REVIEW ARTICLE

A Review on Harnessing Nanomaterials as Promising Materials Interface

Bindu Mangla[1,], Vitashi Kaul[1], Nitika Thakur[2], Sudheesh K. Shukla[3]*

Nanoparticles (NPs) are strong colloidal particles with diameters ranging from 1nm–100 nm. They comprise of macromolecular materials and can be utilized therapeutically as adjuvant in immunizations or as medication transporters. In this paper two fundamental sorts of nanoparticles are discussed i.e., metallic nanoparticle and polymeric nanoparticle. Metallic nanoparticle is nano-sized metals with measurements (length, width, thickness) inside the size range of 1nm - 100nm. The properties, advantages, disadvantages and characteristics of metal nanomaterials are discussed in brief in this review. Polymers are the most common materials for constructing nanoparticle-based drug carriers. Polymers used to form nanoparticles can be both synthetic and natural polymers. This review summarizes the synthesis and fabrication of nanomaterials. It describes about synthesis of metallic and polymeric nanomaterials as well as synthesis of quantum dots. It gives insights of fabrication of nanomaterials. Applications of nanomaterials are also included in this review mainly focusing on biosensor, gas sensor, wastewater treatment and environmental applications. The tunable surface and optical properties of nanomaterials make the perfect contender for biosensing including the analysis of ailments, cellular imaging of cancerous cell and so on. Gas sensors have been utilized in numerous applications like monitoring the oxygen content in fuel mixture, observing food decay, health monitoring etc. Nanomaterials offer the potential for the productive expulsion of pollutants and biological contaminants thus extremely valuable in environment and wastewater treatment. Nanomaterials are highly recommended in future for these properties, mainly for their use in healthcare sector.

Introduction

The field of new discoveries and investigations perturbed with enhancing things, mostly materials and gadgets on the scale of atoms and molecules is known as nanotechnology. Nanotechnology (or "nanotech") is the manipulation of matter on an atomic, molecular, and supramolecular scale. It is the science and technology escorted at the nanoscale of about 1 to 100 nanometers. Nanostructure is molded into some useful nanoscale devices and this is known as nanotechnology [**1**]. The concept of Nanotechnology was first discussed in 1959 by renowned physicist Richard Feynman in his talk, *"There's plenty of Room at the Bottom"*. The history of nanotechnology is based on the experiments and concepts; however, nanotechnology is latest development in scientific research; the concepts related to it have been discovered long ago. The idea initially emerged in the 1980's due to the process of experimental advances namely scanning tunneling microscope in 1981 and the discovery of fullerenes in 1985, followed by the publication of the book *"Engines of creation"* in the year 1986. The early 2000's saw the emergence of commercial applications of nanotechnology. It included the bulk of applications of nanomaterials instead of transformative applications [**2,3**]. Science and technology always come up with new and upgraded devices that are replaced by the earlier automations. There are several possible applications of nanotechnology that have been conceptualized by technology predictors and now become scientific facts [**3**].

The basic concept of Nanotechnology involves creation of building blocks of materials from the lowest level to the top and from the top to the down level to explore the possibility of utilization of the technique in various fields. The areas, which are strongly influenced by nanotechnology, are medicine, electronics, communication, architectural industries, military and many more. Nanotechnology also finds application in forensic

[1]Department of Chemistry, J.C. Bose University of Science and Technology YMCA, Faridabad, India
[2]Department of Biotechnology, Shoolini University of Biotechnology and Management Sciences, Bajhol, Solan, Himachal Pradesh, India
[3]Institute of Advanced Materials, IAAM, Gammalkilsvägen 18, Ulrika 59053, Sweden

*Corresponding author:
E-mail: bindumangla@gmail.com

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investigations that are chemical studies and biological analysis. Other major applications include the impact on the products like paints, catalysis process, plastics, sunscreens, bathroom and window cleaners, and polishing powders and so on [**3**].

Nanomaterials: A journey from Macro to nanoscale

Nanomaterials are the linchpin of nanotechnology. Nanostructure science and technology has the feasible, unutilized quality for entirely changing the ways in which materials and products are made come into existence and the range and nature of workings that can be propelled. Nanoscale materials are formed as a put up of substances where at least one measure is less than approximately 100 nanometers. Nanomaterials are of intrigue on the grounds that at this scale exceptional optical, magnetic, electrical and different properties develop. These rising properties have the potential for extraordinary effects in gadgets, medication, and various different fields. The electrons of nanomaterials are restricted to flow in a definite number of dimensions, which causes nanomaterials to exist in different dimensions [**4**].

Different types of Nano dimensions

2D Nanomaterials

a) Uni-atomic 2D materials

A number of Uni-atomic 2D materials are found, for instance, germanene, stanene, silicene, phosphorene and graphene made up of germanium, tin, silicon, phosphorous and carbon respectively. Among all these, graphene is the most common and convenient material, which is in close proximity to commercialization. Magnificent assembly of optical, physical and electrical attribute is owned by graphene and some other 2D atomic materials, which allow them to be utilitarian for extended applications [**5, 6**].

1D nanomaterials

a) Nanotubes

Nanotubes are broadened in one dimension, with a length to diameter ratio of 132,000,000:1. Nanotubes govern electrons next to the widened axis and are found in numerous forms inclusive of single-walled Nanotubes (SWNT), multi-walled Nanotubes (MWNT), chiral nanotubes, armchair nanotubes and zigzag nanotubes. A lot of hype was taken into account about how one can use carbon nanotubes in various applications but the issues with strewn and aligning carbon nanotubes guide them to go out of commendation for a while. Lately, they have been making a renewal due to refutation of many of these issues [**5,6**].

b) Nanowires

Nanowires, also called quantum wires, are the popular 1D material that is extended in one direction, though it has a lower width to length ratio of 1:1000. The most usual Nanowires are silver Nanowires that are highly electrically conductive. Nanowires manifest various distinct quantum effects, which beside their unidirectional electron movement make them excellent materials for various electronic applications [**5,6**].

0D nanomaterials

a) Quantum dots

In quantum dots, electrons are constricted in all 3-dimensions and it is a very well known and convenient nanoparticle. Quantum dots are tiny semiconducting particle and have been considerably used in displays and solar cells. When either light or electricity comes across quantum dots, they tend to emit a definite wavelength. Cadmium containing quantum dots, for instance cadmium selenide (CdSe), is one of the broad classes of quantum dots [**5,6**].

b) Fullerenes

Fullerenes, or else known as Buckminster fullerenes, have two forms: pure carbon and endohedral. The solitary differentiation is being, endohedral fullerenes include additional atom(s) inside the carbon fullerene. Fullerenes have distinct shapes and sizes, C_{60} being the basic. It is the most dynamically and anatomically stable form. Single, as well as double bonds organized into pentagons and hexagons, make up carbon fullerenes. The shape of fullerenes is due to the 12 pentagons and a different number of hexagons in it [**5,6**].

Altogether, nanomaterials are found in various forms. Among all of them, the well known are:

- Single element nanoparticles, such as gold and silver nanoparticles used in medical imaging, optoelectronics, catalysis, food packaging, textiles, clothing, and other materials to eliminate bacteria.
- Metal oxide nanoparticle, for instance titanium dioxide nanoparticles used in various products. Based on the type of particle it is found in sunscreens, cosmetics, paints and coatings. Moreover, it can be used in eliminating contaminations from drinking water [**5,6**].
- Amphiphilic nanoparticle, such as Janus nanoparticles used as stabilizers in emulsion polymerization. Janus particles permit two contrasting types of chemistry to transpire on same particle. The two surfaces of Janus particle vary on their hydrophobicity or hydrophilicity, external receptors, surface charge, and also in their magnetism [**7**].

Metallic nanomaterials

Metallic nanomaterials have undergone much admiration because of its unvarying size. Being a nano-sized particle, its size varies from 10-100 nm with a distinctive attribute such as Plasmon resonance and optical properties. Faraday first observed the extent of metallic nanomaterials in a solution in 1857 and Mie in 1908 gave the quantitative description of their color. During middle ages, metallic nanoparticles were used in embellishing cathedral windows. Metallic nanoparticles escorted by relevant functional groups have a forte that it can be synthesized and altered and this will allow metallic nanoparticles to bind with ligands, antibodies and drugs. Growth of gram–positive and gram–negative bacteria is mired by silver and gold nanoparticles. Selective and extremely vital catalysts are used in metallic nanoparticles and they have a long lifetime for various chemical reactions. Metallic nanoparticles have strong plasma absorption, ameliorate Rayleigh scattering and give surface enriched Raman Scattering and hence find variety of application because of such advantageous properties over other materials. Chemical information determined can be on metallic nanoscale [**8**].

