the Height of Crude Oil that Diffuse into Different Soil Matrix of Different Capacities of Cylinders.

Volume of cylinders (cm^3)	Regression equations in clay	Regression equations in loamy	Regression equations in sandy
10.00	$y = 0.025X + 0.05$	$y = 0.05X + 0.1$	$y = 0.15X$
100.00	$y = 0.105X + 0.43$	$y = 0.26X + 0.42$	$y = 0.16X + 1.28$
250.00	$y = 0.12X + 0.24$	$y = 0.21X + 0.52$	$y = 0.2X + 1.26$
500.00	$y = 0.085X + 0.41$	$y = 0.13X + 0.62$	$y = 0.245X + 0.85$
1000.00	$y = 0.095X + 0.41$	$y = 0.245X + 0.45$	$y = 0.215X + 0.83$

4. CONCLUSION

The effect of capillarity on diffusion of crude oil in soil environment of five different capacities of cylinders was investigated. The height of crude oil diffused, quantity of crude oil diffused, and rate of crude oil diffused into the soil environment increase with time. Optimal height, quantity and rate of crude oil diffused into the soil environment were obtained using 500cm^3 cylinder at 10 minutes, 90.09cm^3 at 10 minutes quantity and 19.31cm^3/min at 2minutes rate. The diffusion was fastest in sandy than the other two types of soil. This was as a result of the porosities and bulk densities of the soil environment.

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