Advances and Applications in Mathematical Sciences
Volume 21, Issue 12, October 2022, Pages 7145-7156

MAJOR NOVEL APPLICATIONS OF NANOPARTICLES BASED TECHNOLOGY AND ITS IMPACT ON VARIOUS FIELD: A STUDY

IRAM KHAN and ANITA SHARMA

Research Scholar Associate Professor
Department of Chemistry
N.A.S College-250003
Affiliated to C.C.S University, Meerut
U.P. India
E-mail: iramkhan9014@gmail.com
anitasharma1519@gmail.com

Abstract

Nanotechnology is defined as an emerging technology because of its ability to design well established product and to manipulate and create new product with new characteristics and function with enormous potential in various application. In the field of nanotechnology demand of nanoparticles is increases due to its unique optical, electrical and mechanical quantum phenomenon. Engineered surfaces with tailored properties such as large surface area, specific reactivity and self-assemblage ability on support surface increased their demands in various field of applications. Nanomaterial with unique property such as Inorganic nanoparticles, Organic nanoparticles, Carbon-based nanoparticles allow completely novel applications to be found. This review is mainly focus on nanoparticle classification and its potential demand in the field of biology, medicine, agriculture, food, electronics, environment etc.

1. Introduction

Nanoparticles have obviously existed in the nature from a long time and therefore used by artisans, glassmaker and potter from prehistoric time in classical antiquity for example roman Lycurgus cup of dichroic glass (4th century). Later in 1857, Michael faraday provides first description about optical properties of Nano-scale metal. Within this range the particle

2020 Mathematics Subject Classification: 92E99.

Keywords: Nanotechnology, Nanoparticles, Agriculture, Electronics, Environment.
Received September 13, 2021; Accepted November 9, 2021

properties are significantly different from bulk material because of 2 factors; (i) quantum effect and (ii) increase in surface to volume ratio. As size of the nanoparticle decrease the number of particle on the surface increase in comparison to interior portion and it result into change in properties of nanoparticle such as increase in electrical conductivity, improved stability or reactivity in chemical reaction and enhanced mechanical strength [1]. Among these properties improved strength and hardness, increased electrical conductivity are very significant for textile, medicine, cosmetics, aerospace, food, agriculture and electronics and presently these being widely applied throughout these industries [2]. This review is mainly focus on different type of Nanoparticles used in various field of application such as chemistry, physics, biomedical, engineering, biology, medicine etc.

2. Major Novel Applications Application of Nanoparticle: Literature Review

2.1. In Biology or Medicine

The use of nanotechnology in the management of illness is known as nanomedicine. Living organism is a building block of cells that are typically (10um across) and a cell part which is smaller than the protein (5nm) is comparable with manmade nanoparticle [3]. A nanoparticle is used as a very narrow probe to observe cellular machinery without interfering with it. Nanoparticle utilization increased in the field of medicine due to its unique properties such as conductivity, optical sensitivity, reactivity due to controllable size and shape, superparamagnatism larger surface to mass ration, adsorption capacity to carry other compounds such protein, drug, probes and quantum properties [4]. Out of various properties of nanoparticle size dependent properties play a very important part in biological application. Various application of nanoparticle in medicine and biology are given below;

- **Fluorescent biological label:** Labeling of biomolecules is required for detection of genomics and medical diagnosis. Over the last 10 years quantum dots was also known as fluorescent semiconductor nanocrystal have been tested in biotechnological detection application such as cell and animal biology, immune fluorescent array, and DNA and protein array [5, 6].

