



Applications of Nanoadsorbent Technology in Treatment of Industrial Wastewater: A Review

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Abstract

Water pollution and freshwater contamination are one of the global problems that directly affect the lives of organisms that one way or the other rely on water for their livelihood. To alleviate these challenges, various treatment methods such as membrane filtration, ion exchange, coagulation as well as adsorption have been adopted to reduce wastewater generated and improve qualities of effluent discharged from industries to meet specified minimum permissible limits. Among all, adsorption is considered to be more efficient in terms of cost, ease of handling, and re-use for water treatment. Furthermore, adsorption technology exhibits excellent removal efficiency using adsorbents prepared from raw or waste materials or nanoparticles synthesized from wastes. Nano-materials exhibit outstanding properties such as small particle size, catalytic potential, large surface area, and a great number of active sites, hence allowing high removal efficiency. The nano-material in this context referred to as “new generation nano-adsorbent” is capable of removing pollutants even at low concentrations. Numerous pathways of synthesizing nanoparticles fall under two approaches namely: bottom-up and top-down approaches. Different materials have been adopted for bulk and nano-based adsorbent with their efficiency varying for different wastewater sources, nature of the adsorbents, adsorbent dosage, and experimental conditions. This study has reviewed the advancement of wastewater treatment using waste and nano-based materials as an adsorbent from 2015 till 2021 and convincingly establishes the potential of nano-adsorbents for wastewater treatment.

1. Introduction

Nanotechnology was first postulated by Richard Feynman in 1959 and considered as one of the fastest-growing fields of scientific research as well as technology development globally. It involves using a set of techniques to obtain materials with novel functionalities and improved characteristics (Kalantary *et al.*, 2018). Recently, nanotechnology-related procedures are suggested for groundwater, wastewater, and drinking water remediation.

Nanostructures have completely different optical, electrical, and magnetic properties, greater reactivity with polluting atoms as well as faster chemical processes. These unique characteristics make nanotechnology attractive in terms of eliminating contaminants and enabling wastewater treatment. Literature revealed that pollutants emerging from wastewater streams are mostly chemical substances that are non-biodegradable and persist in the environment, thereby, causing

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adverse effects not only to human health but also to the environment (Jadoun *et al.*, 2019). Conventional techniques are limited due to relatively low efficiency especially where micro-pollutants are involved. Adsorption techniques using activated carbon had proven to be a very effective method for environmental control and wastewater management (Okeowo *et al.*, 2020).

Nano-materials have been profoundly employed in water and wastewater treatments, as rendered due to their distinctive properties such as large specific surface area, high reactivity and affinity toward the target contaminants, and high extent of functionalization (Hussain *et al.*, 2016). Nanoparticles usage has been cited in different literature, as one of the most advanced processes for wastewater treatment. Over the years, it has been used for water treatment even in domestic households (Kapoor *et al.*, 2021). Hamdy *et al.* (2018) focused on the removal of methylene blue from aqueous solutions and textile wastewater using Zero-valent iron nanoparticles (nZVI particle). This study revealed that the nZVI particles were appropriate for the adsorption of methylene blue (MB) from aqueous solutions, achieving removal efficiency up to 97.2% at an initial concentration (Co) and time of 10 mg/L and 30 min respectively.

Sethy *et al.* (2020) also synthesized titanium oxide nanoparticles (TiO₂-NP) from *Syzygiumcumini* extract. The synthesized nanoparticles were successfully used as a photo-catalyst for the removal of lead from explosive industrial wastewater in a cost-effective way with 75.5% removal of chemical oxygen demand (COD) and 82.53% removal of lead (Pb²⁺). Similarly, iron –copper bimetallic nanoparticles (FeCu Bi-NPs) were synthesized and applied in coal mine wastewater treatment. The synthesized material proved to be effective in removing Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) with 92 and 97%, respectively, and has high phosphate removal with 98% efficacy (Dlamini

et al., 2021).

