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Mini Review

Innovative Nanotechnology Applications for Water Purification: Mini Review

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ABSTRACT

The challenge of providing clean, affordable water for all in the 21st century is worsened by climate change, increased population, and declining water quality. Nanotechnology can help with improved water management by enabling the development of novel nanomaterials for the treatment of surface water, wastewater, and groundwater pollutants by organic and inorganic solutes, toxic metals, and microorganisms. Current wastewater treatment includes nanoadsorbents, photocatalysis, magnetic nanoparticles, and hybrid catalytic wet air oxidation technology. Nanotechnology's growing significance in various industries, including scientific research, medicine, and food, is because of its capability to monitor and manage hazardous wastes more effectively, economically, and with less energy.

Keywords: Wastewater; Nanotechnology; Nanomaterials; Artificial intelligence.

INTRODUCTION

Substances, including pathogens, organic contaminants, industrial effluent, heavy metals, and anions that do not break down naturally, make it more challenging to access inexpensive, clean water globally [1]. Modern infrastructure may be updated with the help of nanotechnology, which also provides high-performing, low-cost treatments. The application of nanotechnology for water and wastewater has been the subject of research. Methods include catalytic pollution destruction, adsorption of contaminants on nanoparticles, and nanoscale filtration [2,3]. This strategy uses affordable, novel water treatment techniques to prolong and ultimately use the existing water sources while simultaneously addressing the problems associated with existing treatment. Because of their extreme surface-to-volume ratios, nanomaterials have favourable interactions with pollutants and microorganisms [4].

LITERATURE REVIEW

Eliminating waterborne viruses and removing non-biodegradable organic pollutants provide a substantial barrier that must be overcome without producing dangerous disinfection byproducts. Research on eco-friendly, low-cost alternatives to conventional methods-like AOPs-that may mineralize and oxidise organic substances has been directed towards finding a solution to this problem [5]. A well-known Advanced Oxidation Processes (AOP) for increasing the biodegradability of persistent organic pollutants to eliminate microbiological illnesses is photocatalysis. In photocatalytic oxidation, strong reactive radical species i.e., H_2O_2, O_3, $O_2^{\bullet -}$, and hydroxyl radicals ($OH^{\bullet}$) are produced by a catalyst activated by chemicals, light, or other energy sources [6]. Figure 1 represents the several techniques for generating $OH^{\bullet}$ radicals.

Photo-Fenton, heterogeneous photocatalysis, and UV or solar light irradiation are crucial for purifying water. Heterogeneous is a more efficient method of sterilising water and eliminating organic impurities than Photo-Fenton, which is more expensive and complicated. While heterogeneous photocatalysis is more economical, pH rectification is required to regulate photoactive iron complexes [7].

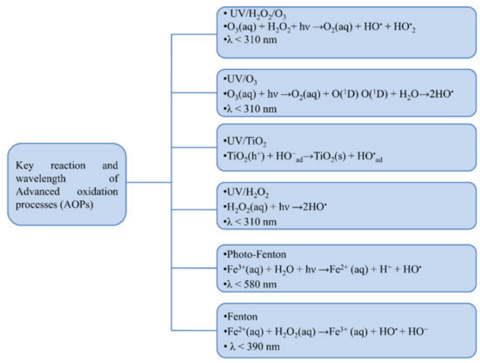

Figure 1: Demonstrates AOPs that generate OH radicals through radiation.

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The synthesis of Pt, Pd, and Ru nanoparticles embedded in a highly cross-linked polystyrene matrix has demonstrated their superiority as CWAO catalysts of phenol [8]. It can potentially directly oxidise harmful contaminants into products that pose no risk (CO_2, H_2O, N_2). Since Ru is the least expensive of the metals mentioned above, ruthenium-containing catalysts are the most effective for treating wastewater. N-doped carbon nanomaterials have recently attracted some attention to support metal catalysts [9]. The addition of nitrogen to the carbon framework greatly improves control over the surface and electrical characteristics of carbon nanotubes, Carbon Nano Fibers (CNFs), or graphene. The use of N-doped carbon nanomaterials as metal catalyst supports is likely to enhance catalytic activity for processes such as ammonia breakdown, isotope exchange, CO oxidation, and selective hydrogenation of cinnamon aldehyde. All these processes use fuel cells to electrochemically oxidise hydrogen or methanol.

One possible technique for eliminating aqueous organic contaminants is photocatalysis, which uses semiconductor particles. It is being thought of as a cutting-edge oxidation method for treating water. Because of their strong photocatalytic activity, low toxicity, and superior chemical stability, TiO_2 nanoparticles are this procedure's most popular and efficient material. Using solar light or artificial UV radiation, photocatalytic oxidation processes may convert completely mineralized organic molecules into CO_2, H_2O, and other inorganic chemicals. The sol-gel process produced Titanium dioxide nanoparticles and calcined in a furnace at 400°C and 700°C. Photocatalysis under UV light irradiation and the presence of TiO_2 nanoparticles was utilized to investigate methyl orange degradation. Methyl orange can be broken down by heat-treated TiO_2 nanoparticles; the lowest dosages showed the greatest clearance rate. The results suggest that Azo dyes in wastewater may be removed by heterogeneous photocatalysis when UV light is present [10].

Because of the small contaminants, quick pathogen identification, and complex water and wastewater matrix, water quality monitoring is essential for wastewater treatment. Developing new devices with increased selectivity, sensitivity, and reaction times is necessary. Various sensors are used for the detection of pathogens and trace pollutants.

