Critical rare earth metal adsorption onto expanded vermiculite: Accurate modeling through response surface methodology and machine learning techniques

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Abstract

The circular economy of rare earth metals (REM), such as dysprosium, is essential for a sustainable future in clean energy and high-tech fields. Adsorption has gained attention to recover and reintegrate REM into the productive chain; however, accurate modeling of adsorptive processes still needs to be addressed, which delays further scale-up studies. Thus, this paper studied the adsorption of Dy on expanded vermiculite and applied novel empirical methods, such as artificial neural networks (ANN) and adaptive neuro-fuzzy inference system (ANFIS), and the classical response surface methodology (RSM) for modeling of dysprosium recovery as a function of adsorbent size, mass, and pH of the solution, variables often ignored in the mathematical modeling of adsorption. In our work, the effect of each operational parameter on Dy removal efficiency was examined by the RSM approach, in which only the adsorbent dosage and pH were the significant factors. So, ANFIS with two input membership functions (Gaussian type) was the most accurate procedure to predict and model the dysprosium removal efficiency ($R^2 = 0.99681$). Also, vermiculite removed dysprosium with high efficiency (99.2%) under the best experimental conditions, at pH around 3.5 and adsorbent mass of 0.64 g, indicating an effective process optimization. The loaded vermiculite, after the adsorption, was characterized by textural and thermal properties that confirmed the stability of the material. Thus, according to basic operational parameters, accurate modeling of the Dy adsorption on expanded vermiculite (a low-cost, available, and non-toxic material) can improve adsorption technology's maturity to reconcentrate and recover rare earth metals.

Keywords

Dysprosium, Adsorption, Vermiculite, RSM, Machine learning