Non-aqueous phase liquids distribution in three-fluid phase systems in double-porosity soil media: Experimental investigation using image analysis

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ABSTRACT

Over the last few decades, contamination of groundwater and soil by non-aqueous phase liquids (NAPLs) has become a serious and wide-spread problem for the environment. In this research, a light transmission visualization (LTV) method was used to observe the migration of dense non-aqueous phase liquid (DNAPL) and light non-aqueous phase liquid (LNAPL) in double-porosity soil within a three-fluid phase system (air-NAPL-water).

The double-porosity characteristics of the soil were created using a composition made up of local sand and sintered kaolin clay spheres arranged in a periodic manner. Toluene was used to simulate LNAPL while tetrachloroethylene (PCE) represented the DNAPL. Both NAPLs were dyed using Oil-Red-O for better visualization.

For comparison purposes, the same experiments were carried out using just local silica sand acting as a type of single-porosity soil. A significant difference in the migration of the toluene and PCE was observed as both the NAPL migration rates in the double-porosity medium were much faster compared to the migration rates found in the single-porosity medium. This result is most likely due to the occurrence of inter-aggregate pores in the double-porosity soil that contribute to increasing velocity of fluid migration through porous media. Other factors such as the wettability of fluids and capillary pressure characteristics that exist in the soil pores were found to be influential factors in fluid migration within porous media. In addition, the results show that chemical properties have a significant influence on the NAPL migration in porous media. It was found that the migration velocity of toluene was much faster compared to the migration velocity of the PCE. This observation is most likely caused by the fact that the distribution coefficient of toluene was higher than that of PCE which in turn means that the retardation factor of toluene is lower than that of PCE in the same porous media. This paper proved that the LTV provides a non-intrusive and non-destructive technique for studying multiphase flow in double-porosity soil media where rapid changes in fluid distribution in the entire flow domain is not easy to measure using conventional tools.

1. Introduction

Contamination of groundwater and soil by non-aqueous phase liquids (NAPLs) has become a serious and wide-spread problem for the environment (Luciano et al., 2012; Tick et al., 2015). Spills of petroleum products and leaks from underground storage tanks are examples of NAPL releases in the subsurface system. Generally, NAPLs are divided into two main types based on its density; dense non-aqueous phase liquid (DNAPL) which is denser than water and light non-aqueous phase liquid (LNAPL) which has density less than water. Chlorinated solvents such as trichloroethylene and tetrachloroethylene are the most spread examples of DNAPL, whereas benzene, toluene, ethyl-benzene and xylene (BTEX) are examples of LNAPL (Sweijen et al., 2014). When LNAPL is released into the subsurface, it will migrate downward until it reaches the water table (Mercer and Cohen, 1990). For DNAPL, its behaviour is similar to LNAPL in the unsaturated zone after being released into the subsurface but while LNAPL tends to pool on groundwater it encountered, DNAPL will continue to...