2. Nanoparticles

Nanoparticles (NPs) have strong adsorption capacities and reactivity due to their small sizes and large surface area. A nanoparticle exists as organic and inorganic components comprising ferritins, liposomes, micelles, and dendrimers. It also exists with magnetic properties in metal and semiconductor NPs such as oxides, nitrides, and sulfides, respectively. The utilization and application of nanoparticles are widely focused on the field of chemicals, energy, healthcare, and cosmetics. Nanoparticles also have a vital role in the modification, production, and shape of the different structures which play a unique role in the manufacturing zone like in environmental applications. NPs are different from macroparticles due to their optical, electrical, and magnetic properties (Jadoun *et al.*, 2019).

NPs synthesis is based on three foremost conditions namely: selection of green or environment-friendly solvent, a good reducing agent, and harmless material for stabilization. Extensive synthetic routes applied for nanoparticles includes physical, chemical, and biosynthetic routes. Generally, the chemical methods used are too expensive and incorporate the use of hazardous and toxic chemicals answerable for various risks to the environment (Sadegh *et al.*, 2017). The biosynthetic route is a safe, biocompatible, environment-friendly green approach to synthesize nanoparticles. Plants, microorganisms as well as animal materials, and their metabolites had been proven to be used in the biosynthesis of different nanoparticles (Akintayo *et al.*, 2020). Nanoparticles synthesis can be carried out with microorganisms, plants, and metabolites of animals such as fungi, algae, bacteria (Singh *et al.*, 2016); leaves, fruits, roots, stem, seeds (Razavi *et al.*, 2015); and cobweb, nest extract of paper wasp, eggshell, fur, wings (Lateef *et al.*, 2016) respectively. Plant parts have been used for the synthesis of various nanoparticles due to the pres-

ence of photochemical in its extract which acts as stabilization and reducing agents (Razavi *et al.*, 2015).

Numerous biological and physicochemical pathways of synthesizing nanoparticles fall under two discrete classes namely: bottom-up, and top-down approaches. The bottom-up approach involves the generation of nanoparticles from small units like molecules and atoms or through the self-assembly of atoms into new nuclei, which further grow into a particle possessing nanoscopic dimensions and employing various chemical and biological methods such as chemical reduction, electrochemical methods, and sono decomposition molecules (Geonmonond *et al.*, 2018). In addition, several synthesis techniques for the “bottom-up” option include co-precipitation, hydrothermal, thermal decomposition, solvothermal, sol-gel, sonochemical, microwave-assisted, micro-emulsion, as well as polyol techniques (Kefeni *et al.*, 2017).

The "Top-down approach" is an approach where nanoparticles are formed by a size reduction method that means suitable bulk material reduces to small units with the use of appropriate lithographic methods, for example crushing, spitting, and milling. It involves the use of external forces to break down solid materials into smaller pieces. This approach is costlier to implement and it is impossible to obtain perfect surfaces and edges due to cavities and roughness that can occur in nanoparticles (Geonmonond *et al.*, 2018). Zlotea *et al.* (2018) proved that the synthesis of dimagnesium cobalt (1) pentahydride (Mg_2CoH_5) nanoparticles using a bottom-up approach was feasible and it was concluded that the synthesis is based on three successive steps: firstly, cobalt (Co) nanoparticles were prepared on the carbon support, followed by the synthesis of MgH_2 nanoparticles on the Co containing carbon and finally the Mg_2CoH_5 nanoparticles were formed by the solid-gas reaction between MgH_2 , Co and hydrogen during heat

treatment under hydrogen pressure.

Batyret *al.* (2021) also synthesized platinum nanoparticles with controllable size and shape using a top-down approach. This research demonstrated the feasibility to synthesize nanoparticles in acidic electrolytes of which alkali cations are present in the solution and the pH is higher than 2.5. The results showed that top-down approach forms strained nanostructures, indicating that the particles are likely to be carved out from the bulk rather than formed through metal ion dissolution. Of all the approaches, bottom-up is more efficient as necessary precision reached down the atomic scale.

