

## Adsorption characteristics of Cu(II) and Pb(II) onto expanded perlite from aqueous solution

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Received 17 January 2007; received in revised form 19 February 2007; accepted 20 February 2007

Available online 24 February 2007

### Abstract

The adsorption characteristics of Cu(II) and Pb(II) onto expanded perlite (EP) from aqueous solution were investigated with respect to the changes in pH of solution, adsorbent dosage, contact time and temperature of solution. For the adsorption of both metal ions, the Langmuir isotherm model fitted to equilibrium data better than the Freundlich isotherm model. Using the Langmuir model equation, the monolayer adsorption capacity of EP was found to be 8.62 and 13.39 mg/g for Cu(II) and Pb(II) ions, respectively. Dubinin–Radushkevich (D–R) isotherm model was also applied to the equilibrium data and the mean free energies of adsorption were found as 10.82 kJ/mol for Cu(II) and 9.12 kJ/mol for Pb(II) indicating that the adsorption of both metal ions onto EP was taken place by chemical ion-exchange. Thermodynamic functions, the change of free energy ( $\Delta G^\circ$ ), enthalpy ( $\Delta H^\circ$ ) and entropy ( $\Delta S^\circ$ ) of adsorption were also calculated for each metal ions. These parameters showed that the adsorption of Cu(II) and Pb(II) ions onto EP was feasible, spontaneous and exothermic at 20–50 °C. Experimental data were also evaluated in terms of kinetic characteristics of adsorption and it was found that adsorption process for both metal ions followed well pseudo-second-order kinetics.

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**Keywords:** Pb(II); Cu(II); Expanded perlite; Adsorption; Isotherm; Thermodynamics; Kinetics

### 1. Introduction

The removal of heavy metals from waters and wastewaters is important in terms of protection of public health and environment due to their accumulation in living tissues throughout the food chain as a non-biodegradable pollutants [1]. The effluents of a wide range of industrial applications, including microelectronics, electroplating, battery manufacture, dyestuffs, pharmaceutical, metallurgical, chemicals and many others causes heavy metals pollution in environment [2–4]. Several methods have been applied over the years on the elimination of these metal ions present in industrial wastewaters and soils. The commonly traditional methods used for removal of heavy metal ions from aqueous solutions include ion-exchange, solvent extraction, chemical precipitation, phytoextraction, ultrafiltration, reverse osmosis, electrodialysis and adsorption [5–8]. Adsorption is the one of the important procedure for the removal

of the heavy metals from the environment. Ion-exchange and adsorption mechanisms of various adsorbents have been used to remove various heavy metal ions from aqueous solution [2–14].

Lead (Pb) is one of the major environmental pollutants. It is mainly discharged from exhaust gases of automobile to environment [15]. Moreover, it diffuses to the water and environment through effluents from lead smelters, battery manufacturers, paper and pulp industries and ammunition industries [15]. On the other hand, copper (Cu) is one of toxic metals. The main sources of copper ions are, essentially, the industrial waste streams of metal cleaning and plating baths, pulp, paper, paperboard and wood preservative-employing mills, the fertilizer industry, etc. [16,17]. In particularly, excessive intake of copper over 1.0 mg/L from drinking results in hemochromatosis and gastrointestinal catarrh diseases because it is accumulated in the livers of human and animals [18,19].

In recent years, various adsorbents have been used for removal of Cu(II) [1,5,7,14,16,19] and Pb(II) [8,13–15,19–24] from aqueous solution. However, new adsorbents with locally available, high adsorption capacity and economic materials are still needed.

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Perlite is an inert glassy volcanic rhyolitic rock and can be expanded up to 10–20 times its original volume when heated rapidly at 700–1200 °C [25]. Expanded perlite (EP) acts as an excellent insulator, both thermal and acoustical, and is classified as ultra-light weight material. Most of perlite contains greater than 70% silica. EP is an excellent filter aid and filler in various processes such as paint, enamels, glazes, plastics and resins since it is adsorptive and chemically inert in many environments [26–30]. The EP is inexpensive and abundantly available in Turkish markets. This could make it a viable candidate as an economical adsorbent for removing heavy metals such as lead, copper, cadmium and chromium [25,29,30].

The objective of the present work is to investigate the adsorption potential of EP in the removal of Cu(II) and Pb(II) ions from aqueous solution. The effects of pH, adsorbent dosage, contact time and temperature on the adsorption capacity of EP were studied. The Langmuir, Freundlich and Dubinin–Radushkevich (D–R) isotherm models were used to describe equilibrium data. The adsorption mechanisms of Cu(II) and Pb(II) ions onto EP were also evaluated in terms of thermodynamics and kinetics.

