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Review

Scientific applications and prospects of nanomaterials: A multidisciplinary review

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Nanotechnology is the science of objects <100 nm in size. Research into the development and application of nanomaterials takes a material science and engineering-based approach to nanotechnology. Nanomaterials often possess interesting optical, electronic and mechanical properties. The capacity to construct large, intricate structures with nanometer precision is rapidly increasing and consists several top-down reductive approaches and bottom-up additive approaches to satisfy its applicability in several fields of science. The physicochemical property of nano-functional materials and structural flexibility, promotes its vast application in chemistry and chemical engineering; physics and electronics; biochemistry and medical science, exploration and mining; computer science and engineering. A large pool of information was accessed via several reputable published books and articles, with the sole aim to contribute to the establishment of a stronger theoretical basis for the growing application of nanomaterials in several field of science. It has been established that nanomaterials and advancement in nanotechnology holds great potential in solving several global problems, and if properly harnessed with the right synergy between disciplines or fields in science, would increase the quality of life on Earth.

Key words: Application, disciplines, nanotechnology, nanomaterials, properties, science.

INTRODUCTION

Scientific research in the development of new materials with functional properties for nanotechnology has received global attention and hundreds of products such as sunscreens, electrical gadgets, cosmetics, textiles, and sports equipment; are all based on scientific advancements that have been made. Nanotechnology has found applications in the field of medicine especially in drug delivery, biosensors, and other biomedical applications. Nanomaterials are also being developed for use in environmental applications, e.g. remediation of different environmental compartments via clean-up of environmental pollutants (Lyddy, 2009).

Several applications that were motivated by advances in nanotechnology exist across several disciplines. This is

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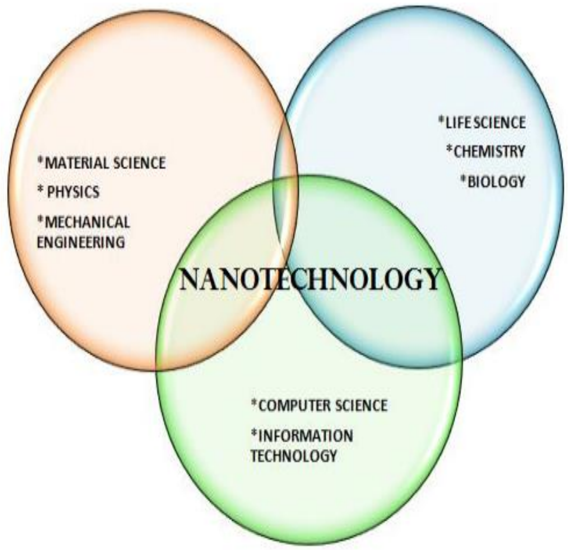

Figure 1. Relationship between Nanotech-nology and several Disciplines

evident in Schummer (2004), where the author sampled and carried out visualization research of 600 publications published in journals considered to be nanotechnology inclined in 2002 and 2003, using the journal subject categories. Also, the work of Grodal and Thoma (2008) identified migration of concepts between nanotechnology and biotechnology. The authors found that the ‘‘nano-biotechnology’’ keyword activity is growing to a greater extent than that of either of the parent nanotechnology or of the biotechnology.

The improvement of the quality of materials via re-arrangement or refining their nano-structures is a form of nanotechnology regarded as incremental nanotechnology. When the size reduction of materials leads to changes in physicochemical properties that provide problem solving potentials and new economic opportunities, then such applications are considered to be examples of what has been termed evolutionary nanotechnology (Jones, 2004). The Venn diagram (Figure 1) gives a pictorial explanation to the relationship that exists in several fields of science and nanotechnology.

In recent times, nanoparticles, nanomembrane and nanopowder have found application in detection and removal of chemical and biological substances such heavy metals (e.g. cadmium, copper, lead, mercury, nickel, zinc), minerals and nutrients (e.g. phosphate, ammonia, nitrate and nitrite), cyanide, trace organics, algae (e.g. cyanobacterial toxins) viruses, bacteria, parasites and pharmaceuticals (e.g. antibiotics). There are four classes of nanoscale materials potentially evaluated as functional materials for water treatment applications; they are metallic nanoparticles, carbon-based nanomaterials, zeolites and dendrimers. Carbon nanotubes and fibers have also shown positive results. Nanomaterials provide better results than other techniques used in water treatment because of its high surface area (surface/volume ratio). Nanoparticles are used in a wide range of applications including pharmaceuticals, cosmetics, medical devices, food ware, clothing and water purification, among other uses, due to their antimicrobial properties (Dhermendra et al., 2008).

Generally, nanotechnology has presented many essential applications in many aspects of oil and gas operations and broad application prospects in oil-field exploration. Various collections of nano-sized materials such as metallic nanoparticles, metal oxide nanoparticles, carbon nanotubes, and magnetic nanoparticles have been widely used in various types of oil and gas operations.

THE CHEMISTRY AND REMEDIAL APPLICATIONS OF NANOMATERIALS

Wastewater treatment processes are designed to achieve improvements in the quality of wastewater. The various treatment processes may reduce: (i) suspended solids, (ii) biodegradable materials, (iii) pathogenic bacteria, (iv) nitrates and phosphates, etc. Wastewater treatment is classified into three types: (a) Primary, (b) Secondary, and (c) Tertiary treatments (Abdel-Raouf et al., 2012). Based on the type of treatment and stages involved in purification, hence, nanomaterials are selected for the effective removal of pollutants and germs from the water systems. Compared to their counterparts in bulk states, carefully synthesized nanomaterials have the merits of better adjustable electronic properties, better tunable optical properties, and higher reactivity (Deniz et al., 2015).

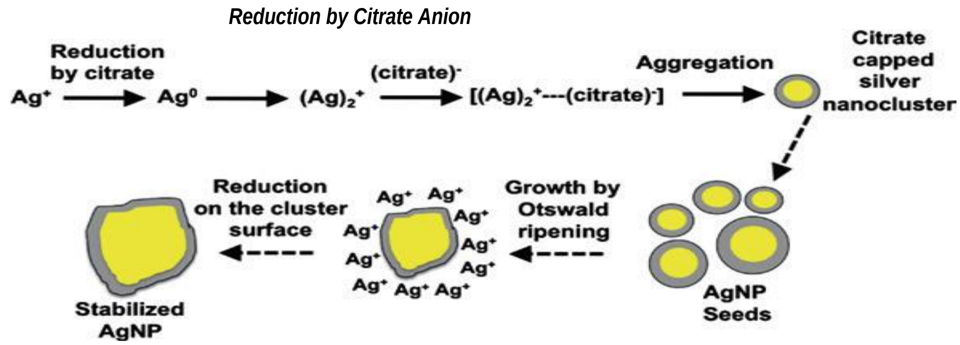

Figure 2. Representation of the nucleation and growth mechanisms for AgNP (Pillai and Kamat, 2004).

