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ANALYSIS OF DNAPL MIGRATION IN AGGREGATED KAOLIN AND SAND USING LIGHT TRANSMISSION VISUALIZATION (LTV) METHOD

HO XI CUI

Thesis submitted in fulfilment of the requirements for the award of the degree of B. Eng (Hons.) Civil Engineering

Faculty of Civil Engineering and Earth Resources UNIVERSITI MALAYSIA PAHANG

JUNE 2016

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LIST OF SYMBOLS

%	Percentage
μ m	Micrometer
Kt	Permeability Coefficient
°C	Degree Celcius
cm ³	Centimeter cube
g	Gram
Gs	Specific gravity
kg	Kilogram
m/s	Meter per second
ml	Milliliter
mm	Millimeter
mm²	Millimeter square
S	Seconds
V	Volume of samples
W	Required weight of the soil samples
¥	Unit weight of soil samples

LIST OF ABBREVIATIONS

BET	Brunauer, Emmett and Teller
BS	British Standard
CCD	Charged-Coupled Device
CCL ₄	Carbon Tetrachloride
DNAPL	Dense Non-Aqueous Phase Liquids
EPA	Environmental Protection Agency
LNAPL	Light Non-Aqueous Phase Liquids
LTV	Light Transmission Visualization
MGP	Manufactured Gas Plant
NAPL	Non-Aqueous Phase Liquids
PCBs	Polychlorinated Biphenyls
PCE	Tetrachloroethylene
TCE	Trichloroethylene
USCS	Unified Soil Classification System

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ABSTRACT

Physical model experiments based on Light Transmission Visualization (LTV) method were conducted to study and observe the migration of dense non-aqueous phase liquids (DNAPL) in both single and double-porosity soil mediums. DNAPL that used in the research is tetrachloroethylene (PCE). Aggregated kaolin was prepared and acts as double-porosity soil medium whereas Ottawa sand represent single-porosity soil medium. A three-dimensional rectangular acrylic model which filled with soil samples was then mounted on a light box and placed inside a dark room. A digital camera starts capture images of DNAPL migration once known amounts of DNAPL is injected into flow chamber. In the end of the experiments, digital images were collected and analyzed by using Image-Pro Premier 9.1 which is an image analysis software. The analysis focused on the cumulative area, depth, saturation as well as rate of DNAPL migration. It was found that the DNAPL migrate much faster in double-porosity soil compared to singleporosity soil. The total cumulative DNAPL migration area in double-porosity soil also larger than single porosity soil. This shows that the existence of inter-aggregate pores in double-porosity soil medium has significant impact on the migration of immiscible fluids within double-porosity soils.

ABSTRAK

Eksperimen model fizikal berdasarkan Light Transmission Visualization (LTV) method telah dijalankan untuk mengkaji dan memerhati migrasi cecair bukan fasa akueus (DNAPL) dalam kedua-dua jenis tanah, iaitu tanah keliangan tunggal dan tanah keliangan dua. DNAPL yang digunakan dalam kajian ini adalah tetrachlorethylene (PCE). Agregat kaolin telah disediakan sebagai tanah keliangan dua manakala pasir Ottawa sebagai tanah keliangan tunggal. Sebual model akrilik tiga dimensi berbentuk empat telah penuh dengan sampel tanah dan dipasang pada kotak cahaya di dalam sebuah bilik gelap. Sebuah kamera digital telah digunakan untuk mengambil gambar setelah DNAPL disuntik ke dalam sampel tanah. Pada akhir eksperimen, imej digital telah dikumpul dan dianalisis dengan menggunakan Image-Pro Premier 9.1 yang merupakan satu perisian analisis imej. Analisis ini memberi tumpuan kepada kawasan migrasi, kedalaman, ketepuan serta kadar migrasi DNAPL. Kajian ini mendapati bahawa migrasi DNAPL lebih cepat dalam tanah keliangan dua berbanding tanah keliangan tunggal. Jumlah kawasan DNAPL migrasi dalam keliangan tanah dua juga lebih besar daripada tanah keliangan tunggal. Hasil kajian ini membuktikan bahawa kewujudan liang antara agregat dalam keliangan tanah dua mempunyai kesan yang besar ke atas migrasi DNAPL dalam tanah keliangan dua.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Of late, more and more research focused on double-porosity in soil. The doubleporosity characteristic exists naturally in soil and can be found in many subsurface media such as agricultural top-soils (El-Zein et al., 2006), rock aquifers (Pao and Lewis, 2002) and compacted soils (Romero et al., 1999). Double-porosity may also be caused by plant roots, natural soil pipes, soil fauna, cracks and fissures (Beven and Germann, 1982). This type of soil is consists of both intra-aggregate pores and inter-aggregate pores.

