Preparation and Integrated of Special-Wettability Materials for Coalescence-Based Separation of Complex Oily Wastewater

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Introduction.

Oily wastewater generated in the petrochemical industry typically features complex oil-phase compositions and high degrees of emulsification, rendering conventional coalescence-based oil removal technologies prone to low separation efficiency and poor stability. The efficiency of coalescence-based oil removal primarily depends on whether the interfacial films of emulsified oil droplets can be effectively ruptured, and is subsequently governed by the wetting, collision-coalescence, and detachment behaviors of oil droplets on material surfaces and within material layers. In particular, coupling interfacial destabilization, wettability regulation, and directional migration of oil droplets is beneficial for full-process intensification from interfacial demulsification to droplet growth and stable separation. Based on this concept, a series of coalescence materials possessing demulsification functionality and special wettability was developed, and gradient-wettability layers were further constructed through biomimetic integration.

Experimental/methodology.

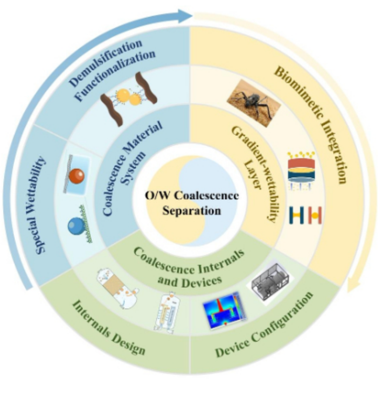
Based on thermodynamic analysis, the surface free-energy characteristics required for oil-droplet demulsification and wetting spreading were identified to guide the surface design of coalescence materials. A mussel-inspired interlayer was firmly deposited onto substrate surfaces through the oxidative self-polymerization of catechol-structured compounds. Subsequently, functional compounds containing amino groups or α,β-unsaturated carbonyl groups were grafted through Michael addition and Schiff-base reactions, yielding a series of demulsification-functionalized/special-wettability materials. This "interlayer–grafted functional layer" strategy enabled the stable construction of functional layers on various organic and inorganic substrates, showing good universality and durability. These materials were then integrated into gradient-wettability layers, and CFD simulation was further used to optimize matched coalescence-internal and device configurations.

Results and discussion.

For complex oil-water systems, this study established a coalescence material system integrating demulsification functionality, special-wettability regulation, and biomimetic integration of gradient-wettability layers, thereby strengthening the key steps of the coalescence process. Demulsification-functional compounds enhanced the destabilization and rupture of the interfacial films of emulsified oil droplets, while gradient-wettability layers promoted the migration, coalescence, and stable release of oil droplets toward strongly oleophilic regions, thus enabling continuous synergy from interfacial destabilization to intensified separation. In real oily wastewater treatment, oil removal efficiencies were improved by 26 and 35 percentage points compared with conventional polypropylene and glass-fiber materials, respectively. The technology requires neither additional energy input nor chemical dosing and generates no secondary pollution such as scum or VOC emissions. Moreover, the developed modular coalescence internals and devices can be coupled with pump-and-treat systems for the remediation of petroleum hydrocarbon-contaminated groundwater.

Keywords:

oily wastewater; coalescence separation; special wettability; gradient wettability; demulsification-functionalized materials



Schematic illustration of the coalescence material system and the corresponding internals and devices for oil/water coalescence separation.