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Nano-Technology and Its Applications in Water Purification

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***Abstract* - Nanotechnology is the engineering and application of atoms, molecules, and particles whose sizes are on the nanometer scale (1-100 nm). Studies have shown that nanoparticles (NPs), most especially the nano metal oxides have improved and/or unusual physic chemical properties when compared with the corresponding bulk materials. Thus, these unique properties make NPs very useful in different field like medicine, electronics, biomaterials, energy production, water and wastewater treatment, etc. Different methods such as the gas phase synthesis (gas condensation processing, chemical vapour condensation, microwave plasma processing, and combustion flame synthesis), ball milling, co-precipitation, sol gel, micro emulsion, and surfactant have been widely reported in literature over the years for the production of NPs. There are few conventional technologies which are affordable and can be produced locally for effective removal of contaminants from water and wastewater. However, there are several challenges with regards to the cost and the removal efficiency of certain pollutants, most especially, the persistent organic pollutants and endocrine disruptors by these conventional technologies. Environmental nanotechnology vis nanotechnology and/or nanotechnology combined with conventional technologies are able to treat organic and inorganic contaminants to acceptable levels. There is currently intense scientific interest in nanotechnology for water and wastewater treatment; nevertheless, there are concerns about the toxicity and environmental impact of NPs. The application of nanotechnology for the removal of toxic pollutants such as the pharmaceutical and personal care products, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, phthalates, furans and dioxins, agrochemicals and pesticides, volatile organic compounds, viruses and bacteria, dyes, inorganic pollutants, etc., has been widely reported by several investigators in the field of nanotechnology. Interestingly, results have shown that environmental nanotechnology could be effectively utilized for the removal of organic and inorganic contaminants from drinking water, sewage, municipal, industrial and process wastewater.**

Keywords: nano, technology, applications, water, purification.

1. Introduction

Clean water defined as water that is free of toxic chemicals and pathogens. This is essential to human health. India as developing countries, 85% of the diseases are due to bacterial and microbial contamination of drinking water [1].

Most of the countries are nowadays facing pure drinking water problems and conditions are very bad especially in developing countries [2]. The world is facing terrifying challenges in meeting rising demands of pure water; as the available supplies of fresh water are continuously reduce due to:

1) Extended droughts
2) Population growth
3) More stringent health based regulations
4) Competing demands from a variety of users [2].

World Health Organization (WHO) suggest that any water intended for drinking should contain fecal and total coliform counts of 0, in any 100 mL sample. When either of these groups of bacteria is found in a sample, immediate investigative action should be taken. The removal or inactivation of pathogenic microorganisms is the last step in the process of treatment of wastewater. The protection of water treatment systems against potential chemical and biological weapon for terrorist acts is also becoming a critical issue in water resources planning [2].

Only 2.5% of the world's oceans and seas harness fresh water, FW (salts concentration of <1 g/L) [3].

However, 70% of fresh water is frozen as eternal ice. Only <1% of FW can be used for drinking. Globally, >700 million people do not have access to potable water [4]. This problem is severe in developing nations and sub-Saharan African countries. Therefore, water treatment must be implemented in these affected places. Available technologies for water treatment are reaching their limits in providing sufficient quality to meet human and environmental needs [5]. Therefore, reuse, recycle, and repurpose are the "needs of the day."

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Water contaminants may be organic, inorganic, and biological. Some contaminants are toxic and carcinogenic and have deleterious effects on humans and ecosystems [6]. Some heavy metals are notorious water pollutants with high toxicity. Arsenic is one of the deadliest elements, well known since ancient times.

Conventional water treatment provides unsatisfactory results, because treatment facilities are not equipped to remove stable low-concentrated pollutants. Produced water containing hydrocarbons as example organic pollutants, such as pesticides, fertilizers, hydrocarbons, phenols, plasticizers, biphenyls, detergents, oils, and greases are associated with toxicities [7]. Emerging contaminants include pharmaceuticals and personal care products (PPCPs) [8]. PPCPs are usually resistant against natural bio- deterioration which is originated from household and hospital water.

Produced water containing hydrocarbons necessitates measures that are fast and simple. For instance, according to Gouma and Lee (2014) [9], the petroliferous shale production in the USA will amount to 5 MIO barrels/d by 2017. Hydraulic fracturing (fracking) of shale or rocks is used to recover oil under high pressure. The US's mining-holes (1 MIO) produce 3.29 × 103 m3 of produced water (frac-water) per year.

Natural organic matter (NOM) is one of the principal characteristics of water quality, and it determines the strategy of purification. Sometimes NOM is represented by total organic carbon and dissolved organic carbon [10]. NOM is omnipresent from remains of animal or plant origins. It negates the effectiveness of certain techniques—flocculation, carbon adsorption, or filtration. Even worse, NOM produces undesirable oxidation products during chlorination treatment. NOM serves as a breeding medium for a large variety of other microorganisms stimulating growth of bacteria in an aquatic habitat. Given that NOM is various, it is not possible to remove all related objects from the environment, disfavoring water authorities. NOM pollution in the surface and ground water makes it unfit for drinking [3]

Today several techniques are used for treatment of water i.e., chemical and physical agent such as chlorine and its derivatives, ultraviolet light [10], boiling, low frequency ultrasonic irradiation [10], distillation, reverse osmosis, water sediment filters (fiber and ceramic) activated carbon, solid block, pitcher and faucet mount filters, bottled water, ion exchange water softener, ozonisation, activated alumina 'Altered' water. Halogens such as chlorine (Cl) and bromine (Br) are well known and widely used as antibacterial agents, but the direct use of halogens as bactericides has many disadvantages because of their high toxicity and vapour pressure in pure form NH4 + is a most common caution in water which affecting human and animal health. Removal of ammonia is very necessary in drinking water to prevent oxygen depletion and algae bloom and due to its extreme toxicity to most fish species It can be replaced with biologically acceptable cautions, like Na+, K+ or Ca2+ in the zeolite. During the past few decades, several investigations have been carried out concerning the use of synthetic and natural zeolites, polymer films and metal ions (Ag+, Cu++, Zn++, Hg++, Ti+++, Ni++, Co++) as bactericides for water disinfection [11].

