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# Hydrocarbon Penetration in Multi-Porosity Soil

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**Abstract.** Groundwater contamination is crucial, particularly due to hydrocarbon liquid leakages. Additionally, the vibration impact affects the migration of hydrocarbon through the subsurface soil to the groundwater surface which is caused by the dynamic stress that is imposed on the soils. Therefore, this paper presents the investigation and discussions on the penetration of Light Non-Aqueous Phase Liquid (LNAPL) in vibrated unsaturated double-porosity laterite soil with 30% moisture content. The apparatus used for this experiment are a vibrating table, acrylic soil column, mirror, LNAPL and a Nikon D90 digital camera. The LNAPL migration pattern in laterite soil was monitored and recorded using a digital image processing technique (DIPT) at certain time intervals. The images were processed using Surfer software and Matlab routine to plot the LNAPL hue-saturation-intensity (HSI) values. As a result, the migration rate of LNAPL decreased with the impact of vibration towards the soil due to the rearrangement and porosity of the soil structure and this was found to affect the speed of liquid penetration.

## 1. Introduction

Asia has progressed in working towards strengthening the role of groundwater by introducing early warning systems, preparing for disasters, as well as focusing on establishing integrated water resource management, sustainable cities and urban planning [1]. Changes in climate have also been found to affect the water sector [2] particularly due to a country's growing demand for water which influences the availability of enough quality water to be provided at both the local and global scale [2 – 4]. The effects caused by vibration towards soil include volumetric deformation of the soil aggregate structures, cracked and unsteady soil structures as well as rearrangement of the macro soil structure. Natural events such as earthquakes, wave and wind loading as well as man-made events such as construction operations, and vibrations caused by vehicle and machinery traffic affects the characteristics and condition of pore sizes of soil [5].

According [6, 7], double-porosity characterization is determined with two specific sub-regions in soil. In agricultural top-soils and compacted soils, it has been found that presence of pore-size bimodal distribution with inter and intra-aggregate pores for aggregated laterite soil [8, 9]. Organic contaminants have been found to exist in three phases which are in an aqueous phase liquid (APL), a



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non-aqueous phase liquid (NAPL) and gaseous phase [10] in subsurface soil. In recent studies, researchers have produced more physical laboratory tests on double-porosity soil [6, 11 – 16] thus contributing to a knowledge of double-porosity soil.

According [17 – 19], there has been a substantial advancement in research regarding the vibration effects on the soil strength and deformation properties. Recent researchers have produced valuable data from various experiments which have been tested and conducted on cohesive and cohesion-less soils with the application of vibration [20 – 22]. Fundamentally, aggregated soil was vibrated using a vibratory table (CN166A8-VP181 Syntron) model.

Thus, in an attempt to fill the research gap, there is a need to study the movement of contaminants in laterite soil because of laterite location at low land areas and the tendency for it to be most widespread in areas in Malaysia with relatively dry climates and argillaceous rocks [23]. A few objectives were set which are; (i) to investigate intra-aggregate and inter-aggregate on the characteristics of double-porosity, and (ii) to determine the pattern of migration on red dyed-oil in aggregated laterite soil by exerting of vibration impact using digital image processing. Section 2 illustrates the process of vibration on the soil samples as well as the digital image processing technique which captures the penetration of LNAPL through the soil media. Results of the image analysis are presented in the form of hue-saturation-intensity plots and discussions and are presented in Section 3 while Section 4 gives the conclusion of this study.

## 2. Materials and Methods

Soil samples were taken from Faculty of Electrical Engineering, at the School of Electrical Engineering in Universiti Teknologi Malaysia, Johor and were tested for Atterberg Limit, Specific gravity, particle size distribution and permeability test based on the Unified Soil Classification System (USCS) and the British Standard BS1377-2:1990, BS1377-5:1990.

