Separation of lead ions from aqueous solutions by adsorption at talc surface

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Separation of lead ions from aqueous solutions containing 5, 10, 20, 50, 100, 200 and 500 ppm lead was studied by adsorption at the surface of talc mineral of Indian origin. The effect of temperature (20, 30, 40, 50, 60, 70°C) on adsorption phenomena was studied and the data was analyzed using Langmuir isotherm. The changes in enthalpy (ΔH), free energy (ΔG) and entropy (ΔS) were evaluated. The negative values of ΔG and ΔH indicate the adsorption of lead ions on talc surface to be spontaneous and exothermic under the experimental conditions.

Keywords: Talc surface, Adsorption, Lead ion, Temperature effect, Langmuir isotherm, Thermodynamic parameters, Ions separation

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Introduction

Lead is widely used in storage battery, hot-dip galvanizing, ceramic glazing, petroleum refining, printing, paper and pulp, electrochemical, chemical and paint industries. About 5 million tons of the metal is produced annually all over the world. However, it is potentially toxic and has the tendency to accumulate in blood, soft tissues and mineralizing tissues like bones, and poses serious health hazards such as anemia and damage to kidney, lung, brain and central nervous system. It has an approx half-life of 25-40 d in blood and soft tissues and more than 25 y in non-labile portion of bones.

For the separation of heavy metal ions such as lead ions from aqueous media, techniques like precipitation, ion exchange, solvent extraction, reverse osmosis, distillation and adsorption have been found to be effective. In the adsorption process for the attenuation of heavy metal ions, substrate materials such as activated carbon, synthetic hydroxyapatite, high grade rock phosphate, clays and clay minerals have been tried. To explore the possibility of utilizing inexpensive minerals for the removal of lead and other heavy metal ions from aqueous solutions, sorption studies were carried out. Talc, a hydroxyl magnesium silicate 

\[ \text{Mg}_3\text{Si}_4\text{O}_{10} (\text{OH})_2 \] 

is another inexpensive mineral of pyrophyllite family occurring widely in India. Its structure comprises of a magnesium-oxygen-hydroxyl tri-octahedral brucite layer, sand-witched between two sheets of silicon-oxygen tetrahedral layers. The adjacent layers are held together by weak van der Waals forces and hence give rise to a soapy feeling in the talc. However, unlike pyrophyllite, where -OH groups are located at the edges, here -OH groups are sand-witched between the layers in talc. This paper reports the adsorption of lead ions on talc surface from aqueous solutions.

Experimental Details

Chemicals and Reagents

Merck A R grade lead nitrate was used to prepare test solutions. The stock solution (1000 ppm lead ions by weight) was prepared by dissolving appropriate quantity of lead nitrate in double distilled water. The test solutions were prepared by serial dilution of the stock solution. The pH of the test solutions was adjusted to 6.0 by addition of dilute HNO₃.

The samples of talc mineral were collected from the mines in Jabalpur district, MP. Representative sample of the mineral, prepared by coning and quartering method, was manually crushed followed by grinding in a Ball Mill. The sieve analysis of powder showed mineral size as follows: + 400 μ, 1.8; -400 +150 μ, 90.2; -150+75 μ, 7.9; and -75 μ, 0.1 %.

The surface area of the powder, determined by Quantachrome (model - Nova 1000) BET surface area analyzer, was 3.4 m²/g. Silica and alumina were
estimated by wet chemical analysis method\textsuperscript{23}, while iron, magnesium and calcium were determined by Inductively Coupled Plasma Spectrometer (Jobin Yvon, model JY-2000), and sodium and potassium were estimated by Flame Photometer (Systronic model - Medi Flame). The results of the chemical analysis are as follows: SiO\textsubscript{2}, 60.35; Fe\textsubscript{2}O\textsubscript{3}, 0.22; Al\textsubscript{2}O\textsubscript{3}, 1.86; MgO, 29.20; CaO, 0.12; Na\textsubscript{2}O, 1.20; K\textsubscript{2}O, 0.80; and loss on ignition at 950 °C, 4.0 wt %.