Adenoviruses, echoviruses, hepatitis A and E, Coxsackieviruses, Giardia, adenoviruses, and Cryptosporidium are a few instances of the crucial or novel illnesses for which pathogen identification is critical to public health. The sensitivity, effectiveness, and multiplex target detection of pathogen sensors based on nanomaterials are being researched. Nanomaterials, including dye-doped NPs, magnetic nanoparticles, CNTs, Quantum Dots (QDs), and precious metals have all been thoroughly researched for sample purification and reduction. Many pathogen detection kits are made with the commercial magnetic nanocomposite Dynabead® [11].

Silica nanoparticles doped with inorganic or organic brilliant dyes make ultra-sensitive sensors. In addition to shielding the pigment particles from the environment and lowering photodegradation and photobleaching, these nanoparticles boost sensitivity by incorporating many dye molecules. Rich silica chemistry allows additional modification and conjugation, making them perfect for intense or extended excitations [12].

Nanomaterials with high adsorption capacities, quick recovery rates, and kinetics, like Carbon Nano Tubes (CNTs), are particularly promising for environmental research. They can detect and concentrate organic and inorganic pollutants with fast adsorption rates, with preconcentration factors ranging from 20 to 300 [13]. To preconcentrate organic compounds, CNTs have been thoroughly investigated; several investigations on water samples have been carried out. Charged species clinging to CNTs alter conductance, which explains the link among current fluctuation and analyte concentration. TiO_2 nanotubes with quantum dots have lower Polycyclic Aromatic Hydrocarbon (PAH) detection limits, and nano-Au, a nanoparticle, has been utilized to detect pesticides at ppb levels. With a nanosensor based on CoTe QDs, bisphenol A in water may be found at low concentrations as 10 nm in about 5s [14].

By integrating microscale and nanoscale manufacturing processes, minute quantities of chemical or biological substances in water may be precisely identified by compact, adaptable, and accurate sensors. Nanomaterials including nanowires, Carbon NanoTubes (CNTs), metal nanoparticles, quantum dots, and nanocantilevers are used to create nanosensors, which are minute devices that can detect things like pathogens, mRNA, proteins, and enzyme activity. Boron-doped silicon nanowires have created sensitive, real-time electrical sensors identifying substances and living things [15]. Parallel viral detection is feasible, and it has been proposed that individual viruses might be identified electrically using nanowires. Additionally, nanosensors can more quickly and affordably detect bacteria and analyses water quality. However, these procedures are time-consuming and require many protocols.

Artificial Intelligence (AI) can successfully remove toxins from polluted Wastewater and Water Treatment Facilities (W&W), but further study is required. An environmental contaminant that is often discharged into industrial effluents is Volatile Organic Compounds (VOCs) [16]. While AI has been utilized to treat VOCs from gas streams, there is little literature on its application to the removal of VOCs from polluted effluents. Increasingly investigation is advised as VOCs are found in wastewater streams increasingly frequently. Microbial electrolysis and microbial desalination cells are two energy-producing techniques that can also employ AI-based approaches [17].

Several AI-specific tools, including Adaptive Neuro-Fuzzy Inference Systems (ANFIS), deep learning, hybrid artificial intelligence, Bismuth Based Nanoparticles (BBNs), genetic algorithms, FL, artificial neural networks, etc., have demonstrated their wide usefulness to desalinate and treat water for several purposes (Figure 2). Because AI approaches are easy to apply, accurate, flexible, and yield desired results. Since AI techniques prioritize predictability above model fit, they are more appropriate for producing models of water treatment processes in actual circumstances and can be constructed more quickly and easily [18]. It is also possible for policymakers to use these strategies efficiently and cost-effectively by using them to solve non-linear water quality data issues [19,20].

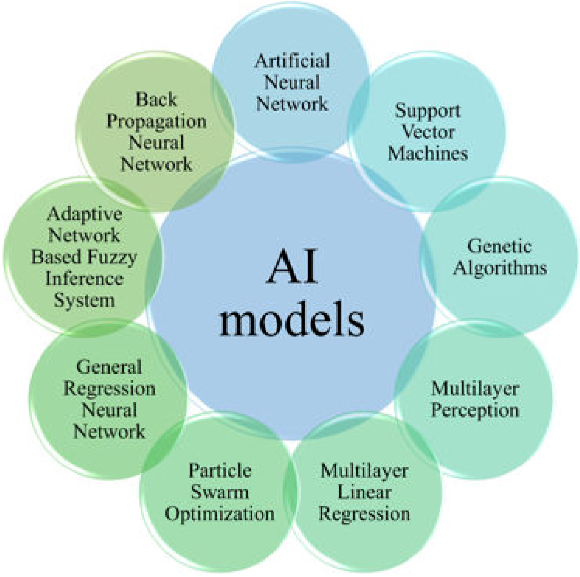

Figure 2: Assessment of water quality using artificial intelligence models.

DISSCUSSION AND CONCLUSION

Water purification processes may become much more effective and efficient because of the growth of novel technologies and materials made possible by nanotechnology. For use in water treatment processes, including filtration, adsorption, and photocatalysis, a broad range of nanomaterials, i.e., nanoparticles, have been created. Nanoparticles have a high surface area, are chemically reactive, and are selective, which allows them to remove a wide range of contaminants from water. Photocatalysts and catalytic wet air oxidation are the most promising nanomaterials for water treatment; they have special qualities that make it possible to effectively remove a wide range of impurities from water. Additionally, novel methods for the real-time monitoring and detection of water quality have been made possible by advancements in nanotechnology-based sensing and monitoring systems. Moreover, combining nanotechnology with AI technologies might result in more innovative and effective water treatment solutions. The worldwide problem of supplying clean and safe drinking water is being addressed by ongoing development and research in nanotechnology for water purification, which offers an intriguing and promising solution.

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CONFLICTS OF INTEREST

The authors declare no conflict of interests.

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