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Water purification from zinc ions using expanded perlite

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Abstract

Adsorptive capacities of expanded perlite, prepared on the basis of natural mineral of Georgia – perlite, in the process of aqueous solution purification from Zn (II) ions, have been first studied in the work. The dependencies of adsorption degree and volume capacity on adsorbent dosage, contact time, adsorbate concentration and pH of solution medium have been studied. Experiments have been conducted under dynamic conditions.

Optimum conditions of Zn(II) ion adsorption have been established. Maximal efficiency of adsorption degree under these conditions was equal to 93,6, while volume capacity – 3,7 mg/g.

Keywords: Expanded Perlite; Zinc Ions; Adsorption; Adsorption Degree.

1. Introduction

The global ecological system is characterized by quite high level of negative effect of industrial production on the environment and substantial negative ecological consequences.

Rapid urbanization and industrialization increase demand for resources, which promote intensified degradation of the environment. Pollution with heavy metals is among several factors promoting such degradation.

Heavy metal ions and their compounds contained in large quantities in sewage waters are one of the most hazardous components for human health and ecosystem condition.

Among main sources of metal-containing sewage waters one can mention the production of chemical and electrochemical treatment of metals, ferrous and non-ferrous metallurgy, ore-dressing, shaft and ore mining industries, mechanical engineering etc.[1-3].

Inhabitation at technogenically disrupted territories leads to population health deterioration, development of diseases caused by bad ecology, including enzyme activity change, respiratory organs and nervous system dysfunction, congenital deformity, mortality etc. While on one hand, certain metal doses are necessary for human organism, since they participate in different forms of metabolism, transfer and synthesis of matter, on the other, they may be hazardous for human health, even when their concentration doesn't exceed allowable limits. They are able to accumulate in human tissues and organs and thereby cause different diseases and mutations [4, 5].

Among heavy metal ions Zn(II) manifests substantial acute and chronic toxicity, and its presence in the water causes serious health problems: symptoms of neuralgia, abdominal pains, vomit, depression, sluggishness etc. [6, 7]. However, shortage of zinc leads to short stature and sexual maturation problems, loss of coordination. Men become bald due to zinc deficit, as well. That is why it is necessary to observe maximum allowable limits of zinc in drinking water. Maximum

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permissible concentration of Zn (II) in drinking water was established as no more than 3mg/l, while according to Chinese recommendations it is below to 1 mg/l [6, 8].

Based on the above cited it is obvious why the problem of sewage waters purification from heavy metal ions is so acute throughout the world.

Ecological situation improvement is an indispensable condition for improvement of life quality, population health and environment protection.

In this regard, the study and development of simple processing methods of sewage water treatment from heavy metal ions is highly relevant.

For this purpose there were developed multiple treatment methods, which include: flotation, chemical and electrochemical precipitation, membrane separation, ion exchange, phytoextraction, reverse osmosis, adsorption etc. [9-12].

Adsorption is of the most effective methods of contaminated water treatment. Adsorption process has number of advantages, such as easy accessibility, low cost, ecological compatibility and economic efficiency. The efficiency of adsorption method first of all is determined by adsorbent properties, including its porous structure, chemical composition, surface characteristics, and mechanical strength, which provide high degree of treatment.

Natural and synthetic materials, activated carbon of different grades, natural alumosilicates, minerals of different structure are the most effective adsorbents etc. [13, 14].

Perlite is one of such minerals. Perlite is glasslike volcanic material, mainly consisted of volcanic silica and alumina. It is characterized by high porosity and large specific surface, is chemically inert and environmentally friendly. Perlite is differed by the presence of two forms of water – free and constitutional in it. More than 1% content of the constitutional water attaches it the expansion (swelling) ability when heated up to 900 - 1100°C, when perlite disintegrates into ball-shaped grains with 20-30-times bulking compared to its initial volume and with 70-90% porosity. Detailed data on the deposits of mining, processing and applications of Georgian pearlite are given in work [15].

The present work has been aimed to investigation of adsorptive capacity of Georgian expanded perlite in the process of Zn(II) ions removal from the aqueous solution. The effect of medium pH, adsorbent dosage, contact time and adsorbate concentration on the Zn(II) ions adsorption degree and adsorption capacity has been studied.

2. Material and methods

2.1. Methods

Expanded perlite samples obtained from the Paravani perlite, have been used without any preliminary treatment in the process of Zn (II) adsorption. Physical data and chemical composition of the Georgian perlite are given in the work [15, 16].

