Chapter-6

Competitive adsorption of Pb$^{2+}$ on Mentha Piperita treated carbon (MTC) in single and quaternary system
6.1. Introduction

Heavy metal ions such as lead, cadmium, mercury, chromium, nickel, zinc and copper are non-biodegradable, toxic and carcinogenic even at very low concentrations, and hence, usually pose a serious threat to the environmental and public health [1]. Lead is a kind of common contaminants in industrial wastewaters, and considerable attention has been paid for its removal from industrial wastewaters.

The traditional methods for the treatment of lead and other toxic heavy metal contaminated in wastewaters include complexation, chemical oxidation or reduction, solvent extraction, chemical precipitation, reverse osmosis, ion exchange, filtration, membrane processes, evaporation and coagulation, nevertheless these techniques have disadvantages including incomplete metal removal, high consumption of reagent and energy, low selectivity, high capital and operational cost and generation of secondary wastes that are difficult to be disposed off [2,3]. Adsorption, on the other hand, is one of the most recommended physico-chemical treatment processes that is well recognized as one of the highly efficient methods for recovery and treatment of heavy metals from their matrices, samples and aqueous solutions based on the utilization of solid adsorbents from either organic, inorganic, biological or low-cost materials[4].

According to the ranking of metal interested priorities referred by Volesky [5]. Pb$^{2+}$ is one of the most interesting heavy metal for removal and recovery considering the combination of environmental risk and reserve depletion. This metal is widely used in many industrial applications, such as storage battery manufacturing, painting pigment, fuels, photographic materials, explosive manufacturing, coating, automobile, aeronautical and steel industries [6-9]. Lead pollution results from textile dyeing, ceramic and glass industries, petroleum refining, battery manufacture and mining operations [10]. Lead is a highly toxic and cumulative poison, accumulates mainly in bones, brain, kidney and muscles. Lead poisoning in human causes severe damage to kidney, nervous and reproductive systems, liver and brain [11]. In drinking water, even at a low concentration may cause anemia, encephalopathy, hepatitis and nephritis syndrome [12]. The permissible limit for Pb$^{2+}$ in waste water as set by Environmental Protection Agency (EPA) is 0.05mgL$^{-1}$ and that of Bureau of Indian
Standard (BIS) is 0.1 mg L⁻¹ [13] and in drinking water intended for drinking, as set by EU, USEPA and WHO are 0.010, 0.015 and 0.010 mg L⁻¹, respectively [14, 15]. It is therefore, essential to remove Pb²⁺ from wastewater before disposal. In our earlier studies we have utilized various type of low cost adsorbents like coniferous Pinus bark powder, treated ginger carbon, Polyaniline/iron oxide composite, alumina reinforced polystyrene for the removal of dyes/metals from aqueous solution [16-18].

In this work a comparative study using a low cost adsorbent Mentha piperita (an agricultural solid waste) treated form of carbon was used for the removal of Pb²⁺ and the combination of (Pb + Cu + Ni + Cd) from aqueous solution by systematic evaluation using a set of parameters like pH, concentration, time, temperature and Ionic strength. The comparative behavior was examined using pseudo first order, pseudo second order, intraparticle diffusion and Elovich equation. Isotherm studies and thermodynamic behavior was also evaluated.

6.2. Experimental methods

6.2.1. Materials:

Solutions of different metal ions (lead nitrate, cadmium nitrate, nickel nitrate and copper nitrate) are of analytical grade. Stock solutions (1000 mg/l) of different metal ion were prepared by dissolving the required quantity in double distilled water. HCl, NaOH, ZnCl₂, NaNO₃ were of analytical grade.

6.2.2. Adsorbent preparation:

The adsorbent was collected from one of the villages of Aligarh city, India. Prior to use, the mentha was washed with double distilled water to remove the adhering dirt and dried at 80 °C. The dried material was then placed in the silica crucible and kept in the muffle furnace at 750 °C. The resultant carbon was cooled in the desiccators, grounded and sieved to (50 -100) mesh size. The carbon prepared was then treated with 0.1M ZnCl₂ for 24 hrs. It was then filtered and washed with double distilled water. The material was further washed with 0.5 M HCl and then again with double distilled water to remove the acid. It was further dried in oven and used as such for adsorption studies.
6.2.3. Characterization

