Chapter

Sewage Treatment Using Nanoparticles

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Abstract

This chapter provides a brief overview of nanomaterials, including classification, shape and structure, nanomaterial types, and applications in the degradation of recalcitrant organic contaminants. With the rapid advancement of nanotechnology science, the use of nanomaterials in environmental applications, particularly water treatment, has piqued the scientific community's interest in recent decades. Nanomaterials have unique properties such as surface-to-volume ratio, quantum effect, low band-gap energy, and so on, which enhance catalytic performance. Wastewater treatment is a critical task of the twenty-first century since it protects the health of our environment and living beings. Because of its ability to affect both living and nonliving organisms, wastewater is always viewed as a serious source of environmental contamination. Many physical, biological, and chemical modes of treatment are implied to comply with wastewater discharge standards set by competent national agencies for environmental protection.

Keywords: nanomaterials, synthetic, lipid based nanoparticle, wastage, sewage

1. Introduction

Sewage treatment is a large component of water enterprise that safeguards public health, natural surroundings and economic development. The rapid population growth in distinctly urbanized and industrialized societies has resulted in the production of enormous volumes of Sewage, which require power and cost-effective remedies to discharge Sewage into receiving water bodies. To meet the discharge limits, present Sewage treatment facilities make use of energy-extensive strategies despite the current medical knowledge which aims in offering known strategies for power saving and restoration of flora. This offers a brief overview of a novel technology that has the potential to reduce the power needs of existing, standard Sewage treatment facilities, both by using replaceable remedies at some point of treatment to lessen the environmental footprint and gain electricity-efficient treatment facilities.

Water and Sewage control are enormously critical and interdependent requirements that can strongly affect a human being. Untreated Sewage contains huge amounts of organic and inorganic material from domestic, industrial and also public facilities, poisonous compounds, and many pathogenic microorganisms. If left untreated, Sewage can pollute surface and floor water reservoirs, consequently posing critical threats to public health and the surroundings. Subsequently, the objective of Sewage management is to offer reliable safety and adequate discharge of Sewage into the aquatic environment. But rapid and localized populace growth has brought about massive volumes of clean water being consumed every day and respectively huge volumes of Sewage being produced, which stresses, even more on the present Sewage management centres. On top of this a rapid deterioration of the high-quality water reservoirs, especially because of the elevated urbanization, industrialization and farming activities, is found. This is evident by the excess of natural pollutants and vitamin (N and P) masses in aquatic bodies. All of the above implies that more intensive Sewage treatment technologies, which are associated with high working volumes need to be adopted to protect public health and the natural environment. Sewage treatment incorporates diverse physical, chemical and organic processes, as well as their combination, that allows you to produce an effluent which can be safely disposed of into the surroundings without causing any sort of long-term unfavorable results to human beings or other living beings. Nevertheless, to meet Sewage discharge, high working volume demands are required, leading to high operational prices and making Sewage management unsustainable. Therefore, additional green and energy-efficient treatment constructions, that require a decrease to zero external quantities of strength to perform and therefore lower operational costs, have to be delivered on a huge scale. Sewage management is usually carried out in five stages as explained below:

1. Pre-treatment consists of bar screens which remove large objects like tree branches, fruit and vegetable peels, plastic wrappers, sheets and papers etc. Then the resulting water is sent into a flow equalization tank followed by a grit elimination channel.

2. Primary Treatment includes a primary sedimentation tank where suspended solids are settled out via gravity.

3. Secondary treatment consists of an activated sludge system where microorganisms are used for the conversion of organic matter into carbon and nitrogen sources.

4. Tertiary treatment includes disinfection of Sewage using UV irradiation and an activated carbon filter.

5. Sludge treatment generally is carried out for sludge thickening and later incineration of the final waste and finally waste disposal is carried out.

2. Current technologies of sewage treatment

2.1 Anaerobic digestion (AD)

Anaerobic digestion (AD) is a familiar method in which biodegradable constituents of Sewage are broken down with the help of micro-organisms in the absence of oxygen. This can be carried out in a single stage or multiple stages. This not only leads to decreased organic loads but also will simultaneously produce biogas. The process takes place under temperatures of about 30 to 38°C, where mesophilic digestion can take place or about 49–57°C where thermophilic digestion takes place [1]. Anaerobic Digestion is usually carried out in three stages [2]:

1. Hydrolysis: In this stage, microorganisms degrade organic matter present in Sewage into smaller constituents in the presence of water

2. Fermentation of volatile acids: Acidogenesis is carried out thus producing acetic acid, carbon dioxide, and hydrogen as end products.

3. Methane formation: At this stage acetic acid, carbon dioxide, and hydrogen which were produced in the previous stage get converted to methane and carbon dioxide.

Sewage s, as well as the Sludge coming out from the last stage generally is found to be rich in organic matter and thus can be used to produce energy in the form of biogas. Biogas obtained from anaerobic digestion plants can be utilized for various purposes like heating, production of electricity etc. This energy utilization makes the anaerobic digesters a versatile piece of equipment as it sustains their energy and heat requirements without the need for looking out for other sources of external energy requirements [3].

