A Review on Nanotechnology: Analytical Techniques used and Applications

Tassew Belete Bahru[1]*and Eyasu Gebrie Ajebe[1]

[1]Department of Chemistry (M Sc in Analytical Chemistry), College of Natural and Computational Science, Wolkite University, Wolkite, Ethiopia, P.O. Box. 07.

***Corresponding author: Tassew Belete Bahru**, Department of Chemistry, College of Natural and Computational Science, Wolkite University, Wolkite, Ethiopia, Email: tasiyye@gmail.com

Summary

The combination of nanotechnology with molecular biology, information technology and instru mentation, is opening the door to a new industr al age. The aim of this review article is to summa rise the current knowledge of nanotechnology in synthesising, identifying and characterization of nanomaterials using analytical techniques. Physical and chemical approach synthesis of nanomat erials befalls challenges in development of analytical techniques used to characteize them. The m ajor techniques include: Transmission Electron Microscopy, Scanning Electron Microscopy, Ato mic Force Microscopy, Dynamic Light Scattering, X ray Photoelectron Spectroscopy, X-ray Dif-fraction, Single Phase Inductively Coupled Plasma Mass Specroscopy, X-ray Fluorescence Spect roscopy, Auger Electron Spectroscopy, X ray Absorption Fine Structure, Capillary Electrophoret ic Separations, Magnetic nanoparticles coupled 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.

1. Introduction

Over the last decade, nanoparticles [30, 63] synthesis become the most active areas because of their unique properties [2, 3,6] and applicable in optics, electronics, magnetics, catalysts, chemical sensing, biomedicine, microreacter etc. [4, 78]. They have discrete functional parts with one or more dimensions of 100 nm or less [5, 39]. The creation of nanoparticle is the directions of material chemistry today [3]. They can be synthesized using "bottom up" or "top down" approaches [9, 10, 62, 67]. Literature indicates that, techniques such as chemical vapor condensation, pulse electron deposition, plasma synthesis, crystallization of amorphous solid, severe plastic deformation , and consolidation of mechanically alloyed or cryomilled powders) are used to synthesise nano materials [7]. i.e. super critical fluid technology offers effective production of polymeric nano-particles by avoiding the use of organic solvents [45, 46].

Nanotechnology has been applied in different areas: food agriculture through 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 helpmetabolomics spectra, improve the ionization efficiency for mass spectrometry or reveal relationships between spectral signals that belong to the same molecule. [13]. The other application is in separation science , miniaturized techniques. Ultra dilute polymer solutions (for long DNA) in microchip electrophoresis. Gold nanoparticles (stationary phases) in gas chromatography with monolayer protected nano particles [13, 14].

As reviewed by Stefanos *et al*, nanostructures have attracted huge interest as a rapidly growing class of materials for many applications. They have been used to characterize the size, crystal structure, elemental composition and a variety of other physical properties of nano particles. In several cases, there are physical properties that can be evaluated by more than one technique. Different strengths and limitations of each technique complicate the choice of the most suitable method, while often a combinatorial characterization approach is needed [65]. Researches indicates that, development of analytical tool for nanotechnology is under way in contrast to trust ed data with considerable context [15]. Enisa and Mirjana reviewed that, there have been a varie ty of biological and toxicological interactions of nanomaterials in *in vitro* and *in vivo* experiment al systems [27, 37].

A large body of data concerning the development of physicochemical characterization of nonma terial is a fundamental issue for coming years [51]. Nanomaterials have been directed to pro infla mmatory 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]. 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 [41]. The objectives of this revie w 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.