The biological route has been considered to be more feasible and greener technique than the chemical route because of the use of non-toxic, cost effective and environmentally beneficial biological materials (Kefeni *et al.*, 2017). Hence, green synthesis is the most advanced, naturally versatile, environmentally sound and economical method for large scale preparation of nano-materials.

In the “Green approach”, plants and plant parts have been well exploited in recent times in the synthesis of a variety of nanoparticles due to the rich biodiversity of plants and their potential secondary metabolites. Plant extracts contain abundant natural compounds such as alkaloids, flavonoids, saponins, steroids, tannins, and other nutritional compounds which act as reducing and stabilizing agents for the bioreduction reaction in the synthesis of metallic nanoparticles (Adelere and Lateef, 2016; Hussain *et al.*, 2016). Plants have successfully been used in the synthesis of various greener nanoparticles such as cobalt, copper, silver, gold, palladium, platinum, zinc oxide, as well as magnetite (Kuppusamy *et al.*, 2016). Exploitation of food and commercial valued plant products for nanoparticles synthesis reduces the overall efficacy of the biosynthetic process because of competition for use as food materials or other economic purposes. Hence, utilization of plentiful agro-

waste resources is an eco-friendly method of synthesis and a sustainable way for effective utilization and management of plant wastes and biomass. Nanoparticles have been successfully synthesized using various agro residues such as *Cocosnucifera* coir, corn cob, fruit seeds and peels, wheat bran, rice bran, pods, and palm oil mill effluent (Lateef *et al.*, 2016).

Ahmad *et al.* (2020) used soxhlet extraction technique to synthesize titanium dioxide (TiO₂) nanoparticles by using *Menthaarvensis* leaf extract. It was revealed that the TiO₂ nanoparticles produced were anatase structures with semi-crystalline character, FTIR examination demonstrates the role of leaves extract in the synthesis of TiO₂ and the round molded particles were affirmed through the SEM examination. The synthesized nanoparticles also showed significant antimicrobial activity against selected pathogenic microorganisms. This provides an idea to develop a new variety of antibacterial and antifungal materials. Similarly, different agro-wastes were used to synthesize nanoparticles and their environmental implications were studied. Research proved that wastes can be used to synthesize different nanoparticles such as nano-cellulose, metals and metal oxide nanoparticles, carbon nanoparticles, and nano-fibers by different methods. This indirectly helps to solve environmental problems, especially pollution, for which they are used as protective agents and adsorbents (Siddiqi and Husen, 2016).

Researchers also proved that nanoparticles can also be synthesized directly from nano compounds. Guilo *et al.* (2017) synthesized antimicrobial coatings based on tailored bi-elemental nanoparticles. The research proved that new nano-structured coatings were radically produced using a one-step gas-phase deposition. The coatings were also characterized by a cluster-in-cluster mixing phase with small metallic ultra-active microbicidal Ag hot-spots embedded in amorphous TiO₂, stable and strongly bonded to the substrate.

3. Impregnation of Nanofluid on Adsorbent

Over the past decades, adsorption process has emerged as one of the most effective and efficient treatment techniques for the removal of pollutants from wastewater. Adsorption is a surface phenomenon and the most widely used technology in water and wastewater treatment, because it has many advantages, such as simple design, low price, easy maintenance, and high efficiency (Wang and Zhuang, 2017). It can be classified into two namely: physisorption and chemisorption, based on the type of bonding between the adsorbent and the adsorbate.

Physisorption, also known as physical adsorption is a system where an electron is not exchanged between the adsorbent and adsorbate and conditions of pressure and temperature are appropriate. It is not specific, can be reversed and activation energy is not needed for the process. Chemisorption is a chemical adsorption process achieved between adsorbent and adsorbate molecules. It may only happen if the system is capable of making a chemical bond. In this process, the produced activated carbon has varied properties; the process is specific and not reversible.

