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The Application of Carbon Nanotubes in Permeable Reactive Barriers (PRBs) for Groundwater Remediation

Chengyin Zheng

Changde Foreign Language School
margarettttttt @sina.com

ABSTRACT
Groundwater pollution is becoming one of the biggest environmental challenges in the 21st century. Groundwater remediation technologies can be classified as in-situ and ex-situ remediation technologies. Carbon nanotubes with permeable reactive barriers (PRBs) are an environmentally friendly in-situ remediation technology which can provide an effective and fast in-situ remediation approach. In this study, the application of carbon nanotubes used in water remediation industry was discussed. The current knowledge and perspectives of application of carbon nanotubes in permeable reactive barriers (PRBs) for groundwater remediation was also studied. After that, the advantages and disadvantages of application of carbon nanotubes in PRBs for groundwater remediation was also discussed.

Keywords: *carbon nanotubes, groundwater pollution, permeable reactive barrier, in-situ remediation, ex-situ remediation.*

1. INTRODUCTION

Groundwater pollution (also called groundwater contamination) is one of the biggest challenges of our times [1]. Groundwater pollution usually comes from man-made products such as gasoline, asphalt, rubber, and other industrial chemicals. Environmental pollutions such as pesticides and fertilizers from the earth surface can pass through the soil and into the groundwater. Groundwater might also be contaminated by road salt, hazardous compounds from mining sites. Untreated sewage from septic tanks, toxic chemicals from underground storage tanks, and leakage from landfills can also contaminate groundwater.

Groundwater remediation technologies can be classified as in-situ (on-site) or ex-situ (off-site) remediation technologies. In-situ remediation is cleaning the contaminated groundwater instead of removing and relocating the water. It is a cost-effective alternative than removing the water and treating it off-site. Ex-situ remediation needs to excavate contaminated groundwater and then disposing of it off-site. The benefit of this ex-situ remediation is no damage to the ecological environment in the current place, but it extends the process and costs more money. Both in-situ and ex-situ remediation technologies should be implemented based on each project’s specific situation.

Permeable reactive barriers (PRBs) are a environmentally friendly in-situ remediation technology. It can be used to remediate groundwater by contaminated heavy metals, chlorinated organic compounds and their breakdown products such as perchloroethylene (PCE) and trichloroethene (TCE). Table 1 shows different types of pollutants which can be removed by PRBs technique [2]. PRBs is a contaminant plume-intersecting underground barrier made up of reactive compounds that target dissolved phase contaminants when the plume passes through the barrier (Figure 1). An impermeable wall is set up to direct groundwater flow via the PRB, if it is necessary.

In recent years, nanomaterials have wide applications in a variety of technological fields such as medical equipment, energy generation, and information technology. Many nanomaterials have been introduced to the water treatment industry and has produced some promising outcomes. Carbon nanotubes are now frequently employed in groundwater pollution remediation. Carbon nanotubes' properties allow them to efficiently degrade the pollutants. Carbon nanotubes have been proven to have better properties than the standard adsorbent, such as a large surface area and excellent material selectivity. They can also combine several reactive agents together and allow fine control over mass transport properties.

Few studies have been conducted in this field due to the rapid growth of nanotechnology. The purpose of this paper is to discuss the knowledge and perspectives of carbon nanotubes in permeable reactive barriers (PRBs) for groundwater remediation. The objectives are to: 1) present the application of carbon nanotubes used in water remediation industry; 2) discuss the current knowledge and perspectives of application of carbon nanotubes in PRBs for groundwater remediation.

Table 1. Pollutants which can be removed by PRBs technique [2]

Reactive material	Nature of pollutant	Initial concentration	Mechanism of pollutant removal	Removal (%)
Oxygen reactive compound and clinoptilolite	NH4-N	5-11 mg/L	Ion exchange and biological nitrification	99
Natural pyrite (FeS_2)	Cr(VI)	10-100 mg/L	Sorption	27-100
Zero-valent iron coupled with polyhydroxybutyrate	1, 2- dichloroethane	10 mg/L	Biological degradation	20-80
Organic substrates and zero-valent iron (ZVI)	Heavy Metals (Al, Zn and Cu)	15, 20 and 1.2 mg/L	Precipitation	>95
Granular oxygencapturing materials	Nitrate and nitrite	40 mg/L	Biodegradation	>94
Bioaugumented Biobarrier (Mycobaterium sp. and Pseudomonas sp. immobilized bead) PRB	Benzene, toluene, ethylbenze and xylene (BTEX)	100 mg/L	Biodegradation	84-97
Bio-barrier (Arthrobacter viscosus)	Polyaromatic hydrocarbons	100 μM	Biodegradation	>80

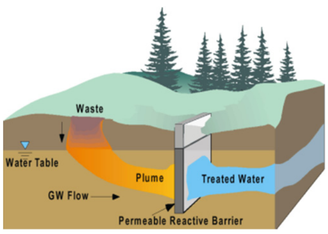

Figure 1 Conceptual schema of an in-situ PRBs [2].

