A Comprehensive Review: Nanomembranes and Nanosorbents for Water Treatment

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Abstract: **Water despite being an indispensable part of human life is facing a major problem of being contaminated worldwide. There are several contaminants present in sewage and industrial effluents being discharged into water bodies making them unfit for drinking. This review explains the various claims of nanomaterial in removing contaminants from polluted water. Due to the unique properties of being nano-scale sized, high reactivity, and nanomaterial have been the major subject of research and development for the last decade. Studies have shown that nanomaterials are highly effective and successfully applied in removing contaminants from wastewater. Due to their exceptional properties of having a larger surface area, and being able to act at very low concentrations, nanomaterials have enormous possibilities to treat wastewater containing metallic & non-metallic substances, different organic and inorganic impurities, etc. Still, there are many challenges and issues with wastewater treatment. This paper discusses the various nanomaterials and the treatment methods using nanomaterials which are flexible, cost-effective, and efficient for the commercialization also.**

Keywords**: nano-sorbents; nano-catalysts; nano-membranes; industrial effluent; wastewater treatment.**

I. INTRODUCTION

Water, the most essential component for life on the planet is facing an adverse situation of being contaminated due to various reasons like inadequate disposal of sewage water, industrial effluent, radioactive waste, and many more [1], [2]. This contamination has an antagonistic influence on the environment which is not only putting the lives of all living creatures in danger but also shows an adverse effect on the economic growth of concerned countries. In a recent report, the UN warned about the survival of living organisms/ creatures and identified the unavailability and scarcity of pure and potable water [3], [4]. To overcome the alarming issue of contamination of drinking water scientists and researchers have made efforts in developing new technologies which are cost-effective and have more potential than the traditional methods of purification of wastewater [5], [6]. Nanotechnology is one such field that is cost-effective and has the potential to purify water efficiently and make it reusable [7].

Since the last decade experts have found that nanoparticles/nanomaterials being unique in their size, larger surface area, reactivity, and other mechanical properties have presented themselves as a better option for the treatment of industrial and domestic wastewater [8]- [11]. In general, nanomaterials can be described as the particles of size) between 1 and 100 nm [12]. Nanomaterials have been a matter of extensive research and development in many fields, such as catalysis [13], medicine [14], sensing [15], and biology [16]. To make things better, the nanoparticles/ materials show very high mobility in the solution [17]. Heavy metal ions [18], organic contaminants [19], inorganic pollutants [20], and microorganisms [21] have been stated to be effectively treated by several nanomaterials. We can thus say, nanomaterials have great promises for wastewater treatment. Currently, zero-valent metal nano-ions, metallic oxide nanoparticles, carbon nanotubes, and Nanocomposites are the most extensively used nanomaterials for the treatment of sewage and industrial wastewater. Heavy metals like Pb, Mo, etc. have been reported to treat organic and inorganic pollutants using different nanomaterials and composites. [22] – [26].

Recent advancements in nanomembranes, nano-photocatalysts, nanomotors, and nanosorbents carry numerous applications for water treatment techniques and some reproduced polymers are meritoriously functional for the treatment process of sewage and industrial wastewater. In nutshell, the application of nanomaterials in the purification of wastewater purification had positive perspectives in recent times [27]. Nanomaterials deliver potential and substantial water treatment tactics which can be easily adaptable with little inadequacy which needs further attention of the researchers. The paper here addresses the limitations & delimitations, advantages & disadvantages with the related future perspectives of the treatment methods using nanomaterials.

II. NANO-WATER TREATMENT METHODS

a. Nanomembranes

Nanomembranes, a pre-treatment process, often used for reverse osmosis are employed for the elimination of contaminants in a liquid phase. These are the exclusive and unique membranes formed from nanofibers that work at a very high eradication speed. [28]. Researchers have been using various polymer bases membrane techniques incorporating reverse osmosis, nanofiltration, etc. in which the membranes contain porous support of significant composite layer is carbon-based material like graphene oxide (GO) and carbon nanotubes (CNTs). These offer promising and significant signs of progress in the aqueous transport and fouling process. Nanomaterials like CNTs, Zeolite, alumina, silver metal particles, titanium oxide, etc. hold antimicrobial properties that minimize fouling and inhibit biofilm formation on the surface of the membrane thus reducing the chances of mechanical failure. They are used to inactivate bacteria and viruses and don't allow the bio-fouling of nanomembranes [29]-[35]. However, membrane clogging and membrane fouling in nanomembranes are the two major challenges that can't be overlooked and need to be overcome to make the treatment process more useful. It's been reported that while making thin-film nanomembranes, the accumulation of hydrophilic nanoparticles like Aluminium oxide, titanium oxide, Silver nanoparticles, CNTs, etc., eases the problem of membrane fouling and clogging.