2.2 Photo-fermentation

In this method anaerobic micro-organisms which are photosynthetic like Rhodobacter and *Rhodopseudomonas* act as catalysts and convert organic acids, such as acetic and butyric acids, and sugars into glucose, fructose and sucrose in the presence of sunlight. There is a similar called as dark fermentation which is mostly carried out in the absence of sunlight where anaerobic bacteria, such as *Clostridium* and *Enterobacter*, convert glucose, sucrose, starch and cellulosic materials to H_2 [4]. But for the above-mentioned processes Sewage s containing huge amounts of carbohydrate content is required to produce adequate amounts of hydrogen typically 15% of the maximum theoretical potential. Due to this constraint, these processes have yet to emerge on a large industrial scale.

2.3 Microbial fuel cells

Microbial fuel cells (MFCs) are showing promising results in Sewage treatment in recent years as these are sustainable technologies which can accomplish the removal of organic pollutants with the help of micro-organisms and also produce electricity, water, CO_2 and other inorganic residues as by-products [5–7]. MFCs come under the category of bioreactors and are usually operated under anaerobic conditions. A positively charged ion membrane separates both the anode and cathode. Reactions at the anode include oxidation of organic materials present in Sewage by microorganisms, therefore generating CO_2, electrons and protons. These electrons are then relocated to the cathode compartment via an external electric circuit, producing electricity, whereas protons are moved to the cathode through the membrane. During this process, water is also formed as electrons and protons combine with oxygen in the cathode [8, 9]. MFCs offer the benefits of low cost, as they utilize inexpensive catalysts, that is, microorganisms present in Sewage s, huge energy efficiencies, and low volume of solid disposal.

2.4 Pyrolysis

Pyrolysis is an age-old technique and also a Green technology in comparison to existing Sewage technologies as it is carried out in absence of oxygen resulting in toxic-free by-products. Pyrolysis thermally breaks down the sewage sludge into biogas, bio-oil, and biochar anaerobically [10]. If seen from a thermodynamic perspective, Pyrolysis is an endothermic process (100 kJ kg^{-1}) which is carried out at temperatures fluctuating between 350–1000°C [11]. For carrying out pyrolysis effectively, Sewage management industries would require complex and expensive equipment. Thus the large-scale applications of this process are limited.

3. Sewage treatment using nanoparticles

Nanoparticles are materials in which the structural components lie within sizes ranging from 1 and 100 nm in at least one dimension [12]. Because of this special nature, nanoparticles highly differ in their properties mechanical, electrical, optical, and magnetic in comparison with other materials. In recent years, nanoparticles have found applications in many fields, such as catalysis [13], medicine [14], sensing [15], and biology [16]. Specifically, due to their nano sizes and huge surface areas available for chemical and biochemical reactions, High mobility of nanoparticles in solutions, nanoparticles are being used in water and Sewage treatment extensively. Sewage s contain toxic metal ions like [Hg(II), Pb(II), Cr(III), Cr(VI), Ni(II), Co(II), Cu(II), Cd(II), Ag(I), As(V), and As(III)] [17]. Numerous Conventional chemical and physical techniques like adsorption, precipitation, ion exchange, reverse osmosis, electrochemical treatments, membrane filtration, evaporation, flotation, oxidation and biosorption processes are being expansively used for the removal of such toxins. These conventional techniques do offer good amounts of toxin removal but to treat huge volumes of Sewage, there is an emerging need to search for new alternatives. In the current scenario, widely used nanoparticles for water and Sewage treatment largely comprise zero-valent metal nanoparticles, metal oxide nanoparticles, carbon nanotubes (CNTs), and nanocomposites.

Current research trends show the use of various zero-valent metal nanoparticles, viz.; Fe, Zn, Al, and Ni, in sewage treatment. Silver nanoparticles (Ag NPs) which come under the category of Zero-Valent Metal Nanoparticles are extremely lethal to microorganisms and hence show a strong antibacterial effect against various microorganisms, including viruses [18], bacteria [19], and fungi [20]. These can adhere to the bacterial cell wall of the microorganisms and increase the permeability of the cell walls [21]. They can easily penetrate through the cell walls resulting in structural changes in the cell membrane leading to the death of the cells [22]. Further, when Ag NPs come in contact with bacteria, they generate free radicals. They can damage the cell membrane and are considered to cause the death of cells. Magnetic nanoparticles can also be utilized in water treatment to remove heavy metals, sediments, chemical effluents, charged particles, bacteria and other pathogens. Lower operating costs, Lower energy requirements, lesser sludge discharge, Reduction in the number of pesticides and VOCs (organic chemicals), and Reduction of heavy metals, nitrates and sulfates, color, tannins, and turbidity are some of the many advantages of Sewage treatment using nanoparticles.

3.1 Carbon nanomaterials

Carbon nanomaterials (CNMs) are sheets made of graphene which are rolled up in the form of cylinders having diameters as minor as 1 nm. Carbon nanomaterials possess exceptional structures, and a great capacity to adsorb a wide range of contaminants like dichlorobenzene, ethyl benzene, Zn2+, Pb2+, Cu2+, and Cd2+, dyes, electrical properties, fast kinetics, large surface area, rich porous structures [23]. All these contribute to their diverse applications in advantages in sewage treatment processes.

