Comparative Analysis and Applications of Nano-Particles in Engineering

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Abstract

Increased application of Nano particles in various areas of modern science and technology has escalated demand for their increased production and this review is provided a detailed overview of Nano particles. Nanoparticles are tiny materials having size ranges from one to 100 nm. They can be classified into different classes based on their properties and sizes. It include different groups like fullerenes, metal nanoparticles, ceramic nanoparticles, and polymeric nanoparticles. Nanoparticles have unique physical and chemical properties due to their high surface area and nanoscale size. Their optical properties are reported to be dependent on the size, which imparts different colors due to absorption in the visible region. Their reactivity, durability and other properties are also dependent on their irreplaceable size, shape and structure. Due to these characteristics, they are suitable for various commercial and domestic applications, which include catalysis, imaging, medical applications, energy-based research, and environmental applications.

Keywords: *Nano particles, properties and applications*

1. Introduction

Nanotechnology was presented by Nobel laureate Richard P. Feynman during his well famous 1959 lecture ‘‘There’s Plenty of Room at the Bottom” (Feynman, 1960), there have been made various revolutionary developments in the field of nanotechnology. Nanotechnology produced materials of various types at nanoscale level. In the last decade, synthesized materials have become important in diverse fields, including medicine, industry, and environmental engineering. In general, chemically synthesized Nanoparticles within the size range of 1-100 nm are highly useful. Chemical approaches employed for the production of Nanoparticles are systematically developed and predetermined. Hence, Nanoparticles synthesized using these chemical approaches are referred to as engineered Nanoparticles (Quigg et al., 2013). Interestingly, the behaviors of Engineered Nanoparticles differ noticeably from those of their bulk (non- Nanoparticles) counterparts (Auffan et al., 2009).

Since the late 1990s, a great number of articles have been published to deal with the application of engineered nanoparticles in the areas of medicine, industry, and electronics (Grillo et al., 2015). For instance, the synthesis of magnetic nanoparticles was achieved through different pathways for the application toward biomedical imaging over the last decade (Laurent et al., 2008). Likewise, nanomaterials were also employed actively in various fields of environmental applications (sorbents, antibacterial agents, dye-degradation, and eco-friendly fertilizers) (Xu et al., 2013; Das et al., 2016; Sarmah and Pratihar, 2017).

Hence, an exhaustive compilation of these reports will be helpful to identify the thrust areas for contemporary and future researchers. In a broad sense, Engineered Nanoparticles consist of a wide range of synthesized materials such as carbon nano-tubes (CNTs), carbon dots, epoxy resin-coated CNTs, polymer-coated Ag, super magnetic iron oxide nano-particles (SPION), mesoporous silica particle, catalytic metals, metal oxides, quantum dots, dendrimers, nanofilms, nanofibres, and composite nano-particles (refer to Table 1 for classification). The properties of Engineered Nanoparticles are generally affected by their particle size; for example, nano-sized ZnO has a different rate of reaction, adsorption capacity, and redox state than bulk ZnO particles. Similarly, the transition temperature of ferromagnetic particles ($MnFe_2O_4$, $MgFe_2O_4$, etc) varies considerably according to size (Tang et al., 1991; Chen and Zhang,1998). Therefore, great effort has been made to alter the physicochemical properties (shape, size, and surface charge) of Engineered Nanoparticles to enhance their reactivity, strength, and electrical properties (Scheckel et al., 2010).

Engineered Nanoparticles are widely used in manufacturing industries (e.g., pharmaceutical, electronics, cosmetics, diagnostic imaging, photothermal therapy, nucleic acid delivery, catalysis and material science, environmental remediation, and cleaner energy production) (Guerrero et al., 2012; Huo et al., 2012; Jafari et al., 2012; Kuo et al., 2012; Naahidi et al., 2013). A number of Engineered Nanoparticles based products (such as implantable devices, antimicrobial commercial products, photo luminescent materials, and semi-conductors) are also available in the global market (Fischer and Chan, 2007; Law et al., 2008; Jafari and Chen, 2009; Scheckel et al., 2010; Bhatt and Tripathi, 2011; Padmavathy et al., 2012). Over a span of eight years (2000e2008), the global market value of Engineered Nanoparticles increased from 125 million USD to 12.7 billion USD (in 2008) and is expected to reach about 30 billion USD by the end of 2020 (Wang et al., 2013). A global market survey in 2013 also revealed that the production of different types of Engineered Nanoparticles will cross the margin of 350,000 tons in 2016.

