Examining The Penetration of Light Non-Aqueous Phase Liquid in Double-Porosity Materials Via Both Computer Modeling and Experimental Methods

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Abstract

Benefits of groundwater availability for human activities in developing countries Groundwater contamination is an important issue, especially given the amount of hydrocarbon water, like that light non-aqueous pasture water (LNAPLs), which migrates and spreads, which contaminates groundwater and makes it unsuitable for domestic and agricultural use. Double-pored soils enable the observation of hydrocarbon liquids diffusing into groundwater. Thus, this work uses computer modeling to measure and predict LNAPL infiltration from physical test data to investigate LNAPL infiltration in double porous soils. LNAPL infiltration parameters and rates described in computers in this example are the practical use of Digital Image Processing Technology (DIPT) and MARA. For calibration and validation purposes, LNAPL volumes of 70 ml and 150 ml were concurrently applied to the the surface of the soil sample. A digital camera was used to capture and monitor the penetration of the two porosities at predetermined intervals. LNAPL penetration patterns were generated on the images using the Matlab program and Surfer software. Data from the physical analyses were used to measure and confirm that LNAPL penetrated the double-pored soil. Consequently, Petrasim's findings are consistent with the results of the actual experiment. The Nash-Sutcliffe function yields coefficients greater than 0.50 with percentage differences of 2.63% and 3.47% between the actual tests and the Petrasim coefficients, respectively. In conclusion, further investigation of LNAPL infiltration into subsurface soils can be carried out using Petrasim simulation.

Keywords: *Groundwater, Contamination, LNAPL, Infiltration, Computer Modeling, Petrasim, Calibration and Validation*

Introduction

Groundwater is the primary **source of water for** homes, businesses, and agriculture. The resources were greatly expanded by the rapid rise of civilization. One of the most important groundwater environmental problems is groundwater leaching of petroleum hydrocarbons, which reduces **the quality and quantity of groundwater, as** seen in Figure 1, and contamination is difficult to detect, causing major issues. Even if the soil were formed by dual porosity, contaminants would move **through the subsurface system**. Dual porosity media have two different pore medium sizes and pore distribution shapes, with an emphasis also placed on inter-aggregate pores, such as compacted agricultural soil [1]. One-sided infiltration in experimental testing can have two effects. Furthermore, certain studies [2] have begun to investigate in detail the properties of double porous soils in the physical laboratory. Due to budget constraints and time constraints, building a physical experiment and simulating computer models is the only practical way to conduct large-scale experiments.

Although computer model simulation can mimic the experimental parameters with boundary conditions, the developed model can better predict the behaviour of the full experimental system, according to Agaoglu et al. [3]. The studies used non-invasive imaging techniques, focusing on system characteristics and monitoring for greater accuracy. Groundwater modeling is used to predict future flow patterns and types to determine areas such as water management, post-spill cleanup, and protection of groundwater quantity and quality. Thus, computer modeling is important. Therefore, attention and emphasis on groundwater seepage are necessary for the sustainability of the terrestrial environment. Consequently, the uptake of LNAPL in a double-pored soil is discussed in this study and verified by Petrasim simulation.

Fig 1. NAPL leak from the subterranean storage petrol station [4]

Theory and empirical analysis of computational modeling

Computer was used to verify the results of the physical test. Once the computer model is validated against the experimental data, the groundwater model can be used to simulate how the LNAPL penet modeling rates the two porosities. Understanding the flow of water in the porous macrostructure is important when developing physical examinations. Two categories of soil systems: monoporous as well as biporous. Single porosity occurs when all soil porosity measurements are the same; on the other hand, bi-porosity occurs when the natural structure of the soil has two distinct porosity scales. The Drake well, discovered in Pennsylvania, was the first oil well, and it was there that the concept of a double-ridge earth was introduced, according to Black, Locke et al. [5], Rahman and Loke [6], all tested flow at bi-porosity. According to previous studies, a non-invasive technology called digital image processing technique (DIPT) can be used to investigate NAPL penetration. Agaoglu et al. employ non-invasive imaging techniques as one of their investigational skills to determine NAPL saturation and subsurface system patterns. A more economical, simple, and effective method is to use image saturation techniques to determine the NAPL saturation model at different times during laboratory experiments. [7].

