Journal of Industrial and Engineering Chemistry 26 (2015) 122–128

Contents lists available at ScienceDirect

Journal of Industrial and Engineering Chemistry

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

Novel membrane reactor design for heavy-metal removal by alginate nanoparticles

Akbar Esmaeili *, Ali Aghababai Beni

Department of Chemical Engineering, North Tehran Branch, Islamic Azad University, PO Box 19585/936, Tehran, Iran

ARTICLE INFO

Article history:
Received 8 September 2014
Received in revised form 2 November 2014
Accepted 23 November 2014
Available online 11 December 2014

Keywords:
Brown algae nanoparticles
Biosorption
Pollution control
Nickel and cobalt
Hazardous waste

ABSTRACT

The membrane reactor was also employed in conjuncton with a membrane composed of *Sargassum glaucescens* brown algae nanoparticles to test its efficacy in removing nickel and cobalt from real effluents. Alginate nanoparticles with an average diameter of 95.75 nm and surface area of 11.25 $m^2 g^{-1}$ were used. Maximum uptake capacities of Ni^{2+} and Co^{2+} were obtained at pH 6.0, optimum biosorption capacity of the alginate nanoparticles was found to be 90.25% for Ni^{2+} and 86.13% for Co^{2+}. An artificial neural network was applied for the prediction of percentages of biosorption capacity.

Introduction

Conventional methods for removing heavy-metal ions from wastewater such as chemical precipitation [1], flocculation, membrane filtration, ion exchange, electrolysis, and electrodialysis are often costly or ineffective [2,3]. Combining membrane technology with algae reactors for the treatment of drinking water and wastewater has potential as an effective and cost-efficient means of separating and recycling solids and extracting organic pollutants from hostile industrial wastewaters [4].

Biosorption is a process that functions by binding heavy-metal ions to the cell wall of a biomass. The major advantages of biosorption, including high efficiency, complete removal of metal ions even at low concentrations, economic technology, energy independency, and generally rapid advancement as a new technology, have attracted much attention.

The membrane reactor (MR) system is a hybrid of biological treatment and filtration [5]. In an MR, membranes function primarily as a selective barrier, retaining suspended solids and allowing the treated water to pass through. Low-cost filters insert such as nonwovens, meshes, filter cloths, and nanofibers have sometimes been found to be suitable substitutes for membranes in MRs [6]. In this study, biosorption of heavy metals was carried out with an MR supported by natural wool felt as nonwoven filter.

An artificial neural networks (ANN) s are data-processing systems that mimic the biological neural networks in the human brain in problem-solving processes [7], in which billions of neurons are interconnected to process a variety of complex types of information [8]. The advantages of ANNs are that they provide simple and easy simulation, prediction, and modeling; the need for extensive experimentation is avoided as limited numbers of experiments are sufficient to predict the degree of nonlinearity; relationships do not need to be formulated beforehand; there are no restrictions on the number of inputs and outputs; they afford excellent support in capturing the nonlinear relationships existing between variables in complex systems; and they require less time for development than traditional mathematical models [7–9]. For this reason, applications of ANNs are considered a reliable tool in solving environmental problems [9].

Experimental

Materials

Samples of *Sargassum glaucescens* (brown algae) were collected from the Persian Gulf on Queshm Island. Natural wool felt was obtained from the Cultural Heritage, Handicrafts, and Tourism Organization in Shahrekord, Iran. Sodium hydroxide and

* Corresponding author. Tel.: +98 912 148 4813; fax: +98 21 88787204.
E-mail address: akbaresmaeili@yahoo.com (A. Esmaeili).

http://dx.doi.org/10.1016/j.jiec.2014.11.023
1226-086X/

hydrochloric acid were purchased from Merck. Deionized water was used for all procedures.

Preparation of biomass

The algae collected were washed several times with distilled water to remove sand and other particles and debris. The wet biomass was dried for 5 days at atmosphere in a glass container (Fig. 1), then biomass was placed for 12 h at 80 °C in an oven. After drying the algae was crushed to particle size range of 100–500 μm using a kitchen mill (Pars Khazar, GR-1.2.3P, Tehran, Iran), and crushed again to a range of 30–300 nm using a planetary ball mill (Fara Pajouhesh, Isfahan FP2, Iran) at 600 rpm for 1 h.

Process design

For this research, we used an MR of our own design. As Fig. 2 shows, the MR was designed and made in cylindrical form of polyethylene with an internal diameter of 110 mm, height of 100 mm, and wall thickness of 8 mm. The mass transfer was increased by creating turbulent conditions using a mixer in the MR. A stainless steel tube with an internal diameter of 15 mm, height of 150 mm, and wall thickness of 1.5 mm was used instead of a mixer shaft at the MR center in vertical status. The blades of the mixer were connected to the tube. For installation of the nonwoven membrane of natural wool felt, 32 holes with a diameter of 4 mm were drilled at the middle of the tube at a depth of 60 mm. The mixer shaft (tube) was attached to an electromotor with a speed ≅800 rpm. In other words, the tube played three roles: mixer shaft, submerged membrane module, and fluid exiting line. Effluent rate was controlled by valves and hydrostatic pressure. Reactor temperature was controlled using a thermal jacket with carbon dioxide at −60 °C (dry ice). The actual volume of the reactor was 850 mL.