Different methods are available for water purification [12, 13, 14]. The most important methods are screening, filtration, micro- and ultrafiltration, crystallization, sedimentation, gravity separation, flotation, precipitation, coagulation, oxidation, solvent extraction, evaporation, distillation, reverse osmosis, ion exchange, electro dialysis, electrolysis, adsorption, setting-out, centrifugal and membrane separation, fluidization, neutralization and remineralization, reduction and oxidation, and so on [6]. Any of the above methods can be combined depending on the type of contaminated water and prospective purpose (Fig.1) [15]. These methods work well, but recent notorious anthropogenic pollutants (result of modern human life style) pose a challenge to purify/treat the contaminated water.

Research is still continued on use of advance nanotechnology in water purification for safe drinking.

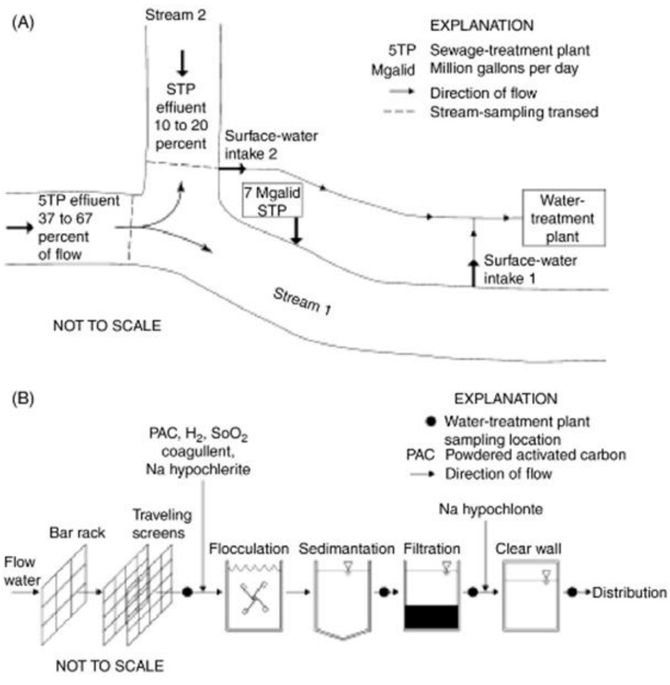

Figure 1: Schematic diagram showing (A) location of stream sampling sites, surface-water intakes, and drinking-water-treatment plant, and (B) physical and chemical processes used in drinking-water-treatment plant. [15]

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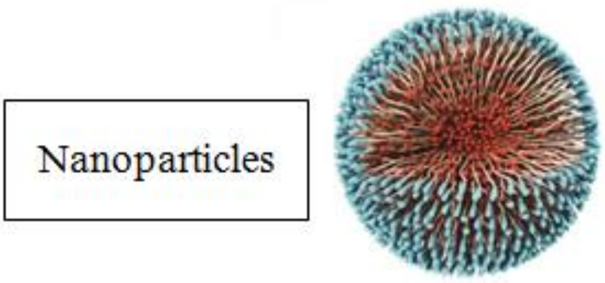
Nanotechnology is the controlled manipulation of matter at size scales of less than 100 nm, holds the promise of creating new materials and devices which take advantage of unique phenomena realized at those length scales, because of their high reactivity due to the large surface to volume ratio [16]. Nanoparticles are expected to play a crucial role in water purification [17].



The environmental fate and toxicity of a material are critical issues in materials selection and design for water purification. No doubt that nanotechnology is better than other technique used in water treatment but today the knowledge about the environmental fate, transport and toxicity of nano-materials [18] is still in infancy.

Advances in nanoscale science and engineering suggest that many of the current problems involving water quality could be resolved or totally diminished by using nonabsorbent, nanocatalysts, bioactive nanoparticles, nanostructured catalytic membranes, submicron, nanopowder, nanotubes, magnetic nanoparticles, granules, flake, high surface area metal particle supramolecular assemblies with characteristic length scales of 9-10 nm including clusters, micromolecules, nanoparticles and colloids have a significant impact on water quality in natural environment (Figure 2) [19]. Nanotechnology used for detection of chemical and biological substances including metals (e.g. Cadmium, copper, lead, mercury, nitrate, nitrite), cyanide organics, algae (e.g. cyanobacterial toxins) viruses, bacteria, parasites, antibiotics and biological agents are used as weapon for terrorism.

Innovations and improvement in the development of novel technologies to desalinate water are among the most exciting and seem to have promise [20].

Opportunities and challenges of using nanomaterials in the purification of surface water, ground water and industrial wastewater streams is a matter of continuing concern. Misconceptions and one of the many impressions that people have about the future of nanotechnology is the expectation that nanoparticles can be used to kill harmful organisms, repair body tissue, in water quality improvement and to cure disease.