Most of the remediation technologies available today are not economical as they involve high costs of chemical consumption (cleaning agents, anti-scaling agents, biocides, etc.), high energy costs, high maintenance costs, low efficiency (≤50%), high costs of concentrate handling; especially when dealing with heavily polluted water e.g. agricultural waste waters, textile waste waters, etc. Furthermore, they are time consuming, particularly the pump-and-treat methods (Sharma and Bhattacharya, 2017). Thus, the capability to remove toxic compounds from surface and sub-surface and other environments are very difficult to access *in situ*, and doing so rapidly, efficiently and within reasonable costs is the ultimate goal and subject to more research. Secondly, the importance of water for domestic and industrial applications cannot be over-emphasized, however the devastating consequences of polluted water is also alarming and attracts global attention.

There are reports of synthetic route which have been used for the production of nanoparticles, they include chemical methods, photochemical methods, electrochemical methods, etc. Nanoparticles can be synthesized using the top-down or bottom-up approach. Research articles have reported different methods for silver nanoparticles (AgNP) synthesis. Most versatile bottom-up approaches include, chemical reduction, photochemical and electrochemical methods. The mechanisms involved in the particle nucleation were discussed as a key to predicting the outcome of any synthetic method. The end use or application of the nanomaterial determines the choice of the synthetic route, and this is not an easy decision as the product size and shape depends on the metal precursor, capping election, temperature of the reaction, amongst other factors (Pacioni et al., 2015). Several nanoparticles have been prepared using the chemical reduction method. The metal salts were reduced using either sodium borohydride, hydrazine or formaldehyde. The metal ions in aqueous solution are expected to produce stable, colloidal particles with appreciable size if treated with strong reducing agent and subsequently with a weaker reducing agent (Landage et al., 2014; Tinwala et al., 2014). Mechanism for the reduction of silver ion to silver nanoparticles (AgNP) using citrate as a reducing agent is described in Figure 2.

Water pollution is a world-wide environmental problem and nanotechnology is an efficient tool which can provide solution to the global menace. Silver nanoparticles among other metal-nanoparticle, are known to exhibit microbial toxicity, with strong biocidal effect yet nontoxic to the human body at low concentration (Harikumar et al., 2010). The antimicrobial potential of biosynthesized Ag nanoparticles for the treatment of water have been reported in literature (Figure 3). Silver materials have been synthesized using *Escherichia coli* and *Klebsiella* species and the *Carica papaya* plant extract. The product was characterized using UV-Visible spectroscopy, scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDS). The silver nanoparticles were adsorbed on granular activated carbon and used as a bacterial filter for treating contaminated water. The enzymatic reaction involved in the synthesis of nanoparticles may be the nitrate reductase provided by the microbe. This enzyme induced by nitrate ions reduces silver, nickel and iron ions to metallic state with zero oxidation number. The possible mechanism that may involve in the reduction of the metal ions is the electron shuttle enzymatic metal reduction process, which was proposed for gold nanoparticles (Harikumar et al., 2010).

Pesticide removal in aqueous solution

Several studies have been carried out to explain the interaction of pesticides in environmental media and the ability of pesticides to get adsorbed on adsorbent has been established (Adeola, 2018; Ololade et al., 2018). Thus, silver oxide nanoparticles loaded or embedded in chitosan beads have been synthesized and applied to remove pesticides from water (Rahmanifar and Dehaghi, 2013). A simple approach was adopted to prepare AgO

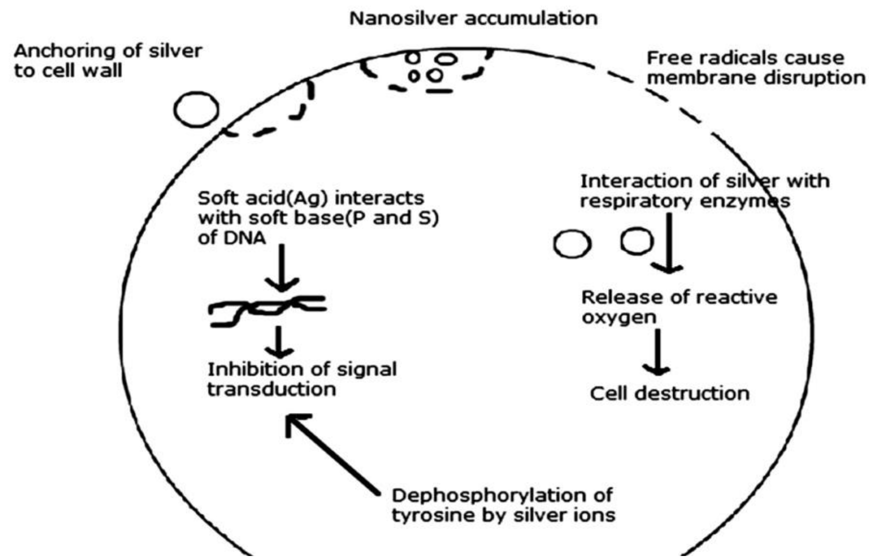

Figure 3. Schematic diagram of antimicrobial activity of AgNP (Prabhu and Poulose, 2012).

nanoparticles on the surface of chitosan. The chitosan-AgO nanoparticles (CS-AgONPs) composite was characterized by infrared spectroscopy (FTIR), X-ray diffraction (XRD), and SEM. The CS-AgONPs composite beads were optimized to remove maximum permethrin (pesticide), while varying parameters such as the amount of sorbent, agitating time, initial concentration of pesticide, and pH parameters. The optimum conditions, room temperature, pH 7, and the CS-AgONPs, the removal efficiency was 99% pesticides of permethrin solution (0.1 mg L^{-1}) which was determined by using UV spectrophotometer at a wavelength of 272 nm. While comparing experimental data with the pure chitosan, the percent removal efficiency of CS-AgONPs beads has been enhanced by 49%. The CS-AgONPs composite beads possess high adsorption capacity as an adsorbent which has potential as a new nano-scale, eco-friendly strategy for pesticide pollution remediation (Altaher, 2012; Zhu et al., 2012).

Dye removal via adsorption

Nickel nanoparticles have also been synthesized, characterized and applied to decolourize dye effluent in aqueous solution (Kale and Kane, 2016). C. I. Reactive Blue 21 was taken as a reference dye and polyvinyl pyrrolidone (PVP) as a stabilizer to prevent agglomeration of nanoparticles. Experimental parameters such as pH, dye initial concentration, nanoparticle concentration, alkali addition, salt addition and contact time was studied for dye decolourization or degradation. To ascertain the attachment of metabolites of dye on the nanoparticles, FT-IR analysis was done. About 98% colour removal efficiency was recorded with concurrent reduction in chemical oxygen demand (COD) (Nateghi et al., 2012).

Abou-Gamra and Ahmed (2015) carried out a similar research involving a successful route for synthesis titania nanoparticles by controlled sol-gel progress. Chitosan as bio-template was used as stabilizer in the synthesis to increase the surface area and create a defined particle and enhanced pore structure. The crystalline behavior and the nanostructure of the synthesized nanoparticles were elucidated using X-ray diffraction (XRD) and transmission electron microscope (TEM). Result obtained depicts that a transition in sample crystallography from anatase to completely amorphous nanoparticles upon adsorption of malachite green dye indicates a strong adherence of the dye which led to a breakdown in the crystalline morphology of titania sample (Li et al., 2013).

