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Placement of Colloidal Silica gel for the construction of a subsurface containment system

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ABSTRACT

A subsurface containment system which is constructed by pumping a gelling liquid (Colloidal Silica) into the unsaturated medium is investigated by developing a mathematical model and conducting numerical simulations. The proposed model is verified by comparing experimentally and numerically determined hydraulic conductivities of gel-treated soil columns at different Colloidal Silica (CS) injection volumes. The numerical experiments indicate that an impermeable gel layer is formed within the time period twice the gel-point. At the same normalized time, the CS solutions with lower NaCl concentrations result in further migration and poor performance in plugging the pore space.

key word : subsurface containment, gel barrier, colloidal silica, modeling, gelation model

1. INTRODUCTION

A chemical grout-based barrier can be installed in high-permeability soils by pumping a chemical grout directly into the porous medium. The injected chemical grout is placed on site when the solution reaches a high viscosity so that it is practically immobile. Colloidal Silica (CS), a stable aqueous dispersion of discrete nonporous particles of amorphous silicon dioxide (SiO_2) is destabilized by adding appropriate electrolytes such as NaCl. The Colloidal Silica (CS) gel system has various advantages such as low permeability ($<10^{-11}\,cm^2$), easy injectivity, and minimal environmental problems (Jurinak et al., 1989). Moreover, the gelled CS is not affected by syneresis (Yonekura and Kaga, 1992) as well as degradation processes such as bacterial action.

The gel barrier formation by injecting a CS solution (Nyacol 1440) in the unsaturated medium has been investigated by Finsterle et al. (1994), Moridis et al. (1999), and Durmusoglu and Corapcioglu (2000). In the modeling studies by Finsterle et al. (1994) and Moridis et al. (1999), a CS solution is treated as one phase and no gelation model is employed. In this study a two-phase approach is suggested and a method by which the solution viscosity is calculated from the phase relevant property, i.e., gel phase volumetric fraction.

2. MODEL DEVELOPMENT

To describe the fluid migration in the unsaturated medium, a correlation between the fluid content and pore pressure head is used. The gel mixture content at a given gel mixture pore pressure is obtained by employing the scaling process for a known water saturation-pressure head relation (Corey, 1986). For the scaling process, the surface tension of the gel mixture is measured by using a tensiometer during the gelation, and the functional surface tension-viscosity relationship is obtained.

In addition to the gel mixture flow equation, the colloidal silica particles and NaCl in each phase are quantified by employing respective mass balance equations with the gelling reaction terms incorporated. A kinetic gelation model is developed by assuming that the gelation rate is proportional to the particle collision rate and the proportionality constant is a function of NaCl concentration. The dependency of k_1 on NaCl concentration is obtained from the temporal viscosity measurements for different NaCl concentrations. Interestingly, the viscosity measurements for different NaCl concentrations fall on the same curve when they are plotted with respect to normalized time in Fig. 1 (Here, $t_{0.5}$ which is named gel-point corresponds to the time at which a rapid viscosity increase is observed). This unique viscosity curve is combined with the proposed gelation model, then, a generalized μ_m- F_g relationship is established.

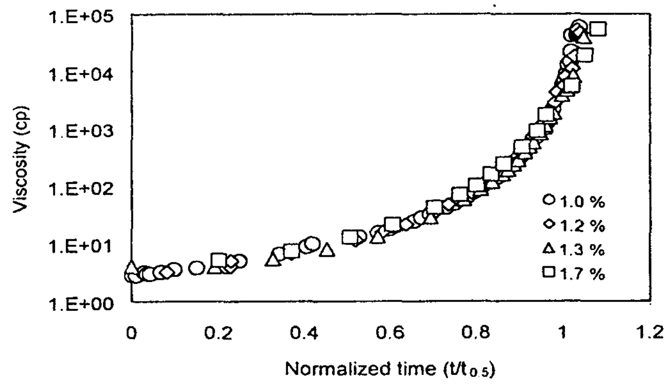

Fig. 1. Time-normalized viscosity curve

3. RESULTS AND DISCUSSIONS

The numerical results are compared with experimental data to verify the predictive capability of the model. As a quantification of in situ gelation, the overall hydraulic conductivity of a gel-treated column is determined experimentally and numerically. The comparison of the measured hydraulic conductivities and the numerically obtained ones for varying CS volumes shows a favorable match in Fig. 2.