The nanocomposite is an emerging field of nanomaterials. Nanocomposites are prepared through the chemical deposition of nZVI on CNTs. The resulting adsorbent has huge potential for rapid and effective removal of nitrate components presenting sewage water. These nanocomposites also have good magnetic properties due to which, the adsorbent can be easily separated from the solution by using a magnetic field [24]. Many such nanocomposites can be fabricated creating a network on polyimide supports. These offer advantages of being nontoxic, long-term stable and low-price materials. In concept, ideal composites for physical applications should be continuous, bulk immobile materials in which the nano reactivity is acquired by impregnating a parent material structure with nanoparticles [25]. Still, much research is underway for creating nanocomposites which can serve sewage treatment in a cost-efficient manner.

3.2 Metallic nanoparticles

Metallic nanoparticles have a great deal of potential for many forms of environmental cleanup because of their adaptability. One, two, or three metals and their oxides can be found in a variety of nanostructures. The shape-controlled, stable, and monodispersed properties of metal-based nanomaterials have been thoroughly studied using physical and chemical methods. Water treatments such as adsorption, photodegradation, membrane separation, and chemical disinfection can all benefit from these positive qualities. They have been utilized for self-cleaning surfaces, air purification, and water disinfection because of their noteworthy antibacterial, antifungal, and antiviral activity, which is employed as water disinfectants [26, 27].

3.3 Nanoparticles based on oxidation

Inorganic oxide-based nanoparticles are often created by combining metals and non-metals. The removal of harmful contaminants from wastewater makes considerable use of these nanoparticles. There are also ferric oxides titanium oxides [28], titanium oxide/dendrimers composites [28–30], zinc oxides [31], magnesium oxides, manganese oxides [32, 33] and ferric-oxide [34]. High BET surface area, less environmental impact, less solubility, and lack of secondary pollutants are the characteristics of oxide-based nanoparticles [35].

3.4 Silver based nanoparticles

Due to its low toxicity, water-based microbial inactivation, and well-documented antibacterial action, silver is the substance that is utilized the most frequently.

Silver salts like silver nitrate and silver chloride are used to make silver nanoparticles, which are known to be excellent biocides. Smaller Ag nanoparticles (8 nm) were the most effective, despite the fact that the antibacterial action is size dependant; increasing particle size (11–23 nm) resulting in reduced bactericidal activity.

Additionally, truncated triangular silver nanoplates outperformed spherical and rod-shaped nanoparticles in terms of antibacterial efficacy, demonstrating the importance of shape.

Ag nanoparticles' bactericidal effects can occur through a variety of methods, such as the production of free radicals that damage bacterial membranes, interactions with DNA, adherence to cell surfaces that change the characteristics of the membranes, and damage to enzymes.

Immobilized nanoparticles have become more significant because of their potent antibacterial properties. Gram-positive and Gram negative bacteria have been observed to be particularly sensitive to embedded Ag nanoparticles. In a study, cellulose acetate fibers that had been directly electrospun with silver nanoparticles incorporated in them were demonstrated to be efficient against both types of bacteria. Ag nanoparticles are also added to several kinds of polymers to create antibacterial nanocomposites and nanofibers. In a study, antimicrobial nanofilters made of poly (−caprolactone) based polyurethane nanofiber mats with Ag nanoparticles were created.

Ag nanoparticles are included in several types of nanofibers that have been manufactured for antimicrobial applications and have shown excellent antibacterial capabilities [36–39].

Ag nanofiber-coated polyurethane foam water filters have demonstrated effective antibacterial activities against *Escherichia coli* (*E. coli*). Other examples of inexpensive drinkable microfilters made with Ag nanoparticles exist and can be applied in rural areas of developing nations [40].

Ag nanoparticles are also used in water filtration membranes, such as polysulfone membranes, where they are effective in reducing biofouling and are effective against a wide range of bacteria and viruses. These membranes with Ag nanoparticles demonstrated effective antibacterial properties against *E. coli*, Pseudomonas, and other microbes. The efficiency of Ag nanocatalyst alone and in combination with carbon covered in alumina for the destruction of microbiological pollutants in water has been proven.

Although Ag nanoparticles have been successfully employed to destroy bacteria, viruses, and reduce membrane biofouling, their long-term effectiveness against membrane biofouling has not been observed. This is mostly because silver ions are lost over time.

Therefore, additional efforts to stop this loss of silver ions are needed in order to permanently control membrane biofouling. As an alternative, the problem can be resolved by doping Ag nanoparticles with other metallic nanoparticles or its composites with metal-oxide nanoparticles. This may also result in the simultaneous removal of inorganic and organic substances from water and wastewater [41].

3.5 Titanium based nanoparticles

TiO2 nanoparticles have mostly been utilized as a catalyst in organic reaction and wastewater breakdown. Because of their special characteristics and lower tendency to aggregate due to the existence of greater repulsive forces, microorganisms (such as bacteria) are often used in the biosynthesis of TiO2 nanoparticles. The morphological structures of TiO2 nanoparticles, such as spherical titania (TNP), titania nanotubes

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(TNT), and titania nanosheets, have been extensively researched in the field of water purification along with development and improvement. High specific surface area, pore volume, and pore size are typical characteristics of TNP. As a result, TNP offers an active site that is very easy to reach and can be employed for organic pollutant adsorption. The typical hydrothermal method for producing TNT from TNP uses a potassium hydroxide/sodium hydroxide (KOH/NaOH) solution. TNT is anticipated to be more advantageous than TNP because of its tubular structure, which also provides bigger pore volume and a higher interfacial charge carrier transfer rate. TNT also offers the high hydrophilicity qualities of TiO2 [42].

