Quantification of the efficiency of free product recovery of heavy chlorinated compounds using chemical and thermal enhancements with permittivity, resistivity and optical density measurements

Stéfan Colombano, Hossein Davarzani, Eric van Hullebusch, D Huguenot, Dominique Guyonnet, Jacques Deparis, Fabien Lion, Ioannis Ignatiadis

QUANTIFICATION OF THE EFFICIENCY OF FREE PRODUCT RECOVERY OF HEAVY CHLORINATED COMPOUNDS USING CHEMICAL AND THERMAL ENHANCEMENTS WITH PERMITTIVITY, RESISTIVITY AND OPTICAL DENSITY MEASUREMENTS

S. Colombano[1], H. Davarzani[1], E.D. van Hullebusch[2,3], D. Huguenot[2], D. Guyonnet[1], J. Deparis[1], F. Lion[1], I. Ignatiadis[1]

[1] BRGM, French Geological Survey, Water, Environment, Process Development and Analysis Division, 3 avenue Claude Guillemin, 45060 Orléans cedex 2, France

[2] Université Université Gustave Eiffel, Laboratoire Géomatériaux et Environnement (LGE), EA4508, UPEM, 77454 Marne-la-Vallée, France

[3] Institut de Physique du Globe de Paris, Université Paris Cité, UMR 7154, CNRS, F-75005, Paris, France

Corresponding authors email: s.colombano@brgm.fr and i.ignatiadis@brgm.fr

ABSTRACT

Background information

Recovery of chlorinated solvents (CSs) as a free product is mainly based on the pumping and pumping/skimming approach. However, this technique is time consuming and does not allow significant recovery of CSs in the form of free product and its associated dissolved emissions. Our study focuses on the beneficial effects of thermal and chemical enhancements for recovering free product composed of heavy chlorinated compounds (Hexachlorobutadiene, Hexachloroethane, Perchloroethylene, Pentachlorobenzene, Trichloroethylene,…).

Main results

Drainage-imbibition experiments were performed in 1D Cells with 0.1 and 0.5 mm glass beads (GB). The experimental data were modeled with the van Genuchten-Mualem (VGM) capillary pressure-saturation function. Parameters α and n, as well as residual and irreducible saturations (S_{rn} and S_{rw}), were obtained in order to use them during multiphase flow modeling.

Four surfactants (SDBS, Aerosol MA-80, Triton X-100 and Tween 80) were tested at their critical micelle concentration (CMC). The best recovery yield was obtained with SDBS: 27.6% for 0.5 mm GB and 46.3% for 0.1 mm GB. Experiments with thermal enhancement were also performed at 50°C, however, no significant improvement in the CSs recovery yield was achieved [a].

The drainage-imbibition experiments were continuously monitored by electrical resistivity, permittivity and optical density methods. With these methods, it was aimed to verifiy if S_{rn} could be indirectly estimated in order to use these monitoring methods during the tests performed with the 1D columns and 2D tanks [b].

The estimation of residual saturations with permittivity fits well with the CRIM model (less than 8% difference). In contrast, the Archie's law used to model variations in resistivity as a function of water saturation (S_w) variations may overestimate the experimetal data by a factor of 2.

It is possible to monitor the variations of S_w and to quantify S_{rn} taking into account factors of corrections for permittivity and resistivity. These factors were quantified according to S_w [c].

Optical density monitoring shows that S_{rn} can be accurately estimated with a linear relation (R^2 = 0.98).

The tests in 1D columns made it possible to fit the two-phase flow model and to confirm the accuracy of indirect monitoring (permittivity, resisitivity and optical density) [b].

The pumping experiments in 2D tanks provide (using indirect monitoring approaches) estimations of the radius of influence (ROI) and of the optimal pumping flow rate (PFR). The ROI of pumping increases significantly with the thermal and chemical enhancements (e.g., it increases two-fold using surfactants). On the other hand, at higher PFRs, the beneficial effect of enhancement is less significant.

Based on the experimental data, it was possible to calibrate numerical model of two-phase flow in porous media (using COMSOL Multiphysics®). In particular, the model can predict the displacement of the water-DNAPL interface [b,d,e].

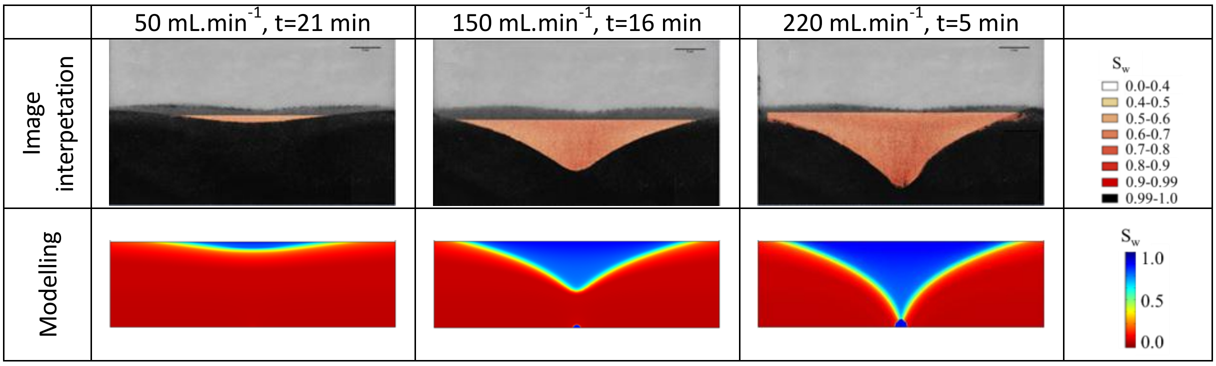

Figure 1: Comparison of measured (with image interpretation) and modelled cone of depression (0.5 mm GB) at the end of the pumping (steady-state condition) for different flowrates [b]

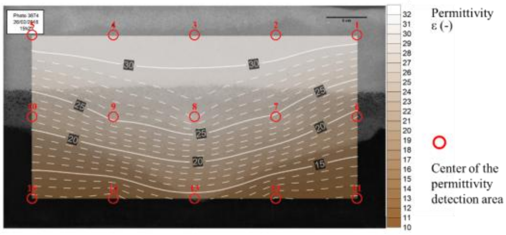

Figure 2: Surface plot of measured permittivity within an image with 0.5 mm GB and a flow rate of 150 mL.min^{-1} (without enhancement) at t=18 min [C]

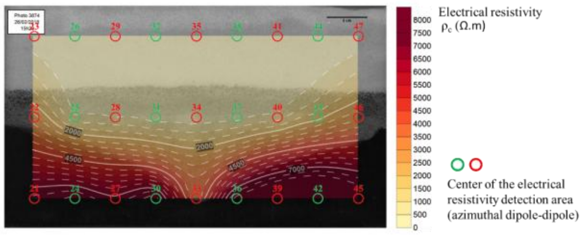

Figure 3: Surface plot of measured resistivity with an image with 0.5 mm GB and a flow rate of 150 mL.min^{-1} (without enhancement) at t=18 min [C]

Conclusions

The experiments carried out have shown that it is possible to determine the residual saturations very precisely with the interpretation of images, permittivity and, to a lesser extent, resistivity. The two-phase model makes it possible to finely reproduce the observed phenomena, in particular the ranges of action and the remediation yields according to the pumping. The experiments and the model can be used to develop other depollution techniques: foam, polymer or gas injection. The heterogeneity of the environments may also be taken into account.

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