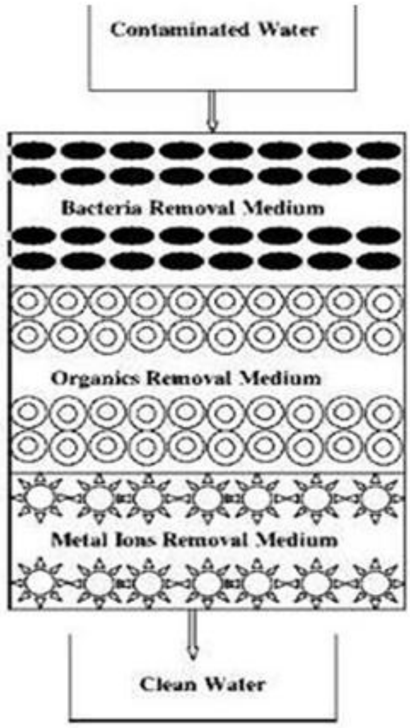


Figure 2: Schematic of a composite nanomaterial packed bed reactor for purification of water Contaminated by mixtures of (i) metal ions, (ii) Organic solutes and (iii) bacteria [20]

2. Importance of Nanotechnology

Recent research shows, applications of nanoparticulate silver have included open wound and burn treatment and preliminary studies have shown that a 20 ppm silver colloidal suspension (~ 30 nm diameters) in purified water has a 100% cure rate for malaria [19].

Titanium dioxide, especially as nanoparticulate anatase, is also an interesting antibacterial, with notable photocatalytic behavior. Nanocapsules and nanodevices may present new possibilities for drug delivery, gene therapy, medical diagnostics, antimicrobial activity etc.

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Iron oxide and titanium dioxide are good sorbents for metal contaminants. Spherical aggregates of nanoparticles that have a similar size and shape to the resin beads already used in water purification.

Nanoparticles can also be designed and synthesized in such manner to act as either separation or reaction media for pollutants. The high surface area to mass ratios of nanoparticles can enhance the adsorption capacities many times of sorbent materials.

Nanotechnology is a deliberate manipulation of matter at size scales of less than 100 nm holds the promise of creating new materials and devices which take advantage of unique phenomena realized at those length scales.

In addition to having high specific surface areas, nanoparticles also have unique adsorption properties due to different distributions of reactive surface sites and disordered surface regions. Their extremely small size is of the same scale as the critical size for physical phenomena for example, the radius of the tip of a crack in a material may be in the range 1-100 nm. The way a crack grows in a larger scale, bulk material is likely to be different from crack propagation in a nanomaterial where crack and particle size are comparable.

3. Types of Nano-Particles

3.1 Zero-Valent Metal Nanoparticles

3.1.1 Silver Nanoparticles

Silver nanoparticles (Ag NPs) are highly toxic to microorganisms and thus have strong antibacterial effects against a wide range of microorganisms, including viruses [21], bacteria [22], and fungi [23]. As a good antimicrobial agent, silver nanoparticles have been widely used for the disinfection of water.

The mechanism of the antimicrobial effects of Ag NPs is not clearly known and remains under debate. In recent years, several theories have been put forward. Ag NPs have been reported to be able to adhere to the bacterial cell wall and subsequently penetrate it, resulting in structural changes of the cell membrane and thus increasing its permeability [24]. Besides, when Ag NPs are in contact with bacteria, free radicals can be generated. They have the ability to damage the cell membrane and are considered to cause the death of cells [25]. In addition, as DNA contains abundant sulfur and phosphorus elements, AgNPs can act with it and thus destroy it. This is another explanation for the death of cells caused by Ag NPs [26]. What is more, the dissolution of Ag NPs will release antimicrobial Ag+ ions, which can interact with the thiol groups of many vital enzymes, inactivate them, and disrupt normal functions in the cell [27].

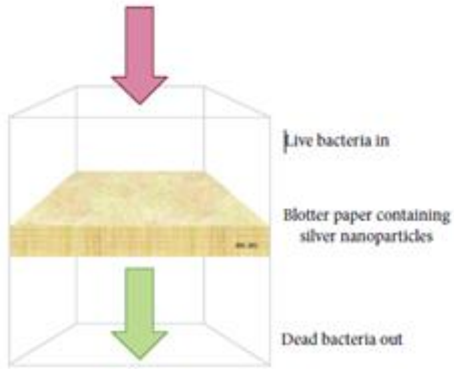

Figure 3: Types of Nano-Particles

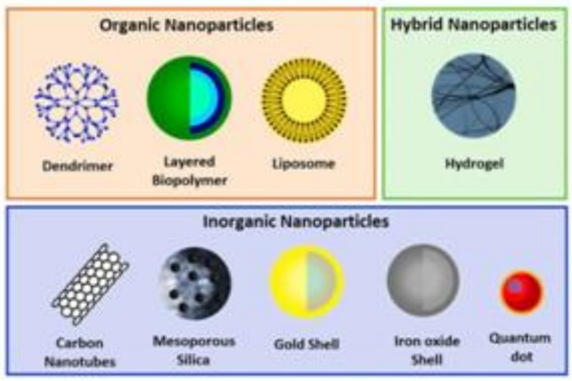

Figure 4: Schematic presentation of the disinfection process of blotter paper

3.1.2 Iron Nanoparticles.

In recent years, various zero-valent metal nanoparticles, such as Fe, Zn, Al, and Ni, in water pollution treatment have drawn wide research interest. The standard reduction potentials of Fe, Al, Ni, and Zn. Due to the extremely high reductive ability, nanozero- valent Al is thermodynamically unstable in the presence of water, which favors the formation of oxides/hydroxides on the surface, impeding (completely) the transfer of electrons from the metal surface to the contaminants [29]. Compared with Fe, Ni has a less negative standard reduction potential, indicating a lower reducing ability.

3.1.3 Zinc Nanoparticles

Although most studies on contaminant degradation in water and wastewater treatment by zerovalent metal nanoparticles have been focused on iron, Zn has also been considered as an alternative [30]. With a more negative standard reduction potential, Zn is a stronger reductant compared with Fe. Therefore, the contaminant degradation

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rate of zinc nanoparticles may be faster than that of nZVI. For the application of nano-zero-valent zinc (nZVZ), most studies have been focused on dehalogenation reaction. Research indicated that the reduction rates of CCl4 by nZVZ were more significantly affected by solution chemistry than particle size or surface morphology. By comparing the reactivity of various types of nZVI.