The remediation of dye in that aqueous system has been studied over wide range of dye concentrations and dosage of catalyst sample was varied (Shu et al., 2015; Olaremu and Adeola, 2018). Adsorption isotherms was studied using Freundlich, Langmuir, Temkin and Dubinin models to ascertain the mechanism of adsorption and calculate the maximum adsorption capacity and correlation coefficients (Deniz et al., 2015; Ololade et al., 2018). The kinetics of adsorption process is well investigated using different models as pseudo first order, pseudo second order, Elovich, Morris and Weber. The adsorption isotherm indicates the adsorption capacity of 6.3 $mg \cdot g^{-1}$ TiO_2. The value of enthalpy change ($\Delta H°$) for malachite green dye adsorption is 19 kJ/mol, which indicates that the removal process is endothermic. The adsorption process follows pseudo-second order rate equation and the negative values of standard free energy

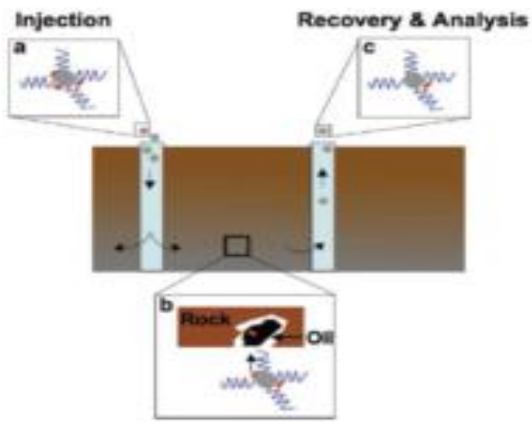

Figure 4. Hydrocarbon detection by nano-reporter (Jacob et al., 2011).

(ΔG°) suggest that the adsorption process is spontaneous (Ghaedi, 2012; Abou-Gamra and Ahmed, 2015).

GEOPHYSICAL AND GEOLOGICAL APPLICATIONS OF NANOMATERIALS

The unique physical and chemical properties of nanomaterials have led to their application in geophysical exploration hydrocarbon, reservoir characterization, drilling, cementing, production and stimulation, enhanced oil recovery (EOR), refining and processing (Munawar et al., 2017). This review article presents brief discussion on the most recent development of nanomaterials and their roles in new or enhanced applications in the exploration and mining industries.

Hydrocarbon exploration and reservoir characterization

One of the most essential yet expensive and high-risk activities in oil and gas industry is hydrocarbon exploration. The objective of this process is simply to find hydrocarbon accumulations beneath the earth's surface. However, it often presents many unique challenges such as the unexpected hazard, which may greatly increase the total cost of production. Many conventional sensing methodologies, with exception of seismic techniques, can only provide little information about reservoir as they can only penetrate a few inches from the wellbore. Current sensing technologies are still unable to obtain high-resolution reservoir imaging and lacking on the ability to penetrate deeply into reservoir to get key information about reservoir characteristics. Furthermore, many sensing techniques like conventional electrical sensors are often unable to provide reliable information at certain extreme reservoir conditions. Despite the advancement of recent state-of-the-art exploration techniques such as 3D and 4D seismic surveys, new, simple, low-cost, non-damaging and sensitive sensing technologies that can accurately locate hydrocarbon accumulation are still desired. The integration between new reservoir mapping and computational strategies is also needed to attain better discovery, sizing, and characterization of reservoirs (Kong and Ohadi, 2010).

Implementation of nanotechnology in accurate prediction of hydrocarbon accumulations and characterization of hydrocarbon reservoirs has been extensively studied. Owing to the virtue of their size-dependent optical, magnetic, chemical and electrical properties, nanoparticles can be used as nanosensor as they would easily migrate through pores of the surrounding geological structures and collect information about the reservoir characteristics. A new sensing technology based on nanoparticles also enables one to probe rock properties in deeper reservoir regions and to obtain data about the complex interaction between reservoir rock and fluids or distribution of immiscible fluids. Polyvinyl alcohol functionalized with oxidized carbon black effectively act as hydrophobic compound in variety of oil field types and releases the compound when rock contains the hydrocarbon, which helps in detection of *in-situ* hydrocarbons in the reservoir as shown in Figure 4 (Jacob et al., 2011).

Drilling and completion

Drilling is one of the most crucial processes in creating access to hydrocarbon reservoir rocks for producing the crude oil and natural gas. The well is created by drilling a hole of 5 to 50 inches in diameter into the earth with a drilling rig that rotates a drill string with a drill bit. Nanoparticles are used in drilling and completion, such as, clay stabilization, enhanced viscosity of drilling fluids, and fluid loss control, sloughing (wall collapse) control, stability of well bore, torque and drag friction, hydraulic fracturing and cementing, etc. In broad-spectrum, several types of additives (commonly polymers) are used to enhance the properties and performances of drilling fluids such as in thermal stability, salty resistance, filter cake generation, rheological and filtration properties. Conversely, the use of several types of nanoparticles has also been reported in drilling fluids formulation recently. For example, several studies have revealed that the presence of nanoparticles in drilling fluid has contributed to the formation of effective, dense, thinner and impermeable cake as sealing for micro-cracks during drilling operation (Cheraghian et al., 2013; Yao et al., 2014).

Production and stimulation

One of the greatest challenges in the current oil and gas productions is the recovery from unconventional resources such as heavy and extra heavy oil, shale gas and liquid, tight gas and oil, coal bed methane (CBM), and bitumen hydrocarbons due to the nature of their physical and chemical properties as well as their geological difficulties. Recently, the development of nanotechnology has enabled one to effectively and efficiently harvest hydrocarbon from unconventional resources. For example, several types of nanocatalysts such as nano-sized transition metals and metal oxide nanoparticles have been used in aquathermolysis process for the improvement of heavy and extra heavy oil production (Khalil et al., 2015; Chen et al., 2009). In aquathermolysis process, it is believed that the significant improvement of oil production is mainly due to the reduction of oil viscosity as a result of degradation of large hydrocarbon molecules such as resin and asphaltene. It is reported that there is a great possibility that some chemical reactions such as hydrocracking, hydrodesulphurization (HDS), hydrodenitrogenation (HDN), and hydrogenation can occur during the process. In addition, it is also believed that one of the main reasons for the degradation of these large molecules is due to the cleavage of CaX (X = S, N, O) bonds (Maity et al., 2010).

Cementing

It has been widely known that wellbore failures and well integrity issues due to cementing and/or cementing stability issues are considered as one of the major problems in oil and gas exploration and production. Typically, these problems may occur during preproduction such as in drilling operation and during production processes (Teodoriu et al., 2013). During drilling operation, several cementing problems such as casing centralization (incomplete cementing), formation damage due drilling operations and cementing, inadequate cement-formation or cement-casing bond, cement shrinkage, incomplete cement placements, filtration of cement slurry, contamination of cement by drilling or formation fluids, and fracture formation with cement can seriously affect well integrity.