- **Drug and gene delivery:** Drugs can be targeted precisely and immediately in the drug delivery mechanism. Nanostructured drugs or delivery system maintain drug level within desired range by release of continuous and controlled therapeutic drug [7]. A particle nucleus, a biocompatible protective layer, and a linker layer (usually have reactive group at both ends) for bioactivity, make up most nanoparticles used for drug delivery [8]. The basic knowledge require for selection of appropriate carrier as a drug delivery system involve incorporation and release of drug, shelf life and stability of drug, bio distribution of drug, biocompatibility and mode of action of drug [9]. Polymer, virus, dendrimers, liposomes, and gold NPs are among the various NP modality used for medication and gene delivering. There are two methods for genes delivering: (i) viral vector based gene delivery, (ii) Gene distribution using non-viral vectors. The most suitable vector for vaccination and gene therapy is a viral vector, which is a bionanoparticle with a diameter of 100nm or less. Non-Viral genes have less gene transfection than viral carrier. Many studies have studied retrovirus, adenovirus, and lentivirus gene transfers for vaccine purposes in the care of neurological disorders and cancer. Nanoparticles are appealing vectors for non-viral gene transmission. They've been studied for in vivo and in vitro gene transmission with great results [9].

- **MRI contrast enhancement:** Magnetic resonance imaging contrast agents have ability to perturbed local magnetic field around proton and alter relaxation time of proton. For example Fe Nps coated with inert polymer such as PEG act as MRI contrast agent [10].

- **As Anti-microbial agent:** Anti-microbial agent either kill microorganism or inhibit growth of microorganism by inhibiting the cell wall synthesis, enzyme activity, altering cell wall permeability and penetrating or interfering cell wall activity. Because of their small scale, strong dispersion, high surface to volume ratio, and ability to communicate with microbial surfaces, various nanoparticles such as Au, Ag, and Cu NPs are used as antimicrobial agents [11].

- **Tissue culture engineering:** The use of nanotechnology, such as carbon nanotube scaffolds, can be used to repair and reproduce damaged tissue [12]. Recently, bioactive glass ceramic (BGC) based nanoparticles is frequently used in regeneration of bone tissue for example chitosan gelatin hydrogel with BGC Nps showed 80% rate of bone formation due to increase in alkaline phosphate activity in compared to other mesophorous BGC Nps[13].

- **In cancer treatment:** In cancer therapy laser technique is used to destroyed tumor cell by atomic oxygen. Such molecular oxygen can destroy tumor cell efficiently and highly cytotoxic in nature. Porous nanoparticle is used to enclose the hydrophobic dye molecule in order to avoid adverse effects on normal cells [14].

Recently, doped metal/metal oxide and metal/metal nanoparticles enhanced its efficiency in biomedical efficiency. Antimicrobial properties of Ag nanoparticles improved against S. aureus, E. coli and C. albicans by doping Ag nanoparticle with carbon monolith [15]. Cu doped nanoparticles improved antimicrobial activity in the presence of reduced graphene oxide and also improved its advance inhibition zone and lesser value of least inhibitory concentration of gram-negative and gram positive bacteria in comparison to pure TiO2 [16].

2.2. In Agriculture and Food Science

Genetically modified foods, chemical pesticides, precision input techniques, and animal processing inputs are likely to facilitate and frame the next level of growth of agriculture through nanotechnology research and development [17]. By the production of chemical fertilizer and pesticide using Nano capsule and nanoparticle with the ability to control and delayed delivery, absorption, environment friendly nature nanotechnology helps agriculture science and reduce environment pollution [18]. Nanotechnology have many application in agriculture such as in precision farming which maximized output and minimize input, increase efficient fertilizers and pesticide, soil management, crop improvement, plant disease detection, analysis of gene expression and regulation, post-harvest technology, and water management using nanomaterial as Nano sensors, Nano pesticides, Nano fertilizer and Nano-biotechnology. Nano fertilizer increased stress tolerating power and nutrient efficiency (3 times) [19]. For example ZnO Nps improve enzyme dehydrogenase activity and also improve the yield parameter and growth of rice by overcoming the deficiency of zinc in soil [20]. Nano pesticide provide protection against abiotic-type stress, their main application include improved the stability and selectivity of the pesticide, encapsulation of pesticide for controlled release, reduce cost of pesticide and improve lifetime of the active organic compound [21]. Nano biotechnology will increase agriculture potential to harvest feed stock for industrial purpose. Nanoparticles have some unique properties like better bioavailability of molecule to the seed radicals, higher nanoparticle solubility *n* suspension, higher mobility, lower toxicity, higher surface area and particle size due to which nanotechnology have same advantage over conventional method of agriculture [22].

