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Experimental and numerical characterization of toluene transport and bioremediation processes using spectral induced polarization

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Workshop session: “Characterization of contaminated subsurface and monitoring of dynamic processes”

Is the first and presenting author a student? Yes

Polluted soils are often the result of more or less recent anthropogenic activities, and constitute major societal issues. A recent study (Froger et al., 2021) estimates that 30% of the surface area of France has polycyclic aromatic hydrocarbon (PAH) concentrations in soils above $100 \mu\text{g.kg}^{-1}$. Once in the underground surface, these pollutants pose a risk to groundwater and drinking water supplies. Biodegradation in many regards can be an environmental-friendly remediation technique. This technique involves the decomposition of organic pollutants by micro-organisms. Many studies have highlighted the sensitivity of spectral induced polarization (SIP) to bacterial growth, biodegradation and bacterial activities such as mineral and biofilm production (e.g. Davis et al., 2006; Atekwana and Slater, 2009; Abdel Aal et al., 2010; Kessouri et al., 2019). All these studies focused on describing the influence of biodegradation on SIP without providing a method for quantification. To date, very little work has been done to quantitatively study the SIP response of bacteria in porous media. This work, part of the ANR project IMAGE, aims to develop: (i) petrophysical relationships at a column scale, linking complex conductivity to toluene biodegradation processes and (ii) a process-based inversion scheme coupled with a stochastic approach.

The experimental part uses two columns: one inoculated with *Rhodococcus wratislaviensis* which biodegrades toluene, and an abiotic control column. In fact, the columns form part of a more complete setup (see Figure 1).

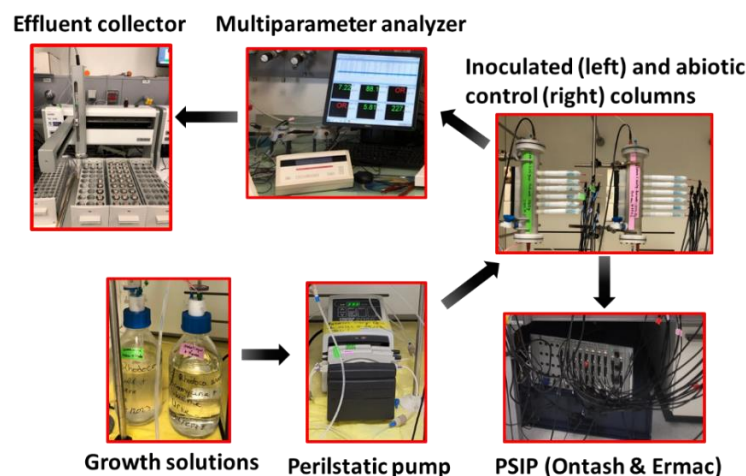


Figure 1: Experimental set-up of the open-loop circulation system.

This includes feeding bottles containing the growth media and toluene, a pressurised oxygen supply at 0.5 bar for oxygenation of the solutions, a multiparameter analyser (pH, Eh, dissolved oxygen and electrical conductivity of the fluid), and a peristaltic pump that allows the fluid to circulate at a constant flow rate through the system. Two configurations of fluid circulation were set up in this system. The first one is a closed-loop circulation: the fluid leaving the column flows back into the feed. The purpose of closed-loop circulation is to allow bacterial colonisation of the solid matrix (sand) in the column. The second configuration is an open-loop circulation: the fluid leaving the column (outflow fluid) does not return to the feed and is renewed regularly. This configuration comes close to natural conditions of biodegradation in groundwater. Moreover, in this configuration toluene concentration is monitored in the outflow fluid. Finally, at the end of the experiment, sand samples are collected at different heights in the column for DNA analysis.

It is worth mentioning that this experimental phase is in progress after a first attempt with technical difficulties. The first trial showed a DNA distribution higher at the bottom (194.4 ng/g) compared to the top (11.9 ng/g) of the inoculated column. This distribution is consistent with the expected distribution of toluene in the column. Indeed, bacteria tend to grow close to the point of entry of toluene in the column. The results also show a DNA concentration of 56.6 ng/g at the bottom of the abiotic column, thus revealing a contamination in the abiotic column. In the second trial, we have solved the issues previously encountered.

The second aspect of this work is devoted to forward modelling and inversion. The approach that we develop in this study aims to satisfy two criteria (i) to include in its expression the biogeochemical processes involved in biodegradation and (ii) to provide a more complete exploration of the solution space. In an effort to satisfy these two criteria, we are implementing a stochastic inversion approach. This approach is based on a Markov chain Monte Carlo algorithm. This method will allow the determination a quantitative relationship between complex resistivity and biodegradation parameters such as pollutant quantity, porosity and bacterial concentration.

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