第Ⅲ部門　**Variability of *S-p* relation of LNAPL under repeated drainage and imbibition**

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1. INTRODUCTION

LNAPLs (*Light Non-Aqueous Phase Liquids*) are liquid contaminants that, because of their low specific gravity values, usually float above the groundwater level and, thus, easily have their plumes spread by changes on the groundwater level. Yamanaka et al. (2017) confirmed that the residual saturation of LNAPLs changes in 1-D vertical column tests when cyclic drainage and imbibition processes were applied. This implies that LNAPL *S-p* relation may not be uniquely defined, and that it may change with repeated drainage and imbibition cycles. In this study, we focused on the dynamic behavior of LNAPL in an air-LNAPL two-phase system by studying its *S-p* relation, a relation commonly used to evaluate the fluid retention of soils, for a better understanding of air-water-LNAPL three-phase systems subjected to groundwater fluctuation.

2. MATERIALS AND METHODS

In this study, Low Viscosity Paraffin with viscosity of 170 mPa・s and density of 0.815 g/cm^3, was used as LNAPL. Toyoura sand, with soil particle density of 2.66 g/cm^3 was used as porous medium. A Toyoura sand specimen was prepared in a tempe cell, which is a small cylindrical of diameter 53.8 mm and height 30.0 mm, equipped with ports on the top and bottom to allow inflow and outflow of fluid. First, the specimen was fully saturated by LNPAL pluviation and packed into the tempe cell, with an obtained void ratio of 0.76 and relative density of 0.64. Then, the tempe cell was assembled and connected to a tank filled with low viscosity paraffin liquid whose vertical location could be adjusted by a lab jack. Figure 1 shows a schematic diagram of the testing system. The top port of the tempe cell was connected to an air pump that could directly adjust the air pressure inside the specimen, and the bottom port was connected to the tank with low viscosity paraffin liquid. Capillary pressure was calculated as a differential pressure, U_a (air pressure) – U_0 (LNAPL pressure), and saturation degree of low viscosity paraffin liquid was calculated by measuring the weight of the tempe cell. The following drainage and imbibition was repeated five times.

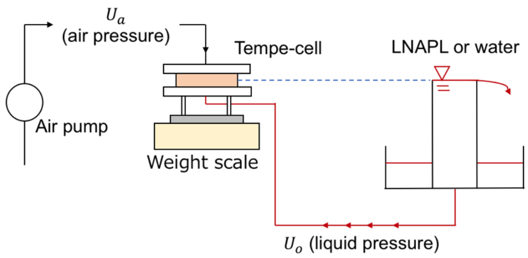

Figure 1. Schematic diagram of tempe cell test system

Drainage: While a variety of air pressures (U_a) were applied from the top of the tempe cell, LNAPL pressure (U_0) applied from the bottom was kept constant. The paraffin level was assumed to be located at the center of the specimen to simplify capillary pressure measurement, i.e., $U_0 = 0$ and p (capillary pressure) = U_a. After the reading of the scale became constant, air pressure was increased stepwise. This drainage step was repeated until there was no paraffin flow from the tempe cell, even under a higher air pressure.

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Imbibition: After the drainage process, imbibition process was conducted. First, the air pressure was disconnected, and then the paraffin level was raised up with the help of a jack to increase its hydraulic gradient and, thus, saturate the specimen. Since imbibition was carried out in one step, S and p values during imbibition were not obtained. After this process, saturation degree was calculated at a capillary pressure of zero, which would be the starting point of the next drainage step.

Fitting: We fitted our obtained S and p values to the van Genuchten Model, by the Least Squares Method, and obtained the corresponding *S-p* relation curves.

3. RESULTS ANS DISCUSSION

S-p curves for 5 cycles of repeated drainage and imbibition obtained by the tempe cell test are shown in Figure 2. S_{rf}, residual saturation, one of the parameters of the van Genuchten model, decreased under the repeated drainage and imbibition cycles. Figure 3 shows the relationship between the number of cycles and the S_{rf} value obtained at the beginning of each cycle. By regression analysis, we can express that relationship with the equation: $S_{rf} = -0.310\log(N) + 1.004$; where, N represents the number of cycles. As seen by the coefficient of determination R^2 of 0.999, the residual saturation seems to converge logarithmically to a fixed value. When it comes to S_{ra}, which is also one of the parameters of van Genuchten and denotes irreducible saturation, it was almost constant between cycles. Any relationship between the other van Genuchten Model parameters and the number of cycles was not observed. This is mainly because the number of data points to plot each *S-p* relation curves was relatively small.

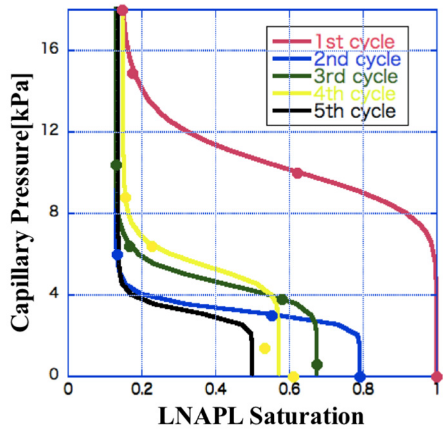

Figure 2. All drainage tests

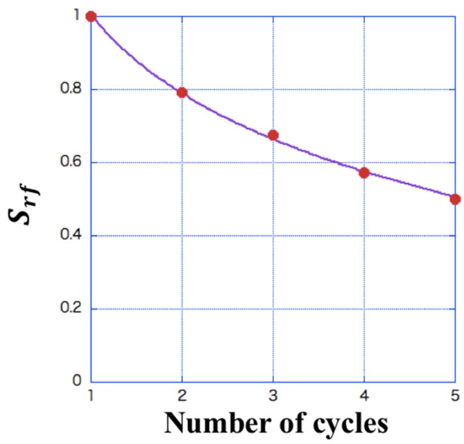

Figure 3. Variability of S_{rf}

Two of the most likely explanations about the decrease of S_{rf} are discussed. First, the decrease can be inferred to be due to the remained air. It gradually made itself harder to be removed by the entry of LNAPL. Second, compaction of the specimen due to groundwater fluctuation might also explain the decrease. After the 5th cycle, it was found that the specimen slightly shrunk mainly by the air pressure. This could make us underestimate the calculated saturation by the volumetric decrease of the whole voids. In order to confirm the alternatives explained here, we need to interpret the physical state or the relationship between the particles and fluids, such as X-ray CT. This is included as further studies.

4. CONCLUSIONS

From these results, it was found that *S-p* relation actually changes under repeated cycles of drainage/imbibition and, residual saturation decreases stepwise. This regularity of the decrease will help me to predict how *S-p* relation curve looks like in air-LNAPL phase. Moreover, the effectiveness of Tempe-cell test, when it comes to a measurement of *S-p* relations, was confirmed.

REFERENCES

Yamanaka, Y., Flores, G., Katsumi, T. and Takai, A. (2017): Study of LNAPL Migration subjected to cyclic groundwater fluctuation, *Geo-Environmental Engineering 2017*, pp.153-158.