For characterization of nano materials, a number of researches have been conducted. Among the m, Gurmit *et al*., summarizes the Engineered Nano Materials (ENMs) in foods and the suitability of existing instrumentation for detection, characterization, and quantification [31]. The recent advances in the development of electrochemical sensors and biosensors based on the click chemistry functionalization [35]. There is development of novel drug delivery systems using nano particles [68].The nano-based analytical methods have been developed to control analytes of interest in foods [26]. As studied by Enisa and Mirjana, 2016 [27], modern techniques were developed to meet the different requirements in food inspection [29, 30], Kanchi *et al*, 2014 reported that, the novel routes in the development of new nano materials and detection of organic and inorganic pollutants [28]. The small size and large surface area to volume ratio of NMs results in increased rates of oxidation and subsequent dissolution compared to larger-scale forms of silver [43, 54]. Researchers had assessed the problem of selecting the suitable method for the preparation of NPs [44]. Nano sensors contributes to the specificity, sensitivity and performance of the methods and improved by using nano materials for their construction [27, 58]. The nanotec hnology based biosensor or nano biosensor technology is revolutionizing the health care industry such as the nano biosensor technology is used in the measurement of metabolites, monitoring of diabetes etc., forensic medicine, homeland security [66]. Additionally, methodologies used to characterize the composition, morphology and biological properties of synthesized nanoparticles by multiple techniques have been presented [62].

2. Analytical Techniques Employed in Nanotechnology

Different researchers reviewed that, analytical tools are deleveraged and applied [73] 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]. Structural characterization is essential for nanomaterials research [69]. Posth et al, 2018, have assessed common MNP analysis techniques under various criteria in order to define the methods that can be used as either standard technique for magnetic particle or those that can be used to obtain a comprehensive picture of a MNP system [77].

2.1 Transmission Electron Microscopy (TEM)

Researchers have been used this 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 suppo rt grids [17]. The electron microscope uses electrostatic and electromagnetic "lenses" to control the electron beam and focus it to form an image [18].

2.2 Scanning Electron Microscopy (SEM)

This technique 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 also 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, bac kscattered electrons, and secondary electrons and convert them into a signal that is sent to a scree n similar to a television screen.

2.3 Auger Electron Spectroscopy (AES)

In this technique, 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, leading 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].

2.4 X-ray Photoelectron Spectroscopy (XPS)

It 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].

2.5 X-ray fluorescence spectroscopy (XFS

It 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. The X-rays penetrated 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].

2.6 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. AFM can be used to explore the nanostructures, properties, surfaces, and interfaces of fibres and fabrics. For example, structu ral characteristics of nanofibre materials, nanolevel surface modification [17,47]. For nonconduct ive nanomaterials, AFM is a better choice [70, 71].

2.7 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.

2.8 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].

2.9 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.

2.10 Magnetic Nano particles 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.

2.11 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].

3 Application of nanotechnology

3.1 Application in food Analysis

Now days, technology with nano materials are being used repeatedly in a number of areas. Food is the variable on which the life is being dependent and it is an exploratory means to analyze them at nono level. Nanotechnology tools are used in the entire food production chain. 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. 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. 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].

3.2 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.

3.3 Applications in Biological Analysis

The unique optical and electrical properties of nanomaterials, such as gold nanoparticles, nanorods, quantum dots, carbon nanotubes, graphenes, nanopores, and polydiacetylene nanovesicles, are closely associated with their dimensions, which are comparable in scale to those of targeted biomolecules [76]. 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 [56]. Gold nano particle (GN) and embedded silicon nano wire (SiNW) configuration were applied for label-free

DNA detection to enhance the sensitivity [54], such as antibacterial, antifungal, antiviral, anti-inflammatory, anti-cancer, and anti-angiogenic.

3.4 Application in Pharmaceutical Analysis

Nanomedicine is the preservation and improvement of human health using molecular tools and molecular knowledge of the human body [75]. Thangaraja. A. *et al.* [57] applied nono material by successfully synthesizing Polyethylene Glycol (PEG) coated silica nanoparticles and used to load the drug Ibuprofen. 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 nanoparticle 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. The antimicrobial activity due to the treatment is found to be good and fast to dry cleaning with loss in strength well within the industrial norms [72].

3.5 Agricultural application

As stated by Waleed, 2018, nanotechnology consider a novel key to growing agricultural production through implementing nutrient efficiency, improve plant protection practices, also, nanotechnology may have real solutions for various agriculture problems like improved crop varieties, plant protection, detect diseases and monitor plant growth. Nanotechnology offers generous visions for the development agricultural sector through advanced applications and the probability of products and increases global crops production volume to feed the world population in next decades [74].