For identification of the phases present in the representative talc mineral sample, X-ray diffraction studies were carried out and lattice constants were calculated as follows: \(a\), 5.15; \(b\), 9.29; and \(c\), 18.89. The corresponding lattice constant values of 5.28, 9.158 and 18.90 are reported\textsuperscript{24} for the tri-layer monoclinic form of talc and it was inferred that the talc used in the present study is a tri-layer monoclinic form.

**Lead Ion Separation Studies**

For optimization of contact time required for the sorptive separation of lead ions at talc surface from aqueous lead solutions, talc powder (1.0 g) was equilibrated with test solution (100 ml thermo-stated at 20°C) containing lead ions (5.0, 10.0, 20.0, 50.0, 100, 200 & 500 ppm) for contact times of 10, 20, 30, 40 and 50 min. The contact time comprised of 10 min by stirring of the talc powder with the test solution using a mechanical shaker followed by equilibration for the remainder period under quiescent conditions. At the end of equilibration time, talc powder was separated by filtration using Whatman 42 filter paper and concentration of the remaining lead ions in solutions was estimated using Atomic Absorption Spectrometer (GBC Model-902) following the procedures adopted earlier\textsuperscript{11}. From these data, separation of lead ions at talc surface was evaluated. From the plot (Fig. 1), a contact time of 40 min was found satisfactory and the same was used in all further studies.

For studying the effect of quantity of adsorbent on separation of lead ions, test solution (100 ml) containing lead ions (100 ppm) was equilibrated for 40 min at 20°C with different quantities of talc powder (0.1, 0.3, 0.5, 0.7, 1.0, 1.2, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 & 5.0 g). Similarly for studying the effect of temperature on the separation of lead ions, talc powder (1.0 g) was equilibrated at 20, 30, 40, 50, 60 and 70°C.

**Results and Discussion**

**Effect of Initial Concentration on Sorptive Separation of Lead Ions**

For studying the effect of initial concentration of lead ions in solution on separation percentage and quantity of lead ions separated per unit weight of adsorbent talc (mg/g), talc powder (1.0 g) was equilibrated at 20°C for 40 min in solutions containing 5, 10, 20, 50, 100, 200 and 500 ppm lead ions (Fig. 2). In dilute solutions (5-20 ppm), lead ion separation was 100 percent. However, with increase in concentration, the separation percentage decreased. The quantity of lead ions separated from talc sample, initially increased rapidly with increase in the lead ion concentration in solution, but in solutions of higher concentrations, it became practically constant (8 mg/g). This may be attributed to the fact that at low concentrations of lead ions in solution, surface coverage (\(\theta\)) is small and hence almost all the available lead ions are removed. However, at higher concentrations, all sites available for adsorption get occupied.
Effect of the Quantity of Adsorbent on the Separation of Lead Ions

The separation of lead ions from test solution (100 ml) containing lead ions (100 ppm) at 20 °C increased almost linearly as the amount of adsorbent increased gradually from 100 mg to 2.5 g and can be attributed to increase in the availability of adsorption sites (Fig. 3). A further increase in the quantity of adsorbent leads to a complete removal of lead ions from the solution and hence the quantity of separated lead ions remains constant.

Effect of Temperature on the Separation of Lead Ions

In general, the quantity of separated lead ions from 100 ml solutions containing 5, 10, 20, 50, 100, 200 and 500 ppm lead ions per unit weight of adsorbent decreased with increase in temperature, indicating that the sorption of lead on talc surface is exothermic in nature (Fig. 4).

