APPLICATIONS OF NANOTECHNOLOGY IN WATER TREATMENT

APLICAÇÕES DA NANOTECNOLOGIA NO TRATAMENTO DE ÁGUA

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ABSTRACT

The industrial contamination, along with domestic effluents, agricultural and urban runoff are contaminating rivers and making it difficult for conventional water treatment to remove all the pollutants. This contamination can impact in the quality of rivers, in the quality of life of aquatic animals and can impact in the human health through the consumption of water. In order to improve the water quality, nanotechnology has been studied as an alternative to better remove contaminants, such as, heavy metals, oily water separation and antimicrobial activity. Besides, with the increase in industrialization along with the contamination of rivers, seawater could be an interesting alternative for drinking water source after adequate treatment. Nanomaterials are being studied as a possibility to remove salt from seawater, making it possible to drink. Howerver, there is a need to elucidate the potential risks to the environemt that these nanomaterials can cause. Therefore, the aim of this review is to describe some applications of nanotechnology in water treatment regarding metals, oil removal from water, antimicrobial activity and desalination in order to improve water quality, as well, as discuss their potential risk to the environment.

Keywords: Antimicrobial activity. Environmental risks. Nanotechnology. Pollutants. Water contamination.

RESUMO

A contaminação industrial, juntamente com efluentes domésticos, agricultura e escoamento urbano, estão contaminando os rios e dificultando para os tratamentos de água convencionais removerem todos os poluentes. Esta contaminação pode impactar na qualidade dos rios, na qualidade de vida dos animais marinhos e pode impactar na saúde humana através do consumo de água. Com a finalidade de melhorar a qualidade da água, a nanotecnologia tem sido estudada como uma alternativa para melhor remover os poluentes, como, metais pesados, separar óleo da água e atividade antimicrobiana. Além disso, com o aumento da industrialização juntamente com a contaminação dos rios, a água do mar poderia ser uma alternativa interessante como fonte de água potável após o tratamento adequado. Nanomateriais estão sendo estudado como uma possibilidade para remover o sal da água do mar, tornando-a possível de ser ingerida. Entretanto, há a necessidade de elucidar os potenciais riscos para o meio ambiente que estes nanomateriais podem causar. Sendo assim, o objetivo deste artigo de revisão é descrever algumas aplicações da nanotecnologia no tratamento de água em relação à remoção de metais e óleo da água, atividade antimicrobiana e a dessalinização a fim de melhorar a qualidade da água, assim como, discutir os potenciais riscos para o meio ambiente.

Palavras-chave: Atividade antimicrobiana. Contaminação da água. Nanotecnologia. Poluentes. Riscos ambientais.

1 INTRODUCTION

The growth in industrialization has consequently polluted rivers through the discharge of hazardous chemicals, including heavy metals, into the environment (ISLAM *et al.*, 2015; RASTMANESH *et al.*, 2018). Along with the industrial contamination, domestic effluents, agricultural and urban runoffs are of concern to the quality of the rivers (DALZOCHIO *et al.*, 2018). This contamination may result in the bioaccumulation of metals in water and aquatic animals (RASTMANESH *et al.*, 2018), being a threat to human and animal health (DALZOCHIO *et al.*, 2018). Aquatic contaminants such as heavy metal ions and dyes are very harmful to living beings and can affect the ecosystem (SANTHOSH *et al.*, 2016).

Conventional water treatments are no longer efficient to remove many of the pollutants found in water in order to achieve water quality standards. They often rely on centralized systems, which the distribution and discharge processes are not sustainable for nowadays' needs (QU *et al.*, 2013). Based on this problem, nanotechnology could improve water treatment because of the size of nanomaterials, in which the surface area is bigger, improving the contact with water; high reactivity; fast kinetics; specificity to contaminants and, another important advantage is the cost of nanomaterials that are decreasing (ZHANG *et al.*, 2016).

It is estimated that approximately 663 million people doesn't have access to potable water, mainly in developing countries (WHO/ UNICEF, 2015). So, it becomes necessary to provide basic water treatment to these people, where water treatment sometimes is non-existent (QU *et al.*, 2013). The removal of pollutants from contaminated water is necessary to prevent damages to human health and to the environment (SANTHOSH *et al.*, 2016). Based on the problems abovementioned, the present review aimed on the application of nanomaterials to improve the quality of water regarding the metals and oil removal, desalination capacity and antimicrobial activity, as well as, discuss the potential risks that these nanomaterails can cause to the environment.

2 METHODS

The present review was undertaken based on the research of manuscripts about nanotechnology and its applications in water treatment regarding the efficiency in metal removal, separation of oil from oily water, antimicrobial activity and the potential risks of nanomaterials to the environment. These manuscripts were searched in Science Direct, Scopus, PubMed, and Periódicos Capes database.

