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A REVIEW ON NANOPARTICLES USES IN WASTE WATER REMEDIATION

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ABSTRACT

Every animate life form depends on water in some way. Without water, a wide range of issues might arise, which could lead to the extinction of human life. To clean water used in industry and to safeguard water sources, many methods should be put into practise. A cost-effective and practical solution to the water shortage is wastewater treatment. Water treatment systems that employ physical, chemical, biological, or a combination of these provide several opportunities for reuse. However, these systems may achieve far higher quality wastewater treatment and overcome these shortcomings by using nanotechnology. One of the best treatment methods that has the ability to delay a water crisis for years is the use of nano-membranes in MBR technology.

Keywords: *Nanoparticles, Nano-Materials, Nanocomposite Membrane, Water Scarcity, Wastewater Treatment, Water Reuse.*

Introduction

Consider a world without water for a moment. The bathroom is often the first place you visit when you get up in the morning to feel refreshed and to get rid of any lingering fatigue from the previous night. But what will happen if the pipes or faucets aren't dripping water? Perhaps on the first day, it would make it difficult for you to concentrate on your job in addition to preventing you from doing even your regular tasks and errands. In fact, a lack of water may have a negative impact on everyone's life, such as making them ill or even leading them to perish away within a few days.

So why is water so crucial to human life? Why should everyone try to preserve water supplies? What would happen if people don't have access to water in reality as the idea of a world without water is terrible? Why do we need to hear about water shortages every day on the news when there is so much water on the planet? Is it feasible to repurpose previously used water? What are the most effective processes for treating water and wastewater so that they can be reused repeatedly? All of these issues will be covered in detail, with the goal of encouraging people to try to prevent the pollution of water.

Water is necessary for the continued existence of all organisms, both micro and macro. There are some microorganisms that can survive without oxygen, but no living things can survive without water. Because humans and marine animals breathe oxygen, water is unquestionably more important than oxygen. Since their bodies are largely made of water and they require water to fuel their metabolism and gain energy, it is true that water is essential to their survival.

The systems of the human body alter when there is not enough water. In public healthcare facilities around the world, nearly two billion people lack access to basic water services. One out of every six healthcare facilities worldwide does not have functional hand washing facilities at clinics or restrooms, despite the fact that hand washing with soap has been proven to have health benefits. It's widely accepted that creating a healthy learning environment requires instruction in fundamental water, sanitation, and hygiene. The body's cells shrivel in its absence. The brains of humans will instruct their bodies to urinate less. Water levels must be sufficient for the kidney to remove waste from the blood.

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Without enough water, people's kidneys cannot operate correctly. The kidneys have to work harder and damage tissues when there is little water. The health of the kidneys and other bodily organs depends on adequate water intake. These organs and others might malfunction if not given enough water to operate correctly. People require more than enough water in their bodies because if they don't, it won't be long before they pass away. Keep in mind that drinking more water can be beneficial for your health when you exercise, it's hot outside, or you're sick. In most cases, thirst will serve as a guide for how much water to consume [1].

The aforementioned causes of water suggest that humanity would go extinct in the absence of water. Although water is used by living things and is thus essential for them, the majority of water use worldwide is related to industrial and agricultural operations. When compared to manufacturing and agricultural operations, the amount of water used by living things is little. Water is a raw resource used by many different firms and businesses to make drinks, make vehicles, separate crude oil, irrigate their fields, etc. Due to its use in many processes and the potential for contamination resulting from those activities, water gets contaminated in such situations. Even if there were an infinite supply of water, it would not be ethical to utilise it in industries and then dump it elsewhere untreated since the pollution would spread pathogenic microorganisms. Oceans are full of water, but since it is salty, it must be removed using astronomically costly procedures before it can be utilised. Since there is no sweet water in our environment, enterprises must purify the water they utilise in their operations. Seawater is much less practical for wastewater treatment. Water shortage is delayed by treating and recycling wastewater, giving people access to a water cycle now. Therefore, each individual must uphold their responsibility to use no more water than is necessary. Governments enact strict laws requiring industries to treat their used water in an appropriate manner. In the twenty-first century, treating and recycling wastewater will be necessary due to water scarcity and the rising demand for clean water.

