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Revealing Microbial Dynamics with Spectral Induced Polarization: A Non-Invasive Approach to Tracking Cell Growth and Activity

DINITHI AMARAWARDANA[1], ADRIAN MELLAGE[1] AND CHRISTINA SMEATON[2]

[1]University of Kassel
[2]School of Science and the Environment,Grenfell Campus-Memorial University of Newfoundland

Spectral induced polarization (SIP) is an emerging (bio)geophysical technique that holds promise as a non-invasive sensing tool for investigating in-situ microbial activity and biogeochemical processes in complex porous environments such as soils and (aquifer) sediments. Recent advancements have highlighted a strong correlation between SIP signals and the presence and metabolic activity of microbial communities. The approach offers the advantage that recorded signals deliver information related to the charging properties of cells and the porous medium while also providing access to both the planktonic and sediment-associated biomass. However, significant questions remain regarding the fundamental mechanisms underlying SIP responses, particularly in relation to (nanoscale) microbial-mineral interactions. A critical area of inquiry is whether SIP signals are generated directly by (individuals or groups of) microbial cells or through their interactions with the surrounding porous media. Shedding conclusive light on these open questions is essential for advancing the application of non-invasive methods in environmental sciences. In this study, we investigated the SIP response of *Shewanella oneidensis* MR-1, a model dissimilatory metal- reducing bacterium, in an “inert” porous medium. To isolate the effect of *Shewanella Oneidensis* MR-1 on SIP response, we synthesized growth medium-encapsulated alginate beads which provided a diffuse source of substrate for growing cells while also serving as a porous medium with a negligible polarization signal. In parallel incubations, we monitored the cell density (CFUs) and adenosine triphosphate (ATP) content during the experiment (i.e., a direct measure of microbial metabolic activity). Our experiments yielded polarization signals that directly resembled a classic microbial growth curve. The magnitude of measured conductivity increased during the growth phase and stagnated during the stationary phase, in line with our cell density measurements. Moreover, a significant decrease in ATP concentrations, presumably due to death, was accompanied by a concomitant decrease in polarization. While the increase in polarization during the log-phase was proportional to both growth and activity, highlighting the interlinked contributions of both on measured SIP signals. Our findings provide compelling evidence that microbes themselves are responsible for polarization signals thereby contributing to the advancement of developing non-invasive tools for targeted monitoring of microbially mediated reactions.