J. Adv. Appl. NanoBioTech

ISSN;2710-4001

Journal web link:
http://www.AANBT.dormaj.com

https://doi.org/10.47277/AANBT/3(1)13

Using nanomembrane to heavy metal removal from wastewater: A mini-review

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Received:30/10/2021 Accepted:12/11/2021 Published: 20/03/2022

Abstract

Clean water is one of the essential factors in all creature's life and human beings. The contamination of various pollutants, especially heavy metals, in water bodies causes environmental pollution and excessive death of living organisms due to industrial development. Many methods have been done to overcome this issue and produce clean water. It should be noted that none of them was as successful as nanomaterials. In this review, nanomembrane as a good candidate was chosen to eliminate the heavy metals from wastewater. Also, the pros and cons and future perspectives of using nanomembrane were introduced, respectively.

Keywords: Heavy metal, Wastewater treatment, Nanomembrane

1 Introduction

Recharging heavy metals into water bodies due to the development of industries and increasing human demands have been increased. So that every year a large volume of wastewater containing heavy metals enters the environment (1, 2). The activity of many industries such as tanning, batteries, textile, mining, plating, and metal smelting cause the entrance of these kinds of toxic compounds and creates a significant risk to the environment and ecosystem (3, 4**).** By polluting the environment with heavy metals, these matters eventually enter the food chain and accumulate in the body of living creatures or humans (5). The entry of even small amounts of these metals into the human body causes cancer, growth retardation, and impaired nervous system (6-10). Also, it should be noted that some living beings need to low concentration of heavy metals to activate their metabolism. Lead, zinc, mercury, nickel, cadmium, copper, chromium and arsenic are the most popular heavy metals. Many methods for heavy metal removal from wastewater have been used, such as evaporation, freezing, ion exchange, membrane filtration, and chemical and electrochemical sediment (11, 12). But none of them were successful utterly due to being expensive for removing low concentration of heavy metals, and producing sludge (1, 13) . These reasons cause to using new technology for wastewater treatment like nanomembrane. These reasons cause to using new technology for wastewater treatment like nanomembrane. Nanomembranes constructed from unique nanofibers are good candidates to eradicate undesirable nanoparticles present in the wastewater treatment process (14, 15). In producing freshwater, nanomembranes can be very selective and play an essential role in treating pollutants. These membranes are porous thin-layered, impermeable to heavy metals, salt, microorganisms, etc. General principles of nanomembranes are using filtration to getting rid of unwanted contaminants (16). The utilization of nanomembranes causes the treatment process very fast, and the rate of fouling can be reduced (17) . Recently many researches have been done to combine different nanomaterial substances with other polymer-based membranes. To produce beneficial nanomembranes to remove heavy metals from wastewater. For example, porous membrane, which is made of porous support with composite layer. Most used materials as composite layers are carbon-based materials with anti-microbial features to control fouling and increase mechanical stability. With doping of some nanomaterial such as zeolite, alumina, TiO_2 in the surface of membrane, the membrane features can be improved, and fouling occurs much less frequently (18-20). Doping metal particle-like silver to produce a polymeric membrane can be an excellent candidate to remove heavy metals and prevent the growth of bacteria (21, 22). Membrane fouling is one of the critical limitations that decrease the efficiency of nanomembrane. To overcome this problem, combining nanoparticles such as Al_2O_3, TiO_2, metal oxide, and to (nano silver, CNTs) make nanocomposite membrane are an excellent solution to increase porosity and fouling resistance of the membrane (23, 24). Also, using nano photocatalysts like

TiO_2 to produce nanomembrane is one way to improve nanomembrane ability in wastewater treatment and destroying different microorganisms (25). One of the famous permeable 2D nanostructural membranes is Zeolite which is wildly used in the separation and purification process (26, 27). Some types of nanomembranes and their ability in heavy metal removal are shown in table 2. Nanomembrane technology provides a great chance in heavy metal removal and wastewater treatment. Nevertheless, there are so many limitations in using these kinds of membranes mentioned in this article. Beside this, different types of nanomembranes and the advantage and disadvantage of them are discussed briefly so that, this technology is widely used in providing clean water.

Table 1. Type of nanomembranes, the pollutant and their ability removal.