However, a few of their properties are really a matter of concern prior to their applications. Some of such properties are as follows:

- ✓ Nanomaterials being thermodynamically unstable undergo transformation and recline in the area of high-energy local minima that worsens the quality and causes deficient corrosion resistance.
- ✓ Holding on to the structure becomes arduous.
- ✓ Formation of nitrides and oxides can exasperate from the adulterated environment during synthesis of nanoparticles.
- ✓ Nanoparticles being extremely reactive, there will be excessive chance of impurity.
- ✓ Nanomaterials are found to be poisonous, carcinogenic and cause infuriation and become transparent to the cell dermis.
- ✓ Fine metal particles being powerful explosive, exothermic combustion can lead to explosion [**9**].

Metallic nanoparticles can be used as efficacious catalysts if ranged between 1 to 10 nm in size. The ratio of surface atoms is inversely proportional to its particle size. Metallic nanoparticles, when used as a catalyst, needs to be sustained under the catalytic conditions else it will effortlessly solidify in solution and forms an aggregate which are less compelling as a catalyst.

However, benefits of utilizing metallic nanoparticles as catalyst can be summarized as follows:

- ✓ The temperature put into the catalyst, where the metallic nanoparticles is scattered in the solution, is less than the boiling point of solvent.
- ✓ Being transparent to light, scattered metallic nanoparticles are used as photo catalysts.
- ✓ Metallic nanoparticles size and shape is effortlessly managed by the preparation.
- ✓ Metallic nanoparticles disabled on solid support acts as catalyst also for the reaction in gaseous state.
- ✓ By adjusting the structures and compositions of nanoparticles, bimetallic and trimetallic nanoparticles can also be prepared.

a) Stabilization of metallic nanoparticles

It is important to stabilize the metallic nanoparticles for contiguous confinement of the particles in nano range. This can be attained either by electrostatic stabilization or by steric stabilization by using a capping agent like surfactant, polymer, solid support or ligand with worthy functional group.

Electrostatic Stabilization has many advantageous points like uniform surface charge density, unchanged electric potential and infinite flat solid surface. It explains the interaction among two approaching particles that are electrically charged and therefore universally welcomed in the research community of colloidal science. However, this technique is associated with some weaknesses also like it is kinetically stabilization method and relevant to dilute system only. It is not pertinent to electrolyte sensitive systems and arduous to apply to multiple phase systems, as different solids develop different surface charge and electric potential. Steric Stabilization also called as polymeric stabilization has lead over electrostatic stabilization since it is not electrolyte sensitive and hence worth applicable for multiple phase system. Steric stabilization being a thermodynamic method, particles is always re-dispersible and by binding of polymer to the particle surface, steric stabilization is attained [**10**].

Polymeric nanomaterials

Polymers are the standard materials for creating nanoparticle-based drug carriers. In 1979, they were used for cancer therapy during the research for adsorption of anticancer drugs to polyalkylcyanoacrylate nanoparticles [**11**]. Polymers, either synthetic or natural, both types are utilized to form nanoparticles [**12**]. These nano-carriers have been verified for a wide scope of applications such as imaging, drug delivery, and apoptosis detection [**11**]. A study for several cationic polymers is carried out both *in vitro* and *in vivo* for the delivery of genes [**13**]. The DNA summarized in polymers might be in a dense or non-consolidated structure according to the idea of the polymer and the procedure of vector system formulation [**14**]. Plasmid DNA can be discharged into the cytosol using Polymer degradation [**13**]. Effective non-viral gene delivery subject to cationic polymers as DNA consolidating agents relies upon various factors such as complex size & stability, immunogenicity, toxicity, protection against DNAs debasement and intracellular trafficking and DNA processing [**15**]. There were various polymers utilized in the conveyance of strong particulate vaccine [**16**]. The immunization antigen is either kept typified or beautified against the surface of the nanoparticles. With the essence of antigenic material, a strategy for antigens delivery can be provided by nanoparticles, which may then diminish rapidly upon infusion or actuate a brief localized immune response. Conjugated antigens with nanoparticles can help present immunogen to the insusceptible framework simply like pathogen present in it, thus generating a similar response [**17**].

a) Polymeric Nanoparticles in Vaccine Delivery

Polymer nanoparticles or microparticles have applied explicitly to deliver genes in immunization structure (e.g., DNA antibodies). Furthermore, gene therapy can astoundingly help patients in various ailment conditions [**18**]. Numerous strategies can be utilized for malignancy gene therapy. Immunomodulation, Prodrug activation, Anti-sense/ RNAi and Induction of apoptosis are some of the strategies to kill or encumber developing malignant growth cells. Polycations-based synthetic vectors are best for gene delivery due to being protected and prepared to modify by the blend of ligands for targeting to precise cell types. Though, the gene articulation levels facilitated by synthetic vectors are low when contrasted with viral vectors [**19**]. There are four conditions remembered for an ideal gene vector is supposed to have effective buildup of DNA, stability in body liquid, ability to target explicit cells and ability to cross membranes and discharge productively. Methodologies to overcome a portion of these obstacles have brought polymer/DNA complexes with improved strength and conveyance skills.

The polyplexes created between cationic polymers and DNA through electrostatic associations; otherwise called polycation/DNA complexes are extensively utilized as non-viral gene delivery vectors. Numerous elements are responsible for influencing gene transfection productivity of cationic polymers such as surface charge, charge density, molecular weight (MW), hydrophilicity, and the structure of cationic polymers. So, enhancing cationic polymers is expected to grow the gene transfection efficiency. Presently, various significant cationic polymers had been utilized for gene delivery such as PLL, Polyethyleneimine (PEI), Chitosan, and PAMAM. A few techniques like PEGylation, blend, and multifunctional modification have been created in the cationic polymeric vectors [**20**]. Doyens are likewise creating biodegradable polymers such as poly (lactic-*co*-glycolic acid) (PLGA) for matrix antigen conveyance. M-cells quickly take up PLGA microspheres and translocate them towards the primary lymphatic tissue within an hour. Acid hydrolytic degradation products can constrain the utilization of PLGA, as they are destructive to the protein and loss of immunogenicity on storage. Additionally, organic solvents that heap the antigen on the polymer can be harmful to the antigen [**16**]. DNA detailing into both liposomal and polymeric cationic nanoparticles entirely blocks immunization actuated antigen articulation in mice and ex vivo human skin. Besides, this negative impact of cationic nanoparticle formulation is identified with a complete block in antibody immunogenicity. According to the reports, surface charge shielding of the nanoparticles by PEGylation advances in vivo antigen articulation above 55-fold. Moreover, these shielding causes' antigen-explicit T-cell responses like those instigated by naked DNA for both lipoplex and polyplex DNA carrier systems. According to the perceptions, dermally immunization formulations are created utilizing a procedure formed by charge shielding [**21**].

b) Polymeric nanoparticles in clinical trials

Currently, the polymeric materials' utilization to deliver DNA immunization responses appears hopeful. Using accessible polymers such as PLGA, chitosan, and PEI is by all accounts effective in pre-clinical and clinical investigations. Polymers such as POEs, PAMAMs, and PBAEs have demonstrated competent strategies for DNA antibody delivery. Scientists have additionally contemplated the improvement of oral bioavailability of various other remedial peptides utilizing exemplification polymeric nanoparticles. Vaccination with DNA encoding HLA-A2-confined epitopes from the HPV16 E7 protein, typified in biodegradable polymer microparticles, could actuate HPV-explicit T-cell reactions in 10/12 patients, which were as yet raised after 6 months [**22**]. Nowadays, antibodies are undoubtedly the best applications for oral delivery of nanoparticles. Certainly, immunological incitement need not bother with a portion as high as those mandatory for acquiring a pharmacologic impact and control of time-release profile could be less critical. Additionally, human clinical trials are being done for different nanoparticles siRNA treatments to gauge their adequacy and wellbeing. Since the RNAi was initially discovered, there have been over 30 clinical preliminaries assessing the capability of siRNA as a novel therapeutic.

