A comprehensive study of the SIP response of soil contaminated with organic pollutants

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In recent years, there is a growing interest in using geo-electrical methods to detect and monitor organic contaminants, their transport, and their fate within the subsurface. To efficiently relate between the electrical properties measured in a geo-electrical survey and the presence, transport and fate of organic contaminants, an understanding of the influence of organic contaminants on the electrical properties of the porous media is required. Such knowledge is usually empirically based, and is mostly limited to the presence of non-miscible contaminants in the saturated zone. The aim of this work is to determine the effect of organic contaminants on the electrical properties of variably saturated porous media by combining laboratory experiments and theoretical modelling.

The experimental part of this work includes three sessions. In the first we measured the effect of a mixture of organic contaminants, namely motor oil or diesel fuel, on the electrical properties of unsaturated soil. In addition we also measured the effect of the contaminants on the electrical conductivity of the pore water. In the second session we investigated how an exchange process between inorganic and specific organic cations affects the electrical properties of saturated soil (i.e. to eliminate the role of saturation). In this session both the SIP signature of the soil and the chemical properties of the soil solution were monitored during the exchange process. In the third session we investigated the effect of free-phase organic contaminant on the SIP signature of an unsaturated soil. In this experiment we added a single non-polar organic contaminant to an unsaturated soil and measured the SIP signal. In addition we also examined the effect of the added organic contaminant on the chemical composition of the soil solution.

In addition to the experiments, we also modelled the effect of adsorbed organic species on the chemical and electrical properties of porous media. Our model includes a chemical complexation module that was used to determine the surface site density of different chemical species. The results of the model were used as an input to a Stern layer polarization module. The model results were used to construct a mechanistic model for the effect of adsorbed organic contaminant on the SIP signature of porous media.

Our results show that addition of free-phase organic contaminants to unsaturated soil (where water saturation remains constant, i.e. contaminant replace air) does not significantly affect the in-phase electrical conductivity of the soil, but does result in a decrease of the soil polarization and relaxation time. Interestingly, further addition of contaminant did not result in a further change of the soil polarization or the relaxation time. In addition, the chemistry of the soil solution did not change after the addition of the contaminant. We conclude that the effect of free-phase contaminant is through the geometry of the conductive phase (water), and the membrane polarization model can explain the resultant effect on SIP signal.

The results of the first two experiments, that take into account exchange processes between inorganic and ionic organic compounds, show that due to the exchange process the in-phase electrical conductivity increases while the polarization decrease. These results were found to hold for both saturated and unsaturated cases. The exchange process affects the chemistry of both the soil solution and mineral surface, and in turn affects the SIP signal. The chemical and electrical models demonstrate the role of the Stern layer polarization on the SIP signal. The model shows that the lower mobility of the ionic organic compounds at the Stern layer (compared to the inorganic ions) is the main factor affecting the decrease in polarization, and that the increase in the in-phase conductivity resulted from the release of inorganic ions to the soil solution.

Clearly, when a mixture of organic contaminants that contains both polar and non-polar compounds (most real contaminants are essentially a "cocktail") is introduced to the subsurface, the two processes mentioned above (i.e. exchange processes and changes in the conductive phase geometry) are expected to take place simultaneously. Still our results indicate that change in the chemical composition of the mineral-liquid interface is more dominant and is also expected to affect the in-phase electrical conductivity. From application point of view, it is worthwhile to note that in any of the cases considered here and regardless of the governing mechanisms, the polarization of the soil is decreasing in response to the addition of organic contaminant. This is of importance as it can serve as a marker in IP surveys conducted at site suspected to be contaminated with organic pollutants.

To conclude, in this work we show that organic contaminants affect the electrical properties of porous media. We provide new experimental evidence for the effect of free-phase organic contaminant in unsaturated porous media and for the effect of adsorption of ionic organic compounds on the electrical properties of the porous media. A new conceptual model that explain the mechanisms by which organic contaminant affect the SIP response was developed, and for the case of adsorbed organic compounds the conceptual model was tested using an existing model for SIP response of porous media. The results of this work can be used to better interpret electrical data collected at site contaminated with organic pollutants, as well as better design of monitoring systems.