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Removal of strontium by electrocoagulation using stainless steel and aluminum electrodes

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ABSTRACT

In the present work, removal of strontium (up to 100 mg/L) from synthetic wastewater by electrocoagulation has been studied. Stainless steel and aluminum electrodes have been used and removal efficiencies have been compared with respect to electrocoagulation time, current density, amount of electrolyte added, solution pH, distance between electrodes, temperature and initial concentration of strontium. Preliminary operating cost estimation has been found out for both electrode materials. The strontium removal data has been used to find adsorption kinetics using pseudo-first-order and pseudo-second-order adsorption kinetics models. Results show that the optimum operating variables values are 50 min of process time, 8 mA/cm^2 current density and solution pH 5 for which around 93% and 77% removal efficiency was achieved with using stainless steel and aluminum electrodes, respectively. Pseudo-second-order kinetic model fitted the data better than the pseudo-first-order model.

1. Introduction

Strontium is one of the rare earth elements present in very low concentration in earth's crust and due to its high reactivity rarely found in pure form but occurs in the form of minerals like strontianite ($SrCO_3$) and celestite ($SrSO_4$). Strontium contains many isotopes from which ^{90}Sr and ^{85}Sr are radioactive and used as fuel in nuclear reactors [1]. Apart from these radioactive isotopes, strontium contains four non-radioactive stable isotopes. ^{87}Sr and its compounds like strontianite and celestite are widely used in the manufacturing of X-ray absorbing glass for cathode ray tubes, removal of lead from zinc sulphate solution in the electrolytic zinc process, electro-ceramic and oxide superconductors, oxygen eliminator in electron tubes, glass for color television. Strontium ion is considered as little toxic and it is due to concerned anion. We can consider the effect of strontium on environment based on its chemical form [2]. Therefore, it is desired to remove strontium and its compounds from wastewater as much as possible. For radioactive ^{90}Sr and its compounds, it is desired to bring the concentration in the wastewater to less than or equal to 8 pCi/L (equivalent to 5.67×10^{-11} mg/L) before discharge, but practically it is very difficult to achieve this target [3].

The methods reported on the removal of Sr(II) from aqueous wastewaters are adsorption using montmoritlonite and zeolite [1], adsorption using activated carbon [2], supported liquid membranes with strip dispersion [3] and complexation-nanofiltration [4]. These methods are efficient but require extra cost in terms of addition of external chemical compounds and/or application of high pressure.

In the last couple of years, electrocoagulation has shown its usefulness for the treatment of water as well as wastewater. Electrocoagulation is efficient for the treatment of wastewaters containing metal ions, like Zn(II), Cu(II), Ni(II), Ag(I), Cr(VI) [5]; Hg(II) [6]; In(III) [7]; As(III) [8]; B [9] and heavy metals from metal plating effluent [10]. We can use variety of electrodes for the treatment of wastewater, which are iron or steel, aluminum, magnesium or combination of them [11]. The possible reactions which occur during the electrocoagulation process are [12–14]:

At the anode:

$$M_{(s)} \rightarrow M_{(aq)}^{n+} + ne^- \quad (1)$$

$$2H_2O \rightarrow 4H^+ + O_2 + 4e^- \quad (2)$$

At the cathode:

$$M_{(aq)}^{n+} + ne^- \rightarrow M_{(s)} \quad (3)$$

$$2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2OH^- \quad (4)$$

Here M is the material used as electrode and n is the number of electrons. During the electrocoagulation process metal hydroxides, polyhydroxides and/or polyhydroxymetallic compounds of the electrode material will be generated. These materials contain strong affinity for dispersed particles and counter ions, which results in coagulation [12].

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Literature survey shows that there is no published material available on Sr(II) removal by electrocoagulation. In this context, laboratory-scale experiments were performed for the removal of Sr(II) from synthetic wastewaters containing up to 100 mg/L of Sr(II) in batch scale mode using stainless steel (SS) and aluminum (Al) electrodes. Effects of operating parameters, viz., electrocoagulation time, current density, presence of electrolyte, distance between electrodes, initial pH and temperature on the Sr(II) removal efficiency have been studied. The Sr(II) removal data have been used to find adsorption kinetics of the process.

2. Materials and method

2.1. Materials

Materials used were stainless steel and aluminum electrodes (commercial grade, total immersed surface area = 2.5 cm^2), strontium chloride hexahydrated (extra pure, Finar, Ahmedabad, India) and distilled water (pH 5.9 ± 0.2, conductivity 1.0 μS/cm produced by Millipore, Elix, Bangalore, India). A 0.1 N HCl solution (Finar, Ahmedabad, India) and 0.1 N NaOH solution (RANKEM, New Delhi, India) have been used to adjust pH. NaCl (GR, Qualigens, Mumbai, India) has been used as an electrolyte.

2.2. Experimental setup

The experimental setup (Fig. 1) consists of 500 mL beaker, stainless steel and aluminum electrodes, multiple DC power supply device (0–30 V, 2 Amp. Scientech Technologies, Indore, India) and magnetic stirrer (Labstar, Mumbai, India).