One of the most significant chemically stable nanoparticles, titanium dioxide (TiO2), has attracted the most interest for its use as a photocatalyst and adsorbent in the removal of contaminants from wastewater. Some microorganisms, such as bacteria, can biosynthesize these nanoparticles as reducing agents for nanofactories in order to create nontoxic, environmentally friendly ways to generate nanoparticles [43].

3.6 Iron based nanoparticles

Ferric oxide is a cheap substance for the adsorption of toxic metals due to the natural abundance of iron and its straightforward production technique. It is an environmentally benign substance that can be utilized in contaminated environments without raising the risk of secondary contamination. The pH, temperature, amount of adsorbent, and incubation period all play a role in how different heavy metals bind to Fe2O3 nanoparticles. Different researchers modified the surface of Fe2O3 to boost its adsorption capability. Recently, there have been multiple publications on the use of magnetic oxides, particularly Fe3O4, as nanoadsorbents to remove hazardous metal ions such Ni2+, Cr3+, Cu2+, Cd2+, Co2+, Hg2+, Pb2+, and As3+ from wastewater. For instance, Shen et al. [44] have found that pH, temperature, the quantity of the adsorbent, and the incubation duration all have a significant impact on the adsorption efficiency of Ni2+, Cu2+, Cd2+, and Cr6+ ions by Fe3O4 nanoparticles. According to Palimi et al. [45], 3 aminopropyltrimethoxysilane was used to modify the Fe2O3 nanoparticles' surfaces.

When it comes to simultaneously removing many contaminants from wastewater, such as Cr3+, Co2+, Ni2+, Cu2+, Cd2+, Pb2+, and As3+, nano-adsorbents have strong affinity.

3.7 Manganese oxide based nanoparticles (MnO)

Due to their high BET surface area and polymorphism structure, manganese oxide (MnOs) nanoparticles have remarkable adsorption capacity [46]. It has been frequently utilized to remove several heavy metals from wastewater, including arsenic [47]. Hydrous manganese oxide (HMO) and nanoporous/nanotunnel manganese oxides are the most commonly used modified MnOs. HMO was created by mixing MnSO4H2O into a NaClO solution. The inner-sphere is usually responsible for the adsorption of numerous heavy metals on HMOs, including Pb (II), Cd (II), and Zn (II). Divalent metals did, however, adsorb on the surface of HMOs in two stages. Metal ions first adsorb on the outside surface of HMOs, and then intraparticle diffusion occurs .

3.8 Zinc oxide (ZnO) based nanoparticles

For the adsorption of heavy metals, zinc oxide (ZnO) possesses a porous micro/nanostructure with a high BET surface area. For the removal of heavy metals from wastewater, nano assemblies, nano-plates, microspheres with nano-sheets, and hierarchical ZnO nano rods are frequently utilized as nano-adsorbents In comparison to commercial ZnO, the aforementioned modified forms of ZnO nano-adsorbent exhibit a high removal effectiveness of heavy metals. ZnO nano-plates and porous nano-sheets were utilized to remove Cu (II) from wastewater. These modified ZnO nano-adsorbents exhibit greater Cu (II) removal effectiveness compared to commercial ZnO because of their distinctive micro/nanostructure. Additionally, nano-assemblies were employed to eliminate a variety of heavy metals, including Co2+, Ni2+, Cu2+, Cd2+, Pb2+, Hg2+, and As3+. Due to their electropositive character, microporous nano-assemblies exhibit strong affinity for the adsorption of Pb2+, Hg2+, and As3+. According to Kumar et al. [48] mesoporous hierarchical ZnO nano-rods have a good removal efficiency for Pb (II) and Cd (II) from wastewater.

Singh et al. [49] reported the removal of numerous harmful metal ions from wastewater using porous ZnO nano-assemblies, including Co2+, Ni2+, Cu2+, Cd2+, Pb2+, Hg2+, and As3+. It has been claimed that Hg2+, Pb2+, and As3+ demonstrate superior removal efficiency (63.5% Hg2+, 100% Pb2+, and 100% As3+) because of their stronger attraction to ZnO nano-assemblies due to their high electronegativity.

3.9 Magnesium oxide based nanoparticles (MgO)

Magnesium oxide (MgO) and iron oxide (Fe2O3) are potential metal oxide nanoparticles (NPs) for the adsorption of textile and tannery wastes. Due to their nanostructure and numerous active sites, these NPs have large surface areas and a high capacity for the adsorption of heavy metals. Ecosystem harm from NP biotreatment is nonexistent. In earlier research, for the purification of textile colors and the eradication of particular heavy metals magnesium oxide (MgO) is utilized. MgO microspheres are a new structure that can increase the removal of heavy metals' adsorption affinity. The shape of NPs has undergone many forms of alteration to boost the adsorption capability of MgO. These include nanorods, nanobelts, fishbone fractal nanostructures, nanowires, nanotubes, nanocubes, and three-dimensional things. Kiran et al. [50], reported that the remediation of Reactive Brown 9 dye was then carried out using MgO-NPs once the reaction's key variables (dye concentration, nanoparticle concentration, pH, and temperature) had been optimized. The highest degree of decolorization (95.8%) was achieved at 0.02% dye concentration, 0.003 mg/L MgO-NP concentration, pH 4, and 40°C. The mineralization of the examined dye samples was evaluated using TOC and COD, and their values were found to be 88.56% and 85.34%, respectively. Other troublesome colors could also be treated using the magnesium oxide nanoparticles in stages. It is imperative to get rid of these harmful colors because they ruin the aquatic environment and spread several diseases.

