The present paper describes the adsorption of lead (II) ions on conventional and nanoporous materials. Equilibrium studies were performed by implementing the empirical Freundlich and Langmuir isotherm models. It was found that all the isotherms constructed on the basis of experimental results fitted well to those models, thereby indicating the efficiency of the nanoporous materials as adsorbents of heavy metals. The experimental lead (II) maximum adsorption capacity of the materials under study—CNTs “Taunit-M”, highly porous carbon, CNTs “Taunit”, BAU-An activated carbon, and bentonite clay—was found to be 23, 14, 13, 10, and 7 mg·g⁻¹, respectively. Due to the high sorption characteristics and unique physical and chemical properties of these materials, the adsorption technologies developed herein may act as good sustainable options for heavy metal removal from industrial effluents.

Keywords: adsorption, heavy metal ions, lead, isotherm, carbon nanotubes.
2.2. Adsorbents

In the present research, the following nanoporous adsorption materials were employed: "Taunit"-series CNTs (Taunit, Taunit-M) produced by JSC “NanoTechCenter” (Tambov, Russia), and highly porous carbon (HPC) also synthesized at JSC “NanoTechCenter” via alkaline activation of a carbon product obtained by heat treatment of a mixture of phenol-formaldehyde resin, carboxymethyl cellulose and graphene nanoplatelets (this procedure may considerably increase the quality of purification of aqueous systems containing heavy metals, in particular, lead. Besides, the efficiency of the above-mentioned nanomaterials was estimated in comparison with the following conventional adsorbents used as references: BAU-A activated carbon produced by JSC “Sorbent” (Perm, Russia), and bentonite clay (BC) acquired from “Bentonit Company” (Moscow, Russia).

3. Adsorption studies

The adsorption capacity is an important factor since it determines how much of an adsorbent is required for quantitative enrichment of adsorbates from a given solution. In the present research to study lead (II) adsorption on conventional and nanoporous materials, the adsorption equilibrium data were fitted using the Langmuir and Freundlich models, which correspond to homogenous and heterogeneous adsorbent surfaces, respectively.

The Langmuir model assumes that adsorption takes place at uniform energy sites on the adsorbent surface, whereas the Freundlich model is an empirical equation that considers multilayer adsorption due to the diversity of adsorption sites. The linear Langmuir and Freundlich isotherm models can be expressed as given in Eqs. (1) and (2):

$$\frac{C_e}{q_e} = \frac{1}{b q_m} + \frac{C_e}{q_m}, \quad (1)$$

$$\log q_e = \log K + \frac{1}{n} \log C_e, \quad (2)$$

where, $C_e$ (mg·L$^{-1}$) is the equilibrium concentration of lead (II) in the solution, $q_e$ (mg·g$^{-1}$) is the equilibrium adsorption capacity of the material, $q_m$ (mg·g$^{-1}$) is the maximum amount of lead (II) adsorbed per unit mass of the adsorbent required for monolayer coverage of the surface, $b$ (L·mg$^{-1}$) is a constant related to the adsorption free energy, $K$ and $n$ are Freundlich constants ($K$ (L·g$^{-1}$) represents multilayer adsorption capacity at unit concentration of adsorbate and is a relative measure of adsorption capacity of adsorbents, and $n$ represents adsorption intensity which varies with heterogeneity of the adsorbent surface – when $n$ approaches to zero, the surface site heterogeneity increases; for a favorable adsorption process, $n$ should lie in the range 1–10 [6]).

The adsorption parameters found using the above-mentioned models are presented in Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Langmuir constants</th>
<th>Freundlich constants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$q_m$ (mg·g$^{-1}$)</td>
<td>$b$ (L·mg$^{-1}$)</td>
</tr>
<tr>
<td>BAU-A</td>
<td>83.33</td>
<td>5.19·10$^{-5}$</td>
</tr>
<tr>
<td>BC</td>
<td>10.20</td>
<td>4.94·10$^{-4}$</td>
</tr>
<tr>
<td>HPC</td>
<td>23.26</td>
<td>9.06·10$^{-4}$</td>
</tr>
<tr>
<td>Taunit</td>
<td>27.74</td>
<td>6.66·10$^{-4}$</td>
</tr>
<tr>
<td>Taunit-M</td>
<td>62.50</td>
<td>3.93·10$^{-4}$</td>
</tr>
</tbody>
</table>

It was found that for a range of small lead (II) concentrations (200–700 mg·L$^{-1}$), it is preferable to implement the Langmuir model. Based on the obtained values of the sorption equilibrium constants of this equation, it can be assumed that the lead ions in lower concentrations interact with active sorption sites located at the surface of the materials under study and are responsible for physical adsorption. The range of high concentrations does not satisfy the boundary conditions for the applicability of the Langmuir model with the monomolecular sorption mechanism, and active sorption within this range can serve as the foundation for an indirect confirmation of the applicability of the Freundlich model. Based on the values of the empirical constants of the Freundlich equation, favorable conditions for chemical adsorption can be assumed. This sorption type is associated with energy heterogeneity of the adsorption sites.
Furthermore, the obtained experimental results demonstrate that the lead (II) sorption capacity increases in the following sequence: BC (7 mg·g\(^{-1}\)) < BAU-A (10 mg·g\(^{-1}\)) < Taunit (13 mg·g\(^{-1}\)) < HPC (14 mg·g\(^{-1}\)) < Taunit-M (23 mg·g\(^{-1}\)).

Thus, it can be concluded that the nanoporous carbon materials can make a significant contribution to the adsorption process and can be successfully used to remove heavy metals (in particular, lead) from water and wastewater in contrast to the materials (activated carbons and clays) commonly used in the industry.

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References