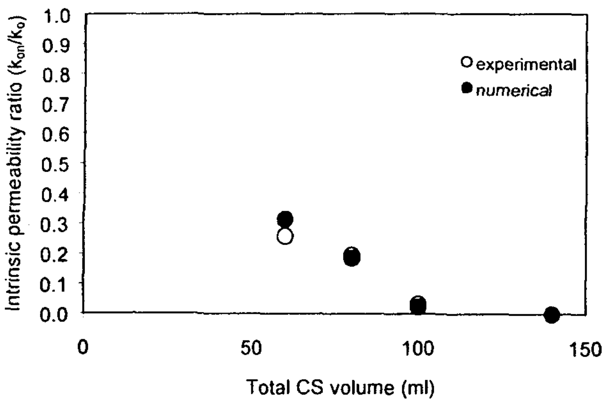

Fig. 2. Comparison of measured and numerically computed hydraulic conductivities of the gel-treated sand column. At the last point, the measured and numerical values overlap.

Fig. 3 demonstrates the simulation results at the end of the CS injection (t = 0.2 hrs), 0.4, 1, and 2 hrs. In the gel mixture content distribution profiles, no change is observed from the surface to a depth of 100 cm at times $t \geq 0.4$ hrs. From the results it is stated that the CS gel placement is completed within the time period corresponding to twice of the gel-point ($= 2t_{0.5}$).

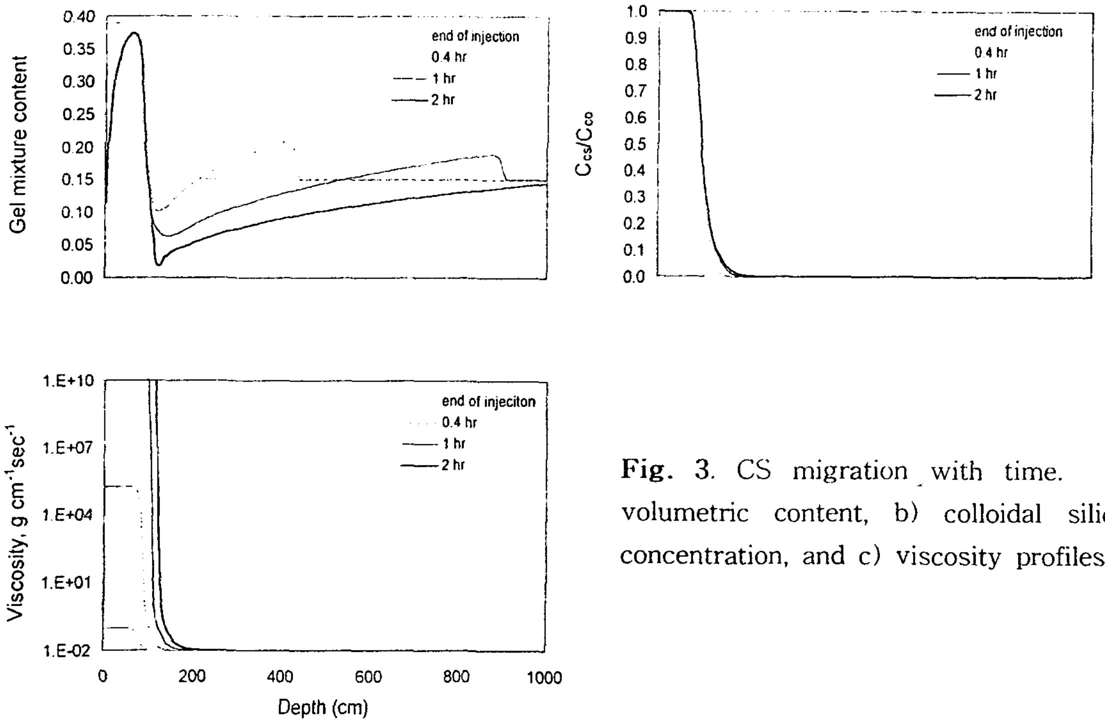

Fig. 3. CS migration with time. a) volumetric content, b) colloidal silica concentration, and c) viscosity profiles.

In Fig. 4 illustrating the gel placement with different NaCl concentrations at the same normalized time, i.e., $2t_{0.5}$, lower NaCl concentrations result in further migration and poor performance in plugging the pore space. This is due to the redistribution of the CS solution with a lower NaCl concentration for a longer time before it becomes immobile.

