Environmental Technology & Innovation 6 (2016) 69–79

Contents lists available at ScienceDirect

Environmental Technology & Innovation

journal homepage: www.elsevier.com/locate/eti

Evaluation of a cactus mucilage biocomposite to remove total arsenic from water

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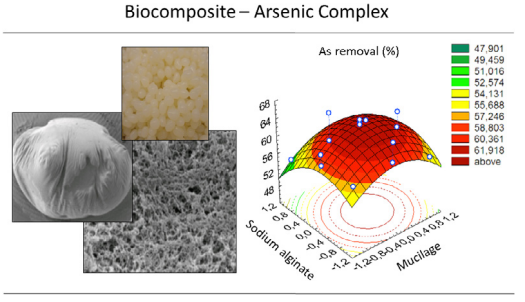
HIGHLIGHTS

- New approach of cactus mucilage from *Opuntia ficus-indica* for As removal.
- Encapsulation of cactus mucilage in alginate beads as a new eco-friendly adsorbent.
- Biomaterial formulation was evaluated using Box–Behnken experimental design.
- Gelling fraction of mucilage has demonstrated great potential for As removal (63%).
- Enhanced separation of mucilage-As complex from wastewater using this biomaterial.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 November 2015
Received in revised form 1 June 2016
Accepted 1 July 2016
Available online 12 July 2016

Keywords:
Alginate
Beads
Arsenate
Bioadsorption
Adsorbent

ABSTRACT

Mucilage fractions extracted from *Opuntia ficus-indica* cactus were captured in calcium alginate biobeads. The beads were tested as eco-friendly adsorbents to remove arsenic (As) from water, and their As removal efficiency was evaluated. Batch adsorption studies were performed using an incomplete factorial design by varying the concentrations of mucilage (0.5–2 mg L^{-1}), sodium alginate (3–5%), and calcium chloride (0.5–1 mol L^{-1}) incorporated in the biobeads. The optimal formulation of these adsorbent biobeads varied depending on the mucilage fraction. Thus, biocomposite formulated with 1.25 mg L^{-1} of gelling mucilage, 4% of sodium alginate, and 0.75 mol L^{-1} of calcium chloride eliminated up to 63% of As from water, with a capacity of 101.6 mg g^{-1}, whereas the composite biobeads formulated with 1.25 mg L^{-1} of non-gelling mucilage reduced 59.8% of As from water, using the least

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http://dx.doi.org/10.1016/j.eti.2016.07.001

Wastewater
Green process

amounts of sodium alginate and calcium chloride in the range tested, with a capacity of 97.1 mg g^{-1}.

1. Introduction

Arsenic (As) is a ubiquitous heavy metal widely distributed in the environment. Its toxicity, even at very low concentrations, may cause serious health hazards, increasing the incidence of cancer and dermatological, vascular, and cerebral vascular diseases (Rosen, 1971). It is estimated that 40 million people worldwide are at risk from drinking arsenic-contaminated water (Nordstrom, 2002; Anawar et al., 2002).

Green technologies based on low-cost adsorbents from agricultural waste, industrial by-product, or natural material currently are growing (Zhang et al., 2007; Gupta et al., 2009; Stebbins et al., 2013; Gauri et al., 2011). The literature includes various works about the use of eco-friendly adsorbents based on lignocellulosic residues to eliminate contaminants such as heavy metals and dyes from water (Villaescusa et al., 2004; Yuan-shen et al., 2004; Paradelo et al., 2009). These new materials involve the ideal of Horizonte 2020 as "zero waste production" in the agro-industrial process.

In previous studies, it was found that cactus mucilage could be a potential complexant of arsenic, although the separation of this mucilage-As complex from water was very difficult (Fox et al., 2012). Thus, it would be useful to design an efficient and heterogeneous contacting system to allow easy separation of the mucilage-As complex. Moreover, it has been demonstrated that eco-friendly adsorbents can be formulated by engulfing various materials in calcium alginate beads to make commercially-viable, environmentally-benign, and manageable adsorbents (Devesa-Rey et al., 2011; Vecino et al., 2013, 2012, 2014, 2015).

In the current study, different mucilage fractions were extracted from the *Opuntia ficus-indica* cactus and engulfed in calcium alginate beads to formulate an eco-friendly adsorbent to remove As from water allowing easy and efficient separation of the mucilage-As complex from water. The formulation of this biocomposite was optimized using an incomplete factorial design, and the morphological structure of cactus mucilage fractions in the adsorbents was observed using a Scanning Electron Microscope (SEM) and attenuated total reflection Fourier transform infrared (ATR-FTIR) spectroscopy.

2. Materials and methods

2.1. Extraction process

Pads of *Opuntia ficus-indica* cactus were obtained from our own set of plants located in Tampa (Florida, USA) originally purchased from Living Stones Nursery in Tucson Arizona, USA. Two fractions of the mucilage—non-gelling extract (NE) and gelling extract (GE)—were extracted from the pads following the method described below.

Non-Gelling Extract (NE). The NE extract was obtained following the method described by Goycoolea and Cardenas (2003) and modified by Buttice et al. (2010) and Fox et al. (2012). The liquid phase obtained from the previous step was filtered by vacuum pumping using a knitted polyester cloth filter (Polx 1200, Berkshire Corp., Great Barrington, MA) and then precipitated from the filtrate using an acetone 2:3 ratio of supernatant to solvent. The precipitated NE extract was washed with ethanol-water solutions in a graded series (70%, 80%, 90%, and 95% ethanol and absolute ethanol) to remove the acetone and any remaining impurities. The NE extract was left to dry at room temperature in a non-sealed, covered glass container. After drying, the material was pulverized with a ceramic mortar and pestle and stored in a closed container at room temperature.

Gelling Extract (GE). The extraction procedure to obtain the gelling extract (GE) was an adaptation of a method developed by Turquois et al. (1999) and modified by Buttice et al. (2010) and Fox et al. (2012). The modifications were made to improve the yield by centrifugation and vacuum filtration using a different dosage of a chelating agent and a shorter sequestering time compared with the original method and using acetone as the precipitating solvent. The solid residue obtained in Step 1 of the mucilage extraction process was mixed with 7.5 g L^{-1} sodium hexametaphosphate [$(NaPO_3)_6$] in 50 mmol L^{-1} NaOH (1:1 mass-to-volume ratio of residue to solution). The mixture was stirred for 1 h and vacuum-filtered using a knitted polyester cloth filter (Polx 1200, Berkshire Corp., Great Barrington, MA). The pH of the obtained filtrate was lowered to 2.0 by titration with a hydrochloric acid solution 1 mol L^{-1} and refrigerated overnight (5°C) to precipitate the GE extract. The precipitate was separated by centrifugation and re-suspended in sufficient DI water to cover it. The pH was adjusted to 8.0 with a 1 mol L^{-1} NaOH solution to re-dissolve the precipitate. The resulting solution was purified by filtration through a 1.2 μm and a 0.45 μm membrane. The GE extract was re-precipitated with acetone in a 2:3 liquid-to-solvent ratio, then washed and dried at room temperature in a non-sealed covered glass container. After drying, the material was pulverized with a ceramic mortar and pestle and stored in a closed container at room temperature.