A Review on Nanotechnology: Analytical Techniques used and Applications

Abstract

The combination of nanotechnology with molecular biology, information technology and instrumentati on, is opening the door to a new industr al age. The aim of this review article is to summarise the curre nt knowledge of nanotechnology in synthesising, identifying and characterization of nanomaterials usi ng analytical techniques. Physical and chemical approach synthesis of nanomaterials befalls challenges in development of analytical techniques used to characteize them. The major techniques include: Tran smission Electron Microscopy, Scanning Electron Microscopy, Atomic Force Microscopy, Dynamic L ight Scattering, X ray Photoelectron Spectroscopy, X-ray Diffraction,, Single Phase Inductively Coupled Plasma Mass Specroscopy, X-ray Fluorescence Spectroscopy, Auger Electron Spectroscopy, X ray Absorption Fine Structure, Capillary Electrophoretic Separations, Magnetic nanoparticles couple d HPLC and Dynamic light scattering. Nanomaterials have been characterized for the extensive potential applications in optics, electronics, magnetics, catalysts; chemical sensing, biomedicine, micro reacter and they have been applied in food, biological, environmental and pharmaceutical point of view. In spite of the extended use of nano particles in diverse consumer products, there is a great concern over the unexpected impact or effects on humans due to exposure.

Keywords: Nano technology; Nano materials; Analytical techniques; Carbon nano tubes.

Introduction

Over the last decade, nanoparticles [30, 63] synthesis become the most active areas because of their uni que properties [2, 3] and applicatble in optics, electronics, magnetics, catalysts, chemical sensing, biom edicine, microreacter etc. [4]. They have discrete functional parts with one or more dimensions of 100

nm or less [5, 39]. What makes nanoparticles so unique is not their small size, but also their large surfa
ce area make them highly reactive [6]. The creation of nanoparticle is the directions of material chemis
try today [3]. They can be synthesized using “bottom up” (from the bottom: atom by atom, molecule b
y molecule or cluster by clusters or “top down” (slicing or successive cutting of a bulk material) appro
aches [9, 10, 62]. Survey of literature indicates that, techniques such as inert gas condensation/ chemic
al vapor condensation, pulse electron deposition, plasma synthesis, crystallization of amorphous solid,
severe plastic deformation, and consolidation of mechanically alloyed or cryomilled powders) are amo
ng the major one used to synthesise nanomaterials [7].

i.e. super critical fluid technology, offers an interesting and effective production of polymeric nano-particles by avoiding the use of organic solvent. Briefly, drug and polymers are dissolved in a supercritical fluid to form a solution, followed by the rapid expansion of the solution across an orifice or capillary nozzle into ambient air. High degree of super saturation accompanied by the rapid pressure reduction in the expansion, results in the homogenous nucleation and well dispersed uniform sized nanoparticles [45, 46].

Nanotechnology has been applied in different areas for instance, it introduce in food agriculture throug
h the effectiveness of pesticide in a case if very small amounts are enclosed in nano capsules [12],
DNA detection assay, biomarker discovery, cancer diagnosis and detection of infectious microorganisms [37]. Recently, reviewer [38] suggested that, the specific interactions of nanoparticles with metabolites or bio macromolecules help, for example, simplify metabolomics spectra, improve the ionization efficiency for mass spectrometry or reveal relationships between spectral signals that belong to the same molecule. [13]. Applications in separation science are in miniat
urized techniques like (microchip and capillary electrophoresis). Ultra dilute polymer solutions (for lon
g DNA) in microchip electrophoresis. Gold nanoparticles (stationary phases) in gas chromatography w
ith monolayer protected nanoparticles [13, 14].

Survey of literature indicates that, development of analytical tools specifically for nanotechnology is under way in contrast to trusted data with considerable context [15]. As reviewed by Enisa and Mirjana , there have been a variety of biological and toxicological interactions of nanomaterials in *in vitro* and *in vivo* experimental systems [27, 37]. A large body of data concerning the development of suitable protocols for the physicochemical characterization of nonmaterial is a fundamental issue for coming years, the survey focuses on the determination of the size distribution of nano-scale particles using Dynamic Light Scattering detector (DLS) and a splitting system. It is also reported that, there is the approach based on a comprehensive physicochemical characterization made by the combination of A4F-MALLS with an UV detector and an Inductively Coupled Plasma Mass Spectrometer (ICP--MS). [51]. Nanomaterials have been directed to pro inflammatory and inflammatory markers since existing knowledge on the health effects of ambient fine particulates identified a central role for oxidative stress and inflammation in the toxicological mode of action [27]. Some reviewer [41] surveyed that, there can be problems and issues faced during various in vitro and in vivo studies concerning nano materials and they had tried to identify a solution as well as alert beginners before hand, thus saving time and effort.

