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Nanomaterials application in air pollution remediation

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One of the most promising environmental implementations of nanotechnology has been the remediation of air pollution. In this context, several nanomaterials such as nano adsorbents, nanocatalysts, nanofilters, and nanosensors have been introduced. Nanomaterials can adsorb the contaminant found in the air. Moreover, distinct semiconducting nanomaterials can be applied as photocatalytic approaches. Despite the significant advantages of nanomaterials in air pollution remediation, current concerns regarding their toxicity need further toxicological examinations. This review aims to address the present literature on the use of nanomaterials in air pollution remediation.

KEYWORDS

Nanomaterials; environmental remediation; air pollution; chemicals.

Introduction

Since air contaminants can induce a detrimental effect on human health, many researchers have paid great attention to different areas [1, 2]. The World Health Organization (WHO) has reported that air contaminants are responsible for a high rate of mortality (7 million worldwide) annually [3]. Additionally, increased levels of an air contaminant are breathed by almost nine out of ten people [4]. Thus, acquiring exact information about the sources of air contaminants and establishing novel technologies for air remediation is crucial [5]. The alterations of the natural composition of the atmosphere due to different physicochemical and chemical substances from different geogenic, biogenic, and anthropogenic sources are referred to as air contamination. Air contaminants might be in gaseous or particulate form and exist exterior or interior [6]. The gaseous form includes different gas-shaped chemicals such as carbon monoxide (CO), ozone, and Sulphur dioxide (SO2).

In contrast, the tiny size of complex chemical components such as bacteria, fungi, and viruses is the particulate form of air contaminants [7]. As the primary energy supply of the world, Fossil fuels are the most important source of contaminants since nearly all daily life activities, and industrial fabrication depends on fuels. The discharge of contaminants such as volatile organic compounds (VOCs) subsequently happens as a pivotal negative ecologic impact [5]. Several monitoring and treatment methods have been developed to control and eliminate this discharge, thus prohibiting human health and environmental destruction [8]. In this context, nanotechnology has been applied as an advanced treatment strategy. It has effectively remediated air contamination using different nanomaterials (NMs) such as nanosensors, nanocatalysts, nano filters, and nano adsorbents [9]. This is important because chemical treatment opportunities can result in harmful environmental effects. The current study will discuss the use of different NMs and factors influencing their effectiveness for remediation purposes of air pollution.

Magnetic nanoparticles as pollutant adsorbents

Magnetic nanoparticles (MNPs) have been particularly engineered as they exhibit high potential in alleviating environmental contaminants due to their unique specifications [10]. Previous studies reported different methods of synthesis and modification of the magnetic nanoparticles' surface [11-13] (Figure 1). Previous studies revealed that using magnetic nanoparticles as $Mg_{0.25}Fe_{2.75}O_4$ efficiently decreased the carbon monoxide (CO), particle mass (PM1.0), and hydrocarbon (HC) emissions [14]. More specifically, the effect of nanocatalysts OSC would be dominated by the impact of increased soot oxidation, leading to PM1.0 reduction

MNPs such as magnetite, maghemite NPs, and zero-valent iron alone or combined with membrane materials can be utilized to remove, remedy, and water treatment [15]. Novel functionalized biocompatible NMs with highly active and large surface areas have been introduced as significant opportunities compared to conventional systems. The unique small size and electronic features are other excellent properties of these NMs [15]

Nanohybrids as pollutant sensors

Sol-gel processes have been utilized to prepare new materials by fabricating several hybrid organic-inorganic compounds [16]. Also, the intermediate NPs between polymers and glasses have opened new avenues in the realm of nanotechnology [17]. Pollutant sensors such as optical apparatuses, functionalized coatings, chemical sensors, and biosensors have been developed [17]. For instance, thin films of amorphous silica with active functional groups of SH and NH2 have been applied as catalysts and adsorbents of air pollution [18].

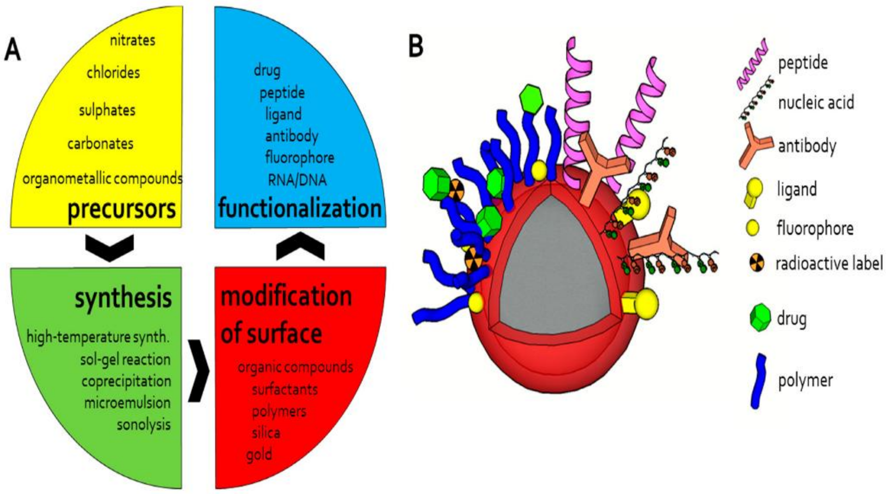

FIGURE 1 The schematic illustration of the design of magnetic particles (A) and potential functionalization and alteration of magnetic particles (B). Reproduced under the terms and conditions of the Creative Commons Attribution (CC BY) license [19]