3.6 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]. Nano particles have already been applied as drug delivery systems with great success. Nano particles 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].

4 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.

5 References

1. Fredy K (2008), New Analytical Applications of Gold Nanoparticles, *PhD Thesis, University of Regensburg, Germany*
2. Kaushik P, Joe P, Samuel CH, Robert N G, Wendelin JS, Majiong J, Cla*ire MC, Byungkwon L, and Younan X (2009). Nan*omaterials controlled Synthesis & Properties. *Material matters Vol. 4 No 1*
3. Chang C, Li W, Guohua J, and Haojie Y (2006). Chemical preparation of metal special *shaped nano materials throug*h encapsulation or inducement in soft solution. *Rev. Adv. Meter. Sci. 11,1-18*
4. Bouwmeester H, Dekkers S, Noordam M, Hagens W, Bulder A, de Heer SC, Voorde Wijnhoven S, Sips A (2007). Health risks and application of nanotechnologies
5. Edimbourg R (2009). Un seen Hazards from Nanotechnology to Nanotoxicity. *Food & Water Europe.*

6. Bing QH, Enrique JL, and Farghalli AM, (2005). Mechanical Properties of Nano structured Materials. *Rev. Adv. Meter. Sci. 9,1-16*
7. Ricardo M (2008). Opportunities and Threats from Nanotechnology in Health, Food, Agriculture and the Environment. *Director of Agricultural Health and Food Safety at IICA. ricardo.molins@iica.int*
8. Khademhosseini, R L (N.D). Nano biotechnology, Drug Delivery and Tissue Engineering, *SBE Special Section pp. 38-42.*
9. http://www.gitam.edu/eresource/nano/nanotechnology/roleofbottom-upandtop-down a.htm
10. Lunsheng Z (2007), Micro-/Nanofabrication in Analytical Chemistry and Temperature Dependent Studies of Under potential Deposition of Mercury (Ii) On Au (111), *PhD Thesis, Auburn University.*
11. Nadejda MS (2015). Application of nanotechnology in detection of mycotoxins and in agricultural sector,*Journal of Central European Agriculture, 16(2), p.117-130 DOI: 10.5513/JCEA01/16.2.1597*
12. Lunsheng Z (2007), Micro-/Nanofabrication in Analytical Chemistry and Temperature Dependent Studies of Underpotential Deposition of Mercury (Ii) On Au (111), *PhD Thesis, Auburn University.*
13. Frolova AM, Chukhlieb M.A, Drobot AV., Kryshta AP, Loginova L.P and Boichenko AP (2009). Producing of Monolithic Layers of Silica for Thin-Layer Chromatography by Sol-Gel Synthesis. *The Open Surface Science Journal, 1, 40-45.*
14. Evans Analytical group (2007). Analytical methods for nanotechnology, PA 109. Pdf *www.EAGLABS.COM*.
15. Li M & Robert LS (2010). Application of Nanotechnology in Cosmetics, *Pharm, Res 27:1746–1749, DOI 10.1007/s11095-010-0139-1*
16. Joshi M, Bhattaaharyya A & Wazad SA (2008). Characterization of techniques for nanotechnology applications in textiles. *Indian Jornal of fibre & Textile Research. Vol. 33, pp. 306-317.*
17. *http://en.wikipedia.org/wiki/Electron_microscope*, Last modified on 9 March 2011.
18. Purdue university, West Lafayette, In 47907, (765) 4946371/EmailWebmaster. (2010). Purdue university / an equal access / equal opportunity university / copyright complaints

19. Rolf M (2007*)*. Nano-analysis with Electron Spectroscopic Methods Principle, Instrumentation and Performance of XPS and AES. *Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim (Germany.)*

20. Mario G, Tamara F, and Eric G(2010). Potential applications of nanotechnology in the agro-food sector. *Ciênc. Tecnol. Aliment., Campinas, 30(3): 573-581, jul.-set.*

21. Xiang Z (2009). Study of Novel Nanoparticle Sensors for Food pH and Water Activity. *Msc Thesis, the State University of New Jersey*

