

Engineered Nanoparticles for Wastewater Treatment System

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ABSTRACT: Industrial and commercial use of engineered nanoparticles is rising. Less care is given to the negative effects on the environment and wastewater treatment systems, which could release hazardous pathogens and microorganisms and threaten human health. Due to their size and features, artificial nanoparticles can easily enter wastewater systems and impair treatment. This paper aimed to focus on nanoparticle detection limitations and their effects on wastewater treatment technologies. Nanoparticles have the potential to be utilised in the treatment of waste water. By virtue of its exceptionally high surface area, it can effectively remove poisonous metal ions, microorganisms that cause disease, as well as organic and inorganic solutes from water. Various groups of nanomaterials, such as metal-containing nanoparticles, carbonaceous nanomaterials, zeolites, and dendrimers, have been demonstrated to be effective for water purification. Composites are two or more materials assembled synthetically. Nanocomposites are vital for environmental rehabilitation because pollution is one of the world's biggest concerns and polluted water management. Population growth has increased the need for clean water. This includes ceramics, metal-based polymers, carbon, and iron-based graphene. Nanocomposites such as carboxyl methyl may adsorb a heavy metal ion and pesticide at a satisfactory rate. This study found that nanocomposites are good for restoring the environment and can be used in countries with low incomes.

KEYWORDS: Heavy metal; pesticides; nanocomposites; environmental remediation; waste removal; advanced remediation processes

1. Introduction

Water pollution is the presence of hazardous chemicals and biological organisms that exceed what is naturally present in the water and may constitute a risk to human health and/or the

environment. In addition, water pollution may be caused by the introduction of chemicals into water bodies as a result of numerous human activities. Regardless of the dangers they represent to human health and the environment, any amount of these substances pollutes the water. Composites are described as materials generated by the synthetic assembly of two or more components or selected fiber or reinforcing agent and a compatible matrix in a binder to obtain a specified set of traits and attributes, such as nanocomposites, one of the composite types [1]. Nanocomposites are multiple-phase solid materials in which one of the phases has one, two, or three dimensions that are less than nanometers in size and have a scale that repeats the distances between the different phases that make up a material; they can be diverse materials on a single nanoplatform [2]. Due to the qualities of the materials, nanotechnology has received considerable attention. It has a greater surface-to-volume ratio and improved reactivity, making it more effective than conventional techniques. Nanomaterials can be functionalized or grafted with functional groups that target specific molecules of interest, such as contaminants, for cleanup, as compared to conventional techniques. Tuning the physical features of nanoparticles (size, shape, porosity, and composition) provides additional benefits that have a direct effect on the material's efficacy in contamination remediation. The chemistry and tuned parameters of the nanomaterial offer significant advantages over conventional methods that develop multiple combinations of nanocomposites, which give the nanomaterial specific properties desired from each of its components, and which are more efficient and stable than alternative methods for increasing the stability of materials when compared to the use of nanoparticles alone. The effectiveness of the item can be improved by using a material with special compounds that target molecules of pollution [3–7].

Despite the fact that environmental degradation is unquestionably one of the most significant problems confronted by modern cultures, with the development of technology being studied for the remediation of air, water, and soil contaminants [8]. Different types of materials have been used for environmental remediation, allowing for a wide range of approaches to be utilised for environmental remediation. However, the degradation of pollutants can be difficult due to the complexity of nanocomposites developed for environmental remediation [9]. Rapid industrialization has led to an increase in the discharge of heavy metals that can have a significant impact on the environment, such as Cr, which is highly toxic and has a recommended maximum concentration of 100 g/L, while arsenic has also been known for its toxicity. Contaminated water with arsenic has become a significant problem in drinking water because it is known to cause lungs, skin, liver, and prostate. This research was conducted to determine how nanotechnologies can be used to remediate heavy metals [10].

