Ferrofluids: Chemical synthesis methods, properties, applications & prospects

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Abstract: Ferrofluids (FF), part of magnetic fluids, are colloidal suspensions of very fine magnetic particles (~ 10 nm). the first synthesis of a ferrofluid was reported in the work of Papell in the sixties. the most used method to prepare magnetic nanoparticles is chemical precipitation and the procedures for this synthesis is to mix FeCl2 and FeCl3 in water then precipitation occurs with the addition of ammonium hydroxide. The Fe3O4 nanoparticles are characterised by (DRX) and the morphology and size of the particles must be established using high-resolution transmission electron microscopy. A contribution to the study of cooling systems is to be made using appropriate software and experimental tools on energy-consuming systems. Finally, some comments on future research directions on the properties of ferrofluids are cited in this work.

Keywords: Ferrofluids, magnetic colloids, nanoparticles, DRX, dynamic sealing

1. INTRODUCTION

A magnetic colloid, also known as a ferrofluid (FF), is a colloidal suspension of single-domain magnetic particles, typically around 10 nm in size, dispersed in a liquid carrier. The liquid carrier can be polar or non-polar (*Scherer,2005)(Kole,2021)(YANG,2022)*. These materials were first synthesised in the 1960s and their technological applications have continued to grow. In order to avoid agglomeration, the magnetic particles must be covered with a suitable coating. Depending on the coating, FFs are classified into two main groups: surfactant (FFS), if the coating is a surfactant molecule, and ionic (FFI), if it is an electric shell(*Scherer,2005)(Kole,2021)*.

The first synthesis of a ferrofluid was reported in Papell's pioneering work in 1965*(Papell,1968)*.

There are essentially two methods for preparing these nanoparticles, size reduction *(*Scherer,2005) and chemical precipitation. In size reduction, a micron-sized magnetic powder is mixed with a solvent and a dispersant in a ball mill and ground for several weeks. Chemical precipitation *(Phor, 2019)* is probably the most widely used method today for preparing magnetic nanoparticles. Various procedures have been developed to achieve this objective. In general, these procedures start with a mixture of FeCl2 and FeCl3 and water.

Co-precipitation occurs with the addition of ammonium hydroxide, then the system is subjected to various procedures including peptization, magnetic separation, filtration and finally dilution.

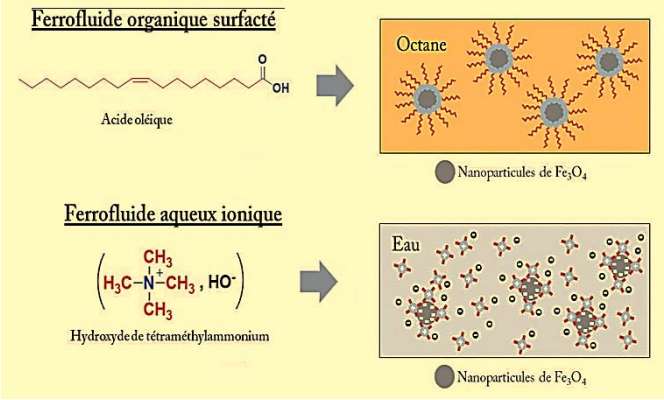

Figure 1. surfactant FerroFluids and Ionic FeroFluids *(Piard, 2021)*

1. Ferrofluid applications

One of the many possible uses for ferrofluids is in the study of materials[1]. Biomedical applications also include magnetic targeting of drugs; hyperthermia; contrast enhancement for magnetic resonance imaging (MRI); and magnetic separation of cells*(Kole,2021)*.

Finally, several categories encompass the many technological applications(*Scherer,2005)*of magnetic fluids: dynamic sealing, heat dissipation, damping, doping of technological materials, etc. Two examples of these applications are given below:

a) Dynamic sealing

In many pieces of equipment, there are two or more different environments, which must be hermetically sealed from each other, but a shaft must transport energy (rotation) from one environment to the other, for example, computer hard disks, which have to operate in a hermetically sealed box because the slightest speck of powder or even the slightest smoke can alter the reading and writing process *(Scherer, 2005)* .It is therefore necessary to hermetically seal the hole through which the spindle passes.
To this end, the hole is placed inside a magnet (Figure 2) and the shaft is made of a soft magnetic material. A groove in the shaft is filled with ferrofluid, which is held in place by the magnetic field, obstructing the passage of any impurities, but leaving the shaft free to rotate, as the obstructing material is liquid.

