Materials Science and Engineering C 79 (2017) 901–916

Contents lists available at ScienceDirect

Materials Science and Engineering C

journal homepage: www.elsevier.com/locate/msec

Review

Synthesis of magnetic nanoparticles and their dispersions with special reference to applications in biomedicine and biotechnology

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ARTICLE INFO

Article history:
Received 1 December 2016
Received in revised form 15 May 2017
Accepted 16 May 2017
Available online 28 May 2017

Keywords:
Magnetic nanoparticles
Nanomagnetic fluids
Biomagnetic medicine
Biomagnetic technology

ABSTRACT

Biomedical and biotechnological applications of magnetic nanoparticles and their dispersions in liquids are found to be potentially useful. An exponential growth in publications of papers, reviews and patents has been observed. Possibilities of their indiscriminate use on individual as well as environmental health hazards are also investigated. Still, there appears to be a good scope for further research work in the field. Even a small improvement either in preparation method or development of novel nanoparticles may prove to be beneficial in longer run. With this aim in mind, the present review discussed the work carried out in author's laboratory on synthesis and characterization of certain biomagnetic particles and biocompatible fluids composed of these particles. Modified methods were used to synthesize these particles. Notable amongst these are direct binding of biomolecules or drug on magnetic nano particles, low Curie point functionalized magnetic particles, targeted drug delivery system, photodyne therapy, anti-bacterial activity and bioremediation of marine fungi. Advantages and limitations of these work in light of recent work is also discussed.

Contents

1. Introduction . . . 902
   1.1. Importance of magnetic nanoparticles . . . 902
   1.2. Advantages of magnetic nanoparticles in biomedicine and biotechnology . . . 903
2. Physics behind Use of Ferrofluid for Biomedical and Biotechnological Applications . . . 903
   2.1. Magnetism is the driving force behind the working of biomagnetic particles. The basic principles of magnetism and classification of magnetic materials relevant to biological applications are well explained by Pankhurst et al. [6]. Here we shall assume that readers are familiar with physics of magnetism . . . 903
   2.2. Applications of SPM in biotechnology . . . 903
   2.3. Force on Nanomagnets:. . . . 904
3. SYNTHESIS OF SPIONS for MAGNETIC SEPARARTION . . . 904
   3.1. In this technique the fluid mixture containing the labelled material e.g. a cell bound to SPION is passed through a region having proper field gradient. The later immobilize the labelled material via the magnetic force Eq. (5) described above. This force should overcome the hydrodynamic drag force given by . . . 904
   3.2. Synthesis of magnetic nanoparticles . . . 904
   3.3. Direct binding technique . . . 904
   3.4. Direct Binding of Lignocane . . . 905
4. Targeted drug delivery . . . 906
   4.1. Above technique of binding is also useful to target other drugs to a specific site in a human body. Targeted drug delivery should not be confused with 'targeted therapy' [75] . . . 906
   4.2. Thermo-responsive MNPs. . . . 907
   4.3. Citrate and dextran bounded MNPs . . . 908
   4.4. Magnetic hyperthermia (MHT) . . . 909
   4.5. Photodyne therapy . . . 910

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http://dx.doi.org/10.1016/j.msec.2017.05.135
0928-4931/

5. Antibacterial activity . . . 910
5.1. Development of antimicrobial agents to combat microbial resistance is a topic of current interest [144,145] . . . 910
5.2. Ag-coated MNPs . . . 910
6. Ferrofluids for antifungal therapy . . . 911
6.1. In recent years, morbidity and mortality rate due to severe fungal infections are increased in patients whose immunity has decreased due to either immunodeficiency virus infections (HIV) or due to cancer chemotherapy [166,167] . . . 911
7. Bioremediation by fungi . . . 912
8. Conclusion . . . 912
Acknowledgements . . . 913
References . . . 913

1. Introduction

Natural sciences have passed through several evolution stages. For example if 19th century is considered as a stage for chemistry and 20th century for physics then 21st century can be said a stage for molecular biology amalgamated with nanotechnology. In nanotechnology, nanosized magnetic particles and fluids involving these particles has a prominent position. The fluids are called ferrofluids (FF) or magnetic fluids (MF) or superparamagnetic fluids (SPM fluids). The last name appropriately characterized magnetic property of the fluid and will be used in this review.

