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Review

A review of functionalized carbon nanotubes and graphene for heavy metal adsorption from water: Preparation, application, and mechanism

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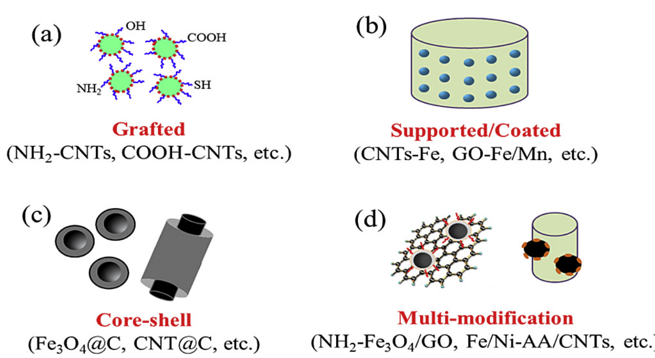
HIGHLIGHTS

- Removal of heavy metals from water has drawn wide attention.
- Various functionalized carbon nanotube and graphene nanomaterials were stated.
- Effects of water environmental chemistry on heavy metals removal were discussed.
- Adsorption isotherms, kinetics, thermodynamics, and pathways were discussed.
- Some research prospects were proposed for future studies and application.

GRAPHICAL ABSTRACT



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ABSTRACT

Carbon-based nanomaterials, especially carbon nanotubes and graphene, have drawn wide attention in recent years as novel materials for environmental applications. Notably, the functionalized derivatives of carbon nanotubes and graphene with high surface area and adsorption sites are proposed to remove heavy metals via adsorption, addressing the pressing pollution of heavy metal. This critical revies assesses the recent development of various functionalized carbon nanotubes and graphene that are used to remove heavy metals from contaminated water, including the preparation and characterization methods of functionalized carbon nanotubes and graphene, their applications for heavy metal adsorption, effects of water chemistry on the adsorption capacity, and decontamination mechanism. Future research directions have also been proposed with the goal of further improving their adsorption performance, the feasibility of industrial applications, and better simulating adsorption mechanisms.

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List of acronyms

AA	Activated alumina
LDH	Layered double hydroxide
AC	Activated carbon
M-CHAP	magnetic carbonate hydroxyapatite
BET	Brunauer-Emmett-Teller
MC-N	magnetic carbon-iron reduced by $Fe(NO_3)_3$
CB[6]	Cucurbit[6]uril
MC-O	magnetic carbon-iron reduced by Fe_3O_4
CMK	Nanoporous carbons
MIO	Magnetic iron oxide
CMPEI	Carboxymethylated polyethyleneimine
MPTS	Mercaptopropyltriethoxysilane
CNTs	Carbon nanotubes
MWCNTs	Multi-walled carbon nanotubes
CS	Chitosan
NPs	Nanoparticles
DBSA	Dodecyl-benzene-sulfonic-acid
nZVI	Nanoscale zero-valent iron
DES	Deep eutectic solvents
OMC	Ordered mesoporous carbon
DFT	Density functional theory
PAA	Polyacrylic acid
EDA	Ethylenediamine
PANI	Polyaniline
Fe_2O_3	Maghemite
RGO	Reduced graphene oxide
GO	Graphene oxide
SMG	Smart magnetic graphene
HA	Humic acid
VP	2-vinylpyridine
HEG	Hydrogen exfoliated graphene
WHO	World Health Organization
HMO	Hydrous manganese dioxide
XPS	X-ray photoelectron spectroscopy
IL	Ionic liquid

Contents

1. Introduction

Water is the most essential and important component for living beings on Earth. In the last century, anthropogenic water demand has increased sevenfold due to the quadrupled global population (Pendergast and Hoek, 2011). Approximately 2.6 billion people have gained access to an improved drinking water source since 1990, while 663 million people still lack improved drinking water sources in 2015, according to the report of "Progress on Sanitation and Drinking Water-2015 Update and MDG Assessment" by the World Health Organization (WHO). The number of people living in water scarce regions will increase to about 3.9 billion by 2030, as estimated by the World Water Council. As a result of rapid developments in urbanization, industrialization, and agricultural activities, the removal of heavy metals from contaminated waters has become a major environmental concern. Many metals are essential nutrients in trace amounts, but become significant threats to environmental and human health at high concentrations. Heavy metals are non-biodegradable and can accumulate in the environment and living organisms (Hashim et al., 2011; Xu et al., 2017a, b). Neurological, mental, and other various adverse effects are caused by exposure to, transportation of, and accumulation of heavy metals, especially Hg(II), Pb(II), Cr(VI), Cd(II), and As(III)/(V) (Meng et al., 2014; Sima et al., 2015; Dong et al., 2017; Rehman et al.,