Nanotechnology improves the food product in term of texture, taste, nutrition value, shelf-life and taste. Nano-encapsulation protect food ingredient from moisture, degradation and heat during various stage of processing, manufacturing and storage for example encapsulation of inner cavity of recombinant soybean with cyanidine-3-0-glucoside improved thermal and photosensitivity [23]. SiO2 NPs act as carrier of flavor in food products because NPs improved bioavailability of nutraceuticals. Antimicrobial properties containing nanoparticles have been used as a safer food packaging. Nanotechnology's current uses in the agro-food chain are mostly based on nanosized food additives and ingredients, bioactive compound delivery systems, and food packaging. Nanomaterial incorporated food contact material improve packaging material such as temperature, moisture, stability, flexibility, gas barrier properties, flame resistant etc. food packaging incorporating with Nano sensor for signaling and sensing biochemical and microbial changes, release of antioxidant, enzyme, antimicrobial, nutraceuticals and flavor to extend shelf-life. Some example of food related nanoparticles are; nanosilver or nanogold are available in the form of mineral supplement. Nanoceuticles incorporated with Nanocages or nanoclusters is commonly used in the form of delivery vehicles. For example casein nanocapsules are used as a vehicle of neutraceuticles. Polylactic acids are common biodegradable nanoparticles used to encapsulate and transport micronutrients and drugs such as irons, proteins, and others. The use of nanotechnology in food production includes nanofrying and nanofiltration [24, 25].

2.3. In Electronics and Semiconductor

Approaching the size of few tens of nanometer is the basic unit of today fabricated integrated circuit and storage media i.e. microelectronic industries. For computer smaller size along with high computational power at low cost and higher portability limit the capability of silicon based electronic industry. Carbon nanotubes have properties similar to silicon transistors and thus they act as a semiconductor and are being suitable as transistor for computer chips. CNTs has a potential to make new generation electronic device which that make use of less energy and run faster in comparison to silicon chips [26]. One of the examples of computational nanotechnology is Nano design. A Nano design (system software) developed by NASA for the investigation of designing molecular machine and fullerene nanotechnology [27].

A semiconducting material CdS has gained lots of attention because its direct band gap is developed in the emission of visible wavelength. CdS used in various optoelectronic applications such photo catalyst, solar cell windows, sensors, light emitting diode [28]. Single electron transistors because of its properties small size, faster rate, sensitive charge management and low energy consumption hold a great importance in nanotechnology [29].

2.4. In Environmental Remediation

Today, pollution of the environment is one of the major issues facing the world. Now, new technologies for contaminant remediation of water, soil, and air are continuously being researched in biotechnology. Remediation means to correct something that has been deficient or corrupted. Bio-remediation means to degrade the contaminants present in the environment into less toxic forms with the help of a variety of biological agent's as protists, fungi bacteria or their enzyme [30]. Nanomaterial at Nano scale have large surface area per unit mass which result large amount of material come in contact of surrounding material, hence reactivity increase. NPs can be used for toxic material detection because it also exhibit surface Plasmon resonance phenomenon. Since nanomaterials exhibit quantum effects, less activation energy is needed to render a chemical reaction feasible. The size and shape of NMs, such as bimetallic nanoparticles and carbon-based nanomaterials, can be used to clean up the atmosphere, because of nanoparticle's penetration or diffusing force into a contaminant region and higher reactivity to redox amenable pollutants such as fe^0 coated with oxide and carbon tetrachloride shape a weak and outer sphere complex, single NPs may be used [31]. The usage of nanoparticles for environmental remediation is growing due to their versatility in ex-situ and in-situ applications in aqueous systems [32]. Now with the support of several microorganisms, nanobioremediation is described as the degradation of organic contaminants using nanocatalysts as a medium that allows them to penetrate deep inside pollutants and manage them safely without affecting the ecosystem [33]. The main advantages of using these nanobioremediation technologies are that they are highly skilled, that they can be selected for specific metals, that they do not need any special dietary requirements, and that there is a chance of metal recovery. Different nanomaterials include oxide nanomaterials, carbon nanomaterials, polymer nanomaterials, nanocomposites, and biological nanomaterials [34].

