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Carbon Nanomaterials Based Membranes

Subrata Mondal*

Department of Mechanical Engineering, National Institute of Technical Teachers' Training and Research (NITTTR), Salt Lake City, Kolkata, India

***Corresponding author:** Subrata Mondal, Department of Mechanical Engineering, National Institute of Technical Teachers' Training and Research (NITTTR), Salt Lake City, Kolkata India, Tel: +97126075150; E-mail: subratamondal@yahoo.com

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Abstract

In the past few years, there is impressive breakthrough for the research on nano structured materials to solve global significant challenges like, water, energy, environment, medicine etc. Among various nanomaterials, carbon nanomaterials (CNMs) are gaining significant interest to the material scientists to develop advanced membranes for novel separation processes. It is believed that CNM based membranes have the potential to overcome the inherent limitations of conventional membranes separations.

Keywords: Carbon nanotube; Gas separation; Graphene oxide; Membrane; Nanocomposite; Water treatment

Introduction

As a low cost, easy to scale up, simple in operation and efficient method, membrane based separations have been widely used in many separation processes e.g. water treatments (desalination and wastewater treatment) and gas separation [1-2]. Separation through membranes is usually achieved based on the selective transport phenomenon of the molecules through the membrane matrix [3]. Reverse osmosis and nanofiltration membranes are widely used for water treatment. However, thick active separating layer of the pressure driven membranes restricts the water flux. Solution could be the reinforcement of nanomaterials in the membrane matrix to enhance the flux while achieving the targeted molecules to be separated [1].

Advanced membrane materials with excellent selectivity is required for controllable separation process of gas purifications and water treatments [4]. Among various nanomaterials, carbon nanomaterials (viz. carbon nanotube, graphene) have drawn tremendous interests in the advanced materials applications. Depending on the number of shell of graphene, carbon nanotube (CNT) can be classified as single walled carbon nanotube (SWNT) with single shell of graphene, similarly, double walled carbon nanotube (DWNT) and multi walled carbon nanotube (MWNT). Whereas, graphene is a one-atom thick sheet of graphite which contain sp2-hybridized carbon atoms nicely arranged in the hexagonal honeycomb lattices, and graphene oxide (GO) nano sheets are oxygen functional groups containing graphene which could be obtained by treating graphite with strong oxidizer [4-6]. One of the prime applications of the CNMs is reinforcing materials in the matrix (e.g. to prepare nanocomposite membranes) due to their unique physical, mechanical and other functional properties. Properties of the nanocomposite membranes depend on several factors such as nanomaterials dimensions, dispersion, distribution and interfacial interaction of nanofillers with the matrix [7]. Other common forms of CNM based membranes are vertically aligned CNT membrane, free standing CNT or graphene membranes etc. The impact of research on carbon nanomaterials for the membrane separation is growing tremendously which is reflected by number of review articles published in this area of advanced material applications [8-10].

Brief overview of CNMs based membranes

There are few approaches to fabricate CNT membranes [8]. Three common types of CNT membranes are schematically shown in Figure 1. Jenus polymer/CNT hybrid membranes can be obtained by grafting of hydrophilic and hydrophobic polymers on different sides of the CNT membranes (Figure 1a) [11]. Synthesized well aligned CNT on the substrate and subsequent filling of gaps between the CNTs, could serve as a novel membrane (Figure 1b). Filling materials could be impermeable materials such as epoxy resin, silicone nitrite, etc. [12]. The tips of the CNT can be opened by plasma treatment. The high aspect ratio, smooth hydrophobic wall and the hollow tunnel of CNT provides frictionless transport of water molecules to enhance flux though the membranes. Third type of CNT membrane is polymer matrix CNT reinforced nanocomposite membrane (Figure 1c). Reinforcement of CNT into the polymeric membrane could enhance performances such as high flux, improve permselectivity, better mechanical properties and improvement of other functional properties for an example antifouling property [13-14]. Reinforcement of amino functionalized MWNT in the chitosan/polyvinyl alcohol (CS/PVA) matrix formed ensures better dispersion and distribution of functionalized MWNT, formed compact structure with improved mechanical property of weak pure CS/PVA adsorptive membrane [15].

