Research Review

Nanostructured Materials: Importance, Synthesis and Characterization-A Review

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Abstract

The current state of research is surveyed. The review covers the catalytic technologies, the importance of nanostructured materials, the methods of preparation and the characterization of these materials is discussed, and here we take an example of iron nanomaterials for the preparation of nanostructured materials. Interest in iron nanoparticles originates from iron’s magnetic properties, for its ready availability and low cost, and its high reactivity, particularly, in reducing atmospheres. Specific applications for iron nanoparticles include Fischer–Tropsch catalysts, oxygen reduction catalysts in fuel cells, and environmental adsorbents for CO or arsenic, nanoscale iron particles also have large surface areas and high surface reactivity. It is also important; they provide enormous flexibility for in situ applications. This review also has shown that nanoscale iron particles are very effective for the transformation and detoxification of a wide variety of common environmental contaminants, such as chlorinated organic solvents and catalysts for CO oxidation.

Keywords: Nanostructured Materials, Iron Nanoparticles, FT-IR, SEM, TEM, STEM, AFM

1. Introduction

Catalytic technologies are critical to present and future energy, chemical process, and environmental industries. For instance, conversion of crude oil, coal, and natural gas to fuels and chemical feedstock, production of a variety of petrochemical and chemical products, and emission control of CO, hydrocarbons, and NO all rely on the catalytic technologies. Catalysts are also essential components of electrodes for fuel cells that use either solid oxide ionic or polymeric proton electrolyte. Satterfield (1991) introduced solid catalyst systems that are significant to industrial application. Rationalizing catalyst designs in terms of chemical compositions and physical structures has long been sought in catalysis and reaction engineering research.

Bell (1990) discussed catalyst designs based on molecular-level understanding of catalyst structure, surface adsorption, and reaction mechanisms. Significant progress in characterization capabilities (such as SEM, TEM, STEM, AFM, etc.), in situ surface adsorption and reaction experimental techniques, and molecular dynamics modeling enables such an approach. Recently, Liu (2005) classified catalyst technologies into three levels, macro-scale, micro- (and mini-scale), and nano-scale. He presented an overview of catalyst development at each scale. Ying (2006) reviewed recent progress in preparation of metal oxide catalysts of nanostructures by the use of novel catalyst synthesis strategies and techniques. The latest advances in nanotechnology have generated materials and devices with new physical characteristics, as well as chemical and biological functionalities for a wide variety of applications such as catalysis, separations, drug delivery systems and tissue engineering.

Nanomaterials catalysis has special interest, as nanostructured catalysts possess higher activity and are capable to work at lower temperatures. However substantial improvement of catalytic properties at transition to nanostructured systems is frequently
accompanied by decrease in their chemical stability that demands more detailed analysis of the given systems with use of modelling on atomistic level and modern experimental methods i.e. studying of the structure, properties of the surface, the nature of the active centres by focusing on molecular and nano-level of processes of transformation of substances and their mobility, for example, in a mesoporous (2-50 nanometres) of catalysts. The understanding of these processes will allow laying the foundation for designing of catalysts of new generation at nano-level and creations of new methods of synthesis in which it would be possible to control the dimensions of formed objects.