Due to their characterized non-toxicity, low-cost, semiconducting, gas detecting, energy converting, and photo catalytic properties, TiO_2 NPs are being extensively researched for self-cleaning of surfaces, as a photo catalyst in water treatment, air purification, and waste treatment applications [35, 36]. Heavy metals such as Cu^{2+} Ni^{2+}, Cd^{2+}, and Zn^{2+}, as well as chlorinated organic solvents, are removed using iron and iron oxide NPs [37, 38]. It has been reported that scavenging of chromium from soil are very efficiently done by zerovalent iron Fe^0 nanoparticles. Utilization of zerovalent iron particle reduces the chlorinated hydrocarbon and metal toxicity when it is used for decontamination of ground water [39, 40]. The usage of amine-surface-modified silica xerogel and mesoporous silica (MCM-48) for CO_2 and H2S separation from natural gas has been recorded. Mesoporous silica has a number of advantages, including a lot of surface space, a lot of pore depth, tunable pore scale, and easy surface adjustment. Chemical dyes are often removed from wastewater using silica [41].” Carbon nanotubes are used in the production of Li-ion battery conductive electrodes [42].

2.5. In Textile and Clothing

Nanotechnology improves the performance of textile materials and mainly focused on using Nano size substance and producing nanostructure during manufacturing and finishing processes. The materials produced by this technology are more durable, lighter weight, sieve like, stronger and conductive [43]. Metal oxide nanoparticles, Nano silicate, graphite Nano fiber also utilized as filler in Nano composite fibers. SiO_2 increase fiber durability, self-cleaning, water/dirt repellant, control fragrance and make that antibacterial [44]. Metallic oxide and Semi-conductor ceramics is used as Nano-finish in textile to get specific properties such as anti-microbial, oil repellency, thermal resistivity, water repellency and flame retardency. Many Nano fibers membrane such as Polyacrylonitrile, polyvinylchloride and cellulose incorporated with Ag nanoparticle possess antimicrobial properties [45]. TiO_2, ZnO and MgO Nps protect nylon fiber from UV light, reduce static electricity and provide self-sterilizing function because it has electrical conductivity, photo-oxidizing capability against chemical and biological organisms, photo-catalytic efficiency, and UV absorption capabilities. Carbon Nano fibers improve composite fiber tensile strength whereas Carbon black nanoparticles improve toughness and abrasive resistance because both possess electrical conductivity and high chemical resistance [46].

3. Conclusions

This review, give a brief overview about different type of nanoparticles such as metal NPs, Carbon nanotube, Quantum dots, organic nanoparticle, inorganic nanoparticle in the various fields of medicine, agriculture, food, electronics, environmental bionaoremediation, textiles etc. The materials produced by this technology are more durable, lighter weight, sieve like, stronger and conductive. Nano composite fibers are rigorously used in military field, automobile and in aerospace. Metal oxide nanoparticles, Nano silicate, graphite Nano fiber also utilized as filler in Nano composite fibers. SiO_2 increase fiber durability, self-cleaning, water repellant, control fragrance and make that antibacterial. Hence it would suggest that nanoparticles having greater futuristic problem solving scope, help to enhance our infrastructure in a systematic way. The research is continuously going on, to see what a new achievement in favour of nanoparticles.

References

[1] C. P. Poole and F. J. Owen, Introduction to Nanotechnology, Hoboken, NJ: Wiley and Sons Inc., 2003.

[2] J. Kreuter, Nanoparticles In: Colloidal Drug Delivery Systems, Marcel Dekker Inc., New York, USA, 219-342, 1994.

[3] Y. Wang and Y. Xia, Bottom-Up and Top-Down Approach to the Synthesis of Monodispersed Spherical Colloids of Low Melting-Point Metals, Nano Lett. 4(10) (2004), 2047-2050.