The objectives of this review article are: to summarise the current knowledge of nanotechnology, to explain the synthesising method of nanomaterials, to identify the applications of nanotechnology in different areas and to mention the analytical techniques employed in nanotechnology.

Characterization of nano materials

A number of researche have been conducted on nanotechnology. Among them, Gurmit *et al*., summarizes the state of knowledge on occurrence of Engineered Nano Materials (ENMs) in foods, strategies currently employed (or potentially required) to prepare foods containing ENMs for analysis, and the suitability of existing instrumentation for detection, characterization, and quantification of ENMs in foods [31]. The recent advances in the development of electrochemical sensors and biosensors based on click chemistry functionalization protocols, are presented focused on a comparative and critical description of different configurations and their applications towards the detection of various target analytes [35]. Reviewers reported that analytical chemistry plays an important role in the food industry, both in the control of its quality as in its safety. Yet relatively few are the nano-based analytical methods that have been developed to control analytes of interest in foods [26].

As studied by Enisa and Mirjana, 2016 [27], modern techniques revealed that nano materials with higher reactivity and ability to cross membrane barrier can lead to different toxico-kinetic and toxico-dynamic properties. Various types of nano sensors are being developed to meet the different requirements in food inspection (nano sensors for detection of external and internal conditions in food packaging, carbon nano tubes based electrochemical sensors for detection of cations, anions and organic compounds in food, various parameters for detection of pesticides, antibiotics, heavy metals, microbial cells and toxins.

Kanchi *et al*, 2014 [30] reported that, the novel routes in the development of new nano materials to desalinate water are among the most thrilling and gifted technologies. Different materials science research teams in the world are exploiting specific nano materials targeting the analyte and making the entire system effective, economical and rapid for the treatment of wastewaters.

Now adays, several advancements came into light on applications of nano materials in analytical chemistry for detection of organic and inorganic pollutants using different instruments. Food safety is a main concern and it is essential to have manners and systems, which enable foodstuffs traceability and monitoring during the whole food chain process [28]. Consequently, nano sensors can be applied along the entire food supply chain, in order to detect different targets in quickly, sensitive, and cost effective manners. This is necessary in the process of ensuring food quality, safety, freshness, authenticity, and t raceability [29].

Let us consider Silver nanoparticles in socks**,** silver is well known for its antiseptic qualities, attributed to the surface oxidation of metallic silver followed by the generation of silver ions, which can be toxic to many bacteria and fungi. This quality has allegedly led to the incorporation of silver nanoparticles into textiles as an anti-microbial agent. Another possibility is incorporation of AgCl nanoparticles. Their small size and large surface area to volume ratio results in increased rates of oxidation and subsequent dissolution compared to larger-scale forms of silver [43, 54]. Mahalingam and Krishnamoorthy had assessed the problem of selecting the suitable method for the preparation of camptothecin loaded polymeric nanoparticles using a multi-criteria decision making approach implementing the analytical hierarchy process [44].

Moreover, nano sensors employing Raman spectroscopy are ideally suited for food forensics is investigation of food origin, adulteration and contamination. The application of nano sensors contributes to the specificity of the method and allows various analytes, which can be probed; ranging from the macro-food, lipids, proteins and carbohydrates, to the minor components, dyes, pigments, and preservatives [27].

Nadejda MS. (2015) [12] had reported that, sensitivity and performance of biosensors could be improv ed by using nano materials for their construction. He puts that a wide varieties of nano scale materials are now available. The use of these nano materials allows the introduction of many new signal transduction technologies in biosensors.

Elemental analysis was conducted by Eastlake et al. on one of the filters from each sampling set. He reported that, occupational exposure criteria do not exist for most ENMs; therefore, TWA measurements (elemental mass analyses) were compared to corresponding occupational exposure criteria for the parent compound [58].