The development of smart cement materials based on nano-sized materials as additives with desired specific properties that solve or minimize many practical issues in the field has widely been reported in literatures. For example, several types of metal oxide nanoparticles such as nanosilica (Lin et al., 2008; Jo et al., 2007; Qing et al., 2007), TiO_2 (Nazari and Riahi, 2010a, 2011b), Fe_2O_3 (Li et al., 2004; Khoshakhlagh et al., 2012), Al_2O_3 (Nazari and Riahi, 2011, 2012), ZrO_3 (Nazari and Riahi, 2010a, 2011b), CuO (Nazari and Riahi, 2011), ZnO_2 (Nazari and Azimzadegan, 2012), and several other types of magnetic nanoparticles (Blyszko et al., 2008) have been used as additives in cement modification. These metal oxide nanoparticles are added mostly to improve several cements and concrete properties such as strength, resistance to water penetration, accelerate hydration reaction, control calcium leaching, to provide self-cleaning properties, and many more.

Refining and fuel production

Unlike in the upstream and midstream sectors, nanotechnology and nanomaterials have been used for over a decade in downstream sector of oil and gas industry, mainly in refining and processing process. One of the most common applications of nanomaterials in the oil refining and petrochemical industry is in the utilization of nanoparticle-based catalysts (Wei et al., 2007). Over the last several years, the advancement in nanotechnology has contributed substantially in the development of more effective and efficient refining and processing processes in converting crude hydrocarbon into useful products such as liquefied petroleum gas (LPG), gasoline, kerosene, jet fuel, diesel, and other valuable chemical feedstock. Nanotechnology has allowed researchers to develop catalysts that can substantially increase refining capacity and speed, improve the efficiency of hydrocarbon conversion, reduce or even eliminate catalyst poisoning issue, and provide better refining efficiency for extra heavy and sour crude oils (Okunev et al., 2015).

Lately, the application of nanomaterials in conversion and upgrading process of heavy crude oil and its derivatives have attracted many attentions since nanocatalysts provide a large surface area for the appropriate catalytic reactions. Over the last few years, different types of nanocatalysts such as metal oxide nanoparticles have been used in hydroprocessing of crude oil due to their good asphaltenes adsorption/ oxidation, and their high oxygen storage/release capacity. For example, Montoya et al., (2016) recently investigated the effect of NiO and PdO supported on fumed silica nanoparticles catalysts in catalytic thermal cracking of n-C7 asphaltenes. Based on their results, it is found that the presence of NiO or PdO was able to show a better catalytic activity than fume silica support alone.

Physicochemical properties of nanomaterials

Size and surface effect

As the unconventional oil and gas resources are developed further, more and more conventional chemicals cannot satisfy the reservoir injection requirements. Nanomaterials can not only improve the injection effectively, but also present peculiar penetrating capacity, especially in unconventional oil and gas resources. It is the small-size effect that increases the diffusion rate of chemicals in reservoirs greatly and injects the nano-fluid into the target areas in the reservoirs, to enhance the recovery factor significantly (Ayatollahi and Zerafat, 2012).

Nano-particles also have strong surface effect. The specific surface area of nanoparticles is large, so the bond strength of chemical bonds between nanoparticles and other media (e.g., mineral surface and metal salt) is increased. The surface of all nanomaterials (oxide of silicon, vanadium, molybdenum, and tungsten) is enriched with active modification sites (e.g., end oxygen and bridge oxygen), which provide the basis for stabilization modification and improvement at the surface of nanomaterials. Only the nanochemicals whose surface is modified present the special properties of wettability alteration, micro-particle migration inhibition, nanofiltration and shear thickening so that they can satisfy the actual requirement at each stage of oilfield development (Liu et al., 2016)

Nanometer photocatalytic property

Nanometer photocatalytic agent has the redox ability under ultraviolet radiation, so nanometer photocatalytic technology is used to purify contaminants. This technology is especially suitable for the purification of organic matter, and it is of great potential in purifying deeply the oilfield sewage (Xu et al., 2010). Nanometer photocatalytic agent is usually acted by TiO_2, whose photocatalytic reaction happens only after being excited by ultraviolet light (wave length less than 385 nm) (Li and Xu, 2010).

Shear thickening property

Existing water plugging and profile control materials are mainly acted by gel, volume expansion particle and polymer microsphere. These materials cannot be deformed by themselves and their physical and chemical properties do not vary with the ambient conditions. The shear thickening property of nanomaterials provides a technical solution to deal with this situation. Shear thickening fluid (STF) consists of shear thickening liquid, shear thickening gel, etc. Bender and Wagner (1996) described the shear thickening mechanism of this type of nanomaterial.

Nano-corrosion and wear resistance

In the sector of oil drilling engineering, the surface and down hole tools suffer complex environments of wear, corrosion, high temperature, high pressure, high H_2S and high CO_2 content, which result in tool damage and corrosion, cost increase and production decline and increase negative impact (e.g., operation hazard and environment pollution). For example, the key vulnerable parts (e.g., drilling bit, expansion cone, plunger, rotator and polished rod) may be improved by using high-performance nanocoating. The new high-hardness wear-resistance nanocoating is different from the traditional wear-resistance coating (e.g., single-phase nanocrystalline). The new nanocoating mainly performs periodic modulation on microstructures by using two-phase ceramics to form multilayer nanomembrane structures of coherent and epitaxial growth, so that the vulnerable parts are characterized by high hardness and wear resistance (Liu et al., 2016).

Particle migration inhibition

In the process of oilfield development, mineral micro-particles migrate at different levels, decreasing the permeability of porous media and damaging the reservoirs. Some solutions can be developed by using nanomaterials or emulsion. The nano-fluids containing nano-particles (magnesia, silica, and alumina) have lower oil-water interfacial tension and strong adsorption tendency. The research results by Al-Malki et al. (2016) showed that if drilling fluid is added with sepiolite nano-particles, its rheological stability is kept and filtration resistance and clay swelling inhibition are improved.

NANOTECHNOLOGICAL ADVANCEMENT IN PHYSICS AND ELECTRONICS

Nanomaterials are materials which possess single unit and size in at least one dimension to the order 10^{-9} m. (Figure 6) Usually, 1 to 100 nm is the usual definition of nanoscale (Buzea et al., 2007). Nanomaterials research takes a materials science and engineering-based approach to nanotechnology, leveraging advances in materials synthesis, micro-fabrication and other developmental research.

Nanomaterials often possess both interesting optical and electronic, or mechanical properties (Hubler and Osuagwu, 2010). Nanomaterials and nanophysics focus on designing, fabricating and controlling materials and its components on the nanoscale dimension.

Nanotechnology can be used to develop new optic and electronic components and new materials for use in communications technology, sensor technology or catalysis. Nanophysics focus on the special electronic and optical characteristics of nanomaterials such that there are numerous possibilities for development of nanotools and nanodevices.