2. Background

2.1. Nanostructured Materials

The increasing interest in nanotechnology is due to the nanostructured materials, with dimensions, i.e. grain size, layer thickness or shapes below 100 nm. Nanomaterials should have two conditions to fulfilled i.e. at least one of dimensions is nano and some properties of these materials are specific to the nano dimension. Nanomaterials are showed in Nanostructured materials like Nanoparticles/ nanocomposites, Nanocapsules, Nanoporous materials, Nanofibres, Fullerenes, Nanowires, Single-Walled & Multi-Walled (Carbon) Nanotubes and Molecular Electronics. Roadmap Report on Nanoparticles in 2005, this wide group of materials enables access to new ranges of electronic, magnetic, mechanical or optical properties. Many Researchers have been developed using magnetic nanoparticles within several ultra-thin layers to develop advanced data storage devices (Mamalis et al, 2004). Nowadays one of the main challenges, in material science concerns the synthesis of nanomaterial since they exhibit interesting properties, which can be different to those of bulk materials (Klabunde, 2001). For instance optical, magnetic and electrical properties are sensitive to size effects. Furthermore, nanosized particles are equally very efficient in the field of catalysis due to its high ratio of surface to volume. Consequently, numerous processes of nanomaterials synthesis have been investigated aiming to control their size, morphology, structure and chemical composition (Grines et al, 2003 and Bell, 2003). A large numbers of studies concerning the production of nanoparticle have been published (Klabunde, 2001). There exist two main routes of material elaboration:

1. Chemical methods e.g. using the aqueous method or the sol-gel technique
2. Physical methods e.g. using spray pyrolysis or vapour deposition method

2.2. Synthesis Methods and Characterization for the Nanostructured Materials

2.2.1. Sol-Gel Method

The sol-gel method is a versatile process used in making various ceramic materials (Hench and West, 1990). In a typical sol-gel process, a colloidal suspension or a sol is formed from the hydrolysis and polymerization reactions of the precursors, which are usually inorganic metal salts or metal organic compounds such as metal alkoxides. Complete polymerization and loss of solvent leads to the transition from the liquid sol into a solid gel phase. Thin films can be produced on a piece of substrate by spin-coating or dip-coating. A wet gel is formed when the sol is casted into a mold. The wet gel is later converted into a dense ceramic with further drying and heat treatment. A highly porous and extremely low-density material called aerogel is obtained by removing the solvent of wet gel under a supercritical condition. Ultrafine and uniform ceramic powder is formed by applying precipitation, spray pyrolysis, or emulsion techniques (Chen and Mao, 2007. Duraes et al (2011) studied the formation of Iron (III) oxyhydroxide xerogels through sol-gel technology by using iron (III) nitrate nonahydrate as precursor, ethanol as solvent and ammonium hydroxide as gelation agent. This base is used for propylene oxide substitution. Synthesis of a gel using NH$_4$OH as a gelation agent gives an innovative result with this type of precursor, since the addition of a strong base commonly results in precipitation of the solid with metal salts. The gel synthesis was achieved by controlling the base addition time. The iron phase prevailing in the produced xerogels can be defined as γ-FeO(OH), according to FT-IR and Mössbauer analyses. The xerogels are formed by large clusters of well connected nanocrystallites of this phase. XRD (X-Ray Diffraction Technique) revealed a crystalline phase retained inside the iron oxyhydroxide amorphous structure, which corresponds to NH$_4$NO$_3$ and results from the combination of NO$_3^-$ and NH$_4^+$ ions in solution. The produced xerogel has a promising composition to be an oxidizing composite for the energetic materials area (Duraes et al, 2011).

