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Utilization of amethyst mining waste as an adsorbent for water defluorination

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Abstract

It is indispensable to ensure access to safe and potable water in an efficient and sustainable manner. Groundwater represents the largest aliquot of liquid freshwater available for consumption, making its treatment a subject of special interest, as most groundwater often contains significant amounts of minerals such as fluoride. Fluoride is beneficial for dental health at low concentrations but can cause serious health problems when present in large amounts. Thus, in line with the Sustainable Development Goals, there is a need to develop an environmentally appropriate methodology for the removal of fluoride from groundwater. Adsorption is an efficient process for the removal of compounds from water, and it was thought to evaluate the adsorptive potential of a material that is typically discarded without reuse: amethyst mining waste. Given this context, the objective of this work is to evaluate the adsorption capacity of amethyst waste in the removal of fluoride. For this purpose, mining waste with particle sizes of 0.25 – 0.42 mm and 1.2 – 2.0 mm was used, along with Permutite T®, a commercial zeolite, employed here for comparison purposes. With fluoride concentrations ranging from 1.0 to 9.0 mg · L^{-1}, removal efficiencies of up to 95% were achieved using the smaller particle size mining waste. This work paves the way for crucial research in the sustainable removal of minerals from groundwater, contributing to advancements in water treatment technologies.

Keywords: Amethyst Mining Waste; Fluoride; Sustainable Development Goals; Alternative Adsorbents.

1. Introduction

Since 99% of the available liquid freshwater comes from underground sources [1], it is crucial to ensure the safety and potability of this resource. Groundwater often contains significant amounts of minerals such as fluoride [2]. At low concentrations, fluoride is beneficial for dental health, helping to prevent cavities and tooth decay. However, in excess, it can be harmful, causing diseases such as fluorosis, which can lead to severe dental and skeletal damage [3]. The World Health Organization (WHO) has set guidelines for fluoride levels in drinking water, but in many regions, these levels are exceeded, necessitating effective removal methods.

Adsorption is a widely used method for removing excess fluoride from water due to its simplicity and efficiency. In the search for alternative and sustainable adsorbent materials, amethyst mining waste was chosen as a potential adsorbent for fluoride ions. This choice is not only driven by the need for effective water treatment solutions but also by the desire to find environmentally friendly and cost-effective materials. Utilizing mining waste helps in reducing environmental pollution and promotes recycling of industrial by-products.

Aligned with Sustainable Development Goals 6 (Clean Water and Sanitation), 11 (Sustainable Cities and Communities), and 12 (Responsible Consumption and Production) [4], this work aims to evaluate the adsorption capacity of amethyst mining waste at a laboratory scale for removing fluoride ions from water.

By investigating the use of amethyst mining waste, this study contributes to sustainable water treatment practices and supports global efforts to ensure access to clean and safe drinking water. Furthermore, the successful application of this waste material in water treatment can provide a dual benefit of managing industrial waste and addressing public health concerns related to fluoride contamination in groundwater.

2. Materials e Methods

The methodology of this work is divided into three stages:

Preparation of Fluoride Solutions

For the preparation of the calibration curve, sodium fluoride solutions with the following concentrations were prepared: 0.02 mg · L^{-1}; 0.1 mg · L^{-1}; 0.5 mg · L^{-1}; 1.0 mg · L^{-1}; 2.0 mg · L^{-1}; 5.0 mg · L^{-1} e 10.0 mg · L^{-1}. For subsequent adsorption assays, the following concentrations were selected: 1.0 mg · L^{-1}; 3.0 mg · L^{-1}; 5.0 mg · L^{-1}; 7.0 mg · L^{-1} e 9.0 mg · L^{-1}. Readings were taken using an Ion-Selective Electrode (ISE).

Preparation of Amethyst Mining Waste Samples

The amethyst mining waste came from the city of Ametista do Sul, Rio Grande do Sul – Brazil (27°21'10.80"S, 53°11'31.30"W). The material was mechanically fragmented at random. Afterward, sieving was performed for particle size analysis, ranging from 150 µm to 2.0 mm. For subsequent analyses, the two most abundant size ranges were selected: 0.25 – 0.42 mm (Figure 01) and 1.2 – 2.0 mm. For comparison purposes, besides the two selected particle sizes, Permutite T®, a zeolite known for its adsorption capacity [5], was also used.