## 2. Experimental procedures

### 2.1. Characterization of adsorbent

Expanded perlite (EP) was obtained from İzper Ltd. (İstanbul, Turkey). The chemical composition of EP supplied by the company is given in Table 1. The solid sample was washed with distilled water several times to remove dust and other water-soluble impurities, dried at 105 °C for 24 h and sieved by a 150 μm sieve.

### 2.2. Batch adsorption procedure

Adsorption experiments were carried out at the desired pH value, contact time and adsorbent dosage level using the necessary adsorbents in a 250 mL stoppered conical flask containing 25 mL of test solution. Initial solutions with different concentration of Cu(II) and Pb(II) were prepared by proper dilution from stock 1000 mg/L Cu(II) and Pb(II) standards. Sodium phosphate buffer (0.1 mol/L) was prepared by adding an appropriate amount of phosphoric acid to sodium dihydrogen phosphate solution to result in a solution of pH 2. Ammonium acetate buffers (0.1 mol/L) were prepared by adding an appropriate

Table 1  
Chemical composition of EP

Constituent	Percentage (wt.%)
SiO <sub>2</sub>	71–75
Al <sub>2</sub> O <sub>3</sub>	12.5–18
Na <sub>2</sub> O	2.9–4
K <sub>2</sub> O	4–5
CaO	0.5–0.2
Fe <sub>2</sub> O <sub>3</sub>	0.1–1.5
MgO	0.03–0.5

amount of acetic acid to ammonium acetate solutions to result in solutions of pH 4–6. Ammonium chloride buffer solutions (0.1 mol/L) were prepared by adding an appropriate amount of ammonia to ammonium chloride solutions to result in solutions of pH 8–9.

Necessary amount of adsorbent material was then added and contents in the flask were shaken for the desired contact time in an electrically thermostatic reciprocating shaker at 110 rpm. The experiments were repeated at 20, 30, 40 and 50 °C. The time required for reaching the equilibrium condition estimated by drawing samples at regular intervals of time till equilibrium was reached. The contents of the flask were filtered through filter paper and the filtrate was analyzed for metal concentration by using flame AAS (Perkin-Elmer AAnalyst 700). The percent adsorption of metal ion was calculated as follows:

$$\text{Adsorption (\%)} = \frac{C_i - C_f}{C_i} \times 100 \quad (1)$$

where  $C_i$  and  $C_f$  are the initial and final metal ion concentrations, respectively. Adsorption experiments for the effect of pH were conducted by using a solution having 10 mg/L of Pb(II) and 10 mg/L of Cu(II) concentration with an adsorbent dosage of 20 g/L. Throughout the study, the contact time was varied from 5 to 120 min, the pH of the solution from 2 to 9, the initial metal concentration from 10 to 400 mg/L and the amount of adsorbent from 2 to 40 g/L.

## 3. Results and discussion

### 3.1. Effect of adsorbent dosage

Adsorbent dosage is an important parameter because this determines the capacity of an adsorbent for a given initial concentration of the adsorbate at the operating conditions. The effect of adsorbent dosage on the adsorption of Cu(II) and Pb(II) ions is shown in Fig. 1. When the adsorbent dosage was increased from 2 to 40 g/L, the adsorption percentage was raised from

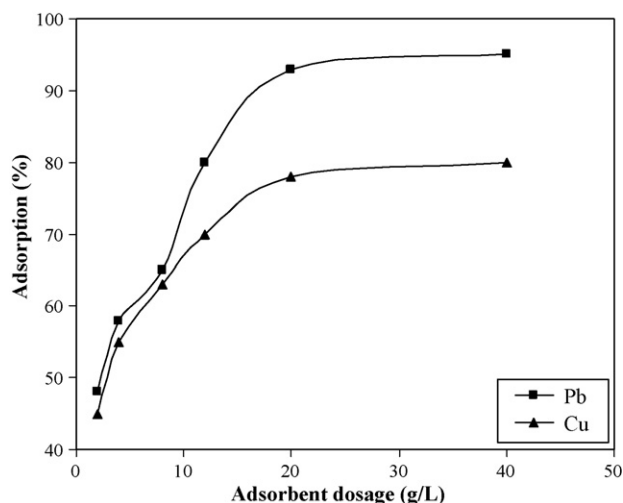


Fig. 1. Effect of adsorbent dosage on the adsorption of Cu(II) and Pb(II) onto EP (metal concentration, 10 mg/L, pH 5; temperature, 20 °C).