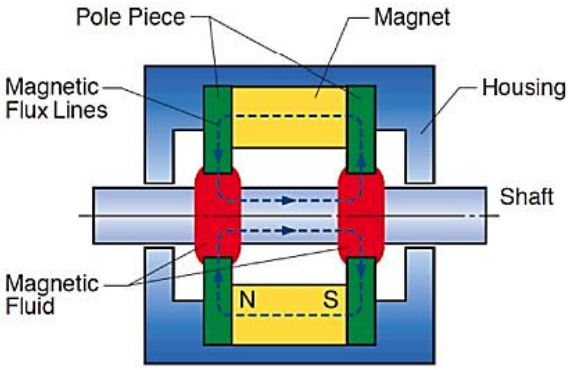

Figure2. Magnetic jouin diagram*(Kole,2021)*

b) heat dissipation

One way of extracting heat from equipment that heats up during operation, and therefore not keeping it too hot, is to use a good heat conductor that connects the equipment to a mass with a much greater thermal capacity and a much larger open surface area to dissipate the heat*(Kole,2021) (Scherer, 2005).*
A good example is a loudspeaker, where the coil heats up during operation and the ferrofluid is held in place by the magnetic field of the magnet attached to the horn *(Scherer, 2005).*

2. Ferrofluid Chemical Synthesis Protocol

Ferrofuid synthesis is generally based on Fe3O4 and paraffin. There are two main stages: the synthesis of Fe3O4 nanoparticles and their dispersion in a suitable carrier liquid, paraffin or octane, to obtain a stable ferrofuide. The Fe3O4 nanoparticles were prepared by the chemical coprecipitation technique using chemical reagents. In the process, iron(II) chloride (FeCl2) and iron(III) chloride (FeCl3) were chosen as initial precursors with a ratio (Fe2+/Fe3+) of 1:2. Each was mixed separately with distilled water in appropriate molar quantities to obtain a homogeneous solution.
These salt solutions are then mixed and stirred, while oleic acid is added drop by drop to the solution to prevent them from agglomerating. Then, with vigorous stirring and constant heating to 85°C, a solution of ammonia (NH3) is added drop by drop to obtain immediate precipitation. The pH of the reaction mixture must be constantly monitored and ammonia is added until the pH reaches 10. The nanoparticles obtained must be washed several times with distilled water. The samples are then dispersed in a suitable liquid (paraffin or octane) and decanted to obtain a stable ferrofuid *(PHOR, 2019).*
The developed nanoparticles should be spherical in shape with a diameter of 15-20 nm. Ferrofuid with different concentrations of nanoparticles (different %) must be prepared to carry out the appropriate study on the role of nanoparticle concentration. The synthesised nanoparticles are characterised by X-ray diffraction (XRD).
The morphology and size of the particles must be established using high-resolution transmission electron microscopy*(Kole,2021)*.

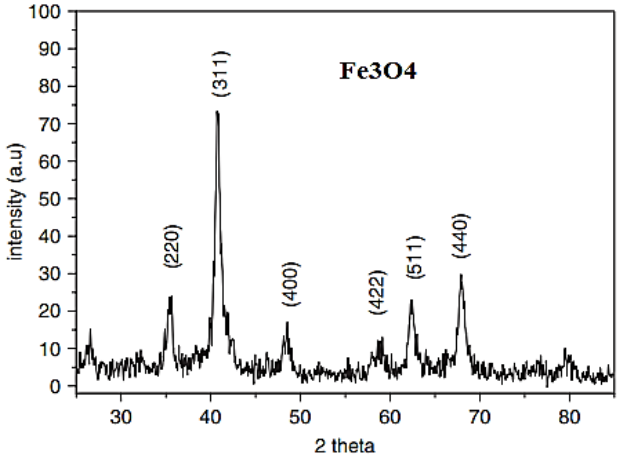

Figure.3.Example of XRD of magnetic particles (*Albornoz* , 2006)

3. Likely application tests

A contribution to the study of cooling systems will be made by modelling (appropriate software) and experimental tools on energy-consuming systems.

4. Prospects for ferrofluids applications

It is impossible to predict with any certainty what ferrofluid research will look like in the years to come. However, some clues can be deduced from the trends in this research over the last few years up to the present day. It is certain that the immense potential applications of ferrofluids will continue to be explored[1]. In particular, biomedical applications such as cancer treatment, drug targeting and the combination of these techniques with radiotherapy, chemotherapy or even surgery will certainly be the subject of intense research in the years to come*(Kole,2021) (Scherer, 2005).*

In terms of fundamental research, the very rapid advances in computer technology, which produces very fast, powerful and inexpensive computers, as well as very practical software, will be used with more realistic models for numerical simulation, making it possible to predict the properties and qualities of ferrofluids, to be tested in the laboratory (Scherer, 2005).

5. CONCLUSION

Ferrofluid, a stable colloidal suspension of magnetic nanoparticles most frequently composed of magnetite (Fe3O4) nanoparticles in a fluid, subjected to a field of a magnet, remains stable and monophasic find numerous applications. In this work we have essentially presented the simplest chemical-physical method used to prepare these fluids and their possible applications

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