IMAGE ANALYSIS ON MIGRATION OF NON AQUEOUS PHASE LIQUID IN COMBINED SINGLE AND DOUBLE POROSITY MEDIA

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor in Civil Engineering (Hons.).

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

_____

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Thesis submitted in fulfillment of the requirements
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

cm	Centimetre
cm^2	Centimetre square
cm^3	Cubic centimetre
g	Gram
g/cm^3	Gram per cubic centimetre
g/ml	Gram per millilitre
g/mol	Gram per mole
kg	Kilogram
kg/m^3	Kilogram per cubic metre
m^3	Cubic metre
mg/ml	Milligram per millilitre
ml	Millilitre
mm	Millimetre
mmHg	Millimetre of mercury
m/s	Metre per second
ppm	Parts per million
s	Second
kN/m^3	Kilo Newton per cubic metre
%	Percentage
^oC	Celsius

LIST OF ABBREVIATIONS

COC	Chemical of Concern
DNAPL	Dense Non Aqueous Phase Liquid
DSLR	Digital Single-Lens Reflex
HDR	High Dynamic Range
HSI	Hue-Saturation-Intensity
HSL	Hue-Saturation-Lightness
JPEG	Joint Photographic Experts Group
LNAPL	Light Non Aqueous Phase Liquid
NAPL	Non Aqueous Phase Liquid
RGB	Red-Green-Blue

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ABSTRAK

Pengangkutan, penyimpanan serta pengurusan sebatian cecair yang berbahaya kepada alam sekitar adalah penting untuk industri kimia dan petroleum. Kebanyakan sebatian ini membentuk fasa cecair yang berbeza dalam hubungan dengan air disebabkan oleh kelarutan yang sangat rendah di dalam air. Mereka dikenali sebagai cecair fasa bukan akueus (NAPLs). NAPLs boleh dihubungkan dengan alam sekitar disebabkan oleh kecuaian ketika tumpahan semasa proses pengangkutan atau akibat daripada kebocoran dalam paip atau tangki bawah tanah. Secara umumnya, terdapat dua jenis NAPLs yang boleh membawa pencemaran kepada subpermukaan persekitaran iaitu yang ringan cecair fasa bukan akueus (LNAPLs) dan padat cecair fasa bukan akueus (DNAPLs). Oleh itu, adalah penting untuk mengkaji penghijrahan NAPLs di dalam tanah. Objektif utama kajian ini adalah untuk mengkaji corak aliran NAPLs dan menyiasat perbezaan dalam LNAPL dan DNAPL terhadap ciri-ciri aliran dalam gabungan keliangan tanah berlapis satu dan dua. Toluene digunakan sebagai LNAPL manakala trichloroethylene sebagai DNAPL. Keliangan tunggal tanah adalah diwakili oleh 0.15mm saiz pasir manakala kaolin agregat digunakan sebagai media keliangan berganda. Terdapat dua lapisan pasir dan dua lapisan kaolin agregat yang diletakkan seli antara satu sama lain dengan pasir sebagai lapisan yang paling bawah. NAPLs kemudiannya dituangkan ke dalam model akrilik yang mengandungi media yang disediakan awal dan kemudiannya kamera DSLR digunakan untuk menangkap imej dan akhir sekali perisian Image-Pro digunakan untuk tujuan analisis imej. Penghijrahan kedua-dua NAPLs dianalisis melalui imej yang ditangkap dengan pemprosesan data oleh perisian Image-Pro. Kesimpulannya, migrasi NAPLs adalah lebih cepat dalam kaolin agregat keliangan berganda berbanding dengan penghijrahan NAPLs dalam pasir keliangan tunggal. Ia juga dapat disimpulkan bahawa toluene iaitu LNAPL yang digunakan dalam kajian ini akan mengambil masa yang lebih lama untuk diserap sepenuhnya oleh media berbanding dengan trichloroethylene DNAPL yang digunakan dalam kajian ini. Ketumpatan yang lebih tinggi daripada DNAPL akan menyebabkan daya graviti untuk menjadi lebih besar untuk menarik titisan NAPL ke bawah. Trichloroethylene mampu berhijrah dengan lebih mendalam kerana ia lebih tumpat daripada air berbanding dengan toluene.

ABSTRACT

Transportation, storage as well as management of environmentally hazardous fluid compounds are essential for chemical and petroleum industries. Many of these compounds form a different fluid phase when in contact with water due to their extremely low solubility in water. They are known as non-aqueous phase liquids (NAPLs). NAPLs can get into contact with the environment due to accidental spills during transportation processes or as a result of leakage in pipes or underground tanks. Generally, there are two types of NAPLs that can bring contamination to the subsurface environments and they are light non-aqueous phase liquids (LNAPLs) and dense non-aqueous phase liquids (DNAPLs). Therefore, it is important to study the migration of NAPLs in the soil. The main purpose of this research is to study the flow pattern of NAPLs and investigate the difference in LNAPL and DNAPL flow characteristics in combined single and double porosity layered soil. Toluene was used as the LNAPL whereas trichloroethylene represented the DNAPL. Single porosity soil was represented by 0.15mm sized sand whereas aggregated kaolin was used as the double porosity media. Two layers of sand and two layers of aggregated kaolin were placed alternately with sand as the bottom layer. NAPL was then poured into the acrylic model with the media prepared earlier and then DSLR camera was used to capture the images and finally Image-Pro software used for image analysis. The migration of both NAPLs was analyzed through the images captured based on data processing using the Image-Pro software. In conclusion, the migration of NAPLs is much faster in double porosity aggregated kaolin compared to the migration of NAPLs in single porosity sand. It is also concluded that toluene, which is the LNAPL used in this research, will take a longer time to be fully spread throughout the media as compared to the DNAPL trichloroethylene used in this research. The higher density of DNAPL will cause the gravitational force to become bigger to pull the NAPL droplets downwards. Trichloroethylene is able to migrate deeper as it is denser than water as compared to toluene.