Nano technology and Analytical Techniques

Among different researchers, Amy *et al*, reviewed that, analytical tools are deleveraged to generate predictive modeling determinations during development. Techniques for predictive in vivo information include those that measure surface chemistry at nano, micro, and macro scales for both inorganic and organic particles [59, 61].

Transmission Electron Microscopy (TEM)

Is a technique whereby a beam of electrons is transmitted through an ultra thin specimen and interacts as passes through the sample? An image is formed from the electrons transmitted through the specimen, magnified and focused by an objective lens and appears on imaging screen. It is sensitive to extended crystal lattice defects is known light field. The specimens must be prepared as a thin foil so that the electron beam can penetrate. Materials that have dimensions small enough to be electron transparent, such as powders or nano tubes, can be quickly produced by the deposition of a dilute sample containing the specimen onto support grids [17]. The electron microscope uses electrostatic and electromagnetic "lenses" to control the electron beam and focus it to form an image [18].

Scanning Electron Microscopy (SEM)

It creates the magnified images using electrons instead of light waves [17, 47, 54, 60]. When the beam of electrons interacts with the atoms of the sample, signals in the form of secondary electrons, back scattered electrons and characteristic X- rays are generated that contain information about the sample's surface topography, composition, etc. it can produce very high resolution images of a sample surface, revealing details about 1-5 nm in size in its primary detection mode i.e. secondary electron imaging. Detectors collect these X rays, backscattered electrons, and secondary electrons and convert them into a signal that is sent to a screen similar to a television screen.

Auger Electron Spectroscopy (AES)

After an inner shell excitation which can be caused by a collision with a primary electron, an atom has energy above its ground state. The atom returns to its ground state by filling the empty level created, with an electron from a higher energy level and this leads to the release of energy and momentum. It uses a primary electron beam to probe the surface of a sample. The electron impact results in a disturbance of the sample in a region of about 1- 3μm depth, lead ing to the emission of secondary electrons, backscattered electrons, Auger electrons and characteristic X-rays. It focuses only on the small part of secondary electrons that are emitted as a result of the Auger process. The identity and quantity of the elements are determined from the kinetic energy and intensity of the Auger peaks which occur at specific kinetic energies in the Auger-spectrum. To separate and locate the Auger peaks from the intense background of scattered electrons the signal is deviated [20].

X-ray Photoelectron Spectroscopy

XPS is used to determine the elements and the quality of those elements that are present within ~ 10 nm of the sample surface. It also detects the contamination, if any, exists in the surface or the bulk of the sample. If the material is free of excessive surface contamination, XPS can generate empirical formula of the sample and the chemical state of one or more of the elements can be identified. It can be also used to determine the thickness of one or more thin layers (1-8 nm) of different materials within the top 10nm of the surface. It can also measure the uniformity of elemental composition of textile surfaces after nano level etching, finishing or coating of the surfaces [17, 54].

X-ray fluorescence spectroscopy (XFS)

XFS is similar to XPS in terms of the excitation mechanism but differs in its detection mechanism. While XPS detects photoelectrons, XFS detects “secondary” or “fluorescent” X-rays from a material that has been excited by high-energy X-rays (or sometimes γ-rays) [42]. The principle behind XFS is relatively straightforward. When a material is exposed to high energy X-rays, ionization or electron ejection can take place if the X-ray photon energy is greater than its ionization energy. Due to the high energy of X-rays or γ-rays, tightly bound electrons in the inner, low energy orbitals of the atom in the material can be expelled.

The resulting ionized atom is not unstable and electrons in outer, higher energy orbitals may fall or make a transition into the lower orbital to fill the hole left behind. In doing so, energy may be released in the form of a photon (usually with energy in the X-ray region still) with energy equal to the energy difference of the two orbitals involved. Because the orbitals are specific to individual atoms, the energy of the emitted photon that can be easily detected has energy characteristic of the atoms involved. The term "fluorescence" refers to the emitted X-ray photons, not visible light, even though visible light can also be generated and observed sometimes when a sample is subject to X-ray radiation. Mono energetic soft X-rays irradiate the surface of the sample. The X-rays peneterate up to a depth of about 1-10 µm. only photo-ionized electrons of the first atomic layers (1-10 µm) can leave the solid without significance energy loss, pass an electrostatic energy analyzer and reach the electron detector. The measured kinetic energy of these photoelectrons depends on the photon energy and the binding energy of the atomic orbital from which the electrons stem [17].