2. Nature and types of Engineered Nanoparticles

Engineered Nanoparticles are derived from engineered nano-materials that are designed and synthesized to have enhanced mechanical, catalytic, optical, and/or electrical (conductivity) properties (Klaine et al., 2008). Different types of Engineered Nanoparticles are described based on their morphology, as shown in Table 1. Based on the synthesis precursors and processes, there are large numbers of existing Engineered Nanoparticles derivatives:

i. Engineered inorganic nano particles i.e. zero-valent metals (such as Fe, Ag, and Au) and metal oxides.

ii. Engineered organic nano particles [carbon nanotubes (CNTs) and buckminster fullerenes].

iii. Engineered polymer nano particles [polyvinyl pyrrolidone coated Ag NPs, TiO_2, ZnO), polyethylene glycol-coated (Ag NP, SiO_2, TiO_2, and Au NPs), PVP, and PEG-coated magnetic polymers (Fe, Co, FeePt, CueNi)].

iv. Miscellaneous types of nanoparticles (i.e., quantum dots, dendrimers, and graphene nano-foils) (Nowack and Bucheli, 2007).

2.1 Engineered inorganic Nanoparticles

Engineered inorganic Nanoparticles (EINPs) cover a broad range of substances including elemental (zero-valent) metals, metal oxides, and metal salts (Table 1). The available preparatory techniques for these Nanoparticles include chemical reduction, irradiation, electrochemical reaction, hydrothermal, solvo-thermal reduction, and photochemical reduction (Pradhan et al., 2011; Ansari et al., 2013; Divbanda et al., 2013; Kim et al., 2013; Choi et al., 2015; Kundu et al., 2015; Li et al., 2015). Many of these EINPs, including ZnO, FeO, SiO2, CeO2, andTiO2, are frequently-used materials because of their distinct photocatalytic properties. Elemental metals (such as Ag, Au, Fe, Cu, Pt, Pd, Ni, and Co) of nano-metric dimensions are widely used for antimicrobial, optical, catalytic, electronic, and sensing purposes as well as for doping agents. Nano-wires of Au, Cu, Si, and Co are commonly used as conductors and semiconductors. Metal oxide NPs are routinely used in various industries (paints, cosmetics, and plastics products) as components of rubber additives, catalytic converters, biomedical imaging, photovoltaic cells, sensors, and for environmental remediation (Quinn et al., 2005; Ghosh et al., 2011; Mittal et al., 2013).

