Complex Electrical Resistivity for Monitoring DNAPL Contamination

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DOE Problems Addressed:

Nearly all Department of Energy (DOE) facilities have landfills and buried waste areas. Of the various contaminants present at these sites, dense non-aqueous phase liquids (DNAPL's) are particularly hard to locate and remove. There is an increasing need for external or non-invasive sensing techniques to locate DNAPL's in the subsurface, to track their spread, and to monitor their breakdown or removal by natural or engineered means.

Research Objectives:

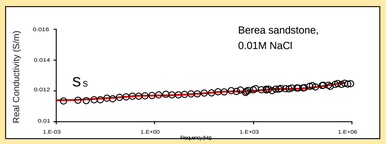
This research is motivated by the following simple hypothesis: as organic compounds are removed (e.g., biodegraded or extracted through engineered remediation) the complex resistivity will change according to the new chemical make-up of the soil/groundwater system. Thus complex resistivity measurements can be used as an effective monitoring tool to indicate the progress of remediation activities.

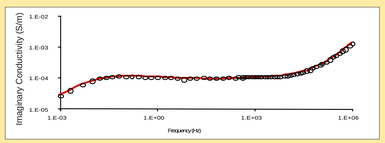
The broadband electrical-impedance response of rocks and soils depends upon the sample microgeometry, the pore solution chemistry, and the surface chemical properties of the system. Organic pollutants can alter both the bulk fluid chemistry and the surface chemical properties of a porous medium. The distribution and reaction of an organic contaminant within a porous solid is a complex function of the chemical, physical and biological properties of the system. Laboratory and field studies suggest that many organic pollutants (e.g. DNAPL's) have distinct signatures that can be identified by measuring the complex electrical resistivity of the contaminated sample. We propose to bring the field measurement of complex resistivity as a means of pollution characterization from the conceptual stage to practice. For this purpose, electrical-impedance spectroscopy experiments will be conducted to more fully characterize the geophysical signatures and detectability of various organic contaminants within well-characterized rock and soil samples. Experiments will also be conducted using synthetic silicate glasses for which we can systematically vary the microgeometries and surface chemical properties of the samples. Physiochemical models will be used to interpret these experiments and integrate the results with published data sets. These laboratory observations and theoretical models will be applied to the development of improved field techniques for the electrical characterization and monitoring of organic pollutants.

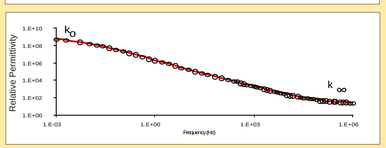
Methodology

- Electrical impedance response is measured over a wide range of frequencies in order to capture the relaxation time distribution.
- A simplified physiochemical model is used to invert the broadband impedance data for apparent grain-size distribution and geochemical parameters.
- Apparent grain size information can be used to predict the sample permeability.
- Electrical-impedance spectroscopy and induced polarization measurements will be used to characterize and monitor the pore-scale distribution and geochemical reaction of organic contaminants within natural and synthetic porous media.
- These methodologies will be applied to the interpretation of complex resistivity and induced polarization data collected at well-characterized field sites containing DNAPL contamination.