2.2.2. Micelle and Inverse Micelle Methods

Aggregates of surfactant molecules dispersed in a liquid colloid are called micelles, when the surfactant concentration exceeds the critical micelle concentration (CMC). The CMC is the concentration of surfactants in free solution in equilibrium with surfactants in aggregated form. In micelles, the hydrophobic hydrocarbon chains of the surfactants are oriented toward the interior of the micelle while the hydrophilic ones are oriented toward the surrounding aqueous medium. The concentration of the lipid present in solution determines the self-organization of...
the molecules of surfactants and lipids. The lipids form a single layer on the liquid surface and are dispersed in solution below the CMC. The lipids organize it selves in spherical micelles at the first CMC (CMC-I), elongated pipes at the second CMC (CMC-II), and into stacked lamellae of pipes at the lamellar point (LM or CMC-III). The CMC depends on the chemical composition, mainly on the ratio of the head area and the tail length. Reverse micelles are formed in non aqueous media, and the hydrophilic head groups are directed toward the core of the micelles while the hydrophobic groups are directed outward toward the non aqueous media. There is no obvious CMC for reverse micelles, because the number of aggregates is usually small and they are not sensitive to the surfactant concentration. Micelles are often globular and roughly spherical in shape, but ellipsoids, cylinders, and bi layers are also possible. The shape of a micelle is a function of the molecular geometry of its surfactant molecules and solution conditions such as surfactant concentration, temperature, pH, and ionic strength. Magnetic and structural studies on CoFe₂O₄ nanoparticles synthesized by co-precipitation, normal micelles and reverse micelles methods were studied by Sharifi et al (2012). X-Ray patterns revealed the production of a broad single cubic phase with the average particle sizes of ~ 12 nm, 5 nm and 8 nm for co-precipitation, normal micelles and reverse micelles methods, respectively. The FTIR measurements between 400 and 4000 cm⁻¹ confirmed the intrinsic cation vibrations of spinel structure for each one of the three methods. Moreover, the average particle sizes were lower than the single domain size (128 nm) and higher than the super-paramagnetic size (2-3 nm) at room temperature. The results revealed that the magnetic properties depend on the particle size and cation distribution, whereas the role of particle size is more significant (Sharifi et al, 2012).

2.2.3. Sol Method

The sol method refers to the non-hydrolytic sol-gel processes and usually involves the reaction of metal chloride with a variety of different oxygen donor molecules e.g. a metal alkoxide or organic ether. Novel alumina materials containing Fe³⁺ ions were prepared by the non-hydrolytic sol-gel route and applied as heterogeneous catalysts in the oxidation of hydrocarbons (cyclooctene and cyclohexane) by the green oxidant hydrogen peroxide. The synthetic route followed an alkyl halide elimination pathway, via ethenolysis/condensation between AlCl₃ and disopropyl ether (Pr₂O), in the presence of Fe³⁺ ions (Fe³⁺ : Al³⁺ : Pr₂O molar ratio of 1:15:30). The obtained xerogel was thermally treated at 400, 750, or 1100 °C and the resulting materials were characterized by mean of different techniques, such as thermal analyses (TG/DTA), ultraviolet-visible (UV-Vis) & infrared (FTIR) absorption spectroscopies, X-Ray powder diffraction (XRD) and electron paramagnetic resonance (EPR). The concentration of Brønsted Acid Sites (BAS) at the surface of the samples was also evaluated by adsorption–desorption of cyclohexylamine. The thermal treatments led to truly heterogeneous catalysts, and the FeAlO-1100 material furnished the highest substrate conversion values. The larger catalytic activity of FeAlO-1100 is probably due to the absence of BAS on its surface. Indeed, the other FeAlO samples presented high BAS concentration, and it is known that H₂O₂ can be non-productively decomposed in the presence of strong acid sites. The catalytic efficiency of FeAlO-1100 can be considered promising (96% cyclooctene and 22% cyclohexane conversions), while the selectivity of cyclohexanone/cyclohexanol achieved in the oxidation of cyclohexane was 1.2 (molar ratio). The catalytic systems obtained here are advantageous because they involve the use of H₂O₂, a green oxidant, and the temperature employed for the oxidation reactions (50-55 °C) is milder than those reported in the literature for other heterogeneous catalyst/H₂O₂ systems (Ricci et al, 2010).