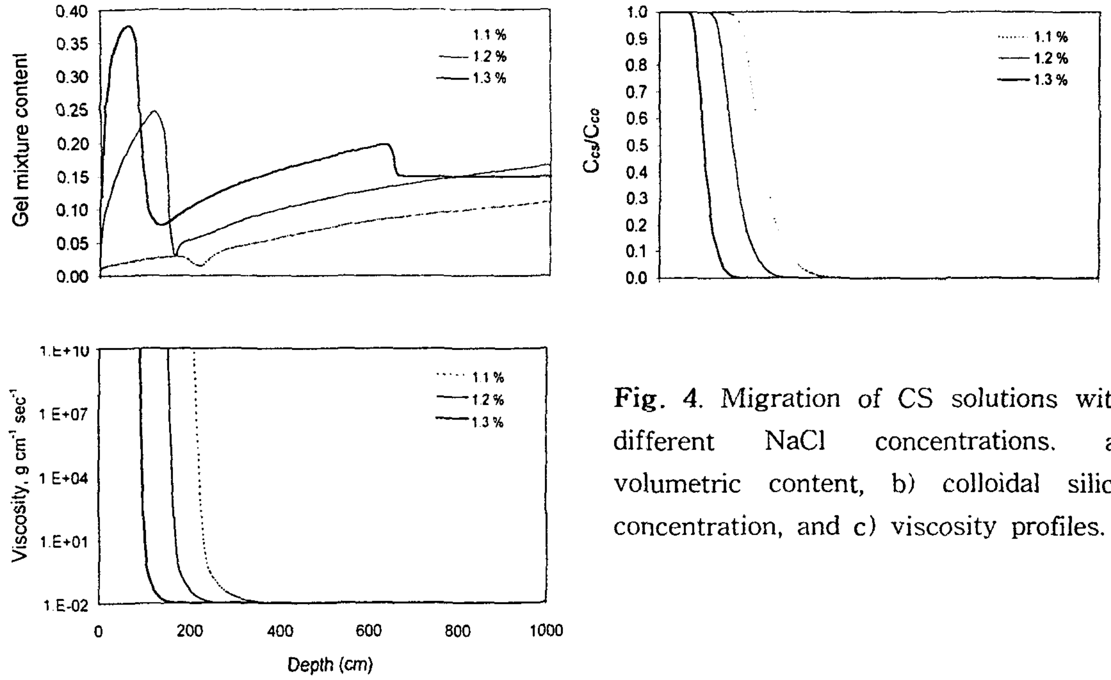

Fig. 4. Migration of CS solutions with different NaCl concentrations. a) volumetric content, b) colloidal silica concentration, and c) viscosity profiles.

It is observed that the initial saturation of pore water has a slight effect on the eventual location and extent of the gel placement, although a decrease in NaCl concentration at the solution front produces a mixing zone distributed over a greater distance.

4. REFERENCES

Corey, A. T., 1986. Mechanics of Immiscible Fluids in Porous Media. Water Resources Publications: Littleton, CO.

Durmusoglu, E., Corapcioglu, M. Y., 2000. Experimental study of horizontal barrier formation by colloidal silica. *J. Env. Eng.*, ASCE 126, 833 - 841.

Finsterle, S., Moridis, G. J., Pruess, K., Persoff, P., 1994. Physical barriers formed gelling liquid: 1. Numerical design of laboratory and field experiments. Rep. LBL-35113, Lawrence Berkeley Natl. Lab.: Berkeley, CA.

Jurinak, J. J., Summers, L. E., Bennett K. E., 1989. Oilfield application of colloidal silica gel. paper SPE 18505 presented at the 1989 SPE Intl. Symp. on Oilfield Chemistry, Houston, Tex., Feb. 8 - 10.

Moridis, G. J., Finsterle, S., Heiser, J., 1999. Evaluation of alternative designs for an injectable subsurface barrier at the Brookhaven National Laboratory site, Long Island, New York. *Water Resour. Res.* 35, 2937 - 2953.

Yonekura, R., Kaga, M., 1992. Current chemical grout engineering in Japan, Grouting, Soil Improvement, and Geosynthetics, Geotechnical Special Publication No. 30, ASCE, 725736.