Techniques for Treating Wastewater

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 filtering methods fall under. Applications involving water purification depend on this technique. The treatment process is just one component of a traditional water treatment system, which offers a wide range of equipment and technological options depending on the treatment's ultimate objective. 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 get rid of wastewater's suspended solids, and in some cases, like when membranes are used, it can get rid of the microorganisms as well. However, it is unable to reduce the wastewater's organic contamination and heavy metal levels on their own, which are dangerous when reused in domestic or industrial settings. One of the most prevalent examples of this process is membrane filtration, whose structure can be easily modified using cutting-edge technology like nanoparticles as well as used with other types of treatment.

Chemical methods 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 neutralise any negative effects they may have. Chemical treatment techniques may be used both alone and in conjunction with physical procedures to address a variety of problems. By using this pricey process, the wastewater's organics will be removed, but new chemicals, some of which may be dangerous, will be introduced. For instance, activated carbon adsorption is often 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 seems straightforward since it depends on natural processes to aid in the breakdown of organic chemicals, it is really complicated, poorly understood, and occurs where biology and biochemistry meet. Organic materials, such as rubbish, organic wastes, partly digested meals, heavy metals, and poisons, may be found in wastewater. Organic debris is often broken down by bacteria, nematodes, and other tiny organisms in biological treatments. Worldwide use of biological therapy is possible due to its adaptability, affordability, and environmental friendliness. Many mechanical or chemical processes fall short of biological treatments in terms of effectiveness or efficiency. A good example of this is the conventional activated sludge (CAS) procedure. The typical components of these systems are an aeration tank that serves as a biological degrading agent and a secondary clarifier for separating treated wastewater sludge from it [2].

Depending on the goals of the treatment, wastewater treatment procedures may use one or a mix of these three technology categories. According to the criteria for reuse, these techniques may be coupled with one another, and it should go without saying that if someone wants to get highly treated water of a level that even allows for drinking, they should combine all three techniques. Overall, the characteristics of the wastewater and the quality required for reuse are the key variables influencing the choice of treatment procedures. Industrial wastewater may have certain organic components, high salinity, heavy metals, acids with high pH, and inorganic particles with high turbidity, depending on the production process. A wastewater treatment facility, whether it be industrial, municipal, or for drilling water, is comparable to, say, an oil refinery or a rubber factory in this sense. High-quality clean water is essential for the majority of industrial and agricultural processes; however, treating water to high standards is expensive; droughts, contaminating water sources, and competing demands invariably restrict the amount of water available for farming and oil and gas extraction, complicating the production of food and energy. In order to successfully treat water of low quality, it must both create water of desired quality and safeguard downstream operations. Multiple sequential treatment steps are frequently required in the treatment of industrial wastewater. The cost of distilling contaminated water is prohibitive, and not all industrial waters necessitate this level of treatment, hence the term "treatment train." Even though distillation can get rid of all impurities, it might not always be practical. Additionally, some technologies have inherent limitations, particularly at high salinity and water recovery. Membranes are constrained by osmotic, hydraulic, and mineral precipitation pressures. Adsorbers can only be used with specified substances that have particular functional groups. The capacity to transform a variety of industrial waste streams into high-value materials and energy, in addition to unit procedures for eliminating pollutants from a number of chemical groups, are specifically required. Industrial wastewater is often pre-treated on-site in specialised wastewater treatment facilities. New methods for treating contaminated and unusual water are essential for both the environment and sustainable economic growth. By using nanotechnology to treat waste streams, it is possible to reuse water, recover energy, and produce highly valuable materials [3, 4, 5].