The porous structure and large surface area related to the sol-gel materials are the vital characteristics reasonable for photocatalytic and adsorbent activities [20]. Silica-based nanohybrids have also been synthesized from amorphous SiO2 NPs as carriers or matrices [21]. The concomitant use of silica and other functional constituents has provided several advantages of these hybridized NMs for different applications [22]. Cost-effectiveness, high efficiency, small-dimension, online function, biocompatibility, and low power consumption have been stated as the benefits of these materials, which can also be used in air pollution remediation technologies [22].

Carbon nanotubes

Several investigations have explored using carbon nanotubes (CNTs) as nano adsorbents of metal ions due to their exceptional physical features, including average pore diameter and volume and high surface area. Thus, nano adsorbents with high affinity, capacity, and selectivity could be fabricated (Figure 2)[23]. CNTs have been utilized for methane and CO2 discharge exhausted from vehicles and industrial chimneys. Also, CNTs can trap greenhouse gases from power generating centers and coal mines. These materials can separate air pollutants as nano adsorbents due to their enhanced specifications, notably high affinity for selective adsorption of contaminants. Moreover, CNTs exhibit high surface area, pore diameter, and pore volume, enhancing the reactive sites attached to the specific air contaminants [24]. The addition of functional groups which surge the reactive sites can improve the adsorptive function of these NMs [25]. Multi-walled CNTs modified with (3-aminopropyl) triethoxysilane (APTES) have been applied for CO_2 adsorption. In this nano adsorbent, the reaction of CO_2 within the amine groups of APTES resulted in the generation of carbamate. It was shown from the thermogravimetric test that elevation of reflux duration results in increased loading of APTES because of the increased number of covalently bonded amino groups on the surface of MWCNT. The final adsorbent could remove CO_2 at a level of 75.4 mg CO_2 adsorbed/ adsorbent.

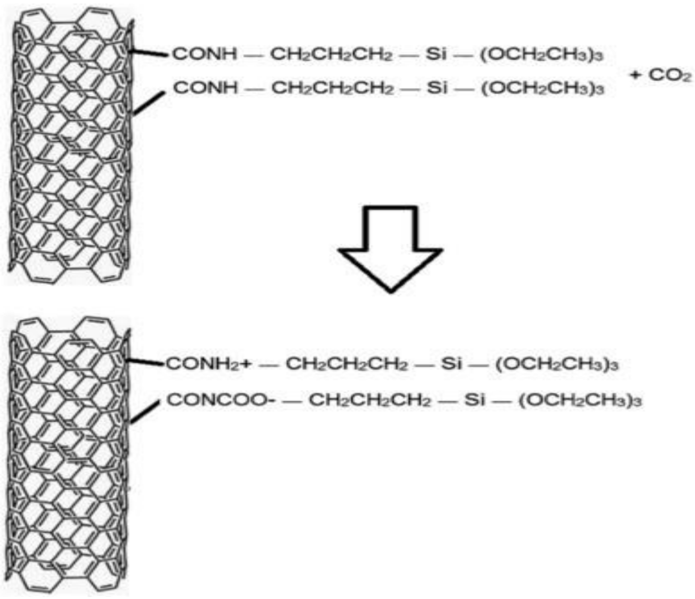

FIGURE 2 Carbon dioxide adsorption mechanism

Nanosheets for pollutant degradation

Quanton dot-loaded ultrathin Bi2WO6 nanosheets have been developed for catalytic activity in the remediation of air pollution. Tetracycline and rhodamine B, two deleterious organic pollutants, have been effectively catalyzed with aforestated nanosheet under wide spectrum light irradiation. Graphene has also been recently used as an exclusive adsorbent for hazardous pollutants. Nanosheets possess different superiorities such as high photocatalytic activity, high stability, and particular light adsorption. Graphene oxide nanosheets have been evaluated for their effects on Cd (II) and Co (II) adsorption. Also, Cu-TiO2 nanosheets for photodegradation of trichloroethane. Nanocrystalline nanofibrous constructs have shown superiority due to their high porosity, gas-capturing efficiency, and functionality (Figure 3) [26-30].

