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Hydrothermal technology for nanotechnology

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Abstract

The importance of hydrothermal technology in the preparation of nanomaterials has been discussed in detail with reference to the processing of advanced materials for nanotechnology. Hydrothermal technology in the 21st century is not just confined to the crystal growth or leaching of metals, but it is going to take a very broad shape covering several interdisciplinary branches of science. The role of supercritical water and supercritical fluids has been discussed with appropriate examples. The physical chemistry of hydrothermal processing of advanced materials and the instrumentation used in their preparation with respect to nanomaterials have been discussed. The synthesis of monodispersed nanoparticles of various metal oxides, metal sulphides, carbon nanoforms (including the carbon nanotubes), biomaterials, and some selected composites has been discussed. Recycling, waste treatment and alteration under hydrothermal supercritical conditions have been highlighted. The authors have discussed the perspectives of hydrothermal technology for the processing of advanced nanomaterials and composites.

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1. Introduction

The hydrothermal technique is becoming one of the most important tools for advanced materials processing, particularly owing to its advantages in the processing of nanostructural

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materials for a wide variety of technological applications such as electronics, optoelectronics, catalysis, ceramics, magnetic data storage, biomedical, biophotonics, etc. The hydrothermal technique not only helps in processing monodispersed and highly homogeneous nanoparticles, but also acts as one of the most attractive techniques for processing nano-hybrid and nanocomposite materials. The term '*hydrothermal*' is purely of geological origin. It was first used by the British geologist, Sir Roderick Murchison (1792–1871) to describe the action of water at elevated temperature and pressure, in bringing about changes in the earth's crust leading to the formation of various rocks and minerals. It is well known that the largest single crystal formed in nature (beryl crystal of >1000 g) and some of the large quantity of single crystals created by man in one experimental run (quartz crystals of several 1000s of g) are both of hydrothermal origin.

Hydrothermal processing can be defined as any heterogeneous reaction in the presence of aqueous solvents or mineralizers under high pressure and temperature conditions to dissolve and recrystallize (recover) materials that are relatively insoluble under ordinary conditions. Definition for the word hydrothermal has undergone several changes from the original Greek meaning of the words 'hydros' meaning water and 'thermos' meaning heat. Recently, Byrappa and Yoshimura define *hydrothermal* as any heterogeneous chemical reaction in the presence of a solvent (whether aqueous or non-aqueous) above the room temperature and at pressure greater than 1 atm in a closed system [1]. However, there is still some confusion with regard to the very usage of the term hydrothermal. For example, chemists prefer to use a term, viz. *solvothermal*, meaning any chemical reaction in the presence of a non-aqueous solvent or solvent in supercritical or near supercritical conditions. Similarly there are several other terms like *glycothermal*, *alcothermal*, *ammonothermal*, and so on. Further, the chemists working in the supercritical region dealing with the materials synthesis, extraction, degradation, treatment, alteration, phase equilibria study, etc., prefer to use the term *supercritical fluid technology*. However, if we look into the history of hydrothermal research, the supercritical fluids were used to synthesize a variety of crystals and mineral species in the late 19th century and the early 20th century itself [1]. So, a majority of researchers now firmly believe that supercritical fluid technology is nothing but an extension of the hydrothermal technique. Hence, here the authors use only the term hydrothermal throughout the text to describe all the heterogeneous chemical reactions taking place in a closed system in the presence of a solvent, whether it is aqueous or non-aqueous.

The term advanced material is referred to a chemical substance whether organic or inorganic or mixed in composition possessing desired physical and chemical properties. In the current context the term *materials processing* is used in a very broad sense to cover all sets of technologies and processes for a wide range of industrial sectors. Obviously, it refers to the preparation of materials with a desired application potential. Among various technologies available today in advanced materials processing, the hydrothermal technique occupies a unique place owing to its advantages over conventional technologies. It covers processes like hydrothermal synthesis, hydrothermal crystal growth leading to the preparation of fine to ultra fine crystals, bulk single crystals, hydrothermal transformation, hydrothermal sintering, hydrothermal decomposition, hydrothermal stabilization of structures, hydrothermal dehydration, hydrothermal extraction, hydrothermal treatment, hydrothermal phase equilibria, hydrothermal electrochemical reactions, hydrothermal recycling, hydrothermal microwave supported reactions, hydrothermal mechanochemical, hydrothermal sonochemical, hydrothermal electrochemical processes, hydrothermal fabrication, hot pressing, hydrothermal metal reduction, hydrothermal leaching, hydrothermal corrosion, and so on. The hydrothermal processing of advanced materials has