Sources of nanomaterials

Engineered

Nanomaterials have been deliberately engineered and

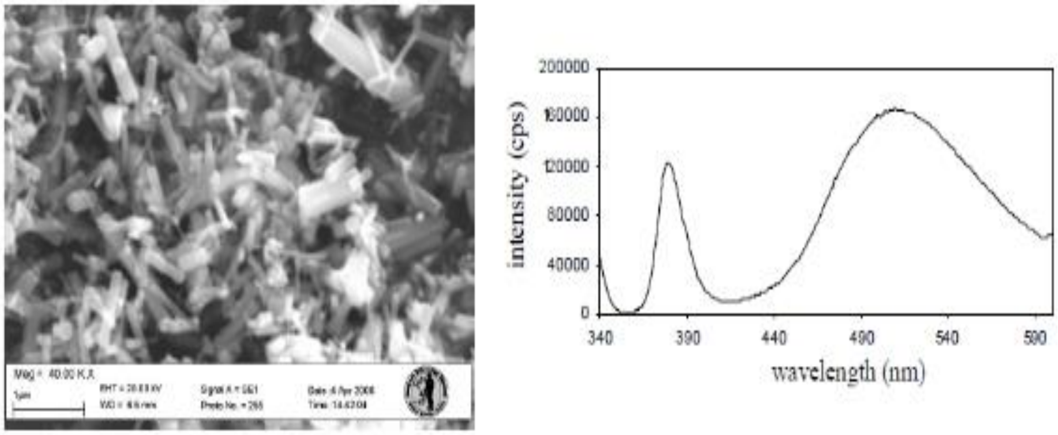

Figure 5. SEM image and photoluminescence spectral of ZnO nanopowders (Pereira et al., 2006).

manufactured in the laboratory placing premium on certain properties over the others (US NIOSH, 2013). The practice of engineering on the nanoscale is called nanoengineering.

Incidental

Nanomaterials have overtime been produced incidentally as a byproduct of mechanical or industrial processes (Sahu and Casciano, 2009).

Natural

Biological systems are characterized by both natural and functional nanomaterials (Figure 9). The structure of foraminifera (mainly chalk) and viruses (protein, capsid), the wax crystals covering a lotus or nasturtium leaf, spider and spider-mite silk (Novel Natural Nanomaterial Spins Off from Spider-Mite Genome Sequencing, 2015).

Application of nanophysics

Semiconductor

Zinc Oxide (ZnO) is a wide bandgap semiconductor and it has been the subject of considerable research due to its potential applications in the areas of photonics, electronics and sensors. Nano-ZnO offers several advantages over existing biosensing platforms, most notably a large surface area for greater bio-functionalization and an inherent photoluminescence (PL) signal, which consist of two emission peaks. The first peak is in the UV region, due to near band edge emission while the other is in the visible (green) region, due to oxygen vacancies caused by crystalline defects (Jason et al., 2006). Two specific semiconducting nanocrystals of interest are titanium dioxide (TiO_2) and zinc oxide (ZnO), however, utilizing TiO_2 as an optical sensing material may be difficult. Concerns regards it inability to optically detect a real-time binding event due to the single broad visible emission band unlike Nano-ZnO which is a wide band gap material with a high exciton binding energy (60 meV) that contains an inherent photoluminescence (PL) signal consisting of two emission peaks. One peak is in the UV, due to near band edge emission and the other is in the visible (green) region, due to oxygen vacancies caused by crystalline defects (Figure 5) (Jason et al., 2006).

In a bid to overcoming some of the current sensing platform limitations, efforts are focused on semiconducting nanocrystalline materials. Large surface area, mechanical and thermal stability, and inherent photoluminescence signal (Lei and Zhang, 2001; Banerjee et al., 2004) make them promising materials for an optically responsive sensing platform. Nano-ZnO has recently been demonstrated as a gas sensor by utilizing changes in its electrical resistivity (Guo et al., 2000; Zhiyong et al., 2004; Zhiyong and Jia, 2005).

Semiconductor nanocrystals (NCs) are made from a variety of different compounds. They are referred to as II-VI, III-V or IV-VI semiconductor nanocrystals based on the periodic table groups into which these elements are formed. For example, silicon and germanium are group IV, GaN, GaP, GaAs, InP and InAs are groups III-V, while those of ZnO, ZnS, CdS, CdSe and CdTe are groups II-VI semiconductors (Sagadevan, 2013). These novel properties of semiconductor nanomaterials have attracted significant attention in research and applications in emerging technologies such as nanoelectronics, nanophotonics, energy conversion, miniaturized sensors and imaging devices, solar cells, detectors, etc.

Nanoelectronics

Nanoelectronics refer to the use of nanotech in

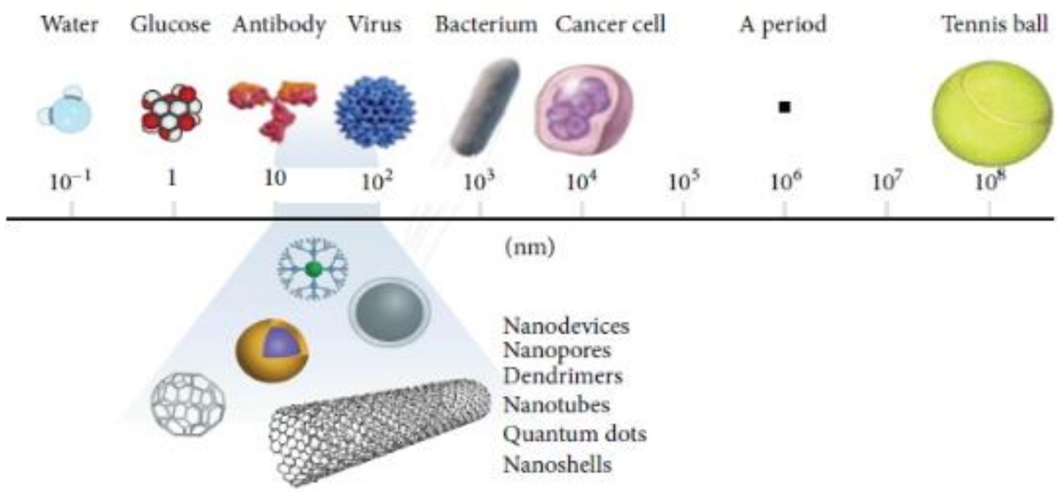

Figure 6. A size comparison of nanoparticles with other larger-sized materials (Amin et al., 2014).

fabricating electronic components. Examples include: hybrid molecular/semiconductor electronics, one dimension nanotubes (nanowires) (e.g. Silicon nanowires/ Carbon nanotubes), electron Transistor or advanced molecular electronics (e.g. New silicon CMOS). Nanoelectronics are sometimes considered as disruptive technology because they are significantly different from traditional electronic components. For example the electron transistors, which involve transistor operation based on a single electron: besides being small and allowing more transistors to be packed into a single chip, the uniform and symmetrical structure of nanowires and/or nanotubes allows a higher electron mobility, a higher dielectric constant (faster frequency), and a symmetrical electron/hole characteristic (Goicoechea et al., 2007).