Alternatives of natural or synthetic polymers

Natural polymers specifically albumin, chitosan, and heparin are utilized for the conveyance of DNA, protein, oligonucleotides and drugs. Different research studies are concentrating on the usage of conjugated polymeric nanoparticles with chemotherapeutic medications to reduce the dreadful impact of the free drug organization. Polymeric nanoparticles have picked up consideration due to being biodegradable and their capacity to convey drugs [**18**]. Chitosan is a predominantly examined polymer amid other accessible cationic water-dissolvable polymers [**12**]. The attention on utilizing nanoparticles in cell culture is increasing with more examination. Chitosan is notably low toxic than poly-l-lysine and PEI [**12**]. For therapeutic applications, medications can either be incorporated in the matrix of the particle or anchored to the particle surface. Control of a medication targeting system is required to determine the possibility of a drug entering the biological environment [**23**]. Chitosan microsphere are likewise useful in novel drug delivery systems like GI-delivery systems, ophthalmic drug delivery, colon and intestinal drug delivery, nasal and transdermal drug delivery, oral, buccal and sublingual drug delivery, plus vaginal drug delivery. The discharge energy of stacked medications from polymeric nanoparticles can be constrained by structural changes to the copolymer. This class of nanoparticles can be set up from scope of polymers counting poly (α-hydroxy acids), poly (amino acids), or polysaccharides to generate a vesicle, which can either oblige or show antigens [**17**]. Usually, chitosan has some perfect properties of polymeric transporters for nanoparticles like biocompatible, biodegradable, nontoxic, and modest. Besides, it owns positive charge and exhibits absorption-intensifying outcome [**12**]. A polyphenolic compound, namely, curcumin, found in the spice turmeric, employs preventive and therapeutic impacts in various cancers [**24**]. Lately, the polymeric nanoparticle epitomized curcumin (nanocurcumin) is under progress for malignancy treatment and furthermore to defeat these challenge. Curcumin stacked biodegradable self-amassed polymeric micelles have been created to beat poor water solubility of curcumin and to meet the prerequisite of intravenous administration. In brief, polymeric nanoparticles have long been picked as transporters for foundational and focused on drug delivery. The capacity of these particles to flow in the circulatory system for an extended timeframe is frequently essential for effective earmarked delivery. The current outcomes propose that an amalgamation coating of PEG and chitosan may speak to a huge advance in the improvement of long circulating drug delivery transporters for tumor drug delivery. PLGA nanoparticles are broadly utilized for the delivery of various chemotherapeutic specialists (particularly hydrophobic drugs) to the target site [**25**].

Various bacteria and fungus like prokaryotic bacteria and eukaryotic fungus are used for synthesizing metallic nanoparticles. Reduction of aqueous metal ions is done by plant extracts. Biological methods have broad distribution in particle size but have a slow reaction rate. The extract is assorted with metal salt solution at room temperature and reaction is completed within minutes. This method helped in synthesizing gold and silver nanoparticles. Plant extract concentration, natural metal salt concentration, temperature and pH affect the rate of nanoparticles production and their quantity.

Synthesis of nanomaterials

Synthesis of magnetic nanoparticles

Iron (II) oxalate (FeO) or iron (III) citrate (FeC) on magnetite nanoparticles (MNPs) stabilized with polyethylene glycol (PEG) when immobilized was used to chemically synthesize iron-based nanomaterials. The consequence of catalyst dosage, hydrogen peroxide concentration and UV-A light exposure were examined, by applying progressed oxidation processes, for Bisphenol A (BPA) conversion, at laboratory scale, in mild conditions. The final result disclosed that BPA degradation was swiftly intensified in the presence of low-concentration, H_2O_2 as well as under UV- light, and is highly relied on the surface characteristics of the catalyst [**26**]. Surface functionalized magnetic nanoparticles have been extensively used in a variety of biological applications. Magnetite (Fe_3O_4) is easily degradable and is utilitarian in bio-separation and catalytic processes. Due to its supramagnetic properties, high biocompatibility and lack of toxicity to humans, magnetite nanoparticles have been widely studied in biomedicine Magnetite nanoparticles possess high surface energy and thus tend to quickly aggregate. After their adsorption properties and magnetic efficiency, such strong aggregations are frequently coated with an organic or inorganic layer to prevent aggregation. In addition to stabilizing nanoparticles, such coatings can be effortlessly used for functionalization [**27,28**].

Uncoated magnetite nanoparticles are extremely vulnerable to leaching under acidic circumstances; hence several methods have been developed for the preparation of magnetic nanoparticles coated with a polymer, such as polyethylene glycol (PEG) and silica containing organic material in the form of a core/shell structure, with the silica/PEG shell coated onto magnetic nanoparticles. The described coating intensifies hydrophilicity and ameliorates biocompatibility. High adsorption capacity and chemical and thermal stability are among few of the several properties of core/shell structure. Binding sites for enzymes, proteins, or drugs are made available as shell provides active groups on its surface. Magnetic nanoparticles have the potential to serve as drug carriers that can selectively target cancer cells and provide controlled release of chemotherapeutics [**29-31**].

Synthesis of Metallic nanomaterials

There are mainly two methods for the synthesis of metallic nanoparticles i.e., top–down and bottom–up approach. Top-down approach incorporates macroscopic structures that are managed externally in the processing of nanostructures. It starts with a pattern build up on a large scale and then lessened to nanoscale, swift to manufacture and not worthy for large-scale production. Bottom-up approach incorporates the devitalization of materials components with additional self–assembly process that causes the development of nanostructures. During self-assembly large stable structures are formed by combining units by utilizing physical forces employing at nanoscale. It starts with atoms or molecules and assembles up to nanostructures, fabrication is cost-effective.

Synthesis of Gold Nanoparticles

Synthesis of gold nanoparticles was hinge on single-phase reduction of gold tetrachloroauric acid by sodium citrate in an aqueous medium and generates particle of size about 20nm. This procedure utilizes two stages that exploit thiol ligands, which emphatically tie to gold because of the delicate character of sulfur and gold. The significant advantage of combining this procedure is ease of preparation; size controlled thermally stable nanoparticles and decreased dispersity [**32**].

Synthesis of Platinum Nanoparticles

The platinum metal precursor either in a molecular state or in an ionic state is extracted for the synthesis of platinum nanoparticles. By the reducing agents' chemical changes are coerced to transform the precursor to platinum metal atoms. Nanomaterials are then formed by combining metal atoms into stabilizers or supported materials. Irradiation and laser ablation methods have also been used for the synthesis of platinum nanoparticles. Irradiation was amalgamated with ultrasonication, so H_2PtCl_6. $6H_2O$ was put into a solution of 10mm polypyrole and SDS. Particle size is managed by ranging the length and time of ultrasonication and irradiation [**33**].

Synthesis of Silver Nanoparticles

Silver nanoparticles are the most attractive inorganic material as they have the environment free nature and their application in different areas like photography, diagnostics, catalysis, biosensor and antimicrobial. Number of methods have been employed for synthesis of silver nanoparticles, keeping in view the specific parameters like stability, cost constrains, scalability and specific particle size. Normally the chemical synthesis procedure depends on three important constituents that is; the silver precursor, associated reducing and stabilising agents. The chemical mode of synthesis includes the procedure emphasizing on the "Polyol process which incorporates a reduction process of silver nanoparticles with ethylene glycol in the presence of PVP (polyvinylpyrrolidone) polymer. In addition, the ethylene glycol serves both the purpose of acting as a solvent and reducing agent respectively. The size and shape of the formed nano cubes were the dimensions obtained from the molar ratios of silver nitrate and PVP used respectively. Furthermore, the process of synthesis and the concerned geometry of Ag-NPs depends on the stage of nucleation and consequently the stacking process of silver nuclei which further depends on different intrinsic and extrinsic parameters like pH, standard temperature and reducing agents. A recent method has been introduced by Mukherji and Agnihotri using silver nitrate as precursor, sodium borohydride as reducing agent and trisodium citrate as stabilizing agent.

This method reveled the different aspects related to size and dose dependency on the formation of silver nanoparticles. The process involves further two consecutive stages of nucleation and subsequent growth which are controlled by the different factors like temperature, reducing agents involved and stabilizing agents associated with the process respectively. Along with the chemical methods some Physical Methods are also marked as alternative methods for carrying out the synthesis of nanoparticles where easy procedures pertaining to evaporation, condensation are being implemented.

The most important loophole in chemical methods is the high energy demand and more time consumption. Therefore, a move towards these physical processes of synthesis has been initiated to finally restore the energy and reduce the preparation time. In such methods, a complexation reaction is being initiated at higher temperature with a particle range of less than 10 nm. Similarly, in another report a heating system has been devised known as the "Ceramic heating process" to generally stabilize the heating processes without any fluctuations, so that there is ease of condensation and evaporation processes. A new method to overcome the glitches of chemical process is has been designed for the physical synthesis of silver nanoparticles with an improved dispersion process and time saving factor with a preferred size less than 5nm. Another process involves the photochemical techniques categorized in to photophysical and photochemical procedures. In photochemical techniques the silver nanoparticles are synthesized through photoreduction procedure of Ag precursor using the photochemically activated intermediates and substrates like Triton x-100 incorporated with UV radiation, which acts as a stabilizing agent. The surfactant thus provides stability and imparts a uniform size to the nano formulationIt has been observed and reported that improved photochemical methods for the synthesis of silver nanoparticles involves direct photoreduction assisted methods including the laser sources capable of emitting radiation in the range of Infrared near region. These methods thus provide an easy of processing, synthesis and product purity respectively. Biological Synthesis is the new mode of utilizing the biological methods by utilizing the potential and vast source of plants and microbes (Algae, Yeasts, Fungi and bacteria) as the reducing and stabilizing agents. The utilization of fungal and bacterial strains like Trichoderma viride and Bacillus spp. has been promising in terms of synthesis of nanoparticles which are highly economical, reproducible, energy friendly, highly stable with a size dimension; less than 50 nm.

