

Taming Instability: Scaffold like Polyaniline for enhancing the sedimentation stability and their Influence on Stability-Magnetization Trade-Off in Viscoelastic Magnetorheological Fluids

Magnetorheological fluids (MRFs) rely on the dynamic interplay of magnetic interaction, particles dispersion, and viscoelastic response, yet achieving long-term sedimentation stability without significantly compromising magnetic properties remains a significant challenge. This study introduces a pioneering strategy by employing polyaniline (PAni) as a scaffold-like additive to enhance the sedimentation stability of Fe-based MRFs. The high surface area and porous architecture of PAni foster a supportive network that evidently enhances particle dispersion, achieving a sedimentation ratio of 43.97% at an optimal 2 wt. % PAni concentration—more than doubling the stability of bare Fe-based MRFs (20.88%). Brunauer–Emmett–Teller (BET) surface area analysis confirms that PAni's porous morphology (~24× higher pore volume than Fe) facilitates enhanced particle dispersion and steric stabilization, mitigating gravitational settling. This investigation elucidates the nuanced trade-off between sedimentation stability and magnetic properties, offering a physics-driven framework to optimize MRFs for practical applications. The incorporation of non-magnetic PAni introduces a deliberate trade-off, wherein enhanced colloidal stabilization and steric hindrance come at the expense of reduced magnetic coupling efficiency and field-induced dipolar interactions. While the saturation magnetization (M_s) reduces from 218.16 emu/g (Fe) to 71.41 emu/g (Fe with 4 wt.% PAni) due to particle dilution and increased interfacial porosity, the magneto-yield stress remains sufficiently high—decreasing from 940.96 Pa to 437.83 Pa at $H = 123$ kA/m—preserving functional field-responsiveness. Oscillatory shear analysis reveals that storage modulus (G') attains 2.22×10^5 Pa at 123 kA/m for FeP 2%, with $\tan \delta < 0.2$ in the linear viscoelastic regime, indicating a strongly elastic character necessary for dissipative control applications. The flow behavior transitions into a pronounced shear-thinning regime ($n \sim 0.7$ – 0.9), which aligns with the breakdown of anisotropic field-induced structures under strain. This rheo-magnetic trade-off between PAni-induced stabilization and reduction in magneto-mechanical coupling is carefully optimized, yielding MRFs with sufficient magnetic actuation and improved structural fidelity. The insights provided herein offer a robust structure-property framework for designing application specific MRFs, where sedimentation stability, magnetic tunability, and rheological integrity must be simultaneously addressed.

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