Achieving sustainable development remains elusive without universal access to safe water and clean cooking. The field of global public health research is littered with examples of underutilised, low-cost water purification systems and obsolete cooking stoves. There are lively discussions as to why so many households in low- and middle-income countries (LMICs) do not use simple, inexpensive measures that could enhance their quality of life. The demand for clean water has increased as a result of the world's growing population and the rapid development of the industrial and agricultural sectors, which use vast quantities of dangerous chemicals, poisonous materials, and pesticides, contaminating groundwater and generating waste. The phenomenon raised the need for clean water, namely drinking water. WHO (World Health Organization) guidelines allow aloe compounds to be present in drinking water without producing health problems. Humans utilise clean waterways for daily activities such as bathing,

drinking, etc. [11]. Development in nanotechnology is currently one of the most rapid trends in the modern period. The use of engineered nanoparticles (ENPs) is prevalent in numerous consumer and industrial items, including cosmetics, dyes, electronic products, etc. [12]. However, nanoparticle discharge in wastewater treatment, surface water, and groundwater would have detrimental effects on the efficacy of wastewater treatment systems, posing a grave hazard to the environment and human health. With the growing use of nanoparticles in consumer products, the amount of ENPs in home greywater is slowly going up. This is a key way for ENPs to get to commercial water treatment plants that don't have the equipment or skills to get rid of ENPs in wastewater.

2. Environmental Remediation

Environmental remediation tackles contaminants from soil and water, so it is important for the continuous growth of human society. Environmental remediation is a way to reduce waste or radiation exposure from groundwater or surface water [13]. Faced with the challenge of organic and inorganic pollution contamination, it is vital and urgent to create novel remediation solutions. Currently, adsorption is a conventional technique that has been widely explored, and numerous new adsorption materials are continually being developed. Several developing technologies, including electrocoagulation, membrane filtration, and nanocomposite, are also being implemented concurrently. Table 1 gives the types of environmental remediation.

Most water treatment processes are designated to treat impurities in the water such as sludge, large aggregate, and metal materials, but lack the capability to remove nanoparticles. Recent studies have shown that the presence of nanoparticles in water has increased intensively in both greywater and industrial effluents. In the current state, there aren't any official protocols or evaluations for ecotoxicity tests or classified characteristics of engineered nanoparticles. Furthermore, current knowledge in this field is scarce due to the insufficient analysis done by scientists on nanoparticles in complex wastewater samples. Also, challenges are faced in the experimental design to test the toxicity of engineered nanoparticles in real wastewater treatment systems. For instance, standard test methods, octanal water partition, and bioaccumulation potential could be affected by the physiochemistry of engineered nanoparticles. So, the standard chemical endpoint measurement and analysis methods, such as lethal concentration (LC), lowest observed effect concentration (LOEC), inhibitory concentration (IC), effective concentration (EC), or no observed effect concentration (NOEC), may not be enough to measure the effect of ENPs on microorganisms [14].

Furthermore, the detection of engineered nanoparticles not only requires advanced tracing, identification and quantification technologies in wastewater treatment systems but also different characteristics of samples. This is due to the fact that there are numerous compositions of wastewater which each contain different organic salts and organic wastes such as amines and carboxylic acids, which could act as ligands to further complex the nanoparticles and add difficulties in classifying the nanoparticles' properties [15].

Table 1. Some methods for wastewater treatment.