Synthesis of Polymeric nanomaterials

Synthesis of polymeric materials is finished utilizing a notable technique considered as Molecular imprinting that has explicit recognition properties for template molecules [**34,35**]. This method incorporates polymerization of a cross-linker and functional monomers around a print molecule. When you extract the template, receptor sites show up in the material with useful and shape coordinating the template. Molecular imprinting has been broadly known as the most proficient methodology for preparing diverse altered materials with selective binding due to its high selectivity, mechanical strength, and obstruction against acids, bases, organic solvents, plus high temperatures and pressures. Likewise, due to the low cost and ease for preparation, molecularly imprinted polymers (MIPs) have been developed for extensive applications such as chromatography, solid-phase extraction (SPE), enzymatic catalysis, and sensor technology [**34-36**]. Usually, the preparation is done via bulk polymerization like the monolithic blocks.

Reducing the blocks into a particulate product in ordinary size is essential for few diagnostic applications. To avoid the dull and tedious procedure, specialists have developed various polymer formats and polymerization techniques, namely suspension polymerization, imprinting of beads, production of thin films or membranes, surface imprinting (for imprinting large molecules), phase inversion, electro synthesized and nano-sized imprinted polymers. Despite all these possible properties and functionalities, just a few studies on MIP materials united with magnetic nanoparticles are published until now. The use of molecularly imprinted polymer-magnetic iron oxide composite materials for (S)-propranolol competitive radio ligand binding examines using a magnet to separate polymer from solution. The pre-polymerization mixture is legitimately joined with magnetic beads. According to the research, magnetic beads are not nano-sized. This was an approved thought, and writers have set up that the expansion of iron oxide's recognition properties of the imprinted polymer particles does not get overstated. As indicated by the progressing reports by Zhang and associates, [**37**] the synthesis of a magnetic molecularly imprinted polymer (MMIP) of bisphenol A (BPA) by mini-emulsion polymerization.

As per the reports, this procedure gives a quick and predictable examination, yet in addition tends to issues with conventional solid-phase extraction (SPE), such as the packing of the SPE column and the tedious idea of the methodology of stacking large-volume samples. Chen and collaborators [**38**] have created magnetic nanoparticles covered with a molecularly imprinted film against estrone. Synthesized Iron Oxide nanoparticles are first covered with a shell of silica using tetraethoxysilane (TEOS), after which the silica modified magnetic nanoparticles react with a silane derivative of estrone, $(CH_3CH_2\text{-}O)_3$-Si-$(CH_2)_3$-NH-COO-estrone, for making another shell of molecularly printed sol–gel. Estrone has been taken out by hydrolysis. The utilization of magnetic nanoparticles empowers the easy expulsion of reagents, the washing of materials, and the detachment of the definitive product with the application of a magnetic field. Physical and chemical approaches arrange the multifunctional nanoparticles. The amalgamation of magnetic molecularly imprinted polymer nanoparticles was played out by Wang and Zhu *et. al.*, for aspirin recognition and drug-controlled release [**39**]. Magnetic nanoparticles are chemically altered using a double bond by directly reacting methacryloxypropyltrimetroxysilane (MPS) and hydroxyl groups at the Iron Oxide (Fe3O4) nanoparticle surface. Double bond directs the development of methacrylic acid-based molecularly imprinted polymer at the nanoparticle surface using radical polymerization. The end product is gathered by an external magnetic field and aspirin is evacuated using a mixture of methanol/acetic` acid. The application of the material is confirmed by in vitro controlled aspirin discharge: in the primary hours, about 50% of the total aspirin stacked is discharged from magnetic MIPs, while 85% of adsorbed aspirin is discharged from the non-imprinted magnetic nanoparticles.

Synthesis of quantum dots

Diverse synthetic methods can be utilized for the preparation of QDs:

(a) **Direct patterning;** for instance, CdSe QDs were set up by utilizing an altered hydrophobic–hydrophilic PDMS surface. The hydrophilic monomer was embossed on a hydrophobic PDMS to create a pattern of hydrophobic–hydrophilic PDMS surface [**40**]. A large portion of the biomolecules, such as, enzymes, peptides, nucleic acids, exist in aqueous environments and majority of the samples are equally aqueous, altering the surface of QDs to be hydrophilic and harmonious to bimolecular and sample assortments a key issue.

(b) **Lithography-based techniques;** a blend of electron beam lithography and etching [**41**].

(c) **Epitaxy-based strategies;** in which requested growth of a crystalline material happens on a previous crystalline substrate, are affordable methodologies for developing high quality crystalline in quantum devices applications [**42,43**]. There are numerous kinds of epitaxy, the primary distinction being the supply of source atoms: the source could be a molecular beam, gas, liquid or even an amorphous solid layer.

(d) **Template approaches;** in which a wide range of materials such as porous alumina, polymer gel, surfactant, initiated carbon and carbon fiber have been utilized as templates to synthesize various types of nanostructured porous materials [**44**].

(e) **Colloidal chemistry;** a straightforward ("one-pot") approach that might be led to quick injection of semiconductor precursors into hot and enthusiastically mixed explicit organic solvents containing molecules that can coordinate with the surface of the precipitated QD particles [**45-47**] or even by a hydrothermal approach in high-temperature water [**48**].

While colloidal chemistry is generally utilized for the synthesis of QDs for (bio) analytical chemistry applications, QDs arranged by the rest of the methodologies are broadly utilized in optoelectronics (lasers, infrared photodetectors) and nanotechnologies. Organically topped QDs created by colloidal chemistry are of high superiority; however, for various analytical applications, specifically clinical/biological related, QDs need to meet numerous standards:

Labeling biomolecules and cells with QDs involves alteration of the surface which makes it water suitable. Non-toxic performance of QDs is essential for in vivo applications.

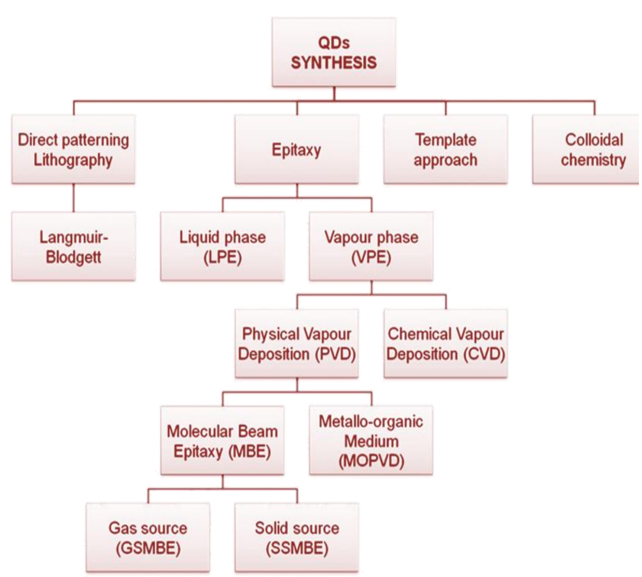

Fig. 1. Flow chart of QDs Synthesis.

The Process for fabrication of nanomaterials

Generally, breakdown or build-up methods are used to fabricate metal nanoparticles. In the breakdown method, the bulk metal is crushed by mechanical grinding (MG) or mechanical milling (MM). One can't easily regulate the particle diameter at the nano-level, though it is an effortless method. Besides, the impurities are simply assorted with robust and durable milling. Still, the method is thought to be inappropriate due to the transformation of plasticity in the case of soft metals. In the build-up method, metallic atoms are assembled and have lots of disparities. This technique is roughly parted into chemical and physical processing.