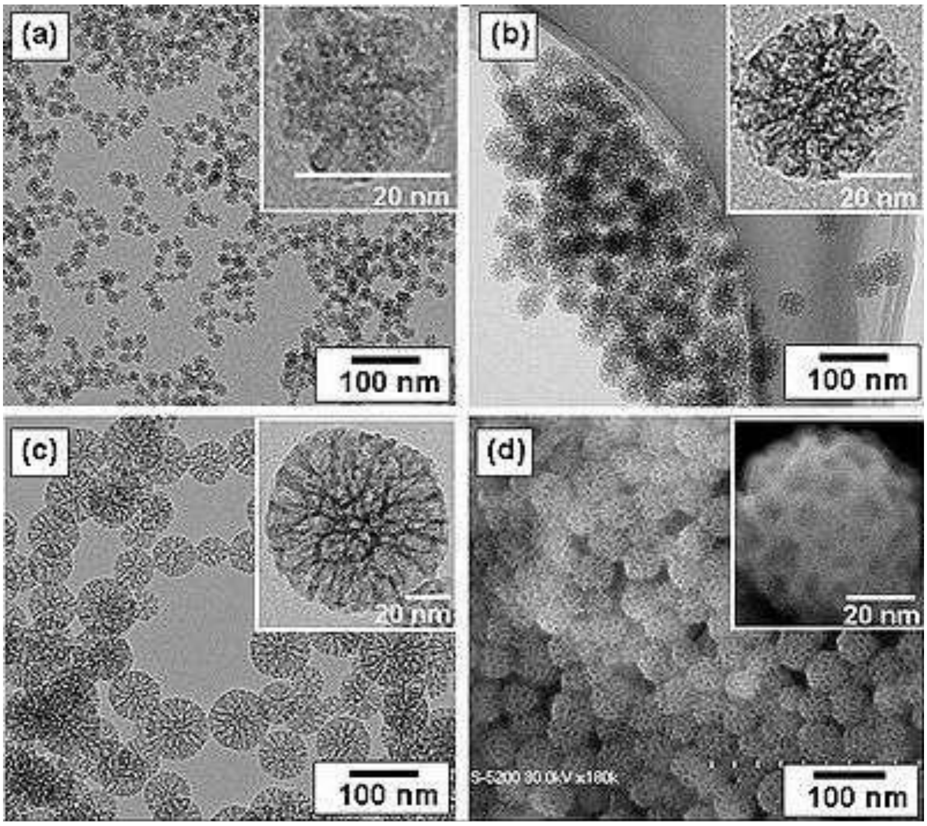

Figure -1 Nano-particles (Thakur and Saikhedkar 2012)

2.2 Engineered organic nanoparticles (EONPs)

This group includes carbonaceous nano-materials and nanosheets. Fullerenes, as one of the major members of this group, comprise a class of engineered nanoparticles with extensive sp2 carbon atoms arranged in fused benzene rings; these engineered nanoparticles have exceptional electrical, chemical, and physical properties (Mauter and Elimelech, 2008). Initially, Kroto et al. (1985) synthesized a highly stable 60 C atom (C60) structure from graphite sheets by laser irradiation. They suggested a truncated icosahedron shape of C 60 and named this a fullerene. Subsequently, there have been reports of multi-layer structures containing 28e1500 C atoms (diameter of 8.2 nm) (Sano et al., 2002). Fullerenes are mainly used as thin films in electro-optical devices and in drug delivery systems (Bosi et al., 2003). Because of the low water solubility of pristine fullerenes, quite a large number of C60 derivatives containing ionize able or hydrophilic groups have been synthesized (Wudl, 2002). Generally, conventional nC60 clusters are produced by dissolving pristine bulk C60 in different organic solvents (Deguchi et al., 2001; Fortner et al., 2005). However, when C60 is dissolved in water with a balanced pH through vigorous mixing, nC60 aggregates form (Brant et al., 2005; Labille et al., 2006).

A typical nC60 bears a strong negative charge due to transfer of electrons (from the organic solvent), surface hydrolysis, and its pronounced electron accepting properties (Brant et al., 2005; Fortner et al., 2005). CNT is another allotrope of carbon with a distinct cylindrical shape. Structure-wise, CNTs are broadly classified as single-, double-, or multi-walled CNTs. Depending on the method of synthesis, separation (from amorphous substances) technique, and cleaning technique adopted, CNTs have various uses (Dai, 2002; Niyogi et al., 2002). CNTs are widely used in electronics, optics, and other fields of material science (Bianco and Prato, 2003) (Table 1).

2.3 Engineered polymeric nanoparticles (EPNPs)

Polymeric nanoparticles are synthesized by reacting a number of elements with organic polymers for common applications in medical fields (especially drug delivery) (Farre et al., 2011) (Table 1). Specific EPNPs are synthesized by modifying their size, surface charge, morphology, and composition depending on their pre-determined use (Auffan et al., 2009). Polymerization can be achieved via cascade synthesis, micro-emulsion, surfactant-free emulsion, interfacial emulsion, sono-chemical, chemical reduction, oil in water emulsion, or sol-gel synthesis (Iwamoto et al., 2009; Zhang et al., 2010; Yang et al., 2012; Padrova et al., 2016). Among EPNPs, magnetic nano particles play an extremely important role in various biomedical applications. These nano particles are synthesized by reacting metal precursors, a reducing agent, and monomer. Their properties and applications are primarily governed by their size and surface to volume ratio (Rao et al., 2015). Interestingly, mostly transition metals (e.g. Fe, Co, FeePt, CueNi) are used in this process in a synergistic nano-hybrid form because of their magnetic properties and biocompatibility (Fuchigami et al., 2011; Neinhaus et al., 2011; Rao et al., 2015).