3.10 Al2O3 based nanoparticles

Aluminum oxide nanoparticles (ANPs) are used in a variety of industrial and personal care products. *E. coli* has been examined for the growth-inhibitory effect of alumina nanoparticles over a broad concentration range (10–1000 g/mL). These metal oxides' antibacterial properties are ascribed to the production of reactive oxygen species (ROS), which results in cell wall breakdown and eventual cell death. However, alumina nanoparticles might neutralize free radicals. The ability of these

NPs to protect cells from oxidative stress-induced cell death appears to depend on the particle's structure but is unrelated to its size between 61,000 nm [51].

3.11 Copper based nanoparticles

A variety of bacterial pathogens responsible for hospital acquired infections were successfully eliminated by CuO nanoparticles (CuO NPs). However, a significant portion of CuO NPs are scavengers. The ability of these NPs to protect cells from oxidative stress-induced cell death appears to depend on the particle's structure rather than its size between 61,000 nm. It is necessary to produce a bactericidal action [52].

3.12 Curcumin-loaded nanocarriers for hospital wastewater treatment

Water contamination with a wide range of chemical, microbiological, and toxic substances is a growing environmental concern. In a study by (Mozhgan et al), the heated high-speed homogenization process was used to create eco-friendly curcumin-loaded nanostructured lipid carriers (NLC-curcumin). NLC-curcumin had an average particle size of 137.9 3.21 nm and a zeta potential of −23.36 3.5 mV. The nanoparticles' morphology, thermal behavior, antioxidant properties, and infrared spectroscopy were also studied. The potential of NLC-curcumin on bacterial growth reduction in the actual environment of hospital wastewater was evaluated using colony forming unit per milliliter (CFU/ml) analysis. The results show that 0.125 M NLC-curcumin in Mueller-Hinton agar media significantly lowers the proportion of wild bacteria strains in autoclaved wastewater at 37°C. NLC-Curcumin (0.125 M) significantly reduced the percentage of the microbial total count at 25°C in the original hospital wastewater treatment as shown in **Table 1** [53].

4. Type of nanomaterials in wastewater treatment

A substantial amount of study has been conducted on the use of nanotechnology for wastewater treatment. Based on the materials used, nanotechnology may be divided into three categories: Nanoadsorbents, nanocatalysts, and nanomembranes present in **Table 1** and **Figure 1**.

4.1 Nano-adsorbents

Adsorbent nanoparticles are nanoparticles composed of organic or inorganic materials with a high affinity for adsorbing chemicals. This implies they can remove a large amount of pollution. Because of their key qualities, such as catalytic potential, small size, high reactivity, and increased surface energy, these nanoparticles may be used to remove many types of contaminants. Metallic nanoparticles, mixed oxide nanostructures, magnetic nanoparticles, and metal oxide nanoparticles all have distinct adsorption mechanisms. Example is Zeolites comprise aluminosilicate minerals having a surface morphology filled with electrostatic pores populated by cations and water molecules. Cations and water molecules have a wide range of movement options, allowing for ion exchange and reversible dehydration. CNTs feature a large surface area, a large number of adsorption sites, and variable surface chemistry as shown in **Table 1**.

S. No	Nanoparticle	Type	Load	Method of action	References
1	Curcumin-Loaded nanocarriers	Nanostructured lipid carriers (NLC)	Curcumin	Antimicrobial properties of curcumin are the main feature of this nanoformulation.	[53]
2	Zeolites	Nano-adsorbents	—	Zeolites comprise aluminosilicate minerals having a surface morphology filled with electrostatic pores populated by cations and water molecules. Cations and water molecules have a wide range of movement options, allowing for ion exchange and reversible dehydration.	[54]
3	CNTs Nanoadsorbents	Nano-adsorbents	—	CNTs feature a large surface area, a large number of adsorption sites, and variable surface chemistry. CNTs are used for pollution cleanup, determining the pre-concentrate, and revealing contaminants. The engagement of carbon nanotubes with metal cations via electrostatic attraction and chemical bonding explained the process of oil contamination in wastewater utilizing carbon nanotubes.	[54]
4	Silica, Clay, Titanium dioxide, Iron, Aluminum Nano-catalysts	Nano-catalyst	Manganese Ferrous Oxides, Silica Oxides and Silver (MnFe2O4-SiO2-Ag)	Nanoparticles provide a wide surface area for chemical interaction that directly affects the reaction rate, providing impressive catalytic performance. Thus its used in catalyzing reactions on removal/transformation of pollutants in wastewater	[55]
5	CNTs Nano membrane	Nano-membrane	—	Carbon nanotubes are employed to create a nanomembrane that can be reused and is capable of eliminating pathogens and pollutants.	[56]

S. No	Nanoparticle	Type	Load	Method of action	References
6	Eugenol NLC	Nanostructured lipid carriers (NLC)	Eugenol	Eugenol induced cell wall breakdown leading to cell death is the primary goal of this NLC. It aims to diminish wild bacterial strains in sterilized wastewater and hospital wastewater.	[57]
7	Algal nanoparticles	Simple Nanoparticles	Silver, Gold	*Euglena gracilis* and other microalgae were used in biosynthesis of metallic nanoparticles, proving to be a potential source for in vivo and in vitro biosynthesis of Ag/Au NPs.	[58]

Table 1.
Varied instances of the use of nanocarriers in the treatment of wastewater.

