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Applications of nanomaterials in wastewater treatment

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ABSTRACT

The accessibility of good quality water is important for all living creatures in the world. The major requirement in the present era is the treatment of wastewater due to scarcity of water resources. Adsorption, flocculation, filtration etc., are some of the techniques but they are used only for primary treatment of wastewater. It is required to develop techniques with low capital requirement and high efficiency. The recent advanced technology, nanomaterials have attracted the attention for wastewater treatment. Nanoscale properties of nanomaterials such as catalysis, adsorption, reactivity, greater surface area makes them effectively useful for the treatment of wastewater. Various types of nanomaterials are being used for the removal of different contaminants from wastewater. Activated carbon, carbon nanotubes, graphene, titanium oxide, magnesium oxide are some examples of nano-adsorbents which are used for the removal of heavy metals from wastewater. For the removal of organic and inorganic pollutants from water nanocatalyst such as electrocatalyst, photocatalyst have been potentially employed. This review article is focused on the advancements which have been made in the area of wastewater treatment by using nanomaterials.

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1. Introduction

Although 71% of the Earth's surface is covered with water, less than 1% is available for human consumption [1]. Water is the basic need and most vital substance required by all on earth. Due to the rapid industrialization different contaminants such as heavy metal ions, radionuclides, pathogenic bacteria, viruses are released into water resources which makes them harmful to human health. When the quality of water is degraded by industrial effluents, organic pollutants or any other compounds then it becomes wastewater. Some factors such as level of groundwater, land use affect the composition of wastewater. Selective treatment should be employed to filter water with the consideration of cost involved in filtration process [2].

Selecting the most efficient method and the right material for wastewater treatment is of utmost important, considering the efficiency and the cost of the treatment. Hence, while selecting the method of wastewater treatment, it's efficiency, reuse of the materials used, eco-friendliness and cost effectiveness must be considered [3,4].

Conventional water treatment techniques like reverse osmosis, distillation, coagulation-flocculation, bio-sand and filtration are not capable enough in removing all heavy metal ions. As adsorption technology is cost effective, highly efficient, and easy to operate, it is regarded as an important method to remove heavy metal ions from wastewater.

Zeolites, activated carbon, chelating materials, clay minerals are some materials which are used to adsorb heavy metal ions from the solution. But the low sorption tendency of traditional sorbents restrict the use of these deeply [5]. Currently, nanotechnology, known due to its unique physiochemical properties of nanomaterials, is emerging as a widely applied technology in different areas of environmental remediation. For the elimination of organic and inorganic pollutants, toxic metals wide range of nanomaterial are being tested. Economically nanotechnology is helpful for the utilization of water resources and energy conservation [6].

Nanostructured adsorbents are also used for wastewater treatment as they exhibit much higher efficiency and reacts at faster rate. For the adsorption of metals and organic compounds magnetic nanoparticles are being developed. Nanofiltration technique

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is also used to remove industrial pollutants such as bisphenol-A, phthalates, alkylphenols, etc. from groundwater. In the modern era, a new term Green Nanotechnology is coined. The main aim of green technology includes minimal health hazards, environmental risks etc. [7]. This review focuses on the use of various nanomaterials applied in the treatment of wastewater.

2. Nanomaterials

Materials with the dimension of 1–100 nm are categorized as nanomaterials. The characteristic properties of nanomaterials such as adsorption, high surface to volume ratio, catalytic activities and reactivity make them significant. As nanomaterials are small in size, the surface area of nanomaterials is greater which make them highly compatible. Variety of nanomaterials are observed which exhibit their own specific properties [8].

2.1. Silver nanomaterials

Silver nanomaterials are widely used as in the form of colloidal silver. Silver nanomaterials has proven to be used as antimicrobial agents and have extensively used against naturally occurring microorganisms [9]. Vital cellular components of microorganism are disturbed by silver nanomaterial which results in death of pathogenic microorganism. Nanomaterial binds on the cell membrane leading to cell lysis. For community water, in hospitals silver nanomaterial are used for water purification. They have been used as a substitute for chlorine in filtration technique [10]. Silver nanomaterials are potentially used in reducing the biofouling and as an effective disinfectant in sewage and wastewater treatment for the removal of *E. coli* and other pathogen [11]. Ag nanomaterial are used with increased efficiency by inserting high porosity filters [12].

