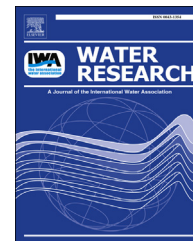




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# Regeneration of iron-based adsorptive media used for removing arsenic from groundwater

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## ARTICLE INFO

### Article history:

Received 9 December 2014

Received in revised form

3 March 2015

Accepted 5 March 2015

Available online 24 March 2015

### Keywords:

Arsenic

Iron media

Regeneration

Laboratory tests

## ABSTRACT

Adsorptive media technology is regarded as a simple, low cost method of removing arsenic from drinking water particularly for small systems. Currently, when the effluent of a treatment system reaches the USEPA maximum contaminant level (MCL) of 10 µg/L, the exhausted media is removed and replaced by new virgin media. Although the commonly used iron-based media products are reasonable in price, the replacement cost accounts for around 80% of the systems total operational costs. One option to media replacement is on-site regeneration and reuse of the exhausted media. To determine whether an iron based media can be successfully regenerated and reused, laboratory batch and column regeneration tests were conducted on six exhausted iron-based media products obtained from six full scale arsenic removal treatment systems. Batch tests conducted on three of the media products to evaluate the effectiveness of 1–6% caustic regenerant solutions found that arsenic desorption increased until around 4%. Using 4% caustic solutions, the column tests on the six exhausted media products showed arsenic removals ranged from 25 to 90% with the best results obtained with the Severn Trent E33 media. Exposing the media to caustic (pH ≥ 13) and acid (pH ≤ 2) solutions found minimal media loss with the caustic solution, but significant media dissolution with a pH 2 acid solution. A six column pilot plant test at an Ohio test site with the lab regenerated media products found that the regenerated media could achieve arsenic removals somewhat similar to virgin media.

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## 1. Introduction

### 1.1. Adsorptive media process

A variety of treatment technologies exist for removing arsenic from drinking water. Commonly used techniques are (1) chemical coagulation/filtration (C/F) using aluminum or iron coagulants; (2) precipitation on oxidized naturally occurring

iron; (3) adsorption (AM) onto solid media; (4) anion exchange (AE) and (5) reverse osmosis (RO). A review of these technologies have been made by a number of authors (Amy et al., 2000; Chen et al., 1999, 2002; Choong et al., 2007; Chowdhury et al., 2002; Cundy et al., 2008; Giles et al., 2011; Jain and Singh, 2012; Jekel, 1994; Kartinen and Martin, 1995; Mohan and Pittman, 2007; Mondal et al., 2013; Sorg and Logsdon, 1978; USEPA, 2003; Wang et al., 2002).

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<http://dx.doi.org/10.1016/j.watres.2015.03.004>

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The AM technology is a simple, fixed bed process where arsenic and other anions are adsorbed onto a packed bed of media. The arsenic removal mechanism of the adsorptive media process is usually an exchange of anions, such as arsenic, for surface hydroxides of the media. The exchange process is generally called sorption or adsorption, although ligand exchange is a more appropriate term for the highly specific surface reactions involved (Clifford et al., 2011). When the arsenic concentration of the effluent from an adsorption system reaches the regulatory limit of 10 µg/L, the media is commonly replaced with new media. The simplicity and the relatively low capital cost of the technology have resulted in AM being utilized by many drinking water systems for removing arsenic, particularly small systems (Chen et al., 1999; Chang et al., 2005, 2005; Giles et al., 2011; Jain and Singh, 2012; Jeong et al., 2007b; Möller et al., 2011; Rubel Jr., 2003a; Wang et al., 2002; Wang and Chen, 2011; Xie et al., 2007; Zeng et al., 2008).

During the past several decades, a substantial amount of research has been conducted on a wide variety of adsorbent materials, both naturally occurring and commercially produced, for the removal of arsenic from drinking water sources (Amy et al., 2005; Choong et al., 2007; Daus et al., 2004; Dixit and Hering, 2003; Kolbe et al., 2011; Melitas et al., 2002.; Mohan and Pittman, 2007; Giles et al., 2011; Mahler and Person, 2013; Mamindy-Pajany et al., 2011; Aredes et al., 2012; Yadanaparthi et al., 2009; Youngran et al., 2007; Xie et al., 2007; Zeng et al., 2008; Westerhoff, 2006). The majority of the commercially available adsorbents are metal oxide/hydroxides that include iron, aluminum, zirconium and titanium (Amy et al., 2005; Chang et al., 2004; Choong et al., 2007; Bang et al., 2005; Jain and Singh, 2012; Lakshmanan et al., 2008; Rubel Jr., 2003a, 2003b). Of the commercially available adsorbents, iron and aluminum-based materials have received the most attention and evaluation for their effectiveness in removing arsenic from drinking water. And of the two metals, the iron-based adsorbents generally have been found to have the higher arsenic adsorptive capacity and efficiency (Amy et al., 2005; Chang et al., 2004; Jain and Singh, 2012; Jekel, 1994; Jeong et al., 2007a; 2007b).