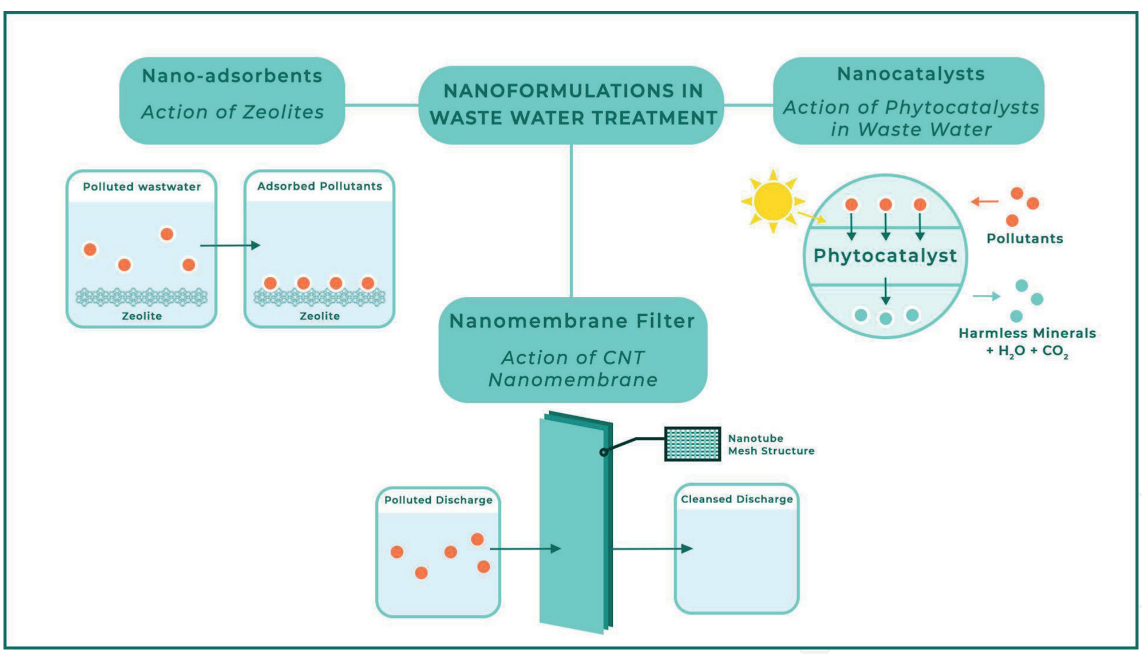

Figure 1.
Schematic explanation of the method of action followed by different types of nanoformulations used in wastewater treatment currently.

4.2 Nano-catalyst

Light energy interacts with metallic nanoparticles in nano-catalysis, resulting in high and broad photocatalytic activity. Because of its great and broad photocatalytic activity, this therapy is gaining favor. Bacteria and enzymes participate in a photocatalytic reaction. Manganese Ferrous Oxides, Silica Oxides and Silver (MnFe2O4-SiO2-Ag) act as catalyst and its mode of action shown in **Table 1**.

4.3 Nano-membrane

The separation of particles from wastewater is the responsibility of a nano-membrane. These filters are extremely good in filtering out dyes, heavy metals, and other contaminants. Nanomaterials utilized as nano-membranes include nanotubes, nanoribbons, and nanofibers.

Nanoparticles integrated into membranes are more convenient and beneficial than nano-adsorbents, nano-catalysts, and nano-membranes because this procedure not only has a powerful physical treatment, but it also contains nanoparticles to increase the quality of the treatment.

To inhibit bacterial development, several eco-friendly nanostructured lipid carriers (NLCs) were created as delivery agents to appropriately carry an antibacterial agent (eugenol) into hospital wastewater. Hot high-speed homogenization was used to create eugenol-loaded nanostructured lipid carriers. The nanocarriers were then analyzed using several methods including transmission electron microscopy, Fourier transforms infrared and dynamic scanning calorimetry. The ability of the produced eugenol-loaded nanostructured lipid carriers to reduce the bacterial growth rate in culture media and hospital wastewater was determined using the turbidity test and colony counting technique, respectively. NLC-mean eugenol's size and zeta potentials were 78.12 6.1 nm and 29.43 2.21 mV, respectively. The maximum inhibitory impact of NLC-eugenol in culture medium was reported in standard and wild *Staphylococcus aureus* strains (43.42% and 26.41%, respectively) at 0.125 M concentration. The antibacterial activity of NLC-eugenol in sterile wastewater on wild bacteria strains revealed that 0.125 M was the most effective concentration to reduce bacterial quantities on wild *S. aureus* and *Enterococcus faecalis* strains (38% and 33.47%, respectively) at 37°C. At 25°C, NLC-eugenol at 0.125 M had the best impact, lowering total microbiological agents by 28.66% in hospital wastewater as shown in **Table 1** [57].