The adsorbent or adsorbate can either be bounded by a covalent or ionic bond. If bounded by a covalent bond, it is called weak chemisorption, but if bound by an ionic bond, it is called strong chemisorption. Chemisorption is predominant in the case of surface-functionalized nanoparticles (Baruah *et al.*, 2019).

Because commercially produced activated carbon is expensive, numerous researchers have used adsorption process in treating effluent discharged by industries using green adsorbent processed from agricultural residues. Adsorption techniques have been in vogue in recent years for wastewater treatment owing to the economic benefits. Despite its popular usage, developing the properties of green adsorbents to merge the commercial one in term of adsorptive capacities remain a challenge.

Therefore, the need for more effective, safe, economical methods has encouraged research interest towards the modification of green adsorbents used in adsorption process (Aremu *et al.*, 2020). This review only considered adsorbent modified through impregnation of nanofluid on its structure. Applying the synthetic nanoparticles for modification of activated carbon is one of the impregnation methods found in the literature.

Under this category, Olajire *et al.*(2017) reported the removal of dibenzothiophene (DBT) from model oil (DBT dissolved in n-

heptane) by silver nanoparticles modified activated carbon (AgNPs-AC) prepared from brewer's spent grains using wet impregnation. The result proved that Ag nanoparticles-modified AC is a promising adsorbent for desulphurization of liquid fuels. Aremu *et al.* (2020) also removed phenol from wastewater using silver nanoparticle modified Palm Kernel shell activated carbon (AgNPs-PKSAC) produced by impregnating palm kernel shell activated carbon (PKSAC) with silver nanoparticles synthesized by reduction of AgNO₃ using *Cola nitida* shell ex-

Table 1: Applications of Green Nano-adsorbents in Wastewater Treatment

Adsorbent	Types of Nanoparticles (NPs)	Sources of Reducing agents	Applications	Efficiency (%)	References
Copper nano-adsorbent	Copper NPs	Tilia leaves	removal of pharmaceutical pollutants from real wastewater samples	100, 87 and 80 for diclofenac, naproxen and ibuprofen respectively	Husein <i>et al.</i> (2019)
Starch – silver NPs and feather-silver NPs	Silver NPs	Cocoa pods	Adsorption of rhodamine B (Rh-B)	89 and 70 for feather and starch AgNPs respectively	Azeez <i>et al.</i> (2019)
Silver nanoparticle modified Palm Kernel Shell Activated Carbon	Silver NPs	<i>Cola nitida</i> pod	Phenol sequestration from aqueous solution	90.3	Aremu <i>et al.</i> (2020)
<i>Moringa oleifera</i> leaf extract capped magnetic nanoparticles	Magnetic NPs	<i>Moringa oleifera</i> leaves	Removal of dye from simulated wastewater	90	Gautam <i>et al.</i> (2020)
ZnO-NPs Parthenium weed activated carbon	Zinc oxide (ZnO) NPs	Parthenium weed plant	Removal of methylene blue and chromium from aqueous solution	91	Kamaraj <i>et al.</i> (2020)
Fe ₂ O ₃ -Ag Nanocomposite	Silver-iron oxide Nanocomposite	<i>Psidium guajava</i> leaf	Remediation of chromium (VI) ions from aqueous media	95	Biswal <i>et al.</i> (2020)
Titanium-dioxide Nanoadsorbent	Titanium dioxide NPs	<i>Syzygium cumini</i> leaves	Photocatalytic removal of lead (Pb) in explosive industrial wastewater	82.53	Sethy <i>et al.</i> (2020)

tract. It revealed that the efficacy of PKSAC was improved by surface modification with Ag-nanoparticles. SEM analysis also revealed a larger pore diameter in Ag-NPs-PKSAC compared to PKSAC and PKS. The increased pore diameter is desirable for effective and efficient accommodation of phenol inside the pore spaces.

