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Can carbon-based nanomaterials revolutionize membrane fabrication for water treatment and desalination?

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HIGHLIGHTS

- Recent studies on the membrane preparation with CNMs have been summarized
- CNM incorporation, in some cases, has a pronounced effect in creation of novel membranes
- Further research is required to evaluate the feasibility of CNM membranes in water treatment

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ABSTRACT

Due to their exceptional mechanical, conductive and antibacterial properties carbon-based nanomaterials (CNMs) have been widely used in attempts to fabricate novel membranes for water treatment and desalination with advanced characteristics. This paper reviews the current state of the application of CNMs, including carbon nanotubes, graphene, graphene oxide, carbon nanofibers, MXene, carbide derived carbon and fullerene for membrane preparation. A brief description of different CNMs and their properties has been provided with reference to membrane requirements. Thereafter the recent studies on the membrane fabrication/modification with CNMs as well as the properties of the developed membranes have been critically summarised. It was shown that, in some cases, using CNMs results in novel membranes with high flux, high rejection, low-fouling, and enhanced conductive, thermal and mechanical properties. However, further research including determining the optimum CNM quantity and characteristics, feed-specific membrane performance and long-term operability should be conducted to better evaluate the feasibility of CNM-based membranes in water treatment and desalination. This review paper is potentially important for researchers involved in the membrane fabrication using CNMs.

1. Introduction

A sharp growth in the worlds' population coupled with urbanization has resulted in a rapidly increasing demand for fresh water [1]. More than 1.2 billion people in the world lack access to clean and safe drinking water and problems with water are expected to grow worse in the coming decades [2]. Nowadays the membrane processes such as reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF), microfiltration (MF), membrane distillation (MD) and pervoparation (PV) are regarded as the most attractive methods for drinking water treatment, brackish and seawater desalination, waste water treatment and reuse [3]. Polymeric membranes currently are the most common on the market, however, there are still several problems with practical application of these membranes, which are related to their fouling, chemical, mechanical and thermal stability [4,5]. This situation has compelled scientists to search for novel membrane to improve their performance and properties [6]. The advanced membranes should be designed to meet specific water treatment applications by tuning their structural and physicochemical characteristics, including hydrophilicity, porosity, membrane charge, and thermal and mechanical stability as well as introducing additional functionalities such as antibacterial, photocatalytic or adsorption capabilities. In recent years there has been a growing interest in using of nanomaterials for development of novel membranes with advanced properties [6]. Due to their exceptional mechanical, chemical and thermal stability and conductive and antibacterial properties carbon-based nanomaterials (CNMs) are among the most promising candidates to tackle this challenge [5,7–9].

Several research papers have been recently published on using some specific CNMs such as carbon nanotubes (CNTs) [7–11] and graphene oxide (GO) [12–17] in the membrane synthesis. This paper reviewers the current state of application of different CNMs, including CNTs, graphene, GO, carbon nanofibers (CNFs), MXene, carbide derived

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carbon and fullerene for membrane fabrication with focus at water treatment and desalination. The challenges facing preparation and application of CNT-based membranes are also outlined.

2. CNM materials and their basic properties

The most common types of CNMs are CNTs, graphene, GO, CNFs, MXene, carbide derived carbon and fullerene (Fig. 1). Due to their unique characteristics such as high chemical, thermal, and mechanical strength, conductivity, optical properties and low density CNMs have been widely explored in chemistry and material science [18].

Since the first discovery in 1991 CNTs have attracted enormous research interest [19]. CNTs consist of a sheet of carbon atoms that are rolled into hallow smooth cylindrical tubes (Fig. 1a–d). Two types of CNTs, namely single-walled carbon nanotubes (SWCNTs) and multi-walled carbon nanotubes (MWCNTs), which differ by the number of carbon atom cylindrical arrays arranged around the hallow nanotube core, have been developed and studied extensively. The properties of each of the two types of CNTs vary depending on the atomic