2.4 Miscellaneous nanoparticles

Quantum dots (QDs) are another group of semiconductor nanocrystals characterized by a reactive core to control their optical properties (Farre et al., 2011). Graphene nano-foil is another carbon-based nano material of interest. It is composed of a series of superimposed layers of hexagonal networks of C atoms, each of which is bound by three neighboring layers in a planar network (Petersen and Henry, 2012). Modification of the synthesis process and fabrication of graphene nano-foil structures has resulted in its widespread application in anticorrosive electrodes and conductors used in modern electronic engineering (Vlassiouk et al., 2011). Nano-polymers such as dendrimers are efficient water-soluble chelators (Xu and Zhao, 2005, 2006). Nanoparticles Ag Au alloys dealloying from Ag37.75 Cu38.75 Si22.5 Au1 had the finest spongy structure, and the size of pores was 5–10 nm and the grain size of ligaments was 10–20 nm. It also had the highest surface area of 106.83 m^2g^{-1} and the best catalytic activity towards electro-oxidation of formaldehyde with the peak current of 665 mA mg^{-1} (Cuiting Lia and Tao Zhang 2017). Semiconductor materials possess properties between metals and nonmetals and therefore they found various applications in the literature due to this property (Ali et al., 2017; Khan et al., 2017a). Semiconductor NPs possess wide bandgaps and therefore showed significant alteration in their properties with bandgap tuning. Therefore, they are very important materials in photo-catalysis, photo optics and electronic devices (Sun, 2000). As an example, variety of semiconductor nanoparticles are found exceptionally efficient in water splitting applications, due to their suitable bandgap and bandage positions (Hisatomi et al., 2014). Ceramics NPs are inorganic nonmetallic solids, synthesized via heat and successive cooling. They can be found in amorphous, polycrystalline, dense, porous or hollow forms (Sigmund et al., 2006). Therefore, these NPs are getting great attention of researchers due to their use in applications such as catalysis, photo catalysis, photo degradation of dyes, and imaging applications. (Thomas et al., 2015).

Table 1						
SN	**type**	**Surface Coating**	**Particle Size(nm)**	**Synthesis Method**	**Application**	**References**
A-	**Polymeric nano Particle**					
1	Ag-PEG	Polyethylene glycol, AgNO3	10 to 80	Chemical reduction	Biomedical	Tejamaya et al., 2012; Rao et al.,2012
2	Ag-PVP	Polyvinylpyrrolidone, AgNO3	50	Chemical reduction	Optical application, antimicrobial,food industry, textile, biosensors	Ahmed et al., 2010
3	Ag-citrate	Na citrate, AgNO3, Ag per chlorate, NaBH4	20-60	Chemical reduction	DDSa, antibacterial, luminescence	Tejamaya et al., 2012; Brown et al., 2013
4	Cu2O	Polyvinylpyrrolidone	35-60	Thermal reduction,sonochemical reduction,and micro emulsion	Conductors, catalysts, electrodes, diodes; thin-film transistors, and solar cells	Radi et al., 2010; Dwivedi et al., 2015
5	CeO2	Polyvinylpyrrolidone, Cerium (III) acetate hydrate	8 to 40	Sol-gel synthesis,hydrothermal, therml reduction	Fuel cells, catalysis, luminescent,gas sensors, polishing and ferromagnetic material	Dwivedi et al., 2015
6	SiO2	Polyethylene glycol	20-30	Sol-gel synthesis	Luminescence, photovoltaic cells	Binks et al., 2013; Dwivedi et al.,2015
7	7 TiO2	Poly (acrylic acid), N,Ndimethyl acetamide	20 to 60	Sol-gel reaction,hydrothermal, chemical vapour deposition	Solar cells, catalysts, sensor	Dwivedi et al., 2015
B-	**Magnetic iron-polymer NPs**					
8	PEG	Aqueous FeCl2, NaBH4,	70 to 150	Chemical reduction	Biomedical	Padrova et al., 2016
9	Poly (GMA),	Ferrite intermediate hydrazine	80 to 120	Mini emulsion	Biomedical	Padrova et al., 2016
10	Polystyrene (PS)	FeSO4. 7H2O, NaBH4, Cyclohexane, NP-9, Octanol	150 to 50	Mini emulsion	Biomedical	Padrova et al., 2016
11	PS	Fe(CO)5	10 to 20	Thermal decomposition	Biomedical	Padrova et al., 2016
12	Poly (iso-butylene)	Fe(CO)5, Ammonia	20 ± 4	Thermal decomposition	Biomedical	Padrova et al., 2016
13	Poly (styrene-GMA)	Fe (III) acetylacetonate hexadecanediol	100 to 200	Seed polymerization	Bioscreening	Padrova et al., 2016
14	PMMA	Bis[bis(trimethylsilyl) amido] iron (II)	98	Emulsion polymerization	Biomedical	Padrova et al., 2016
C-	**Magnetic bimetallic polymer NP**					
15	PIB-alt-MA	Fe(III) acetylacetonate, Pt (II) acetylacetonate, TEG	12	Chemical reduction	Biotechnology	Neinhaus et al., 2011; Padrova et al., 2016
16	PDDAc	Fe(III) acetylacetonate, Pt (II) acetylacetonate, TEG	3 to 5	Chemical reduction	Magnetically-guided DDS	Fuchigami et al., 2011; Padrova et al., 2016
17	PVP	Fe(III) acetylacetonate, Pt (II) acetylacetonate, TEG	5.2 ± 1.3	Chemical reduction	Biomedical	Padrova et al., 2016
18	PEG	Ni acetate tetrahydrate, Cu acetate monohydrate,	200 to 500	O/W emulsion	Hyperthermia	Padrova et al., 2016