Nanotechnology for the Treatment of Wastewater

Metals and microorganisms cannot always be removed from water using conventional water treatment methods. Another issue is the development of disinfection by products (DPBs), which may be harmful to human health. When organic material and inorganic ions in the water react with chemical disinfectants, DPBs are created. Nanomaterials have been investigated for the removal of metals, microorganisms, and oil from polluted water in several investigations. Contaminant removal has been replaced by the use of nanomaterials. The nanometre scale is used to study phenomena in nanoscience. Materials used in nanotechnology have at least one component with a size less than 100 nm [6]. Due to their nanoscale dimension, these materials are quite different from normal materials in terms of their mechanical, electrical, optical, and magnetic characteristics. The nanoparticles are very adsorbent and reactive due to their tiny size and huge surface area. Additionally, it has been shown that nanoparticles are quite mobile in solutions. There have been reports of the removal of heavy metals, organic contaminants, inorganic anions, and microorganisms using different kinds of nanomaterials. Numerous nanomaterials, such as metal oxide nanoparticles, carbon nanotubes, and nanocomposites have all been thoroughly studied for their potential use in the treatment of water and wastewater.

Nanoparticles made of Zero-Valent Metal

- **Nanoscale Silver Particles**

The high toxicity of silver nanoparticles to microorganisms including bacteria, viruses, and fungus has been linked to their antibacterial effects. Since they work well as antibacterial agents, silver nanoparticles are often employed to purify water. Ag NPs have antibacterial properties, although the exact processes by which they work are yet unknown. Ag nanoparticles have been theorised to cling to bacterial cell walls before penetrating, which led to structural alterations inside the membrane and enhanced its permeability. Furthermore, free radicals are created when Ag NPs come into contact with bacteria. These free radicals damage cell membranes, which results in cell death. DNA is rich in sulphur and phosphorus, two components that also contribute to cell death. More significantly, the breakdown of the NPs will release Ag^+ ions, which will bind with the thiol groups of the enzymes, inactivate them, and impair the cell's ability to function normally [7, 8, 9].

- **Nanoparticles of Iron**

Zero-valent metal nanoparticles, such Fe, Zn, Al, and Ni, have recently attracted a lot of study attention in the field of water treatment. Due to its strong reductive properties, nanozero-valent aluminium is thermodynamically unstable in water. This causes oxides and hydroxides to develop on the surface, completely preventing electron transmission from the metal surface to impurities. While nano-zero-valent Fe or Zn have a modest standard reduction potential and are suitable reducing agents in comparison to the majority of redox-labile pollutants, the standard reduction potential of Ni is less negative than that of Fe, suggesting poorer reduction capacity. Fe is a great adsorbent, precipitates, oxidises (if oxygen is available), and has various impacts on water pollution despite having inferior reduction capacities. It is also reasonably affordable. The most in-depth research on zerovalent metal nanoparticles to far has focused on zerovalent iron nanoparticles [10].

Nanoparticles of Metal Oxides

- **TiO_2 nanoparticles**

By oxidising pollutants into low molecular weight intermediate molecules, which ultimately decompose into CO_2, H_2O, and anions like NO_3, PO_3, and Cl for reuse, photocatalytic degradation technology has been shown to be effective in the treatment of water and wastewater. The most prevalent photocatalysts are semiconductors made of sulphide and metal oxides. Due to its strong photocatalytic activity, affordable price, photostability, and chemical and biological stability, TiO_2 has been the subject of the most current research [11]. The fact that titanium dioxide (TiO_2) is inexpensive, toxic-free, chemically stable, and widely accessible on Earth makes it one of the greatest photocatalysts ever created. One of TiO_2's three natural states is anatase. Other states include rutile and brookite. Anatase is still regarded as a suitable material for nanophotocatalysis [12]. A semiconductor like TiO_2 absorbs light carrying electron-hole pairs (e-h+) when the light's wavelength is larger than or equal to the width of the semiconductor's band gap. The electrons and holes may move to the catalyst surface by further separating the charge, where they combine with the sorbed species to create the redox reactions. Surface-bound hydroxyl radicals are produced when h+vb reacts with water, and oxygen selects ecb to produce superoxide radicals.

