Microstructure dynamics induced by biaxial fields in dipolar suspensions

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Magnetic fluids exhibit interesting dynamical behavior when subjected to biaxial rotating magnetic fields as has been reported in previous experimental studies on magnetic holes[1] and magnetic droplets[2,3]. These systems show synchronous and non-synchronous regimes depending on the value of the driving frequency. J.C. Bacri et al.[2] found unexpected spiny, starfish shaped magnetic microdroplets when a high frequency rotating magnetic field was applied. At lower frequencies, O. Sandre et al.[3] found that the magnetic droplets break up to decrease their viscous drag and facilitate tracking the field rotation. Computer simulations of colloidal suspensions subjected to high frequency biaxial fields have been developed by J.E. Martin et al.[4]. They predicted the formation of 2D sheetlike structures aligned in the field plane.

In this work, scattering dichroism and video microscopy experiments have been combined to study the dynamics of induced dipolar chains in magnetorheological (MR) suspensions subject to rotating magnetic fields.

We used scattering dichroism to study the orientation dynamics of low concentration MR suspensions ($\phi \sim 0.01$) when rotating magnetic fields of moderate frequencies (up to 10 Hz) were applied[5]. In these suspensions, dichroism arises from the formation of optically anisotropic chains upon imposition of the magnetic field and gives information about the number of aggregated particles. We found that the induced chain-like aggregates rotate synchronously with the field but lag behind with a constant phase angle. Furthermore, two different behaviors were found below or above a crossover frequency. Below this value, the dichroism remains almost constant but above the crossover frequency, the viscous drag overcomes the magnetic force and reduces the dichroism following a power law with an exponent approximately -1.

The interplay between magnetic and viscous forces over the crossover frequency has been studied. We found a linear dependence of the crossover frequency with the square of the magnetization and the inverse of the viscosity indicating that the Mason number, Ma (ratio of viscous to magnetic forces), governs the rotational dynamics[6]. Consequently, we find a crossover Mason number, Ma_c, below which the dichroism remains almost constant and above which the viscous drag prevents the particle aggregation process from taking place.

We have also performed videomicroscopy experiments[7] to visualize the dynamics of chains for a range of Mason numbers around the crossover value (where both magnetic interaction and viscous drag are comparable). Direct observations show that chains rotate synchronously with the field adjusting their size to decrease the viscous drag. We find that the average size of the structures decreases with Ma following a power law with exponent close to -1/2 being the hydrodynamic forces the cause of the chains break up. However the total number of aggregated particles shows two different behaviors depending on Mason number in agreement with scattering dichroism experiments. Once the crossover Mason number is surpassed, the viscous forces start to dominate the magnetic ones and the aggregation process is inhibited. Furthermore, for $Ma > Ma_c$, the magnetic field is not strong enough for the structures to remain aligned in the field direction when rotating at these high frequencies and more isotropic structures are formed. These two mechanisms, the increase of the number of isolated particles and the formation of more isotropic structures, contribute to the decrease of the dichroism.

Our experimental findings have been interpreted also with the help of athermal molecular dynamics simulations that show good agreement with the experimental results.

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