		ethylene glycol				
D-	**Metal oxide and inorganic NPs**					
19	Ag	AgNO3, Au, citrate, tannic acid,EDTA, graphene	10 to 34	Chemical reduction, electrochemical techniques, photochemical reduction	Surgical equipment, contraceptive devices, water purificants	Chen and Schluesener , 2008;
20	Au	HAuCl4, Ag, Pd, citrate, tannic acid, cysteine, biotin, bovine serum albumin	1 to 50	Citrate reduction, microemulsion	Biomedical, catalysis, DNA labeling, biosensors, cancer therapy, DDS	Ghosh et al., 2011; Mittal et al.,2013
21	CeO2	Ce(NO3)3$6H2O, citrate, trioctylphosphine oxide and oleic acid	05 to 40	Hydrothermal, reverse micellar synthesis	Catalytic converter, solar cells, gas sensors, metallurgical applications	Hoecke et al., 2009
22	Cu2O	CuCl2$2H2O, NaOH, tetraoctyl ammonium bromide	10 to 120	Electro-deposition, micro emulsion	Biomedical; gas sensors, solar energy conversion, electrodes	Lal et al., 2011
23	FeO	Fe3O4; Au, SiO2	3 to 20	Thermal and sono-chemical reduction; sol-gel reaction; hydrothermal	MRI, DDS, catalysts, spintronics devices	Yang et al., 2011; Chaudhuri and Paria, 2012
24	SiO2	Sodium silicate, 3-aminopropyl, tetraethylorthosilicate, CTAB	30 to 200	Sol-gel method, reverse microemulsion	Cancer cell imaging, DNA and microarray detection, bar coding, gene or drug delivery	Tang et al., 2012
25	TiO2	Oleic acid, oleyl amine, triethanolamine, Pt, Au, Ag	10 to 20	Sol-gel method, inverse micelle method, chemical vapor deposition	Paints, fabric coatings, catalysis, cosmetics, papers	Kim et al., 2012a,b
26	n ZVIb	FeSO4$7H2O; FeCl2$4H2O; carboxymethyl cellulose, starch	4 to 60	Chemical reduction; electrolysis; carbothermal; micro-emulsion	Ground water purificants; Fenton catalyst; heavy metal remediation	Crane and Scott, 2012; Hwang et al., 2014
27	ZnO	Zn acetate, polysaccharides, 2-mercaptoethanol, TEA, LiOH	2 to 30	Hydrothermal,solvo thermal, electrodeposition	Catalysts, cosmetics, sensors, photovoltaic cells	Kim et al., 2013; Choi et al., 2015; Kundu et al., 2015
E-	**Caon nano tube(CNTs)**					
28	Single-walled CNTs	Graphite, Si, TiO2, methane	0.4 to 0.3	Electric arc technique, laser ablation and vaporization, catalytic CVD	Electrodes, hydrogen storage media, sensors and probes, field emission devices	Futaba et al., 2006
29	Double-walled CNTs	Graphite	0.5 to 3.25	Catalytic CVD, hydrogen arc discharge method	DDS, genomic delivery, capacitors, sensors and probes, hydrogen storage media	Bianco et al., 2005
30	Multi-walled CNTs	Graphite, hydrocarbons	1.4 to 100	Carbon arc discharge, laser ablation, CVD, electrolysis, pyrolysis over metal	Electrodes, hydrogen storage media, sensors and probes, field emission devices	Bianco et al., 2005
F-	**Miscellaneous (fullerenes, nano- foils, dendrimers, quantum)**					
31	Buckminsterfullerene	Graphite, CTAB chloride, Triton X-100, BSA	0.5	Laser irradiation and vaporization, carbon arc discharge method	DDS, optical devices, hydrogen storage, sensors, photovoltaics, electronics, antioxidants	Trojanowicz, 2006