Preparation and characterization of ANP

Fourier transform infrared spectroscopy (FT-IR) with spectra in the range of 400–4000 was used to determine the functional groups of *S. glaucescens* alginate nanoparticles (ANP) (Nicolet 8700, Thermo Fisher Scientific, Yokohama, Japan, FT-IR spectrometer).

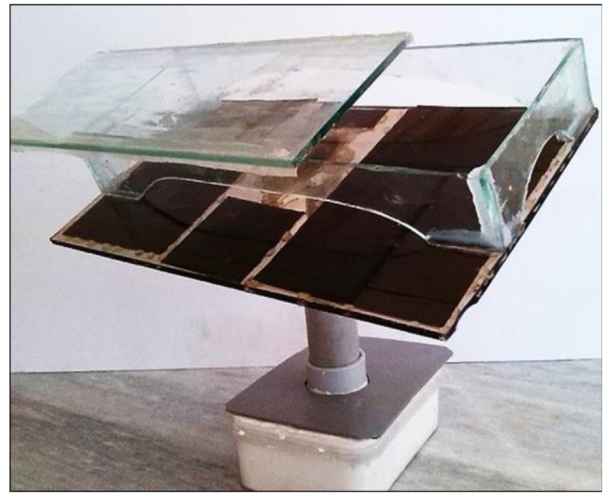

Fig. 1. Glass container for drying the wet biomass at atmosphere.

The *S. glaucescens* ANP morphology after gold coating was studied using a scanning electron microscope (LEO 435VP SEM). Image-processing software was used to measure the nanoparticle diameter from the SEM micrographs. The specific surface area was determined using the Brunauer–Emmert–Teller (BET) theory (Costech International Sorptometer 1042, Costech, Italy). Heavy-metal concentration in the sample solution was determined with atomic absorption spectrometry (Varian Atomic Absorption 240, USA). Algae biomass before and after the biosorption was determined by X-ray powder diffraction (Philips PW3040, PW3040, Holland). An X-ray diffraction (XRD) analysis was performed for two samples.

Batch biosorption studies

Two different types of effluents were collected from a zinc ingot plant in Shahrekord. The two samples contained nickel and cobalt ions, respectively. The initial concentration of total nickel in the first sample measured 80.115 mg L^{-1} and the total cobalt in the second sample measured 10.523 mg L^{-1}. Batch biosorption

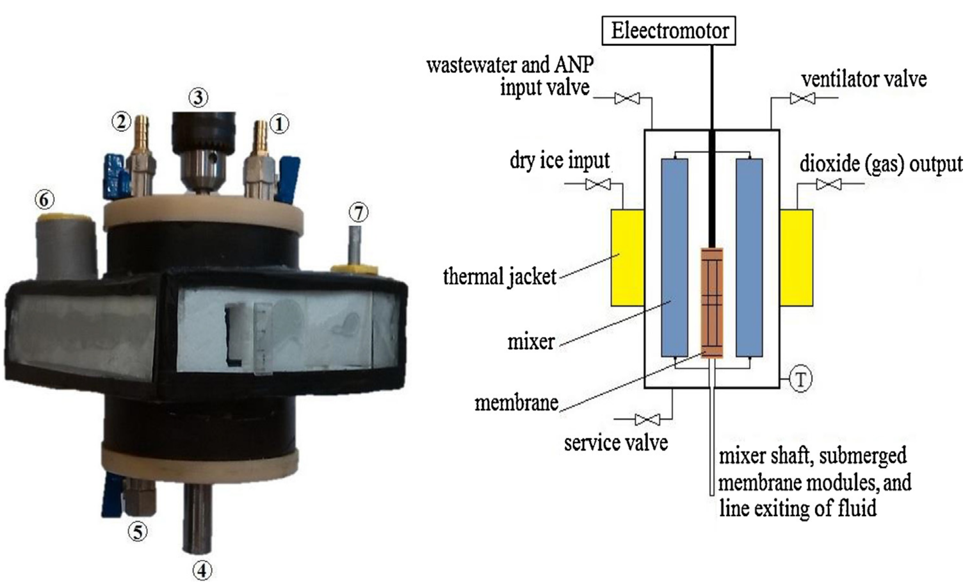

Fig. 2. Membrane reactor: (1) wastewater and ANP input valve; (2) ventilator valve; (3) electromotor; (4) mixer shaft, submerged membrane modules, and line exiting of fluid; (5) service valve; (6) carbon dioxide input to thermal jacket; (7) carbon dioxide output of thermal jacket.