The surface structure of MTC particles was analyzed by scanning electron microscopy (SEM, LEO-450, England) at 1500 magnification. The characterizations were done to study the functional groups in the range of 400-4000 cm\(^{-1}\) by FTIR spectrophotometer (Inter-spec 2020, Spectrolab, U.K.) in KBr pellets. The concentration of Pb\(^{2+}\) and combination of metal ions was analyzed using Atomic absorption spectrophotometer (GBC 902, Australia). The pH measurements were made using a pH meter (Elico LI-120, India). The elemental analysis of adsorbent was performed using EA1108 (Carlo-Erba). The specific surface area of the adsorbent was determined by the BET Analysis (Quantachrome Autosorb, U.S.A). The total number of acidic sites matching carboxylic, phenolic and lactonic sites was neutralized using alkaline solutions (0.1N NaOH, 0.1N Na\(_2\)CO\(_3\), 0.1 N NaHCO\(_3\)) [19].

6.2.4. Point of Zero charge

The determination of point of zero charge (pHzpc) was done to investigate the surface charge and acid and basic character of adsorbent [20]. For that 0.1 M KCl solution was prepared and its initial pH was adjusted between 2 to 12 by NaOH and HCl and then 25ml of 0.1M KCl was taken in the 100 ml flasks and 0.05g adsorbent was added to each solution. The flasks were kept for 24 hrs and the final pH of the solution was measured by using the pH meter. The graph was plotted between initial and final pH and the point of Zero charge was determined.

6.2.5. Batch adsorption study

The batch biosorption experiments were carried out in 250 ml erlenmeyer flasks containing 25 ml Pb\(^{2+}\) and a quaternary system (50 mg/l) on a rotary shaker at 120 rpm and a temperature of 30 °C. The samples were taken at definite time intervals of (5, 10, 15, 30, 60, 120 and 180 min) and were filtered after 3hr. The Pb\(^{2+}\) in the remaining solution was then analyzed. The effect of solution pH was performed in the range (2-7) for 50mg/l. The initial metal ion concentration was determined between (20-100 mg/l). The adsorption efficiency (%) and capacity of adsorbent were calculated from following equation:
% = 100 × (C₀ - C)/C \hspace{1cm} (1)
Qₑ = (C₀ - C)/W×V \hspace{1cm} (2)

Where
C₀ is initial metal ion concentration (mg/l), C is final metal ion concentration (mg/l), Qₑ is adsorption capacity (mg/g), W is weight of the adsorbent in gm, V is the volume of the metal ion solution (l).

6.3. Results and Discussions
6.3.1. Characterization
The SEM micrograph of MTC surface is shown in Fig. 6.1, which displays flask type amorphous particles with smooth surfaces and pores which have been occupied by lead particles after adsorption. The FTIR spectra of menthe treated carbon before and after adsorption of Pb²⁺ was shown in Fig 6.1. The shift in the peak from 2361.2 cm⁻¹ to 2358.7 cm⁻¹ is attributed to CH-groups. The shift in the peak from 1457.9 cm⁻¹ to 1590.4 cm⁻¹ is attributed to C-C- bonds of aromatic rings [21]. The peaks 1702.1 cm⁻¹ to 1723.0 cm⁻¹ is due to C=O groups. The shift in the peaks from 1221.4 cm⁻¹ to 1219.8 cm⁻¹ is attributed to C-O groups.

Fig 6.1: SEM Micrographs (A) before adsorption and (B) after adsorption
6.3.2. Elemental Analysis

The elemental analysis of menthe treated carbon is shown in table 6.1. The high percentage of carbon (77.96%) present in the material is responsible for greater amount of adsorption of lead from aqueous solution. The active sites are shown in table 6.2. The BET Analysis for the specific surface area has been presented in table 6.3:

<table>
<thead>
<tr>
<th>Table 6.1: Elemental analysis of menthe treated adsorbent</th>
</tr>
</thead>
<tbody>
<tr>
<td>element</td>
</tr>
<tr>
<td>Carbon</td>
</tr>
<tr>
<td>Hydrogen</td>
</tr>
<tr>
<td>Nitrogen</td>
</tr>
</tbody>
</table>
Table 6.2: Determination of active sites

