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Nanoparticles synthesis using supercritical fluid technology – towards biomedical applications ☆

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Abstract

Supercritical fluid (SCF) technology has become an important tool of materials processing in the last two decades. Supercritical CO_2 and H_2O are extensively being used in the preparation of a great variety of nanomaterials. The greatest requirement in the application of nanomaterials is its size and morphology control, which determine the application potential of the nanoparticles, as their properties vary significantly with size. Although significance of SCF technology has been described earlier by various authors, the importance of this technology for the fabrication of inorganic and hybrid nanomaterials in biomedical applications has not been discussed thoroughly. This review presents the nanomaterial preparation systematically using SCF technology with reference to the processing of biomedical materials. The basic principles of each one of the processes have been described in detail giving their merits and perspectives. The actual experimental data and results have been discussed in detail with respect to the selected nanomaterials for biomedical applications. The SCF synthesis of nanoparticles like phosphors, magnetic materials, carbon nanotubes, etc. have been discussed as they have potential applications in bio-imaging, hyperthermia, cancer therapy, neutron capture therapy, targeted drug delivery systems and so on. The more recent approach towards the *in situ* surface modification, dispersibility, single nanocrystal formation, and morphology control of the nanoparticles has been discussed in detail.

Keywords: Nanomaterial fabrication; SCF technology; RESS; GAS; SEDS; ASES; PGSS; SFEE; Supercritical hydrothermal synthesis; Surface modification; Size and morphology control; Bio-imaging; Hyperthermia; Drug delivery system; Neutron capture therapy

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1. Introduction

The nanomaterials exist in nature ever since the earth came into existence. Nature has created these materials in vivid environmental conditions. Nature made nanophase materials such as clays, oxides and/or hydroxides of Fe, Al, Si, etc. and magnetite in magnetotactic bacteria, etc., long before man attempted to produce them, in some cases imitating the natural processes. Similarly, the organic molecules in the nanometer scale are the foundations of the life formation. However, from 1990s the scientists are popularly using the term nanotechnology to refer designing, characterization, production and application of structures, devices and systems that exist in between those of atoms and bulk materials with at least one dimension in the nanometer range (1 nm = one thousand millionth of a meter, 10^{-9} m). The size range of nanotechnology is often delimited to 100 nm down to the molecular level down up to 0.2 nm because; this is where materials have significantly different properties. The development of new sophisticated tools like STM, TEM, AFM, etc., to observe, measure and manipulate processes at the nano-scale level gave a breakthrough to the nanotechnology. The term nanotechnology was first used by the Japanese researcher Taniguchi in 1974 when he referred to the ability to engineer materials at the nanometer scale [1]. The main idea behind this terminology was the miniaturization in the electronics industry. Even as early as 1970s a huge number of nanostructures were created as small as 40–70 nm using electron beam lithography. The term nanomaterials covers materials in one dimension (thin films), two-dimension (nanofibers, nanowires, nanotubes, etc.), and three-dimension (nanoparticles/nanopowders, nanocapsules, fullerenes, dendrimers, molecular electronics, quantum dots, nanostructured materials, nanoporous materials, etc.). The world market in these materials was estimated to be about $120 billion in 2002, and it is growing at an annual rate of 15% to reach $370 billion by 2010. NSF has predicted that by 2015 the nanotechnology will become a trillion dollar industry worldwide.

The nanomaterials are known for their unique mechanical, chemical, physical, thermal, electrical, optical, magnetic, biological and also specific surface area properties, which in turn define them as nanostructures, nanoelectronics, nanophotonics, nanobiomaterials, nanobioactivators, nanobiolabels, etc. In the last one decade a large variety of nanomaterials and devices with new capabilities have been generated employing nanoparticles based on metals, metal oxides, ceramics (both oxide and non-oxide), silicates, organics, polymers, etc. One of the most important properties of materials in nano-size regime is the changing physical properties. During 1980s, the concept of size quantization was formulated for semiconductors [2]. Since then considerable progress has been achieved in this field to understand the size related properties in materials. As the size of semiconductor nanoparticles decreases, a threshold value characteristic of each type of semiconductors is reached. At smaller nanoparticle sizes, the energy gap (band gap) increases, and the optical spectrum is shifted toward the short-wavelength region [3]. So in the quantum dot state (at sufficiently small size) there occurs a transition from a continuous to discrete energy spectrum of conduction electrons [4]. As a result nanoparticles possess unique optical and electronic properties not observed for corresponding bulk samples. Owing to a substantial increase in the fraction of surface atoms and to increasing role of the surface effects not only the optical properties but also other characteristics of materials (structure of electronic energy levels and transitions, electron affinity, conductivity, phase transition temperature, magnetic properties, melting points, affinity to biological, polymer and organic molecules, etc.) also become dependent on the nanoparticle size and shape. Such a size dependent properties have been exploited for biological tagging, for example, as fluorescent biological labels. Hence, it is extremely important to control the size and also shape of the nanoparticles/nanocrystals in order to