It is interesting to note that the first commercial ferrofluid application was used to stop blood flow during surgery, and at that time it was hard to predict that in future, swarms of nanomagnets flowing through a biocompatible liquid will take a prominent position in biotechnology and biomedicine. A large number of reviews describing possible applications in these fields are available in literature [1–14]. Magnetite and maghemite are the most commonly used materials for such applications; however, other ferrites or their composites have certain distinct advantages over the iron ferrite. This author and his collaborators have synthesized a large number of nanosized magnetic particles of mixed ferrites and developed techniques to bind them with biocompatible molecules or therapeutic drugs. Here, advantages of these systems *vis a vis* other similar systems will be reviewed. First we shall describe importance of such particles in biomedical and biotechnological applications flowed by a brief discussion about physics behind their applications. Subsequently certain prominent applications of such particles will be described. Lastly we shall discuss our two decades of work on synthesis of magnetic nanoparticles and their applications in biomedicine and biotechnology.

Nomenclature

Symbol	*parameter*
B	Magnetic induction
H	Magnetic field
μ_0	Permeability of free space $4\pi \times 10^{-7}$ TmA^{-1}
M	Magnetization
$M_{s.}$	Saturation magnetization
m	magnetic moment
v	volume
χ	volume susceptibility
τ	Relaxation time
τ_o	pre-exponential factor in Neel relaxation time τ_N
ΔE	energy barrier
k_B	Boltzmann constant
T	Absolute temperature
K	anisotropy constant
V	volume of the particle
F_m	Drag force
∇	Gradient
η	viscosity
q	Velocity
w	weight of particle
φ	Volume fraction
G	Conductance
I	Current
V	Voltage
P	Power efficiency
c	Specific heatf
	Frequency
M	Magnetization
	Suffix 'd' stands for domain, and 's' stands for saturation magnetization

1.1. Importance of magnetic nanoparticles

Though there is no clear demarcation line, but in general when at least one dimension of a material particle is below 100 nm it may be called nanoparticle. Depending on the dimension it is referred as quantum dot (0-D), nanowire or nanotubes (1-D), nano film (2-D) or nanostructure (3-D). Their properties like mechanical strength, electric polarization, magnetization and optical properties are drastically different from the respective bulk materials and hence have made a great impact in almost branches of science and technology. It is not that all the properties and applications of nano size materials are discovered or developed only in recent times. Optical and medicinal applications of nanosized gold particles date back to 4th century. Gold is still used as medicine called '*swaran Bhasma*' in India in their traditional medicinal system called 'Ayurveda' [15,16]. However, first indication of tremendous potential of nanosized matter was made by Feynman [17] in his famous 1959 lecture at CALTECH, in which he has predicted that '*there is a plenty of room at the bottom*'. Soon after this, a systematic follow up for the development of nanotechnology began and gather momentum after availability of several instruments like STM (Scanning Tunnelling electron Microscopy), AFM (Atomic Force Microscopy) and like. Several new techniques to synthesize nanoparticles by physical, chemical and what is now emphasized as environment friendly green chemical methods are developed in recent past. Nano sized particles of metals like gold, silver and carbon nanotubes(CNT), metal oxides like SiO_2 and iron oxide, organic molecules like dendrite and biomolecules like lipid, liposome are available for drug carriers, diagnostics, immobilization and other pathological techniques. For all these several extensive reviews are available [15,16,18–23].

The scope of the present review is limited to synthesis, characterization and possible applications of certain magnetic nanoparticles in fields of biotechnology and biomedicine. It may be recalled that applications of a magnet and magnetic field in surgery date back to 500 BCE An Indian surgeon Sushruta was first to use a magnet to remove iron arrows from wounded soldiers [24]. He referred the magnet as '*ious kantam*' means iron loving material. In recent times too, magnet assisted surgeries are being carried out [25]. With advent of nanotechnology there