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Consequences of Sheep Blood Used as Diluting Agent for the Magnetoviscous Effect in Biocompatible Ferrofluids

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Abstract:
Magnetic nanoparticles suspended in suitable carrier liquids can be adopted for use in biomedicine. For this to be achieved, the biocompatibility of these ferrofluids needs to be ascertained. In cancer treatment, potential applications currently under investigation include, e. g. drug targeting by using magnetic fields and the destruction of diseased cells by applying alternating magnetic fields, which cause heating of magnetic nanoparticles. To enable the use of ferrofluids in the actual biomedical context, detailed knowledge of the flow characteristics is essential to ensure safe treatment. From ferrofluids used in the engineering context, a rise of viscosity when a magnetic field is applied – the magnetoviscous effect – is well known. This effect, which leads to an increased viscosity and profound alteration of a fluid's rheological behavior, has also been demonstrated for biocompatible ferrofluids used in the aforementioned applications. In biomedical applications, ferrofluids will be diluted in the blood stream. Therefore, the interaction between whole blood and the ferrofluid has to be investigated. This is the focus of the current experimental study, which makes use of two different ferrofluids diluted in sheep blood to gain a deeper understanding of the fluid mixtures primarily regarding the relative change in viscosity if an external magnetic field is applied. The results demonstrate a strong interaction between blood cells and structures formed by the magnetic nanoparticles and show a high deviation of results compared to ferrofluids diluted in water. These findings have to be taken into account for future research and applications of similar biocompatible fluids to guarantee safe and effective use in living organisms.

Key words:
Magnetoviscous effect, ferrofluid, rotational rheometry, magnetic nanoparticles, biomedical materials

1 INTRODUCTION

Ferrofluids are suspensions of magnetic nanoparticles in suitable carrier liquids with a wide range of applications. The particles are prevented from agglomeration caused by e.g. van der Waals interaction by a surfactant layer of varying thickness [1, 2]. The resulting suspension can be considered as stable. Regarding applications, two areas are currently the focus of research: Ferrofluids used in the engineering context – an area which has been investigated in some detail in recent years [1, 3] as well as ferrofluids utilised in the biomedical context [4, 5]. The current study focuses on the investigation of ferrofluids used in the latter field of research. While for biomedical purposes such fluids have been used as contrast agents for magnetic resonance imaging (MRI) with success for several years [6], recent research has focused on magnetic drug targeting [7, 8], and magnetic fluid hyperthermia (MFH) [9].

Magnetic fluid hyperthermia is a novel approach for inducing cell death by concentrating ferrofluids within a tumor and applying a magnetic field that induces localised heat production. Initial results using, e. g. a breast cancer model [10], mice prostate tumor [11], ovarian cancer cells [12], and rat glioma [13] demonstrate its potential. Computed tomography (CT)-guided magnetic thermoablation of malignant kidney tumours in rabbits resulted in localised tumor necrosis [14]. It has been shown as well that MFH destroys tumor tissue whilst leaving healthy surrounding structures untouched [15].

Besides those promising examples of the use of ferrofluids in biomedicine, magnetic particle imaging (MPI) can be regarded as another continuously improving approach. This technique enables imaging of the spatial distribution of the magnetic nanoparticles [16]. Compared to non-invasive imaging using conventional X-ray or CT, it carries several advantages. Non-toxicity of contrast agents used in the treatment of chronic kid-

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