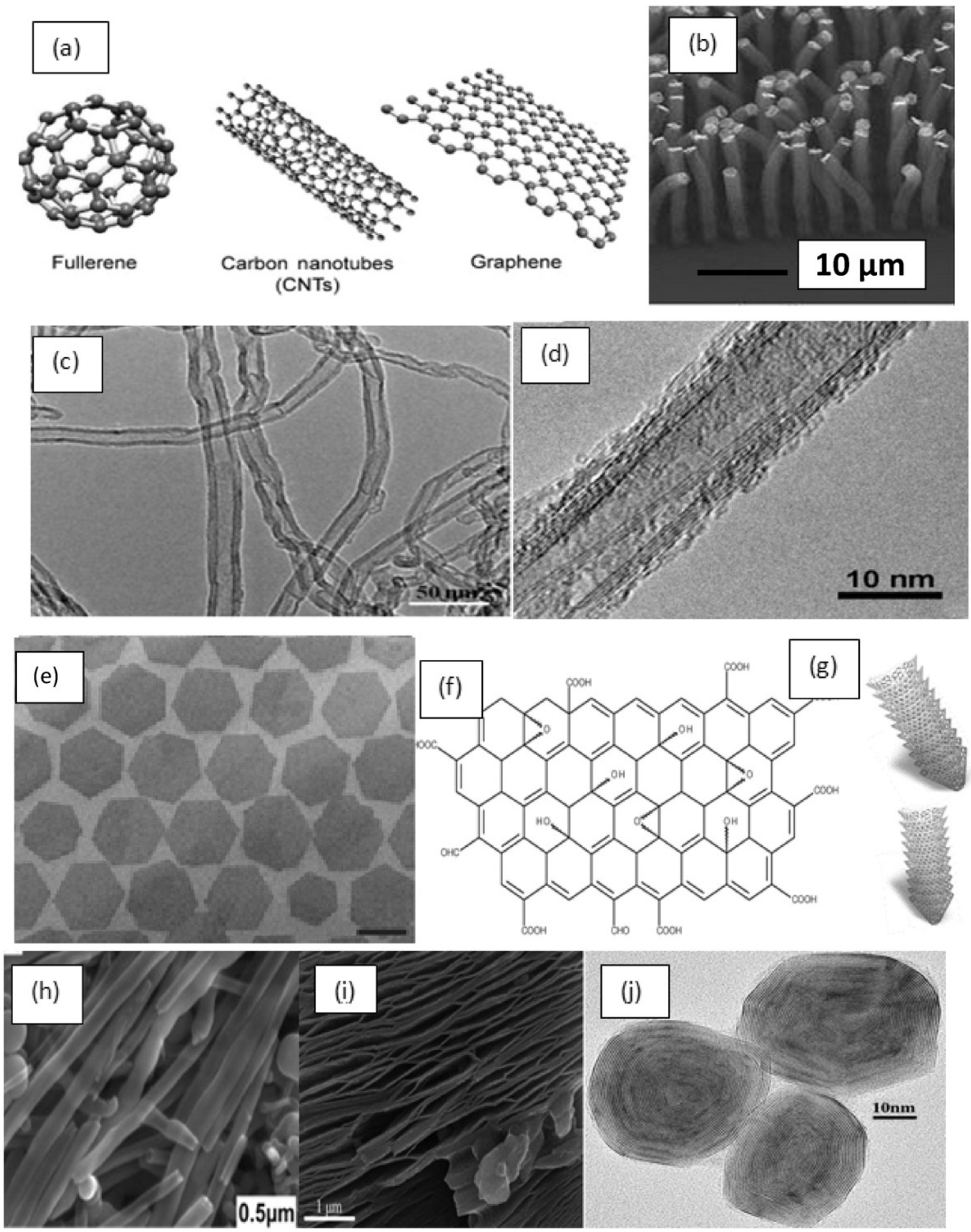

Fig. 1. (a) A schematic representation of CNTs, graphene and fullerene [41], (b) scanning electron microscopy (SEM) image of aligned bundles of CNTs [42,43], (c) transmission electron microscopy (TEM) image of CNTs [43], (d) TEM image of CNTs [44], (e) TEM image of graphene grain array [45], (f) schematic presentation of GO structure [44], (g) schematic presentation of herringbone-like CNFs [46], (h) SEM image of CNFs [47], (i) SEM of multilayered MXene [48] and (j) TEM of onion-like fullerene [49].