3 NANOTECHNOLOGY

Nanoscience studies the phenomena on a nanometer scale (CHATURVEDI *et al.*, 2012). Nanotechnology involves nanomaterials that have at least one component with one dimension less than 100 nm (TEOW; MOHAMMAD, 2017). Nanotechnology had its beginning in 1959 with the lecture entitled "There's plenty of room at the bottom" given by the physicist Richard Feynman at the annual American Physical Society meeting (SAVOLAINEN *et al.*, 2010). Nanotechnology has been studied for wastewater treatment and has been cited as one of the most advanced process in this field. Based on the nanomaterial, the water treatment can be divided into three main groups: nano-adsorbents, nano-catalysts and nano-membrane (ANJUM *et al.*, 2016).

- Nano-adsorbents are nanoparticles made of organic or inorganic materials with a high affinity to adsorb substances (SANTHOSH *et al.*, 2016), in another words, they have a capability to remove many pollutants. These nanoparticles are developed and used to remove different types of contaminants. This kind of material have important characteristics, such as, catalytic potential, small size, high reactivity, and large surface energy (BASHEER *et al.*, 2018). They can be classified based on their adsorption process, which includes metallic nanoparticle, nanostructured mixed oxides, magnetic nanoparticles and metallic oxide nanoparticles (ANJUM *et al.*, 2016).
- Nano-catalysts are based on the interaction of light energy with metallic nanoparticles. This treatment is becoming of great interest due to the high and broad photocatalytic activities (AKHAVAN, 2009). Photocatalytc activities are based on the destruction of bacteria and organic substances by the reaction with hydroxyl radicals (KHAYDAROV *et al.,* 2013). The materials used in nano-catalysts usually are inorganic materials such as semiconductors and metal oxides (ANJUM *et al.*, 2016). However, to be considered a nano-photocatalytic, they must follow some requirements: to be harmless and have their concentration in the water and air lower than the maximum permissible value; to form agglomerates, coagulate and precipitate; and to form safe ordinary particles (KHAYDAROV *et al.,* 2013).
- Nano-membranes are responsible for the separation of particles from the wastewater (ANJUM *et al.*, 2016). They can be very efficient in the removal of dyes, heavy metals, and other contaminants (JIE *et al.*, 2015). The nanomaterials used as nano-membranes are nanotubes, nanoribbons, and nanofibers (LIU *et al.*, 2014).

Conventional water treatment sometimes cannot be very effective in removing some contaminants, such as, metals and microorganisms (ADELEYE *et al.*, 2016). Another problem is the formation of disinfection byproducts (DPBs), which are dangerous to human health (LI *et al.*, 2008). These DPBs are

the result of the reaction of chemical disinfectants with organic matters and inorganic ion present in the water (CORTÉS; MARCOS, 2018), which are added to the wastewater secondary effluent in order to prevent biofouling (XU *et al.*, 2018). Antimicrobial nanomaterials, for example, usually do not produce these DPBs because they are not strong oxidants, so they can be important decontaminants, improving the water treatment (LI *et al.*, 2008).

The access to potable water is an important factor to avoid people from getting ill. Waterborne diseases are the lead cause of death worldwide, mainly in developing countries. Diarrhea, a consequence of this situation, kills approximately 2.2 million people every year, specially affecting children under 5 years old (LI *et al.*, 2008). If no potable water is available for drinking purposes, many sanitary problems can occur and lead to health and economic problems (HATAMIE *et al.*, 2016).

Some studies have been evaluating the capability of nanomaterials to remove contaminants from water. Nanomaterials have been studied as an alternative to remove metals, microorganisms and oil from contaminated water. Also, nanomaterials were developed to desalinate water as a possibility to use seawater as a drinking source. Some examples of these applications are described below.

3.1 METALS REMOVAL

Heavy metals as well as some anions present high toxicity and this property can cause real damages to humans and ecossystems (HATAMIE *et al.*, 2016). Based on that, Hatamie and collaborators (2016) studied the efficacy of magnetic nano-ferrofluid, which acts as a coagulant in the water, as a possible absorbent of heavy metals. The results demonstrated that the metal removal efficiency increased to almost 100% when the pH was also increased from 4 to 8, these heavy metals were Fe^{2+}, Pb^{2+}, Zn^{2+} and Cu^{2+}. The other metals analyzed (Ni^{2+}, Mn^{2+}, Co^{2+}, Cd^{2+}) also had an increase in the metal removal efficiency, however they remain lower that 90%.

Some methodologies are used to remove heavy metals from water such as ion exchange, chemical precipitation, membrane filtration, coagulation, biological or electrochemical remediation and adsorption (VILARDI *et al.*, 2018). Among these processes, adsorption demonstrated to be more flexible in design and operation, and can generate treated water with high-quality (HUA *et al.*, 2012).