The solution under study containing Zn(II) has been prepared as follows: a grained zinc metal has been dissolved in concentrated nitrogen acid, filled by distilled water up to 1 liter and a standard solution with 100 mg/l concentration has been obtained so.

2.2. Experimental part

Experiments related to zinc ions adsorption on the expanded perlite have been conducted in periodical regime taking into account main experimental factors, such as adsorbent dosage (0,5-7 g), adsorption duration (15-150min), adsorbate dosage (25-300mg/l) and hydrogen index pH values (2-11). The rest of experimental parameters have been specified in the course of tests (solution volume – 100 ml, temperature of experiment – 20°C).

In order to determine the optimum quantity of adsorbent, different amounts (1-7 g) of the expanded perlite have been placed in the containers, then poured with zinc solution under study in quantity of 100 ml and concentration 100 mg/l; containers have been closed, shook up for 1 hour and then filtered. The optimum quantity of adsorbent has been selected and it was equal to 3 g.

The optimum contact time (60 min) and concentrations of solution under study (100 mg/l) have been established the same way.

The influence of hydrogen index pH on Zn(II) adsorption has been studied as well. It is known that solution pH is one of the most important parameters in the adsorption process. For determination of medium pH impact on zinc adsorption, pH has been varied in the range of 2-11 via addition of hydrochloric acid or caustic potash.

The solution under study with given pH, 100 ml quantity and 100 mg/l concentration has been poured into containers, where 3g of expanded perlite has been already placed, the contents have been mixed for 60 minutes, filtered and the filtrate has been analyzed for zinc content.

Analyses have been taken using atomic-adsorption (AAC Perkin-Elmer-200) and chemical methods.

Experiments have been conducted three times and the mean values with standard deviations have been used.

The amount of zinc adsorbed per unit weight of adsorbent surface (adsorption capacity) A mg/g, and Zn (II) adsorption degree R have been calculated according to formulas:

$$A = \frac{C_o - C}{m} \cdot V \text{ mg/g}$$

$$R = \frac{C_o - C}{C_o} \cdot 100\%$$

Where C_o - initial solution concentration, mg/dm^3;
C - aposteriori (after the test) concentration;
m - sorbent weight, g;
V - volume of purified solution, dm^3.

3. Results and discussion

It is known that perlite mainly consists of silica (silicon earth) in the form of SiO_2 (72-76%) and alumina (aluminum earth), which mainly includes aluminum oxide – Al_2O_3 (13,5-16,9%), potassium oxide (3-6%), sodium oxide (3-5%) and relatively small amounts of oxides of other metals.

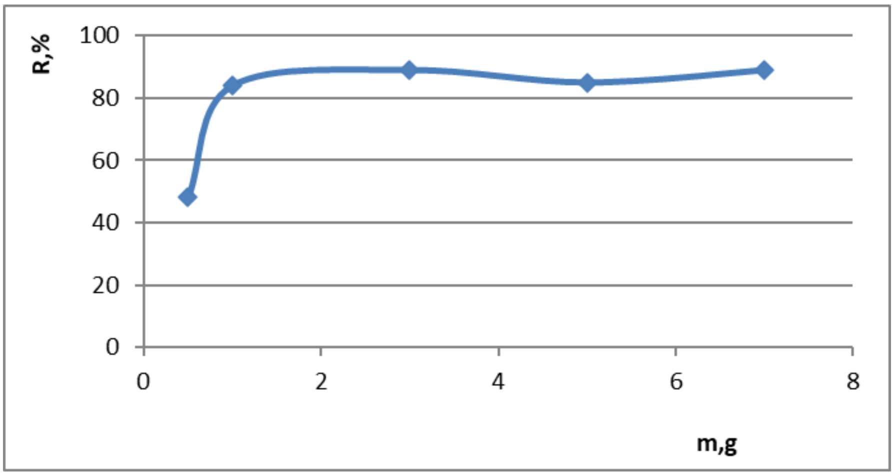

Figure 1 Adsorbent dosage (m, g) impact on Zn (II) adsorption degree (R, %). pH=3,83, τ=1h, t = 20°C, C_{Zn2+} =100mg/l

Silica atoms are tended to maintain at the surface their tetrahedral site (coordination) with oxygen, which is completed through addition to univalent hydroxyl groups with formation of silanol groups: silanol – SiOH, silan-diol – $Si(OH)_2$ and silan-triol – $Si(OH)_3$; hydroxyl groups of aluminum hydroxide – Al(OH) или $Al(OH)_3$ are formed as well. The mentioned groups improve adsorption capacity of perlite [17].