3.2 Metal Oxides Nanoparticles

3.2.1 TiO_2 Nanoparticles

As an emerging and promising technology, photocatalytic degradation has attracted great attention since 1972 when Fujishima and Honda [31] observed electrochemical photolysis of water on TiO2 semiconductor electrode. In recent years, photocatalytic degradation technology has been successfully applied in the contaminant degradation in water and wastewater. At the presence of light and catalyst, contaminants can be gradually oxidized into low molecular weight intermediate products and eventually transformed into CO_2, H_2O, and anions such as NO_3^{-}, PO_4^{3-}, and Cl−.

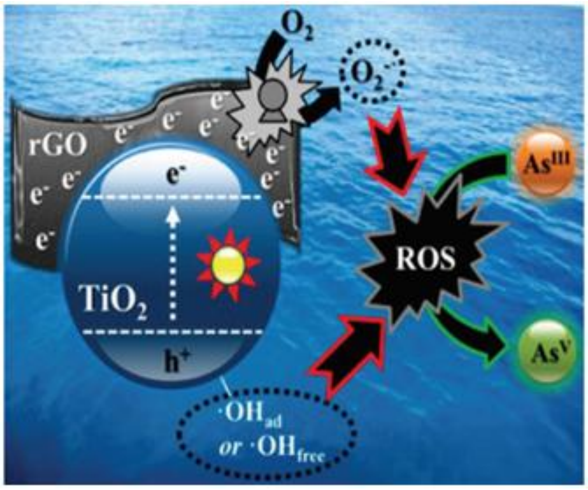

Figure 5: Schematic presentation of the mechanism of TiO_2 photo-catalytic process [32]

3.2.2 ZnO Nanoparticles

In the field of photocatalysis, apart from TiO_2 NPs, ZnO NPs have emerged as another efficient candidate in water and wastewater treatment because of their unique characteristics, such as direct and wide band gap in the near-UV spectral region, strong oxidation ability, and good photocatalytic property [33-35].

3.2.3 Iron Oxides Nanoparticles

In recent years, there is a growing interest in the use of iron oxides nanoparticles for the removal of heavy metal due to their simplicity and availability. Magnetic magnetite (Fe3O4) and magnetic maghemite and nonmagnetic hematite are often used as nanoadsorbents.

3.3 Carbon Nanotubes

Carbon nanomaterials (CNMs) are a class of fascinating materials due to their unique structures and electronic properties which make them attractive for fundamental studies as well as diverse applications, especially in sorption processes [63]. Their advantages for water and wastewater treatment are due to (1) great capacity to adsorb a wide range of contaminants, (2) fast kinetics, (3) large specific surface area, and (4) selectivity towards aromatics [6]. There are several forms of CNMs, such as carbon nanotubes (CNTs), carbon beads, carbon fibers, and nanoporous carbon [6]. Among them, CNTs have attracted the most attentions and progressed rapidly in recent years.

3.4 Nanocomposites

As mentioned above, every nanomaterial has its own drawbacks. For example, nZVI has the disadvantages of aggregation, oxidation, and separation difficulty from the degraded systems. The light adsorption of TiO_2 NPs and ZnO NPs is limited in the ultraviolet light region due to their big band gap energies. Nano filtration membranes are troubled by the problem of membrane fouling. Carbon nanotubes are mainly limited by their low volume of production and high cost as well as the need for supporting medium or matrix. In order to overcome these problems and achieve better removal efficiency, it is a common and effective strategy to fabricate nanocomposites for water and wastewater treatment [36].

4. Techniques for Water Purifications

4.1 Household water-treatment systems

- Boiling
- Household slow sand filter
- Domestic chlorination

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4.2 Community water-treatment system

- Storage and sedimentation
- Up-flow roughing filter
- Slow sand filtration
- Chlorination in piped water-supply systems

Techniques for Water Purifications:

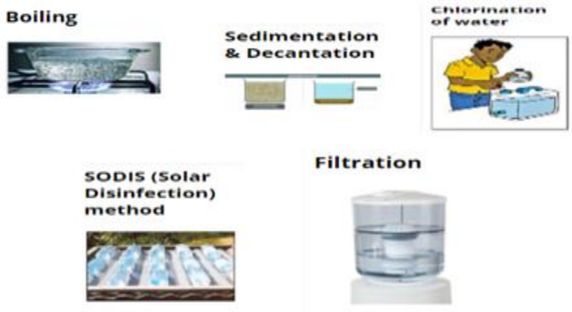
Boiling: In this process, water needs to be rolling boiled and should be kept in a clean pot and covered. It is the cheapest and safest method of water purification. Easy to kill the microorganisms in household system

Sedimentation & Decantation: Sedimentation is a process of removing solids that lies at the bottom of the surface through gravity. Decantation is a process for the separation of mixtures of immiscible liquids and solids such as suspension. It is a commonly used method for water purification. Fewer chemicals are required for water treatment. Removal of settable solids can reduce turbidities and make the water more amenable to other treatment methods to reduce microbes. Low-cost technology to reduce settable solids and perhaps some microbes for water

Chlorination of water: is the process of mixing chlorine in the water that kills germs and purifies the water. However, pregnant women are not recommended to drink chlorinated water. This method is usually considered appropriate during emergency conditions. In this method, a chlorine tablet or drop is kept in the water. The mixture should be then stirred and left for at least 30 minutes. Within this time frame, the chlorine will react and oxidize any organic matter in the water. Chlorine is a powerful oxidizing agent thereby getting rid of many bacteria in water. Chlorine is easily available. Chlorination of water is a cost-effective method.

