Assessment of the adsorption capacity of sepiolite for antimony(III)

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INTRODUCTION

Different clay minerals have been studied for their adsorbent behavior toward antimony (Sb), with most efforts focused on those with two-dimensional morphologies such as kaolinite and smectite-group minerals (mainly nontronite and montmorillonite) (Xi et al., 2011, 2016; Ilgen and Trainor, 2012). However, the adsorbent characteristics of other clay minerals toward this metalloid have received very little attention to date. This is the case of sepiolite, a magnesium silicate with a one-dimensional fibrous morphology and a 2:1 (tetrahedral–octahedral–tetrahedral) structure. Sepiolite has periodically inverted tetrahedral chains and a discontinuous octahedral sheet, which generate numerous active silanol groups and channels where zeolitic water and exchangeable cations are present. This structure gives sepiolite a high specific surface area and porosity (Wang and Wang, 2019). All these structural and surface features underpin the adsorption properties of sepiolite. The adsorptive performance of sepiolite with respect to cationic metals has been thoroughly studied, showing considerable removal capacities (8–38 mg/g) for elements such as copper, cadmium, nickel, and zinc (Álvarez-Ayuso and García-Sánchez, 2003; Bourliva, 2025), and it has been proposed as an amendment for stabilizing metal-polluted soils. The main mechanisms identified for the adsorption of cationic metals by sepiolite include surface complexation on surface hydroxyl groups, magnesium replacement at octahedral edges, and cation-exchange processes. In contrast, the adsorption of metalloids by clay minerals has been found to be mainly associated with variable-charge surface groups, and these more limited mechanisms may restrict removal efficiencies. The main objective of this work was to determine the adsorption capacity of natural sepiolite for Sb(III).

MATERIALS AND METHODS

A sepiolite sample from Orera (Zaragoza, Spain), supplied by the MYTA, SA Company (SAMCA Group), was employed in this study. This mineral sample was characterized to establish its mineralogical composition, specific surface area (SSA), and point of zero net proton charge (PZNPC). The mineralogical composition was determined by X-ray powder diffraction (XRD) using a Bruker D8 Advance diffractometer, the SSA was analyzed by the single-point method using a Micromeritics FlowSorb II 2300 analyzer, and the PZNPC was determined by the titration method as described by Van Raij and Peech (1972). Batch adsorption studies to establish the adsorption isotherm of Sb(III) on the sepiolite sample were performed in polypropylene flasks (50 mL) by subjecting a sepiolite dose of 5 g/L to an interaction period of 48 h with Sb(III) solutions of different concentration (1–30 mg/L) adjusted to pH 8. The interaction period was carried out on a rotary shaker in a thermostatic chamber set at 22 °C. After the interaction period, the adsorbent was separated by centrifugations (4000 rpm, 10 min) and Sb was analyzed in the resulting supernatants by inductively coupled plasma–atomic emission spectrometry using a Varian 720-ES instrument.

RESULTS AND DISCUSSION

As determined by XRD (Fig. 1), the sepiolite sample was composed of sepiolite, along with dolomite, quartz, and illite. Its SSA and PZNPC showed values of 270 m^2/g and 8.2, respectively. The adsorption isotherm obtained for the removal of Sb(III) by the sepiolite sample is shown in Fig. 2. According to the classification of Giles et al. (1960), the isotherm for the adsorption of Sb(III) on the sepiolite sample within the studied Sb(III) concentration range is C-type (constant partitioning). A linear partitioning was observed between the equilibrium concentrations (Ce) of

Sb(III) in solution and the Sb(III) amounts (X/M) removed by the sepiolite sample [$R^2 = 0.9921$ ($p < 0.001$)]. This isotherm type is characteristic of substances removed at relatively low levels. The distribution coefficient (Kd), defined as Kd = (X/M)/Ce, showed a value of 0.076 L/g. The maximum adsorption capacity attained by the sepiolite sample within the studied Sb(III) concentration range was 1.72 mg/g, which is considerably lower than the adsorption capacities reported for cationic metals. Above the PZNPC of the sepiolite sample, the net charge of surface hydroxyl groups becomes negative. Nevertheless, Sb(III) is present in solution in neutral form [$Sb(OH)_3^0$] in the pH range 2–10 (Filella et al., 2002); therefore, its adsorption is not expected to decrease significantly until it becomes negatively charged [$Sb(OH)_4^-$]) at pH values above 10. In this regard, the adsorption of Sb(III) on variable-charge minerals has been found to remain approximately stable within this pH range (Yang et al., 2019).

