Incorporating Benefits of Nanomaterials in Membrane Filtration Process for Producing Safe Drinking Water

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ABSTRACT

Membrane technology for water treatment, covering microfiltration, ultrafiltration, nanofiltration and reverse osmosis, is gaining significant attention from scientists and practitioners as well as decision makers in water utilities and industries. The superior water quality and small footprint make this technology a promising alternative for future water treatment system. However, retention of impurities (organic and inorganic) e.g. natural organic matter, metal salts during filtration results in membrane fouling and eventually reduces the life of the membrane. Although, two methods: (1) pretreatment of raw water and (2) Backwashing and chemical cleaning are generally used to control fouling. However, it can lead to increase in overall filtration time/treatment steps, addition of extra chemicals, and concentrated brine. The objective of this study was to address this issue and to study feasibility of improving removal effectiveness of membrane filtration process by incorporating nanomaterials in membranes. This study identified three different factors describing effects of nanomaterials on membrane filtration: (1) Antifouling properties, (2) Membrane flux, and (3) Surface characteristics. For example, addition of nanoboehmite and TiO_2 addition in PES membrane improve its hydrophilicity, reducing it fouling tendencies. Lastly, current knowledge gaps in these factors were identified which need to be researched further for improving potential of incorporation of nanomaterials in membranes. These efforts are expected to result in use of membrane filtration processes for providing safe drinking water.

Keywords: nanomaterials; membrane filtration; safe drinking water

1. INTRODUCTION

Membranes have been considered to be a suitable alternative to conventional water treatment process because of selective separation, continuous and automatic operation, easy and well arranged process conduction, purification without chemical addition, easy scale up and small footprint (Sonune and Ghante, 2004).The most critical issue of membrane filtration process is fouling of membrane that occurs due to blocking of pores and/or formation of cake layer on membrane by different constituents present in water like natural organic matter (NOM), colloidal impurities and metallic salts. The fouling of membrane causes reduction in flux of permeates (at constant transmembrane pressure), increase in pressure (at constant flux operation of filtration), changes in surface properties of membrane and reduce in life span of membrane. A number of studies have been performed to reduce fouling of membranes by using- (1) coagulation (as pre-treatment applied to raw water before filtration), (2) backwashing of membrane, and (3) cleaning of membrane using chemical coagulants. In coagulation method, settleable impurities can be removed due to use of coagulants. In this method, small impurities agglomerate and thus their removal becomes easier during membrane filtration. But, use of chemical coagulants results in addition of extra chemicals to raw water, which might pose harmful damage to human beings (Nishi et al, 2012), if not removed from water. Backwashing of membrane is done to regain the flux lost during filtration. In this method, membrane can be backwashed by permeate or clean water. But even after backwashing, obtained flux values have been observed to be lesser than initial flux (also called as irreversible fouling). During cleaning of membrane using chemical agents, chemical agents interact with foulant layer of membrane and influence cleaning efficiency of membrane process (Ang et al, 2006). However, some of the cleaning agents are also reported to cause corrosive effects on polymeric membranes (Ng et al, 2013). All of the above mentioned methods increase the time taken for overall process of water treatment; moreover the latter two methods are not able to recover flux to initial value of flux. To overcome the shortcomings of the above methods, studies have impregnated nanomaterials in membranes (Kim and Bruggen 2010; Leo et al, 2011; Zhang et al, 2012). The objective of this study was to understand changes in properties of membranes during impregnation of nanomaterials in membranes.

2. METHODOLOGY

Published reports were referred to understand the shortcomings in application of coagulation, backwashing and chemical cleaning agents. Secondly, use of nanomaterials in membrane filtration was studied and analysed to understand current knowledge gaps in these methods.

3. RESULTS AND DISCUSSION

Effects of nanomaterials on membranes can be categorized in three different categories-

3.1 Antifouling properties: controlling biofouling due to microbes and extracellular polymeric substances (EPS)-

The effect of biofouling on membranes is reduced by using biocides for decades. Recently, an effective biofouling control was achieved by using antimicrobial nanomaterials impregnated membranes (Zhang et al, 2012).Silver nanoparticles exhibit strong antibacterial properties due to which they can be efficiently used for biofouling control. Leaching of silver ions has been attributed to this effect. However, studies have observed leaching of silver ions fro membrane. To control leaching of silver ions from membranes, studies have suggested immobilization of silver nanoparticles with the help of other nanoparticles (Huang et al, 2014). This study used Ag-SiO_2 nanoparticles for providing antibacterial effects to PES membrane and reported that silver nanoparticles were more stable on membranes and also well distributed along the cross-section of the membrane. After conducting anti-bacterial experiments on membrane using *Escherichia coli* and *Pseudomonas sp.*, it has been found that membranes showed a remarkable increase in antibacterial properties as depicted by SEM images. Similar effects were shown by conducting halo zone test and shake flask method using *Escherichia coli* as the control organism. (Sawada et al, 2012) Halloysite nanotubes loaded with copper ions has shown antibacterial effects both in case of Gram-negative bacteria (*Escherichia coli*) and Gram-positive bacteria (*Staphylococcus aureus*) when used to modify PES membranes. (Chen et al, 2012).