Selectivity of Nanomembranes: Selectivity and permeability of nanomembranes for nanoparticles, less period required, ease of handling; easy optimization, and high uniformity make nanomembranes more prolific for wastewater treatment [36.] Apart from this bio-membranes are also reported to have high selectivity and permeability for organic pollutants [37], [38]. The incorporation of nanocatalysts like titanium oxide, and nanostructured metal-free radicals like iron make the nanofilm highly effective against membrane bio-fouling and degradation of contaminants [39]-[41]. The constructive development and advanced growth in synthesizing these nanostructured catalytic membranes/nanomaterials have not only enhanced the rate of degradation but made the process more selective and thus it became possible to make the treatment process more useful without using any harmful chemical [42]. There are various studies reported where immobilization of chitosan, polysulfones, etc. on nanomembranes was found effective for dichlorination and surface reduction [43]- [45].

Advantages & Disadvantages: Nanomembranes have the advantage in the removal of toxic substances from drinking water as compared to conventional treatment methods. Throughout the whole process of filtration of the ions Ca2+ and Mg2+, no other ion is required to compensate as an exchanger as is needed in other conventional treatment methods [46]-[48]. With all the advantages the limitations involved with nanomembranes are making it less efficient as compared to other treatment approaches. Pore blocking, conceivably discharge of nanofibers, reduced mechanical stability, membrane blocking, and requirement of resistant material while oxidation of nanomaterial, less reliability, slow operation process, less selectivity, high maintenance cost, and reduces working efficiency are some very common disadvantages w what is making it less valuable [49]-[53] Fouling makes the process inefficient as the working environment is not suitable overall temperatures [54] Optimizations is another factor responsible for fouling of membranes [55].

Applications of nanomembranes: Nanomembranes are used for the removal of organic and inorganic pollutants in ionic form from water resources through the solution using diffusion and size exclusion. Though these operations have these described nanomembranes are shown good results at the laboratory level, however, commercializing them is still a challenge. By upgrading resistivity for membrane fouling and improving the membrane selectivity it can yet be made more useful. Use of Zwitterion a surface grafting-based polymer can be an excellent option for next-generation membranes [56].

Table: 1 Applications of nanomembranes

Type of Nanomembranes	Applications	Reference
Aquaporin-based membranes	Less pressure desalination	[57]
Nanofiltration membranes	Colour, Reduction of hardness, odor	[58]
Nanocomposite membranes	Entirely dependent on composites	[59]
Self-assembling membranes	Ultrafiltration	[60]
Nanofiber membranes	Ultrafiltration, filter cartridge, water handling, separate filtration devices	[61]

Limitations of Membrane Stability: Membrane stability depends on the chemicals used in the treatment process and nanomembranes usually fail to keep the stability for a longer period. And there is a frequent need of changing the membrane. This further results in other issues such as high maintenance charges, slow treatment process, an increase in impurity content, etc. these all reasons make it less useful in water treatment operations [62], [63].

b. Nanosorbents:

These are Nanoscale particles made up of organic or inorganic materials that have high sorption capacity for the contaminants present in air or water and are also more appropriate and useful treatment processes in remediation of groundwater or wastewater treatment processes [64]. One of the most prominent examples of a conventional sorbent for environmental application is activated carbon. This material is cost-effective and is widely used drinking water industry for water decontamination. However, nanostructured sorbents offer the opportunity of an even greater sorption capacity and may be designed to target specific contaminants. Different carbon-based Nano compounds and metal oxides are under investigation for the treatment of a wide variety of contaminants. However, most potential nanosorbents are in the state of research; very few applications are market-ready and will require both translations from lab to field-scale plus appropriate safety testing [65].

The most frequently used nanosorbents are carbon black, graphite, and graphene oxide which is based on carbon. However, the composite like Ag/polyaniline, Ag/carbon, C/TiO2, certain metals & their metal oxide, and other polymeric nanosorbents have significant importance in reducing the toxicity of wastewater [66]. Copper ions along with the polymeric dendrimers in ultra-filtration systems are found exceptionally functional for reducing and eliminating organic pollutants and heavy metals from industrial wastewater [67], [68]. The removal percentage of organic dyes is almost 99% [69]. Zeolite is another important anti-microbial nanosorbents in which nanoparticles like copper and silver ions can be implanted within their absorbent structure [70], [71].