Computer modeling was used to confirm the findings of the physical tests. Computational modeling, especially for groundwater flow and transportation systems, government policy formulation, and groundwater management, is becoming increasingly important. Understanding multimodal behaviours underground in groundwater system technology and operations would be beneficial. Additionally, water conservation and restoration efforts can benefit economically from modeling aids in the development of technical design, regulations, testing, and new policies [8]. The numbers of researchers who use multimodal systems under isothermal or isothermal conditions in 2-dimensional soil structures with deformable soil structures to determine NAPL flux with specific phases in numerical analysis Tough2 computer models are the best bottom flow model for multiphase systems under unsaturated conditions. The Tough2 simulator is used to develop a wide variety of groundwater flow transport challenges, including geothermal and other reservoir simulations.

Objectives of the study

- To investigate LNAPL infiltration in a double-pored soil by using physical experiments and computer modeling.
- To determine LNAPL infiltration parameters by using MARA and Digital Image Processing Technology (DIPT).
- To validate LNAPL penetration models by using Petrasim software simulation and physical analysis and check LNAPL penetration with 150 and 70 ml LNAPL volumes.
- To test the consistency between results from the Petrasim system and field observations through validation and calibration.
- To analyse Nash-Sutcliffe performance efficiency for verification and measurement purposes.
- To compare the LNAPL infiltration rate to determine the velocity difference between two soil wells to calculate the appropriateness.
- To consider how LNAPL penetration may affect the long-term safety and cleanliness of laterite soils.

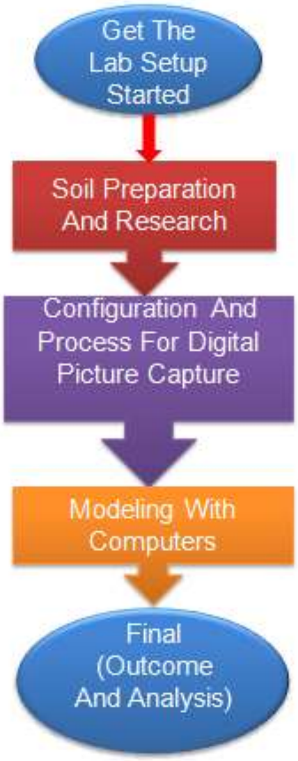
Need of the study

Through a combination of computer modeling and physical experiments, the study seeks to investigate LNAPL penetration into two porous soils, which is important for assessing the risk of groundwater contamination, and useful mitigation strategies have been developed.

Material and methods

The materials and methods used in this study are described below. Figure 2 shows the schematic of the experimental design. Digital image collection, computer modeling, soil analysis, and preparation of the installation and process will all be covered by the method. The next sections briefly discuss the LNAPL intrusion model in computational and experimental models.

Fig 2. Framework Workflow



Investigation

Laterite soil sample was taken one metre below ground level to avoid collecting dry soil samples, and the degraded material obtained from the analysis of laboratory soils The results were based on British Standards BS1377-1:1990 and BS1377-2:1990. Table 1 shows the following values: 32.5%, 31.2%, 1.18 kg/m2, 33.25%, and 32.5% for natural moisture content, Optimum Moisture Content, maximum dry density, moisture limitation, plastic limit, and plasticity index, respectively.

Table 1. Laterite soil properties

Characteristics	Value
Natural Moisture Content	32.5%
Optimum Moisture Content	31.2%
Maximum Dry Density	1.18 Kg/m^3
Liquid Limit	65.75%
Plastic Limit	33.25%
Plasticity Index	32.5%
USCS Classification	CH

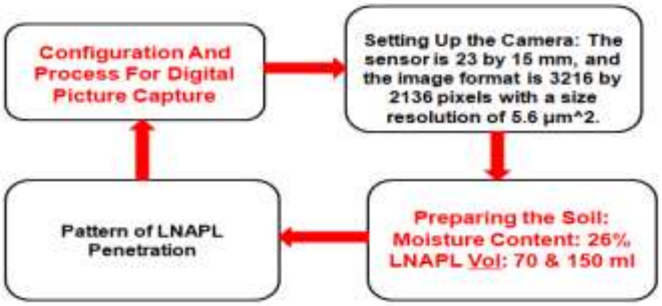
Fig 3. Perspectives of the double-porosity laterite soil: (a) Plane and (b) Front