**Table 1.** Laterite soil properties

Property	Unit	Value
Liquid Limit	(%)	66
Plastic Limit	(%)	33
Plasticity Index	(%)	33
Particle Density	(Mg/m <sup>3</sup> )	2.74
USCS	Classification	(CH) Clay with High Plasticity
Permeability, $K_{average}$	(m/s)	$4.62 \cdot 10^{-7}$

### 2.1 Vibration setup

Preparation of the double-porosity aggregated soil samples follow the methods [7, 14, 23, 24]. Dried aggregate soil was passed through a 2.36mm sieve and mixed with 30% of water content and labelled as Sample 2 and Sample 1. The soil samples were stored in resealable plastic bag and placed in dark room with room temperature to ensure the moisture content equalize between the soil particles and does not evaporate at least 24 hours for curing process.

After curing process, each sample was put inside the circular acrylic column, and was compressed until the soil sample height reached 100mm as shown in Figure 1. Figure 2 shows the soil samples that were prepared. Acrylic soil columns with sealed bases were used and were specifically designed according to [25, 26] as Figure 3. Bolts and nuts were used to secure the column on the vibratory table and the transparent acrylic soil column was observed from all angles to ensure all the bolts and nuts fix with the surface of vibratory table.



**Figure 1.** Surface of soil sample



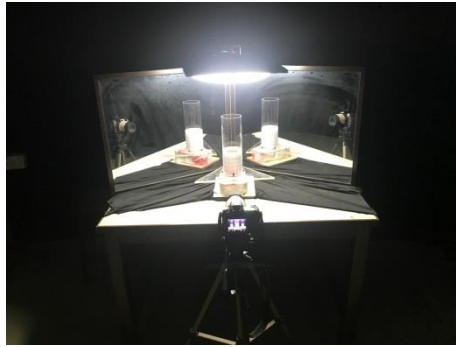
**Figure 2.** Compressed soil sample



**Figure 3.** Vibration on soil sample

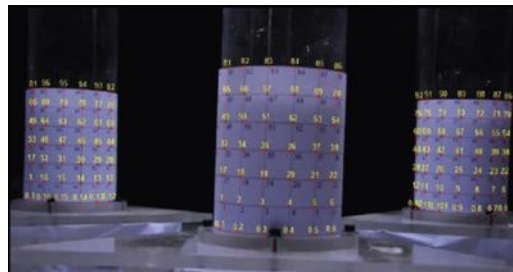
### *2.2 Migration setup*

A Nikon D90 DSLR digital camera with ISO speed and aperture setup 2500 and f/5.6 was used to capture horizontally migration pattern of LNAPL for all experiments. The samples were sheathed with a 20mmx20mm gridline as a control reference image on digitization process and 150 ml red dyed toluene was poured onto the soil sample. The images were taken with specific time intervals as shown in Figure 4.



**Figure 4.** Digital image preparation

Surfer Software and Matlab routine was used to carry out the image processing and the images in JPEG were extracted as digitization control points referring to the boundary area of migration for Sample 1 and Sample 2 as shown in Figure 5.