3.2 Effect on Membrane Flux due to changes in Hydrophilicity of Membrane-

Hydrophilicity of membrane also influence membrane flux. For example, use of poly (vinylidene fluoride) (PVDF) membranes with incorporation of different concentrations of polydopamine (PDA) nanoparticles resulted in increase of hydrophilicity of the membranes and significant change in mechanical stability of the membrane. There was increase in porosity while decrease in tensile strength and modulus of elasticity for PDA/PVDF membrane. (Jiang et al, 2014) Incorporation of ZnO nanoparticles in polyethersulfone membranes from ultralow to high concentrations (0.035 wt.% to 4%) led to increase in antifouling properties, membrane flux, permeability and lower flux decline, due to increase in hydrophilicity of membrane with respect to neat polymeric membranes. (Balta et al, 2012).Blending TiO_2 nanoparticle with polyethersulfone fibres have led to increase in hydrophilicity and also pure water flux with respect to nascent membrane. (Vatanpour et al, 2012a) Due to the presence of extra hydroxyl groups on the surface of nanoboehmite, hydrophilicity of polyethersulfone membranes increased, resulting membranes with better surface properties and anti-fouling properties. (Vantanpour et al, 2012b) Using silver nanoparticles impregnated PES membranes, it has been seen that with increase in silver content there was a decrease in contact angle, thus an increase in hydrophilicity of membrane.

3.3 Effect on Membrane flux due to changes in Surface Characteristics of Membrane-

Smaller the size of TiO_2 nanoparticles used in modification of PVDF, better were the antifouling properties. Due to smaller nanoparticles, porosity of membrane was increased. However, surface roughness of membrane was decreased due to better antifouling characteristics (Cao et al, 2012). Increased size of nanoparticles leads to uneven distribution of nanomaterials in membrane matrix due to aggregation/ disaggregation of nanoparticles in solvent. There are wide number of factors that could lead to aggregation of nanoparticles in the solvent, such as pH and ionic strength of solvent and concentration of nanoparticles in solvent (Bian et al, 2011; Hyunh and Chen 2011). The aggregation of nanoparticles in the solvent leads to improper dispersion of nanoparticles in membrane. Few studies have been performed focusing on surface interactions between nanoparticles and solvent. However, these studies can only provide information about stability of membranes formed by using nanoparticles.

Multiwalled carbon nanotubes (MWCNTs) have led to increase in hydrophilicity of membrane, pure water flux, and better regain in flux when cleaned with caustic solution. However, it results in an increase in membrane surface roughness (Celik et al, 2011). The findings of this study indicated that doping of CNTs with other materials and additives may results in even distribution of CNTs along the membrane surface (Phao et al, 2013). Nitrogen- treated CNTs when blended with PES membranes lead to increase in even distribution of carbon nanotubes in polymer matrix of the membrane. It also results in an increase in hydrophilicity of membrane and also low surface roughness of membrane (Phao et al, 2013).

Atomic force microscopy (AFM) performed on HNTs-CS@ Ag/PES prepared via phase inversion method has shown increase in surface smoothness of membrane along with increase in hydrophilicity and pure water flux through membrane. (Chen et al. 2013) Membranes prepared with poly (2-hydroxyethyl methacrylate) grafted silica nanoparticles shows great influence on membrane porosity and thickness. At concentration lesser than (6wt %) there was increase of membrane porosity and thickness due to thermodynamic instability caused by PHEMA@ SiO_2 nanoparticles. High concentrations (> 6 wt. %) led to more viscosity, resulting in decrease in porosity and thickness of membrane (Zhu et al, 2014). Apart from improvement in surface characteristics of membrane, there could be some other influences of nanoparticles on membrane that may lead to better antifouling properties and higher pure water flux through membrane. More studies are required to be performed in this direction where changes in internal structure due to nanomaterials are seen.

4. CONCLUSIONS

Incorporation of nanoparticles in membranes and their effects on membrane properties have been studied. Due to better hydrophilicity, improvement in surface morphology, changes in pore size and reduction in thickness of membranes, it results in increase in pure water flux, increase in anti-fouling properties and better anti-corrosive properties of membrane against cleaning solutions. But there is the other side of these developments that remain unreported is the long term studies on these membranes. Very few studies have shown the long-term behaviour and leaching of ions from nanoparticles with time. Such studies need to be conducted to know whether the use of nanomaterials in membranes is safe or not.

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