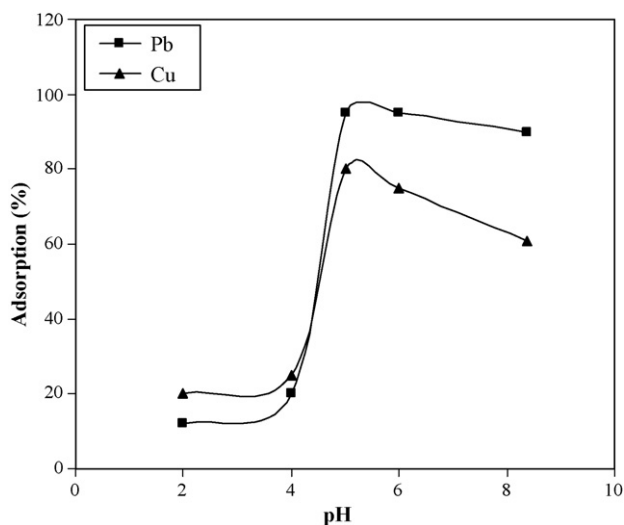


Fig. 2. Effect of pH on the adsorption of Cu(II) and Pb(II) onto EP (metal concentration, 10 mg/L; adsorbent dosage, 20 g/L; temperature, 20 °C).

48 to 95% for Pb(II) ions and from 45 to 80% for Cu(II) ions. The increase in the adsorption percentage with rise in adsorbent dosage is due to increase in active sites on the adsorbent and thus making easier penetration of the metal ions to the sorption sites. The adsorption percentages of both metal ions were almost over 20 g/L adsorbent dosage. Therefore, the amount of EP was selected as 20 g/L for further adsorption experiments. With increasing adsorbent dosage, more surface area is available for adsorption.

### 3.2. Effect of pH

The pH of solution is the most important variable affecting metal ions adsorption. This is partly because hydrogen ions themselves are strongly competing with metal ions. Fig. 2 shows the effect of pH on the adsorption of Cu(II) and Pb(II) ions onto EP. The adsorption was found to increase from 12 to 95% for Pb(II) ions and from 20 to 80% for Cu(II) ions when the pH was increased from 2 to 9. At low pH values, the low adsorption observation was explained due to increase in positive charge (protons) density on the surface sites and thus, electrostatic repulsion occurred between the metal ions ( $M^{2+}$ :  $Pb^{2+}$  or  $Cu^{2+}$ ) and the edge groups with positive charge ( $Si-OH^{2+}$ ) on the surface [25–27]. In an alkaline medium, the surface of EP becomes negatively charged and electrostatic repulsion decreases with raising pH due to reduction of positive charge density on the sorption edges thus resulting in an increase metal adsorption. A similar theory was proposed by several earlier workers for metal adsorption on different adsorbent [6,9,18,22,30]. A considerable increase in the adsorption was occurred at pH 4–6 and the maximum Cu(II) and Pb(II) adsorption was observed at the almost pH value (pH 5). At higher pH values than 5, metal precipitation appeared and adsorbent was deteriorated with accumulation of metal ions [13,15,19,24]. Therefore, pH 5 was selected to be the optimum pH for further studies.

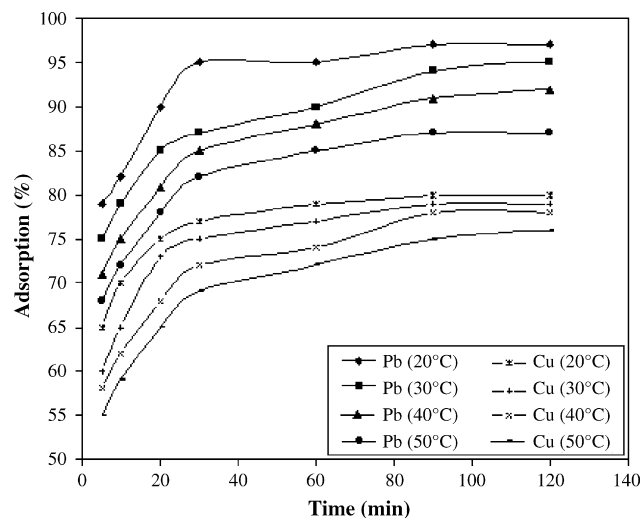


Fig. 3. Effect of contact time and temperature on the adsorption of Cu(II) and Pb(II) onto EP (metal concentration, 10 mg/L; adsorbent dosage, 20 g/L, pH 5).