Adsorption Tests

For each of the five selected fluoride concentrations, approximately 1.0 g of each material was added to 100 mL. The samples were then subjected to agitation at 120 rpm, at 25°C, for 64 hours (Table 1).

Table 1. Sample weighing data.

Fluoride concentrations (mg · L^{-1})	0.42 – 0.25 mm (g)	2.0 – 1.20 mm (g)	Permutita T® (g)
1.0	1.0010	1.0056	1.0024
3.0	1.0009	1.0087	1.0021
5.0	1.0013	1.0088	1.0048
7.0	1.0062	1.0011	1.0002
9.0	1.0093	1.0075	1.0033

Figure 1. Photograph of amethyst waste with a particle size of 0.25 – 0.42 mm.

3. Results and Discussion

Figure 2 shows the calibration curve and the equation for calculating fluoride concentration.

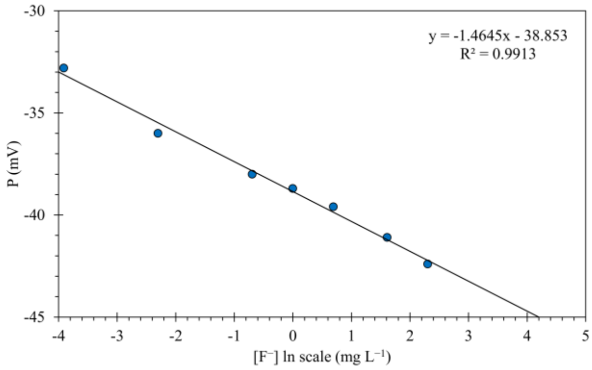

Figure 2. Calibration curve.

The results of the adsorption tests are shown in Table 2.

Table 2. Results of the adsorption tests.

Sample	Fluoride concentrations (mg · L^{-1})	Adsorbed amount (mg . g^{-1})	Removal efficiency (%)
0.25 – 0.42 mm	1.0	0.095	95
	3.0	0.210	70
	5.0	0.281	56
	7.0	0.392	56
	9.0	0.495	55
1.2 – 2.0 mm	1.0	0.079	79
	3.0	0.096	32
	5.0	0.192	38
	7.0	0.236	34
	9.0	0.331	37
Permutita T ®	1.0	0.095	95
	3.0	0.244	81
	5.0	0.309	62
	7.0	0.412	59
	9.0	0.522	58

As expected, Permutite T® performed better, especially in the adsorption of lower fluoride concentrations. Regarding the waste materials, the material with a particle size of 0.25 – 0.42 mm showed high efficiency, superior to that of the smaller particle size material and with values very close to those found with Permutite T® (Figure 03). A trend of decreasing adsorption capacity is observed as the fluoride concentration increases.

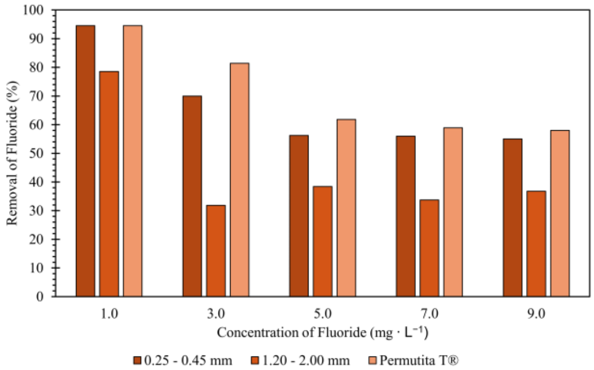

Figure 3. Fluoride adsorption efficiencies.

3. Final Considerations

The results presented in this work are preliminary and are part of a larger, ongoing research project. For future tests, other fluoride concentrations, contact times, temperatures, and particle sizes will be tested. Additionally, amethyst mining waste from other locations will be used. With the characterization of the materials used and the performance of new tests, including those using groundwater, it will be possible to more precisely determine the best combinations for fluoride adsorption. This work and its developments play a crucial role in advancing water treatment and adsorption technology. By combining the reuse of mining waste with the problem of excess fluoride in water, a promising solution is achieved, in accordance with the Sustainable Development Goals.

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