Methods	Roles	Advantages	Disadvantages	Mechanism	Ref.
Electrocoagulation	-Metal Electrodes are used to create coagulants	-Produce less sludge and effectively and destabilizes tiny colloidal particle -Could be used in industrial scales -Less energy requirement	-Lack of reactor design -Electrode passivation -Need for maintenance	Metal cations are dissolved from the reactor anode while hydroxyl ions and hydrogen gas are formed at the cathode.	[16,17]
Membrane filtration	-Solution containing the contaminants passed through the physical holes of the membrane under high pressure.	-There are no chemicals necessary -Water pollutants such as bacteria viruses, heavy metals, dissolved organic materials, and ions are removed	-High pressure is necessary -Disposal of filtered residuals -High Cost - Fouling/biofouling	-Uses a straining mechanism to extract particles from water	[16,17]
Biological degradation	-To dispose of alkaloids	-Low gaseous emissions -Low energy consumption -High degradation yield -More environmentally friendly	-Low decomposition rate -High capital investment -High disposal cost	-Chemical–biological reactions produced by the treatment of the polymer with microorganism-secreted enzymes	[18]
Coagulation/Agglomeration	-Use to remove solids from water by manipulating electrostatic charges	-Chemical coagulants were reduced -Sludge production was Reduced -DBP has been minimized	-Water quality is affected -Specific pH levels are required -Added coagulant	-Platelet activation, adhesion, and aggregation, as well as fibrin deposition and maturation	[16,17]
Photocatalysis	-Instead of chemical substances this technique uses harmless semiconductors that capture light with the right wavelength	-Using natural lighting -Reusable and no oxidizing chemicals are necessary -Match the temperature in the environment	-The response is temperature and relative humidity dependent	-Can directly capture and convert solar energy for environmental remediation, has been identified as the most green-sustainable and appropriate ways for resolving global environmental pollution issues.	[16,17]
Nanocomposite	-Play important role in the interaction with oxygen, surface defects, and morphology parameters	-Large adsorption capacity -Convenient for Recycling	-There is not much study covering nanocomposites such as using bacterial toxicity that is caused by the breakdown of ZnO rods in aqueous media, which produces Zn ²⁺ ions.	-There are many ways remediate the environment such as	[19]

3. Nanoparticles

Nanoparticles are defined as particles that are shaped and sized with at least one dimension between 1 and 100 nanometres (nm). There are various nanoparticles which each component contributes to disrupting different water treatment processes. Among all the engineered particles, silver nanoparticles and micro/nano plastic particles are focused on the interaction with wastewater treatment processes. Silver nanoparticles (AgNPs) are considered one of the

most commonly used nanomaterials due to their antibacterial properties, unique optical merits, high electrical conductivity, and aid in restraining the growth of catalytic activities [20]. Even though silver nanoparticles bring numerous benefits, silver nanoparticles are more noxious than their bulk counterparts due to their high surface fraction [21]. This is due to the fact that silver atoms are in direct contact with the microbial surface. In terms, silver nanoparticles are assumed to constrain microbial growth through the generation of reactive oxygen species (ROS). Hence, silver nanoparticles could pose a threat to the efficiency of wastewater treatment [22]. There are two types of lamellar nanoparticles that are intercalated nanocomposites and exfoliated Nanocomposites and lamellar composites can be divided into two distinct classes: intercalated and exfoliated nanocomposites [23]. As in Figure 1, nanocomposites can also be distinguished into two types: those that are polymer-based and non-polymer-based.

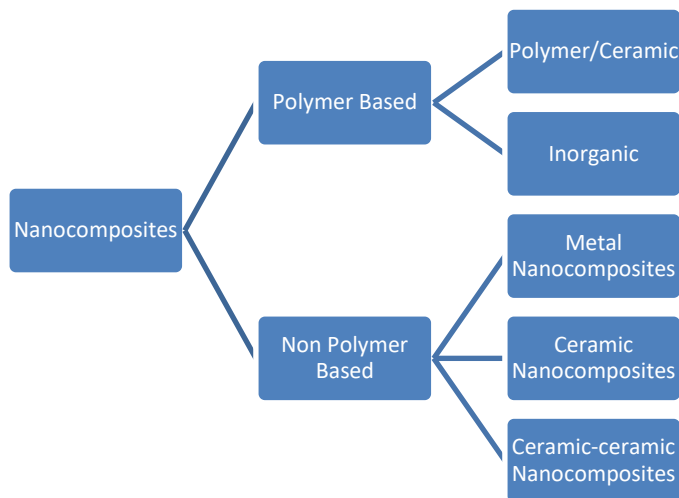


Figure 1. Types of nanocomposites.