4.4 Microalgal

Nanoparticles can be utilized for a variety of applications, including medical treatment, solar and fuel cells for efficient energy generation, water, and air filters to minimize pollution, and as catalysts in existing industrial processes to remove the usage of harmful ingredients. Wet techniques are the most traditional and widely utilized ways of producing nanoparticles (physical and chemical). These strategies are classified into two approaches: top-down and bottom-up. Growing nanoparticles in a liquid medium containing reducing and stabilizing agents such as potassium bitartrate, sodium dodecyl benzyl sulfate, methoxypolyethylene glycol, polyvinyl pyrrolidone, or sodium borohydride are how nanoparticles are created chemically. In addition, physical processes include pyrolysis and attrition. Unfortunately, the physical and chemical procedures utilized in both approaches have some implications due to their poor environmental effect, lengthy manufacturing methodology, and prohibitively high cost. According to research, nanoparticles attract atoms and molecules owing to their high surface energy, modifying their surface characteristics. As a result, they are unable to live in their natural habitat in their naked state. Nanoparticles are not suitable for therapeutic use due to these environmental interactions. This mechanism of action has raised awareness about the importance of developing nontoxic and environmentally friendly procedures for the assembly and synthesis of nanoparticles.

Physical processes also include pyrolysis and attrition. Unfortunately, both systems' physical and chemical procedures have some issues because of their bad environmental impact, delayed production methodology, and excessively expensive cost. Nanoparticles, according to study, attract atoms and molecules due to their high surface energy, changing their surface features. As a result, they are unable to survive in their native habitat while nude. Because of these environmental interactions, nanoparticles are not suited for therapeutic usage. This mechanism of action has increased awareness of the importance of developing nontoxic and environmentally friendly procedures for nanoparticle assembly and synthesis and mode of action as shown in **Table 1** [59].

I. Direct exploitation of extracted biomolecules from disrupted cells of microalgae

II. Exploitation of cell-free supernatants made of microalgae culture media

III. Biosynthesis of nanoparticles of different natures from whole cells of microalgae

IV. Using living cells of microalgae

To make gold nanoplates, the microalgal biomass is lyophilized and then exposed to RP-HPLC, or reverse-phase high-performance liquid chromatography, until the gold shape-directing protein (GSP), which controls the shape of nanoparticles, is separated. Furthermore, this protein is exposed to an aqueous $HAuCl_4$ solution, resulting in the formation of gold nanoparticles of various forms. In the case of silver nanoparticles, PLW (proteins with low molecular weight) and PHW (proteins with high molecular weight) found in microalgae biomass is responsible for converting silver ions into their metallic counterparts. Tang et al. biosynthesized silver and gold nanoparticles using a fine powder of *Spirogyra insignis* (Charophyta) [58].

Many studies on the fate of NPs and their effects on biological wastewater treatment have been conducted, and many successes have been reported [60].

1. At certain concentrations, most NPs, including Ag, ZnO, CuO, Al_2O_3, SiO_2, CNTs, and magnetic NPs, can cause varied degrees of harm to microorganisms. When compared to other NPs, Ag, Cu, and ZnO NPs have significantly large hazardous effects at similar exposure doses. TiO_2 NPs, in instance, do not exhibit high toxicity to microorganisms in both short-term (even at 500 mg L1) and long-term (50 mg L1) exposures.

2. By interacting with biomass, WWTPs utilizing activated sludge have the capacity to remove most forms of NPs, including Ag, Cu, ZnO, CuO, and TiO_2, but not SiO_2. Under specific circumstances, Ag NPs, Cu NPs, and ZnO NPs can be partly converted into Ag^+, Cu^{2+}, and Zn^{2+}, respectively. The low removal of SiO_2 NPs is attributed to their strong colloidal stability in wastewater and their limited biosorption proclivity.

3. Most NPs have varying degrees of influence on the efficacy of biological wastewater treatment, including the removal of nitrogen, phosphorus, and organic

contaminants. Under most situations, the effects are dose-dependent, and exposure length (short-term or long-term) also plays a role in unfavorable consequences.

a. At low concentrations, Ag, CuO, and ZnO NPs have small or moderate effects on TN removal; TiO_2 NPs have some inhibitory effects on nitrifying and denitrifying bacteria, as well as AMO and NOR; and Al_2O_3 and SiO_2 NPs have negative effects on nitrification and denitrification.

b. Al_2O_3, TiO_2, and SiO_2 NPs have no significant adverse effects on phosphorus removal, but ZnO NPs can result in net phosphorus removal failure at certain concentrations.

c. Ag NPs can reduce COD removal when it comes to organics removal. During anaerobic biological wastewater processes, ZnO NPs and CuO NPs can suppress methane formation. Under most situations, the effects are dose-dependent. Some of the effects are caused by the NPs themselves, whereas others are caused by liberated ions such as Ag^{+}, Cu^{2+}, and Zn^{2+}.

