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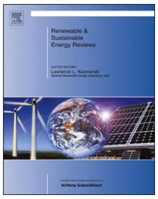

Magnetoviscous effect and thermomagnetic convection of magnetic fluid: A review

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ABSTRACT

This article discusses on stability and agglomeration of particles, an important occurring phenomenon that greatly affects the properties of magnetic fluid. Magnetoviscous behaviour and thermomagnetic convection is a special characteristic of this fluid, which have promising prospects in advanced applications like in electronic cooling devices and pipe systems, heat exchangers, magnetic clutch, dynamic sealing and servo rheological devices. The purpose of this article is to review recent investigations in this field that focuses on the magnetoviscous effects and thermomagnetic convection of magnetic fluids. This review also emphasises both numerical and experimental approaches for deeper understanding of those properties.

Contents

1. Introduction

In recent years, the exploration of nanotechnology within the areas of science and technology has been gaining interests, as these kinds of materials exhibit great characteristics because they can be manipulated at nano-scale and possess various outcome possibilities. In other words, nanomaterials can have different physical and chemical properties in the atomic and molecular stage than that of materials of larger scale. In the field of nanofluids, one of the special fluids that received extensive attention from researchers is magnetic nanofluid. Magnetic fluid, which is also acknowledged as ferrofluid, is an engineered fluid, which consists of colloidal suspension system of magnetic nanoparticles dispersed in a carrier liquid. Some of the main categories of carrier fluids are organic solvent based (heptanes, kerosene), inorganic solvent based (water) and oil based (synthetic ester, synthetic hydrocarbons, perofluoroalkyl polyethers, polyphenyl ethers). The typical size of magnetic solid particles is about 10 nm. Magnetic fluids possess outstanding characteristics of both the fluid properties of liquids and also the magnetic properties of solids. Ferrofluids and its theory of application were discovered in NASA Research Centre in the 1960s, when NASA scientists were investigating liquid manipulation for space technology. Since the first appearance of magnetic fluids, much progress has been made in producing various types of high quality magnetic fluids associated with applications in many fields such as information technology, medicine, energy production and storage, instrumentation, security and materials science [107]. Most applications of magnetic fluid were based on the following properties [78]: (1) It goes to

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where the magnetic field is strongest and stays there; (2) It absorbs electromagnetic energy at convenient frequencies and heats up; (3) Its physical properties may change with the application of magnetic field. There are two methods used for synthesising magnetic nanofluid, either using a single step method or two steps method. For the single step method, both synthesis and dispersion of magnetic nanoparticles in the carrier liquid is done simultaneously. Magnetic nanoparticles can be prepared by different synthetic routes, such as grinding/ball-milling, co-precipitation, hydrothermal technique, microwave-assisted synthesis, microemulsion, polyol method, or by thermal decomposition [16,3,54]. In the two steps method, magnetic particles that were initially prepared are coated with stabilizing agents using techniques like imposed ultrasound or high pressure to the solution.

The magneto-rheological and superparamagnetic properties possessed by ferrofluid, which lead to the magnetoviscous effects and thermomagnetic convection occurrence, make these types of magnetic fluids very useful for many technological purposes. This is due to the fact that its physical properties may change with the application of a magnetic field. The findings reported by the India Gandhi Centre of Atomic Research reveal that the use of correlated magnets in conjunction with magnetic nanoparticles creates a large enhancement in thermal conductivity, more than 300% compared to a conventional medium. Percolating nanoparticle paths generated in the colloid solution provide an efficient heat transport from the system. These findings offer promising applications in future 'smart' cooling devices, such as microfluidic devices, micro and nanoelectromechanical systems and other nanotechnology miniature devices.

The use of ferrofluid in high-power loudspeakers has proven that using a material with paramagnetic properties can not only remove heat from the system, but can also improve the quality of the speakers by passively dampening the unwanted resonances. Electronic power applications also seem promising for the betterment of liquid cooling systems. A recent experimental study reported that ferrofluid can be successfully created hydrostatic pressure, which can replace the role of the mechanical pump in the system and still effectively cool through thermomagnetic convection [72]. Furthermore, removing a mechanical pump from electronic power devices may improve a system's performance and its reliability.

