DYNAMICS OF DILUTE MAGNETIC NANOPARTICLE SUSPENSIONS

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Dilute suspensions of magnetic nanoparticles (MNP) have attracted a lot of attention due to their immense technological and biological applications. These MNP suspensions can be used as labels for sensing applications [1]. The main reason behind their wide applicability is the ease with which these can be detected and manipulated. Biological applications such as magnetic resonance imaging, targeted drug delivery, biomarkers and biosensors rely on transport and manipulation of individual particles with size ranging from few nanometers to tens of nanometers [2]. This size range enables them to interact or bind with biological entities like proteins, genes, viruses and cells. Thus, these MNP's provide a means of tagging biological entities and eventually be driven and manipulated by external fields. It is hence crucial to understand the dynamics of single domain magnetic nanoparticles.

When analysing the dynamics of such nanoparticle suspensions, several factors play competing roles. The system behavior is governed by the mutual strengths of the various interaction energies present, which include magnetic dipolar and vanderwaal's (attractive) as well as steric and thermal (repulsive) interactions. This leads to competing aggregation and fragmentation processes within the system leading to cluster formation (refer figure 1). We present a simple model incorporating aggregation and fragmentation process (as ratio D/w) by appropriately writing down the rate equations for these processes. We wish to mention here that most of the earlier studies are based on irreversible aggregation process. By including fragmentation, the cluster aggregation process becomes self-limiting. The average cluster size in the initial stages exhibits power law dependence similar to irreversible aggregation based models. However it converges to a time independent value at later times. This behavior for various ratios of aggregation to fragmentation strengths exhibits scaling as shown in figure 2. The simulation results are compared with experimental data on a variety of MNP suspensions [3]. The comparisons are satisfactory.

Further the relaxation mechanism of single domain magnetic nanoparticles within the suspensions can either be dominated by either Neel and or Brownian relaxation [4]. The response times of the particles are altered by magnetic volume, enhanced volume due to surfactant coatings, anisotropy constant and temperature. Also, all experimental samples have an inherent particle size distribution leading to polydispersity. Polydispersity considerably alters the response functions. This is demonstrated in figure 3 where we plot the AC susceptibility $\chi(\omega)$ vs ω for monodisperse and polydisperse samples. In this study, we systematically analyse the effect of polydispersity on $\chi(\omega)$. We also provide a procedure to extract particle size distribution from $\chi(\omega)$ if the later is unavailable in experiments using Cole-Cole plot analysis [5].

To conclude, the study is an attempt to understand—

(i) factors which affect single particle relaxation and polydispersity which is ubiquitous in experimental samples.

(ii) clustering of MNP and its effect on response functions.

The two are important in distinct physical settings.

References:

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Figures:

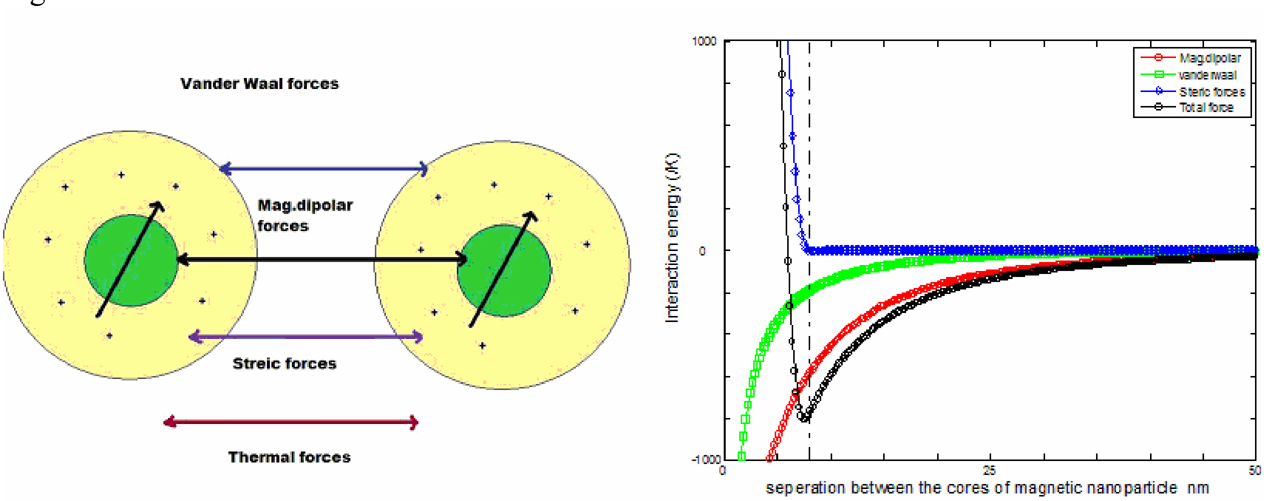

Figure1: Interaction energies between two nanoparticles

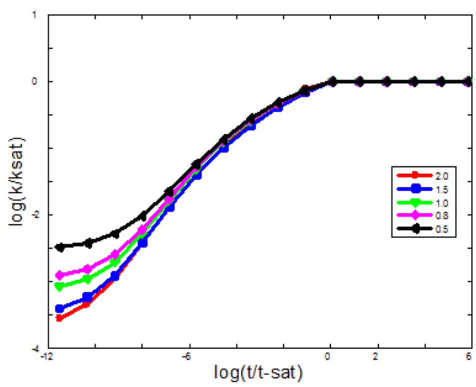

Figure 2: Variation of K_avg vs time for different ratios of aggregation and fragmentation depicting (i) Power law behavior initially (ii) steady state behavior at later times (iii) scaling at all ratios.

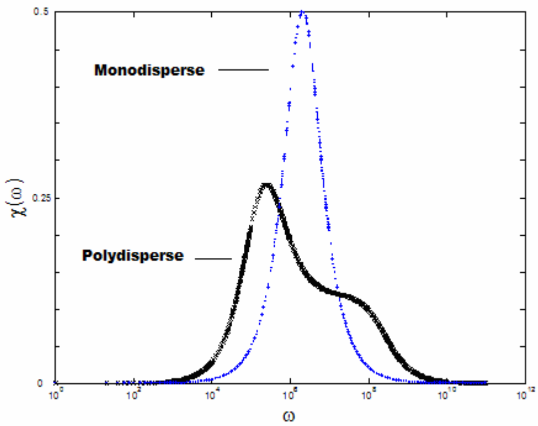

Figure 3: Effect of polydispersity on response function (lognormal distribution with r_m=7.5 nm , std.dev=0.35 respectively)