Atomic force microscope (AFM)

It is an ideal for quantitatively measuring the nanometer scale surface roughness and for visualizing the surface nano-texture on many types of material surfaces including polymer nano composites and nano finished or nano coated textiles. In AFM a probe consisting of a sharp tip (nominal tip radius is in the order of 10 nm) located near the end of a cantilever beam is raster scanned across the surface of a specimen using piezoelectric scanners. Changes in the tip specimen interaction are often monitored using an optical lever detection system, in which a laser is reflected off the cantilever and onto a position sensitive photodiode. During scanning, a particular operating parameter is maintained at a constant level, and images are generated through a feedback loop between the optical detection of textile surfaces (by plasma or UV eximer lamp, etc) can be easily accessed by this sophisticated technique. It provides powerful tools for nondestructive characterization of textiles AFM can be used to explore the nanostructures, properties and surfaces and interfaces of fibres and fabrics. For example, structural characteristics of nanofibre materials, nanolevel surface modification [17,47].

Single-particle ICP-MS

Mitrano *et al.* 2012 [34] reported that, due to its sensitivity, flexibility, and analysis speed, ICP-MS performed in single-particle mode (SP-ICP-MS) is gaining popularity for detecting and measuring inorganic-based engineered nano materials (ENM), as traditional inductively coupled plasma mass spectroscopy (ICP-MS) already does, but with the important distinction that single-particle mode has the ability to detect a difference between ionic and whole-ENM elemental sources. In single-particle mode, ENMs are introduced into an ICP and completely ionized, with the resulting ions being detected by a mass spectrometer. To ensure that only a single particle is measured, the sample has to be diluted to have temporal resolution between particles that is, so that only a single particle is introduced into the plasma at a time. The mass spectrometer must also be capable of making extremely rapid measurements to ensure ENM detection (data should be acquired at least every 100 μs) as the transient signal of a 50-nm gold nanoparticle can vary, on average, between 600 and 800 μs depending on the instrument operating conditions and ion optics design.

X-ray Absorption Fine Structure (XAFS)

XAFS is used to measure the fine structure of an analyte near the absorption edge when subjected to X-ray radiation. It is similar to UV-visible electronic absorption spectroscopy, in principle, except that the spectral range is in the X-ray region and electronic-XAFS focuses on the fine structure specifically since it provides local structural information about specific atoms or ions. EXAFS relates to the details of how X-rays are absorbed by an atom at energies near and above the core-level binding energies of that atom. EXAFS measurements reflect the modulation of an atom's X-ray absorption probability due to the chemical and physical states of the atom. EXAFS spectra are especially sensitive to the formal oxidation state, coordination chemistry, and the local atomic structure of the selected element. One advantage of EXAFS is that it works for crystalline as well as noncrystalline or even highly disordered materials, including solutions [42].

Capillary Electrophoretic Separations

Yang-Wei Lin *et al.* [46] had used Capillary electrophoresis (CE) and microchip capillary electrophoresis (MCE) using polymer solutions are two of the most powerful techniques for the analysis of DNA. They reported about DNA separation using chip-based nanostructures and nano materials in CE and MCE. Based on the dependence of the mobility of DNA molecules on the size and shape of nanostructures, several unique chip-based devices have been developed for the separation of DNA, particularly for long DNA molecules. Unlike conventional CE and MCE methods, sieving matrices are not required when using nanostructures.

Magnetic Nanoparticles and HPLC

Laleh *et al.* [49] had used a micro extraction method using Ag modified-magnetic nano particle (Ag-MNPs) coupled with high performance liquid chromatography (HPLC) for determination of cefteriaxone in plasma. They had synthesized magnetic nano particles via a mild solution route. The prepared nanoparticles were modified with a thin layer of silver and characterized with different methods such as X-ray diffraction (XRD), transmission electron microscopy (TEM), FTIR and ultraviolet-visible (UV-Vis) spectroscopy. Effect of several parameter such as pH of donor and acceptance phase, amount of magnetic particle and extraction and desorption time were optimized. They reported that, under the optimal condition the enrichment factor was obtained. The detection limit was 0.02 mg/mL and a wide linear range as 0.06 to 40µg/mL were obtained.