Chemical processing

Chemical processing has covered several build-up methods. Substantially, this technique reduces ions in solution by a reducing agent and heating. Reduction methods also include supersonic waves and radiation, etc. The basic conception of fabrication is like a traditional metallic reduction method using hydrazine and metal salt solution, improved for the nanoparticle fabrication and control of the reactive rate is different from the older methods. Supersaturation control is vital in the fabrication of metal nanoparticle. The usage of metallic salt as the source in nanoparticle fabrication lets the reducing agent become specifically significant. A slight reducing agent is appropriate for nanoparticle fabrication, as the reduction speed is decelerated, and one can easily control particle size. Particles grow large with regards to the strong reducing agents such as hydrazine. The nanoparticle size can't be easily controlled with a fast reaction rate. Besides the choice and balance of a reducing agent and a metallic source, heating is also an essential element to control.

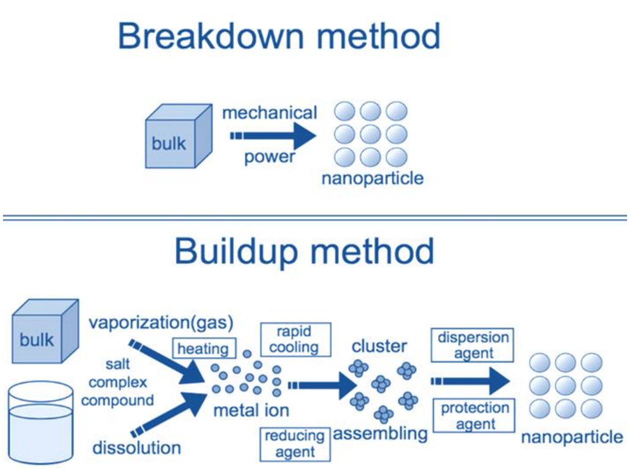

Fig. 2. Fabrication concepts of breakdown and build-up methods [132].

Physical processing

Physical processing specifies physical power supported with a phase reaction, in contrast to a chemical solute reaction. The physical process of the breakdown method is an example of physical power. Phase reactions are segregated into gas and liquid phase methods. The method of gas condensation is the prevalent nanoparticle fabrication technique amid physical processes. In the gas condensation method, an inorganic or metallic material, or organometallic compound, is vaporized through thermal evaporation sources like Joule heated refractory crucibles, electron beam evaporation devices under low pressure, or inert gas. The metallic cluster is designed near the source by homogeneous nucleation in the gas phase. In this technique, particle size relies on the particles' residence time in the growth regime and can be affected by the gas pressure and the type of inert gas, vapor pressure, or evaporation rate. Usually, the regular particle size of the nanoparticle flows with gas and vapor pressure. The atomization method is another technique [**49**], where the molten metal is swiftly cooled into droplets. The industry is making progress in the metallic particle fabrication techniques at the micron and submicron levels.

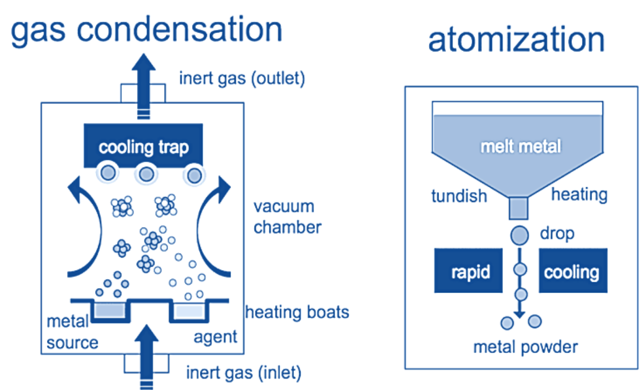

Fig. 3. Gas condensation and atomization methods [132].

Novel processing routes for eco-fabrication

The traditional fabrication methods of metal nanoparticles are mostly either physical or chemical methods. The reduction of metal ions usually needs reducing agents, high temperature, and supersaturated conditions to attain nanoparticles. However, in industrialization, significant issues are cost and environmental issues, which are linked closely. In the physical method, one can quickly fabricate high purity nanoparticles due to their production in inert gas. Still, it's necessary to have high temperature heating and large-scale chamber filled with noble gas. Similarly, both large initial and high running costs are essential. On the contrary, the spontaneous chemical reduction reaction makes the chemical method cost-effective. Though, there is an issue with the raw material. Mostly, one can use metal salt as a metal source while using a reducing agent and many metallic salts contain the ions NO^{3-}, SO_4^{2-}, Cl^- etc., that creates an acid deposition issue which requires a wet scrubber and washing of the nanoparticles to expel. While using the organometallic compound as the metallic source, 80 wt% or more might convert into organic waste, so it's better to eliminate this waste, so the cost hardly changes between physical and chemical methods. In industry, the cost can be controlled and the environment can be protected through well-balanced fabrication. However, these methods can't help managing both low cost and low environmental impact. For that, an innovative fabrication design is required.

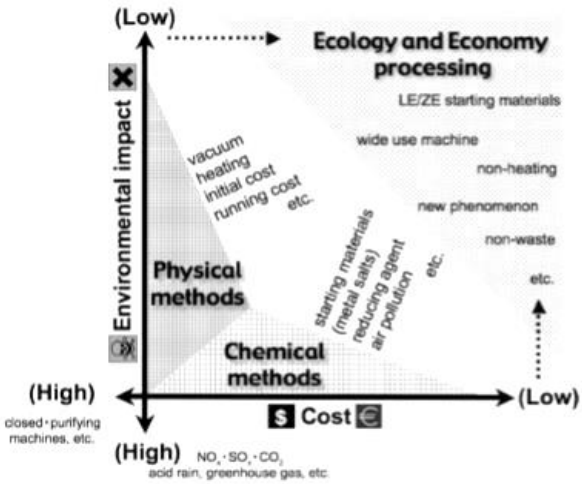

Fig. 4. Cost vs environmental impact in metal nanoparticle fabrication.

The existence of high performance and low environmental influence will become gradually imperative in nanotechnologies containing nanopackaging. Additionally, low product cost is also essential for maintaining a global competitive edge. Here's an example of metallic nanoparticle fabrication techniques that achieve both ecological and economic goals:

Liquid-Solid sonochemical reaction

Ecological and economical fabrication is vital in the industry. One can achieve this synthesis through numerous approaches. Instead of an exclusive unique purpose device, a low-priced general-purpose production device is looked-for. When synthesizing, it is desirable that neither waste nor air pollution is produced nor use of safe and non-hazardous raw materials is always encouraged. Moreover, the ambient temperature can be used for synthesis and is desirable in relation to energy conservation. It has been found that a new metal nanoparticle synthesis method has been developed to offer these elements. This new method utilizes an ultrasonic cleaner as a general-purpose device and metal oxide (M_xO_y) and alcohol (C_xH_yOH) as raw materials. The metal oxide doesn't liquefy in ethanol, so one needs to ultrasonically agitate the liquid-solid (alcohol–metal oxide) phase. When pyrolytic treatment is done to a solid substance with a generating gas, it transforms the raw material into fine powder [**50,51**]. Inert metal oxides are simply deteriorated by heating in air, i.e., without requirement of active reducing atmospheres [**52**]. This reduction is fresh and natural as noble metal oxides are almost poisonous materials and only produce O_2 when decomposed. The ultrasonic cleaner is a reasonably-priced home appliance, and metal oxide and alcohol are usually cost-effective and harmless. Another name for ultrasonic processing as a chemical process is the Sonochemical process. Overall, the properties of a precise energy source regulate the course of the chemical reaction. The ultrasonic irradiation is different from traditional energy sources in pressure, duration, and energy per molecule. It's exclusive in the interaction between energy and matter. The chemical effects of ultrasound do not come from straight interface with molecular species. As an alternative, they are resulted mainly from acoustic cavitation to produce high temperatures like the surface of the sun and high pressures similar to those at the bottom of the ocean [**53**].

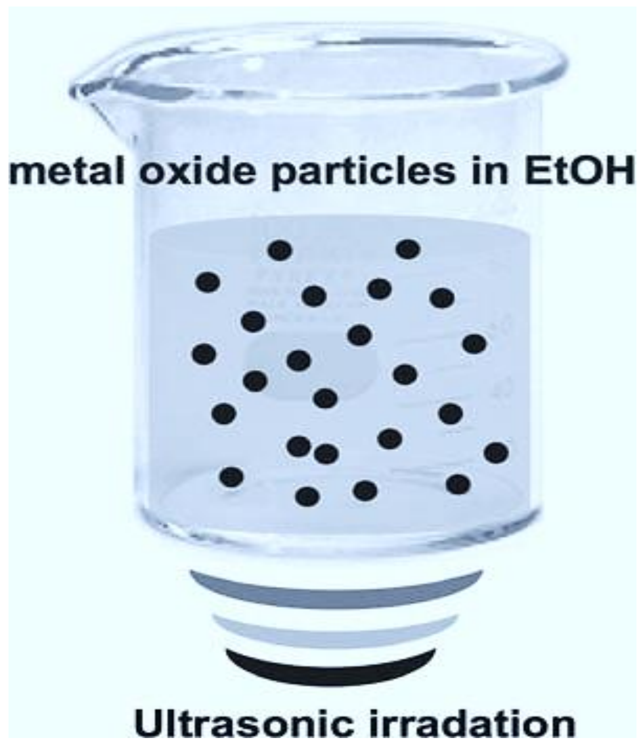

Fig. 5. Experimental procedure in liquid–solid sonochemical reaction [133].

