THEORETICAL AND NUMERICAL MODELING OF THE BIODEGRADATION OF OIL MICRODROPLETS MOVING IN A WATER COLUMN

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ABSTRACT

Natural seeps and accidental releases of crude oil in the sea result in swarms of droplets that are carried away by underwater sea currents. The droplets may be created either at the sea surface during the breakup of an oil slick by sea waves, or at the seafloor during the extrusion of crude oil from natural cracks or broken wellheads. A high concentration of oil droplets in seawater disturbs the established ecosystem dynamics and poses a significant risk of toxic effects to fish and other marine animals. The fate of underwater droplet swarms is determined by natural attenuation processes, mainly dissolution into the seawater and biodegradation by oil-eating microbes. We have recently developed a compound particle model for the biodegradation of solitary oil microdroplets moving through a water column[1]. The compound particle is of the core-shell type and consists of an oily core successively surrounded by an ultrathin skin of oleophilic microbes and another biofilm layer of finite thickness. Here, we present an extended version of the model that accounts for three major biodegradation modes[2] (i.e., interfacial uptake, bioreaction in the biofilm layer and bulk seawater), as well as for the effects of oxygen limitation (hypoxia) and multiple oil components with varying toxicity and bioavailability. In the general case of nonlinear microbial kinetics, the governing set of advection-diffusion-reaction equations is solved numerically for oxygen and multiple oil components, whereas analytical solutions have also been established for certain limiting cases. The model provides estimates for the shrinking rate, size evolution and residence time of oil microdroplets in a water column as functions of key system parameters (drifting velocity, microbial kinetics, diffusivity, solubility, density).

ACKNOWLEDGEMENT

EU Horizon 2020 MSCA Grant 741799 - "OILY MICROCOSM".

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