<table>
<thead>
<tr>
<th>Active sites</th>
<th>Conc (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidic</td>
<td>0.1</td>
</tr>
<tr>
<td>Carboxylic</td>
<td>0.03</td>
</tr>
<tr>
<td>Lactonic + Carboxylic</td>
<td>0.13</td>
</tr>
<tr>
<td>Phenolic</td>
<td>0.09</td>
</tr>
<tr>
<td>Basic</td>
<td>0.057</td>
</tr>
</tbody>
</table>

Table 6.3: BET analysis for treated menthe carbon.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface area</td>
<td>2.450 m²/g.</td>
</tr>
<tr>
<td>R²</td>
<td>0.996883</td>
</tr>
<tr>
<td>Total pore volume</td>
<td>1.459 cc/g</td>
</tr>
<tr>
<td>Pore diameter</td>
<td>2.383 Å</td>
</tr>
</tbody>
</table>

Fig 6.3 Point of zero charge

6.3.3. Effect of contact time

The contact time was studied in the range of 5-180 min at 30 °C 50 mg/l for both Pb²⁺ and combination of metal ions (fig 6.4). This shows a very fast adsorption in the beginning and then slows down. The adsorption equilibrium is attained in about 180 minutes and after this time the amount of metal ion adsorbed did not change significantly with time. The rapid uptake of metal ion on the adsorbent may indicate
that most of reaction sites of the adsorbent were exposed for interaction with metal ion. Furthermore, the presence of hydroxyl group in adsorbent forms a complex between metal ion and adsorbent surface causing faster adsorption.

Fig 6.4 Effect of contact time

6.3.4. Effect of pH

The pH plays an important role in the adsorption process by affecting the surface charge of adsorbent, the degree of ionization and speciation of the adsorbate. Thus the effect of pH in the solutions on the removal efficiency of Pb\(^{2+}\) and quaternary system was studied at different pH range from 2 to 7 and the results are shown in fig. 6.5. The acidity of medium affects the competition of H\(^+\) ion and the metal ion for active sites on the adsorbent surface [22]. At lower pH, there is the more competition of H\(^+\) ion and metal ions for the available adsorption sites. However, as pH increases, this competition decreases as these surface active sites become more negatively charged, which enhances the adsorption of the positively charged metal ions through electrostatic force of attraction [23]. The maximum % removal of Pb\(^{2+}\) ion was observed at pH 6.
6.3.5. Adsorption isotherms

The adsorption equilibrium is usually described by an isotherm equation whose parameters express the surface properties and affinity of the adsorbent. Adsorption isotherms can be generated based on theoretical models where Langmuir and Freundlich models are the most commonly used ones [23]. The Langmuir model assumes that uptake of metal ions occurs on a homogenous surface by monolayer adsorption without any interaction between adsorbed ions. The linear form of Langmuir isotherm equation is given as [24].

\[ \frac{C_e}{q_e} = \frac{1}{b.q_m} + \frac{C_e}{q_m} \]  

(3)

Where \( q_e \) is the equilibrium capacity of Pb on adsorbent (mg/g), \( C_e \) is the equilibrium concentration of lead solution (mg/L), \( q_m \) is the monolayer adsorption capacity of adsorbent (mg/g), \( b \) is the Langmuir constant (L/mg) which is related to free energy of adsorption. A plot of \( C_e/q_e \) vs. \( C_e \) at different temperature is shown in fig. 6.6 and the values obtained are given in table 6.4.
Freundlich isotherm is applied for multilayer adsorption on heterogeneous adsorbent and it is assumed that adsorption sites increases exponentially with respect to heat of adsorption and Freundlich equation is an empirical equation. The linear form of Freundlich equation is given as [25].

$$\log q_e = \log K_f + \frac{1}{n} \log C_e$$  \hspace{1cm} (4)

Where $K_f ((\text{mg/g}) (\text{L/mg})^{(1/n)})$ and $1/n$ are Frendlich constant related to adsorption capacity and adsorption intensity respectively. The plot of $\log q_e$ vs. $\log C_e$ at 30 $^\circ$C is shown in fig. 6.7 and the values of the constant and $R^2$ values are given in table 6.4. The value of $n$ and correlation coefficient ($R^2$) predicts the feasibility and favorability of adsorption isotherm.
Heat of adsorption and the adsorbent–adsorbate interaction on adsorption isotherm was studied by Temkin and Pyzhev [26]. The Temkin isotherm equation is given by

$$Q_e = \frac{RT}{b} \ln (K_t C_e)$$ (5)