Nanoelectronic device includes computer processors (nanomaterials such as nanowires or small molecules in place of traditional CMOS components, field effect transistors now operational using both the semiconducting carbon nanotubes (Postma et al., 2001), memory storage which uses a carbon nanotube based memory (called Nano-RAM) and the Hewlett-Packard has proposed the use of memristor as a replacement of Flash memory). Optoelectronic devices are replacing the traditional analog electronic devices due the enormity of their bandwidth, Displays (Silicon nanowires and carbon nanotubes), Quantum computing (which rely heavily on the understanding and application of the quantum nature/behavior of atomic charge carriers), etc.

Material science and engineering

Material engineering process dates to the proper understanding of surface physics such that engineered materials are deliberately made by humans to possess certain required characteristics for specific functionality. Most current nanomaterials could be organized into four types: Carbon Based Materials, Metal Based Materials, Dendrimers, and Composites. One outstanding application of nanotechnology in material engineering involves providing affordable solutions to water/ wastewater treatments by the use of nanoparticles/fibers for the removal of pollutants from water/wastewater (Abdo, 2016). This process does not rely on large infrastructures or centralized systems (Amin et al., 2014). Developments in nanoscale research have made it possible to invent economically feasible and environmentally stable treatment technologies and one of such suggested that nanotechnology can adequately address many of the water quality issues by using different types of nanoparticles and/or nanofibers (Savage and Diallo, 2005).

Carbon nanotubes (CNT) are one of an illuminative example for the potential of nanotechnology. The tensile strength of high carbon steel is around 1.2 GPa but the tensile strength of carbon nanotubes (CNT) is 63 GPa. While the longer carbon nanotubes will increase inter-tube contact areas and therefore yield higher tensile strength, decreasing the CNT diameter may also increase the yarn tensile strength (Mottal et al., 2005; Zhang et al., 2007a, b; Liu et al., 2008). Also they are known to be one of the strongest materials by nanotechnology so far. Figure 7 shows some examples of different type of nanomaterials based on nano-engineered dimension.

NANOTECHNOLOGICAL CONTRIBUTIONS TO COMPUTER SCIENCE

Major advancements in computer science began with miniaturization. The idea of miniaturization started in the

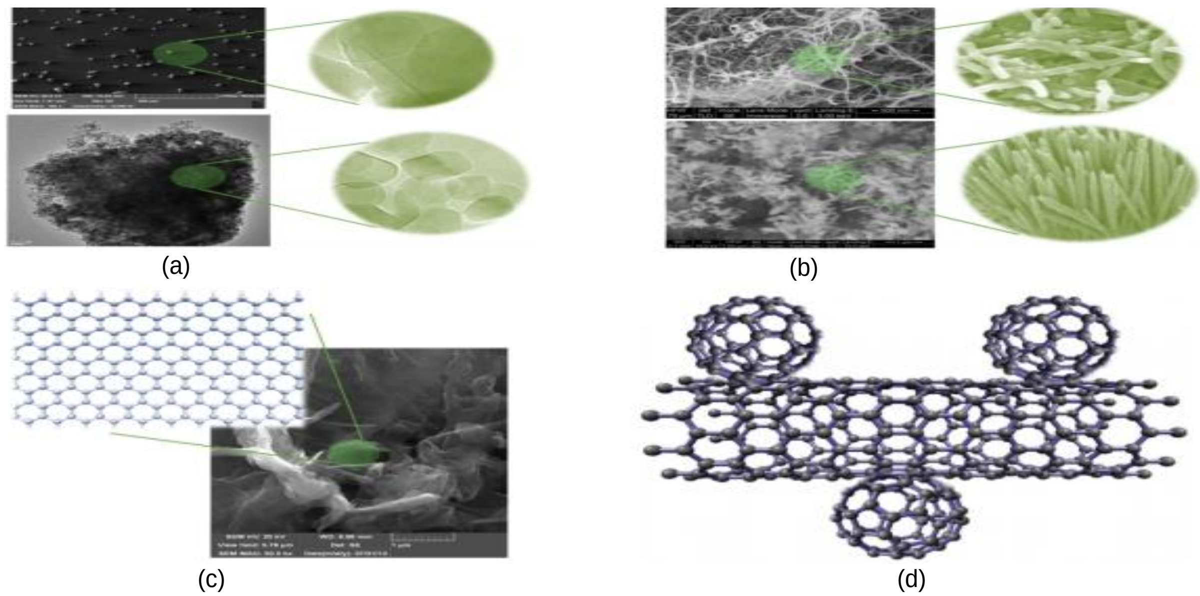

Figure 7. (a) Typical scanning electron microscopy (SEM) image of 0-D nanostructured materials; silver nanoparticles (upper image) and titania nanoparticles (lower image) with transmission electron microscopy (TEM) of each (right side). (b) Typical scanning electron microscopy (SEM) image of 1-D nanostructured materials: carbon nanotubes (upper image) and zinc oxide nanorods (lower image) with enlarged part of each image. (c) Typical scanning electron microscopy (SEM) image of graphene nanosheet and its structure as an example of 2-D nanostructured materials. (d) Carbon nanobud formed of carbon nanotube and fullerene as an example of 3-D structure (Abdo, 2016).

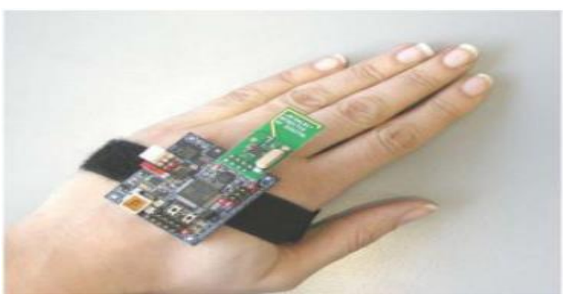

Figure 8. iNEMO board placed on hand (Brigante et al., 2011).

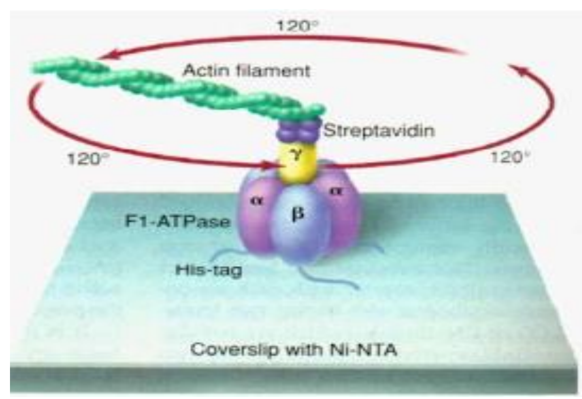

Figure 9. The molecular motor protein F1-ATPase (A naturally occurring nanomachine) (Nikalje, 2015).

early 1980s and it is regarded as the foundation of nanotechnology (Mamalis, 2007). The work of Kostoff et al. (2007) defined nanotechnology as the development and use of techniques to study physical phenomena and construct structures in the physical size range of 1 to less than 100 nm, as well as the incorporation of these structures into applications. Several researchers have worked on the area of nanotechnology and its applications (Zahn, 2001; Chen and Bruce, 2012). Porter and Youtie (2009) carried out extensive research to emphasize that nanotechnology is interdisciplinary. The result showed that nanotechnology cuts across almost all disciplines, most especially computer science. Nanotechnology is made possible through technological advances made in several disciplines (Mamalis, 2007).

