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Review

Overview of microbes based fabricated biogenic nanoparticles for water and wastewater treatment

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ABSTRACT

Treatment of toxic and emerging pollutants (T&EPs) is increasing the threats to the survival of conventional wastewater treatment (WWTs) technologies. The high installation and operational costs of advanced treatment technologies have shifted the research interest to the development of economical and reliable technology for management of T&EPs. Thus, recently biogenic nanoparticles (BNPs) fabricated using microbes/microorganisms are getting tremendous research interest due to their unique properties (i.e. high specific surface area, desired morphology, catalytic reactivity) for the biodegradation and biosorption of T&EPs. In addition, BNPs can be manufactured using metal contaminated water which indicates a hidden potential for resource recovery and utilization. Therefore, the present study discusses the adsorptive and catalytic performance of BNPs in the removal of T&EPs from water (W) and wastewater (WW). In addition, inspired by the superior performance of BNPs in advance WWT, a model of BNPs based WWT resource recovery and utilization process is also proposed. Finally, main issues i.e. mass production, leaching, poisoning/toxicity, regeneration, reusability and fabrication costs and process optimization are discussed which are main hinders in the transfer of BNPs based WWT technologies from laboratory to commercial scale.

1. Introduction

Currently, the discovery of additional toxic and emerging pollutants (T&EPs) is increasingly sabotaging the survival of conventional wastewater treatment technologies (Puvol et al., 2016; Zhuang et al., 2015). Emerging or priority pollutants (E/PPs), such as toxic heavy metals, organic and inorganic micro-pollutants, pharmaceuticals and halogenated compounds, pigments, toxic dyes and pathogenic microorganisms are increasingly reported in many studies (Xiao et al., 2017; Kim et al., 2016; Jain et al., 2016). The concentration and volume of these pollutants are increasing continuously due to a rapid increase in domestic, industrial and agricultural activities (Zhou et al., 2016). On the other hand, the stringent limits of these T&EPs are creating limitations for the existing water and wastewater treatment technologies (W/WWTT) to discharge these contaminants safely into the natural water environment (Liu et al., 2015). Thus, there is a need to discover the alternate options that can address these issues.

Since the development of the conception of microbial interaction with metals, biogenic nanoparticles (BNPs) have been getting tremendous research interest from last few decades (Gillan, 2016). Owing to their unique properties, BNPs have been employed in the applications of biomedical, electronic, and W/WWT approaches (Ali et al., 2017a, 2017b). The engineering of BNPs fabrication via microbial interaction is now well documented (Holmes and Gu, 2016). In contrast, the fabrication of nanoparticles (NPs) via conventional methods is often expensive and hazardous due to the involvement of toxic reducing and stabilizing agents (Rezić, 2011). However, BNPs can be manufactured in a safe environment using microbes as reductant (Kitching et al., 2015; Kharissova et al., 2013). In addition, heavy metal polluted water can also be used instead of salts to fabricate BNPs. It is also a method for

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Nomenclature

ABCSBR Aerobic bubble column sequencing batch reactor
AFM Atomic force microscope
AI-FeNPs Azadiracta indica
AMMC-Fe_3O_4 Acid-modified maize cob impregnated with ferroso-ferric oxide
BET Braunauer–Emmett–Teller
BioMnOx Biogenic manganese oxide nanoparticles
Bio-Pd Biogenic nano-palladium
BioSeNPs Biogenic elemental selenium nanoparticles
BMNPs Biogenic magnetic nanoparticles
BMO Biogenic Mn oxide; BnM: Biogenic magnetite
CSNPs-Fe_3O_4-Ag Core shell nanoparticles
CueO Biocatalyst multicopper oxidase
DEAMTPP@Fe_3O_4 MNP Diethyl-4-(4-amino-5-mercapto-4H-1,2,4-triazol-3-yl)phenyl phosphonate
DHPCT@Fe_3O_4 MNP 3,4-dihydroxyphenethylcarbamodithioate (DHPCT)
DLS Dynamic light scattering DMSA@Fe3O4 MNRs Dimercaptosuccinic acid (DMSA) anchored Fe3O4 magnetic nanorods (MNRs)
DRS Diffuse reflectance spectroscopy
DSC Differential scanning calorimetry
ECueO cueO-overexpressing Escherichia coli strain
EDDS (S,S)-ethylenediamine-N,N0-disuccinic acid ()
EDS Energy dispersive X-ray spectroscopy
EDTA Ethylenediamine tetraacetate
EL-Fe Eucalyptus leaves extract
Fe_3O_4@2D-CF composite Bioinspired graphene oxide-like 2D-carbon flake (CF) Fe_3O_4 nanoparticles
Fe_3O_4@DAPF-CSFMNR Core–shell ferromagnetic nanorods
Fe_3O_4 TW Tea waste
FTIR Fourier transformed infrared analysis
HAuCl4•3H2O Hydrogen tetrachloroaurate (III) hydrate
HRTEM High resolution transmission electron microscopy
INPB Ironoxide nanoparticle beads
MB Methylene blue
MG Malachite green
MO Methyl orange
MOB Manganese oxidizing bacteria \
MRGO Magnetite/reduced graphene oxide
Ms Magnetic saturation
Na2PdCl4 Sodium tetrachloropalladate
Na2-SeO3 Sodium selenite
NaBH4 Sodium boro-hydride
NMR Nuclear magnetic resonance
ORS/Fe3O4/PCL-NCs Modified rice straw/Fe_3O_4/polycaprolactone nanocomposites
PXRD Powder X-ray Diffraction
RhB Rhodamine B
SAED Selected-area electron diffraction
SEM Scanning Electron Microscopy
SMNPs Bio-inspired Fe_3O_4 spherical magnetic nanoparticles
SQUID Superconducting quantum interference device
TCE Trichloroethylene
TEM Transmission Electronic Microscopy
TGA Thermal gravimetric analysis
UASB Up-flow anaerobic sludge blanket
UV-VS UV–visible Spectrometer
VSM Vibrating sample magnetometer
XPS X-ray photoelectron spectroscopy
XRF X-ray fluorescence
ZP Zeta-potential