The advancement in nanotechnology has led to the latest magnetic nanoparticles which involve application that involves extracting heavy metal ions from different water sources. These magnetic nanoparticles exhibit exceptional properties such as larger surface area, surface-volume ratio, low toxicity, ease of separation, and most importantly easily and efficiently recoverable. Besides, magnetic nanoparticles can be easily and efficiently recovered after adsorption compared with other typical adsorbents [72], [73]

However, despite all the advantages certain toxic effects nag health risks have been reported. [74], [75]. So, there is a need to give attention to overcoming the toxicity issues. Bio-adsorbent such as graphene oxide, being highly biodegradable, biocompatible, and nontoxic can be one such option that can replace the chemically synthesized nanosorbents [76], [77]

*Advantages and Disadvantages***-** The role of nanosorbents has received great interest due to their ability of rapid adsorption rate, excellent r sorption efficiency towards the removal of a wide range of heavy metal ions in wastewater, and photochemical properties. [78], [79]. These properties make them distinct from other conventional sorbents. Properties such as large surface areas, excellent rate of adsorption, and short time adsorption have gained more interest from researchers. Literature reviews suggest that nanosorbents have proved to be an excellent separation medium in eliminating the organic, and inorganic water decontamination [80], [81]. However, some challenges are still required to be addressed to make it useful for commercial purposes.

*Future Perspectives of Nanosorbents***:** The prospects of nanosorbents look promising as the researchers, consultants and the whole scientific community is working to improve adsorption mechanisms to reduce the health risks associated and to make them suitable to be used at an industrial scale [82].

*Applications of Nanosorbents***:** In the last decade, nanotechnology has emerged as one of the striking technologies for water treatment for wastewater treatment applications. Water treatment using the nanosorbents like activated carbon, silica gel, zeolites, low-cost agro-industrial adsorbents, bio-sorbents, mineral-based adsorbents, magnetic adsorbents, and layered-double hydroxides is one of the most widely used and potential adsorbents [83], [84]

Table: 2 Applications of Nanosorbents

Type of Nanosorbents	Applications	Reference
Polymer Fibres	Removal of arsenic and other toxic metals	[85]
Nano-metal oxides	Removal of Heavy metals	[86]
Carbon-based nanosorbents	Removal of Nickel ions in industrial and domestic wastewater	[87]
Regenerable polymeric Nano sorbents	Removal of organic pollutants, inorganic contaminants of wastewaters	[88]
Graphene Oxide	Removal of dyes	[89]
Nano-clay	Removal of Hydrocarbons, Dyes	[90]
Nano-Aerogels]	Removal of uranium from drinking water	[91]
Nano-iron oxides	Elimination of hormones and toxic pharmaceuticals materials from water	[92]

III. NANOMATERIALS: CHALLENGES FOR WATER TREATMENT

Emerging nanotechnology possesses several challenges in the field of wastewater treatment [93]. It offers numerous options for the treatment of domestic and industrial wastewater containing various contaminants. The advances in commercial applications of nanomaterial are too rapid and the production of nanomaterial is not easy to match with the pace of increasing demand for treatment at a global level [94]. Nano-materials have been used in various methods of purification of wastewater such as photocatalysis, adsorption, and nanosorbents [95], [96]. These procedures and measures taken for the treatment need some changes to work more efficiently. However, even after considering the risk of toxicity involved with nano-materials, not much improvement has been made in nanotechnology as rapidly as research has given possibilities to different applications of nano-materials. Lack of information about the treatment process and disposal of waste is the major challenge [97]. Another matter of concern is human health because such nanomaterials' do have some adversarial and toxicological effects associated with them. However, it is not easy to come to any conclusion as the ongoing research needs some necessary to know more about the toxicity involved.

The major challenge faced in the membrane–wastewater treatment fouling process is the blockage of pores during filtration resulting in a decrease in efficiency [98]. In the case of nanosorbents, lack of reusability is the main concern [99.]. The United State Environmental Protection Agency (USEPA) listed some basic challenges during the process of water treatment where nano-particles are used. [100]–[103]. (a) What is the mechanism to recover nanoparticles from wastewater? (b) What is the effect of nanoparticles on other contaminants during treatment? (c) How much is the treatment method effective in working? There is a basic need to design a treatment method that answers all these questions raised for nanomaterials.

IV. CONCLUSIONS

Given the current speediness in the development and application, nano-materials look enormously promising for water treatment. Nanotechnology water with the help of RO membranes has made low-cost treatment of waste feasible, especially for desalination, cyclization, and reuse of wastewater. Nano based materials have been developed through a combination of nanotechnology, such as Zeolite, ceramics coated with zeolite, transition metal bases nanomaterials, carbon bases nanosorbents, polymeric and hybrid protein nanomembranes, titanium oxide membranes, silver nanoparticles, Zinc oxide nanoparticles, etc have made their great contribution to nano. These nanomembranes and nanosorbents promise high selectivity toward water treatment. High-performance thin-film nano-composite with nano-silver coating possesses good resistance to fouling. Similarly, titanium nanoparticles have potential application in self-cleaning with a notable property of self-alignment and extraordinary adaptability for manipulation as per the need of the treatment process. However, the challenges are tough. Still, a significant amount of work has to be done on R&D to incorporate nanotechnology in multidisciplinary streams.

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