SODIS (Solar Disinfection) method: is a method of water purification that relies on solar energy where contaminated water transparent container is exposed to direct sunlight usually for not less than 6-8 hours. The principle underlying solar disinfection is that microorganisms are vulnerable to light and heat. It has been proven that as soon as the water temperature reaches 50 °C, the inactivation process is accelerated which usually leads to complete bacteriological disinfection.

It's safe and easy method of water purification. Economical method compared with other methods of water purification as it relies on locally available resources, plastic bottles, and sunlight environment flexibility.



Filtration: This process includes removing harmful toxins from the hard water where the water will go through various kinds of equipment. It also helps in the reduction of high concentration of the minerals in the water. Likewise, it is a very common method for water purification. It is very easy and straightforward to use. The taste and odor of the water will improve, also gets rid of chlorine present in the water. This method makes sure about the removal of toxins from hard water.

5. Nano-adsorption

Adsorption is a surface process wherein pollutants are adsorbed on a solid surface. Adsorption takes place in general by physical forces, but sometimes this can be attributed to weak chemical bonds. The efficiency of conventional adsorbents may be restricted by their surface area, and the lack of selectivity [5]. Usually nano-adsorbents are used to remove inorganic and organic pollutants from water and wastewater.

5.1 Carbon-Based Nano-adsorbents

Removal of Organic Contaminants: Carbon-based nanoadsorbents, such as carbon nanotubes (CNTs) are cylindrical. CNTs are explored as substitutes for activated carbon. CNTs are categorized as single-walled nanotubes and multi walled nanotubes (MWCNTs) depending on their preparation. CNTs contain a high specific surface area with highly assessable adsorption sites. Their surface chemistry can also be modified accordingly [37]. The hydrophobic surface of CNTs makes them form loose bundles/aggregates in aqueous medium, which reduces the active surface area. These aggregates are high-energy sites for the adsorption of organic contaminants in water.

5.2 Removal of Heavy Metal Ions

Surface-oxidized CNTs using hydrogen peroxide, $KMnO_4$, and nitric acid are used in the removal of Cd^{2+} from aqueous solutions. The oxidation of CNTs may have high adsorption capacity for metal ions with faster kinetics. The surface of oxidized CNTs contains functional groups, such as carboxylic acid, hydroxyl, and carbonyls (Fig. 5) (38). These groups have good adsorbing capacity for heavy metal ions

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when the pH is above the isoelectric point of the oxidized CNT [39, 40, 41]. A sponge made of CNTs with a dash of boron showed a very good adsorbing capacity for oil from water. These sponges are reusable once the oil is removed from them, and they are promising in the removal of oil spills for oil remediation.

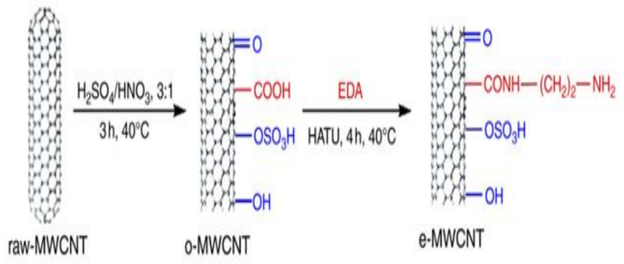

Figure 6: Functionalization of MWCNT for the removal of heavy metals [38]

5.3 Metal-Based Nanoadsorbents

Metal-based nanoadsorbents, such as iron oxide, titanium dioxide, zinc oxide, and alumina are used in heavy metal removal during water decontamination. They are effective and low-cost materials. The mechanism of action is that the oxygen in metal oxides complexed with heavy metals dissolves in contaminated water [3]. As the particle size decreases, the adsorption capacity increases several fold (Fig. 6).

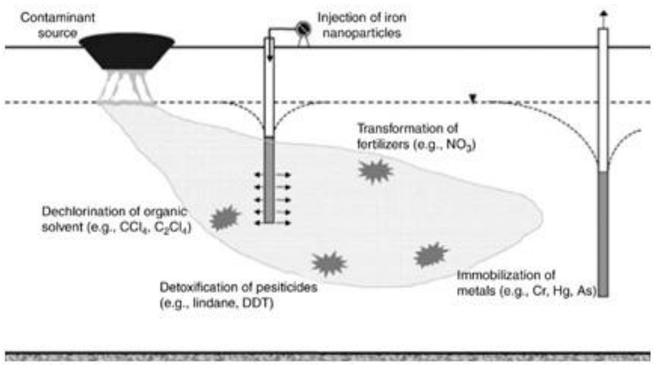

Figure 7: Nanoscale iron particles for in situ remediation [42]

5.4 Polymeric Nanoadsorbents

Polymeric nanoadsorbents gained interest recently. They are used either as a system into which inorganic nanosized materials can be inserted or as a bed or template to prepare nanoparticles [43].The most important advantage of the polymer-inorganic nanoadsorbents is their good adsorption capacity and very good thermal stability over a wide range of pH. Further, the resistance of polymeric groups and their linkages to acid and base hydrolysis is an added advantage.

6. Membranes and Membrane Process

A membrane is a porous thin-layered material that allows water molecules to pass through it, but at simultaneously restricts the passage of bacteria, viruses, salts, and metals. Membranes use either pressure-driven forces or electrical technologies. Pressure driven membrane technology is a perfect method for water purification to any desired quality [44]. Membrane separation processes are increasingly advanced methods for the treatment of water and waste water. Membranes separate substances depending on pore and molecule size. It is a reliable and automated process for wastewater treatment [45]. The challenge of membrane technology is the inherent tradeoff between membrane selectivity and permeability. This technique requires high-energy consumption due to the pressure-driven process. Fouling of membranes makes the process very complex and also reduces the life time of membranes and membrane modules [5]. The performance of the membrane system depends on the type of membrane material. Functional nanomaterial inclusion into membranes is definitely advantageous in the improvement of membrane permeability, fouling resistance, mechanical, and thermal stability.

