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Original Article

Removal of Uranium from Uranium Plant Wastewater Using Zero-Valent Iron in an Ultrasonic Field

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ABSTRACT

Uranium removal from uranium plant wastewater using zero-valent iron in an ultrasonic field was investigated. Batch experiments designed by the response surface methodology (RSM) were conducted to study the effects of pH, ultrasonic reaction time, and dosage of zero-valent iron on uranium removal efficiency. From the experimental data obtained in this work, it was found that the ultrasonic method employing zero-valent iron powder effectively removes uranium from uranium plant wastewater with a uranium concentration of 2,772.23 μg/L. The pH ranges widely from 3 to 7 in the ultrasonic field, and the prediction model obtained by the RSM has good agreement with the experimental results.

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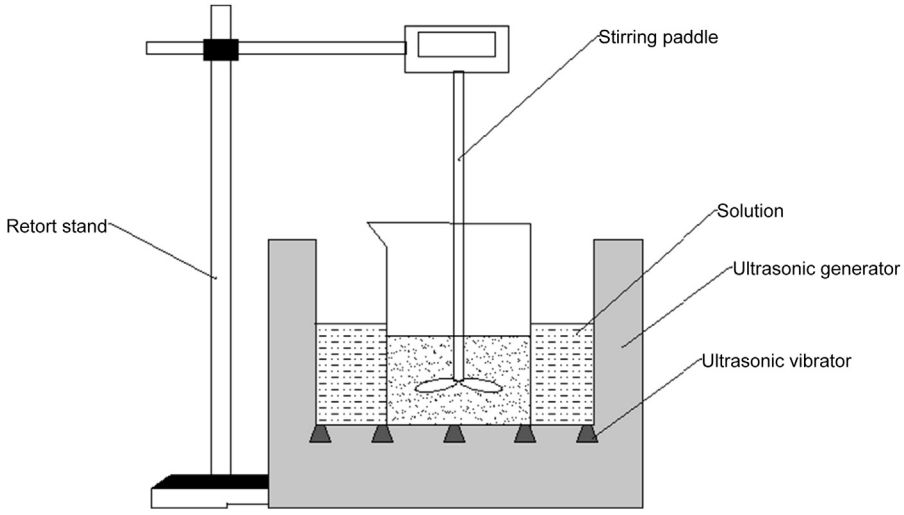

Fig. 1 – The experimental device.

1. Introduction

Uranium and its compounds are threats to human health and the ecological balance because of their radioactivity and heavy-metal toxicity [1]. Elevated levels of uranium have been found in agricultural irrigation drainage water and industrial wastewater [2,3]. The toxic nature of uranium(VI) ions, even at trace levels, has been a public health problem for many years [4]. Therefore, research on uranium removal from wastewater is important.

Uranium in industrial water is usually found in the environment in the quadrivalent uranium [U(IV)] and hexavalent uranium [U(VI)] forms, which coexist with other metal compounds or oxides. Uranium(IV) could be removed in the form of precipitation because it easily forms stable complex-shaped precipitation. Uranium(VI) usually exists in the form of uranium dioxide (UO_2^{2+}), which has good solubility and is difficult to remove. Therefore, the removal of uranium from wastewater generally refers to the removal of U(VI) and its compounds.

Zero-valent iron was used as the medium in the ultrasonic field to remove uranium from uranium plant wastewater in this study. Iron is an active metal with strong reducibility. It can reduce a variety of pollutants, including uranium. When there is sufficient zero-valent iron and corrosion (i.e., iron hydroxide) in the system, UO_2^{2+} is reduced as quadrivalent U(IV) deposited on the iron surface, which could allow complete removal of uranium.

Acoustic cavitation, thermal effect, and chemistry effect have tremendous positive effects; therefore, many researchers have focused much attention on applying ultrasonic technology [5–7]. Studies have indicated that ultrasonic mixing is efficient, timesaving, and economically functional, and it offers many advantages over the classical procedure [6,7]. Therefore, an ultrasonic field was employed in the uranium removal in uranium plant wastewater research.

In this paper, the effect of pH, ultrasonic reaction time, and dosage of zero-valent iron rates on uranium removal efficiency were evaluated in an ultrasonic field by using response surface methodology (RSM). In addition, the uranium content of the solution, which was treated by zero-valent iron in an ultrasonic field, was detected by inductively coupled plasma mass spectrometry (ICP-MS). The relative standard deviation is less than 5%, and the detection range is between 10^{-9} ng/mL and 1 mg/L.

2. Materials and methods

2.1. Experimental procedure

Uranium plant wastewater with a uranium concentration of 2,772.23 μg/L and pH value of 8.69 was obtained from purification processing. All experiments in the ultrasonic field were performed using 500-mL flat-bottomed glass beakers (diameter, 9 cm) containing 200 mL of uranium plant wastewater. The uranium plant wastewater was stirred by mechanical agitation with a stirring speed of 55 r/min. The wastewater was pretreated by pH adjustment using extraction raffinate with the uranium concentration of the raffinate of 2,984.1 μg/L and pH value of 0.12. A certain amount of zero-valent iron powder was then added to the wastewater after pH adjustment had been finished. An ultrasonic reactor with 500 W power was started.

After a period of time, the reaction was finished. The reaction mixture was pumped through a filter. The uranium removal efficiency was calculated by the uranium concentration of the filtrate detected by ICP-MS. The experimental device is shown in Fig. 1.

2.2. Experimental design

To optimize and analyze the effects of solution pH, ultrasonic reaction time, and dosage of zero-valent iron (per 200 mL of