22. Ricardo M (2008). Opportunities and Threats from Nanotechnology in Health, Food, Agriculture and the Environment. *Director of Agricultural Health and Food Safety at IICA. ricardo.molins@iica.int*

23. Shrivastava S (2010). Metallic and organic nanomaterials and their use in pollution control: A Review. *Archives of Applied Science Research, 2 (6): 82-92*

24. Anupreet K and Usha G (2009). Preconcentration of Nickel Using Chemically Modified Silic a Nanoparticles. *Eurasian J. Anal. Chem. 4(2): 175-183*

25. Aristides CV and Díaz GM (2009). Analytical nanotechnology for food analysis.,Microchim Acta., 166:1–19. DOI 10.1007/s00604-009-0165-z

26. Enisa OM, Mirjana MN (2016). Applications in agriculture and food industry. *Bulletin of the Chemists and Technologists of Bosnia and Herzegovina* Print ISSN: 0367-4444. Online ISSN: 2232-7266

27. Maksimovic, M et al (2015). Application of Internet of Things in food packaging and transportation. *Int. J. Sustainable Agricultural Management and Informatics*, Vol. 1, No. 4, pp. 333-350

28. Fraceto et al (2016). Nanotechnology in Agriculture: Which Innovation Potential Does It Have?. *Front. Environ. Sci*.

29. Suvardhan K (2014). Nanotechnology for Water Treatment.Kanchi, *J Envi 1:2. http://dx.doi.org/10.4172/ jreac.1000e102*

30. Gurmit S, *et al* (2014). Measurement Methods to Detect, Characterize, and Quantify Engineered Nanomaterials in Foods.13, *Comprehensive Reviews in Food Science and Food Safety*

31. Dudkiewicz A, Tiede K, Loeschner K, Jensen L H S, Jensen E, Wierzbicki R, Boxall AB, Molhave K (2011). Characterization of nanomaterials in food by electron microscopy. Trends Anal Chem 30:28–43.

32. Weir A, Westerhoff P, Fabricius L, Hristovski K, von Goetz N (2012). Titanium dioxide nanoparticles in food and personal care products. Environ Sci Technol 46:2242–50.

33. Mitrano DM, Lesher EK, Bednar A, Monserud J, Higgins CP, Ranville JF (2012b). Detecting nanoparticulate silver using single-particle inductively coupled plasma-mass spectrometry. Environ Toxicol Chem 31:115–21.

34. Andreea C, Mihaela T, Cecilia C, Robert S. (2015). Applications of Click Chemistry in the Development of Electrochemical Sensors. *Int. J. Electrochem. Sci.,* 10: 6324 – 6337

35. Fadri G, Tian Y, and Bernd N (2013). Environmental concentrations of engineered nano materials: Review of modeling and analytical studies. *Environmental Pollution 181: 287-300*

36. Rajasundari K, and Ilamurugu K (2011). Nanotechnology and Its Applications in Medical Diagnosis.*J. Basic. Appl. Chem.*, 1(2)26-32

37. Bo Z, *et al* (2018). Nano particle-Assisted Metabolomics. Metabolites, 8, 21; doi:10.3390/metabo8010021

38. Niemeyer, MC, Mirkin, CA (2004.) Nanobiotechnology: Concepts, Applications and Perspectives;Wiley-VCH: Weinheim, Germany, ; Volume 1.

39. Hermann S (2009). Overview of the Methods andTechniques of Measurement of Nanoparticles.nananotrust-Possible Health Effects of Manufactured Nanomaterials, Vienna, 24 Vienna, 24

40. Alok D & Vyom S (2010). Toxicity assessment of nanomaterials: methods and challenges. Anal Bioanal Chem, 398:589–605. DOI 10.1007/s00216-010-3996-x

41. Shalini C, and Pragnesh N (2012). Microscopy in Nanotechnology.*Current Microscopy Contributions to Advances in Science and Technology (A. Méndez-Vilas, Ed.). p 946-956*

42. Environmental protection Agency (EPA), (2015). Requirements to measurements of Nanomaterials and Nanoproducts. *Minestry of Environment and Food of Denmark.No. Environmental project 1802.*ISBN: 978-87-93352-95-7

43. Manikandan M, and Kannan K (2015). Selection of a Suitable Method for the Preparation of Polymeric Nanoparticles: Multi-Criteria Decision Making Approach. *Adv Pharm Bull*, 2015, 5(1), 57-67.