The impact of adsorbent quantity, sorbate dosage, contact time and medium pH on adsorption capacity of the expanded perlite is studied in the work. Adsorbent quantity is one of the most important parameters in the adsorption processes. Ion exchange capacity (volume capacity) and adsorption percentage to a great extent depends on surface activity, in particular, from specific surface area accessible for interaction of dissolved substance with adsorbent surface. Therefore, one may assume that adsorption percentage rises with increase of adsorbent surface area, since the expanded perlite composition includes a large portion of silicon earth.

As is seen from Fig. 1, zinc adsorption degree rises from 48% to 87% (while volume capacity increases from 2,2 to 2,9 mg/g) with increase of adsorbent dose; at that the adsorption process becomes nearly constant when adsorbent mass is 3 g, which has been used for further studies.

Adsorption properties of expanded perlite with regard to zinc ions have been also evaluated depending on contact time, which has been varied from 15 to 150 minutes. At that, the values of main parameters were as follows: zinc concentration – 100 mg/l, solution amount 100 ml, adsorbent dosage-3g.

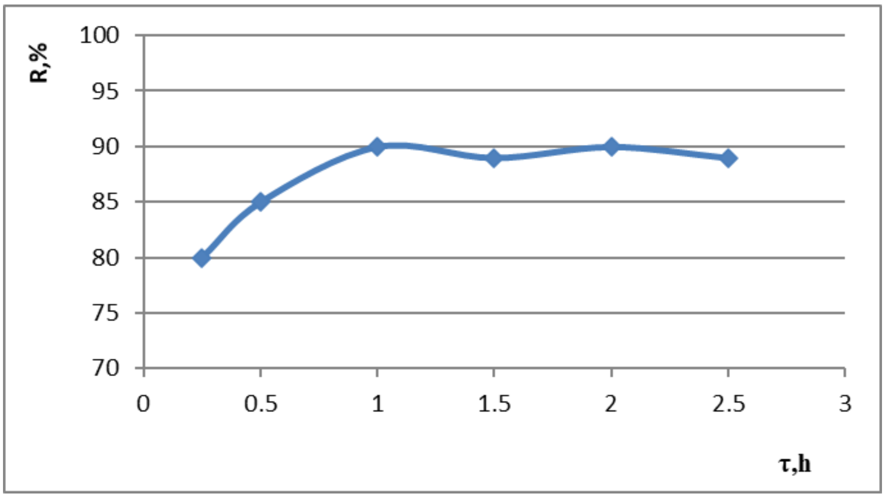

Figure 2 Contact time impact on Zn (II) adsorption degree. pH =3,83, m=3g, t=20°C, $C_{Zn^{2+}}$ =100mg/l.

As is seen from Fig. 2, in the process onset a rapid growth of Zn (II) absorption is observed and the amount of adsorbed Zn(II) increases, as well. After 60 min the adsorption rate decreases and reaches nearly constant value of 90% that determines the state of equilibrium.

In the process onset, the surface adsorption centers actively interact with Zn (II) ions and effectively adsorb these ions. With adsorption time prolongation zinc ions occupied vacant places and after a time almost all active centers have been occupied by ionic Zn(II), so no additional ions could be adsorbed by the surface of expanded perlite that has led to the state of equilibrium [18].

The impact of initial concentration of Zn (II) ions on the adsorptive capacity of expanded perlite has been studied, as well. Experiments have been conducted at initial adsorbate concentration varied from 25 to 350 mg/l. It is known that adsorption depends heavily on initial adsorbate concentration and rises with increase of input concentration of metal. The input concentration provides the necessary driving force for overcoming all resistances to metal mass exchange between aqueous and solid phases [19].

As is seen from Fig. 3, the Zn (II) adsorption degree rises with adsorbate concentration increase and reaches maximum at 100 mg/l concentration, following which the adsorption rate nearly doesn't drop and attains constant values.

Literary sources explain this fact by the increase of Zn (II) ions driving force, and therefore, by rise of the probability of collision and interaction between dissolved metals and active centers placed on the adsorbent surface that has led to improvement of adsorptive capacity, following which a complete saturation of perlite surface with Zn (II) ions and, respectively, an equilibrium state is observed [20].