### 3.3. Effects of shaking time and temperature

Fig. 3 shows the adsorption percentages of Cu(II) and Pb(II) ions as a function of shaking time and temperature. It can be seen that the Cu(II) and Pb(II) adsorption yield onto EP increases by increasing shaking time up to 90 min at 20–50 °C. Maximum adsorption was attained as 97% for Pb(II) ion and as 80% for Cu(II) ion up to 90 min at 20 °C. After that a maximum removal for both metal ions was attained. Therefore, 90 min was selected as optimum shaking time for all further experiments. The almost same equilibrium times were reported in several earlier works which related with the adsorption of Cu(II) and Pb(II) ions on various adsorbents [8,10,18,21]. Fig. 3 also shows the influence of the temperature on the adsorption of Cu(II) and Pb(II) ions onto EP. As seen, the adsorption percentages of Cu(II) and Pb(II) ions were decreased with increasing temperature of solution. When the temperature was increased from 20 to 50 °C the

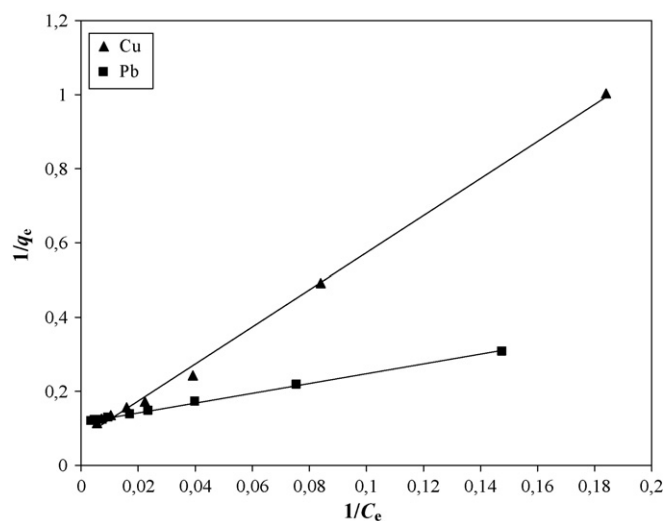


Fig. 4. Langmuir isotherm plots for the adsorption of Cu(II) and Pb(II) onto EP (adsorbent dosage, 20 g/L; shaking time, 90 min, pH 5; temperature, 20 °C).

adsorption percentage decreased from 97 to 85% for Pb(II) ion and from 80 to 75% for Cu(II) ion at equilibrium time (90 min). A decrease in the adsorption of Cu(II) and Pb(II) ions with the rise in temperature may be explained by being more active of adsorbent sites at low temperatures [13,14]. This result also indicated that the exothermic nature of Cu(II) and Pb(II) ions adsorption onto EP. The optimum solution temperature was selected as 20 °C.

### 3.4. Adsorption isotherm models

The adsorption isotherms reveal the specific relation between the concentration of sorbate and its sorption degree onto adsorbent surface at a constant temperature. Three important isotherms are selected in this study, which are, namely the Langmuir, Freundlich and the D–R isotherm models.

The Langmuir model assumes that adsorptions occur at specific homogeneous sites on the adsorbent and is used successfully in many monolayer adsorption processes. This model can be written as follows [31]

$$\frac{1}{q_e} = \frac{1}{q_m} + \left( \frac{1}{q_m K_L} \right) \frac{1}{C_e} \quad (2)$$

where  $q_e$  is the equilibrium metal ion concentration on the adsorbent (mg/g),  $C_e$  the equilibrium metal ion concentration in the solution (mg/L),  $q_m$  the monolayer adsorption capacity of the adsorbent (mg/g) and  $K_L$  represents the Langmuir adsorption constant (L/mg) and related to free energy of adsorption.

The Freundlich model [32] can be applied for non-ideal sorption on heterogeneous surfaces and multilayer sorption. The Freundlich model in linear form is

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \quad (3)$$

where  $K_f$  is a constant related to the adsorption capacity and  $1/n$  is an empirical parameter related to the adsorption intensity, which varies with the heterogeneity of the material.

Fig. 4 shows the Langmuir isotherms obtained by plotting the  $1/q_e$  versus  $1/C_e$  values. The correlation coefficient ( $r^2$ ) were found to be 0.998 for the adsorption of Cu(II) ion and 0.996 for the adsorption of Pb(II) ion indicating that the equilibrium data fitted well the Langmuir model. From Fig. 4, the value of maximum adsorption capacity ( $q_m$ ) was found to be 8.62 mg/g for Cu(II) ion and 13.39 mg/g for Pb(II) ion.  $K_L$  value was found as 0.088 L/mg for Cu(II) ion and 0.015 L/mg for Pb(II) ion.