44. Varshosaz J, Hassanzadeh F, Mahmoudzadeh M, and Sadeghi A (2009). Preparation of cefuroxime axetil nanoparticles by rapid expansion of supercritical fluid technology. *Powder Technol; 189*(1):97-102.
45. Sekhon BS (2010). Supercritical fluid technology: An overview of pharmaceutical applications. *Int J PharmTech Res*; 2(1):810-26.
46. Sovan L, et al., (2011). Nanoparticle: An overview of preparation and Characterization. Journal of Applied Pharmaceutical Science 01 (06); 2011: 228-234
47. Yang W, Ming F, and Huan T (2005). Nanomaterials and chip-based nanostructures for capillary electrophoretic separations of DNA. *Electrophoresis* 2005, *26,* 320–330
48. Assis DN, Mosqueira VC, Vilela JM, Andrade MS., and Cardoso VN (2008). Release profiles and morphological characterization by atomic force microscopy and photon correlation spectroscopy of 99m Technetium – fluconazole nanocapsules. Int J Pharm. 349: 152 –160.
49. Menta M, et al (2017). Analytical Developments for the Characterization of Nanomaterials in Consumer Products, Environmental and Medicinal Samples. Pro*oceedings of the 2nd World Congress on Recent Advances in Nanotechnology (RAN'17).* DOI: 10.11159/icnnfc17.120
50. US EPA NR Nanomaterials EPA is Assessing. [Online]. Available: http://www.epa.gov/nano science/quickfinder/nanomaterials.htm.
51. Cushen M, Kerry J, Morris M, Cruz M and Cummins E (2012). Nanotechnologies in the food industry – Recent developments, risks and regulation," *Trends Food. Sci. Technol.,* vol. 24, no. 1, pp. 30-46.
52. Xi F, Zhi G, Wei S and Sangiliyandi G (2016). Silver Nanoparticles: Synthesis, Characterization, Properties, Applications, and Therapeutic Approaches. Int. J. Mol. Sci. 2016, 17, 1534; doi:10.3390/ijms17091534
53. Kun-Chan H, Pei-Jane T, Ya- S, and Yu-C (2004). Using Biofunctionalized Nanoparticles to Probe Pathogenic Bacteria. *Anal. Chem, 76, 7162-7168*
54. Seong-Wan R, et al (2010). Gold nanoparticle embedded silicon nanowire biosensor for applications of label-free DNA detection. *Biosensors and Bioelectronics 25, 2182–2185*
55. Thangaraja A, Savitha V and Jegatheesan K (2010). Preparation and Characterization of Polyethylene Glycol Coated Silica Nanoparticles for Drug Delivery Application. *Int. J. Nanotech. and Applications. ISSN 0973-631X Volume 4, pp. 31-38*

56. Liu Y, Tsapis N, and David AE (2003). Investigating Sustained-release Nanoparticles for Pulmonary Drug Delivery. *Division of Eng. and A. Sci. (DEAS) Harvard University, MRSEC REU Program.*

57. Hirsjärvi S (2008). Preparation and Characterization of Poly (Lactic Acid) Nanoparticles for Pharmaceutical Use. *PhD thesis, University of Helsinki, Finland.*

58. Adrienne CE (2016). Refinement of the Nanoparticle Emission Assessment Technique into the Nanomaterial Exposure Assessment Technique (NEAT 2.0*). J Occup Environ Hyg. 2016 September ; 13(9): 708–717. doi:10.1080/15459624.2016.1167278.*

59. Amy RB, Margareth M, Johannes K, Vinod P S, and Horst-Di (2017). Summary Report: Nanomedicines: Technical and Regulatory Perspectives Co-sponsored by: USP, AAPS, and FIP. dx.doi.org/10.14227/DT240417P52

