

# Arsenic Removal from Drinking Water Using Carbon Nanotubes

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## INTRODUCTION

High concentrations of arsenic are found naturally in groundwater worldwide and pose a potential health hazard to humans from long-term exposure. Arsenic exposure can come from drinking water, contaminated irrigated crops, and food preparation with contaminated water. The organic form of arsenic is less harmful than the inorganic form. The inorganic form of arsenic is present in groundwater and highly toxic, therefore hazardous to humans. Long-term exposure to arsenic in water can cause numerous health problems, primarily skin, bladder, and lung cancer. Additional studies have also indicated that the ingestion of arsenic may lead to internal malignancies, such as cancers of the kidney, bladder, liver, lung, and other organs (Naghizadeh et al., 2012). For these reasons the United States Environmental Protection Agency (EPA) and the World Health Organization (WHO) have set the drinking water standard to 10 parts per billion or 10  $\mu\text{g/L}$  (Ma et al., 2013; Velickovic et al., 2011). Certain countries such as India, Bangladesh, Vietnam, and the southwestern

United States are afflicted with high levels of arsenic in their groundwater much larger than this set standard, and are therefore in need of an efficient treatment process for arsenic removal (Vadahanambi et al., 2013).

## BACKGROUND

Studies have found Carbon Nanotubes (CNTs) can effectively remove arsenic levels to a tolerable for humans (Ntim & Mitra, 2012). CNTs form nanoscale pores from the entanglement of hundreds of tubes that are held together by Van der Waal forces. CNTs “provide large external surface areas that can immobilize contaminants including bacteria and viruses” (Upadhyayula et al., 2009). They are known for their strength, as well as their unique electrical and thermal properties. The structure and function of CNTs allows for this high adsorption of contaminants. They can be formed with either single or multi-wall properties.

Single-wall CNTs are one sheet of graphene, whereas multi-wall CNTs are multiple layers of gra-

phene sheets (Naghizadeh et al., 2012). Although the internal structure of the CNTs does not adsorb the contaminants on account of its massive size, the interstitial pore spacing between the tube bundles provides sufficient space for metal ions, such as arsenic, to attach. The metal ions attach to the bundles, grooves, and exterior of the CNT. Pristine CNTs also possess cytotoxic abilities that prohibit the growth of pathogens on their structure. CNTs are ideal for removal because this capability is unlike other carbon-based adsorbents. The CNTs also can be functionalized allowing for surface modification with covalent and non-covalent attachment of functional groups as shown in Figure 1. The non-covalent bonds can be used to make the CNTs more water-soluble, therefore preferred. Slightly water soluble CNTs can be used for practical treatment purposes by enhancing their chance for surface contact (Upadhyayula et al., 2009).

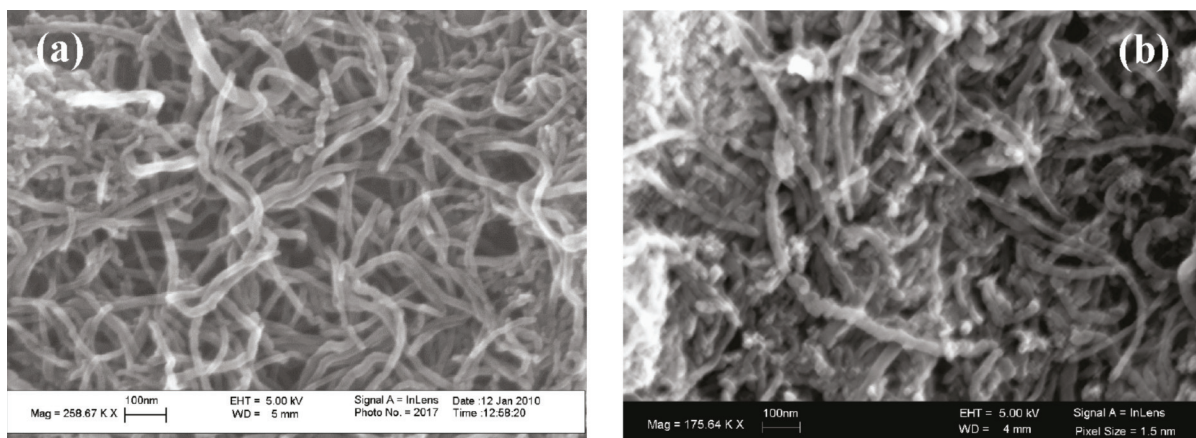
As a result of CNTs structural and functional capabilities, it has been sought after as an adsorbent to remove contaminants in water. In order to gage the success of the current usage of CNTs, a range of applications for heavy metal and arsenic removal have been summarized. This article outlines several studies that have examined different forms of CNT and their treatment of arsenic contaminated water.

The scope of this article describes the adsorbent capacities of CNTs on different types of heavy metals. This is the focus of the article because future research is based off of these literary reviews.

## Carbon Nanotubes as Adsorbents for Heavy Metals

The novel properties of CNTs have made them useful in a range of applications in nanotechnology, electronics and water treatment. Multi-wall carbon nanotubes (MWCNTs) have been used in a number of studies to remove metal ions, such as lead, copper, cadmium, silver, and nickel (El-Sheikh, 2008). Lead removal from water with CNTs can be highly effective depending on the pH level. Similarly chromium can be removed with CNTs from water at a pH higher than 4 or 5 (Atieh et al., 2010). The increased pH of the water improves the adsorption capabilities of the CNTs. At acidic pH, free metal ions exist in solution, while surface functional groups present are in the protonated form. Contrarily, at basic pH, metals are precipitated as their hydroxides, while functional groups on the adsorbent surface exist in the deprotonated form. Hence, with the increase of pH, the removal of chromium increases and as the degree of protonation of the surface decreases, the adsorption capacity increases (Atieh et al., 2010). As-produced CNTs have some level of adsorbent properties for nickel. In a study by Kandah and Meunier (2006) it was determined that as-produced CNTs have an adsorption of 18.01 mg/g, which was lower than commercial activated carbon or activated carbon made from peanut shells. They hypothesized the reduced adsorption was due to the as-produced CNTs being inert and not possessing a surface charge. This is

Figure 1. (a) acid-functionalized MWCNT, (b) iron-oxide coated hybrid (Fe-MWCNT) (Ntim and Mitra, 2011)



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