32	Dendrimers	Ammonia, methanol, methyl acrylate, ethylene diamine (PAMAM G1, PAMAM G6)	1 to 10	Cascade synthesis	DDS, therapeutic agents for prion diseases, chemical sensors, electrodes	Abbasi et al., 2014
33	Graphene nano-foils	Graphite, Si or SiO2, Cu, and Al	100 to 300	CVD, electrolysis	Anticorrosion agent; electronicdevices; electrodes and sensors, Libatteries	Hu et al., 2015; Zhu et al., 2016
34	Quantum dots	CdCl2, H2Te, Citrate, Glutathione	10 to 20	Organometallic synthesis	In-vivo bio-imaging, labeling cell organelles and cell receptors	Hardman, 2006; Sturzenbaum et al., 2013

2.5 Synthesis of Nanoparticles

Various methods can be employed for the synthesis of NPs, but these methods are broadly divided into two main classes i.e. (1) Bottom-up approach and (2) Top-down approach (Wang and Xia, 2004) as shown in Scheme 1 (Iravani, 2011). These approaches further divide into various subclasses based on the operation, reaction condition and adopted protocols.

3. Characterization of Nanoparticles

Different characterization techniques have been practiced for the analysis of various physicochemical properties of NPs. These include techniques such as X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), and infrared (IR), SEM, TEM, Brunauer–Emmett–Teller (BET), and particle size analysis.

Morphological characterizations

The morphological features of NPs always attain great interest since morphology always influences most of the properties of the NPs. There are different characterization techniques for morphological studies, but microscopic techniques such as polarized optical microscopy (POM), SEM and TEM are the most important of these.

Structural characterizations

The structural characteristics are of the primary importance to study the composition and nature of bonding materials. It provides diverse information about the bulk properties of the subject material. XRD, energy dispersive X-ray (EDX), XPS, IR, Raman, BET, and Zieta size analyzer are the common techniques used to study structural properties of NPs.

Particle size and surface area characterization

Different techniques can be used to estimate the size of the NPs. These include SEM, TEM, XRD, AFM, and dynamic light scattering (DLS). SEM, TEM, XRD and AFM can give better idea about the particle size (Kestens et al., 2016), but the zeta potential size analyzer/DLS can be used to find the NPs size at extremely low level.

Optical characterizations

Optical properties are of great concerned in photocatalytic applications and therefore, photo-chemists acquired good knowledge of this technique to reveal the mechanism of their photochemical processes. These characterizations are based on the famous beer-lambert law and basic light principles (Swinehart, 1962). These techniques give information about the absorption, reflectance, luminescence and phosphorescence properties of NPs.

4. Properties of Nanoparticles

Various properties such as large surface area, mechanically strong, optically active and chemically reactive make nanoparticles unique and suitable applicants for various applications. Some of their important properties are discuss in the following -

Thermal properties

It is well-known fact that metals NPs have thermal conductivities higher than those of fluids in solid form. For example, the thermal conductivity of copper at room temperature is about 700 times greater than that of water and about 3000 times greater than that of engine oil. Even oxides such as alumina (Al2O3) have thermal conductivity higher than that of water. Therefore, the fluids containing suspended solid particles are expected to display significantly enhanced thermal conductivities relative to those of conventional heat transfer fluids. Nanofluids are produced by dispersing the nanometric scales solid particles into liquid such as water, ethylene glycol or oils. Nanofluids are expected to exhibit superior properties relative to those of conventional heat transfer fluids and fluids containing microscopic sized particles. Because the heat transfer takes place at the surface of the particles, it is desirable to use the particles with large total surface area. The large total surface area also increases the stability suspension (Lee et al., 1999). Recently it has been demonstrated that the nanofluids consisting of CuO or Al2O3 NPs in water or ethylene exhibit advance thermal conductivity (Cao, 2002).