Electrical Data







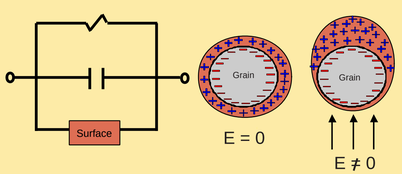
$s^* = s' + is''$

$s^* = s + iwke_o$

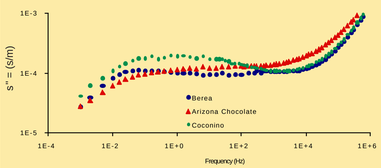
$k^* = k' + i\,k''$

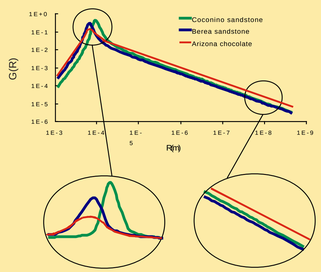
$k^* = k + \frac{is}{we_o}$

Model

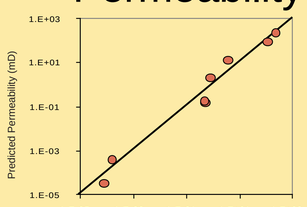


Microgeometry



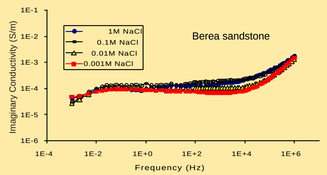


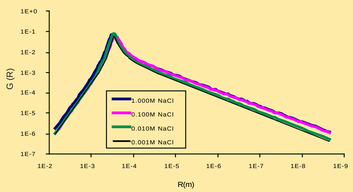
Permeability



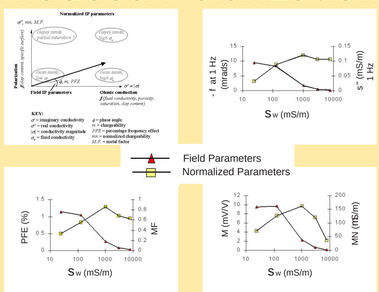
$K = 5.1\times10^{-6} f^{5.1} M d^{2} e^{-1.385\,PDj}$ (Berg, 1970)

Chemistry





Induced Polarization



Cole - Cole Model

$$e^*(w) = \frac{De}{1+(iwt_o)^{1-a}} + (e_\infty + i\frac{S_s}{W})$$

$$y(t) = \frac{1}{2p}\,\frac{\sin pa}{\cosh\{(1-a)\ln(t/t_o)\} - \cos pa}$$

Grain Model

Single Grain:

$$De = \frac{eSR}{kT}$$

$$t_o = \frac{R^2}{2pkT}$$

Distribution of Grains:

$$G(R) = \frac{y(t)}{R}\cdot Q$$

$$D = 2a + 2$$

Normalized IP Parameters

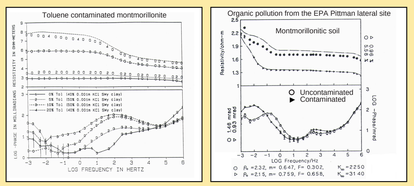
$$s'' = f\cdot s' = \frac{emSS_o}{3/2}\left[\sin\left(\frac{ap}{2}\right)(wt_o)^a\right]$$

$$MF = PFE\cdot s' = a[s'(w_1) - s'(w_2)]$$

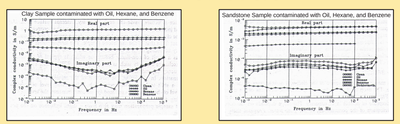
$$Mn = M\cdot s' = \frac{s'}{V_{max}(t_1 - t_o)}\int_{t1}^{to} V(t)\,dt$$

Contaminants

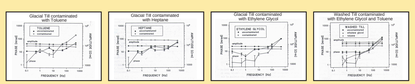
Olhoeft



Borner et al.



Van Hala et al.



Conclusions

Complex resistivity and induced polarization measurements show great promise as means of characterizing the surface chemical and hydraulic properties of rocks and soils. These geophysical methods should ultimately be able to yield in-situ information about chemical and physical parameters that control the transport and reaction of organic pollutants (e.g. DNAPL's) within geological aquifers and reservoirs. Recent advances in geophysical instrumentation and interpretation programs have facilitated the use of complex resistivity and induced polarization methods in environmental applications. An improved understanding of the physical and chemical mechanisms that control the electrical impedance responses of contaminated rocks and soils will lead to more effective and wide-spread uses of these powerful tools for task such as the non-invasive characterization and monitoring of DNAPL contamination.

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Acknowledgements

The U.S. Department of Energy has funded this research project through the EMSP program:
grant numbers FG07-96ER14714 and FG07-99ER15005.

We thank the following colleagues and students who have contributed to this project:
Dale Morgan, Lee Slater, Kevin Fyye, John Sturrock, Rebecca Gird, Hâna Baker, and Alessandra Scodinu.