Nanocomposites, particularly polymer nanocomposites, must be manufactured for their optimal application; the nanocomposites depending on the synthesis method used, such as solution blending, in situ polymerization, and melt processing. The primary basic materials for synthesis are polymers ranging from vinyl to exotic polymers [23].

4. Role of Nanocomposites in Environmental Remediation

Nanocomposites have numerous applications in a variety of disciplines, including air purification, wastewater treatment by removing heavy metals, soil enhancement, fertiliser delivery systems, food packaging, and flame retardancy. Nanocomposite composition provides a substantial surface area with unique features. Recently, nanocomposite structures have been utilised to filter water, improve fertiliser retention in soil, and promote plant growth, resulting in agricultural advancement, food packaging, and flame retardancy. The qualities of these nanocomposites depend on both the properties of their ingredients and the polymer/nano-filler combination [24]. Table 2 describes the roles of nanocomposites in wastewater treatment system.

Table 2. Roles of nanocomposites in wastewater treatment system.

Nanocomposite	Remediation	Advantage	Disadvantage	Ref
Metal Based	Remediation for Aquatic Pollutants	Portable Power Source	Expensive to make	[24-26]
Polymer Based	Pollutant sensing and detection; Cleaner Production	Light weight, Flexible	Expensive	[27-29]
Ceramic Based	Disinfection of Indoor Air	Resist to oxidation and corrosion	Expensive, Have a low toughness and Impact	[30-32]
Carbon Based	Removing Air Pollutants	Increased Hardness, 50% reduction in filling shrinkage	Expensive	[33,34]
Iron Based	Dye Degradation; Fluorite removal	Doesn't require synthetic reducing agents which is environmentally hazardous.	Can't work with plants	[35]
Graphene Based	Pollutant Detection; Gas Sensors	Improve electric performance	Needed high working temperature	[36,37]

Nanocomposites are also essential for removing heavy metals in wastewater for environmental remediations in Table 3 is explained what type of metal ions that these nanocomposites could adsorb [38-40]:

Table 3. Applications of Nanocomposites for removing heavy metal ions.

Type of Nanocomposite	Metal ions	Removal/Adsorption	Reference
Carboxymethyl	UO ₂ ²⁺	4.7 × 10 ⁻⁴ mol g ⁻¹ in 24 Hours	[38,40]
Metallic iron nanoparticles-PANI composite	As(V)	42.37 mg g ⁻¹ In 24 Hours	[39,40]
Polyacrylonitrile/PPy core/shell nanofiber	Cr(VI)	61.80 mg g ⁻¹ In 24 Hours	[40]
Starch/SnO ₂ nanocomposite	Hg(II)	192 mg g ⁻¹ In 24 Hours	[40]

DDT are harmful for the environment that can pollute the food that are grown from the earth such as the cases in most countries such as China and India with DDE which is why nanocomposites has also been used to remove pesticides from wastewater and can also remove heavy metals, insecticides, germs, and fungus from wastewater while remaining recyclable [41,42] (Table 4).

Table 4. Applications of nanocomposites for removing pesticides.

Type of Nanocomposite	Pesticides	Removal/Adsorption	Reference
Imprinted polymer nanocomposites	DDT	5 mg/MI	[43]
Graphene Oxide Composites	DDE	1534 mg/g	[42]
TiO ₂ Nanocomposites	DDD	57.14%	[44]
TiO ₂ Nanocomposites	Hept Epoxide	70.27%	[44]

The last role of nanocomposites for environmental remediation is to remove synthetic dyes are frequently referred to as "coal tar dyes" since they are made from chemicals that were previously exclusively available from coal tar. All these compounds are derivatives of the hydrocarbon benzene (C₆H₆), which is made up of 6 carbon atoms in the corners of an equal-sided hexagon, each with a hydrogen atom attached [45]. Applications of nanocomposites for removing synthetic dyes is shown in Table 5.

Table 5. Applications of nanocomposites for removing synthetic dyes.

