Modeling coupled DNAPL migration and complex resistivity evolution in saturated porous media

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Abstract

Induced Polarization (IP) is the measurement of the response of electrical conductivity (or resistivity) to an applied range of frequency (usually between a few millihertz to a few tens of kilohertz). It can be applied as a non-intrusive method to investigate Dense Non-Aqueous Phase Liquid (DNAPL) contamination/remediation process. Multiphase flow in porous media can be coupled with the electrical current to simulate the process of DNAPL migration and deliver a broader view in space and time esp. when the results are supported by field measurements or laboratory experiments. In addition to previous works in the literature regarding the coupled simulations of two-phase flow and in-phase electrical resistivity, in this work, we aimed to perform coupled simulations of two-phase flow in porous media and sinusoidal electrical current (i.e. frequency ranging from 0.7Hz to 3000Hz) via the application of complex electrical resistivity.

The domain and the scenarios of the simulations (i.e. fill-up and pumping) are based on previously published laboratory experiments [1,2]. The simulations are developed in 3D and are performed in COMSOL Multiphysics®. The fluid flow equations are, first, discretized (i.e. by Finite Element Method) and solved using the pressure-saturation approach and by application of the Van Genuchten-Mualem constitutive relationships. Then, the saturation of water and the DNAPL is translated into in-phase and quadrature conductivities via the chosen petrophysical relationships [3,4] and then the system of partial differential equations governing the electrical current (i.e. Amper's law) is solved and the electrical potential is calculated in the domain for each time-step. The electrical potential, then, can be translated into complex resistance and then to complex resistivity. The results of the fluid flow and the phase transport are validated against the results of laboratory experiment measurement. Figure 1 shows selected results of the phase transport validation for the pumping scenario. The results of the complex resistivity measurements and simulations are validated and one of the electrical injection configurations for the fill-up scenario is selected and shown in Figure 2.

The used formulation and tool for simulation of the fluid flow (i.e. pressure-saturation in 3D) has been discussed briefly to give insights regarding the application of three-phase flow in future studies. The choice of petrophysical relationships for in-phase and quadrature conductivity are verified and are consistent with the experimental study, yet the exponents of the water in the petrophysical relationship were estimated to be lower than those reported previously by the experimental study [2]. The simulations and the experiments are in complete accordance with each other in the parts of the domain where the saturation of DNAPL is relatively low (esp. in the cone of depression in the pumping scenario). The simulations also predict the time of evolution of in-phase and quadrature resistivity (i.e. when DNAPL front passes the injection and potential electrodes) with satisfying accuracy. However, the points associated with high saturation of DNAPL (i.e. close to S_n=1-S_{rw}) show high errors between the results of in-phase resistivity calculated simulations and the previously reported experiments. Yet, this error is decreased when comparing the quadrature resistivities. The present study can be regarded as a preliminary study toward further applications of coupled IP-Multiphase flow for more accurate detection and monitoring of non-aqueous phase liquids. We suggest that our choice of tool/approach can be extended to larger-scale studies for further investigation.

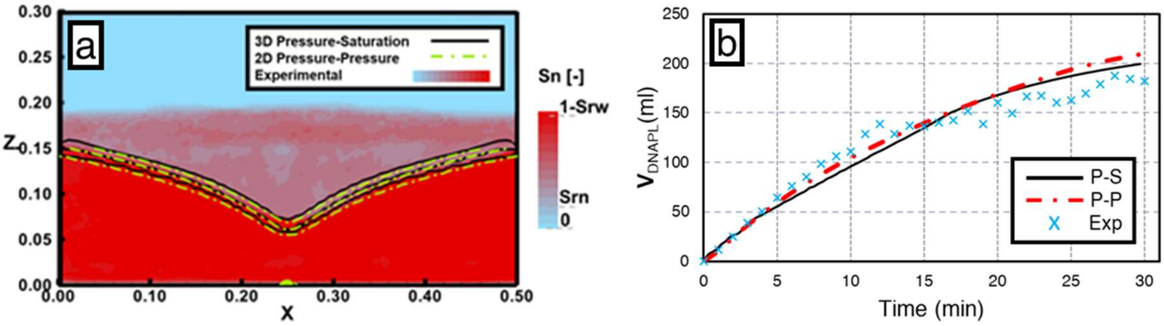

Figure 1. Simultaneous representation of experimental measurements and two simulation approaches for the 150 ml.min-1 flowrate for: (a) distribution of water and DNAPL at the end of pumping scenario and (b) temporal evolution of the retrieved DNAPL

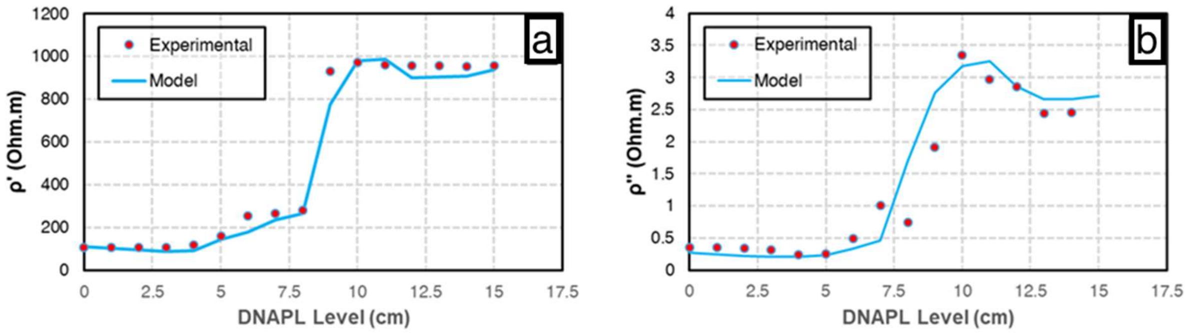

Figure 2. Simultaneous results of complex resistivity evolution through the fill-up scenario for an electrical injection/potential configuration at the bottom part of the domain: (a) in-phase resistivity and (b) quadrature resistivity

Reference

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