Pure graphene membrane without pore is impermeable to small molecules due to the closely packed carbon atom in the lattice and repulsion of molecules by electron density of its hexagonal rings. Whereas, nanoporous graphene/graphene oxide with its high surface area can be used for advanced membrane separation due to its molecular sieving property [6,16]. Nanoporous membrane can be fabricated by arranging graphene (G)/graphene oxide (GO) with specific architecture and size. Graphene and graphene oxide based membrane could be fabricated by deposition of graphene on a substrate as and also reinforcing graphene/graphene oxide in the polymeric membrane matrix [17-18]. Graphene oxide membrane can be prepared by vacuum filtration of GO solution on a template support or spraying of GO solution on solid support by doctor blade and subsequent removing the solid support [16]. Thin and uniformly aligned graphene oxide membrane can be obtained by spin coating [19]. Single layer GO membrane has few limitation for bulk production and uses, such as durability, stability and fragile, hence, difficult to handle [16].

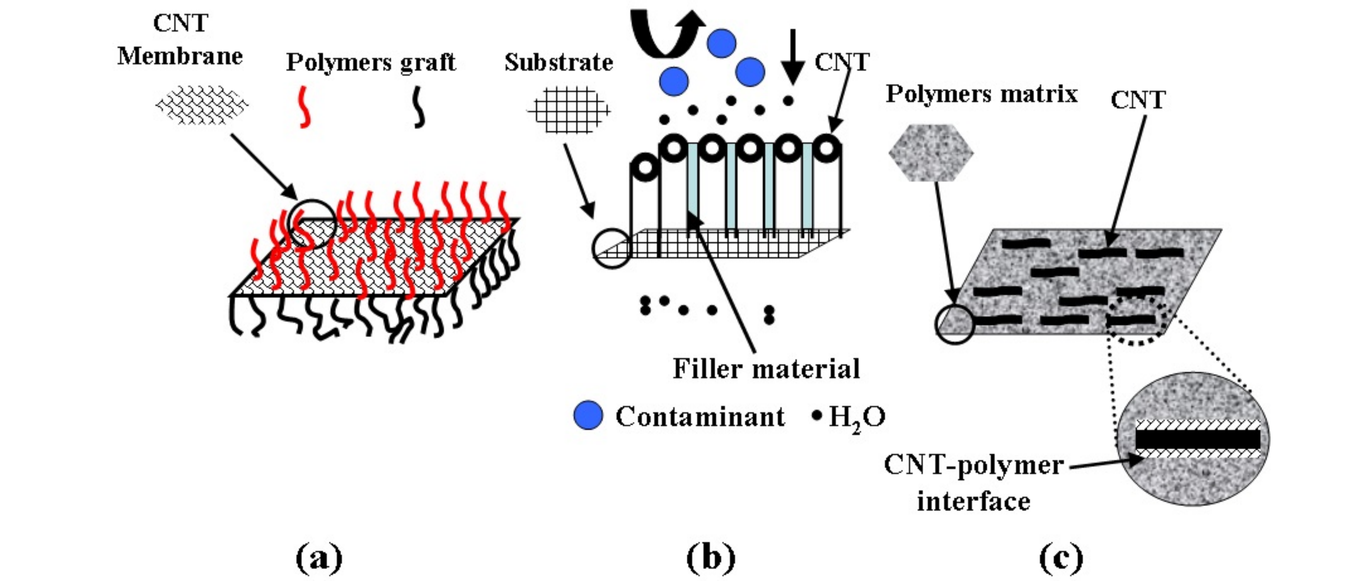

Figure 1: Schematics showing three common types of CNT membranes: (a) polymer1-g-CNT-g-polymer2 Janus membrane; (b) vertically aligned CNT membrane and (c) polymer-CNT nanocomposite membrane.