Inert metal nanoparticles were synthesised through ultrasound in a liquid–solid (EtOH–noble metal oxide) slurry. The synthesis technique is very simple. EtOH and the inert metal oxide powder are merely engaged into a measuring glass and irradiated by ultrasound. Once the liquid–solid slurry is irradiated by ultrasound, it decreases to metal nanoparticles. In this synthesis, ultrasonic irradiation is significant. As the stress is induced in the liquid by the passing of a sound wave through the liquid, cavitation occurs [**54-56**]. These froths are presently exposed to the stresses induced by the sound waves. The froths are loaded up with vapour and gas and bubble implosions takes place. These implosions are the significant part of sonochemical methods. All of these imploding froths can be viewed as a high-temperature hot spot having pressures of numerous atmospheres. Hot spot reaction is reflected to signify direct reduction with the decrease of metal oxide prompted by hot spots made from ultrasonic cavitation and alcohol. EtOH is additionally significant in this reduction. Ultrasonic reduction is enhanced by alcohol and shields metals from reoxidization. The nucleation of metal happens at the hot spot in arrangement, followed by the development and immobilization of the inert metal particles.

Applications of nanomaterials

Nanomaterials are utilized in a diversity of fabricating methods, products and healthcare comprising paints, filters, insulation and lubricant extracts. In medical sector, nanozymes which are nanomaterials with enzyme-like features, are a developing kind of artificial enzyme, have been utilized for broad applications like as in biosensing, bioimaging, tumor diagnosis, antibiofouling, gas sensor, water treatment, environment and more. In paints nanomaterials are used to enhance UV protection and advance ease of cleaning. Superior quality filters may be delivered using nanostructures. These filters are equipped for expelling particulate as minute as a virus as seen in a water filter. In the air purification field, nanotechnology was utilized to battle with the spread of epidemic Middle East Respiratory Syndrome (MERS) in Saudi Arabian hospitals during 2012. Nanomaterials are used in recent human-safe insulation technologies. As a lubricant additive, nanomaterials have the capability of reducing friction in moving parts. Moreover, nanomaterials can be utilized in three-way-catalyst (TWC) applications. TWC converters have the benefit of monitoring the emission of nitrogen oxides (NOx), which are precursors to acid rain and smog. Nanomaterials form shell as the catalyst support in core shell structure to shield the noble metals such as palladium and rhodium. The key purpose is that the supports can be utilized for carrying catalyst active components, creating them highly dispersed, decreasing the use of noble metals, improving catalysts activity, and enhancing the mechanical strength. A major and popular application of nanomaterials is witnessed in keeping the environment clean by waste water treatment, combating air pollution, analyzing soil irregularities etc.

Wastewater treatment

Waste water treatment by metal/metal oxide

Magnetite nanoparticles coated with aminopropyltriethoxysilane (APTS) have many applications as adsorbent layers for the removal of aqueous heavy metals during wastewater treatment. Wastewater is a highly complex media having a broad diversity of contaminants. Multi-step procedures or expensive techniques are required to remove contamination from wastewater. Endocrine disruptive chemicals (EDCs) are among the wide class of such hazardous compounds, which involves natural hormones and synthetic compounds. Advanced oxidation process is the strongest process for wastewater remediation i.e., stopping the environmental damage [**57,58**]. Biodegradability and detoxification of effluents that consists of emerging pollutants such as EDCs is increased though AOPs. Silver nanoparticles are acknowledged for their strong antibacterial impacts against a broad cluster of organisms such as viruses, bacteria, and fungi. Hence, silver nanoparticles are broadly used for the sterilization of water [**59-61**]. Numerous materials containing iron, like iron sulfide, iron bearing oxyhydroxides and alumina silicate minerals, were effectively utilized in the decrease and precipitation of metal ions. Elemental iron was seen as the most efficacious out of all iron-based materials, for ground water remediation. With the emergence of nanotechnology, iron nanoparticles substituted the use of mass iron-based systems for water purification [**62**].

The application of noble metal nanoparticles for the elimination of halogenated organics and pesticides from drinking water also came into existence. Gold nanoparticles evince the potential to expel inorganic mercury from drinking water. Zero-valence state metals, like Fe^0, Zn^0, Sn^0 and Al^0 are effective for the remediation of impurities in filthy groundwater [**63**]. The swift and complete dechlorination of all the chlorinated impurities was accomplished for the water and groundwater slurries using bimetallic nanoparticle systems made up of Pd/Fe [**64**]. Pollutants, such as tetrachloroethene (C_2Cl_4), could be converted to ethane by accepting electrons from the oxidation of iron by the reaction: $C_2Cl_4 + 4Fe^0 + 4H^+ \rightarrow C_2H_4 + 4Fe^{2+} + 4Cl^-$.

The evacuation proficiency was seen to be better than 99% using iron nanoparticles without a palladium coating after 24 h. Moreover, bimetallic coupling with a second catalytic metal is extensively applied for the deprivation of impurities in filthy water. The degradation rate by bimetallic combinations was seen to be quicker than that detected for metal iron alone. Bimetallic Pd/Au nanoparticles comprise of two catalytic metals, however bimetallic nanoparticles of iron comprises of catalytic material (Pd or Ni) and an electron donating material (i.e. Fe). Bimetallic Pd/Au nanoparticles can upsurge the catalytic activity by a factor of 15 when contrasted to Pd nanoparticles, Al-supported Pd nanoparticles and Pd black [**65**].

Nanofiltration

Membrane technologies are increasingly productive these days because of their consistent impurity elimination without creating any harmful derivatives, particularly in water and wastewater treatment processes. The elementary norm of membrane filtration is to apply semi-permeable membranes to eradicate fluids, gases, particles and solutes. For parting materials from water, membranes must be water permeable and less permeable to solutes or other particles. Pressure-driven membrane processes, for instance, microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO), have been applied for water treatment, reuse and purification systems throughout the world. Nanofiltration (NF), as a favorable membrane technology, is a technique for evacuating low molecular weight solutes, like salts, glucose, lactose and micro-pollutants, in filthy water [**66**]. The accessibility of clean water has developed as one of the most significant issue confronting the worldwide economy in the 21st century. The exclusion of viruses and bacteria is enormously vital in drinking water sanitization. The elimination of the *protozoa giardia* and *cryptosporidium* from surface water sources is a fundamental need for several administrations and drinking water firms. Traditional chlorination is still frequently applied as a sterilization method, but the drawbacks of chlorination were found to be:

- The development of disinfection by-products (DBPs)
- The resistance of *cryptosporidium* to chlorine and chloramines.

Membrane filtration may enable a progress in the cleansing process since it is an additional obstacle for viruses and bacteria. Bacteria (0.5–10 mm) and protozoan cysts and oocysts (3–15 mm) are bigger and their deduction can be assured with ultrafiltration (UF) membranes. The minor viruses might be excluded by nanofiltration (NF) membranes, having pore size less than 1 nm.

The filtration membrane comprises of an empty cylinder with radially lined up carbon nanotube (CNT) walls have been reported. Srivastava *et. al.,* [**67**] proficiently led the exclusion of *Escherichia coli* from drinking water by means of the CNT-aligned membrane. Membranes that have CNTs as pores could be utilized in detoxification and demineralization and those tubes act as the pores in the membrane. A membrane filter having both super hydrophobicity and super oleophilicity was amalgamated from vertically lined up multi-walled carbon nanotubes on a stainless-steel network for the conceivable partition of oil and water. Both super hydrophobicity and super oleophilicity could be acquired because of the double scale structure and needle-like nanotube geometry of the network with micro-scale pores joined with the low surface energy [**67**]. The nanotube filter could disperse diesel and water layers and also surfactant-stabilized emulsions. The effective phase partition of the high viscosity lubricating oil and water emulsions was additionally done.

