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Review

Application potential of carbon nanomaterials in water and wastewater treatment: A review

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ABSTRACT

Advanced science and technology based on carbon-based nanomaterials is experiencing a rapid rate of change in the performance capabilities to substitute or serve as alternative approaches for the existing technologies. One of the major environmental concerns is the water pollution by the heavy metals. Heavy metals in water are the main preoccupation for many years because of the toxicity towards aquatic-life, human beings and also the environment. In the context of water and wastewater treatment, significant numbers of breakthroughs have been achieved to drive accelerated change for ceaseless capability improvements. In this contribution, the unique features of promising carbon-based nanomaterials that have generated tremendous interest among the material researchers are described along with their potential applications in water and wastewater treatment. Carbon-based nanomaterials stand out to be one of the highly efficient nanomaterials due to it is a vast availability and lower production cost compared to other nanomaterials. This paper critically reviewed the application of different type of carbon-based nanomaterials in water and wastewater treatment. The carbon nanomaterials role in adsorption, disinfection and membrane separation mechanisms that enable the applications are discussed. Advantages and limitations as well as barriers and research needs are highlighted. Challenges include technical hurdles, high cost, and environmental and health risk.

1. Introduction

The salt water oceans makes up to 71% of the earth's surface and remaining balance 29% is made up of Earth's continents and islands. Hence, three quarter of Earth is made up of water and the demand of water is increasing due to the growth in the industrial sector and population. The main threat for this increase in water demand would be to provide clean water to the required sector. Besides household usage as drinking water and for cooking, clean water also a demanding feedstock for growing industries such as food, pharmaceuticals, electronics and medical. In addition, the attainable supply of freshwater is going through a complication in which the total amount of freshwater is reducing due to global warming, population growth and more drastic regulation based on health. A study carried out by World Health Organization (WHO) states that approximately 1.1 billion people have no direct access of clean water supply sources [1]. On that note, 2 million people die yearly due to diarrhoeal disease due to the lack of any improved sanitation facility. Hence, a continuous supply of clean water is essential for our daily life usage. Furthermore, paper, plastic, and metal industries depends on the supply of clean water for production. Hence, one can conserve the usage of water by further

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understanding on the usage and reuse of products being made by water. An increase in the demand of clean water accelerates the trend in the use of wastewater and greywater for agriculture and aquaculture as well. As to meet this demand, a more advanced water treatment technologies and framework are required as the current ones are reaching their final stages of providing satisfactory water treatment to fit into daily human and environmental needs.

Generally, water is polluted due to the effluent of industrial sector or due to lack of improved sanitation facility. Inconsiderate human's behaviour as deploying rubbish into any water resources such as river or lake also contribute to water pollution. Traditional method of water treatment, water distribution and discharge practices are no longer sustainable as it relies highly on a centralized system. Recently, research has been done by utilizing nanotechnology to replace the current water treatment technology. Qu et al. explained through his research that nanotechnology which was enabled by an efficient and multifunctional processes are anticipated to offer a satisfaction water treatment solutions which might not rely on any large and expensive infrastructures [2]. Hence, this astounding nanotechnology can be utilized with other water treatment method as adsorption, coagulation, membrane technology and photo catalysis to establish a water treatment method with a higher efficiency, lower cost and environmentally acceptable [3]. This article provides a brief summary of the extensive utilization of carbon based nanomaterials based on the application in water treatment and collaboration with other treatment technology. The main objective of this paper would be to discuss the opportunities and challenges of utilizing carbon based nanomaterials co-joint with different type of water treatment technology.

2. Carbon nanomaterials employment on water treatment

Nanomaterials can be defined as materials which possess a minimum of one external dimension in the size ranging from 1 to 100 nm while nanoparticles are objects composed of three external dimensions at the particular nanoscale. The behaviour and characterization of nanomaterials are associated to it is a particle composition and the properties of surface of the carbon nanomaterials. Besides that, the chemical reactivity and properties can be enhanced as well by reinforcing the surface properties of these carbon nanomaterials. These nanomaterials can be utilized either solely by itself or by embedding it with other materials such as membranes or other structural media.