As shown in Fig. 3, the soil sample was designed as a double-porosity soil [10]. To avoid contamination, the dried laterite soil was added to 25% water and stored in zip-lock plastic bags at room temperature, and the soil samples were kept for at least 24 hours to dry. The soil sample was placed in an acrylic glass cylinder with 2.36 mm connecting rods. The soil sample was pushed 100 mm into the acrylic glass cylinder using a special rolling machine. The double porous laterite soil is shown in Fig. 3 in plane and side view. The double porous soil is shown in Fig. 3(a) as a plane view and in Fig. 3(b) as a front view. The soil sample shows typical features of laterite grains and fine inter aggregate pores. The structure of unique grains and fine aggregate pores is comparable to that of previous researchers [11].

Planning and procedure for digital photography

The physical testing procedure was designed to best meet the objectives of this study. The flowchart of the actual experimental setup is shown in Figure 4. A specimen with a height of 300 mm, a diameter of 100 mm, and a diameter of 94 mm, which was designed for acrylic cylinder glass with a perforated base as shown, was used in Figure 5 to test the initial room temperature. It was set to 23 degrees Celsius. As mentioned earlier, two-layered laterite soil were produced. A spherical sample of soil was placed in an acrylic glass cylinder to measure and analyse the amount of LNAPL loaded on the total soil surface. Figure shows the acrylic glass cylinder wrapped around the printed aircraft paper grid strips, 30 mm in diameter. With DIPT taking reference images, grid lines were used to check the accuracy of the measurements. For calibration and validation, LNAPL volumes of 70 and 150 ml were used and poured immediately on the soil sample.

Fig 4. Physical Experimental setup flowchart



Configuration And Process For Digital Picture Capture

Setting Up the Camera: The sensor is 23 by 15 mm, and the image format is 3216 by 2136 pixels with a size resolution of 5.6 μm^2.

Preparing the Soil: Moisture Content: 26% LNAPL Vol: 70 & 150 ml

Pattern of LNAPL Penetration

Fig 5. Actual Experimental Configuration

Application of computer graphics

Advances in technology have increased the importance of understanding contaminant remediation through numerical modeling in groundwater systems [11]. PetraSim software was used to confirm the calibration and validation of physical experiments in the 19th century. By automatically dissecting model meshes or meshes in fully 3-dimensional views, this system makes domain analysis and parameter understanding accessible to all users [14]. Now multiphase flow software development for the TOUGH family of codes has become the norm, difficult and interesting, especially in relation to the resulting simulation multiphase flow. It has been tried. Similarly, the infiltration rate was selected for the LNAPL volume of 70 ml for the calibration of the Petrasim simulation.

Results and analysis

The results were analysed by a physical experiment and a Petrasim simulation of the LNAPL infiltration process in biporous soil. According to Locke [13], there was a continuous seepage of coloured LNAPL into the subsoil of the two pores. As seen in the study, it shows how soils with two porosities are identical, and the LNAPL model is a horizontal x-axis line on the soil model. When spherical soil is removed, columns are displayed as the formation of a 2D flat pattern, where the soil depth is represented by the y-axis and column width by the x-axis. Soil colour yellow and toluene yellow effects in contour plot analysis and sample plotting are selected and used. Pattern plots were selected at 3, 45, 90, and 116 seconds for 150 ml of LNAPL volume in Experiments for 70 ml of LNAPL volume was selected at 3, 30, 45, and 430 seconds. In these experiments it was observed that LNAPL with penetrating columns took 116 seconds and 430 seconds to reach the bottom of the soil sample, respectively. In initial experiment LNAPL penetration through an acrylic glass cylinder increased with a higher LNAPL concentration on a double-pored soil than in the subsequent experiment and faster LNAPL penetration in double-porous soils is affected by pore pressure. With increasing LNAPL concentration, the pore pressure increases in double-porous soil. It was shown that within 30 seconds, the LNAPL had risen to half the depth of the soil sample.

