# Effects of physical properties on LNAPL migration in porous media under fluctuating water table conditions

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*Keywords: fluctuating groundwater, LNAPLs, saturation, porous media, Simplified Image Analysis Method*

## 1. INTRODUCTION

Petroleum hydrocarbons do not readily mix with water and are known as Non-Aqueous Phase Liquids (NAPLs) which are classified into two types. Dense Non-Aqueous Phase Liquids are NAPLs with a specific density of more than 1. Light Non-Aqueous Phase Liquids are NAPLs with specific density less than 1. When released to soil and groundwater environments can lead to unacceptable risks. Understanding the distribution of NAPL in the subsurface is important to allow the installation of effective monitoring system and cost-effective strategies for remediation of contaminated aquifers (Palmer and Johnson 1989).

In order for the NAPLs to be successfully analyzed by the saturation image technique used in this study, this linear relationship had to be established for the 8 selected NAPLs. This was done with the use of two cameras with two band-pass filters with different wavelengths ($\lambda$ =450 & 640) and water and NAPL are dyed with predominant colors of wavelength 450 and 640. As proposed by Flores *et al* (2009) mixing different saturations of oil and water, taking photograph of the system for analysis obtained two sets of linear equations that can be solved to attain the values of saturation of water ($S_w$) and NAPL ($S_o$).

## 2. MATERIALS AND METHOD

A $3.5 \times 3.5 \times 50$ cm one-dimensional column with a transparent glass-wall was used to easily study the behavior of LNAPL affected by a fluctuating groundwater table in Toyoura sand (particle density $\rho$ = 2.63 g/cm$^3$). The wetting fluid used was blue-dyed water (Brilliant Blue FCF, 1:10000) and the non-wetting fluids used were dyed with red dye (Sudan III, 1:10000). These were Ethylbenzene, Low Viscosity Paraffin, Motor Oil, N-decane, NEOVAC, N-dodecane, Nitrobenzene and Silicone Oil. In the column tests the 3 LNAPLs selected for their behavior studies are shown in Table 1 with the values of its viscosity and density.

**Table 1: Tested LNAPLs Viscosity and Density**

| LNAPL | Viscosity (mPa.s) | Density (g/cm$^3$) |
|---|---|---|
| Ethylbenzene | 1.5 | 0.87 |
| Low Viscosity Paraffin | 7 | 0.88 |
| N-Decane | 1.4 | 0.73 |

2.1Simplified Image Analysis Method (SIAM):

The Simplified Image Analysis Method is an imaging technique for measuring saturation that is designed to produce photographic images of the dynamic domain in the duration of the experimental in its desired conditions comparing it with photographs of 3 extreme conditions (Photo 1: $S_w$ = 0%, $S_o$= 0%; Photo 2: $S_w$= 100%, $S_o$= 0%; Photo 3: $S_o$= 100%, $S_w$= 0%). The images are analyzed giving the Average Optical Density ($D_i$) from both digital cameras with band-pass filters of wavelengths λ =450 & 640. This method from previous studies provides an error percentage of less than ±10%.

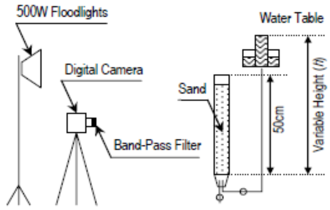


**Figure 1: Column experiment set up**

2.2 Column Experiment Conditions

In the initial conditions the 1-D Column was filled with fully saturated Toyoura Sand. Throughout the experiment the room temperature was kept controlled at 20˚C, humidity was kept constant at 70%. In the drainage stage the watertable was lowered to -5cm for 72hours then in the imbibitions stage watertable was raised to 40cm for 24 hours.

## 3. RESULTS AND DISCUSSIONS

Ethylbenzene penetrated to 15cm depth. When the watertable was at -5cm, Ethylbenzene reached equilibrium at *h*=25cm. $S_w$ drops quicker during the 2nd drainage compared to the 1st drainage this can be due to the *hysteresis effect*. Low Viscosity Paraffin migrated to a depth of 25cm. N-decane penetrated to about 20cm depth at 1st drainage. When the watertable was lowered to -5cm, N-decane reached equilibrium at column height 20cm for the first drainage.

## 4. CONCLUSION

The 8 selected non-aqueous phase liquids all provided linear relationships between average optical density ($D_i$) and saturation ($S_o$ and $S_w$). Low Viscosity paraffin migrated the slowest out of the 3 LNAPLs migrating to the least depth in the first half hour of the test. N-decane and Ethylbenzene with similar viscosity penetrated to the same depth at the first half hour of the test thus we conclude that both move at a similar speed. Low Viscosity Paraffin which has the highest viscosity appeared to have penetrated the deepest out of the 3 LNAPLs.