[4] Xiaoli Wu, Han Yang, Weitao Yang, Xingmeng Chen, Junxiao Gao, Xiaoqun Gong Hanjie Wang Yue Duan, Daohe Wei and Jin Chang, Nanoparticle-based diagnostic and therapeutic systems for brain tumours, J. Mater. Chem. B, 7 (2019), 4734-4750. DOI: https://doi.org/10.1039/C9TB00860H

[5] C. Jin, K. Wang, A. Oppong-Gyebi and J. Hu, Application of Nanotechnology in Cancer Diagnosis and Therapy - A Mini-Review, Int. J Med Sci. 17(18) (2020), 2964-2973. DOI: 10.7150/ijms.49801

[6] Maura C. Belanger, Meng Zhuang, Alexander G. Ball, Kristen H. Richey, Christopher A. DeRosa, Cassandra L. Fraser and Rebecca R. Pompano, Labelling primary immune cells using bright blue fluorescent nanoparticles, Biomater Sci. 8 (2020), 1897-1909. DOI: https://doi.org/10.1039/C9BM01572H

[7] Y. Deng, X. Zhang, H. Shen, Q. He, Z. Wu, W. Liao and M. Yuan, Application of the Nano-Drug Delivery System in Treatment of Cardiovascular Diseases, Front. Bioeng. Biotechnol 7 (2020), 489. DOI: 10.3389/fbioe.2019.00489

[8] P. Trucillo, Drug Carriers: Classification, Administration, Release Profiles, and Industrial Approach, Processes 9 (2021), 470. DOI: https://doi.org/10.3390/pr9030470

[9] S. Jin and K. Ye, Nanoparticle-mediated drug delivery and gene therapy, Biotechnology Progress 23(1) (2007), 32-41. DOI: 10.1021/bp060348j

[10] C. G. Hadjipanayis, M. J. Bonder, S. Balakrishnan, X. Wang, H. Ma and G. C. Hadjipanayis, Metallic Iron Nanoparticle for MRI Contrast Enhancement and Local Hypothermia, NIH Public Access 4(11) (2008), 1925-1929. DOI:10.1002/smll.200800261.

[11] F. Regan, J. Chapman and T. Sullivan, Nanoparticle in Anti-Microbial Material Use and Characterization RSC Nanoscience and Nanotechnology 23 (2012), 159-1. ISBN:978-1-84973-DOI: https://doi.org/10.1039/9781849735261

[12] A. K. Bigdeli, S. Lyer, R. Detsch, A. R. Boccaccini, J. P. Beier, U. Kneser, R. E. Horch and A. Arkudas Nanotechnology In Tissue Engineering Nanotechnology Reviews 2(4) (2013) 411-425. DOI: https://doi.org/10.1515/ntrev-2013-0015.

[13] I. Roy, T. Y. Ohulchanksy, H. E. Pudavar, E. J. Bergey, A. R. Oseroff, J. Morgan, T. J. Dougharty and P. N. Prasad, Ceramic Based Nanoparticles Entrapping Water-Insoluble Photosensitizing Anticancer Drugs: A Novel Drug-Carrier System For Photodyanamic Therapy, J. Am. Chem. Soc. 125 (2003) 7860-7865. DOI: http://doi.org/10.1021/ja0343095

[14] C. Covarrubias, M. Cadiz, M. Maureira, I. Celhay, F. Cuadra and A. Von Marttens, Biocomposite Scaffolds based on Chitosan-gelatin and nanodimensional bioactive glass particles: in vitro ptoperties and in vivo bone regeneration, J. Biomater. Appl. 32 (2018), 115-1163. DOI:10.1177/0885328218759042

[15] F. S. Arakawa, Q. L. Shimabuku-Biadola, M. Fernande Silva and R. Bergamasco, Development of a new vaccum impregnation method at room atmosphere to produce silver –copper oxide nanoparticles on activated carbon for antibacterial applications. Environ. Technol. 1 (2019) 1-12. DOI:10.1080/09593330.2019.1567607

[16] M. Dhanasekar, V. Jenefer, R. B. Nambiar, S. G. Babu, S. P. Selvam, B. Neppolian, et al., Ambient light antimicrobial activity of reduced graphene oxide supported metal doped TiO_2 nanoparticles and their PVA based polymer nanocomposite films, Mater. Res. Bull. 97 (2018), 238-243. DOI: 10.1016/j.materresbull.2017.08.056