Similarly, Nayeri and Mousavi (2020) focused on dye removal from water and wastewater by nanosized metal oxides - modified activated carbon (AC-NMOs). It was reviewed that many researchers moved on to adsorption using metal oxide nanomaterials loaded on activated carbon as a promising method to overcome the previous shortcomings of adsorption by activated carbon (AC). However, this study proved that the technique was preferred because of many advantages such as the recovery of magnetized powdered activated carbon, synergistically improves the operation feature of integrated adsorbent, high effective dye removal and economic point of view.

Azeez *et al.* (2020) proved that Silver Nanoparticles (AgNPs) functionalized starch and feather were preferred as substitutes for the removal of Rhodamine B (Rh-B). This study investigated the functionalization of biocompatible and biodegradable natural polymers with silver nanoparticles (AgNPs) biosynthesized using extracts of cocoa pods to improve their adsorption performances. It was reported that rougher surface, change in surface chemistry with appearance of additional peak and less crystalline surfaces confirmed that functionalization truly occurred.

4. Water Treatment

Improper wastewater management is one of the major challenges facing the whole world. The disposal of wastewater directly into streams and rivers without proper treatment has a negative effect on the quality of water in surface water bodies. However, pollutants emerging from wastewater streams are mostly chemical substances that are non-biodegradable and persist in the environment,

thereby, causing adverse effects not only to human health but also to the environment (Jadoun *et al.*, 2019). Pollutants such as heavy metals, dyes, and pharmaceuticals among others enter into wastewater either from industrial effluents, or they may arise due to leaching of rocks from the nearby regions, resulting in contaminated water to be used for industrial or domestic purposes.

Treatment of wastewater should be considered in all aspects related to the contaminant remediation, and also, it has to be ensured that the discharged water is free from any substance that might adversely affect human health and the environment (Hussain *et al.*, 2016; Jadoun *et al.*, 2019).

Recently, nanotechnology found its place to treat wastewater effectively without much adverse effect on the surroundings, which makes the process to be cost-effective and environmental friendly. Nanotechnology may be classified based on the nano-materials nature into three main categories namely nano-catalysts, nano-membranes and nano-adsorbents. Nanocatalyst treatment includes photocatalytic activities which involve the interaction of light energy with metallic nanoparticles. The photocatalytic activities destroy microorganisms (bacteria) and organic substances via the reaction with hydroxyl radicals. The materials used in nanocatalysts are typically inorganic materials such as metal oxides and semiconductors (Moosavifar *et al.*, 2020).

Research was conducted by Nasrollahzadeh *et al.* (2021) on green-synthesized nanocatalysts and nanomaterials for wastewater treatment. It was confirmed that green-synthesized and biogenic nanocatalyst methods are cost-effective. Nano-membranes are extensively used for the removal of heavy metals, dyes, and other contaminants. Nanotubes, nanoribbons, and nanofibers are commonly used nano-membranes. The nanofibers are more effective in removing micropollutants from wastewater because of their loose and stable structures compared to tubes and ribbons. They have been profoundly employed in

water and wastewater treatments due to their distinctive properties such as large specific surface area, high reactivity and affinity toward the target contaminants, and high extent of functionalization (Hussain *et al.*, 2016).

The nano-adsorbents treatment utilizes organic or inorganic nanomaterials with a high affinity to adsorb substances. These adsorbents are highly capable of removing many contaminants. The ideal adsorbent is small, has a large surface area, great catalytic potential, and high reactivity. Carbon-based nano-adsorbent such as activated, porous, and graphite carbon are widely used and they interact with contaminants through hydrophobic, hydrogen bonding and covalent bonding interactions (Kurwadkar *et al.*, 2019). Clay nano-adsorbents have been proved to be a reliable material for manufacturing purposes because they provide cost-effective sustainable solutions to different industries for environmental health and safety (Awasthi *et al.*, 2019).