The techniques used for nanotechnology applications are the energy beam processes, based on the principle that the energy carried on a beam can remove material by melting, vaporization or ablation (Chen and Bruce, 2012).

The most significant application of nanotechnology is in the production of microchips. Example of this is in Brigante et al., (2011), where a wearable system for real-time human motion capture called iNEMO was developed. The developed system makes use of nanotechnology to embed several MEMS sensors on its board (Figure 8).

The developed system, due to its performance, size, and weight can be easily embedded in a tracksuit for total body motion reconstruction. Also, the production cost for the iNEMO system when compared with other systems that performs the same function reduced by a factor of about eight. This was made possible by advances in nanotechnology.

Nanotechnology has immeasurably improved and revolutionized information technology. Early research on the application of nanotechnology in the Computer Science field such as Heath et al. (1998), developed a defect fault tolerant computers using nanotechnology. The developed system called “Teramac”, incorporates a very high communication bandwidth that enables it to easily route around defects, and also paved way for future nano metre scale computer paradigm. The work concluded that future nanoscale computers may consist of extremely large configuration memories that are programmed to perform specific tasks.

In recent time, nanoscale transistors that are faster, more powerful, and energy-efficient are being developed; soon our computers’ entire memory may be stored on a single tiny chip (Kumar et al., 2014). Computer scientists believe that nanotechnology will eventually bring them closer to the goal of creating computer systems that can simulate and emulate the brain's abilities for sensation, perception, action, interaction and cognition (Berger, 2010). Nanotechnology has witnessed four generations till date (Ullah, 2012), and the fourth generation of nanotechnology basically deals with the manufacturing and development of nano computers.

APPLICATIONS OF NANOTECHNOLOGY TO BIOCHEMISTRY AND MEDICAL SCIENCES

Nanotechnology is a leading scientific technique that offers sensing technologies and miniature devices to diagnose disease accurately and within time. There is wide range of applications of nanotechnology in the field of drug delivery and furthermore, to simplify the oral absorption of proteins and peptides nano carriers are modified with specific ligands (Veiseh et al., 2015). Nanotechnology holds a promising future in the field of Biochemistry both in Clinical Biochemistry and in Food and Nutrition Biochemistry. Diseases like diabetes, cancer, Parkinson’s disease, Alzheimer’s disease, cardiovascular diseases and multiple sclerosis as well as different kinds of serious inflammatory or infectious diseases (e.g. HIV) constitute a high number of serious and complex illnesses which are posing a major problem for the mankind. Nano-medicine is an application of nanotechnology which works in the field of health and medicine. Nano-medicine makes use of nano materials and nano electronic biosensors.

Clinical biochemistry

Drug delivery

In nanotechnology nano particles are used for site specific drug delivery. In this technique, the required drug dose is used and side-effects are lowered significantly as the active agent is deposited in the morbid region only. This highly selective approach can reduce costs and pain to the patients. Thus variety of nano particles such as dendrimers, and nano porous materials find application. Micelles obtained from block co-polymers, are used for drug encapsulation. They transport small drug molecules to the desired location. Similarly, nano electromechanical systems are utilized for the active release of drugs. Iron nano particles or gold shells are finding important application in the cancer treatment. A targeted medicine reduces the drug consumption and treatment expenses, making the treatment of patients cost effective. Nano medicines used for drug delivery are made up of nano scale particles or molecules which can improve drug bioavailability. For maximizing bioavailability both at specific places in the body and over a period of time, molecular targeting is done by nano engineered devices such as nano robots (Cavalcanti et al., 2008). The molecules are targeted and delivering of drugs is done with cell precision.

Parkinson's disease

Parkinson's disease (PD) is the second most common neurodegenerative disease after Alzheimer's disease and affects one in every 100 persons above the age of 65 years. PD is a disease of the central nervous system; neuro inflammatory responses are involved and lead to severe difficulties with body motions. The present day therapies aim to improve the functional capacity of the patient for as long as possible but cannot modify the progression of the neurodegenerative process (Ravichandran, 2009a, b)

The aim of the applied nanotechnology is regeneration and neuro protection of the central nervous system (CNS) and will significantly benefit from basic nanotechnology research conducted in parallel with advances in neurophysiology, neuropathology and cell biology. The efforts are taken to develop novel technologies that directly or indirectly help in providing neuro protection and/or a permissive environment and active signaling cues for guided axon growth. In order to minimize the peripheral side-effects of conventional forms of Parkinson's disease therapy, research is focused on the design, biometric simulation and optimization of an intracranial nano-enabled scaffold device (NESD) for the site-specific delivery of dopamine to the brain, as a strategy. Peptides and peptidic nano particles are newer tools for various CNS diseases. Nanotechnology will play a key role in developing new diagnostic and therapeutic tools. Nanotechnology could provide devices to limit and reverse neuro pathological disease states, to support and promote functional regeneration of damaged neurons, to provide neuro protection and to facilitate the delivery of drugs and small

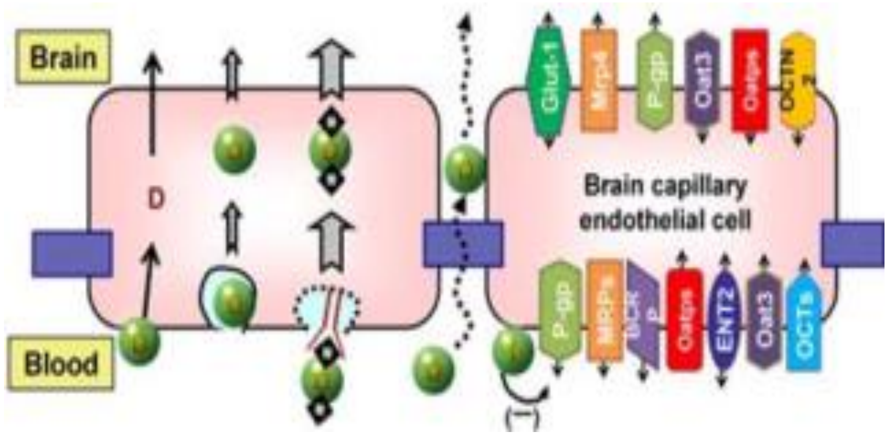

Figure 10. Delivery of nano medicine to CNS through BBB (Nilkaje, 2015).

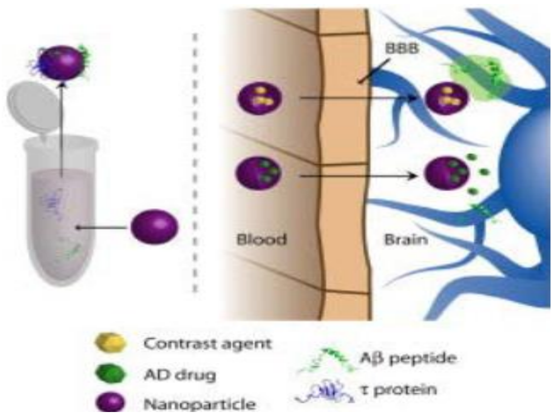

Figure 11. Use of nano particles in Alzheimer's disease (Nilkaje, 2015).

molecules across the blood-brain barrier.