60. Ruby P, Chanmeet K , Umar F , Tokeer A (2018). Ascorbic acid assisted synthesis, characterization and catalytic application of copper nanoparticles. *Material Sci & Eng Int J. 2018;2(4):90–94.*

61. Tawfik AS (2016). Nanomaterials for Pharmaceuticals Determination. *Bioenergetics ISSN:2167-7662 BEG, an open access journal, Volume 5 • Issue 1 • 1000226*

62. Zewde B, Ambaye A, Stubbs J III, Dharmara R (2016) A Review of Stabilized Silver Nanoparticles – Synthesis, Biological Properties, Characterization, and Potential Areas of Applications. *JSM Nanotechnol Nanomed 4(2): 1043.*

63. Heera P and Shanmugam S (2015). Nanoparticle Characterization and Application: An Overview. *Int.J.Curr.Microbiol.App.Sci. 4(8): 379-386*

64. *Ruud JB (2014).* Characterisation of titanium dioxide nanoparticles in food products: Analytical methods to define nanoparticles. *J. Agric. Food Chem* Downloaded from http://pubs.acs.org on June 18, 2014

65. *Stefanos Mourdikoudis, Roger M. Pallares and Nguyen T. K. Thanh (2018).* Characterization techniques for nanoparticles: comparison and complementarity upon studying nanoparticle propertie. *Nanoscale, 10, 12871–12934*

66. Suravi Pandit, Debaprotim Dasgupta, Nazneen Dewan and Prince Ahmed (2016). Nanotechnology based biosensors and its application. *The Pharma Innovation Journal 2016; 5(6): 18-25*

67. Susmita K and Venugopal V. R. (2017). Synthesis and Structural Analysis of Different CuO Nano Particles. *International Journal of Applied Science and Engineering 2017. 14, 3: 133-146*
68. Sovan Lal Pal, Utpal Jana, P. K. Manna, G. P. Mohanta, R. Manavalan (2011). Nanoparticle: An overview of preparation and Characterization. *Journal of Applied Pharmaceutical Science 01 (06); 1: 228-234*
69. Shalini Charurvedi1 and Pragnesh N Dave1 (2012). Microscopy in Nanotechnology. *Current Microscopy Contributions to Advances in Science and Technology (A. Méndez-Vilas, Ed.)*
70. Binnig G., Quate C.F.and Gerber C., (*1986).* Atomic force microscope; *Phys. Rev. Lett.;* 56: 930-933.
71. Guntherodt H.J., Anselmetti D. and Meyer E., (1995). eds. NATO ASI series. Series E, Applied sciences. Vol. 286, Kluwer Academic.; 644.
72. Gokarneshan N (2018) A Review of Some Significant Insights on Nano Finishing of Protein Fibres. J Nanosci Nanotechnol Res Vol.2: No. 1:4.
73. Faraji M. Recent analytical applications of magnetic nanoparticles. *Nanochem Res, 2016; 1(2): 264-290.* DOI: 10.7508/ncr.2016.02.014
74. Waleed Fouad Abobatta. "Nanotechnology Application in Agriculture". *Acta Scientific Agriculture 2.6 (2018): 99-102.*
75. Syed Abeer (2012). Future Medicine: Nanomedicine. *JIMSA July-September, Vol. 25 No. 3*
76. Min CL. and Young RK (2016). Analytical Applications of Nanomaterials in Monitoring Biological and Chemical Contaminants in Food. *J. Microbiol. Biotechnol. (2016), 26(9), 1505–1516* http://dx.doi.org/10.4014/jmb.1605.05071
77. Posth, O., Hansen, M. F., Steinhoff, U., Bogart, L., Southern, P., Svedlindh, P., Johansson, C. (2015). Classification of analysis methods for characterization of magnetic nanoparticle properties. In Proceedings of IMEKO XXI World Congress (pp. 1362-1367). Czech Technical University, Prague.
78. Sandeep KV et al., (2012). Nanotechnology-Based Biosensors and Diagnostics: Technology Push versus Industrial/Healthcare Requirements. *BioNanoSci. (2012) 2:115–126*