Magnetic fluid can also be used in civil damping applications, in which the fluid acts as a shock absorber in order to stabilise a building against earthquakes. Once a disturbance is detected by sensors on the building, signals are instantaneously sent to the dampers and activate a magnetic force inside the damper. Then, the magnetic fluid in the dampers will change from solid to liquid and back, so that the changing is in line with the movement of the building. The use of magnetic fluid in civil may thus reduce the amount of destruction during seismic activity.

In the automotive industry, the use of magnetic fluid is currently being implemented in semi-active suspension systems to dampen vibrations for drivers in large on- and off-road vehicles, such as trucks. This technology is also being developed for car suspension systems. When the piston is working, the energised coil may create a magnetic field, which controls the behaviour of the magnetic fluid in order to provide variable damping whenever needed by the system. The industry found that replacing conventional oil with magnetic fluid in a car's suspension allows damping to be adjusted by 1000 times per second. The advantage of this technology is the ability of the magnetic fluid to adapt to the changing road and driving conditions and also real-time control.

2. Stability: Agglomeration of particles

When magnetic nanoparticles are suspended in a solution, they are subjected to two major attractive forces: van der Waals and anisotropic dipolar forces [46]. Shinoda et al. [90] experimentally found that magnetic ultrafine particles tend to agglomerate even under zero magnetic fields applied to a water-based magnetic fluid. Kikura et al. [41] and Jeyadevan and Nakatani [38] described this formation of particle agglomeration as a primary cluster and it disperses throughout the fluid medium. When an external magnetic field is introduced in the ferrofluid, the primary cluster may induce a secondary cluster which is in the form of doublets, triplets or short chains of magnetic nanoparticles. This happens because the magnetic field possesses the ability to encourage magnetic interaction that exists between magnetite particles along the field direction [42,45,50,73,74]. Furthermore, the growth rate process and the length of aggregated structure are influenced by the strength of the magnetic field [36].

Therefore, in order to hinder the aggregation of the particles and stabilise the suspension of magnetic particles in non-magnetic carrier liquid, the particles are coated with adsorbed surfactant of polymer or long chain molecules, which provide the generally required steric repulsion between the particles [53]. The effectiveness of the steric barrier depends on the length and the structure of the surfactant, the adsorption energy and the properties of the liquid carrier [8,58]. Conventional surfactants that are widely used are from acid group [16], oleate group [84], polymer group [11] and [82]. López-López et al. [53] reported that iron particles coated with lecithin, oleic acid and AIST dispersed well in a non-polar carrier than bare iron particles. On the contrary, bare iron particles dispersed fairly well in polar carriers, but the applied surfactants did not seem to improve the dispersion. The results are in agreement with the work done by Huang and Wang [34] for the same kind of surfactant and magnetic particles used. According to the report by Lalatonne et al. [47], when the thickness of the surface coating is increased, the van der Waals forces rapidly diminished thus dominated by repulsive forces, which tend to break up the structures into its initial state. Another method to counteract the attractive forces is by charging the surface of the particles to produce a coulombian repulsion [63,70]. For some particular applications, where there is a surface coating of magnetite nanoparticle matter, a bilayer surfactant is needed to guard against flocculation and enable stable colloidal suspension in magnetic fluids [27]. An experimental study by Shen et al. [89] showed that the first layer of fatty acid surfactant allowed dispersion in various nonpolar solvents, while the second surfactant of fatty acid with the exposed hydrophilic headgroups allowed a stable dispersion in aqueous magnetic fluid. For bilayer surfactant coated nanoparticles, Bateer et al. [5] used the phase transfer method to coat Fe_3O_4 nanoparticles with oleic acid. Then, the bilayer surfactant, succinimide, wraps the oleic acid coated Fe_3O_4. Transmission electron microscopy images showed that dispersibility of bilayer Fe_3O_4 is much better than that of the uncoated ones and its stability is nearly constant for 360 days at room temperature.

However, a contradicting behaviour of bilayer surfactant coating has been observed by Hajduova et al. [29] for the same kind of iron oxide nanoparticles. Dynamic light scattering studies have found that the oleate bilayer coating on Fe_3O_4 nanoparticles has promoted the formation of compact aggregates with the characteristic size of about 2 μm. However, the addition of a double hydrophilic block polyelectrolytes layer affects the aggregation size of oleate–Fe_3O_4 nanoparticles by reducing the size and form of large aggregates into two times smaller size linear aggregates [96]. Saville et al. [79] also observed that the polymer coating is capable of reducing attractive inter-particle interactions, slowing the