Mechanical properties

The distinct mechanical properties of nanoparticles allow researchers to look for novel applications in many important fields such as tribology, surface engineering, nanofabrication and nano manufacturing. Different mechanical parameters such as elastic modulus, hardness, stress and strain, adhesion and friction can be surveyed to know the exact mechanical nature of NPs. Beside these parameters surface coating, coagulation, and lubrication also aid to mechanical properties of NPs (Guo et al., 2014). Nanoparticles show dissimilar mechanical properties as compared to micro particles and their bulk materials. Moreover, in a lubricated or greased contact, the contrast in the stiffness between NPs and the contacting external surface controls whether the NPs are indented into the plan surface or deformed when the pressure at contact is significantly large. This important information could divulge how the nanoparticles perform in the contact situation. Decent controls over mechanical features of nanoparticles and their interactions with any kind of surface are vital for enlightening the surface quality and elevating material removal. Fruitful outcomes in these fields generally need a deep insight into the basics of the mechanical properties of nanoparticles, such as elastic modulus and hardness, movement law, friction and interfacial adhesion and their size dependent characteristics (Guo et al., 2014).

Magnetic properties

Magnetic nanoparticles are of great curiosity for investigators from an eclectic range of disciplines, which include heterogenous and homogenous catalysis, biomedicine, magnetic fluids, data storage magnetic resonance imaging (MRI), and environmental remediation such as water decontamination. The literature revealed that NPs perform best when the size is <critical value i.e. 10–20 nm (Reiss and Hu¨ tten, 2005). The uneven electronic distribution in NPs leads to magnetic property. These properties are also dependent on the synthetic protocol and various synthetic methods such as solvothermal (Qi et al., 2016), coprecipitation, micro-emulsion, thermal decomposition, and flame spray synthesis can be used for their preparation (Wu et al., 2008).At such low scale the magnetic properties of nanoparticles dominated effectively, which make these particle priceless and can be used in different applications (Faivre and Bennet, 2016; Priyadarshana et al., 2015; Reiss and Hu¨ tten, 2005; Zhu et al., 1994).

Electronic and optical properties

The optical and electronic properties of nanoparticles are interdependent to greater extent. For instance, noble metals nanoparticles have size dependent optical properties and exhibit a strong UV–visible extinction band that is not present in the spectrum of the bulk metal. This excitation band results when the incident photon frequency is constant with the collective excitation of the conduction electrons and is known as the localized surface plasma resonance (LSPR). LSPR excitation results in the wavelength selection absorption with extremely large molar excitation coefficient resonance Ray light scattering with efficiency equivalent to that of ten fluorophores and enhanced local electromagnetic fields near the surface of nanoparticles that enhanced spectroscopies.

6. Applications of Nanoparticles

Nanoparticles can be used in variety of applications. Some important of these are given below.

Applications in mechanical industries

As revealed from their mechanical properties through excellent young modulus, stress and strain properties, NPs can offer many applications in mechanical industries especially in coating, lubricants and adhesive applications. Besides, this property can be useful to achieve mechanically stronger nanodevices for various purposes. Tribological properties can be controlled at nanoscale level by embedding NPs in the metal and polymer matrix to increase their mechanical strengths. It is because, the rolling mode of NPs in the lubricated contact area could provide very low friction and wear.

In addition, NPs offer good sliding and delamination properties, which could also effect in low friction and wear, and hence increase lubrication effect (Guo et al., 2014). Coating can lead to various mechanically strong characteristics, as it improves toughness and wear resistance. Alumina, Titania and carbon based NPs successfully demonstrated to get the desirable mechanical properties in coatings (Kot et al., 2016; Mallakpour and Sirous, 2015; Shao et al., 2012).

Applications in manufacturing and materials

Nano crystalline materials provide very interesting substances for material science since their properties deviate from respective bulk material in a size dependent manner. Manufacture NPs display physicochemical characteristics that induce unique electrical, mechanical, optical and imaging properties that are extremely looked-for in certain applications within the medical, commercial, and ecological sectors (Dong et al., 2014; Ma, 2003; Todescato et al., 2016). NPs focus on the characterization, designing and engineering of biological as well as non-biological structures < than 100 nm, which show unique and novel functional properties. The potential benefits of nanotechnology have been documented by many manufacturer at high and low level and marketable products are already being mass-produced such as microelectronics, aerospace and pharmaceutical industries (Weiss et al., 2006). Among the nanotechnology consumer products to date, health fitness products from the largest category, followed by the electronic and computer category as well as home and garden category.