Type of Nanocomposite	Dyes	Removal/Adsorption	Reference
TiO ₂ /hydrogel nanocomposite	Direct Blue 78	Could not be removed completely	[46]
TiO ₂ /hydrogel nanocomposite	Reactive Black 5	10%	[46]
TiO ₂ /hydrogel nanocomposite	Reactive yellow 17	55%	[46]
TiO ₂ /hydrogel nanocomposite	Acid Red 18	75%	[46]

5. Potential solution to limit/eliminate nanoparticles

The combination of imaging techniques such as transmission electron microscopy (TEM) and mass spectroscopic approaches such as single particle inductively coupled plasma mass spectrometry (SP-ICP-MS) could potentially aid in the analysis of the diverse physical and chemical properties of ENPs in wastewater treatment systems. As a result, a guideline and standard for proving the toxicity and classification of engineered nanoparticles in wastewater treatment systems has been established. Density separation can be utilised to remove microplastics from wastewater by increasing the density of the water, which allows microplastics and nanoplastics to have a lower density than the water and be removed through skimming. Since most plastics have a density close to one, adding salt such as NaCl or NaI will increase the density from 1.00 g/cm³ to 1.2 g/cm³ and 1.8 g/cm³ so that NPs/MPs float, even the denser ones such as those made of PET. However, this technique involves static wastewater as flowing water would disperse the particles. As micro/nano plastic particles would take a long time period to disintegrate, a biodegradation solution would prompt the growth of biodegrading agents that feed on plastic materials as a carbon source. One study suggested utilising the propensity of the fungus *Zalerion maritimum* to degrade PE particles and had achieved 43% of the plastic being degraded after 14 days of exposure to the fungus. Also, other bacteria strains like *Rhodococcus* showed 6.4% of the polymer mass being degraded in 40 days, whereas *Ideonella sakaiensis* demonstrated a complete degradation of a PET film after 6 weeks of exposure [47]. Hence, further studies and improvements had to be conducted to accelerate the degradation process and could be implemented in the wastewater treatment system in the future.

Carbon nanotubes have a higher adsorption rate of bacteria and other micro-organisms than other common adsorbent methods such as granulated activated carbon (GAC) and powdered activated carbon (PAC) that are widely used in wastewater treatment systems. This is due to the fact that carbon nanotubes consist of filtration nanotubes that are smaller in diameter, resulting in higher aspect ratios. Furthermore, CNT can be modified into multiple frameworks such as double-walled carbon nanotubes or single-walled nanotubes (SWNT) depending on the requirement. Besides, carbon nanotubes also have high thermal and electrical conductivity which could remove metal nanoparticles in the wastewater and can be enhanced by increasing the pH value. Furthermore, this technique also promotes fast filtration of water [48]. This technique utilises organic nanosorbents which consist large surface areas and polyfunctional groups to provide a wide area of active sites for absorption reactions, whereas polyfunctional groups such as amino and imino groups can efficiently remove metal ions. Furthermore, there is a hybrid polymer from the ring-opening polymerization of pyromellitic acid dianhydride (PMDA) and phenylaminomethyltrimethoxysilane (PAMTMS) that not only

removes contagious ENPs but also recovers metal nanoparticles from the wastewater. Other organic polymer techniques also include the use of calcium carbonate nanoparticles (ACC), which can both efficiently remove capacity and decontaminate trace ions in the wastewater [48].

6. Conclusions

Therefore, this research has been undergone to know what the different and yet potential application of nanocomposites in environmental remediation are, although it is somewhat expensive it has a very high removal rate and have been used in modern countries such as the US and Canada in this research, we can see that the nanocomposites have several different types and have uses for removing synthetic dyes, heavy metal ions, and pesticides. The nanocomposites can be applied to developing country such as Malaysia and Indonesia. While there are such major downsides to use nanocomposites it is an effective way to remediate organic and inorganic pollutants in the environment.

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Conflicts of Interest

The authors declare no conflict of interest.

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