Water Surface Remediation Using Liquid Marbles Formed by Self-Assembled ZnO Micro-Nanostructures

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Oil pollution on water surfaces remains a critical environmental challenge, with over 20 million liters of oil discharged into aquatic ecosystems each year. These spills endanger marine life, damage coastal economies, and threaten public health. Traditional cleanup methods—including dispersants, skimmers, and sorbents—typically recover less than 40% of spilled oil and often cause secondary environmental harm. To address these limitations, we engineered free-floating Liquid Marbles (LMs) as a sustainable and selective hydrocarbon recovery solution. These marbles are formed by encapsulating water droplets in a shell of self-assembled Zinc Oxide (ZnO) micro-tetrapods, which exhibit superhydrophobicity with contact angles above 120°, enabling efficient oil absorption from the surface. Liquid Marbles with a volume of 10 µL exhibited maximum mechanical resistance, absorbing up to 90% of their own mass in hydrocarbons. Their buoyant structure and mechanical resilience allow straightforward retrieval post-deployment, minimizing the risk of contamination during collection. Initial observations of surface motion were supported by empirical results showing that surface tension gradients induced by volatile compounds enable directional self-propulsion, while ZnO's piezoelectric properties offer potential for electromagnetic steering and automated deployment. To enhance resilience under dynamic conditions, we developed polymer-based LMs exhibiting over two orders of magnitude greater mechanical stability than water-based counterparts, as confirmed by force–deformation analysis. Future work will focus on leveraging ZnO's photoactive surface to achieve in situ photocatalytic degradation of captured hydrocarbons, completing a circular, eco-safe remediation cycle.

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