The linearized form of equation is

$$Q_e = B_1 \ln K_t + B_1 \ln C_e$$ (6)

Where $B_1 = \frac{RT}{b}$, $T$ is the absolute temperature in Kelvin, $R$ is the universal gas constant (8.314 J/mol K), $K_t$ is equilibrium binding constant (L/mg) and $B_1$ is related to heat of adsorption. A plot of $\ln q_e$ vs. $\ln C_e$ at different temperature is shown in fig 6.8 and the values of constant are given in table 6.4.
The Dubinin–Radushkevich isotherm (D–R) is more general than the Langmuir isotherm, because it does not assume a homogeneous surface or constant sorption potential. The D–R Eq. is described as follows [27].

\[
\ln q_e = \ln q_m - \beta \varepsilon^2
\]  

(7)

Where, \( \beta \) is a constant related to the mean free energy of adsorption per mole of the adsorbate (mol\(^2\)/kJ\(^2\)), \( q_m \) is the theoretical saturation capacity, and \( \varepsilon \) is the Polanyi potential, which is equal to \( RT \ln (1 + (1/C_e)) \), where \( R \) (8.314 J mol\(^{-1}\) K\(^{-1}\)) is the gas constant, and \( T \) is the absolute temperature. A plot of \( \ln q_e \) vs. \( \varepsilon^2 \) at different temperature is shown in fig 6.9. The adsorption isotherm studies shows that data in case of \( \text{Pb}^{2+} \) ion is fitted well with Freundlich and Temkin isotherm whereas in case of combination of metal ion it follows the Temkin isotherm.
The Freundlich type adsorption isotherm is an indication of surface heterogeneity of the adsorbent, while Langmuir type isotherm demonstrates surface homogeneity of the adsorbent. This leads to the conclusion that the surface of adsorbent is made up of small heterogeneous adsorption patches which are very much similar to each other in adsorption capability. This study found that metal uptake differences in adsorption
capacity are due to the individual properties of each adsorbent, such as structure, functional groups and surface area [28]

6.3.6. Adsorption Kinetics

In order to examine the controlling mechanism of adsorption process various models such as Pseudo first order, pseudo second order kinetics, intraparticle diffusion and Elovich equation were used to test the experimental data. The pseudo-first-order equation given by Lagergren [29] was widely used for the adsorption of liquid/solid system on the basis of solid capacity. Its linearized form of equation is

\[
\log(q_e - q_t) = \log q_e - K_1 t / 2.303
\]  

Where \( q_e \) is the adsorption capacity of heavy metals (mg/g), \( q_t \) is the adsorption capacity at time \( t \) (mg/g); \( K_1 \) is the rate constant (min\(^{-1}\)). The values of \( K_1 \) and \( R^2 \) at 50 mg/l for Pb\(^{2+}\) and combination of metal ions were calculated from linear plot of log \((q_e - q_t)\) vs. \( t \) as shown in fig 6.10 and are given in table 6.5. The calculated values of \( q_e \) does not match with the experimental values of \( q_e \) and \( R^2 \) values are also low, so it does not follow pseudo first order kinetics.

![Fig 6.10 Pseudo 1st order](image-url)
Therefore, the kinetic data were further analyzed by using pseudo second order kinetics equation. The linearized form of equation is as follows [30]

\[ \frac{t}{q_t} = \frac{t}{q_e} + \frac{1}{K_2 q_e^2} \]

(9)

Where \( q_t \) is the amount of metal ion adsorbed (mg/g) at given time \( t \) (min), \( q_e \) is the amount of metal ion adsorbed at equilibrium (mg/g) and \( K_2 \) is the second order rate constant for adsorption (g/mg min). A plot of \( t/q_t \) vs. \( t \) is shown in fig 6.11. The results were compared with the correlation coefficient \( (R^2) \) as are given in table 6.5. The \( R^2 \) value for second order is highest as compared to first order kinetics. The \( q_e \) (exp) value of second order also agreed well with the \( q_e \) (cal) as compared to first order kinetics and therefore, the data is best followed the second order kinetics in both the cases.