2.2.4. Hydrothermal Method

Hydrothermal synthesis is normally conducted in steel pressure vessels called autoclaves with or without Teflon liners under controlled temperature and/or pressure with the reaction in aqueous solutions. The temperature can be elevated above the boiling point of water, reaching the pressure of vapour saturation. The temperature and the amount of solution added to the autoclave largely determine the internal pressure produced. It is a method that is widely used for the production of small particles in the ceramics industry. Many groups have used the hydrothermal method to prepare iron oxide nanoparticles, for example, Microstructure and magnetic properties in Sn₁₋ₓFe₂O₃ (x = 0.01, 0.05, 0.10) nanoparticles synthesized by hydrothermal method was studied by Fang et al (2010). X-Ray diffraction (XRD) reveals that all samples are pure rutile type tetragonal phase and the grain size decreases with the increase of Fe content. High-resolution transmission electron microscopy (HRTEM) images show that the samples are spherical in shape and most grains are uniform in size with diameters of 5-6 nm. Magnetic measurements by using magnetic property measurement system (MPMS) show that the Fe-doped SnO₂ nanoparticles exhibit paramagnetic behaviour and the decrease of magnetic moment per iron atom with the increase of iron concentration could be attributed to the antiferromagnetically coupled spins (Fang et al, 2010).

2.2.5. Chemical Vapour Deposition

Vapour deposition refers to any process in which materials in a vapour state are condensed to form a solid-phase material. These processes are normally used to form

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coatings to alter the mechanical, electrical, thermal, optical, corrosion resistance, and wear resistance properties of various substrates. They are also used to form free-standing bodies, films, (and fibers) and to infiltrate fabric to form composite materials. Recently, they have been widely explored to fabricate various nanomaterials. Vapour deposition processes usually take place within a vacuum chamber. If no chemical reaction occurs, this process is called physical vapour deposition (PVD); otherwise, it is called chemical vapour deposition (CVD). In this method, thermal energy heats the gases in the coating chamber and drives the deposition reaction. Multiwall Carbon Nanotubes (MWNTs) filled with Fe Nanoparticles (NPs) have been synthesized by thermal chemical vapour deposition of ferrocene alone as the precursor by Bhatia and Prasad (2010). The MWNTs were grown at different temperatures i.e. 980 and 800 °C. Characterization of prepared MWNTs was done by scanning and transmission electron microscopy and X-Ray diffraction. The transmission electron microscopic study revealed that Fe NPs, encapsulated in MWNTs, grown at 980 and 800 °C are spherical and rod shaped, respectively. Room-temperature vibrating sample magnetometer studies were done on the two samples up to a field of 1T. The magnetization versus magnetic field loop reveals that the saturation magnetization for the two samples varies considerably, almost by a factor of 4.6. This indicates that Fe is present in different amounts in the MWNTs grown at the two different temperatures (Bhatia and Prasad, 2010).

2.2.6. Chemical Vapour Condensation

Oh et al (2004) studies the magnetic properties of Fe-Co nanoparticles synthesized by Chemical Vapour Condensation (CVC) process. Effect of CVC processing variables on the magnetic properties was analyzed in detail, using Mössbauer spectroscopy, XRD, BET and HRTEM. The synthesized particles were nearly spherical, and their surfaces were identified to be α-FeOOH, γ-FeOOH and Fe$_3$O$_4$ but not α-Fe$_3$O$_4$. The magnetic properties were strongly influenced by CVC processing parameters. The increase of cobalt content had changed the magnetic property of the sample. Magnetic property, however, was reduced with increase in the decomposition temperature and the oxygen content in the carrier gas (Ar), thus decreasing the average particle size. On the other hand, magnetic field reinforced by increasing the vacuum pressure in the chamber, hence increasing average particle size (Oh et al, 2004). Lee et al (2008) studied the fabrication of iron carbide using chemical vapour condensation process. Formation of the iron carbide nanoparticles strongly depended on reaction temperature and pressure-mainly on pressure e.g. at 1.33 Pa (0.01 Torr) pressure, the synthesized nanoparticles were all α-Fe regardless of the reaction temperature, whereas the iron carbide was formed only above 650 °C by enhancing the pressure to 101 kPa (760 Torr). The iron carbide nanoparticles were spherical in shape with the average particle size of 30 nm at 650 °C and 50 nm at 800 °C. Their Curie temperature was about 240 °C. The particles formed at 650 °C clearly possessed the core-shell structure i.e. Fe$_2$C core enclosed with a mixture of iron oxide (Fe$_3$O$_4$) and free carbon, whereas those formed at higher temperature i.e. 800 °C, were covered only with very thin layer of free carbon (Lee et al, 2008).