Recent studies exhibit an increase in the application of carbon based nanomaterial on the research of wastewater treatment and extremely of positive outcomes are being collected from these research. The reason behind the rapid development of the different types of industrial sectors would be the impact left on the environment. There are many industries such as mining, batteries manufacturers, galvanization and metal finishing which generates wastewater consists of heavy metal ions and emits it directly or indirectly to the nearest water resources [4]. Hence, a crucial step should be implemented to save the environment from further being polluted and to reduce the industrial cost as well by recycling the purified water after treatment. Furthermore, the treatment of contaminated groundwater and surface water also should be taken into a serious consideration as it plays a vital role in keeping the environment clean and healthy as well. The upcoming section will review the application of different types of carbon nanotube nanomaterials in different type of water treatment process.

2.1. Adsorption in water treatment

Adsorption is one the most impressive water treatment methods employed generally to remove organic and inorganic contaminants from any water. An adsorption process can be defined as the process in which the gas or liquid solutes gets attracted and accumulated on the adsorbent, which is usually a solid molecule [5]. Adsorption can be split into two categories, which is physisorption and chemisorption. Physisorption occurs when the concerned molecules adsorbate and adsorbent are attracted together by the van der Waals force while chemisorption occurs when the concerned molecules are attached to the surface of the adsorbent by a strong chemical bond [6]. The performance of an adsorption process depends on the removal percentage of the contaminants from the water and it is very much related to the adsorption capacity of the adsorbent being used. The adsorption capacity of an integral adsorbent depends vastly on the surface characterization such as the specific surface area, active sites available on the surface and the affinity towards the contaminants. Hence, activated carbon, CNT impregnated on activated carbon and nanomaterial proves to be an essential adsorbent due to high specific surface area along with efficient active sites [7–10]. This upcoming section will review the application of different type of carbon nanomaterial as adsorbent for the adsorption of contaminants as organic and inorganic pollutants from the water resources.

2.1.1. Carbon nanotubes nanomaterials and employment in water treatment

Generally, carbon is one of the most multilateral elements present in the periodic table due to strength and ability to form bond with other elements. Carbon nanotubes (CNTs) which were discovered back in the year 1991 by Iijima [11] has been extensively adapted by many researches to study show capability into water treatment. CNTs are cylinder-shaped macromolecules which consists of radius as small as few nanometres and as large as 20 cm in length. Burghard et al. discovered that the main constituent of the tubes walls is hexagonal lattice of carbon atoms which is equivalent to the graphite's atomic planes. CNTs can be classified as single walled CNTs (SWCNTs) and multi walled CNTs (MWCNTs) where MWCNTs consist up to dozens of concentric tubes while SWCNTs are just made up of a single layer of carbon atoms [12]. MWCNTs diameter can reach up to 100 nm while SWCNTs diameters range from 0.4 to 3 nm. SWCNTs has an excellent property compared with MWCNTs that it is able to rolled up into different type of graphene sheets to produce few different types of CNTs. CNTs has been considered as one of the most auspicious nanostructured materials and the forecast of producing CNTs in a big scale has caught the attention among all the researchers [13]. CNTs which is considered as the new member in the carbon family were found to have an excellent property lead to the enormous application such as hydrogen storage [14], chemical sensors [15], protein purification [16, 17] and as reinforcement in composite materials [18]. On the same note, CNTs consist of hollow and layered structure along with a large specific surface area [19] which leads to a remarkable application in removal of heavy metals in waste water treatment by utilizing the adsorption method [8,20,21].

The optimum performance of CNTs can be increased by functionalizing it in the presence of acid and alkali solution. Generally, pristine CNTs lack to provide the most optimum performance due to the impurities produced during the synthesis of CNTs. The impurities would be carbonaceous species and residues from the metal catalysts utilized for the preparation of CNTs. The present of these impurities on the surface of CNTs would be the alteration of vital properties of CNTs. Hence, to avoid the alteration of the properties, CNTs will be treated with acid or alkaline solution to remove the impurities. On that note, functionalization process will alter the surface of CNTs by attaching an additional functional group on the surface of CNTs. An additional of negatively charged functional group either at the open end or at the sidewall of the CNTs would increase the solubility in any type of solvents [22] and strengthen the surface of CNTs by replacing the weak van