![Fig 6.11 Pseudo 2nd order](image)

The kinetic data were analyzed by the intra particle diffusion model to elucidate the diffusion mechanism [31].

\[ q_t = K_{id} t^{1/2} + C \]

(10)

Where \( K_{id} \) (mg/g min\(^{-1/2}\)) is the intra-particle diffusion constant and \( q_t \) is the adsorption capacity at time \( t \) (mg/g). The value of \( K_{id} \), \( C \), and \( R^2 \) were calculated from
the slope of plot $q_t$ vs. $t^{1/2}$ as shown in fig 6.12 and given in table 6.5. The value of intercept gives an idea about the boundary layer thickness i.e. larger the intercept; greater is the boundary layer effect [32]. It is seen from the table 6.5, the value of intercept is not zero but high and increases in the case of combination of metal ions. This result implies that boundary layer diffusion is the rate controlling step for the adsorption process and it is dominant when Cu$^{2+}$ ion concentration is higher.

![Fig 6.12 Intraparticle diffusion](image)

The adsorption data was further tested with the Elovich equation which is expressed as [33].

$$Qt = A + B \ln t$$

(11)

Where A and B are Elovich constant. The values of A, B and $R^2$ are calculated from fig. 6.13 and given in the table 6.5. From the table 6.5, it is evident that the experimental data is best followed by pseudo second order kinetics in both the cases.
Table 6.5: Kinetic parameter of Pb\(^{2+}\) ion

<table>
<thead>
<tr>
<th></th>
<th>Pb (50 ppm)</th>
<th>Pb+Cu+Ni+Cd (50 ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pseudo 1st order</td>
<td></td>
<td></td>
</tr>
<tr>
<td>qe(cal)</td>
<td>5.33</td>
<td>2.88</td>
</tr>
<tr>
<td>qe(exp)</td>
<td>18</td>
<td>23.5</td>
</tr>
<tr>
<td>K(_1)</td>
<td>0.10824</td>
<td>0.0693</td>
</tr>
<tr>
<td>R(^2)</td>
<td>0.9744</td>
<td>0.9905</td>
</tr>
<tr>
<td>pseudo 2nd order</td>
<td></td>
<td></td>
</tr>
<tr>
<td>qe(cal)</td>
<td>18.11</td>
<td>23.58</td>
</tr>
<tr>
<td>qe(exp)</td>
<td>18</td>
<td>23.5</td>
</tr>
<tr>
<td>K(_2)</td>
<td>6.3807x10(^3)</td>
<td>25.045x10(^3)</td>
</tr>
<tr>
<td>R(^2)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>intraparticle diffusion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K(_{id})</td>
<td>0.0294</td>
<td>0.018</td>
</tr>
<tr>
<td>C</td>
<td>14.98</td>
<td>21.393</td>
</tr>
<tr>
<td>R(^2)</td>
<td>0.8184</td>
<td>0.9143</td>
</tr>
<tr>
<td>Elovich equation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>14.274</td>
<td>20.776</td>
</tr>
<tr>
<td>B</td>
<td>0.8129</td>
<td>0.584</td>
</tr>
<tr>
<td>R(^2)</td>
<td>0.8444</td>
<td>0.9112</td>
</tr>
</tbody>
</table>

6.3.7. Effect of ionic strength

The effect of ionic strength for the lead ion was studied using 0.1N NaNO\(_3\), 0.001N NaNO\(_3\), and 0.5 N NaNO\(_3\) solutions. The percent adsorption was observed more in the case of 0.1N NaNO\(_3\). It also suggested that increasing electrolyte
concentration can cause screening of surface negative charges by the electrolyte ions leading to a drop in the adsorption of the metal ions [34]. Therefore, a decrease in adsorption of metal ion with increasing ionic strength of electrolyte implies that increasing ionic strength is making the potential of the adsorbent surface less negative and thus would decrease metal ion adsorption [22].