Dynamic light scattering (DLS)

Sovan *et al* [49] reviewd that currently, the fastest and most popular method of determining particle size is photon-correlation spectroscopy (PCS) or dynamic light scattering (DLS). DLS is widely used to determine the size of Brownian nanoparticles in colloidal suspensions in the nano and submicron ranges. Shining monochromatic light (laser) onto a solution of spherical particles in Brownian motion causes a Doppler shift when the light hits the moving particle, changing the wavelength of the incoming light. This change is related to the size of the particle. It is possible to extract the size distribution and give a description of the particle's motion in the medium, measuring the diffusion coefficient of the particle and using the autocorrelation function. The photon correlation spectroscopy (PCS) represent the most frequently used technique for accurate estimation of the particle size and size distribution based on DLS [50].

Application of nanotechnology

Application in food Analysis

Now days, technology with nano materials are being used repeatedly in a number of areas. Analysis is the widely known qualification and quantification point of view of globalised quality control. Food is the variable on which the life is being dependent and it is an exploratory means to analyse them at nono level. Nanotechnology tools are used in the entire food production chain (table 1) e.g. during cultivation (e.g. pesticides), industrial processing or packaging of foods. [5, 21].

To check the quality of food products at nano level, scientists have been participating in different researches using several analytical techniques. Accordingly, Xiang Zhang *et al.* [22] have used nanotechnology in picking nano materials by developing fluorescent sensors for food pH based on nanoparticles and investigated water activity probes. They reported that Quinine and Harmane were non-covalently attached onto starch nanoparticles, while gelatin nanoparticles were covalently labeled with fluorescein isothiocyanate (FITC). The results shows that, quinine sensors exhibited blue shifts of emission spectra as pH increased; the ratio of peak intensity or peak area of emission spectra at two different emission wavelengths also decreased dramatically in the range of pH~3.0-5.0. Harmane labeled starch nanoparticle (HSNP) sensors and FITC labeled gelatin nanoparticle (FGNP) sensors did not present any emission spectra shifts. These results support a new methodology of using nanoscopic sensors for the measurement of food pH.

In the study of Peters *et al,* seven food grade TiO_2 materials (E171), food products and three personal care products were investigated for their TiO_2 content and the number-based size distribution of TiO_2 particles present in these products [64].

Application in Environmental Analysis

Fadri *et al.* [36] reviewed that, there are still major knowledge gaps (e.g. on ENM production, application and release) that affect the modeled values. In food safety, photo catalysis could find uses in cleansing the surface of fresh fruits and vegetables of toxic agrochemical residues and in destroying bacteria on such produce [23]. The surface-to-volume ratio increases drastically with the reduction of the size of the adsorbent particle from bulk to nano dimensions [24]. V. S. Shrivastava [24] applied nano materials in the area of metallic and organic nano particle synthesis. They used these nano materials based chemistry for waste water treatment for three major types of contaminants: halogenated organics including pesticides, heavy metals and dyes.

Kaur and Gupta [25] applied nano materials for the pre-concentration of trace amounts of Ni(II) in different samples using 1-(2-pyridylazo)-2-naphthol modified SiO_2 nanoparticles as solid-phase extractant. They had optimized various parameters such as pre-concentration factor, effect of pH, sample volume, shaking time, elution conditions and effects of interfering ions for the recovery of analyte. They had found adsorption capacity of SiO_2-PAN nanoparticles to be 42.81μmol g^{-1} at optimum pH. They found detection limit (3σ) 0.43 μg L^{-1}. They got the adsorption equilibrium of Ni (II) on SiO_2-PAN nanoparticles within 10mins. Adsorbed Ni (II) was easily eluted with 5 mL of 6 $molL^{-1}$ HCI.