5. Discussion

Sixth of the world's population, on average, lacks access to clean drinking water. The availability of freshwater supplies is limited, making it difficult for the world to meet growing demands for clean water. Depletion as a result of (i) protracted droughts, (ii) rising population, (iii) stricter health-based laws, (iv) conflicting demands from various users, and (v) water contamination. Therefore, it is vital to take action to create an inventive technology that can supply clean, affordable water to suit human needs. A healthy existence requires access to clean drinking water. 80% of diseases in nations like India are caused by water, especially drinking water. The World Health Organization (WHO) advises that any water meant for drinking should have zero fecal and total coliform levels in each 100 mL sample. Today, a variety of methods, including chemical and physical processes, are employed to clean water. These methods include the treatment of chlorine and its derivatives, ultraviolet light, boiling, low-frequency ultrasonic irradiation, distillation, reverse osmosis, and water sediment filters [61].

The three primary categories of wastewater treatment techniques are physical, chemical, and biological. Filtration is a key component of solid-liquid separations, which are the main focus of physical wastewater treatment. There are two broad categories that conventional and unconventional filtration methods fall under. Applications involving water purification rely on this technique. The treatment process is just one component of a conventional water treatment system, which offers a variety of technology and equipment alternatives based on the treatment's objectives. Understanding the function of filtration in water purification in comparison to other technologies and the goals of various unit processes is crucial. This cost-effective method can eliminate wastewater microorganisms and suspended particulates in specific circumstances, such as when membranes are used. However, it is unable to reduce the wastewater's organic pollution and heavy metal levels on its own, which are dangerous when reused in the home or industrial settings. One of the most prevalent instances of this technique is membrane filtration, whose structure may be easily adjusted utilizing cutting-edge technology like nanoparticles as well as used with other types of treatment.

Chemical techniques of treatment depend on chemical reactions between the contaminants and the person using the chemical agent, and they help either completely remove contaminants from water or neutralize any negative effects they may have. Chemical treatment techniques can be used both alone and in conjunction with physical processes to treat a variety of problems. By using this pricey process, the wastewater's organics will be removed, but new compounds, some of which may be dangerous, will be introduced. For instance, activated carbon adsorption is frequently used in home and industrial treatments to eliminate turbidity and the smell of water without causing any negative side effects.

Although the biological treatment of wastewater appears straightforward because it depends on natural processes to aid in the breakdown of organic chemicals, it is actually complicated, poorly understood, and occurs where biology and biochemistry meet. Organic materials, such as rubbish, organic wastes, partially digested foods, heavy metals, and poisons, can be found in wastewater. Organic debris is typically broken down by bacteria, nematodes, and other tiny organisms in biological treatments. Worldwide application of biological treatment is possible due to its adaptability, affordability, and environmental friendliness. Many mechanical or chemical techniques fall short of biological treatments in terms of effectiveness or efficiency. A notable example of this is the conventional activated sludge (CAS) procedure. These systems frequently consist of an aeration tank that serves as a biological degrading agent and a secondary clarifier to separate treated wastewater sludge [62].

The primary purpose of a wastewater treatment system is to remove primary pollutants such as suspended particles, biochemical oxygen demand (BOD), nutrients (organic and inorganic), toxicity, and coliform bacteria. The sedimentation process is used in a traditional wastewater system to remove dissolved organic matter and suspended particulates. Sewage preliminary treatment removes 60% of large solid materials through a well-designed sedimentation tank and approximately 35% of BOD delivered by sewers responsible for obstructing flow through the plant or damaging equipment. Heavy grit particles, rags, fecal materials, and wood can be removed from sewage by passing it through screen bars. The secondary treatment method seeks to minimize suspended particles and BOD by lowering organic matter by 85 percent. This is mostly accomplished by a diverse population of heterotrophic bacteria capable of exploiting the organic ingredient for energy and development. Some of the secondary wastewater treatment operating systems include fixed film and suspended growth reactors. Tertiary treatment techniques strive to eliminate 95% of organic ions. It can be done either biologically or chemically, but it is a costly process. Chemical precipitation, reverse osmosis, carbon adsorption, and ozonation are examples of advanced treatment methods based on technologically complex techniques. These methods remove nutrients like phosphorus and nitrogen, which can cause eutrophication in surface water. To remove tiny particles on a small scale, technologies such as land application, filtration, and lagoon storage are utilized. Several primary and secondary treatment plants have been installed in a variety of locations to remove settled materials and oxidize organic material from wastewater. Furthermore, even after tertiary treatment, complete removal of the incoming waste load is not possible, and as a result, many organisms remain in the water bodies.

6. Conclusion

Waste water treatment could greatly benefit from the usage of nanoparticles. Its distinctive quality of having a large surface area can be effectively employed to remove harmful metal ions, microbial pathogens, organic, and inorganic solutes from water. Numerous kinds of nanomaterials, including zeolites, dendrimers, carbonaceous nanomaterials, and metal-containing nanoparticles, have also been shown to be effective for treating water. The chapter discusses recent developments on various nanomaterials, including molecularly imprinted polymers (MIPs), bioactive nanoparticles, molecularly structured catalytic membranes, nanosorbents, nanocatalysts, and nanosorbents with applications in waste water treatment. On both a small- scale and a large-scale, waste water may now be treated in a variety of effective ways with the help of nanotechnology.

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