Nanotechnology has been touted as the next revolution in many industries including food processing and packing. Resonant energy transfer (RET) system consisting of organic dye molecules and noble metals NPs have recently gamed considerable interest in bio photonics as well as in material science (Lei et al., 2015). The presence of NPs in commercially available products is becoming more common. Metals NPs such as noble metals, including Au and Ag have many colors in the visible region based on plasmon resonance, which is due to collective oscillations of the electrons at the surface of NPs (Khlebtsov and Dykman, 2010a, 2010b; Unser et al., 2015). The resonance wavelength strong depends on size and shape of NPs, the interparticle distance, and the dielectric property of the surrounding medium. The unique plasmon absorbance features of these noble metals NPs have been exploited for a wide variety of applications including chemical sensors and biosensors (Unser et al., 2015).

Applications in energy Harvesting

Recent studies warned us about the limitations and scarcity of fossil fuels in coming years due to their nonrenewable nature. Therefore, scientists shifting their research strategies to generate renewable energies from easily available resources at cheap cost. They found that NPs are the best candidate for this purpose due to their, large surface area, optical behavior and catalytic nature. Especially in photocatalytic applications, NPs are widely used to generate energy from photoelectron chemical (PEC) and electrochemical water splitting (Avasare et al., 2015; Mueller and Nowack, 2008; Ning et al., 2016). Beside water splitting, electrochemical CO2 reduction to fuels precursors, solar cells and piezoelectric generators also offered advance options to generate energy (Fang et al., 2013; Gawande et al., 2016; Lei et al., 2015; Li et al., 2016; Nagarajan et al., 2014; Sagadevan, 2015; Young et al., 2012; Zhou et al., 2016). NPs also use in energy storage applications to reserve the energy into different forms at nanoscale level (Greeley and Markovic, 2012; Liu et al., 2015a, 2015b; Sagadevan, 2015; Wang and Su, 2014). Recently, nano generators are created, which can convert the mechanical energy into electricity using piezoelectric, which is an unconventional approach to generate energy (Wang et al., 2015).

Applications in electronics

There has been growing interest in the development of printed electronics in last few years because printed electronics offer attractive to traditional silicon techniques and the potential for low cost, large area electronics for flexible displays, sensors. Printed electronics with various functional inks containing NPs such as metallic NPs, organic electronic molecules, CNTs and ceramics NPs have been expected to flow rapidly as a mass production process for new types of electronic equipment Kosmala et al., 2011).

Unique structural, optical and electrical properties of one dimensional semiconductor and metals make them the key structural block for a new generation of electronic, sensors and photonic materials (Holzinger et al., 2014; Millstone et al., 2010; Shaalan et al., 2016). The good example of the synergism between scientific discovery and technological development is the electronic industry, where discoveries of new semiconducting materials resulted in the revolution from vacuumed tubes to diodes and transistors, and eventually to miniature chips (Cushing et al., 2004).

Applications in drugs and medications

Nano-sized inorganic particles of either simple or complex nature, display unique, physical and chemical properties and represent an increasingly important material in the development of novel nanodevices which can be used in numerous physical, biological, biomedical and pharmaceutical applications (Loureiro et al., 2016; Martis et al., 2012; Nikalje, 2015). NPs have drawn increasing interest from every branch of medicine for their ability to deliver drugs in the optimum dosage range often resulting in increased therapeutic efficiency of the drugs, weakened side effects and improved patient compliance (Alexis et al., 2008). Iron oxide particles such as magnetite ($Fe3O4$) or its oxidized form maghemite ($Fe2O3$) are the most commonly employed for biomedical applications (Ali et al., 2016). The selection of NPs for achieving efficient contrast for biological and cell imaging applications as well as for photo thermal therapeutic applications is based on the optical properties of NPs. The development of hydrophilic NPs as drug carrier has represented over the last few years an important challenge. Among the different approaches, polyethylene oxide (PEO) and polylactic acid (PLA) NPs have been revealed as very promising system for the intravenous administration of drugs (Calvo et al., 1997).

8. Conclusion

Based on the various studies carried out over the past decade, this review paper present a detail overview about Nanoparticles, their types, synthesis, characterizations, properties and applications. Through different characterization techniques such as SEM, TEM and XRD, it was revealed that Nanoparticles have size ranges from few nanometer to 100 nm. While the morphology is also controllable. Due to their tiny size, Nanoparticles have large surface area, which make them suitable for various applications, as it is use to control the pollution of environment. Beside this, the optical properties are also dominant at that size, which further increase the importance of these materials in photocatalytic applications. Synthetic techniques can be useful to control the specific morphology, size and magnetic properties of Nanoparticles.

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