Activated alumina (AA), an aluminum oxide/hydroxide media, has a relatively long history for removing arsenic from water (Bellack, 1971; Fox and Sorg, 1987; Fox, 1989; Ghosh and Gupta, 2012; Hathway and Rubel, 1987; Jain and Singh, 2012; Jekel, 1994; Rosenblum and Clifford, 1984; Rubel and Williams, 1980; Rubel Jr, 2003a; Singh et al., 2001; Stewart and Kessler, 1991; Wang et al., 2002; Lin and Wu, 2001). Because of its historical application, AA adsorption was listed by the US Environmental Protection Agency (USEPA) as a best available technology (BAT) when the USEPA revised its maximum contaminant level (MCL) for arsenic from 50 µg/L to 10 µg/L in 2001 (USEPA, 2001, 2003). None of the newer, granular iron media products were listed as BAT because they had been available and used in drinking water treatment for only a few years and thus lacked sufficient full scale system performance information required by the USEPA for them to be listed (USEPA, 2003).

Several iron media products have been introduced in the drinking water treatment market during the past 10–15 years (Choong et al., 2007; Clifford et al., 2011; Mohan and Pittman,

2007; Rubel Jr., 2003a; Wang and Chen, 2011). Two of the more commonly used products are granular ferric hydroxide, GFH<sup>®</sup>, (GFH) and granular ferric oxide Bayoxide<sup>®</sup> E33 (E33) (Amy et al., 2005; Badruzzaman et al., 2004; Choong et al., 2007; Nguyen et al., 2011; Sperlich et al., 2005; Sperlich et al., 2008; Thirunavukkarasu. et al., 2003; Wang and Chen, 2011). GFH is produced by GEH Wasserchemie GmbH 7 Co. in Germany and has been commercially available since 1997 (Driehaus et al., 1998; Driehaus, 2002). E33, a ferric oxyhydroxide media, was developed and produced by Bayer AG in Germany in 2000 in partnership with Severn Trent Water, Fort Washington, PA (Amy et al., 2005; Choong et al., 2007; Rubel Jr, 2003a; Wang et al., 2005).

### 1.2. Adsorptive media operational cost

When adsorptive media no longer has the ability to reduce the arsenic to less than the MCL, the common practice is to remove and replace the exhausted media with new virgin media. The exhausted media, that normally passes the federal toxicity characteristic leach procedure (TCLP) (USEPA, 1992), can be disposed in a sanitary landfill (Chen et al., 1999; Cornwell and Roth, 2011; Clifford et al., 2011; MacPhee et al., 2001). In California, a waste extraction test (WET) (California Code of Regulations (1985)) is required for media disposal. Frequently, the exhausted media products will failed the California WET even though they passed the federal TCLP test (Jing et al., 2005). When an exhausted media fails the WET procedure, the State of California requires that the media be disposed at a California hazardous waste designated landfill.

The operation and maintenance (O/M) cost elements of the adsorptive media process include media replacement, chemicals, electricity, and labor (Wang and Chen, 2011). In the USEPA Arsenic Demonstration Program (ADP), where capital and operating costs were collected on 15 AM systems having to undergo media replacement, the cost of media replacement (that included exhausted media disposal) averaged around 80% of the total O/M cost (Wang and Chen, 2011). In only two cases was the media replacement cost less than 50% of the total O/M cost. Some systems had to replace the media within only a few months resulting in an O/M cost as high as \$20 per 1000 gal of treated water (Wang and Chen, 2011).

### 1.3. Options for adsorptive media cost reduction

The cost of media replacement is a function of the cost of the media and the life of the media. Two options to reduce the O/M cost is (1) to replace the existing media with a lower cost media having the same bed life or (2) to replace the media with one of high performance (longer bed life). The ideal situation is the combination of both options: replace the media with one of lower cost and higher performance. A third option that is rarely considered is on-site regeneration and reuse of the adsorptive media.

Conventional anion exchange resins, that have low arsenic removal capacities, must be regenerated (with salt) to be a competitive arsenic removal technology (Clifford et al., 2011; Rubel Jr., 2003b). Because the AE requires frequent regeneration (1–3 days), produces a large quantity of brine waste and is more costly than AM, AE has generally been limited to treating

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