Nikalje (2015) reported that for the delivery of CNS therapeutics, various nano carriers such as dendrimers, nano gels, nano emulsions, liposomes, polymeric nano particles, solid lipid nano particles, and nano suspensions have been studied (Figure 10). Transportation of these nano medicines has been effected across various *in vitro* and *in vivo* BBB models by endocytosis and/or transcytosis, and early preclinical success for the management of CNS conditions such as, Alzheimer's disease, brain tumors, HIV encephalopathy and acute ischemic stroke has become possible. Future development of CNS nano medicines needs to focus on increasing their drug-trafficking performance and specificity for brain tissue using novel targeting moieties.

Alzheimer's disease

Worldwide, more than 35 million people are affected by Alzheimer's disease (AD), which is the most common form of dementia. Nano technology finds significant applications in neurology. These approaches are based on the, early AD diagnosis and treatment is made possible by designing and engineering of a plethora of nano particulate entities with high specificity for brain capillary endothelial cells. Nano particles (NPs) have high affinity for the circulating amyloid-β (Aβ) forms and therefore may induce "sink effect" and improve the AD condition. *In vitro* diagnostics for AD has advanced due to ultrasensitive NP-based bio-barcodes and immune sensors, as well as scanning tunneling microscopy procedures capable of detecting Aβ1-40 and Aβ1-42. The recent research on use of nanoparticles in the treatment of Alzheimer's disease is as shown in Figure 11 (Davide et al., 2011).

Tuberculosis treatment

Tuberculosis (TB) is the deadly infectious disease. The long duration of the treatment and the pill burden can hamper patient lifestyle and result in the development of multi-drug resistant (MDR) strains. Tuberculosis in children constitutes a major problem. There is commercial non availability of the first-line drugs in pediatric form. Novel antibiotics can be designed to overcome drug resistance, cut short the duration of the treatment course and to reduce drug interactions with antiretroviral therapies. A nanotechnology is one of the most promising approaches for the development of more effective and compliant medicines. The advancements in nano based drug delivery systems for encapsulation and release of anti-TB drugs can lead to development of a more effective and affordable TB pharmacotherapy.

Food and nutrition biochemistry

Food technology is regarded as one of the industry sectors where nanotechnology will play an important role in the future (The Eleventh ASEAN Food Conference, 2009). It is commonly distinguished between two forms of nanofood applications: food additives (nano inside) and food packaging (nano outside). Nanoscale food additives may for example be used to influence product shelf life, texture, flavor, nutrient composition, or even detect food pathogens and provide functions as food quality indicators. In the context of food packaging, nano-technologies are mainly considered to be of use to increase product shelf life, indicate spoilt ingredients, or generally increase product quality, e.g., by preventing gas flow across product packaging (Nickols-Richardson and Piehowski, 2008).

For food applications, nanotechnology can be applied by two different approaches, either “bottom up” or “top down” (Ravichandran, 2009a, b). The top down approach is achieved basically by means of a physical processing of the food materials, such as grinding and milling. For example, dry-milling technology can be used to obtain wheat flour of fine size that has a high water-binding capacity (Degant and Schwechten, 2002). This technology has been used to improve antioxidant activity in green tea powder. As the powder size of green tea is reduced to 1000 nm by dry milling, the high ratio of nutrient digestion and absorption resulted in an increase in the activity of an oxygen-eliminating enzyme (Shibata, 2002).

By contrast, self-assembly and self-organization are concepts derived from biology that have inspired a bottom-up food nanotechnology. The organization of casein micelles or starch and the folding of globular proteins and protein aggregates are examples of self-assembly structures that create stable entities. Self-organization on the nanometer scale can be achieved by setting a balance between the different noncovalent forces (Dickinson and Van, 2003). The electron microscope and, more recently, the development of tools such as probe microscopes have provided unparalleled opportunities for understanding heterogeneous food structure at the submolecular level (Chaudhry et al., 2008). This has provided new solutions to previously intractable problems in food science and offers new approaches to the rational selection of raw materials, or the processing of such materials to enhance the quality of food products.

CONCLUSION AND FUTURE PROSPECTS

In the light of exponential increase in world population and the growing rate of environmental pollution from domestic and industrial indiscriminate release of chemicals to the environment, the development and application of nano-remediation strategy is needful and must be further explored. Several metal and metal oxides nanoparticles have biocidal activities on harmful microorganisms and biodegradative properties on chemicals such as dyes, pesticides and other pollutants. The “easy to handle, easy to recover” attributes of nanomaterials especially magnetic nanomaterials, provide a vast research potential for how nanotechnology would provide an easier, cheaper and effective means of saving our environment from imminent collapse due indiscriminate release of harmful substances that can lead to disease outbreak, global warning as a result of ozone depletion, poisoning from polluted water, agricultural products, etc.

With the rapid development of nanotechnology, it is predicted that new crucial technologies will arise successively in the future. The future of nanotechnology in computer science and even other fields of science is hinged on the development new systems capable of promoting and enhancing scientific revolution and evolution in world of research, development and technology. In the field of computer science, new quantum computers are being designed, which will allow all electronic systems like computers, storage devices, mobile phones, power, sensors, and artificial intelligent systems to fit onto a micro-chip. Miniaturization which is a concept of reduction in size, for convenience and ease of transportation, yet effective is the future of computer and other electronic gadgets. Such systems cannot be developed except suitable nano-functional materials are developed.

Generally, nanotechnology has presented many essential applications in many aspects of oil and gas operations and broad application prospects in oilfield exploration. Various collections of nano-sized materials such as metallic nanoparticles, metal oxide nanoparticles, carbon nanotubes, and magnetic nanoparticles have been widely used in various types of oil and gas operations. In the future, the oilfield development technologies have to be equipped with “objective orientation” and “complex function”, and nanomaterials provide the technical feasibility for it (Liu et al., 2016). For example, nano-molecular deposition film can be used to decrease the pressure and increase the injection rate of low-permeability oil reservoirs. Intelligent nano-fluid can be used for water plugging and profile control. Nano-particles can be used to improve drilling fluid behavior. Nano-catalyst and nano-filter membrane can be used for *in-situ* oil reservoir stimulation and late water treatment. Nano-coating can be used for engineering anti-corrosion.

In the future, nano medicine will benefit molecular nanotechnology. The medical area of nano science application has many projected benefits and is potentially valuable for all human races. With the help of nano medicine early detection and prevention, improved diagnosis, proper treatment and follow-up of diseases is possible. Certain nano scale particles are used as tags and labels, sensors capable of monitoring biological processes quickly (Figure 9), testing has become and will become more sensitive and more flexible. Gene sequencing will be more efficient with the invention and possible optimization of nano devices like gold nano particles, which if tagged with short segments of DNA can be used for detection of genetic sequence in a sample. With the help of nanotechnology, damaged tissue can be reproduced or repaired. The invention of nano-engineered artificially stimulated cells can be used in tissue engineering, which might revolutionize the transplantation of organs or artificial implants.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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