- **ZnO Nanoparticles,**

Due to its distinctive qualities, such as high oxidation capacity and strong photocatalytic capability, ZnO nanoparticles have become a significant photocatalytic contender in the water and wastewater treatment industry in addition to TiO_2 nanoparticles. ZnO NPs are suitable for sewage treatment due to their compatibility with organisms and environmental friendliness. Their band gap energies are comparable, and as a result, their photocatalytic capacity is comparable to that of TiO_2 NPs. ZnO NPs are less expensive compared to TiO_2 NPs [14]. More light quanta and a wider variety of solar spectra may be absorbed by ZnO nanoparticles than by a few semiconducting metal oxides [15]. Similar to TiO_2 NPs, ZnO NPs likewise have a limited ability to absorb light in the UV area. Additionally, since ZnO NPs are photocorrosion-prone, photogenerated charges recombine quickly, decreasing the photocatalytic efficiency [16]. ZnO nanoparticles are often doped with metals to enhance their photodegradation. Numerous metal dopants, including anionic, cationic, rare-earth, and codopants, have been examined by researchers [17].

- **Nanoparticles of Iron Oxides**[i]

Due to their accessibility and simplicity, iron oxide nanoparticles have gained attention as adsorbents for the removal of heavy metals. Hematite (Fe_2O_3), which is non-magnetic, has also been used recently for the elimination of heavy metals. Due to their tiny size, nanosorbent compounds are often challenging to separate and recover from polluted water. By using an external magnetic field, it is simple to separate and recover magnetic magnetite (Fe_3O4) and magnetic maghemite. These substances have been used successfully as sorbent substances to remove different heavy metals from water systems. Polymer shells have also been shown to improve nanostructure dispersibility and inhibit particle aggregation. Metal ions discovered in treated water may be "carried" as binders by polymer molecules 18].

- **Carbon Nanotubes**

These materials are a fascinating family of materials that have drawn scientists for basic study and a variety of applications, including sorption processes. They are unusual in their structures and electrical characteristics. They are very effective for the treatment of water and wastewater due to their high capacity for adsorbing a broad variety of pollutants, quick kinetics, large specific surfaces, and selectivity towards aromatics. There are several different kinds of carbon nanomaterials (CNMs), including carbon beads, filaments, and nanoporous carbon, in addition to carbon nanotubes (CNTs). CNTs have received the most attention of these and have made the greatest development in recent years. Carbon nanotubes are 1 nm-diameter cylinders made from rolled-up graphene sheets. CNTs are a highly alluring adsorbent due to their exceptional features. Due to their abundance of porous structures, CNTs exhibit extremely high specific surface areas and adsorption efficiencies for a variety of contaminants. To increase their surface area, mechanical properties, optical properties, and electrical properties, carbon nanotubes are frequently combined with metals or other supports [19,20].

The inhibition of cell growth by nanoparticles occurs as a result of the release of metal ions that interact with cellular components through a variety of pathways, including the generation of reactive oxygen species (ROS), pore formation in cell membranes, cell wall damage, DNA damage, and cell cycle arrest. As a result, they can be used to treat water and wastewater to produce usable water that is also safe to drink. However, there are a number of fundamental issues with nanotechnology that the general public and activist groups find troubling. Researchers admit that the danger associated with nanomaterials may vary from the risk associated with bulk forms of the same substance because of the significantly larger surface area to volume ratio of nanoparticles. In contrast to bulk materials, this might result in undeveloped and untested interactions with biological surfaces [21].

- **Nanocomposite**

There has been an increase in the manufacture of different nanocomposites in recent years. On the back of numerous studies, a tremendous amount of research has been done globally. The findings show that the adsorbent has a strong chance of efficiently and swiftly extracting nitrate from water. Additionally, the adsorbent may be simply extracted from the solution using a magnet because to its distinct magnetic feature. Real composite materials should be slick, heavy, and immobile and achieve nano reactivity by embedding or impregnating nanoparticles into parent material structures. Additionally, nontoxic, long-term stable, affordable materials are required for the treatment of wastewater and water. To achieve desirable nanocomposites, further study is still required [22].

Wastewater Treatment using Different types of Nanoparticles

Since nanotechnology cannot be utilised on its own to treat water or wastewater, it has been shown that nanomaterials work best when they are included into industrial water treatment systems. The use of nanotechnology in the treatment of wastewater has been the subject of much investigation. According to the types of materials they use, nanotechnology may be divided into three primary categories: nano-adsorbents, nano-catalysts, and nano-membranes [6].