6.1 Nanofiber Membranes

Electro spinning is a simple, inexpensive, and efficient technique to fabricate nanofibers. These nanofibers contain high surface area, porosity, and form nanofiber mats with complex pore structures. The physical and chemical parameters of electro spun nanofibers can be easily manipulated for different applications. This class of membranes removes micron-sized particles from water without any significant fouling. Thus, nanofibers can be used in pretreatment prior to ultra-filtration or reverse osmosis. Electro spinning is a widely employed technology in air treatment, not so common in wastewater treatment [46]. The fibers are free flowing, but get rid of dirt, bacteria, viruses, and proteins through Columbic interactions. Nano Ceram can be applied in commercial/industrial water treatment as a microbiological sampler or as a stand-alone filtration device .Membranes made of hydrophobic nanofiber materials might become very appropriate for separation of organic solvents, leading to higher flux efficiency [47].

6.2 Nano-composite Membranes

Nano-composite membranes are promising filtration units; they may be fabricated from mixed matrices and surface-functionalized membrane. Mixed matrix membranes use nano fillers, and most are inorganic. They are mixed to a polymeric or inorganic oxide matrix, and have substantial surface area [45]. Hydrophilic metal oxide nanoparticles (Al_2O_3, TiO_2, and zeolite), antimicrobial nanoparticles (nano-

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Ag and CNTs), and (photo) catalytic nanomaterials (bimetallic nanoparticles, TiO_2) are some of the nanomaterials used for such applications [5]. Nano composite membranes are made up of ordered mesoporous carbons as nanofillers fabricated as thin-film polymeric matrices. They are semipermeable, the top surface used in reverse osmosis. Atmospheric pressure plasma converts hydrophobic mesoporous carbons to a hydrophilic one.

6.3 Thin-Film Nano-composite Membranes

Thin-film nano-composite (TFN) membranes are a new category of composite membranes prepared by an interfacial polymerization process. Nanoparticles are incorporated within the thin layer of the polymer to improve the properties of the interfacially polymerized layer [40]. Nanomaterials, such as nanozeolates, nano-Ag, nano-TiO2, and CNTs were incorporated as nanoparticles into active thin layers of thin film composite [40, 45]. Zeolite-polyamide nanocomposite thin films were prepared by interfacial polymerization, which results in reverse osmosis membranes with improved permeability and interfacial properties when compared to similarly formed pure polyamide thin films.

6.4 Aquaporin-Based or Biologically Inspired Membranes

Aquaporins are pore-forming protein channels. They are ubiquitous in living cells. Under specific conditions they regulate water flux to reject most ionic molecules [45]. They are selectively permeable to water; ideal material for making efficient biomimetic membranes for water purification. Aquaporin is unstable, so incorporated into small vesicles embedded in a matrix [45]. Aquaporin Inside (Aquaporin A/S, Copenhagen, Denmark), first commercial membrane with embedded aquaporin. They withstand pressures up to 10 bar, and water flux rate >100 L/(hm2). One of the examples of using this product is in desalination.

7. Photocatalysis

Photocatalysis is an advanced oxidation process employed in the treatment of water and wastewater. This technique is based on the oxidative elimination of micro-pollutants and microbial pathogensn [45]. Most organic pollutants can be degraded by heterogeneous photocatalysis [48]. TiO_2 is a validated photocatalyst as it is readily availability, safe, and inexpensive [5]. When TiO2 is irradiated by UV light in the range of 200–390 nm, electron-hole pair (e−-h+)s is photoexcited. They move into the conduction (CB) and valent (VB) bands, which results in charge separation for an effective photocatalytic function depending on redox potential of a substrate. Therefore, the biodegradability of heavily decomposable substances can be increased in a pretreatment step.

8. Antimicrobial Nanomaterials in Disinfection and Microbial Control

Current disinfection methods applied in the treatment of drinking water can effectively control the microbial pathogens. Research conducted in the past few decades, however, discloses a dilemma between effective disinfection and formation of harmful disinfection by-products (DBPs) [49]. The commonly used chemical disinfectants in the water industry are chlorine, chloramines, and ozone. They can react with other constituents in the water and generate harmful DBPs. Most are carcinogenic [50]. There were more than 600 DBPs, such as halogenated DBPs, carcinogenic nitrosamines, bromate, and so on, reported in the literature. UV-disinfection processes have come out as an alternative for oxidative disinfection, since they generate fewer DBPs, while the required high dosage for certain viruses, such as adenoviruses. All these limitations urge the development of alternative methods that can enhance the robustness of disinfection while avoiding DBP formation.

The ideal disinfectant should have the following properties (modified from Hossain et al., 2014):

1) Very-broad antimicrobial activity at ambient temperature within short time;
2) Cannot produce any harmful by-products during and after their use;
3) Does not affect human health;
4) Inexpensive and easy apply for the intended use;
5) Easy to store, highly soluble in water, and must not be corrosive for any equipment or surface; and
6) Amenable to safe disposal. Materials, such as nano-Ag, nano-ZnO, nano-TiO2, CNTs, and fullerenes exhibit antimicrobial properties without strong oxidation; they have lower tendency to form DBPs [49, 50].