Fig. 5 shows the Freundlich isotherm obtained by plotting  $\log q_e$  versus  $\log C_e$  values. The values of  $K_f$  and  $1/n$  were found to be 0.374 and 0.331 for Cu(II) ion and 0.913 and 0.347 for Pb(II) ion. The  $1/n$  values were between 0 and 1 indicating that the adsorption of Cu(II) and Pb(II) onto EP was favourable at studied conditions. The  $r^2$  value was found to be 0.983 for Cu(II) ion and 0.982 for Pb(II) ion indicating that the Freundlich model was able to adequately to describe the relationship between  $q_e$  and  $C_e$  values. However, the Langmuir isotherm model ( $r^2 = 0.99$ ) fitted the equilibrium data better than the Freundlich isotherm model ( $r^2 = 0.98$ ) obtained for the adsorption

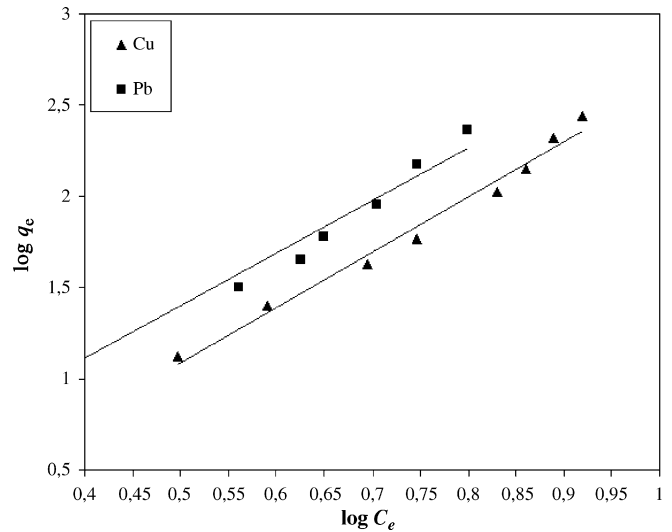


Fig. 5. Freundlich isotherm plots for the adsorption of Cu(II) and Pb(II) onto EP (adsorbent dosage, 20 g/L; shaking time, 90 min, pH 5; temperature, 20 °C).

of both metal ions. The similar results were reported for Cu(II) and Pb(II) adsorption on different adsorbents by several authors [15,18,21].

The equilibrium data were also applied to the D–R model [33] to determine if adsorption occurred by physical or chemical processes [5,11,16]. The linearized form of the D–R isotherm is as follows:

$$\ln q_e = \ln q_m - \beta \varepsilon^2 \quad (4)$$

where  $\beta$  is the activity coefficient related to mean adsorption energy ( $\text{mol}^2/\text{J}^2$ ) and  $\varepsilon$  is the Polanyi potential ( $\varepsilon = RT \ln(1 + 1/C_e)$ ). The mean adsorption energy,  $E$  (kJ/mol) is as follows:

$$E = \frac{1}{\sqrt{-2\beta}} \quad (5)$$

This adsorption potential is independent of the temperature, but it varies depending on the nature of adsorbent and adsorbate. The mean free energy of adsorption  $E$ , gives information about adsorption mechanism as chemical ion-exchange or physical adsorption. If the  $E$  value is between 8 and 16 kJ/mol, the adsorption process follows by chemical ion-exchange and if  $E < 8$  kJ/mol, the adsorption process is of a physical nature [34–36]. The mean adsorption energy ( $E$ ) was calculated as 10.82 kJ/mol for the adsorption of Cu(II) and 9.12 kJ/mol for the adsorption of Pb(II) onto EP (Fig. 6). These results indicate that the adsorption processes of the metal ions onto EP may be carried out via chemical ion-exchange mechanism. The similar results for the adsorption of Cu(II) and Pb(II) were reported by earlier workers [4,20].

### 3.5. Comparison of adsorption capacity of EP with other adsorbents for Cu(II) and Pb(II)

The comparison of the EP with various adsorbents in terms of adsorption capacity for Cu(II) and Pb(II) ions from aqueous solution at 20 °C is given in Table 2. The EP has a high adsorption capacity as comparable with those of other adsorbents in