Sorbents

Furthermore, nanomaterials-based methods are turning out to be favorable choices for applications in water treatment. The adsorption strategy is the most commonly considered technique to disinfect water. Sorption is the exchange of ions from the solution phase to the solid phase and it truly defines a group of procedures, which incorporate adsorption and precipitation reactions. Fundamentally, adsorption is a mass exchange process through which a substance is relocated from the liquid phase to the surface of a solid and gets limited by physical as well as chemical interactions [**68**]. Several cheap adsorbents, resulting from agricultural waste, industrial by-products, natural materials, or modified biopolymers, have been grown lately and applied in the exclusion of substantial metals from metal-sullied wastewater.

Practical applicability and cost-adequacy are the main factors that play significant roles in the choice of the most reasonable adsorbent to treat wastewater. Magnetic sorbents or magnetic ion exchange (MIEX) pitches have been familiarized for the exclusion of natural organic matter (NOM) from encompassing crude water and was seen to be better than coagulation methods. Coagulation evacuated 60% of the dissolved organic carbon (DOC) related with the 1–10 k fraction however had little influence on the DOC concentration of the <1 k fraction. Treatment with MIEX expelled around 80% of the DOC related with the 1–10 k fraction and nearly 60% of the DOC related with the <1 k fraction.

Moreover, sorbents can be of mineral, organic or biological origin (such as zeolites, activated carbons, silica beads, and clays), cheap adsorbents (such as biomass, industrial by-products and agricultural wastes) and polymeric materials (such as macroporous hyper-cross-linked polymers and organic polymeric resins). Polysaccharide-based materials can be utilized as sorbents in waste water treatment. Chitosan has been widely applied in numerous exploration areas of water/waste water treatment. Chang and Chen reported that improved the chitosan polymer and grafted carboxylic groups. At that point, the carboxylated chitosan was covalently bound to magnetic nanoparticles. Subsequently, modified chitosan nanoparticles were utilized for the evacuation of metals from wastewater [**69,70**].

Dendrimers

Polyamidoamine (PAMAM) dendrimers were created for applications in the remediation of waste water polluted with a diversity of transition metal ions, like copper Cu (II). The utilization of PAMAM dendrimers for copper exclusion was first stated by Diallo et al. in 1999. Dendritic nanopolymers can summarize a wide range of solutes in water with cations such as copper, silver, gold, iron, nickel, zinc and uranium, by bonding to functional groups of dendrimers, such as primary amines, carboxylates and hydroxymates [**71**]. They may disable bacteria and viruses after binding. Polyamidoamine dendrimers can expel metal ions Cu (II), Ag (I), Fe (III) and others by working as chelating agents and ultrafiltraters. The expulsion limit can be enhanced by joining metal ions to the functional groups of dendrimers, such as primary amines, carboxylates and hydroxymates. Dendritic nanopolymers like PAMAM dendrimers have substantially less propensity to go through the pores of ultrafiltration membranes than linear polymers of an analogous molar mass as a result of their much smaller polydispersity and globular shape. Thus, dendritic nanopolymers have been utilized to improve UF and MF processes for the recovery of dissolved ions from fluid arrangements. First, filthy water is blended with a solution of functionalized dendritic nanopolymers and afterwards the blends of nanopolymers and bound impurities are moved to UF or MF units to improve the clean water. In those units, the bound objective substance is parted from the nanopolymers by altering the acidity i.e., the pH of the solution. Lastly, the improved concentrated solution of impurities is gathered for removal or the nanopolymers may be recycled.

The significant originality of the dendritic polymer filtration procedure is the blend of dendritic polymers with various chemical functionalities with UF and MF. This may empower the growth of a new generation of water treatment methods that are adaptable, reconfigurable and scalable. Dendritic polymer filtration methods are accessible and can be utilized to grow small and portable water treatment systems as well as enormous and stable treatment systems. Moreover, dendritic nanopolymers have smaller inherent viscosities than linear polymers with a similar molar mass due to their globular shape [**72**]. Thus, relatively lower operating pressures, vitality utilization and the loss of ligands by shear-force actuated during filtration can be accomplished with dendritic polymers in cross-flow UF systems and this dendritic filtration can be applied in industrial water treatment.

Carbon nanomaterials

Nanoscale activated carbon usage may have benefits over customary materials because of the bigger surface area of the nanoparticles on a mass basis. Activated carbon from different sources like coconut coir, jute stick, rice husk, and so on is well known of all the adsorbents. The treatment of water by adsorption techniques utilizes explicit ion exchangers or extractants and a blend of adsorption with catalytic treatment techniques, redox methods and magnetic procedures. Recently, a new strategy in adsorption has been stated that applies carbon nanotube clusters. The extraordinary feature of these clusters is their capacity to eliminate bacteria from water by an adsorption technique. Adsorption-based separation procedures are broadly applied in the sanitization of drinking water and natural gas polluted air. The division of metal ion carriers i.e., nanoparticles with metal ions, from water after treatment is a demanding issue. So as to improve the partition of carriers of metal ions from cured water, the metal ions can be bound to polymeric molecules as well as carbon nanoparticles creating nanocarbon conjugates or polymer nanocomposites in water that can precipitate quickly. This prompts a huge increase in the size of the nanocomposites with the arrangement of precipitates. The precipitates can be effortlessly expelled from water by filtration or centrifugation with the ensuing extraction of the metals.

Environmental application

The rapidly growing nanotechnology has added a great value in the environmental applications of nanomaterials. The challenge remains the treatment of pollutants in water and air and nanomaterials are vital for the environmental remediation. Nanomaterials are outstanding adsorbents, catalysts and sensors because of their large specific surface areas and high reactivities. The high surface area-to-mass ratio of nanomaterials can significantly enhance the adsorption capacities of sorbent materials. Surface area of nanomaterials grows exponentially at the same density because of the reduced size as the diameter lessens. Further, there is high mobility of nanomaterials in solution and the entire volume can be swiftly scanned with the help of small sized nanomaterials. These exclusive properties can be applied to reduce and rummage contaminants in air and water. The species adsorbed against the nanomaterials can be detached by applying on mild, gravitational, or magnetic force.

Environmental remediation by metals/metal oxides

For environmental remediation, broadly contemplated nanoscale metals (NMs) and metal oxides (NMOs) consists of silver, iron, gold, iron oxides, titanium oxides, and so on. The size and shape of NMs and NMOs are significant factors that influence their performance. Metallic nanoparticles are utilized as catalysts in order to deflect ecological contamination that is monoxide and nitrogen oxide because of metallic nanoparticles being amazingly vivacious as far as physical, chemical and mechanical properties is concerned. Silver ions are photoactive before UV irradiation, creating a development in the UV inactivation of bacteria and viruses [**80**]. Sulphur dioxide (SO_2) is normally released to the atmosphere by the combustion of fossil-derived fuels in industries, power plants, houses and automobiles. The deterioration of buildings due to acid rain by SO_2 is a severe task. TiO_2 is the frequently utilized catalyst to change SO_2 to sulphur through the reaction: $SO_2 + 2H_2S \rightarrow 2H_2O + 3S$

Rodriguez found that the amalgamation of a gold (Au) and TiO_2 system created profoundly effective desulfurization. Metallic gold has exceptionally low chemical and catalytic activity. Though, when gold was scattered on some metal oxides such as MgO, TiO_2, MnO_x, Fe_2O_3, Al_2O_3, it gave the positive outcomes of catalytic activity because of charge transfer among the oxide and gold and a narrow nanoscale size (usually less than 10 nm).

Environment remediation by polymer supported nanocomposites

The use of the NPs in environmental remediation gave over the top pressure drops throughout effective in fixed bed or some other flow-through systems, demanding partition and restriction to reuse and conceivable hazard to ecosystems and human well-being brought about by the potential release of nanoparticles into the environment. The broadly utilized host materials for nanocomposite production consist of carbonaceous materials like granular activated carbon, silica, cellulose, sands and polymers. Polymeric host materials must hold exceptional mechanical strength for long-term use [**81**]. The common catalytic nanoparticles comprises of nano-sized semiconductor materials (nano-TiO_2, ZnO, CdS), zero valence metals (Fe^0, Cu^0 and Zn^0) and bimetallic nanoparticles (Fe/Pd, Fe/Ni, Fe/Al, Zn/Pd). They are generally applied as catalysts or redox reagents for degradation of an enormous assortment of ecological pollutants like PCBs (polychlorinated biphenyls), azo dyes, halogenated aliphatics, organochlorine pesticides, halogenated herbicides and nitroaromatics.