Type of nanomembranes	Major pollutant	Removal efficiency (%)	Ref
Nano-composite membrane	Copper ion	92	(28)
Nanofiber membrane	Cr (VI) Se (IV)	70,97/3	(29)
PES	Cd	27	(30)
PVC	Cr, Cd	70, 85	(31)
polyethersulfone (PES) mixed matrix membranes	Zn^{2+}, Ni^{2+}	90	(32)

2 Polymeric Nano-composite membrane for water treatment

Polymer nano-composite membranes are made by dispersing nano-material in the matrics of polymeric membranes (33, 34). Thin-film nano-composite membranes and Blended nano-composite membranes are two kinds of these membranes. The difference between the two types is in the way of the Construction method. In the first group, a thin film of nano-particles can be formed by accumulating on the membrane with pressure or using the dip-coating method. But for the making of the second grope, nano-particles should be dispersed whit polymer casting solution before membrane casting (35). Generally, polymer Thin Film Nano-composite (TFC) Membranes are popular in wastewater treatment because of their stability in different pH and High-temperature resistance. Also, these kinds of membranes are known for their mechanical stability, permeability, selectivity, thermal resistance, and hydrophilicity because of fabricating nano-particles on the membrane surface. There are two ways to this purpose: interfacial polymerization and encapsulation within TFC or sedimentation on the surface of the membrane immediately. Most of the nano-fillers used for these membranes are silica, zeolite, titanium dioxide, graphene oxide, silver, and carbon nanotubes (36-41).

3 Type of nanocomposite membrane

Generally, nano-composite-based membranes are inorganic membranes, and different nano-particles are used to prepare them. These kinds of membranes are efficient because of their chemical, thermal and mechanical stability and photocatalytic capability. The Materials used in the construction of them are in nanocrystalline form and include Al_2O_3, Fe, GO, SiO_2, GO-Ag, Ag, ZnO, Cu, TiO_2, Zeolit, Fe_2O_3 and ZrO_2 (42-44).

3.1 Silver based nano-composite membranes

Today, silver is one of the best choices for membrane surface modification because of its chemical strength and antibacterial ability. Also, silver is a routine antibacterial agent used in medical device coatings, surgical wounds dressings, and commercial products (45) . Interaction of silver with groups that contain sulfur like thiol groups of bacterial DNA is rooted in the antibacterial property of silver. By releasing ionic silver and interfacing with sulfur groups present in bacterial protein, bacterial growth is constrained. However, its antiviral properties prevent electron transport and dimerize DNA. But the main point about silver is leaching silver from the membrane surface because biofouling generally happens on the surface of the membrane. Membrane performance reduces during the time due to leaching. And also can be a critical threat to marine life and human being while using the water achieved from wastewater treatment. Immobilizing silver nano-particles on membrane surface with blending silver with other nano-particles can be one of the solutions to overcome this issue and improve the antibacterial capability (46).

3.2 Copper based polymeric nano-composite membrane

Copper is a very common nano-particle due to its excellent antibacterial properties, cost-effectiveness, and easy availability. Recently many researches have been done about high antimicrobial activity of copper ions and their oxides. This ability of cooper is rooted in immobilization of Cu-NPs with using the methods which are in situ formation that causes great control of fouling (47).

3.3 Titanium dioxide based polymeric nano-composite membrane

TiO_2 nanomaterial has appeared as an excellent choice for assembling nano-composites membranes because of its hydrophilic, photocatalytic properties and high stability for wastewater treatment and Purification of organic matters. Due to TiO2 large band gap of about 3.2 eV and cannot absorb visible light, its photocatalytic activity is limited to the UV region (48, 49). As showen in Fig 1. when the TiO_2 is irradiated, the electron at valence band of photo-catalyst, due to equal or greater photon energy than the band gap, move to the conduction band and leaving positive holes at the valence band These photo-generated holes react with H_2O or OH^- and produce hydroxyl radicals Both the photo-generated holes and hydroxyl radicals can oxidize the contaminate Furthermore, hydrogen ions react with the electrons to produce the water, and oxygen molecules either can be reduced by the mentioned electrons and form superoxide radical anions However, the hydroxyl radicals and superoxide radicals can degrade the organic compounds too (50).

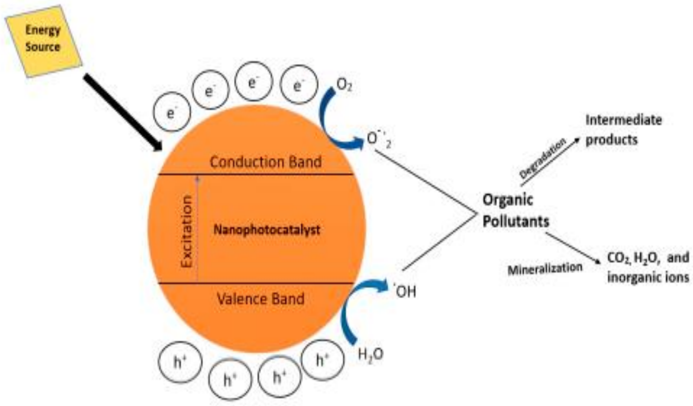

Fig 1. General mechanism of TiO_2 to destroying the contaminant (17).