Adsorption Isotherms

The data obtained for the adsorption of lead ions at talc surface were analyzed using Langmuir isotherm:

\[
\frac{1}{q_e} = \frac{1}{\theta^o b} \left( \frac{1}{C_e} \right) + \frac{1}{\theta^o} \]

where \(q_e\) is the amount of lead ion adsorbed per unit weight of adsorbent (mg/g), \(C_e\) is the equilibrium concentration of lead ions in test solution (mg/l), \(\theta^o\) is the adsorption capacity and \(b\) is the equilibrium constant of adsorption.

The dependence of \(1/q_e\) on \(1/C_e\) with varying concentration of lead ions in test solution at different temperatures is observed to be linear indicating the applicability of the Langmuir model to the adsorption of lead ions on talc surface (Fig. 5). From the values of slope and intercept, \(\theta^o\) and \(b\) were calculated for isotherms obtained at 20, 30, 40, 50, 60 and 70°C (Table 1). The values of \(b\) so obtained were plotted against \(1/T\) (Fig. 6) following the Eq. (2):

\[
\ln b = - \left( \frac{\Delta H}{RT} \right) + \text{Constt} \]

Exp. 3— Plot of % separation of lead ions vs quantity of adsorbent talc from 100 ml test solutions containing 100 ppm lead ions at 20°C

Exp. 4— Effect of temperature on quantity (mg) of separated lead ions at 1 g talc from test solutions containing different initial concentrations of lead in solutions at 20°C

Exp. 5— Langmuir isotherm plot for the adsorption of lead ions at different temperatures

Exp. 6— Plot of ln \(b\) vs 1/T for the adsorption of lead ions on the talc surface
The value of change in enthalpy was calculated from the slope of the straight line and was observed to be -2.6614 kJ m\(^{-1}\) indicating the process to be exothermic in nature\(^{25}\). The change in free energy of the system due to adsorption at different temperatures of study was calculated using Eq. (3):

\[ \ln(b) = -\frac{\Delta G}{RT} \]  

As expected, the values of \(\Delta G\) obtained for different temperatures of study are observed to be negative (Table 1). The change in entropy of the system due to adsorption at different temperatures was calculated using Eq. (4):

\[ \Delta S = \frac{(\Delta H - \Delta G)}{T} \]  

The values of \(\Delta S\) (Table 1) at different temperatures are positive indicating the affinity of lead ions for talc, similar to the observation for adsorption of lead ions on tea leaves\(^{26}\). The essential characteristics of the Langmuir isotherm are embodied in a dimensionless equilibrium parameter \(R\) expressed as

\[ R = \frac{1}{1 + bC_o} \]  

Accordingly, values of \(R\) at different temperatures, calculated at different concentrations of lead ions in test solution (Table 2), were positive (0-1).

**Conclusions**

Talc minerals were effectively used for the separation (> 98%) of lead ions from its dilute aqueous solutions containing up to 20 ppm lead but decreases in more concentrated solutions. The adsorption of lead at talc surface is spontaneous and exothermic as evidenced by negative values of the changes in free energy (\(\Delta G\)) and enthalpy (\(\Delta H\)).

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**References**


**Table 1** — Langmuir constants and thermodynamic parameters for the adsorption of lead ions on talc at different temperatures

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Temperature°C</th>
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<tr>
<td>Langmuir constant, (\theta^o), mg/g</td>
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<tr>
<td>Langmuir constant, (b), L/mg</td>
<td>0.1352</td>
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<tr>
<td>(\Delta G), KJ/mole</td>
<td>-4.8777</td>
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<tr>
<td>(\Delta S), J/mole</td>
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</tbody>
</table>

**Table 2** — Dimensionless equilibrium parameter, \((R)\); quantity(mg) of lead adsorbed/g of talc, \((q_e)\) and rate constant for adsorption of lead on talc

<table>
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<tr>
<th>Initial conc. of lead ions in solution(ppm)</th>
<th>20°C</th>
<th>30°C</th>
<th>40°C</th>
<th>50°C</th>
<th>60°C</th>
<th>70°C</th>
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<td>6.332</td>
<td>0.0128</td>
<td>6.141</td>
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