Pathogenic bacteria are killed by silver nanomaterials by inducing physical perturbation with oxidative stress through disturbance of vital cellular component. They are cost effectiveness possessing high antibacterial activity which have been considered as the most promising for water disinfection [13]. Polyethersulphone (PES) microfiltration membranes was used for incorporating silver nanomaterials synthesized by chemical reduction and the microorganisms present nearby the membrane were not active enough [14]. Environmental Protection Agency (EPA) and World Health Organization (WHO) has put forward that the standard for silver in drinking water was greater than the silver loss from silver nanomaterials [15].

2.2. Carbon nanomaterials

Carbon nanomaterials prepared from most abundant element carbon are extensively used for the purification of water. Carbon nanomaterials have the capability of regeneration by which the adsorption capacity of carbon spent can be recovered through which the economic application of activated carbon can be determined. But during regeneration some percentage of adsorption capacity will be lost [16].

The discovery of the first fullerene in 1985 has opened a new horizon for the synthesis of carbo nanotube (CNTs) [17]. The first CNT was fabricated in the year 1991 [18]. CNTs are synthesized from graphite using arc discharge; laser ablation; or by chemical vapor deposition from carbon-containing gas. Owing to their hydrogen bonding, hydrophobic interactions, ion exchange, electrostatic interactions with the pollutants of wastewater, CNTs have gained considerable interest in recent years. Researchers are now focusing on the incorporation of CNTs in several devices due to their outstanding adsorbance of organic and inorganic pollutants.

CNTs have been reported as strong sorbents for 1,2-dichlorobenzene [19], atrazine [20], butane [21], dichlorodiphenyltrichloroethane (DDT) [22], dioxin [23], peptone and α- phenylalanine [24], and other polar and nonpolar organic chemicals. Synthesized CNT-based membrane filters consisting of hollow cylinders coupled with radially aligned CNT walls have been effectively used to remove bacteria and viruses from contaminated water [25].

Heavy metals which are discharged into aquatic environment and absorbed in living tissues are to be removed from water and this can be achieved by using multi-walled CNTs whose adsorption capacity can be increased by oxidizing it with nitric acid [26]. CNTs possesses high capability as sorbents for organic compounds such as polycyclic aromatic hydrocarbons, phenolic compounds, endocrine disrupt compounds and antibiotics [27]. For some pharmaceuticals compounds like diclofenac sodium, carbamazepine, CNTs exhibit good mechanical strength, high sorption capacity, hydrophilicity and during regeneration process these compounds can be decomposed [28]. For improving the properties of CNTs sometimes they are mixed with other metals by which the number of oxygen, nitrogen or other groups increases on the surface of CNTs which enhances their dispersibilty and results in the improvement of their specific surface area [29–31]. The interstitial spaces and grooves present in the CNTs are sites of high adsorption for organic molecules and because of larger pores in bundles of CNTs they have high adsorption capacity for bulky organic molecules [32]. Due to short intraparticle diffusion distance and highly accessible adsorption sites, CNTs are used as better adsorbents for heavy metals [33].

2.3. Iron nanomaterials

Iron nanomaterials are widely used in wastewater treatment. The treatment done by using iron nanomaterials is mostly based upon reductive dehalogenation reaction. Iron nanoparticles are cost effective and on reaction with contaminants they are converted into hydroxides which works as flocculant, used in the removal of inorganic and organic contamination [34]. The hydrophobic membrane which is present around the nanomaterial of zinc act as a protective covering for it which otherwise might react with the contaminants and decreases the capacity of nanomaterial [35]. Iron oxide nanomaterial which possesses large surface area and high reactivity bind with the solid and colloidal impurities of water by acting as a solid sorbent. Elemental iron in combination with metal catalyst such as nickel, palladium, platinum forms bi metallic nanomaterial which increases the kinetics of redox reaction [36].

Iron nanomaterials can be used for the treatment of contamination depending upon their mobility; mobile contaminations and immobile contaminations. For static contaminant body, mobile iron is used and is directly injected upstream for treatment [37]. When immobilized into iron surface some contaminants such as Ar(III/V), U(VI), Se(VI) can be reduced to lower oxidation state [38]. Under anaerobic conditions, oxidation of Fe^0 can be done by H_2O or H^+ that produce Fe^{2+} and H_2 which are used as potential reducing agents for contaminants [39]. Halogenated organic compounds [40], nitroaromatic compounds [41], metalloids [42], inorganic anions such as phosphates and nitrates [43] have been successfully removed with the effects of adsorption, reduction, precipitation and oxidation by iron nanomaterials.

2.4. Iron oxide nanomaterials

Strong sorption capability, simple to operate, resourcefulness, and availability have attracted the attention towards the use of iron oxide nanomaterials in wastewater treatment. Magnetite,

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