Nanosized metal oxides are important adsorbents which includes iron oxides, manganese oxides, aluminum oxides, and titanium oxides. The size and shape of these materials are important factors to the adsorption performance (HUA *et al.*, 2012). The use of iron oxides nanomaterials in water treatment can occur from two different applications: (i) using iron nanomaterial as a kind of nanoadsorbent and, (ii) using as a photocatalysts, converting the contaminants to less toxic substances (XU *et al.*, 2012).

Carbon based materials are being used as adsorbents, one example is carbon nanotubes (CNT), they have high surface area to volume ratio and pore size distribution. With these characteristics the CNT presents important sorption capability in comparison to granular or powder activated carbon. Another carbon based material is graphene, they are considered efficient adsorbents because of their large specific area and electron rich environment. Graphene oxide also demonstrated to have high adsorbent capacity due to their strong functional groups (SANTHOSH *et al.*, 2016).

3.2 OIL REMOVAL

Oil is an important energy source in the world, however, when it is explored, transported or stored there is a risk of spillage (SYED *et al.*, 2011). Spill accidents involving oil has occurred from natural sources or disposal disaster from industries and consequently it has been impacting the ecosystem (TAN *et al.*, 2015). Along with industries, domestic effluents can also contain oil and their use are increasing fast (LU; YUAN, 2018).

Different methodologies are applied to separate oil from an oil-contaminated water, nevertheless they are expensive and sometimes not very effective (VELAYI; NOROUZBEIGI, 2018). New technologies have been studied for this purpose and nanotechnology demonstrated to be more cost-effective so far (SYED *et al.*, 2011). Some nanomaterials properties can become interesting in separating oil from water effectively, which includes, high separation efficiency, good recyclability, environmental friendliness and easy fabrication (LU; YUAN, 2018).

Some researchers developed structures with nanomaterials to separate oil from water. A research performed by Syed and collaborators (2011) used hydrophobic nano-silica to remove gasoline and diesel from water. Their results demonstrated that this material was more effective in removing these oils when compared to organic or inorganic adsorbents available in literature data.

Tan *et al.* (2015) evaluated the possibility of different structures of titanium dioxide (TiO_2) nanoparticles (nanowire, nanotube, and nanosheet) to perform as a filter. They developed nanostructures membranes that had superhydrophilic and underwater superoleophobic characteristics. The results demonstrated that the nanosheet of TiO_2 had the best capability of separation of oil from oil-contaminated water.

Lu and Yuan (2018) developed a sponge capable of removing oil from the water. They utilized silver nanoparticles coated on the surface of a porous sponge. The results showed that it had superhydrophobicity and self-cleaning properties and that the sponge could be reutilized for several times. However, from the many organic solvents and oils tested, the absorption capacity of the sponge was dependent on the density, viscosity and surface tension of the materials, which resulted in different volumes absorption capacity.

3.3 DESALINATION

The population growth and urbanization will eventually require for new accessible fresh water supply, and the desalination is being studied as an important source of drinking water, once seawater represents a huge supply of water (SURWADE *et al.*, 2015). Desalination in characterized by the extraction of mineral components from different sources of water, such as, sea water, brackish water and treated water. Some conventional methods are known to remove salt from water, these processes include precipitation, oxidation, reduction, ion exchange, membrane filtration and adsorption (ZAHED *et al.*, 2018).

Conventional water treatment is not very effective in removing salt from water (TEOW & MOHAMMAD, 2017), however, some methodologies such as reverse osmoses membranes require high pressures and results in substantial quantities of liquid wastes. Therefore, the utilization of nanomaterials that require less pressure as well as low energy consumption and high salt rejection are being studied as a viable route for sustainable membrane desalination (GOH *et al.*, 2016).

One nanomaterial that is of great interest is graphene, an allotrope of carbon and, because of its properties such as strength, chemical and thickness, it became more studied. Researches performed with graphene demonstrated the potential that nanoporous graphene can have as a selective membrane for water desalination (SURWADE *et al.*, 2015). Graphene oxide (GO), a form of graphene, contains functional groups that results in a hydrophilicity and high negative charge density, and these characteristics are essential to the desalination process (ZAHED *et al.*, 2018).

Another research, conducted by Abo-Almaged and Gaber (2017), evaluated the ability of nano-hydroxyapatite membranes to reject salt from water. The results demonstrated that when the NaCl concentration increased, the salt rejection by the membrane increased as well, reaching a rejection of 73% to a 5000 ppm concentration of salt.

3.4 ANTIMICROBIAL ACTIVITY

According to the Guidelines for Drinking-Water Quality (World Health Organization, 2017), pathogenic bacteria, viruses and parasites can cause infectious diseases which are the most common and widespread health risks associated with drinking-water.

