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Treatment technologies for aqueous perfluorooctanesulfonate (PFOS) and perfluorooctanoate (PFOA): A critical review with an emphasis on field testing

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HIGHLIGHTS

- Review of existing technologies for the treatment of PFOS/PFOA contaminated water.
- Activated carbon has been the most widely used adsorbent for PFOS/PFOA removal.
- We summarised adsorption capacities of available and recently developed adsorbents.
- Tool for remediators and researchers.

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ABSTRACT

Perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) are used in fire-fighting foams but this is now being questioned because concerns are growing about their toxicity and impacts on the environment. Past use has resulted in their widespread accumulation in water sources, sediments and biota. They may pose risks to human health and the environment. Several technologies have been tested for removing PFOS and PFOA from water but most have only been developed at laboratory scale. This paper provides a critical review of existing methods for removing PFOS and PFOA from wastewaters with an emphasis on identifying processes that show promise for the development of practical industrial-scale remediation technologies. It is concluded that among the remediation technologies cited in the literature, removal by activated carbon has been the most widely used, with several successful field tests being reported. However, a number of limitations to the use of activated carbon exist, such as being ineffective at removing PFOA and other PFCs. Other adsorbents that have the potential to treat aqueous PFOS and PFOA include organo-clays, clay minerals and carbon nanotubes.

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1. Introduction

Perfluorinated compounds (PFCs) have been used extensively in a variety of products and industries due to their particular chemical characteristics and resistance to degradation by heat or acids. PFCs are used for surface treatment of textiles because they repel both water and oil (Herzke et al., 2007). Their use is widespread and routine for the formulation of Aqueous Film Forming Foams (AFFF). AFFFs are commonly used for combating hydrocarbon fires (Chen et al., 2009; Mak et al., 2009) because they act as low-viscosity vapour sealants to inhibit combustion of jet fuel (Kishi and Arai, 2008; Moody, 1999). Among the PFCs, perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) have received the most attention in recent years due to their persistence, bioaccumulation and toxicity (Taniyasu et al., 2005; Nakata et al., 2006; Higgins et al., 2007; Hongjian, 2009; Murakami et al., 2009).

Main physical and chemical characteristics of PFOS and PFOA are described in Table 1.

PFOS and PFOA have been used for many decades but concerns about their toxicity began in the early 2000s. In 2003 the 3M Company decided to phase out the production of PFOS-related products and replaced PFOS with perfluorobutane sulphonate (PFBS) and shorter chain PFCs (Oliaei et al., 2006). In 2009 PFOS was listed as a new Persistent Organic Pollutant (POP) by the Conference of Parties, Stockholm Convention, and the United States Environmental Protection Agency (EPA) has classified perfluorooctanoic acid (PFOA) as a "likely carcinogen" and its use was restricted.

Despite their restricted use, and concerns about the effects of PFOS and PFOA on the environment and human health, they are still used by industries, especially those that manufacture semiconductors (SIA and ISMI, 2008). Moreover, due to the strength of the highly polarized carbon-fluorine bond and their hydrophobic/lipophobic properties, PFOS and PFOA are very persistent in the environment and show little or no natural degradation (Herzke et al., 2007; Hatfield, 2001a,b). Several studies have found that PFCs, including PFOS and PFOA, have accumulated in biota (Kannan et al., 2001, 2002). These compounds have also been found in water bodies as remote as the Arctic Ocean (Martin et al., 2004; Yamashita et al., 2005). PFC compounds are widely distributed in the environment, especially in aqueous media.

Remediation and treatment of PFOS and PFOA contaminated water are extremely challenging. This paper provides an overview of the state-of-the-art methods for the removal and treatment of PFOS and PFOA from contaminated water. The main goal is to assist remediators and researchers by critically reviewing existing methods of PFOS and PFOA removal from wastewaters, with an emphasis on identifying processes that show promise in laboratory studies for developing practical industrial-scale remediation technologies.

2. Existing technologies

2.1. Adsorption

2.1.1. Process description

The most common remediation technology for water contaminated with PFOS and PFOA is based on their adsorption onto granular activated carbon (GAC). Qiu (2007) has identified four steps in the adsorption mechanism of activated carbon. The

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