Takmil *et al.* (2020) carried out batch experiments to determine the highest adsorption efficiency of fluoride ions by studying the impact of several factors including pH, type and amount of buffer, contact time, sorbent dosage, electrolyte concentration, and temperature on the adsorption process. The results indicated that the specific surface area (SSA), pore volume (PV) and the mean pore size (MPZ) of the iron oxide (Fe_3O_4) were $65.439 \text{ m}^2/\text{g}$, $0.3963 \text{ cm}^3/\text{g}$ and 24.226 nm , respectively. Also, these properties were measured for the Fe_3O_4 /activated carbon (AC) nanocomposite as $226.78 \text{ m}^2/\text{g}$, $0.3301 \text{ cm}^3/\text{g}$, and 5.822 nm , respectively. The specific surface area of the composite was greater than Fe_3O_4 , which shows that the AC has resulted in improving the surface area of the Fe_3O_4 . Also, the mean pore size of both materials was between 2 and 50 nm, which indicated that both materials have mesoporous structures. It was confirmed that the maximum adsorption efficiency of fluoride ion using the Fe_3O_4 /AC composite of

97.4% was obtained in the sorption experiments at conditions; pH = 3, the composite dose = 1.5 g/L, time = 25 min, temperature = 40 °C, and fluoride ion concentration = 20 mg/l.

Similarly, Iron oxide-silver nanoparticles (Fe_3O_4 -AgNPs) were used to adsorb ibuprofen from wastewater (Vicente-Martínez *et al.*, 2020). This research focused on the effect of temperature on the adsorption process, it was observed that for temperature $T=298$ and 303 K , the adsorption efficiency reaches the same value, maximum while for T greater than 303 K , Fe_3O_4 -AgNPs is dissolved in the media. Equilibrium temperature choice for the adsorption procedure was then 298 K . This work proposes a novel simple method for the adsorption of Ibuprofen in water using Fe_3O_4 -AgNPs. The results show a maximum removal efficiency of ibuprofen to be 93% from aqueous solutions, achieving the maximum adsorption at neutral pH and room temperature. The procedure takes 45 min and employs a dose of adsorbent equal to 7 mg in 500 μL of suspension, which can be completely removed from the medium using a magnet. As a final remark, a simple method in acid media by using nitric acid at pH=1 has been proposed for the recycling and reuse of the adsorbent, which reaches 89.3% removal efficiency after three regenerations.

Aremu *et al.* (2020) adsorbed phenol from an aqueous solution using silver nanoparticle modified palm kernel shell activated carbon (AgNPs-PKSAC). The percentage removal of phenol by palm kernel shell activated carbon (PKSAC), silver nanoparticles-PKSAC (AgNPs-PKSAC) and commercial activated carbon were 85.6, 90.3 and 91.7%, respectively at conditions; initial phenol concentration, adsorbent dosage, contact time, and agitation rate of 200 mg/L, 0.25 g, 74 min and 156 rpm respectively. It was concluded that the increased pore diameter is desirable for effective and efficient accommodation of phenol inside the pore spaces.

Sethy *et al.* (2020) synthesized TiO₂ nanoparticles by a green approach using *Syzygiumcumini* leaf extract and the obtained nanoparticles were characterized to evaluate the physical, chemical, structural and morphological behavior of the NPs. The research investigated the effect of lead (Pb) concentration on the photocatalytic degradation rate. Decrease in Pb concentration from 8.6 ppm to 1.5 ppm in the presence of TiO₂ + UV after 17 h treatment was achieved. This sharp decline in concentration was due to the photo-catalytic activity of TiO₂ NPs on lead ion present in the water sample, while the minor change in concentration in dark condition was due to the adsorption of Pb on TiO₂ surface. However, a considerable decrease in chemical oxygen demand (COD) was observed after the photocatalytic treatment of wastewater using synthesized nanoparticles i.e. TiO₂ NPs. Synthesized TiO₂ nanoparticles were spherical and aggregated into an irregular structure with an average diameter of 18 nm in size. They possess average crystalline size, surface area, pore size diameter and total pore volume of 10 nm, 105 m² /g, 10.50 nm, and 0.278 cm³ /g, respectively. Synthesized nanoparticles were successfully used as a photo-catalyst for removal of lead from explosive industrial wastewater in a cost-effective way with 75.5% removal of Chemical Oxygen Demand (COD) and 82.53% removal of lead (Pb²⁺).