[17] D. Mittal, G. Kaur, P. Singh, K. Yadav and S. A. Ali, Nanoparticle-Based Sustainable Agriculture and Food Science: Recent Advances and Future Outlook, Front, Nanotechnol 2 (2020), 579954. DOI: 10.3389/fnano.2020.579954

[18] Muhammad Usman, Muhammad Farooq, Abdul Wakeel, Ahmad Nawaz, Sardar Alam Cheema, Hafeez ur Rehman, Imran Ashraf and Muhammad Sanaullah, Nanotechnology in agriculture: current status, challenges and future opportunities, Science Total Environment 721 (2020), 137778. DOI: 10.1016/j.scitotenv.2020.137778

[19] W. F. Abobatta, Nanotechnology Application in Agriculture Acta Scientific Agriculture (2018), 99-102.

[20] M. Pascolli, P.J. Lopes-Oliveira, L. F. Fraceto, A. B. Seabra, H. C. Oliveria, State the art of polymeric nanoparticles as carrier systems with agriculture application: A minireview, Energy Ecol. Environment 3 (2018), 137-148. DOI: https://doi.org/10.1007/s40974-018-0090-2

[21] R. Bala, A. Kalia, S. S. Dhaliwal, Evaluation of Efficacy of ZnO Nanoparticles as Remedial Zinc Nanofertilizer for rice, J. Soil Sci. Plant Nutr. 19 (2019), 379-389. DOI: https://doi.org/10.1007/s42729-019-00040-z

[22] S. B. Manjunatha, D. P. Biradar and Y. R. Aladakatti, Nanotechnology and its Applications in Agriculture: A Review J. Farm Sci. 29(1) (2016), 1-13.

[23] K. Nakagawa, Nano- and Micro- Encapsulation of Flavor in Food System in nano- and microencapsulation for foods, Chap.10, ed. H.-S. Kwak (Oxford: John Wiley and Sons), (2014), 249-272. DOI:10.1002/9781118292327.ch10

[24] T. Zhang, C. Lv, L. Chen, G. Bai, G. Zhao and C. Xu, Encapsulation of anthocyanin molecule within ferritin nanocage increase the stability and cell uptake efficiency, Food Res. Int. 62 (2014), 183-192. DOI:10.1016/j.foodres.2014.02.041

[25] N. Pradhan, S. Singh, N. Ojha, A Shrivastava, A. Barla, V. Rai and S. Bose, Facet of Nanotechology as Seen in Food Processing, Packaging, and Preservation Industry BioMed Research International, Article ID 365672 (2015), 17. DOI: https://doi.org/10.1155/2015/365672

[26] M. A. Subhan, K. P. Choudhury and N. Neogi, Advances with Molecular Nanomaterials in Industrial Manufacturing Applications, Nanomanufacturing 1 (2021), 75-97. DOI: https://doi.org/ 10.3390/nanomanufacturing1020008.

[27] B. Kaewkamnerdpong and P. J. Bentley, Computer Science for Nanotechnology: Needs and Oppurtunities Department of Computer Science University College London U.K.

[28] S. Kumar and J. K. Sharma, Stable Phase Cds Nanoparticles for Optoelectronics: A study on Surface Morphology, Structural and Optical Characterization Material Science-Poland 34(2) (2016), DOI: 10.1515/msp-2016-0033.

[29] Coronado, A Review of Quantum Wires and Dots in Nanotechnology 2605672 EEE-5425, Introduction to nanotechnology Spring, (2013).

[30] A. Thenmozhi and M. Devasena, Remediation of 2, 4, 6-trinitrotoluene Persistent in the Environment – A review, Soil and Sediment Contamination: An International Journal, 29(1) (2020), 1-13. DOI: 10.1080/15320383.2019.1664394

[31] J. T. Nurmi, et al., Characterization and Properties of Metallic Iron Nanoparticles: Spectroscopy, Electrochemistry, and Kinetics, Environmental Science and Technology, 39(5) (2005), 1221-1230. DOI: https://doi.org/10.1021/es049190u

[32] S. Das, B. Sen, N. Debnath, Recent Trends in Nanomaterials Applications in Environmental Monitoring and Remediation. Environ Sci. Pollut. Res. 22 (2015), 18333-18344. DOI:10.117/s11356-015-5491-6.