CHAPTER 1

INTRODUCTION

1.1 Background

Transportation, storage as well as management of environmentally hazardous fluid compounds are essential for chemical and petroleum industries. Many of these compounds form a different fluid phase when in contact with water due to their extremely low solubility in water. They are known as non-aqueous phase liquids (NAPLs) (Francisca and Montoro, 2014). Due to accidental spills during transportation processes or leakage in pipes or underground tanks, NAPLs can get into contact with the environment (Fetter, 1993). Before reaching and entering the phreatic zone, NAPL contaminants will percolate through the vadose zone. Therefore, the unsaturated zone is crucial in determining how and when the contaminants will reach the groundwater table. Some NAPL such as fertilizers and pesticides need the moisture existing in the soil and also the infiltration of either the rain or irrigation water in order for the downward movement to take place. Due to both the capillary forces and the surface tension of the different phases in the subsurface, NAPL usually leaves a fraction of themselves trapped in some or all of the pores of the soil when moving through the vadose zone (Mitchell and Soga, 2005).

Generally, there are two types of NAPLs that can bring contamination to the subsurface environments. First type is the lighter hydrocarbons whose density is less than that of the water which is also known as light non-aqueous phase liquids (LNAPLs). The second one which is the heavier one and is denser compared to the water are known as dense non-aqueous phase liquids (DNAPLs). LNAPL will pass through the unsaturated soil and float on groundwater surface whereas DNAPL will move in the downward direction through the saturated soil in order to settle. The key to the disposition of NAPLs in the subsurface is the geologic configuration. As the bulk

liquid does not penetrate the saturated zone, movement in the unsaturated zone is taken as the main consideration. On the other hand, DNAPL disposition will be adversely affected by the structure of both saturated and unsaturated regions.

In terms of soil, there are several factors that can contribute to the double-porosity condition of the soil such as cracks, soil pipes, root holes and soil fauna (Beven and Germann, 1982). Aggregated soil which consists of soil aggregates and inter-aggregate pores also contributes to the double-porosity in soil. These features in soil are known as secondary porosity features. They act as the paths with least resistance for NAPL to flow through the soil (Ngien et al., 2012).

1.2 Problem Statement

Leakage and spills of hydrocarbon through the Earth's subsurface often lead to groundwater contamination, causing the groundwater to become toxic and unfit for consumption and irrigation purposes. Groundwater contamination caused by hazardous chemicals is of great concern in this era due to the scarcity of water. Groundwater contamination is difficult to detect and control and this may persist for decades. This is especially true when the contamination is a result of non-aqueous phase liquids (NAPL), which have been considered as one of the more ubiquitous groups of groundwater contaminants. A lot of research has been conducted to study the migration of NAPL in the soil. In this research, the media used is the combination of the single porosity sand and the double porosity aggregated kaolin in order to study the flow pattern of NAPLs through combined single and double porosity media as well as the flow characteristics difference in LNAPL and DNAPL. This can contribute to the determination of the method of remediation to mitigate the risk associated with aquifer contamination by NAPLs. Obtaining the appropriate flow pattern is important because the remaining contaminant is usually in the area of lower permeability whereas the reduction of this concentration with respect to its initial value is essential to the contribution to the reduction of the level of contamination of groundwater source. Image analysis is a viable method to observe and visualize the migration of NAPL based on optical saturation and area invaded by NAPLs. Flow pattern of NAPLs can be investigated based on the area invaded by NAPLs through the image analysis done by this software.

1.3 Objective of Study

In any research, there are several objectives that are required to be accomplished. In this research, the objectives are:

i. To study the flow pattern of NAPLs through combined single and double porosity layered media.
ii. To investigate the difference in LNAPL and DNAPL flow characteristics in soil with combined single and double porosity layered media.

1.4 Scope of Study

In this research, samples were prepared with single porosity sand as the first layer followed by double porosity aggregated kaolin as the alternate layer. Samples of kaolin aggregates were prepared with a moisture content of 30%. Each layer had a thickness of 7 cm and there were a total of 4 layers. In this case, the LNAPL used was toluene while the DNAPL used was trichloroethylene. A physical acrylic model with size of 10 cm x 4 cm x 30cm was used to accommodate the combined media sample with a size of 10 cm x 4 cm x 28 cm. NAPLs were poured into the samples prepared and pictures were captured by using a camera. Time was taken until the NAPLs settle down and dried up. After that, image analysis was conducted by using Image Pro-Premier 9.1. Lastly, the migrations of different NAPLs in a combined media sample were studied and analysis was done through the images taken from DSLR camera. In this research, one set of LNAPL and DNAPL was prepared respectively to study the migrations of different NAPLs in a combined media sample.

1.5 Research Significance

The research conducted can provide a clearer study and analysis on migration of NAPLs in the sample consisting of single porosity sand as the first layer at the bottom which is then followed by the double porosity aggregated kaolin sample and this was repeated twice, in which the whole sample consisted of two layers of sand and also two layers of aggregated kaolin. NAPL body may act as the long-term origin of chemicals of concern (COC) for the aqueous (dissolved) and vapor phases which are known as compositional plumes. The dissolution or volatilization of the COC from NAPL body into other phases creates unacceptable risks over time. The NAPL body may also

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