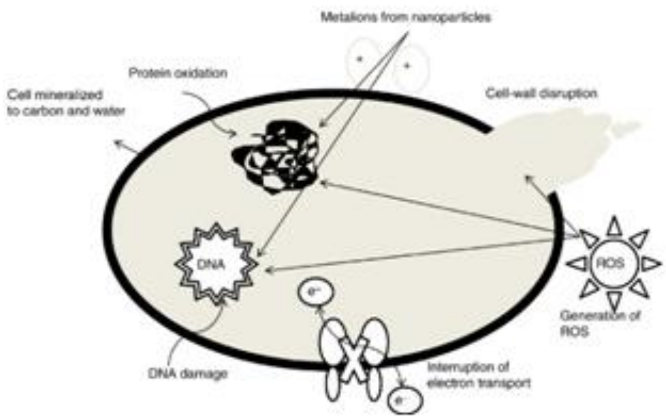

Figure 8: Different mechanisms of antimicrobial activities showed by nanomaterials

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8.1 Nano Antimicrobial Polymers

Polymeric nanoparticles kill microorganisms either by releasing antibiotics, antimicrobial peptides, and antimicrobial agents or by contact-killing cationic surfaces, such as quaternary ammonium compounds, alkyl pyridiniums, or quaternary phosphonium. Different antibacterial mechanisms are reported to show how these cationic groups are able to disrupt bacterial cell membrane. The main mechanism is that the hydrophobic chains of certain lengths will penetrate and burst the bacterial membrane. It has been shown that high levels of positive charge are capable of conferring antimicrobial properties irrespective of hydrophobic chain length, perhaps by an ion exchange mechanism between the bacterial membrane and the charged surface.

9. Safety, Toxicity, and Environmental Impact of Nanomaterials

Due to our current poor understanding of the fate and behavior of nanoparticles in humans and the environment, toxicity is becoming one of the urgent issues of nanotechnology. The main concerns related to nanotechnology are the hazardousness of nanoparticles and the exposure to risk [52]. Biological and chemical effects on humans or the environment is the first major issue. The second is of leakage, spillage, circulation, and concentration of nanoparticles that might cause a hazard to humans or the environment. Properties, such as size, shape, reactivity, and so on, are making these nanomaterials very useful. The same properties can also make them harmful to the environment and toxic to humans [3]. The entry of nanoparticles into our body is possible through the skin, inhalation, ingestion, and so on. After reaching the bloodstream, they can travel to various body parts, such as the brain, heart, liver, kidneys, spleen, bone marrow, and nervous system. The toxicity of nanoparticles is due to their properties and can lead to high chemical reactivity and production of ROS. Production of ROS is possible from CNTs and metal oxides. The ROS generated will cause oxidative stress, inflammation, which results in damage to proteins, membranes, and DNA [3]. There is a possibility that nanoparticles can adsorb on the body surface and alter the mechanisms of enzymes and certain proteins. Nanoparticles show their toxicity in the environment by agglomeration. Environmental risk analysis of nanoparticles is mentioned in the literature. Knowledge of hazards and exposure risks of nanoparticles to the ecology is less among the scientific community, so risk assessment and management is crucial.

The challenge is to resolve problems before nanoparticle usage starts on a large scale in water purification. There must be safety evaluation, large-scale production facilities, safe disposal of wastes, and energy efficiency. These are the major challenges that may cause delay in the large-scale application of nanotechnology in water purification. However, the behavior of nanoparticles inside the body is still a major question that needs to be addressed.

10. Limitations of Nano Technology in Water Purification

However, further studies are still needed to address the challenges of nano-materials. Up to now, only a few kinds of nanomaterials have emerged commercially. Since low production cost is crucial to ensure their wide spread applications in water and wastewater treatment, future research should be devoted to improving the economic efficiency of nanomaterials. Besides, with increasingly extensive applications of nanomaterials in water and wastewater treatment, there are growing concerns on their potential toxicity to the environment and human health. Available information in the literature has revealed that several nanomaterials may have adverse effects on the environment and human health. Nevertheless, standards for assessing the toxicity of nanomaterials are relatively insufficient at present. Hence, comprehensive evaluation of the toxicity of nanomaterials is in urgent need to ensure their real applications. What is more, the evaluation and comparison of the performance of various nanomaterials in water and wastewater treatment are still short of uniform or recognized standards. It is difficult to compare the performances of different nanomaterials and figure out promising nanomaterials that deserve further development. Therefore, the performance evaluation mechanism of nanomaterials in water and wastewater treatment should be perfected in the future.

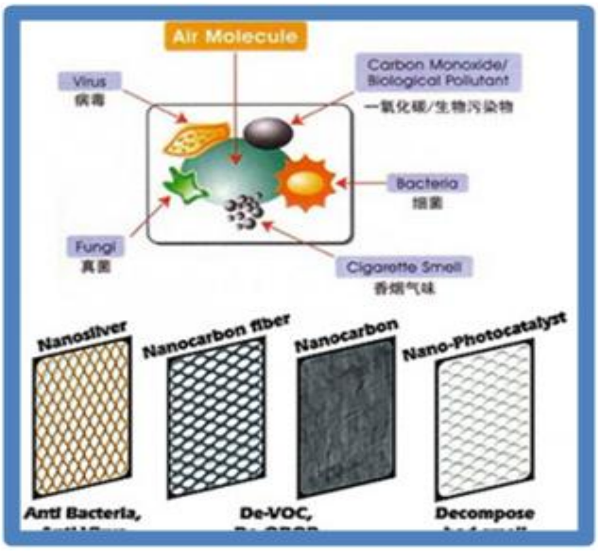

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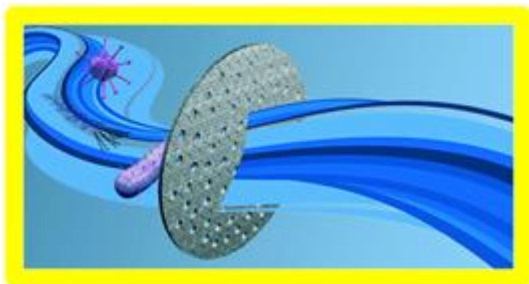
Table 1: Major Limitations Associated with Conventional Water Purification Methods [3]