Monitoring and assessment strategies to reduce the nanotoxicity

The monitoring and assessment strategies associated with the use and development of nanomaterials highlights a very important move by the European agencies known as “SAPHIR MOVE” which represents a safe [**82-85**] controlled and integrated production strategy for the recycling of the multifunctional materials. The term “risk” basically relates to the occurrence of negative consequences [**86**] in terms of health and safety [**87,88**]. Further, the source associated with risk is a hazard or a situation including hazardous factors, while, its consequences includes, injury (physical), health, property and environment damage. So, risk analysis focuses on the sequence of events linking the hazards to associated harms respectively. Similarly, both chronic and accidental risks are being reported risks associated with nanomaterials, which should necessarily involve some important risk assisted assessment methodologies, such as “ATEX4” specially designed for assessing risks of explosion, IPPC for evaluating chronic health problems and risks associated with environment and [**89**] SEVESO II [**90**] for observing the outbreaks of chemical hazards.

The general framework adopted for estimation of risk comprises of a method known as the conventional/ classical assessment of risk which includes:

a) Defining and searching out the scope related to assessment of risk.
b) Potential identification of the situations relating to occurrence of hazards.
c) To set up a relationship between the hazard and its associated impact.
d) To estimate the exposure doses by finding out the extent of exposure.
e) Finally, to quantify the estimation of the associated risk.

These conventional methods, however, were not found compatible in case of nanomaterials/nano-objects, so a different strategy like “SAPHIR” was formulated which is basically a five-step cascade for assessment of risk factors associated with nano-objects.

a) Initially it starts with creation of a perfect working group involving different experts (chronic and accidental risks) [**88**].
b) Providing a clear guide for installation mechanisms, associated products and environment targets.
c) Potential identification of both chronic and accidental based risks throughout the proposed event cycle.
d) Screening the potential methods for safety and efficient reduction in emission of toxic effluents.

The rapid production of nanomaterials/nano-objects has been fastened during the last few decades to be utilized in automotive, textiles, therapeutics and textiles etc. The major problem which is witnessed during development of nano-objects is the risks associated with the production stage. So, a proper monitoring strategy should be employed in terms of extra costs and production processes during addition of nano-objects during nano safety operations, so that they do not turn in to hazardous products which are toxic (nanotoxicology) [**90,91**].

The economic analysis of nano-oriented processes

The cost analysis of various manufacturing processes related to the nano-World depends on the cost of material, the use of nano metric filters, thermal and electrical conductivity and all the technical advancement makes it economically competitive than the conventional materials. The remarkable progress such as enhancement in performance parameters (like much reduced filler loading) and exceptional variation in multifunctional processes. The cost assessment includes the different costs like measures for protection and mitigation pathways, the consumables like fluids, filters and energy utilization, the cost related to training, management, maintenance and manpower associated with it. In addition, the cost associated with the waste management or adjuvant screening etc is also included. The economic analysis should undertake wider aspects for cost analysis and should not be restricted to mere comparison of cost of production for nanomaterials and products. Further a circular flow should be followed known as “The life cycle approach” which includes risk evaluation, cost to benefit analysis, accidental hazards related to nanoproducts and also the toxic reversibility of the nano product [**92**].

Future recommendation of nanomaterials

Over the last couple of decades, nanomaterials are playing an important role in commercial growth. Certainly, we might expect to create various breakthroughs and new projections for the global economy from nanotechnology advances. With wide range of prospects of nanomaterials in future, it may be widely used in several fields, particularly tumor therapy. On the basis of their size, surface chemistry, biocompatibility, stability, and flexible toxicity in biological systems, clinical diagnosis can be done through nanomaterials. As expected, the application of these substances in tumor therapy will substantially boost current procedures of tumor-cell detection, imaging, and therapy, while reducing toxicity. Along with a wide range of applications comes a set of challenges in the field. There are disputes around the possible risk of antitumor therapies. The most persistent issues are potential chronic and severe toxic effects; the potential toxicity of nanomaterials in antitumor therapy cannot be overlooked [**93**]. Nanomaterials may be linked to the surface of biological membranes by adsorption or electrostatic interactions, and the substances can even damage the cells by fabricating reactive oxygen species, resulting in protein denaturation, DNA damage, lipid peroxidation, and eventually cell death [**94**]. For example, carbon nanotubes and nanoparticles can harm the cardiovascular and respiratory systems, and can enter the central nervous system through the blood–brain barrier, giving rise to various nervous system ailments [**95**]. As per studies, CNTs can bring cell apoptosis, reduce cell feasibility, and disturb the cell cycle and inflammatory responses. CNTs can also damage lung tissue and they can harm the immune system of mice. Also, the blood incompatibility of CNTs restricts their usage in the clinic [**86,87**]. However, many studies depicting the functionalization of CNTs to improve their water-solubility, proof of their biocompatibility and safety is presently inadequate. Once quantum dots are applied in the body, their noxiousness cannot be overlooked, as they comprise heavy metals. It is essential to execute a thorough toxicity study to certify well being prior to more applications in humans. More research won't be advantageous to the clinical application of nanomaterials and industrial fabrication without the toxicity issue being resolved. Furthermore, US Food and Drug Administration have only approved some types of materials, and limited nanomaterials have been approved as antitumor agents to enter the market or Phase III clinical trials. It implies that one needs to understand nanomaterials thoroughly before utilizing their potential application in tumor therapy. Consequently, the enduring toxicity of nanomaterials to living systems requires intensive studies. It is essential to research the mechanisms of injury in cells because of nanomaterials broadly before the substances can be used in tumor treatments [**96**]. Growth of tumor therapies is a multidisciplinary field, and by diving deep in the field of tumor immunology, tumor biology, molecular biology, and nanomaterials, the best therapy or Nanomaterial can ultimately be produced for the tumor treatment. The alteration of nanotechnology to routine clinical practice will require a multidisciplinary method guided by clinical, ethical, and social perceptions. Considering the noteworthy research results being associated with the field, we can expect that humans will significantly benefit from nanotechnology and nanomaterial in the forthcoming time, especially in tumor therapy.

Conclusion and future prospective

Nanomaterials are of maneuver on the grounds that at this scale special optical, magnetic, electrical, and diverse properties build up. The rising properties can potentially affect medication, gadgets, and various fields. Metallic nanoparticles assisted by appropriate functional groups have a specialty that one can alter and synthesize them. It will help metallic nanoparticles to connect with ligands, drugs and antibodies. Also, one can use metallic nanoparticles as efficacious catalysts when ranged between 1 to 10 nm in size. These substances should be able to withstand under the catalytic conditions else it will effortlessly solidify in solution and form a combination, which are less convincing as a catalyst. Polymeric nanomaterials have been verified for a wide scope of applications such as imaging, drug delivery, and apoptosis detection. A study for several cationic polymers is carried out both in vitro and in vivo for the delivery of genes. Bottom up and top-down approaches can help in synthesizing the metallic nanomaterials. One can use these materials in several applications after synthesis such as biosensors, diagnosis, photography, healthcare sector, etc. The synthesis of polymeric nanomaterials is done using molecular imprinting. It's the most competent method for preparing various altered materials with selective binding because of its mechanical strength, high selectivity, and obstruction against organic solvents, acids, bases, including high pressures and temperatures. Direct patterning, Lithography-based techniques are some of the methods used to synthesize Quantum dots.

Biosensors might play a pivotal role in offering powerful analytical tools in the ailments diagnostic areas or health sector, mainly where there is a need of rapid, high-sensitivity, low-cost, and specificity measurements in field situations. Easy processing, minimal device configuration, doping ability, compatibility with different sub-crystals, high temperature resistance, and strong mechanical strength make nanomaterials perfect for electronic nose applications and future gas sensor even in harsh environments. The nanomaterial-based gas sensors have been proved to show high selectivity and sensitivity for gas sensing, therefore providing great potential for practical applications. Through more in-depth research, nano-gas sensors and electronic noses will be extensively used in the market in the future. In chemical methods, the production of metallic nanoparticles can be done using ionic solutions that consist of chlorides, nitrates, cyanides, and carbonates amongst others. These starting materials and reducing agents cause pollution during fabrication due to their toxic nature. Moreover, toxic ions, such as NO_3^{2-}, Cl^- and CN^- remain in the preparation solutions after fabrication. These solutions need to be treated, as these ions causes the environmental pollution issues such as acid rain and generate green house and toxic gases. The application of nanomaterials while detecting and removing pathogens offers greater sensitivity, shorter turn-around times, low cost, in-line and real-time detection, smaller sample sizes, higher throughput, and portability in environmental remediation. Additionally, metal and metal oxide nanomaterials can help in removing organic pollutants and metals by reduction or oxidation of nanomaterial. The degree of removal can be enhanced through functionalization with chemical groups that can obtain selectively target pollutants in water and air media. This technique is efficient and promising and can be used in the engineering of air and water improvements.

Keywords

Catalytic nanomaterials; carbon nanotubes; molecular imprinting; nanofiltration; dendrimetic nanocomposites; sonochemical degradation.

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