[33] M. Rizwan, M. Singh, C. K. Mitra and R. K. Morve, Ecofriendly application of nanomaterials: Nanobioremediation, J. Nanoparticles (2014), 1-7. DOI: https://doi.org/10.1155/2014/431787

[34] J. C. Sousa, K. K. Yadav, J. K. Singh, N. Gupta and V. A. Kumar, A review of nanobioremediation technologies for environmental cleanup: A novel biological approach. J. Mater. Environ. Sci. 8 (2017) 740-757. http://www.jmaterenvironsci.com

[35] K. Jain, A. S. Patel, V. P. Pardhi, S. J. S. Flora, Nanotechnology in Wastewater Management: A New Paradigm Towards Wastewater Treatment, Molecules 26 (2021), 1797. DOI: https://doi.org/10.3390/ molecules26061797

[36] A. A. Adesine, Industrial Exploitation of Photocatalysis: Progress, Perspective and Prospects, Catal. Surv. Asia. 8 (2004), 265-273. DOI: 10.1007/s10563-004-9117-0.

[37] S. E. Ebrahim, A. H. Sulaymon and H. Saad Alhares, Competitive Removal of Cu^{2+}, Zn^{2+}, Cd^{2+} And Ni^{2+} Ions onto Iron Oxide Nanoparticles from Wastewater, Desalin. Water Treat 57 (2016), 20915-20929. DOI: 10.1080/19443994.2015.1112310

[38] M. Guo, X. Weng and Chen Z. Wang, Biosynthesized Iron-Based Nanoparticles Used as a Heterogeneous Catalyst For The Removal of 2,4-Dichlorophenol, Sep. Purif. Technol. 175 (2017), 222-228. DOI:10.1016/j.seppur.2016.11.042

[39] R. Singh, V. Mishra and R. P. Singh, Synthesis, Characterization and Role of Zero-valent Iron Nanoparticle in the Removal of Hexavalent Chromium from Chromium-spiked soil J. Nanopart Res 13 (2011), 4063-4073. DOI: https://doi.org/10.1007/s11051-011-0350-y

[40] W. A. Arnold, A. L. Roberts, Pathways and Kinetics of Chlorinated Ethylene and Chlorinated Acetylene Reaction with Fe (0) Particles Environ Sci. Technol. 34(9) (2000), 1794-1805. DOI: https://doi.org/10.1021/es990884q

[41] H. Y. Huang, R. T. Yang, D. Chinn and C. L. Munson, Amine-Grafted MCM-48 and Silica Xerogel as Superior Sorbents for Acidic Gas Removal from Natural Gas. Ind. Eng. Chem. Res. 42(2003), 2427-2433. DOI:10.1021/ie020440u

[42] C. H. Tsai, W. C. Chang, D. Saikia, C. E. Wu and H. M. Kao, Functionalization of Cubic Mesoporous Silica SBA-16 with Carboxylic Acid via One-Pot Synthesis Route for Effective Removal of Cationic Dyes J. Hazard. Mater. 309 (2016), 236-248. DOI:10.1016/j.jhazmat.2015.08.051

[43] M. Trivedi, and Reecha, Recent development and applications of carbon nanotubes, Chem. Sci. Rev. Lett. 9(33) (2020), 1-5. DOI:10.37273/chesci.CS20510188

[44] C. Ngo and M. H. Van de Voorde, Nanotechnology for the textile Industry, In Nanotechnology in a Nutshell Atlantis Press. (2014), 321-329.

[45] M. Haque, Nano Fabrics in the 21st Century: A Review Asian J. Nanoscience and Material, (2019). Doi:10.26655/AJNANOMAT.2019.3.2

[46] B. S. Hassan, G. M. N. Islam and A. N. M. A. Haque, Application of Nanotechnology in Textiles: A Review, Adv. Res. Text Eng. 4(2) (2019), 1038.