Applications in Biological Analysis

The category of biological nano materials is defined as materials of biological origin that are used for nano technological applications. There are a magnitude of different materials and approaches that are being investigated. However, altogether it seems that bioanalytical applications are most developed. Kun-Chan *et al*. [55] applied nono material by Using Bio functionalized nanoparticles to probe pathogenic bacteria. They reported a method for fabricating bio-functionalized nanoparticles by attaching human immunoglobulin (IgG) onto their surfaces through either electrostatic interactions or covalent binding. Their results demonstrate that such Au-IgG nanoparticles may serve as useful nanoscale probes for exploring the interactions between IgG and pathogens. Seong-Wan Ryu and coworkers [56] applied Gold nano particle (GN) and embedded silicon nano wire (SiNW) configuration for label-free DNA detection to enhance the sensitivity. They measured electric current flow between two terminals, a source and a drain electrode, to sense the immobilization of probe oligonucleotides and their hybridization with target oligonucleotides. The researchers' results support that the LOD can be improved by reducing the SiNW doping concentration. Herein, we are interested in emphasizing the applications of AgNPs in various biological and biomedical applications [54], such as antibacterial, antifungal, antiviral, anti-inflammatory, anti-cancer, and anti-angiogenic.

Application in Pharmaceutical Analysis

Thangaraja. A. *et al.* [57] applied nono material by successfully synthesizing Polyethylene Glycol (PEG) coated silica nanoparticles and used to load the drug Ibuprofen. They had prepared mono disperse, spherical PEG –coated silica nanoparticles and characterized for the purpose of drug loading. They analyzed it through scanning electron microscope (SEM) and their size ranged from about 150 – 400 nm in diameter. They stirred PEG coated silica particle mixed with ibuprofen solution (1.8 mg/ml) for 48 hrs and determined the amount of the drug 16 % (by wt) for the mono disperse, spherical PEG coated silica nano particle. Yao Liu *et al.* [58] applied nanomaterial by investigating Poly-lactic-glycolic acid (PLGA) nanoparticles for sustained drug-release properties. They got the results of PLGA particles with 90% or greater efficiency (approx. 200 nm diameters) to incorporate the drug estradiol. Hirsjärvi, S. [59], used nanoparticles by preparing from a biodegradable poly (lactic acid) (PLA) polymer. They studied the effect nano precipitation, a nano particle preparation method, on the physicochemical properties of the polymer and model drugs encapsulated in the nanoparticles as well as the effect of the drugs on the polymer by thermo analytical and spectroscopic methods.

Future Opportunities and Challenges

Nanomaterials (NM) open huge prospects for innovation in different fields such as medicine, electronics, cosmetics and materials. However, their uses raise questions about possible risks to the environment and humans. The development of suitable protocols for the physicochemical characterization (size distribution, shape and chemical composition) of such materials is a fundamental issue for coming years [51]. Nanoparticles have already been applied as drug delivery systems with great success. Nanoparticles provide massive advantages regarding drug targeting, delivery and with their potential for combine diagnosis and therapy and one of the major tools in nano medicine. These are many technical, challenges in developing the following techniques:- Virus-like systems for intracellular systems, Architecting of bio mimetic polymers, control of sensitive drugs, functions (of active drug targeting, bio responsive triggered systems, systems interacting with me body smart elivery), nano chips for nano particle release, carriers for advanced polymers for the delivery of therapeutic peptide / proteins. Drug delivery techniques were established to deliver or control the amount & rate. Most major and established internal research programmes on drug delivery that are formulations and dispersion containing components down to nano sizes [49]. In spite of the extended use of NPs in diverse consumer products, there is a great concern over the unexpected impact or effects on humans due to exposure [52]. Thus, recently, regulations focused on the allowed and not allowed appearance of NPs in daily products have released [53].

Conclusion

Nanotechnology is moving into the centre of worldwide because of its wide applications. The materials with nano meter size in one or three dimensions have the properties those are neither that of bulk materials nor those of molecular compounds. Synthesizing nano materials play a role for the development of analytical methods, to characterize the nano scale structure. There are many analytical methods using focused electron, ion or photon beams as well as mechanical tips as a probe for the excitation of a sample. Nanomaterials have been, exploited for the extensive potential applications in optics, electronics, magnetic, catalysts; chemical sensing, biomedicine, micro reactor. Nanotechnology has been applied in different areas, mainly in commercial, foods, e nvironmental, pharmaceutical and biology. In spite of the extended use of NPs in diverse consumer products, some researchers reported a great concern over the unexpected impact or effects on humans due to exposure. However, researchers are going to search solutions for these challenges.

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