6.3.8 Thermodynamic studies

The thermodynamic factors were studied in the temperature range of 303-323 K. The thermodynamic parameters such as enthalpy change ($\Delta H^0$), entropy change ($\Delta S^0$) and Gibbs free energy change ($\Delta G^0$) were estimated using the following reactions [35].

$$K_c = \frac{C_a}{C_e} \quad (12)$$

$$\Delta G^0 = -RT \ln K_c \quad (13)$$

Where $K_c$ is the equilibrium constant, $C_e$ is the equilibrium concentration in solution (mg/L), $C_a$ is the solid phase concentration at equilibrium (mg/L). $\Delta H^0$ and $\Delta S^0$ were determined by Van’t Hoff equation:

$$\log K_c = \frac{\Delta S^0}{2.303R} - \frac{\Delta H^0}{2.303RT} \quad (14)$$

The values of $\Delta H^0$ and $\Delta S^0$ were obtained from the slope and the intercept of the plot log $K_c$ vs. $1/T$ as shown in fig. 6.14 and presented in table 6.6. The values of $\Delta G^0$ are negative confirming the adsorption of Pb$^{2+}$ and combination of metal ions onto adsorbent as spontaneous and thermodynamically favorable at high temperature. The positive value of $\Delta H^0$ indicates the reaction to be endothermic in nature. While the positive value of $\Delta S^0$ indicates randomness at solid/liquid solutions interface during adsorption of Pb$^{2+}$. It was observed that the values of $\Delta G^0$, $\Delta H^0$ and $\Delta S^0$ were higher in quaternary system as compared to single system.
The magnitude of activation energy explains the type of sorption. Two main types of adsorption can occur, physical or chemical. In physical adsorption, the equilibrium is usually attained rapidly and easily reversible, because the energy requirements are small. The activation energy for physical adsorption is usually not more than 4.2 KJ/mol, because the forces involved in physical adsorption are weak. Chemical adsorption is specific and involves forces much stronger than physical adsorption. Therefore, activation energy for chemical adsorption is of the same magnitude as the heat of chemical reactions [36]. A plot of ln $k_2$ versus $1/T$ gives a straight line, and the corresponding activation energy was determined from the slope of linear plot as given by Arrhenius relationship [37].

$$\ln K_c = -\frac{E_a}{RT} + \ln K_0$$  \hspace{1cm} (15)

The value of activation energy is found to be 20.60 KJ/mol K and $K_0$ is found to be 17.931 for lead ion; whereas in case of combination of metal ions is found to be 19.06 KJ/mol K for activation energy and 21.33 KJ/mol for $K_0$. 

Fig 6.14 Log $K_c$ vs $1/T$
Table 6.6: Thermodynamic parameter of Pb$^{2+}$ ion

<table>
<thead>
<tr>
<th>ions</th>
<th>temp(K)</th>
<th>$\Delta G^0$(KJ/mol)</th>
<th>$\Delta H^0$(KJ/mol)</th>
<th>$\Delta S^0$(KJ/molK)</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb</td>
<td>303</td>
<td>-4.176</td>
<td>4.25</td>
<td>0.081</td>
<td>0.8642</td>
</tr>
<tr>
<td></td>
<td>313</td>
<td>-5.18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>323</td>
<td>-6.55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb+Cu+Ni+Cd</td>
<td>303</td>
<td>-6.151</td>
<td>19.28</td>
<td>0.0835</td>
<td>0.9158</td>
</tr>
<tr>
<td></td>
<td>313</td>
<td>-7.13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>323</td>
<td>-8.51</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

6.4. Desorption

The desorption of lead ions were carried out using 0.1M HCl and 0.1M acetic acid. It was found that more than 90% of Pb$^{2+}$ ions are desorbed by 0.1M HCl.

6.5. Conclusion

The mentha treated carbon (MTC) is proved to be a good adsorbent for the removal of Pb$^{2+}$ from aqueous solution. The equilibrium was attained in 180 mints. The maximum adsorption was observed at pH 6. The adsorption isotherm studies shows that data is fitted well with Freundlich and Temkin isotherm in single system whereas in case of quaternary system it follows the Temkin isotherm. The kinetics data shows that boundary layer diffusion is the rate controlling step for the adsorption process and it is dominant when Pb$^{2+}$ ion concentration is higher. The adsorption of Pb$^{2+}$ increases with the increase in the ionic strength of the solution. The positive value of $\Delta H^0$ indicates the reaction to be endothermic in nature. While the positive value of $\Delta S^0$ indicates randomness at solid/liquid solutions interface during adsorption of Pb$^{2+}$ ion. The value of activation energy is found to be 20.60 KJ/molK indicating the process to be chemisorption in nature.
REFERENCES