- **Nano-adsorbents**

Adsorbent nanoparticles are tiny particles, either organic or inorganic, with a great attraction for compounds that are subject to adsorption. This indicates that they have a large capacity for pollution removal. These nanoparticles' significant qualities, such as their catalytic potential, small size, high reactivity, and greater surface energy, make them useful for the elimination of many types of contaminants. Metallic nanoparticles, mixed oxide nanostructures, magnetic nanoparticles, and metal oxide nanoparticles may all have different adsorption mechanisms [6].

- **Nano-catalyst**

Light energy interacts with metallic nanoparticles in nano-catalysis, producing strong and widespread photocatalytic activity. The strong and widespread photocatalytic activity of this therapy is contributing to its rising popularity. Hydroxyl radicals eliminate bacteria and organic matter during a photocatalytic reaction. Most materials used as nano-catalysts contain inorganic elements like metal oxides and semiconductors. To qualify as a nanocatalyst, a nanophotocatalyst must fulfil a number of requirements, including being harmless, having a concentration in air and water below the maximum allowable level, forming agglomerates and precipitates, and forming regular particles [6].

- **Nano-membrane**

Wastewater is separated from particles via a nano-membrane. These filters are highly good at eliminating pollutants including dyes, heavy metals, and others. Nanomaterials utilised as nano-membranes include nanotubes, nanoribbons, and nanofibers.

Nanoparticles integrated into membranes are more practical and beneficial than nano-adsorbents, nano-catalysts, or nano-membranes since they not only include a potent physical therapy but also nanoparticles to enhance the quality of the treatment. Consequently, the topic of the next conversation is nano-membranes.

Making nanocomposite membranes has expanded in importance and effectiveness as nanotechnology has developed quickly. As a consequence, the effects of a broad variety of nanoparticles

(NPs) on the engineering characteristics of polymeric nanocomposite membranes have been studied; in many instances, these NPs have dramatically enhanced mechanical, thermal, and antifouling capabilities [23]. It is well known that when NPs are evenly scattered throughout the polymeric matrix and establish strong interfacial interactions with the matrix, they improve the mechanical and thermal characteristics of polymeric membranes. In order to treat diverse forms of wastewater, membrane bioreactor (MBR) systems are widely employed. The MBR method, which combines activated sludge with membrane filtration, generates much greater effluent quality, a lower environmental impact, a higher organic loading rate, and less sludge than traditional procedures. Membranes are contaminated during this process not just by organic debris but also by microorganisms and their products. Membrane fouling in MBRs is greatly influenced by operating circumstances, although membrane properties also play a significant impact [24].

Various methods, such as embedding organic nanoparticles in polymer matrices, may be employed to increase the hydrophobicity of polymer membranes and their antifouling qualities. As shown in Table 1, adding nanoparticles to membrane matrix has the following three clear effects:

- The fouling of the membrane may be significantly reduced by employing anti-bacterial nanoparticles and changing operation parameters.
- Prevent the attachment of microorganisms and the creation of their bodies, which are mostly made of proteins and carbohydrates and produce severe fouling, to membrane surfaces and holes reducing the need for regular cleaning to aid in recuperation.
- It should be emphasised that several studies have used a single nanoparticle in a membrane matrix and shown that in these situations, the nanoparticle's release is seen as a drawback. In order to make nanoparticles larger and trap them in the membrane matrix with the least amount of releasing, researchers attempt to employ multiple nanoparticles.

Conclusion

Nanotechnology should be used in conjunction with other wastewater treatment methods as an additional technology. Incorporating or coating nanomaterials on membranes and composites is the best way to use them in this process. When compared to conventional systems, nanofilters have the following key advantages: They are more effective, have a much larger surface area that can be easily cleaned by back-flushing than conventional systems, and require significantly less pressure to pass water across the filter. In a nutshell, nanotechnology greatly reduces the drawbacks of treatment technologies, but it does not entirely eliminate all of their issues. As a result, there is still much to learn and understand about the best ways to combine various treatment systems in order to develop the best treatment methods that will allow people to preserve Earth's water supply for future generations.

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