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Torque and flow induction in magnetic emulsions under rotating and traveling-wave magnetic fields

Authors: Aura M. Perdomo-Sanchéz[1]; María Daniela Contreras Mateus[2]; Arlex Chaves-Guerrero[3]

[1] *School of Chemical Engineering, Universidad Industrial de Santander, Bucaramanga, Colombia.*

[2] *Postoctoral Associate at TUD Dresden University of Technology Dresden, Germany.*

[3] *School of Chemical Engineering, Universidad Industrial de Santander*

Magnetic fluids, including ferrofluids and magnetorheological fluids, constitute a rapidly developing research domain due to their technological potential. Their rheological behavior is governed by particle length scales and magnetically induced structuration. Magnetorheological fluids contain micrometer-sized particles that form field-induced chains, leading to strong magnetoviscous responses but limited stability and sedimentation. In contrast, ferrofluids consist of superparamagnetic nanoparticles (5–30 nm) stabilized by Brownian motion and surface effects, ensuring high colloidal stability but moderate magnetorheological performance.
Building on these properties, magnetic emulsions (MEs), composed of ferrofluid droplets dispersed in a nonmagnetic continuous phase, combine long-term stability with enhanced magnetoviscous responses. However, most studies have focused on static magnetic fields, while their behavior under time-dependent fields remains largely unexplored. Therefore, this study investigates the effects of rotating magnetic fields (RMFs) and traveling-wave magnetic fields on the rheological behavior and flow induction of MEs.
An oil-in-water magnetic emulsion was formulated using kerosene-based ferrofluid droplets dispersed in an aqueous surfactant solution. Rheological, morphological, and magnetic characterizations were performed. Experiments evaluated torque generation on the inner and outer surfaces of hollow and solid cylinders under RMFs. Flow induction was additionally studied in a cylindrical container and in a closed-loop flow system coupled with ultrasound velocity profiling measurements.
The results demonstrate that both magnetic-field configurations effectively induce flow in the emulsion. The flow behavior resembles that of ferrofluids under comparable conditions, while exhibiting a stronger magnetoviscous effect. Under RMFs, measurable torque was generated on both cylindrical surfaces, with magnitudes dependent on field strength, excitation frequency, and contact area. The torque direction was reversibly controlled by changing the rotation sense of the magnetic field. For traveling-wave magnetic fields, the induced flow increased systematically with field intensity and frequency. These findings contribute to the understanding of magnetic-fluid hydrodynamics and support the development of magnetically driven transport systems.

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