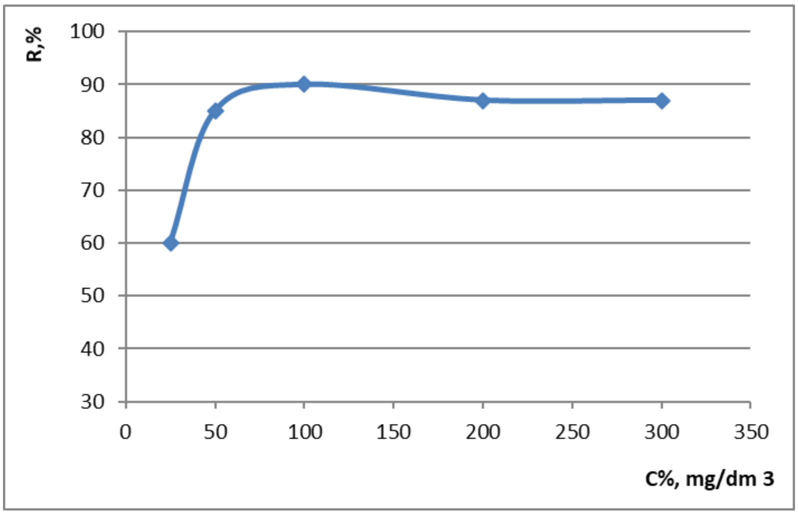

Figure 3 The effect of the solution concentration on Zn (II) adsorption degree. pH=3,83, m=3g, t=20°C, τ=1h.

The impact of solution pH on the zinc adsorption on expanded perlite has been studied. Experiments have been conducted in the range of pH = 2-11, with perlite dosage 3 g, test duration 60 min, zinc concentration 100 mg/l and solution volume 100 ml. It is seen from Fig. 4 that adsorption percentage sharply rises with increase of pH up to pH = 4. Afterwards it increases rather slowly and reaches its maximum at pH = 10.

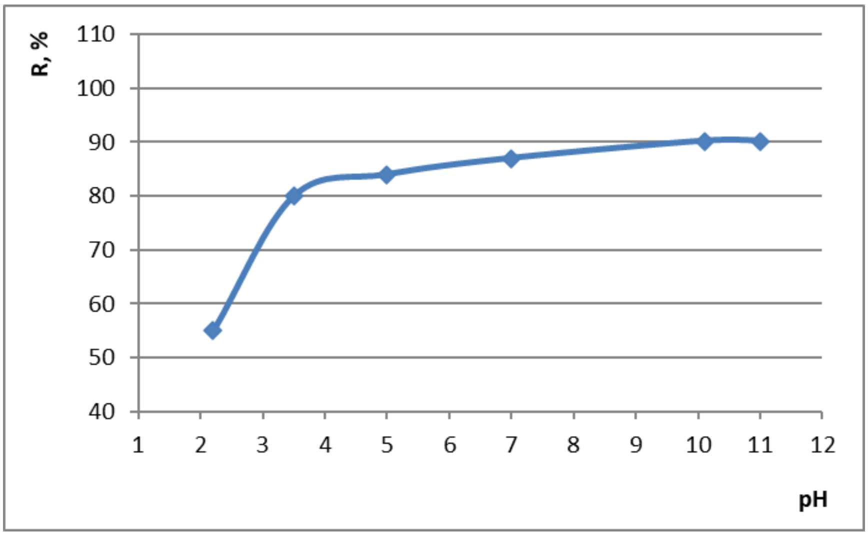

Figure 4 Impact of medium pH of solution under study on Zn (II) adsorption degree. m=3g, τ=1h, t = 20°C, $C_{Zn^{2+}}$ =100mg/l.

In case of low values of pH (2-4) zinc ions are present in the solution in form of Zinc (II) cations, while hydrogen ions totally dominate, so adsorbent surface promotion takes place that assists electrostatic repulsion of metals and decrease of their adsorption, when pH increases from 7 to 12. Thereby the best conditions are created to attain significant electrostatic attraction of zinc ions. As far as the positive charge density on the surface decreases, and adsorbent surface is heavily saturated with electrically negatively charged hydroxylic radicals, all this leads to electrostatic attraction of zinc ions and increase of metal adsorption on the adsorbent.

It is established that such type of adsorption degree dependence on medium pH is related to the state changes of sorbent active centers [21].

4. Conclusion

The applicability of the Georgian expanded perlite as a cheap and active adsorbent for water purification from zinc ions have been explored in the presented work. Adsorptive properties of expanded perlite in the process of zinc adsorption depending on adsorbent dosage, contact time, adsorbate concentration and solution pH values have been studied.

Optimum conditions for Zn(II) adsorption on the expanded perlite have been selected. The maximum adsorption percentage has been reached when contact time is 1 h, adsorbent quantity – 3g, adsorbate concentration 100 mg/l and pH value – 8-10.

Compliance with ethical standards

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Disclosure of conflict of interest

All authors of the Article, have no conflict of interest.

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