Applications of CNM based membranes

Rapid rise of global population demands more energy, fresh water, and subsequent needs for waste water treatment facilities. The application of carbon nanomaterial based membranes are promising in many areas such as water treatment (viz. desalination, waste water treatment), gas treatment, fuel cells are few fields of many to states. Both gas separation as well as large-scale water treatment could be benefited by using CNMs based membranes. Membrane prepared by using aligned encapsulated CNT with open both ends allows low resistance flow of fluids, and this could be used to develop energy efficient membrane as compared with the energy intensive reverse osmosis membrane to desalinate sea water, and for gas separation as well [7]. Functionalized MWNT reinforced adsorptive membrane could be used to remove metal ions from the aqueous solution. Functional groups on MWNT can provide additional functionalities for the metal ion adsorption further creation of nano channel by the nanofillers reduces diffusive hindrance and provide supplementary pathways for the transport of metal ion to the active sites for the effective adsorption [15].

Ultrathin composite membrane of SWNT/TiO_2 prepared by coating of TiO_2 on SWNT network via sol-gel technique. Membrane shows excellent performance for separating oil-in-water with high separation efficiency. Further, membrane shows excellent antifouling and self-cleaning performance due to the photo-catalytic degradation of organic compounds by the TiO_2 nanoparticles [20]. Hydrophobic polymer/CNT hybrid membrane can be fabricated via grafting of hydrophobic polymers on the surface of CNT membrane which can separate wide range of organic solvent from the water with excellent adsorption capacity and good recyclability of membranes [21]. While, Janus polymer/CNT hybrid membrane with hydrophilic and hydrophobic polymers grafted on different sides of the membranes can separate both surfactant stabilized oil-in-water and water-in-oil emulsion due to the anisotropic wettability of membranes, membrane maintain high separation efficiency and good flux [11]. Single-layer or multilayer nano-porous graphene membranes are promising for the desalination of water [22].

Advanced membrane technology can offer economic, environmental friendly and high performance solution for the gas separation. CNT reinforcement in the polymeric membrane matrix demonstrated high transport rate due to the inherent smoothness of the carbon nanotubes. Up to a threshold value of CNT loading, all gas molecules pass through the CNT tunnel, hence, increases the permeability. Whereas, higher loading of CNT limits the increase of gas permeability due to the tortuosity of the agglomerated CNT [23]. Nano-porous graphene membrane can be used for high efficiency membrane separation due to its ultrafast molecular permeation rate which could be promising for the applications in energy, environment and water solution, including carbon sequestration, fuel cells, gas separation, desalination [4-6].

Conclusion

Carbon nanomaterials have been received tremendous attention as potential in the advanced material applications including in the field of novel membrane science and technology. Application of CNM could improve the membrane separation process. However, homogeneous bulk fabrications of CNM based membranes are still at the premature stage and required further improvements. Major challenges for the CNMs reinforced membrane are poor dispersion and distribution, and weak interfacial interaction between the dissimilar surface of CNM and matrix. Further, some form of CNM based membranes are fragile and causes significant challenges for handling and uses. Considering these challenges, however, it is very hard to predict how CNM based membranes will shape the future membrane processes.