2. CARBON NANOTUBES TECHNOLOGY AND ITS APPLICATION IN GROUNDWATER REMEDIATION

2.1. Carbon nanotube classification

Nowadays, nanotechnology has been widely implemented in water industry and wastewater treatment water and wastewater treatment industry. With the development of nanotechnology in the last decade, research has begun to utilize carbon nanotubes' properties. A carbon nanotube is made up of a layer of carbon atoms that are bonded together in a hexagonal pattern (Figure 2). The diameter of carbon nanotubes is typically ranging from 0.4 to 40 nm. Their length can vary 100,000,000,000 times in the range 0.14 nm to 55.5 cm. Carbon nanotubes are attracting a lot of research interests due to their exceptional adsorption, uniform pore distribution, and large surface area. Carbon nanotubes can be classified in two categories. One is the single-walled carbon nanotubes (SWNTs) which is a single tube with a diameter ranging from 1 to 5 nanometers. Another one is the multiwalled carbon nanotubes (MWNTs) which is a series of nanotubes with lengths ranging from 100 nanometers to 20 micrometers. Carbon nanotubes have been attracted much attention since their discovery because of their unusual features. Chemical vapor deposition can be used to make carbon nanotubes. The type of catalyst and carrier gas employed in this process determine the features of carbon nanotubes produced.

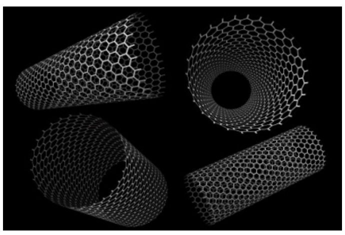

Figure 2 Structure of carbon nanotube [3].

2.2. Carbon nanotubes for removal of water pollution

Carbon nanotubes are a promising adsorbent material which could be a good alternative for activated carbon. The hexagonal arrays of carbon atoms in the graphite sheets of carbon nanotubes have a strong interaction with other molecules. To improve the performance of pollutant adsorption, the surface of carbon nanotubes can be modified by different type of functional groups such as -COOH, -OH, and -NH2 by chemical oxidation. As a result, they can be used to remove many pollutions such as heavy metals and persistent organic pollutants. Due to their porous structure and surface area, carbon nanotubes have a better adsorption performance than that of the regular carbon materials with the same surface area. Therefore, carbon nanotubes are an effective adsorbent for environmental pollutions as compared to other adsorbents.

The unique properties of carbon nanotubes (e.g., chemical, and thermal stability) were used to remove heavy metals and natural organic matter (NOM) from water. Liu et al. developed two different carbon nanomaterial–biochar nanocomposites (SG-PySA-CNT and SG-PySA-GO). Their results indicated that both SG-PySA-CNT and SG-PySA-GO had a better sorption ability to Pb(II) and Cd(II) from solution than the pristine biochar. Carbon nanotubes are excellent fluoride adsorbents, with a capacity for fluoride removal that exceeds that of an activated carbon filter. They can significantly remove dioxins from different environments [4]. Zhou et al. found that carbon nanotubes have higher adsorption efficiency than that of regular activated carbons, even though carbon nanotubes have a smaller Brunauer-Emmett-Teller (BET) surface. Carbon nanotubes can remove 86.8% of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzo-p-furans (PCDD/Fs). Two other activated carbons can only remove 70.0% and 54.2% of PCDD/Fs [5].

2.3. Application of carbon nanotubes in PRBs for groundwater remediation

Depending on the chemical characteristics of the pollution plume, the materials utilized in the permeable reactive barrier are varied [6]. Carbon nanotubes include in single-walled and multiwalled versions. Arsenic is effectively absorbed from groundwater by carbon nanotubes. The large surface area of the carbon nanotubes is more effective in absorbing the arsenic contamination in water in nanotechnology [6]. Carbon nanotubes used in groundwater remediation are usually costly and time-consuming. This is mainly attributed to the fact that the treatment zone requires a permeable reactive barrier where immobilized the pollutants and only allowing groundwater passing [6]. In many cases, the permeable reactive barrier needs outside pressure-building operations in order to maintain an appreciable water flow. In addition, the permeable reactive barrier is only useful in pollutant plumes which can pass through it. This is one of the most serious limitations of using carbon nanotubes in PRBs. Carbon nanotubes with PRBs allows for an effective in-site remediation. However, the carbon nanotubes that absorbed pollutions also may not be easily discarded.

3. CONCLUSION

Nanotechnology is being developed at an exponential rate, and it will revolutionize the groundwater remediation industry. The carbon nanotubes have high chemical and thermal stability, which can be manipulated for the groundwater remediation. Carbon nanotubes with PRBs can provide an effective and fast in-situ remediation approach for groundwater remediation. According to the discussion in this paper, carbon nanotubes have a better adsorption performance than that of the regular carbon materials with the same surface area. Last but not least, carbon nanotubes with PRBs is an effective adsorbent for environmental pollutions as compared to other adsorbents. However, three are still many drawbacks of application of carbon nanotubes in PRBs for groundwater remediation. Carbon nanotubes used in groundwater remediation are usually costly and time-consuming. Moreover, the characteristics of the carbon nanotubes in the contaminated area are still not clear. The carbon nanotubes that absorbed pollutions cannot be easily discarded. It may have a negative impact on the remediation process. Before this technology can be widely used in groundwater remediation, the disposal problem of the carbon nanotubes after absorbing the pollutions during the remediation process must be addressed, and more research is needed regarding the characteristics.

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