Khaydarov and collaborators (2013) synthesized nanocarbon-titanium with functional groups on the surface of carbon nanoparticles with nano-photocatalysts properties. They evaluated the antimicrobial activity on *Escherichia coli* in water under sunlight irradiation at 11 am during 6 hours. The results demonstrated that the water disinfection is time dependent on the bacteria concentration (around 1 hour), it was successfully capable of destructing the bacteria.

Another example of antimicrobial activity using nanotechnology is the research accomplished by Pina and collaborators (2014) that developed a poly(ethylene) glycol (PEG)-coated magnetic nanoparticles, functionalized with (RW)$_3$ (an antimicrobial peptide) to act as an antimicrobial against *E. coli* and *Bacillus subtilis*. These magnetic nanoparticles are widely used in different contaminants, such as, metals removal, detection of bacteria, parasites, viruses, or antibiotic and in the separation of pollutants. Nevertheless, these magnetic nanoparticles can be functionalized with molecules that can interact or destruct bacteria. The results showed that the nanoparticle was able to disinfect the water, decreasing significantly both bacterial populations (*E. coli* and *B. subtilis*).

Carbon nanotubes have been demonstrating to have interesting results when evaluating the removal or even inactivation of pathogenic bacteria and viruses from water. Based on this statements, Parham and collaborators (2013) developed carbon nanotubes that grew in the open pores of a porous ceramic matrix. They tested the capability of this filter to remove microorganism from water, they utilized *Saccharomyces cerevisiae* as a model. After the filtration, some procedures were carried out to analyze the efficiency of the filter. The results showed that the filter had the yeast attached to the carbon nanotubes network. They also analyzed the influence of the filter length and aqueous flow, which demonstrated to have a strong effect on the efficiency of the yeast filtration. The filter length of 50 and 70 mm with an aqueous flow of 20 mL/h demonstrated an efficiency of 98% yeast filtration.

4 POTENTIAL RISKS TO THE ENVIRONMENT

Although nanotechnology has proven to be very effective in different areas by improving the environmental quality, some aspects need to be discussed whether nanomaterials and/or nanoparticles can affect the environment and the aquatic biota. However, giving the increasing progress in nanotechnology, there isn't enough information about the effects on human health. Another issue is that nanomaterials cannot be yet detected in the environment and, this can result in different types of environmental problems (KABIR *et al.,* 2018).

There are many different sources of nanomaterials in the environment, they include intentional releases and unintentional releases which can occur from atmospheric emissions and solid or liquid waste streams from production services (KLAINE *et al.,* 2008). Some aspects influence the effect of nanomaterials in the environment, such as, concentration, presence of organic or inorganic materials, pH. Also, the period that the particle remains in the ecosystems reflects in its toxicity, the longer the period, the more toxic it becomes (PUROHIT *et al.,* 2017). For example, if photosynthetic microorganisms, base of

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many trophic chains, are exposed to nanomaterials, many severe effects could occur on the whole trophic chain (MOTTIER *et al.*, 2017).

A literature review was performed by Naasz and collaborators (2018) in order to analyze publications regarding the evaluation of ecotoxicology effects in organisms (cell line, bacteria, algae, crustaceans, fish, mollusks, nematodes and plants) exposed to mixtures of nanomaterials and chemicals. From their research, 151 publications were found concerning these topics, TiO_2 was the nanomaterial with more publications in relation to exposure and, crustaceans were the most used organism tested. From the 151 publications, 127 studies (66%) reported that mixture exposure increased the toxicity comparing to single-substance exposure. And the remaining studies (26) stated a decrease in the toxicity when the organisms were exposed to mixture of chemicals.

An important key role to determine the effects that nanomaterials can cause to organisms is the knowledge of the main sources, pathways, transformations, and sinks of the nanomaterials, providing information about the areas, such as, water, sediment, and biota, that will suffer from this exposure (LEAD *et al.*, 2018). In conclusion, besides nanotechnology can provide innumerous improvements in water treatment, it can also be causing damages to organisms exposed to nanomaterials and/or nanoparticles, however, many new researches need to be carried out in order to provide more conclusions about their potential risks to the environment.

5 CONCLUSIONS

In the present review, some nanomaterials were described for their application in water treatment. Conventional water treatment sometimes is not very effective in removing some pollutants, such as, heavy metals, oil and microorganism. To improve this treatment, nanomaterials are being studied as a possible alternative to remove these contaminants. Also, with the growth of urbanization and industrialization with consequent water contamination, in the future it will be necessary to use another source as drinking water. One possibility is seawater, and the desalination performed by nanomaterials is an interesting alternative to remove salt from water. However, since nanotechnology is considered new, its effects cannot be all predicted, so many reaserches need to be performed aiming in its potential risks to the environemnt and biota. In conclusion, many nanomaterials have been demonstrating their effectiveness in removing contaminants from water, being a possible alternative for water treatment in the future.

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