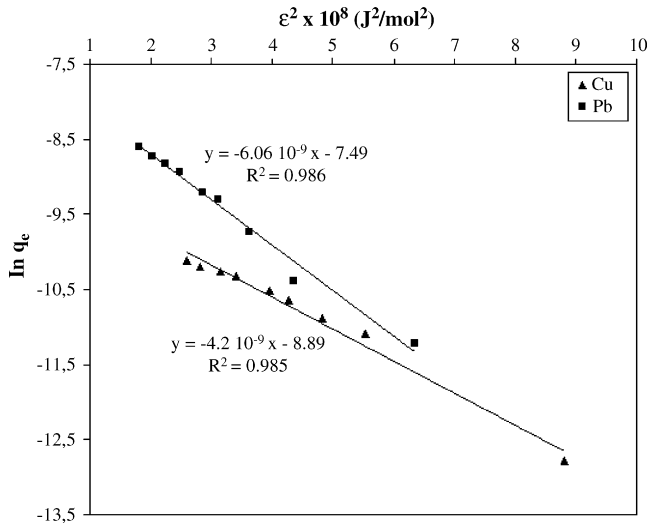


Fig. 6. D–R isotherm plots for the adsorption of Cu(II) and Pb(II) onto EP (pH 5; adsorbent dosage, 20 g/L; shaking time, 90 min; temperature, 20 °C).

literature [4,5,8,10,13–15,21,23,37,38]. Therefore, the EP has significant potential for removal of Cu(II) and Pb(II) ions from aqueous solutions.

### 3.6. Adsorption kinetics

In order to clarify the adsorption kinetics of Cu(II) and Pb(II) ions onto EP, Lagergren's pseudo-first-order and pseudo-second-order kinetic models were applied to the experimental data.

The linearized form of the pseudo-first-order rate equation by Lagergren [39] is given as

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (6)$$

where  $q_t$  and  $q_e$  (mg/g) are the amounts of the metal ions adsorbed at equilibrium (mg/g) and  $t$  (min), respectively, and  $k_1$  is the rate constant of the equation ( $\text{min}^{-1}$ ). The adsorption

rate constants ( $k_1$ ) can be determined experimentally by plotting of  $\ln(q_e - q_t)$  versus  $t$ .

The plots of  $\ln(q_e - q_t)$  versus  $t$  for the Lagergren-first-order model were not shown as figure because the  $r^2$  values for this model at studied temperatures is low (0.796–0.897 for the Cu(II) adsorption and 0.859–0.968 for the Pb(II) adsorption) (Table 3). The adsorption of Cu(II) and Pb(II) ions onto EP does not fit a pseudo-first-order kinetic model. The similar results were found for the adsorption of same metal ions on various adsorbents by several authors [1,19,20].

Experimental data were also applied to the pseudo-second-order kinetic model which is given in the following form [40–43]

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \left(\frac{1}{q_e}\right) t \quad (7)$$

where  $k_2$  (g/mg min) is the rate constant of the second-order equation,  $q_t$  (mg/g) the amount of adsorption time  $t$  (min) and  $q_e$  is the amount of adsorption equilibrium (mg/g).

This model is more likely to predict the kinetic behaviour of adsorption with chemical sorption being the rate-controlling step [4,40,41]. The linear plots of  $t/q_t$  versus  $t$  for the pseudo-second-order model for the adsorption of Cu(II) and Pb(II) ions onto EP at 20–50 °C are shown in Fig. 7a and b, respectively. The rate constants ( $k_2$ ), correlation coefficients of the plots together with the  $q_e$  value is given in Table 3. It is clear from these results that the  $r^2$  values are very high (0.995–0.999 for the Cu(II) adsorption and 0.991–0.997 for the Pb(II) adsorption). These results suggest that the adsorption of Cu(II) and Pb(II) ions onto EP follows well the pseudo-second-order kinetics. The similar results were reported for the adsorption of Cu(II) and Pb(II) on different adsorbents which have similar chemical structure with that of EP [19,20,24].

### 3.7. Adsorption thermodynamics

Thermodynamic parameters including the change in free energy ( $\Delta G^\circ$ ), enthalpy ( $\Delta H^\circ$ ) and entropy ( $\Delta S^\circ$ ) were cal-

Table 2  
Comparison of adsorption capacity of EP with different adsorbent materials

Adsorbent	Adsorption capacities (mg/g)		Reference
	Cu(II)	Pb(II)	
Turkish clay (Celtek)	–	18.08	[13]
Turkish siderite	–	10.32	[10]
Turkish bentonite (MTA)	–	16.66	[14]
Rice husk ash	–	10.86	[23]
Activated carbon prepared from coconut shell	–	12.64	[15]
Olive cake	–	19.53	[21]
Turkish siderite	–	10.32	[10]
Modified peanut husk	10.15	29.14	[8]
Sawdust	6.6	21.05	[8]
Turkish bentonite	2.62	–	[14]
Sporopollenin	1.24	–	[4]
Tree fern	10.6	–	[5]
Natural zeolite	8.90	–	[37]
Tea waste	8.64	–	[38]
Activated poplar sawdust	13.50	–	[18]
Expanded perlite (EP)	8.62	13.39	This study