Abussaud *et al.* (2015) examined the adsorption characteristic for phenol on modified activated carbon by nanoparticles of iron oxide, aluminum oxide and titanium oxide. Analysis of modified and unmodified activated carbon was carried out to determine the physicochemical properties using SEM, EDS, TGA and BET surface area analysis. The effects of adsorbent dosage, contact time, pH, initial phenol concentration and shaking speed on the removal of phenol were also investigated on sorption of phenol from waters on activated carbon impregnated with iron oxide, aluminum oxide and titanium

oxide. SEM images reveal the presence of the white spots of AC–Al₂O₃ and AC–TiO₂. Hence, higher removal efficiency was observed titanium oxide, iron oxide and aluminum oxide impregnation has improved its phenol removal efficiency from aqueous solution due to additional adsorption sites. Table 1 shows summary of some nano-adsorbent used in wastewater treatment.

5. Challenges and Future trends in Nano Adsorbents Technology

Nanotechnology is the future of advanced development. It is everything today from clothes to food, there are in every sector of our lives. It should be promoted for our future and more developments in our current life. Nanotechnology is astounding, as it is the scientific research being done to make and control staggering nanomaterials. It can change dental medicine, healthcare, and human life profoundly than several developments of the past. However, they even have the potential to evoke important advantages, like improved health, higher use of natural resources, and reduced environmental pollution. It has effectively improved the world in ways we could not have imagined just a few years prior, and it will just keep on doing that in the future.

Along with the benefits, nanotechnology is not without its dangers and cautions. Among all risks associated with nanotechnology, the possible toxicity of nanomaterials should first be considered as science revealed that when a matter is shrunk to small sizes, the matter that is harmless in macroscales can become fatal at nanoscales. Although most nanomaterials are not toxic, however necessary precautions must be taken during future developments.

In addition, a large proportion of nanotechnology is focused on military applications, which may have negative implications on societal and political relations within the community. It is likely that nanotechnology will further widen the gap between the political violence available to the

military and those available to the civilian population and indirectly contribute to terrorism.

Another concern is employment, during the improvement of nanotechnology, industries are likely to have high demands for the scientists, engineers, and technicians who have to build and integrate the new ideas into processes and products. But at the same time, the demand for unskilled labour would drop drastically causing an imbalance in labour market. In conclusion, Nanomaterials will become an essential component of industrial and public wastewater treatment systems as more progress is made in nanotechnology in terms of economically efficient and eco-friendly technology development.

6. Conclusion

Nanotechnology-based treatments are more cost-effective, less time and energy-consuming with very small waste generations than conventional bulk materials-based methods. Nano-materials can integrate various properties, resulting in multifunctional systems such as nanocomposite membranes that enable both particle retention and elimination of contaminants. A nanomaterial also enables higher process efficiency due to its unique characteristics, such as a high reaction rate.

Nanoparticles have received special attention in the environmental field, because of their high surface-to-volume ratio, high mechanical strength, high ordered structure, and lower size. The loaded nanoparticles on the AC can improve the adsorption capacity and make the possible recovery of powdered adsorbents when using magnetic nanomaterials, especially iron oxide for developing a magnetized activated carbon (MAC) by simple economic separation.

Considering the challenges faced by wastewater treatment nanotechnologies is important despite that many of these challenges are only temporary. These challenges include technical hurdles, potential environmental and human risk as well as the recovery and

reuse of the nanomaterial and nano composites. To overcome these barriers collaborates efforts between research institutions, industry, government, and other stakeholders are essential. We believe that advancing nanotechnology by carefully making findings in its direction while avoiding unintended consequences can continuously provide robust solutions to wastewater treatment challenges.

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