2.2.7. Electrodeposition

Electrodeposition is commonly employed to produce a coating, usually metallic, on a surface by the action of reduction at the cathode. The substrate to be coated is used as cathode and immersed into a solution containing the salt of the metal to be deposited. The metallic ions are attracted to the cathode and reduced to metallic form. Crystalline maghemite (γ-Fe$_3$O$_4$) nanoparticles were cathodically electrodeposited at room temperature from environmentally benign electrolytes was studied by Park et al (2008). The shape, size, and production rate of nanoparticles were strongly influenced by electrochemical conditions (e.g. FeCl$_3$ concentration, current density). X-Ray photoelectron spectroscopy (XPS) and X-Ray diffraction (XRD) analysis confirmed that randomly oriented polycrystalline maghemite nanoparticles were synthesized having the same peaks as the main diffraction peaks. Transmission electron microscopy (TEM) revealed that average particle size decreased with increased current density. Magnetic saturation (M$_s$) of maghemite nanoparticles was determined to be 66 emu g$^{-1}$ (66 Am$^2$ kg$^{-1}$) at 300 K. The present maghemite nanoparticles showed a greater A$_c$ (V) adsorption compared to iron nanoparticles, which might be attributed to a higher specific surface area (Park et al, 2008).

2.2.8. Mesoporous / Nanoporous Materials

The iron nanoparticles confined in highly ordered mesoporous carbons (OMCs) have been directly synthesized through a simple soft templating method by using resorcinol–formaldehyde (RF) as a carbon precursor, triblock copolymer Pluronic F127 as a template agent and hydrated iron nitrite as an iron source. This synthesis was carried out by the carbonization of the F127/[Fe(H$_2$O)$_3$(NO$_3$)$_3$/RF composites self-assembled in an acidic medium, which was generated from the self-hydrolysis of precursory salt. The effects of iron loading contents on the morphology pore feature and magnetic properties of the iron nanoparticles confined in OMCs were characterized by the X-Ray diffraction, transmission electron microscopy, nitrogen-sorption and vibrating-sample magnetometer measurement. It was found that Fe$^{3+}$ was captured by the network of F127/RF and further reduced into metallic Fe nanoparticles during the...
carbonization. The results showed that the carbon material exhibited highly ordered mesoporous structure, and the iron nanoparticles were uniformly confined in the OMC walls when the Fe/R molar ratio was around 0.1. The Saturation Magnetization (MS) and Remanent Magnetization (MR), of the Fe/OMC composites increased with the increasing of Fe/R molar ratio. The Fe/OMC composites exhibited the soft ferromagnetic behaviour and the magnetization parameters could be adjusted by the content of iron (Zhang et al, 2010). Direct formation of iron oxide/MCM-41 nanocomposites via single or mixed n-alkyltrimethylammonium bromide surfactants using sol gel method highly dispersed Fe₂O₃ nanoparticles were formed in all cases even with the highest iron oxide percentage by Khalil et al (2012). Formation of the nanocomposites was postulated to be determined by fast nucleation and slow growth of iron oxide species, which facilitated formation of well-dispersed iron oxide nanoparticles inside and on the wall of the MCM-41 material (Khalil et al, 2012).

2.2.9. Sonochemical Method

Bang & Suslick (2010) extensively explored the sonochemistry of metal carbonyl compounds (e.g. Fe(CO)₅, Co(CO)₅NO, Mo(CO)₆, and W(CO)₆) and utilized this non-conventional technique to produce unusual nanostructured inorganic materials They observed that volatile organometallic compounds can fully dissociate their carbonyl ligands inside a bubble during acoustic cavitation, and the resulting metal atoms agglomerate to form a variety of nanostructured materials. A powerful aspect of the sonochemical synthesis resides in its versatility; various forms of nanostructured metals, oxides, sulfides and carbides can be prepared simply by changing reaction conditions (Figure 1). For instance, sonochemical decomposition of Fe(CO)₅ in hexadecane yields amorphous iron metal powder. In the presence of organic or polymeric stabilizers (e.g. oleic acid or polyvinylpyrrolidone), colloidal iron nanoparticles are obtained instead. Adding a sulfur source into the precursor solution produces nanophase iron sulfide, and replacing argon gas with oxygen as the purging gas leads to the formation of nanoscale iron oxide.