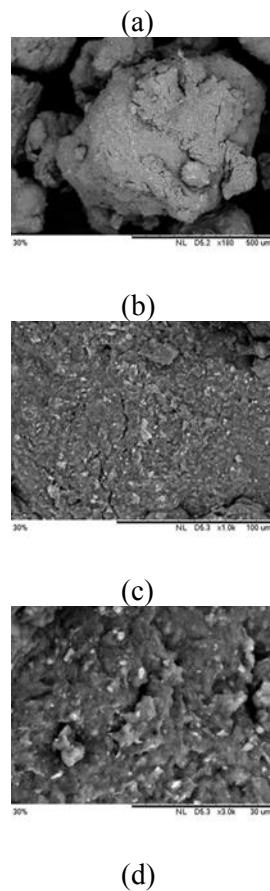


**Figure 5.** Digitization control points for image processing

### 3. Results and Discussion

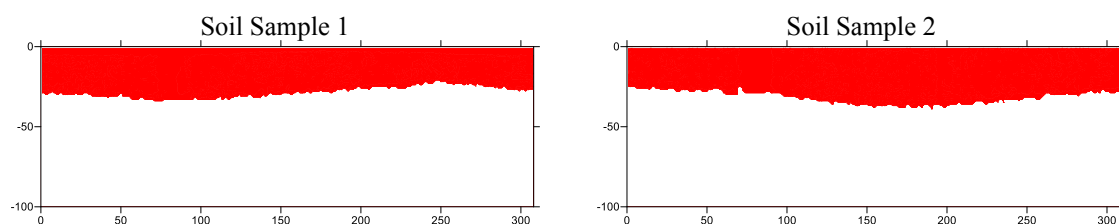
Soil sample with 30% moisture content porosity were validated using Scan Electron Microscopy (SEM) as seen in Figure 6. SEM test displays the inter-aggregates and intra-aggregates pores in multi fold magnification value such as 180, 1000 and 3000 with individual laterite granule split up among the soil sample [26, 27]. The sample has a coarse granule structure and displayed the characters of soil liquidity. Therefore, the double-porosity characteristics of laterite soil were expected to contribute to the speed of liquid penetration and migration [7, 12, 24].

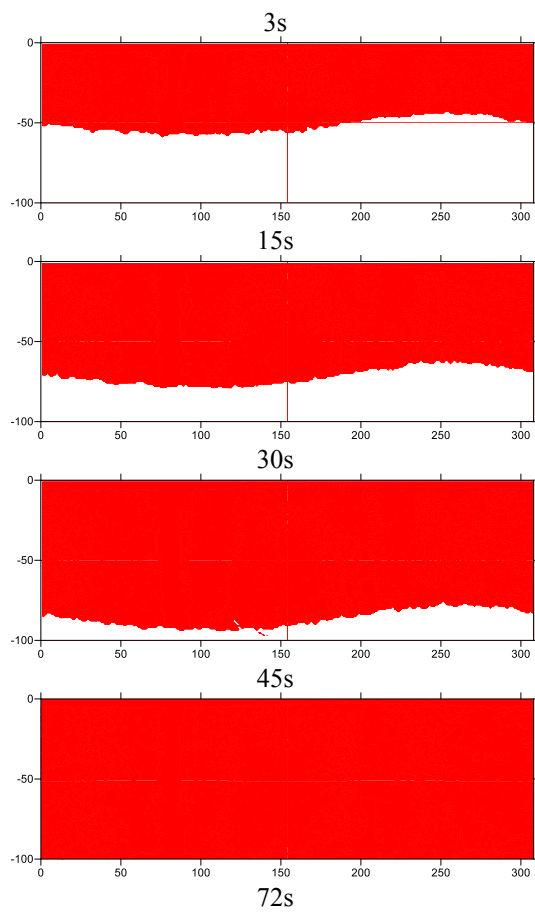




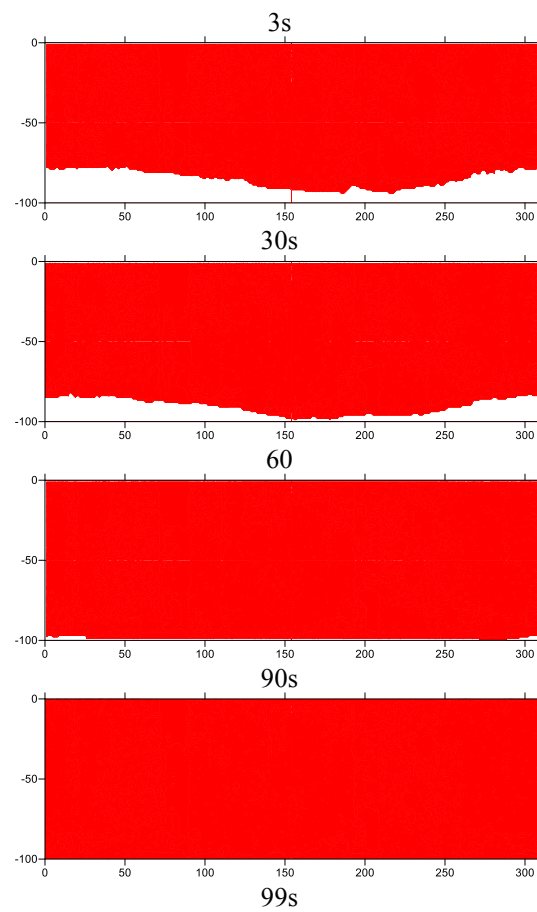
**Figure 6.** (a) Soil sample, (b) 180-fold magnification, (c) 1000-fold magnification and (d) 3000-fold magnification using scan electron microscopy double-porosity Soil