resource recovery and the safe utilization of domestic and industrial wastewaters (Meerburg et al., 2012). The rapid increase in price of metals which are being used as a raw material in most industries including leather tanning, cement production, metallurgy, electroplating, electronics, has propelled our research interest to recover these metals from polluted waters and soils (Quan et al., 2015; Hennebel et al., 2011a,b).

Apart from the safe fabrication protocol, BNPs have been exploited for the generation of electricity, remediation of polluted soils and waters, and removal/recovery of scarce and precious metals (Martins et al., 2017; Qu et al., 2017). In this regard, Fig. 1 shows an increasing research interest in BNPs applications in W/WWT. Owing to the presence of a unique bacterial carrier matrix, BNPs have been used as biocatalysts, adsorbents, oxidants, and reductants in the removal of T&EPs from drinking water and wastewater (Gusseme et al., 2012). Most studies stated that the presence of specific functional groups (i.e. hydroxyl, carboxylate, methyl and amide I, II &II) and the variety of reducing substance generated by the bacterial cells (charged opposite to targeted pollutants) are primarily responsible for the removal of contaminants via electrostatic interactions and the ion exchange process (Ahluwalia et al., 2016; Qu et al., 2016; Yue et al., 2016; Furgal et al., 2015). In addition, BNPs can be activated by providing hydrogen gas (H_2) or formate as an electron donor for the degradation of T&EPs (Suja et al., 2014; De et al., 2012; Hennebel et al., 2010). Few studies have demonstrated that molecular oxygen can be produced using Mn-oxidizing bacteria for the bio (degradation) of recalcitrant pollutants via the combination of electrostatic interaction, co-precipitation and bacterial co-metabolism (Su et al., 2014; Meerburg et al., 2012). Although BNPs have shown superior performance in the removal of T&EPs, however, certain aspects (detail in section 4) are mainly creating barriers in the market penetration of BNP based W/WWT technologies.

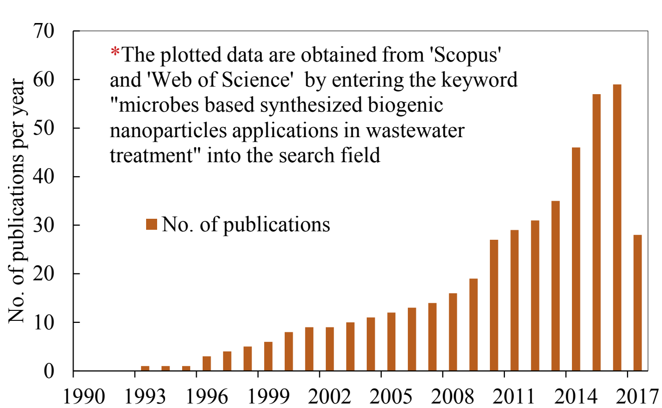

Fig. 1. Literature survey and research developments about biogenic nanoparticles (BNPs) applications in water and wastewater treatment (W/WWT).

1.1. Scope of the study

Several studies have reviewed different features of BNPs based on the fabrication and extensive application of BNPs in different fields of modern science. The reviews on BNPs fabrication and application can be found in literature (Zan and Wu, 2016; Shamaila et al., 2016, Siddiqi and Husen, 2016a,b; Huang et al., 2015, Sharma et al., 2015, Moritz and Geszke, 2013; Narayanan and Sakthivel, 2010). Different kinds of BNPs e.g. organic, inorganic, semiconductor, chalcogenide quantum dots, can be manufactured using different microbial strains and their applications would also vary. For instance, Rubilar et al. (2013) reported a detailed description of the applications of BNPs fabricated using copper, copper sulphides and copper oxides. Quantum dots have