Further, when Fe(CO)₅ is irradiated with a solid support material (e.g. silica), nanometer-sized iron particles are deposited on the support.

2.2.10. Ultrasonic Spray Pyrolysis (USP)

In contrast with sonochemistry, where ultrasound directly induces chemical reactions, in USP, ultrasound doesn’t induce any chemical reaction, which is in fact thermally driven. Instead, the role of the ultrasound in USP is to provide the phase isolation of one micro droplet reactor from another. While high intensity ultrasound with a low frequency (typically 20 kHz) is used in sonochemistry, USP generally utilizes lower intensity ultrasound with a high frequency (e.g., ~2MHz). Spray pyrolysis has been widely used in industry for ultrafine and nanoparticle production as well as film deposition, in part because the apparatus is simple and continuous and can be scaled easily for mass production. In general, spray pyrolysis involves the thermal decomposition of aerosols (i.e. solid or liquid particles suspended in a gas) generated by a nebulizer (e.g. pneumatic, ultrasonic, or electrostatic nebulizers) in a gas flow (Okuyama & Lenggoro, 2003). USP has several advantages over other traditional methods i.e. production of micron- or submicron-sized spherical particles, high product purity, continuous operation, and ease of controlling composition (Bang & Suslick, 2010; Okuyama & Lenggoro, 2003 and Messing et al, 1993).

Unlike conventional solid- or liquid-phase synthetic methods (e.g., precipitation, hydrothermal method, and solid-state reaction) where batch reactions are performed to produce materials, the USP technique is a continuous flow process that enables both large and small-scale production of products with excellent reproducibility. Several research groups have revived USP as a generalized synthetic method for the preparation of nanostructured materials. This clear transformation of the USP technique into a powerful synthetic tool has originated from its outstanding ability to produce nanocomposites. In a majority of cases, the nanocomposites are composed of desired materials (e.g. metal oxides, sulfides, or carbon etc.) combined with sacrificial materials (e.g. surfactants, colloidal silica, polymers, or metal salts). The sacrificial materials are subsequently removed by several methods (e.g. chemical etching, calcination, or dissolution), introducing various nanostructures (e.g. porosity) into final products (Messing et al, 1993).

3. Application of Iron Nanomaterials

Batch experiments were performed by Giasuddin et al (2007) to investigate the feasibility of humic acid (HA), removal by synthetic nanoscale zerovalent iron (NZVI) and its interaction with As(III) and As(V)-the most poisonous and abundant of groundwater pollutants. High-resolution transmission electron microscopy (HR-TEM) and X-Ray diffraction (XRD) were used to characterize the particle size, surface morphology etc. It was determined that HA was completely removed by NZVI (0.3 g/L) within a few minutes, at a wide range of initial pH values (~3.0-12.0). Long-term time-resolved studies of XRD and field emission scanning electron microscopy (FE-SEM) with energy-dispersive X-Ray (EDX), revealed the formation of various types of new iron oxides (magnetite, maghemite, and lepidocrocites etc.) during the continuous reaction of HA in the presence of water and NZVI at 1, 30, 60 and 90 days (Giasuddin et al, 2007).
Biabani and Rezaei (2012) investigated low temperature CO oxidation over iron-cobalt mixed oxide nanocatalysts with different Co/Fe molar ratios. The nanocatalysts were prepared with a facile co-precipitation method. The prepared samples were characterized by X-Ray diffraction (XRD), N$_2$ adsorption (BET), temperature programmed reduction (TPR), Thermal Gravimetric and Differential Thermal Analyses (TGA/DTA) and Transmission Electron Microscopy (TEM) techniques. The BET results revealed that the samples have a mesoporous structure and decreasing in Co/Fe molar ratio shifted the pore size distributions to smaller values. The TEM analysis showed a nanostructure for all samples with crystallite sizes smaller than 20 nm.