Selected HSI plots of hydrocarbon liquid migration can be seen in Figure 7 and Figure 8 at intervals of 3, 15, 30, 45, and 72 seconds, and sample 2 at intervals 3, 30, 60, 90 and 99 seconds. The observation shows that the migration of LNAPL penetrated downwards on the horizontal line one-directional through the soil samples. However, the second image of HSI shows that the migration rates were affected by vibration effect. It can be concluded that the results differentiated and had identified that with and without the impact of vibration soil sample 1 had the fastest migration compared to soil sample 2 as it took the red-dyed oil a shorter time to cover soil sample. Furthermore, a longer time was taken for the red-dyed oil to cover soil sample when added with vibration compared to the soil sample without vibration.





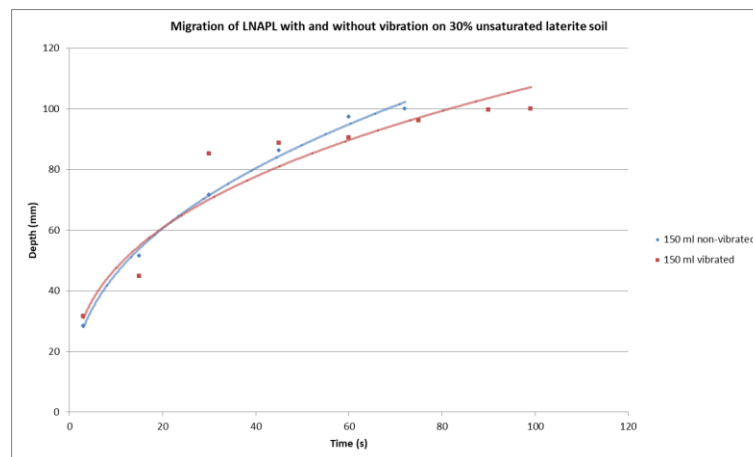
**Figure 7.** Hue-saturation-intensity (HSI) image without vibration impact to soil sample



**Figure 8.** Hue-saturation-intensity (HSI) image with vibration impact to soil sample

Based on Figure 9, it was proven that the rate of migration for soil sample 1 (3.37 mm/s) was faster than in soil sample 2 (2.91 mm/s). The rate of migration was affected by the pore space between the soil arrangement and grain size of soil [29] and the density of soil [29, 30] due to densification process from vibration impact. The presence of vibration makes the soil more compact by filling up the pores found between intra and inter aggregates that act as double-porosity soil as denser soil thus reducing the rate of migration in soil sample 2 making the rate of migration slower as compared to soil sample 1.





**Figure 9.** Migration of LNAPL through soil sample

#### 4. Conclusion

Laboratory experiments on red dyed-oil migration through an aggregated laterite soil with 30% water content with and without vibration were conducted. The experiment study was deliberately designed to observe the red dyed-oil migration behavior and pattern in aggregated laterite soil placed in a soil column model. In conclusion, the observation demonstrated that for the downward migration experiment, the dyed-oil migrated uniform faster in the soil sample with vibration effect compared to without vibration effect. It was proven that the presence of vibration effect has an influence on the migration behaviour due to densification process of soils' density. It shows that the presence of vibration affect the migration speed rate and giving an improvement on soil structure for remediation process. Issue of storage tank from gas station can be solve by implant vibration method on subsurface soil that intact with storage tank underground to make sure the migration of contaminants did not penetrate until groundwater table .

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