2.3. Experimental procedure

All the experiments were performed in a 500 mL beaker in batch mode. Each batch contained 200 mL of feed. After each run, solution obtained was collected and filtered using filter paper (Sonar 1, Delhi, India). Filtrate was collected and analyzed. Analysis has been carried out by inductively coupled plasma - mass spectrometry (ICP-MS, Perkin Elmer, California, USA).

3. Results and discussion

In the present study effects of parameters like electrocoagulation time, current density concentration of electrolyte solution, distance between electrodes, initial pH and temperature have been investigated on the final Sr(II) removal efficiency. Percentage of Sr(II) removal has been calculated using the relation $[(1-(C/C_o))\times 100]$, where, C_o and C are concentrations of Sr(II) before and after treatment, respectively.

3.1. Effect of time of electrocoagulation

Time of electrocoagulation is the most important parameter in the process of electrocoagulation. It is the time provided to the process to generate metal hydroxides and to complete coagulation of the impurities. Normal process time is from 15 min [6] to 175 min [10] for highest possible removal of different metal ions. Heidmann and Calmano [5] achieved almost 100% removal of Zn(II), Ni(II) and Cu(II) in electrocoagulation time of 20 min using a pair of aluminum electrodes for the initial concentration of 250 mg/L. More than 99% removal of iron from drinking water has been achieved by Vasudevan et al. [11] for the initial concentration of 25 mg/L using a pair of Mg–Al electrodes. Chou et al. [7] could achieve only 50% removal of In(III) after electrocoagulation of time of 90 min for the initial concentration of 100 mg/L using iron electrodes. In the present work electrocoagulation time used was from 10 min to 60 min. Highest removal efficiency (94.03% for SS electrodes and 78.57% for Al electrodes) has been achieved at 60 min, but 93.49% and 77.38% removal efficiencies were achieved, respectively, for SS and Al electrodes at 50 min (Fig. 2). Therefore, 50 min electrocoagulation time was taken as optimum value.

3.2. Effect of applied current density

Current density is defined as current applied per unit surface area of the electrode. Generally, more applied current density results in more removal of solutes, but it may not be true after some value of current density. Sayiner et al. [9] applied current density in the range of 10 to 30 mA/cm^2 and achieved more than 90% removal efficiency of boron for the initial concentration of 1000 mg/L using Al and Fe electrodes. In our study, selected range of applied current density was from 1 to 12 mA/cm^2 and selected optimum value of current density was 8 mA/cm^2 for which 93.49% and 76.62% removal efficiencies were achieved using SS and Al electrodes, respectively (Fig. 3).

3.3. Effect of amount of electrolyte added

Electrolyte is a substance which is responsible for increasing the conductivity of the solution. The motion of the ions can be measured by measuring the resistance R, of the solution. The conductance G of the solution is the inverse of the resistance. G = κA/l; where κ is the conductivity. The conductivity of the solution depends on the number of ions present. Increase in the concentration of the electrolyte results

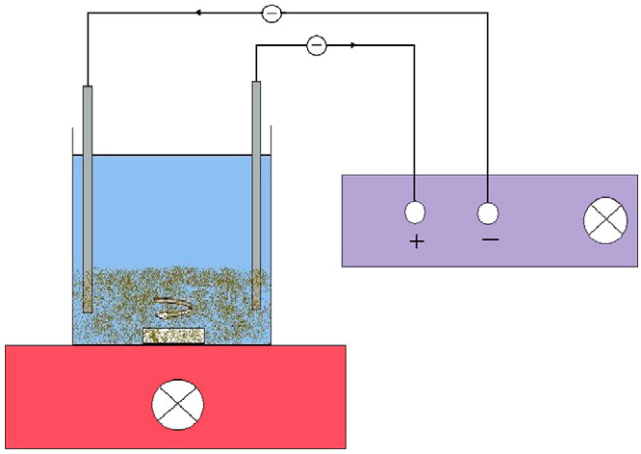

Fig. 1. Experimental setup of lab-scale electrocoagulation unit.

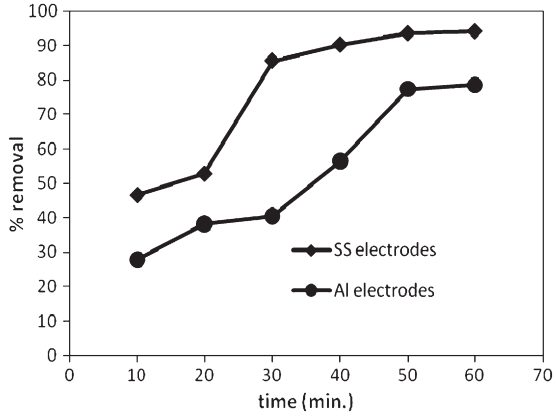

Fig. 2. Sr(II) removal as a function of time (Operating conditions: current density = 10 mA/dm^2, distance between electrodes = 6 cm, initial Sr(II) concentration = 10 mg/L, initial pH = 5, 10 mL 1 M NaCl solution added).