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Bioinspired Green Synthesis of Magnetite Nanoparticles Using Room-Temperature Co-Precipitation: A Study of the Effect of Amine Additives on Particle Morphology in Fluidic Systems

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Abstract : Magnetite nanoparticles (MNP) have been an area of increasing research interest due to their extensive applications in industry, such as in carbon capture, water purification, and crucially, the biomedical industry. The use of MNP in the biomedical industry is rising, with studies on their effect as Magnetic resonance imaging contrast agents, drug delivery systems, and as hyperthermic cancer treatments becoming prevalent in the nanomaterial research community. Particles used for biomedical purposes must meet stringent criteria; the particles must have consistent shape and size between particles. Variation between particle morphology can drastically alter the effective surface area of the material, making it difficult to correctly dose particles that are not homogeneous. Particles of defined shape such as octahedral and cubic have been shown to outperform irregular shaped particles in some applications, leading to the need to synthesize particles of defined shape. In nature, highly homogeneous MNP are found within magnetotactic bacteria, a unique bacteria capable of producing magnetite nanoparticles internally under ambient conditions. Biomineralisation proteins control the properties of the MNPs, enhancing their homogeneity. One of these proteins, Mms6, has been successfully isolated and used in vitro as an additive in room-temperature co-precipitation reactions (RTCP) to produce particles of defined mono-dispersed size & morphology. When considering future industrial scale-up it is crucial to consider the costs and feasibility of an additive, as an additive that is not readily available or easily synthesized at a competitive price will not be sustainable. As such, additives selected for this research are inspired by the functional groups of biomineralisation proteins, but cost-effective, environmentally friendly, and compatible with scale-up. Diethylenetriamine (DETA), triethylenetetramine (TETA), tetraethylenepentamine (TEPA), and pentaethylenehexamine (PEHA) have been successfully used in RTCP to modulate the properties of particles synthesized, leading to the formation of octahedral nanoparticles with no use of organic solvents, heating, or toxic precursors. By extending this principle to a fluidic system, ongoing research will reveal whether the amine additives can also exert morphological control in an environment which is suited toward higher particle yield. Two fluidic systems have been employed; a peristaltic turbulent flow mixing system suitable for the rapid production of MNP, and a macrofluidic system for the synthesis of tailored nanomaterials under a laminar flow regime. The presence of the amine additives in the turbulent flow system in initial results appears to offer similar morphological control as observed under RTCP conditions, with higher proportions of octahedral particles formed. This is a proof of concept which may pave the way to green synthesis of tailored MNP on an industrial scale. Mms6 and amine additives have been used in the macrofluidic system, with Mms6 allowing magnetite to be synthesized at unfavourable ferric ratios, but no longer influencing particle size. This suggests this synthetic technique while still benefiting from the addition of additives, may not allow additives to fully influence the particles formed due to the faster timescale of reaction. The amine additives have been tested at various concentrations, the results of which will be discussed in this paper.

Keywords : bioinspired, green synthesis, fluidic, magnetite, morphological control, scale-up
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