References

1. Mondal S (2015) Polymer nanocomposite membranes. J Membr Sci Technol 5: 134.
2. Zhu YZ, Wang D, Jiang L, Jin J (2014) Recent progress in developing advanced membranes for emulsified oil/water separation. NPG Asia Materials 6: e101.
3. Kubaczka A (2014) Prediction of Maxwell–Stefan diffusion coefficients in polymer–multicomponent fluid systems. J Memb Sci 470: 389-398.
4. Xu Q, Xu H, Chen J, Lv Y, Dong C, Sreeprasad TS (2015) Graphene and graphene oxide: advanced membranes for gas separation and water purification. Inorg Chem Front 2: 417-424.
5. Jiang DE, Cooper VR, Dai S (2009) Porous graphene as the ultimate membrane for gas separation. Nano Lett 9: 4019-4024.
6. Sun CZ, Wen B, Bai BF (2015) Recent advances in nanoporous graphene membrane for gas separation and water purification. Sci Bulletin 60: 1807-1823.
7. Michael FL, Volder D, Tawfick SH, Baughman RH, Hart AJ (2013) Carbon nanotubes: Present and future commercial applications. Science 339: 535-539.
8. Kar S, Bindal RC, Tewari PK (2012) Carbon nanotube membranes for desalination and water purification: Challenges and opportunities. Nan Tod 7: 385-389.
9. Das R, Ali ME, Hamid SBA, Ramakrishna S, Chowdhury ZZ (2014) Carbon nanotube membranes for water purification: A bright future in water desalination. Desalination 336: 97-109.
10. Goh PS, Ismail AF, Ng BC (2013) Carbon nanotubes for desalination: Performance evaluation and current hurdles. Desalination 308: 2-14.
11. Gu JC, Xiao P, Chen J, Zhang JW, Huang YJ (2014) Janus polymer/carbon nanotube hybrid membranes for oil/water separation. ACS Appl Mater Interfaces 6: 16204-16209.
12. Hinds BJ, Chopra N, Rantell T, Andrews R, Gavalas V, et al. (2004) Aligned multiwalled carbon nanotube membranes. Science 303: 62-65.
13. Mondal S, Hu JL (2008) Microstructure and water vapor transport properties of functionalized carbon nanotube reinforced segmented polyurethane composite membranes. Polym Eng Sci 48: 1718-1724.
14. Reddy AVR, Mohan DJ, Bhattacharya A, Shah VJ, Ghosh PK (2003) Surface modification of ultrafiltration membranes by preadsorption of a negatively charged polymer. I. Permeation of water soluble polymers and inorganic salt solutions and fouling resistance properties. J Membr Sci 214: 211-221.
15. Salehi E, Madaeni SS, Rajabi L, Vatanpour V, Derakhshan AA, et al. (2012) Novel chitosan/poly(vinyl) alcohol thin adsorptive membranes modified with amino functionalized multi-walled carbon nanotubes for Cu(II) removal from water: Preparation, characterization, adsorption kinetics and thermodynamics. Sep Purifi Technol 89: 309-319.
16. Joshi RK, Alwarappan S, Yoshimura M, Sahajwalla V, Nishina Y (2015) Graphene oxide: the new membrane material. Appl Mater Today 1: 1-12.
17. Shen J, Zhang MC, Liu GP, Guan KC, Jin WQ (2016) Size effects of graphene oxide on mixed matrix membranes for CO2 separation. AIChE J 62: 2843-2852.
18. Zahri K, Goh PS, Ismail AF (2016) The incorporation of graphene oxide into polysulfone mixed matrix membrane for CO2/CH4 separation. Earth Environ Sci 36: 012007.
19. Chi CG, Wang XR, Peng YW, Qian YH, Hu ZG, et al. (2016) Facile preparation of graphene oxide membranes for gas separation. Chem Mater 28: 2921-2927.
20. Gao SJ, Shi Z, Zhang WB, Zhang F, Jin J (2014) Photoinduced superwetting single-walled carbon nanotube/TiO2 ultrathin Network Films for Ultrafast Separation of Oil-in-Water Emulsions. ACS Nano 8: 6344-6352.
21. Gu JC, Xiao P, Chen J, Liu F, Huang Y, et al. (2014) Robust preparation of superhydrophobic polymer/carbon nanotube hybrid membranes for highly effective removal of oils and separation of waterin-oil emulsions. J Mater Chem A 2: 15268-15272.
22. Cohen TD, Lin LC, Grossman JC (2016) Multilayer Nanoporous Graphene Membranes for Water Desalination. Nano Lett 16: 1027-1033.
23. Kim S, Chen L, Johnson JK, Marand E (2007) Polysulfone and functionalized carbon nanotube mixed matrix membranes for gas separation: Theory and experiment. J Membr Sci 294: 147-158.