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IMAGE ANALYSIS OF NON-AQUEOUS PHASE LIQUID MIGRATION IN AGGREGATED KAOLIN

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ABSTRACT

Double-porosity is an important feature in soil due to its influence on the migration of fluids within the soil. Conventional ways of measuring fluid saturation involves intrusive use of equipment that may disturb the original setting of the sample being measured. The use of image analysis has overcome this problem but has rarely been applied in research concerning double-porosity soil media. The study presented in this article applies image analysis to study the migration of non-aqueous phase liquid (NAPL) in soil with double-porosoity features. In this study, the laboratory experiments were conducted in a three-dimensional rectangular acrylic model and images were acquired using the photographic technique. Immiscible NAPL was chosen as the fluid applied as it is relatively less studied in double-porosity media compared to miscible contaminants. Aggregated kaolin was used as the double-porosity soil samples. Image analysis was utilized to observe the migration of the NAPL based on migration area coverage, the optical saturation of the NAPL as well as the intensity of the NAPL during migration. The experiments were performed over a range of different moisture content contained in the aggregated soil samples and the effect of different soil moisture content on the migration of NAPL in double-porosity soil was analyzed. The experimental results showed that the rate of NAPL migration will increase as the moisture content increases. In summary, image analysis was found to be a viable method in observing and visualizing the migration of NAPL based on optical saturation, intensity, and area invaded by NAPL in double-porosity soil.

Keywords: double-porosity, moisture content, photographic technique, subsurface contamination.

INTRODUCTION

Contamination of the subsurface by hydrocarbons through accidental spillage or poorly designed disposal is one of the most challenging environmental problems faced by many countries. Some of the most commonly encountered organic subsurface contaminants are petroleum by-products such as benzene, toluene, ethylbenzene and xylene as well as chlorinated solvents, usually from industrial activities (Tian et al. 2014). These compounds usually exist in the subsurface in the form of non-aqueous phase liquids (NAPL) because of their low aqueous solubility that comes from their non-polar molecular structure (Pankow and Cherry, 1996). Due to their low solubility in water, residual NAPLs constitute a long-term source of groundwater contamination. NAPLs are able to migrate to the water table and eventually become trapped in the saturated zone as residual ganglia occupying the soil pores and held in place by capillary forces.

The soil structure will also influence the migration of NAPLs. Natural geomaterials frequently exhibit two distinct scales of porosity, with the macro pores surrounding the micro pores (Burger and Shackelford, 2001; Manrique et al. 2007). Double-porosity may arise due to root holes, worm holes, fissures and cracks in soil (Beven and Germann, 1982) or due to the aggregated nature of the medium (Ghezzehei and Or, 2003). Fissuring and cracking are common defects in soil usually observed in heavily over-consolidated or desiccated clay (Garga, 1988) whereas aggregation are often found in agricultural soils as well as soils that were compacted on the dry side of the optimum moisture content (Romero et al. 1999). Figure-1 illustrates the concept of double-porosity.

Image analysis is a type of computer analysis that is used to extract meaningful information from images. In the field of civil engineering, image analysis is often used (Maas and Hampel, 2006) to study the movement and behaviour of very small or tiny properties such as the propagation of cracks in a structure or the occurrence of boundary layers in flow over immersed objects. Voids or porositiness in soils are hard to see with the naked eye, hence the application of image analysis can be a fitting method to study the migration of NAPL in the subsurface.

In this research, image analysis was used to study the migration of NAPL in double-porosity soil represented by aggregated kaolin clay. The fabric of the aggregated kaolin can be divided into inter-aggregate pores and intra-aggregate pores, as shown by the works of Ngien et al. (2012). They have also found that within the same duration, organic contaminants will actually travel further in soil with double-porosity features compared to in single-porosity soil. This is due to the fact that secondary porosity features such as inter-aggregate pores or cracks are usually larger than the primary porosity of the soil media. Therefore, the NAPL has to overcome a relatively lower capillary pressure to enter the secondary porosity features.