Table 3  
Pseudo-first-order and pseudo-second-order parameters for the adsorption of Cu(II) and Pb(II) onto EP at different temperatures

Temperature (°C)	Pseudo-first-order			Pseudo-second-order		
	$k_1$ (min <sup>-1</sup> )	$q_e$ (mg/g)	$r^2$	$k_2$ (g/mg min)	$q_e$ (mg/g)	$r^2$
<b>Cu(II)</b>						
20	$4.85 \times 10^{-2}$	0.14	0.897	0.95	0.90	0.999
30	$4.70 \times 10^{-2}$	0.13	0.860	0.81	0.87	0.999
40	$4.44 \times 10^{-2}$	0.12	0.796	0.75	0.84	0.998
50	$4.14 \times 10^{-2}$	0.11	0.848	0.73	0.82	0.995
<b>Pb(II)</b>						
20	$4.86 \times 10^{-2}$	0.17	0.968	0.34	0.91	0.995
30	$4.53 \times 10^{-2}$	0.11	0.856	0.30	0.89	0.997
40	$1.94 \times 10^{-2}$	0.10	0.947	0.27	0.87	0.994
50	$1.70 \times 10^{-2}$	0.09	0.859	0.25	0.86	0.991

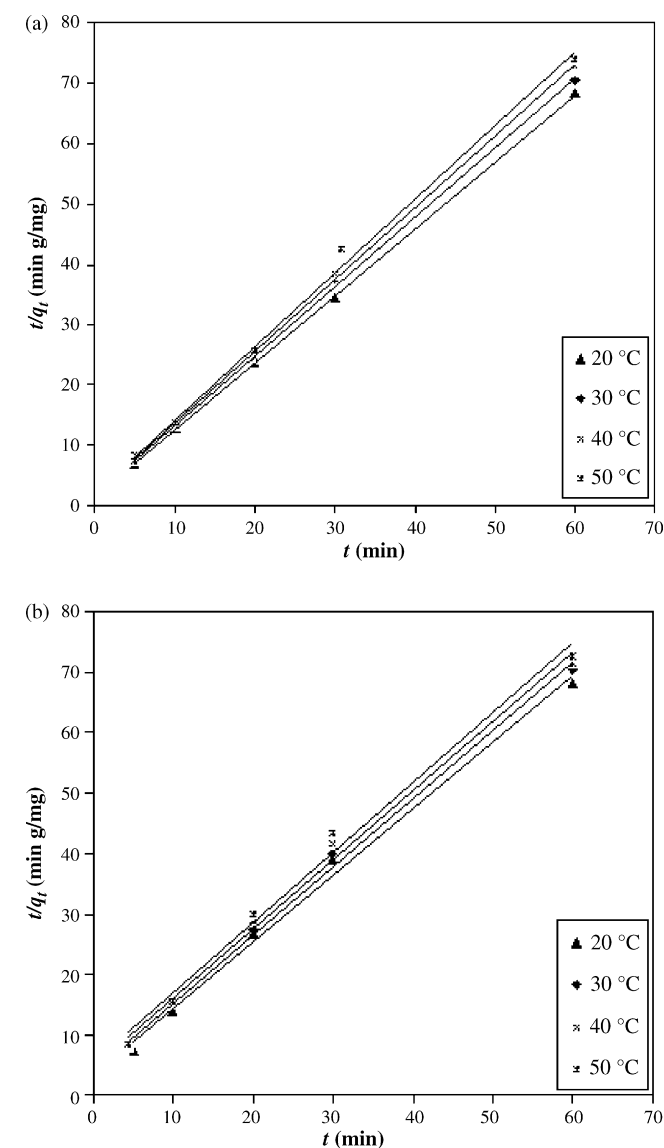


Fig. 7. Pseudo-second-order kinetic plots at different temperatures: (a) for the adsorption of Cu(II) onto EP (b) for the adsorption of Pb(II) onto EP.

culated from following equations

$$\Delta G^\circ = -RT \ln K_D \quad (8)$$

where  $R$  is the universal gas constant (8.314 J/mol K),  $T$  is the temperature (K) and  $K_D$  is the distribution coefficient. The  $K_D$  value was calculated using following equation [12–14]

$$K_D = \frac{q_e}{C_e} \quad (9)$$

where  $q_e$  and  $C_e$  are the equilibrium concentration of metal ions on adsorbent (mg/g) and in the solution (mg/L), respectively.

The enthalpy change ( $\Delta H^\circ$ ) and entropy change ( $\Delta S^\circ$ ) of adsorption were estimated from the following equation

$$\ln K_D = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{RT} \quad (10)$$

According to Eq. (10),  $\Delta H^\circ$  and  $\Delta S^\circ$  parameters can be calculated from the slope and intercept of the plot of  $\ln K_D$  versus  $1/T$  yields, respectively (Fig. 8).