Conventional Methods	Limitations
Distillation	Most contaminants remain behind and require high amounts of energy and water. Pollutants with boiling point > 100°C are difficult to remove
Chemical transformation	Excess reagents are required. Product may be a low-quality mixture and cannot be released into environment. Inactive in harsh conditions. This is not highly selective method
Coagulation and flocculation	This is a complex and less-efficient method and requires alkaline additives to achieve optimum pH
Biological treatment	Microorganisms are sensitive to environmental factors and difficult to control. Intermediates damage the microbial cells. This is not cost effective. Time consuming
Ultraviolet treatment	Expensive method and inactivated by water cloudiness and turbidity. Ineffective for heavy metals and other nonliving contaminants removal
Reverse osmosis	This method removes minerals from water which is unhealthy, and the treated water will be acidic. This method cannot remove volatile organics, chemicals, chlorine, chloramines and pharmaceuticals. Requires high energy
Nanofilteration	This technique requires high energy, and pretreatment. Limited retention for salts and univalent ions. Membrane fouling will occur with limited lifetime and expensive
Ultrafiltration	This method will not remove dissolved inorganics. Requires high energy. Susceptible to particulate plugging and difficult to clean
Microfiltration	Cannot remove nitrates, fluoride, metals, sodium, volatile organics, color, and so on. Requires regular cleaning. Membrane fouling will occur. Less sensitive to microbes, especially virus
Carbon filter	Cannot remove nitrates, fluoride, metals, sodium, and so on. Clogging occurs with undissolved solids. Susceptible to mold. Requires frequent changing of filters

11. Nanotechnology applications in water purifications

Applications of nanotechnology the applications of nanotechnology are broad in scope and are involved in many industrial, military, medical, agricultural and other fields, for example that a large group of raw materials are improved to effect a change in the physical properties of small or nanoscale sizes. Nanoparticles, for example, benefit from an apparent increase in surface area to volume ratio. Hence its optical properties, including fluorescence, become a function of particle diameter. When incorporated into a bulk material, the nanoparticles strongly affect the mechanical properties of the material, including stiffness or ductility. For example, conventional polymers can be reinforced through the use of nanoparticles in the new materials, which may be used as lightweight alternatives to metals. As a result, the social benefit of nanoparticles can be expected to increase.

These nanostructured materials will enable a reduction in weight associated with an increase in stability and an improvement in functionality. In addition, practical nanotechnology imperatively represents the increased ability to delicately manipulate matter according to previously impossible scales, thereby providing a host of capabilities that others had previously not imagined - so it is not surprising that few areas of human technology have been excluded from the benefits of using And the application of nanotechnology.



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12. Applications of nanotechnology to sterilize wastewater

Water pollution is the most difficult environmental challenge facing society, so pollutants from sewage or industrial wastewater must be considered a threat to the environment. Therefore, distinguishing the physical, chemical and biological aspects of raw water and treated water is crucial to ensuring that it is safe to dispose of in the aquatic or desert environment.

The arrival of pollutants to groundwater from sewage or industrial water causes serious health problems, because groundwater can be used by humans for drinking purposes and for other purposes in some areas. Heavy metals are likely to be the most common water problem consumers' face. Heavy metals (such as arsenic, zinc, iron, manganese, aluminum, cadmium, lead, etc.) cause many health problems if they are found in drinking water in concentrations higher than permissible. Nanotechnology first appeared millions of years ago as particles began to arrange into complex shapes and structures that launched life on Earth.

The use of nanotechnology in treating polluted sites has proven worthwhile, saving time and reducing the concentration of pollutants to the minimum permissible levels. Advances in nanoscience indicate that many of the current problems related to water quality can be solved or avoided by using nanomaterials, such as bioactive nanoparticles, nanopowders, nanotubes or nanosensors. Nanomaterials have been used in many environmental applications such as treating polluted water for drinking, agriculture, and modern applications more than traditional methods. The rapid development in nanotechnology research has provided new strategies in the field of environmental remediation.

The degree of removal of impurities present in the water depends on the nature of the stage and the application in which it is used. Nanotechnology purification can be used to get rid of and remove sediments, chemical effluents, charged particles, bacteria and other pathogens, remove toxic elements such as arsenic, and get rid of high-viscosity liquid impurities such as oils.

The team involved in the study says, "The main advantages of using nanofilters - unlike conventional filtration systems - Is that this nanofilter enables water to pass through it easily without high pressure and more efficiently due to its large surface area. The reversal of the water flow is carried out to ensure that any pollutants that have built up are expelled through the filtration system. It is much smoother than traditional methods.

For example, membranes of tubes and nanopanels can remove nearly all kinds of contaminants in water that include turbidity, oils, bacteria, viruses, and organic pollutants.

Although their pores are very small, carbon nanotubes have a higher flow rate than those with large pores. This is because the tubes are smooth on the inside. (The Smooth Interior Of the Nanotubes)

Nanofibrous Alumina and other types of nanofibers remove negatively charged contaminants such as viruses, bacteria, and organic and inorganic colloids much faster than conventional filtration and filtration systems. "Although the current generation of nanofiltration systems is relatively simple, it is expected that during the coming future of nanotechnologies based on water treatment and purification through nanoscale devices, the benefits of the properties of new nanomaterials will double."

Research scientists have acknowledged that the risks associated with nanomaterials cannot have the same risks associated with materials themselves in their bulk state because the area-to-volume ratio in nanoparticles can make them more reactive than bulk materials, which in turn lead to unknown and untested interactions with biological surfaces.

13. Conclusion

It should be noted that water technology using nanotechnology has not yet led to any health or environmental problems, but the team of scientists is striving to conduct more research and studies on the biological interactions of nanoparticles. It should be noted that water technology using nanotechnology has not yet led to any health or environmental problems, but the team of scientists is striving to conduct more research and studies on the biological interactions of nanoparticles.

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