The pure cobalt nanocatalyst showed uniform hexagonal closed packed structure. The catalytic results showed that the addition of Co to iron oxide even in small amount has a dramatic effect on increasing CO conversion at lower temperatures. The results indicated that the stability of catalysts was affected by reaction temperature, O$_2$/CO ratio and CO concentration in feed composition. The results showed that increase in reaction temperature increased the stability of catalyst (Biabani & Rezaei, 2012).

Porous carbon microspheres impregnated with iron-based nanoparticles are prepared in a single step, continuous process using ultrasonic spray pyrolysis (USP) by Atkinson et al (2011). Precursor solutions containing a carbon source, an inorganic salt, and an iron salt are ultrasonically aerosolized and pyrolyzed. Solutions containing nitrate or chloride salts are examined. During pyrolysis, sucrose is dehydrated to carbon, and the metal salt is converted to crystalline or non-crystalline iron species, depending on processing conditions. The product’s porosity is generated from i.e. (1) aromatization of carbon around an in situ template, (2) in situ gasification of isolated carbon, or (3) in situ chemical activation of the carbon precursor. Porous carbon spheres (0.5-3 Lm diameter) containing well-dispersed iron oxide nanoparticles (4-90 nm diameter), referred to here as Fe-C, are prepared. Iron loadings between 1 and 35 wt% are achieved while maintaining well-dispersed Fe nanoparticles with as-produced surface areas up to 800 m$^2$/g. Post-pyrolysis heat and hydrogen treatments increase the surface area of the materials while reducing iron species. USP, Fe-C materials may have useful catalytic applications due to their potential for high-loading of well-dispersed metal nanoparticles. Despite negligible surface Fe content, chromium reduction tests indicate that internal Fe sites are catalytically active (Atkinson et al, 2011).

Catalytic properties of carbon materials differ from properties of usual oxides, in particularly, as catalyst carriers. For example, Carbon Nanotubes (CNT) possess distinct tubular structure and special electronic structure of graphene walls where π-electrons owing to a curvature are shifted to outside. It provides the remarkable environment for localization of nanocatalysts and catalytic reactions in such small cavities. In literature there are the data in which unique effects of localization of CNT electrons and the subsequent modulation of catalysis are illustrated. For iron- containing samples it is revealed that oxidation-
reduction properties of iron oxide and metallic iron change, when they are concluded in CNT channels. For example, reduction of iron oxide localized in CNT is easier in comparison with oxide distributed on CNT external surface. Distinct simplification of Fisher-Tropsch process in using Fe capsulated in CNT has been in the same way revealed the usefulness of formation of the reduction of iron, for example carbides, in CNT channels (Malek et al, 2009).

4. Conclusions

The following conclusions have been drawn from the present review:

1. Research areas in the field of nanosciences and nanotechnologies, Nanoparticles, Nanorods, nanofibers as well as mesoporous nanoporous structures have been provided.

2. In this review, we have pointed out the different synthetic methods of preparation of nanostructured materials which have high yields, relatively short reaction times, low cost, simple experimental and as isolation procedures, and finally, it is in agreement with the green chemistry protocols.

3. These new nanomaterials show size-dependent as well as shape- and structure-dependent optical, electronic, thermal, and structural properties.

4. This great variety of using these methods of preparation of nanostructured materials is playing an important role in the protections of the environment and in the search of renewable and clean energy technologies.

5. We have also pointed out the applications of iron nanomaterials as oxygen reduction catalysts, catalysts for CO oxidation, and environmental adsorbents.

References


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