From Eq. (8), Gibbs free energy change of adsorption ( $\Delta G^\circ$ ) was calculated using  $\ln K_D$  values for different temperatures. It was found as and  $-11.67$ ,  $-11.16$ ,  $-10.57$  and  $-9.84$  kJ/mol for the adsorption of Cu(II) and  $-16.44$ ,  $-15.62$ ,  $-15.04$  and

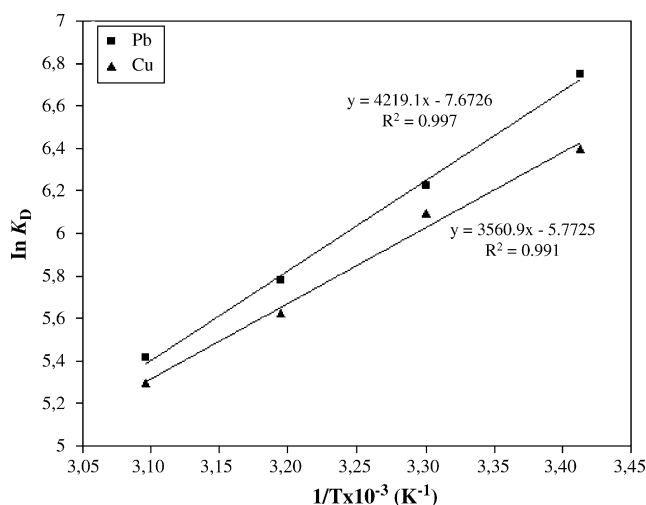


Fig. 8. Plot of  $\ln K_D$  vs.  $1/T$  for estimation of thermodynamic parameters for the adsorption of Cu(II) and Pb(II) onto EP.

–14.54 kJ/mol for the adsorption of Pb(II) at 293, 303, 313 and 323 K, respectively. The negative  $\Delta G^\circ$  values indicated that thermodynamically feasible and spontaneous nature of the adsorption of Cu(II) and Pb(II) onto EP. In addition, the decrease in  $\Delta G^\circ$  values with increase in temperature shows a decrease in feasibility of adsorption at higher temperatures. The  $\Delta H^\circ$  parameter had a value of –29.61 and –35.08 kJ/mol for the adsorption of Cu(II) and Pb(II) ions, respectively, indicating the exothermic nature of the adsorption of both metal ions onto EP in temperature range of 20–50 °C. The  $\Delta S^\circ$  parameter was found to be –47.58 and –63.79 J/molK for the adsorption of Cu(II) and Pb(II), respectively. The negative value of  $\Delta S^\circ$  suggests a decrease in the randomness at solid/solution interface during the adsorption of Cu(II) and Pb(II) ions onto EP.

#### 4. Conclusions

The following conclusions can be drawn from the results obtained for Cu(II) and Pb(II) ions adsorption onto EP from aqueous solution:

- (1) For the solution of 10 mg metal ion/L, the maximum adsorption yield was found as 95% for Pb(II) and 80% for Cu(II) ion at the conditions of adsorbent dosage, 20 g/L, pH 5; shaking time, 90 min shaking time and temperature, 20 °C. The adsorption yields of Pb(II) and Cu(II) decreased with the increasing temperature indicating that the exothermic nature of adsorption of both metal ions onto EP.
- (2) For the adsorption of both metal ions the Langmuir isotherm model fitted to equilibrium data better than the Freundlich isotherm model. Using the Langmuir model equation, the monolayer adsorption capacity of EP was found to be 8.62 and 13.39 mg/g for Cu(II) and Pb(II) ions, respectively. The D–R isotherm model was also applied to the equilibrium data and the mean free energies of adsorption were found as 10.82 kJ/mol for Cu(II) and 9.12 kJ/mol for Pb(II) indicating that the adsorption of both metal ions onto EP was taken place by chemical ion-exchange.
- (3) By applying the kinetic models to the experimental data, it was found that the kinetics Cu(II) and Pb(II) ions adsorption onto EP followed by the pseudo-second-order rate equation.
- (4) The thermodynamic calculations indicated the feasibility, exothermic and spontaneous nature of the adsorption of Cu(II) and Pb(II) ions onto EP in temperature range of 20–50 °C.

Taking into consideration of the results above, it can be concluded that the EP is a suitable adsorbent for the removal of Cu(II) and Pb(II) ions from wastewaters in terms of high adsorption capacity, natural and abundant availability and low cost.

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