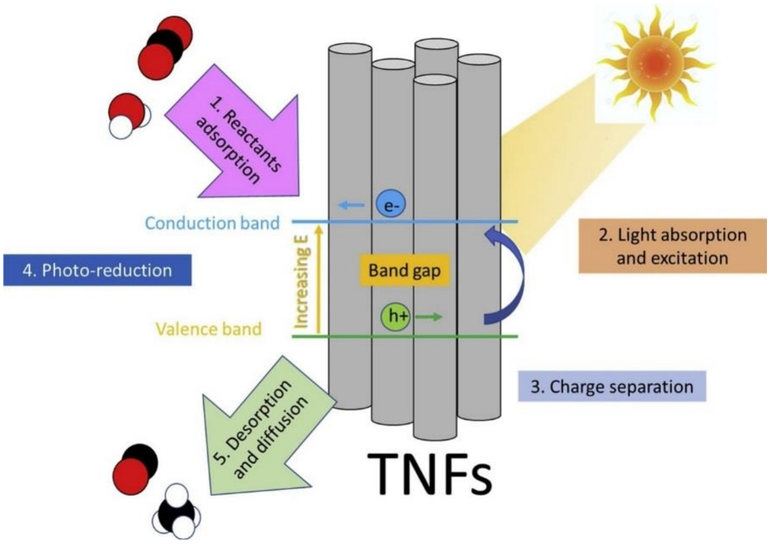

FIGURE 3 Photocatalytic reduction of CO_2 with undoped and Cu-doped TiO_2 nanofibers [26]

A combination of nanomaterials with natural products effeiciently, could detect and remove pharmaceutical pollutants [31-35]. Since air contaminants can induce a detrimental effect on human health, many researchers have paid great attention to different areas[36-37]. The automobile exhaust is one of the serious air pollutants in an urban environment. Previous studies showed that nanomaterials-based photocatalyst could be activated by a light source and produce a substantial oxidation/reduction (REDOX) potential on the surface of the nanoparticles (Figure 4)[38]. NOx and HC levels can be monitored using a real-time exhaust analysis device to measure REDOX potential (Figure 5).

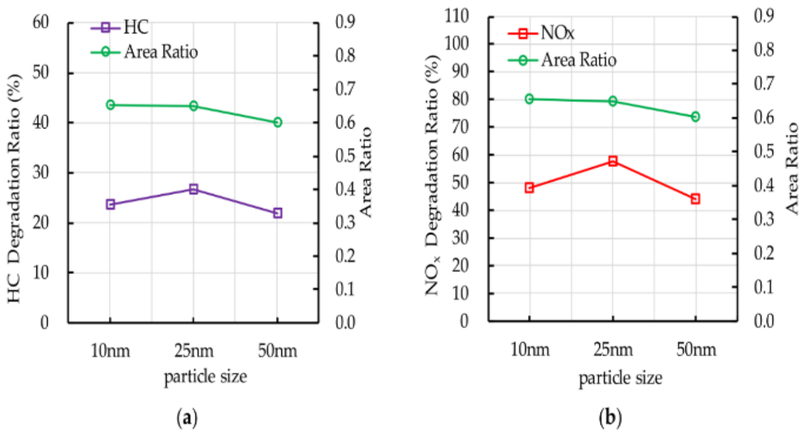

FIGURE 4 photocatalytic degradation of nitrogen oxides (a) and hydrocarbons (b) using TiO2 particles. Reproduced under the terms and conditions of the Creative Commons Attribution (CC BY) license [38]

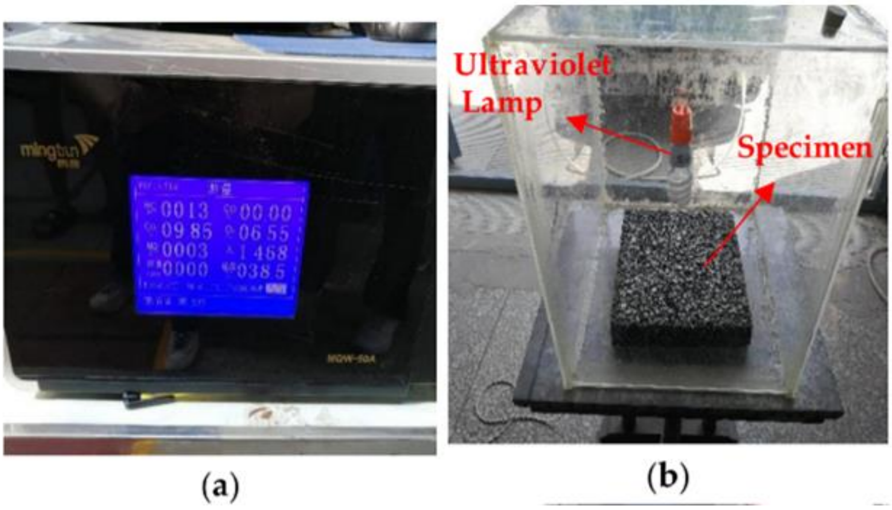

FIGURE 5 (a) Instrument for automobile exhaust analysis; (b) reactor [38]

Conclusion

Nanoparticles have shown promising potential in air pollution remediation due to their high reactivity, efficiency properties, and lower cost compared to conventional strategies. Atmospheric heavy metal pollution could be significantly adsorbed via NMs. Also, indoor air pollutants could be cleaned via different engineered nanoparticles. Therefore, nanotechnology has opened a new avenue in air pollution remediation with great hope.

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