Non-aqueous phase liquids (NAPL) are present in numerous contaminated soil and groundwater sites. NAPL are hydrocarbons that are immiscible with water and form a visible, separate oily phase in the subsurface. It can be classified into two general categories which are light non-aqueous phase liquids (LNAPL) and dense non-aqueous phase liquids (DNAPL). LNAPL have specific gravity lesser than water whereas DNAPL have specific gravity greater than water. Examples of LNAPL are kerosene, benzene and toluene and the most common DNAPL are chlorinated solvents such as trichloroethylene (TCE), carbon tetrachloride (CCl₄) and tetrachloroethylene (PCE). NAPL are released into the subsurface due to accidental spills, pipe leakage and leaks from underground storage tanks. Migration of NAPL is affected by capillary forces, gravity and viscous forces of gravity and soil capillarity. DNAPL tends to migrate laterally through soil capillarity after reach a stratigraphic unit of lower permeability.

Previous studies found that double-porosity soil have great impact on the migration of immiscible fluids (Ngien et al., 2012a). Hence, this research concentrate on the influence of double-porosity features in soil to the migration of DNAPL, which are one of the immiscible contaminants. Light transmission visualization (LTV) method which is a non-invasive laboratory technique will be adopted to observe the migration of DNAPL in single and double-porosity soil media. Digital images will be collected to monitor DNAPL migration within single and double-porosity soils.

1.2 PROBLEM STATEMENT

Soil contamination issues are currently gaining global attention. Soil contamination occurs when chemical substances are discharged into soil due to accidental oil spills, pipe leakage, leaks from underground storage tanks and being buried directly in soil. Contaminants then flow into the adjacent groundwater and causes contamination of groundwater. Groundwater is the world's major freshwater store and source of drinking water. It is also one of the most important sources of water for irrigation. NAPL are one of the contaminants that are always associated with human activity and released into soil which causes soil and groundwater contamination.

There are thousands of DNAPL impacted sites in North America, continental Europe and other industrialized areas of the world (Kueper et al., 2003). NAPL can cause severe environmental and health hazards which is a threat to the soil ecosystems and to the groundwater reserves. NAPL components dissolve in water in very small quantity and at very low rates. Thus, a small volume of NAPL in soil can threaten the groundwater quality in the long run. Moreover, NAPL can exist in the subsurface for decades, giving it more chance to contaminate large volumes of groundwater. However, migration of DNAPL in double-porosity soil has not yet been widely studied. In fact, the double-porosity characteristic which occur naturally in soil will increase the complexity of transport and fate of DNAPL. Thus, it is necessary to carry out this research in order to study the behavior and migration of DNAPL through double-porosity soil medium.

1.3 OBJECTIVES

The main objectives of this research can be outlined as follow:

- i. To determine the physical properties of soil samples that serve as single and double-porosity medium.
- To investigate and study DNAPL migration in both single and double-porosity media using light transmission visualization (LTV) method.
- iii. To compare the behaviour of DNAPL migration in double-porosity medium under different release method.

1.4 SCOPE OF STUDY

The soil adopted for this study is kaolin S300 and Ottawa sand. Samples from both of the soil will be put through a series of experiments such as sieve analysis, hydrometer test, atterberg limits, pycnometer test, porosity test as well as BET test and falling head permeability test to obtain physical properties of the soil. Both of the soil will then be classified according to the Unified Soil Classification System (USCS) based on the physical properties of soil samples. After that, two sets of experiments designated as Experiment 1 and Experiment 2 will be carried out in this research. The methodology for these two experiments is basically the same. For Experiment 1, the soil medium that will be used is Ottawa sand which is a single-porosity soil medium whereas for Experiment 2, the soil medium that will be used is aggregated kaolin which is a double-porosity soil medium. The method of DNAPL release is by injection. The migration of DNAPL in these two experiments will be observed in a flow chamber made of acrylic. The dimensions of each flow chamber is 30 cm (width) x 45 cm (height) x 1 cm (thickness). DNAPL that will be used in this research is tetrachloroethylene (PCE). Physical model experiments based on LTV method will be adopted to observe the migration of DNAPL in both single and double-porosity soil media. During experiments, Canon EOS Kiss X6i will be used to capture images at specific time intervals. At the end of the experiments, digital images will be collected and analysed to monitor DNAPL migration.

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