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Q11 Removing ammonium from water and wastewater using cost-effective adsorbents: A review

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ABSTRACT

Ammonium is an important nutrient in primary production; however, high ammonium loads can cause eutrophication of natural waterways, contributing to undesirable changes in water quality and ecosystem structure. While ammonium pollution comes from diffuse agricultural sources, making control difficult, industrial or municipal point sources such as wastewater treatment plants also contribute significantly to overall ammonium pollution. These latter sources can be targeted more readily to control ammonium release into water systems. To assist policy makers and researchers in understanding the diversity of treatment Q14 options and the best option for their circumstance, this paper produces a comprehensive review of existing treatment options for ammonium removal with a particular focus on those technologies which offer the highest rates of removal and cost effectiveness. Ion exchange and adsorption material methods are simple to apply, cost effective, environmentally friendly technologies which are extremely effective at removing ammonium from treated water. The review presents a list of adsorbents from the literature, their adsorption capacities and other parameters needed for ammonium removal. Further, the preparation of adsorbents with high ammonium removal capacities and new adsorbents is discussed in the context of their relative cost, removal efficiencies, and limitations. Efficient, cost effective, and environmental friendly adsorbents for the removal remove of ammonium on a large scale from commercial or water treatment plants are provided. In addition, future perspectives on removing ammonium using adsorbents are presented.

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Introduction

Ammonium concentrations in unspoiled waterways are usually low (Marañón et al., 2006); however, these days, agricultural, domestic and industrial effluent and runoff contribute substantially to ammonium pollution of surface and ground water resources. This pollution finds its way into these vital resources *via* various point sources such as: municipal and industrial wastewater, leachate and runoff from waste disposal sites, construction sites, animal feed lots and so on (Camargo and Alonso, 2006; Carlson et al., 2013; Chen et al., 2002; La Cour Jansen et al., 2004), as well as non-point sources such as agricultural runoff, atmospheric deposition and land developments nearby waterways (Camargo and Alonso, 2006; Nolan and Hitt, 2006; Zhu et al., 2013). High nutrient loads can stimulate nuisance algal growth in polluted waters, which can contribute to hypoxia or anoxia zones, and highly undesirable changes in ecosystem structure and function (Bhatnagar and Sillanpaa, 2011; Camargo and Alonso, 2006; Smith et al., 1999). In addition, ammonium needs to be removed from grey water for reuse purposes due to its potential risk to human health (Britto and Kronzucker, 2002). This is especially true in the case of laundry, bathroom, and swimming pool wastewaters (Widiastuti et al., 2011).

Ammonium (NH_4^+) and unionised ammonia (NH_3) are readily interchangeable depending upon the pH and temperature of natural and urban waters (Nollet, 2013). Unionised ammonia is much more toxic than ammonium (Batley and Simpson, 2009; CCME, 2007; USEPA, 2006), because it is a neutral molecule that freely diffuses across the epithelial membranes of aquatic organisms. It can damage gill epithelia causing asphyxiation, stimulate glycolysis, and suppress the Krebs cycle leading to progressive acidosis which reduces the oxygen-carrying capacity of blood, disrupts blood vessels, and affects liver and kidney functions (Augspurger et al., 2003). However, in natural waters, ammonium is present at much greater concentrations than ammonia due to the predominance of circum-neutral pH. A number of guidelines to protect against the effects of eutrophication have been developed to deal with global concerns regarding the ecological effects of ammonium (ANZECC, 2000; CCME, 2007; EU, 2006; USEPA, 1999).

Accordingly, many methods, such as biological, physical, chemical, or a combination of these methods, have been developed for the removal of ammonium from wastewaters and other point sources. They mainly include ion exchange and adsorption, biological technology, air stripping, breakpoint chlorination, chemical precipitation, reverse osmosis, microwave radiation, and supercritical water oxidation (Bermejo et al., 2008; Bernet et al., 2000; Bodalo et al., 2005; Booker et al., 1996; Guštin and Marinšek-Logar, 2011; Huang et al., 2015a; Lin et al., 2009; Siegrist, 1996; Turan, 2016). The advantages and disadvantages of these technologies are summarised in Table 1. There are several limitations for the current technologies, including high cost, low removal rate, high sensitivity to pH and temperature, and introducing new pollutants (Bermejo et al., 2008; Bernet et al., 2000; Bodalo et al., 2005; Booker et al., 1996; Guštin and Marinšek-Logar, 2011; Huang et al., 2015a; Lin et al., 2009; Siegrist, 1996; Turan, 2016). Compared to other techniques, ion exchange and adsorption technique have many favourable characteristics. It demonstrates a high affinity towards ammonium, high removal efficiency, low-cost, simplicity of application and operation as well as environmental friendliness (Turan, 2016; Uğurlu and Karaoğlu, 2011; Widiastuti et al., 2011). These advantages make it competitive to apply on a large scale for commercial and water treatment plants to remove ammonium. Therefore, the following study focuses on this method. In this review, over 70 adsorbents are presented and their performance in removing ammonium is compared based on several criteria, which examine the efficiency, cost effectiveness, ease of use, and environmental friendliness of adsorbents in the removal of ammonium.

1. Removal of ammonium from water and wastewater using the adsorption and ion exchange method

This review provides criteria based on source, process, and waste for identifying the most suitable adsorbents for removing

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