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High-performance, recyclable ultrafiltration membranes from P4VP-assisted dispersion of flame-resistive boron nitride nanotubes

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ABSTRACT

Regenerable ultrafiltration membranes were fabricated via filtration of thermally-stable, highly dispersed boron nitride nanotubes (BNNTs). The highly debundled BNNTs were produced by employing judiciously-chosen poly (4-vinylpyridine) (P4VP) as an efficient steric stabilizer. Density functional theory calculations showed strong adsorption energies of P4VP monomers on top of the BNNTs, illustrating the role of P4VP stabilizers. High performance of the BNNT ultrafiltration membranes with large permeation flux was demonstrated by exclusion of polystyrene and gold nanoparticles (~ 25 nm) with higher than 99% removal efficiency. The BNNT membranes were successfully regenerated and recycled continuously at 450 °C due to their excellent mechanical and thermal properties, demonstrating a stark contrast to the membranes from the carbon nanotubes. Our work indicates that unlike the membranes from carbon nanotubes, BNNT membrane can be a promising candidate for the application in cost efficient industrial ultrafiltration.

1. Introduction

Ultrafiltration using membranes with pore diameters of 10–100 nm has been an emerging technology in desalination of drinking water and food processing, owing to its high selectivity and low operation cost [1–5]. However, the ultrafiltration membranes are vulnerable to membrane fouling by excluded particulates and micro-organisms, resulting in loss of permeation flux and corresponding increase in energy demand [6–8]. Therefore, cleaning and recycling these membranes [9–14] are critical issues that need to be addressed prior to their practical usage including water purification. Often, calcination at high temperature (i.e. 400–500 °C) can be an effective way to regenerate the membranes by removing all of the filtered organic impurities and, as such, the thermal stability of the membranes is a critical requirement for their successful long-term usage [15].

Most ultrafiltration membranes are fabricated with polymers such as polyacrylonitrile, polysulfone, cellulose acetate, and regenerated cellulose due to simple processing and low cost in achieving nanometer-sized pores [16]. However, the polymeric membranes are mechanically, chemically, and thermally unstable during membrane regeneration involving either acid/base cleaning or calcination process to remove any of filtered organic matters. Inorganic membranes mainly composed of metal oxides (including anodic aluminum oxide (AAO)) can be used alternatively [17–19], but there are other detrimental issues such as high production cost and dissolution/degradation of metal oxide membranes during operation [20]. For all these reasons, the development of a simple protocol to fabricate ultrafiltration membranes with high mechanical strength, chemical stability, and thermal durability against calcination remains a key challenge.

Recently, boron nitride nanotube (BNNT) has attracted a growing amount of attention as an inorganic analogue of carbon nanotube (CNT) [21] with its excellent properties such as high mechanical strength (elastic modulus ~ 1.18 TPa) and chemical inertness against strong acid/base. More importantly, unlike the CNTs, the BNNTs have high temperature tolerance up to 900 °C in air, [22,23] which makes them perfectly suitable for the fabrication of reusable membranes by calcination. Despite these advantages, the use of BNNTs has been limited because they are typically synthesized into the form of aggregates bundled by van der Waals attractions among the sidewalls, which hinder their solubilization in most solvents [24]. Therefore, for potential applications including membranes, the BNNTs have to be debundled and dispersed individually in solvents [25–27]. To improve the dispersion stability of BNNTs in solvents, significant efforts have been exerted on the functionalization of BNNTs by covalent attachment using

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