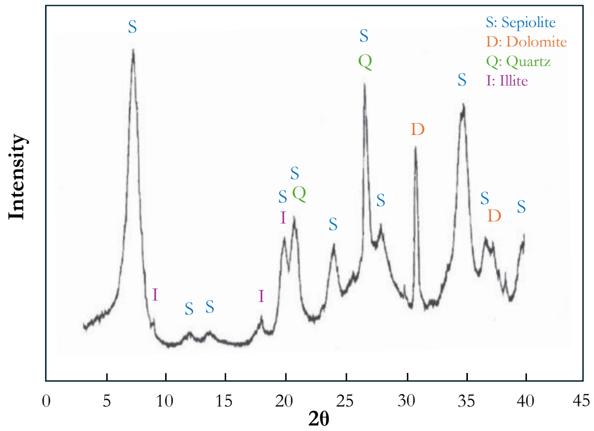

***Fig 1**. XRD pattern of sepiolite sample.*

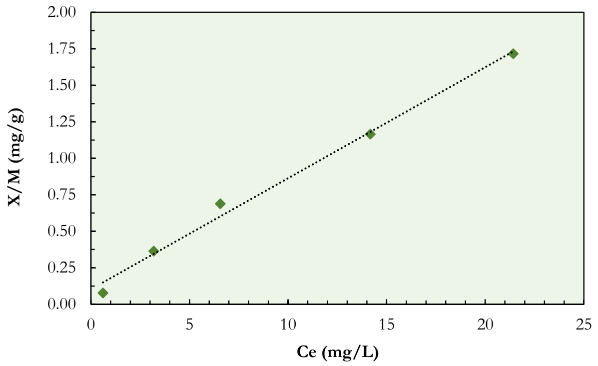

***Fig 2.** Adsorption isotherm of Sb(III) on sepiolite.*

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REFERENCES

Álvarez-Ayuso, E., García-Sánchez, A. (2003): Sepiolite as a feasible soil additive for the immobilization of cadmium and zinc. Sci. Total Environ., **305**, 1–12.

Bourliva, A. (2025): Heavy metal adsorption and desorption behavior of raw sepiolite: A study on Cd(II), Cu(II), and Ni(II) ions. Minerals, **15**, 1110.

Filella, M., Belzile, N., Chen, Y.W. (2002): Antimony in the environment: a review focused on natural waters: II. Relevant solution chemistry. Earth-Sci. Rev., **59**, 265–285.

Giles, C.H., McEwans, T.H., Nakhwa, S.N., Smith, D. (1960): Studies in adsorption: Part IX. A system of classification of solution adsorption isotherms and its use on diagnosis of adsorption mechanisms and in measurement of specific areas of soils. J. Chem. Soc., **786**, 3973–3993.

Ilgen, A.G., Trainor, T.P. (2012): Sb(III) and Sb(V) sorption onto Al-rich phases: Hydrous Al oxide and the clay minerals kaolinite KGa-1b and oxidized and reduced nontronite NAu-1. Environ. Sci. Technol., **46**, 843–851.

Van Raij, B. & Peech, M. (1972): Electrochemical properties of some oxisols and alfisols of the tropics. Soil Sci. Soc. Am. J., **36**, 539–695.

Wang, A., Wang, W. (2019): Nanomaterials from clay minerals-A new approach to green functional materials. Elsevier. Cambridge, 693 p.

Xi, J., He, M., Kong, L. (2016): Adsorption of antimony on kaolinite as a function of time, pH, HA and competitive anions. Environ. Earth Sci., **75**, 1–7.

—, —, Lin, C. (2011): Adsorption of antimony(III) and antimony(V) on bentonite: Kinetics, thermodynamics and anion competition. Microchem. J., **97**, 85–91.

Yang, R., Tao, J., Huang, Q., Tie, B., Lei, M., Yang, Y., Du, H. (2019): Co-adsorption of Cd(II) and Sb(III) by ferrihydrite: a combined XPS and ITC study. J. Soils Sediments, **19**, 1319–1327.