LNAPL fluxes reached the bottom of the soil model in both the Petrasim simulation and the practical analysis of lateritic soils with two porosities. The values based on Nash-Sutcliffe efficiency for calibration and validation were 0.84 and 0.51, respectively. Anything above 0.50 indicates satisfactory calibration and validation [15]. Table 2 shows that there is less than a 10% difference between the computer simulation and the experiment. In order to calibrate and verify the Petrasim system, physical tests were used with two porous soils filled with 70 ml and 150 LNAPL. One hundred differences between physical and Petrasim software measurements, respectively, 1.34% and 5.47%, both are well situated and acceptable [16]. As a result, there is a consistent design, as shown in the calibration and validation curves in Figures 6 and 7, indicating that the differences between the physical tests and Petrasim software are relatively small and are accepted. Physical testing and comparison of Petrasim software calibration and validation findings Table 2 is developed on a basis. It is necessary to justify LNAPL penetration by bi-porosity to determine whether LNAPL will move faster or slower. Laterite soil has field areas for long-term cleanliness and safety.

Fig 6. PetraSim software calibration graph using a 70 ml LNAPL volume penetration rate in relation to a real experiment.

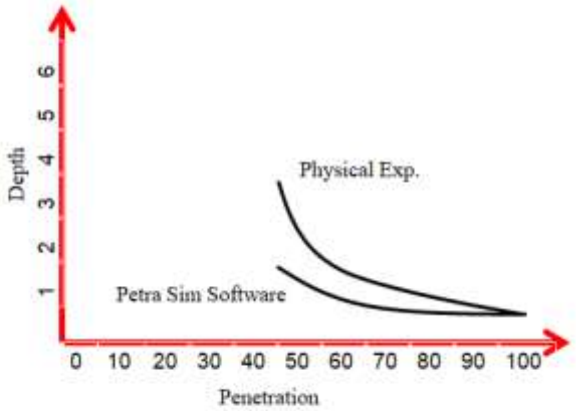


Fig 7. Validation graph for PetraSim programme using 150 ml LNAPL volume penetration rate in relation to an actual experiment

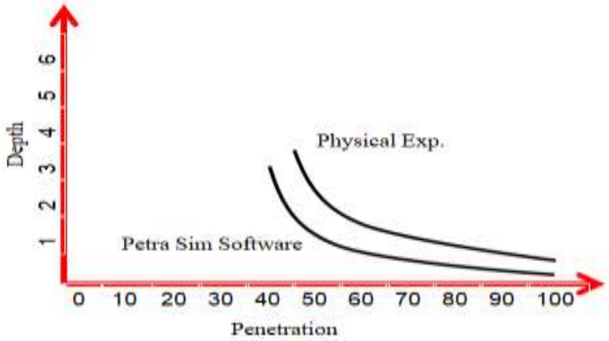


Table 2. Penetration Validation and Calibration for PetraSim and Physical Experiment

Parameter	Physical Experiment	PetraSim Software	Percentage Difference (%)
25% moisture content; 70 ml LNAPL volume; (mm/s); Calibration	0.74	0.76	2.63
25% moisture content; 150 ml LNAPL volume; (mm/s); Validation	1.68	1.62	3.57

Conclusion

In conclusion, high-dose LNAPL penetrates the double-pored soil more rapidly than low-dose LNAPL. The penetration rates in Experiment 1 (a) with 150 ml and Experiment 1 (b) with 70 ml were 1.68 mm/s and 0.74 mm/s, respectively. Due to the amount of LNAPL used, the muscle of the surface affects absorption. Increasing the amount of LNAPL applied to the soil surface had an effect on the pore pressure. Petrasim software was also used to analyse and verify the physical test. The Nash and Sutcliffe robustness of measurement and validation performance were 0.84 and 0.51, respectively, with 2.63% and 3.57% percent differences between the actual test and the Petrasim software. The Petrasim system is suitable and easily demonstrated as environmental factors cause long-term collision problems, and further research has been done on groundwater quality protection and mitigation (e.g., fuel tank leaks or spills).

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