3.4 ZnO/ZrO$_2$ based polymeric nano-composite membrane

ZnO nano-particles have received much attention in the different industrial and biomedical fields, electronics, and membrane technology due to their exclusive properties, especially anti-corrosive, anti-microbial, and anti-fungal. For improving ZnO nano-composites ability in rejection capability, hydrophilicity, and antifouling properties, many kinds of research have been done about the combination of ZnO with different polymer matrices such as Polyethersulfone (PES), Polysulfone (PSF), and Polyvinylidine Fluoride (PVDF). Forasmuch as ZnO nanoparticles are great choices to improve membrane quality, they have been used to synthesize Ultrafiltration (UF) membrane or as nanofiller in the construction of polymer nanocomposite membranes such as SiO_2, TiO_2, and Al_2O_3 (51-53) . Also, ZnO nanocomposite membranes have an excellent ability to absorb heavy metals like (Cu^{2+}), dye rejection, and reduce oleic acid fouling and collagen separation (54).

3.5 Carbon based polymeric nano-composite membrane

Carbon-based nanomaterials have outstanding features such as high mechanical, chemical, thermal stability, and surface adsorption properties and are divided into unique structural like carbon nanotubes (single-walled and multi-walled CNTs) 1D hollow carbon sphere, graphene oxide, and mesoporous carbon. CNTs are familiar with user-friendly, cost-effective, and high purity and are widespread choices for membrane surface modification. Even though the thickness of carbon-based nanomembrane is 1nm, these membranes show exceptional mechanical stability (55, 56).

4 Zeolite membrane

Zeolite Membrane performance is directly related to the structure of pores and the size and shape of its crystal. Therefore, providing freestanding zeolite nanosheets with acceptable mechanical features is very critical. For making zeolite membranes, uniform nanosheets, colloidal stability in suspensions, and deposition techniques are necessary (57).

5 Nanofiber membrane

Nanofiber is one of the practical approaches in waste water treatment because of specific features like high size uniformity and high porosity. These kinds of membranes are made in different ways, including template synthesis, phase separation, and electrospinning (58). Among the methods mentioned, electrospun nanofibers are famous for removing inorganic pollutants like heavy metal, oil, and dyes because of their high specific surface area and surface morphology (59).

6 Advantage and Disadvantages of Nanomembrane

Separating the toxic particles from water bodies is the primary purpose of using the nanomembrane. Besides this, for evaluating and measuring the safety level of drinking water, nanomembranes also are used (60). In comparison between traditional methods and nanomembranes, it can be noted that the main advantage of nanomembrane is that through the treatment process, there is no need for Na+ ions or other ions to compensate, however in old methods of filtration, calcium and magnesium need other ions to exchange (61). Like other treatment methods, Nanomembranes face various limitations that reduce efficiency. For example, one of the widespread problems is fouling nanomembrane, mainly used for the first time. But considering the optimal conditions such as suitable temperature and pressure, fouling can be controlled (62).The second disadvantage is low resistance and stability of membrane for a long time, which eventually decreases the efficiency. Therefore, the nanomembrane should be changed for excellent results, which is not cost-effective (63, 64). Generally, nanomembrane disadvantages are less reliability, low selectivity, being expensive, and decreasing efficiency with time passage (65).

7 Future perspective

As discussed, inorganic and organic ions, nanoparticles viruses-based pollutants can be separated by using nanomembranes. These novel nanomembranes are very cost-effective and act effectively on a laboratory scale. But for being suitable to large magnification and using in industries, much effort and research are still needed. And also, to overcome the existing limitation, manufacturers and the laboratory should cooperate closely. The first step to developing the nanomembrane is improving their selectivity and resistance to control fouling. For this purpose, Surface grafting-based polymers can be an excellent choice to produce novel membranes (66). The other significant step is, increasing the sensitivity of polyamide membranes to some kinds of oxidants like ozone and chlorine. Despite all these efforts, there are still many limitations and problems to be solved so that these membranes can be used in large-scale wastewater treatment (17).

8 Conclusion

This review article discussed the importance of removing heavy metals from water bodies by using nanomembranes as new technology. Using Polymeric Nano-composite membranes due to their low fouling rate, high specific surface area, and cost-effectiveness can be influential factors in overcoming the limitation of nanomembrane-like fouling. Besides this, nanofiber membrane is one of the significant ways in treating water because of its unique features.

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