(RESEARCH ARTICLE)

Iron (III) adsorption on perlite

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Abstract

The present research set a goal of study of applicability of the expanded perlite obtained on the basis of perlite – natural mineral of Georgia, from adsorption removal of Fe^{3+} ions from aqueous solution.

Adsorptive characteristics of the expanded perlite have been studied in the process of aqueous solution purification from trivalent iron ions in regard to adsorbent dosage, contact time, adsorbate concentration and solution pH. The dependence of adsorption degree and adsorptive capacity of the expanded perlite from the above-mentioned parameters have been uncovered.

Optimum conditions of Fe^{3+} ions adsorption have been established. Maximum values of adsorption degree and adsorptive capacity were equal to 89% and 4,45mg/g, respectively.

Keywords: Expanded perlite; Adsorption; Adsorption degree; Adsorptive capacity

1. Introduction

Enhancement of the ecological state is an indispensable condition of improvement of quality of life and population health, and is necessary for provision of ecological safety and environment protection.

Stage-by-stage development of the extraction and processing technology in the mining, coal-mining, chemical industries, ferrous and non-ferrous metallurgy, machine building etc. leads to the gradual increase of the environmental pollution.

Due to large quantities of untreated waste waters formed during engineering processes and thrown away by the industrial enterprises, a rapid deterioration of ecological situation takes place. Among the substances most dangerous to human health and ecosystem conditions one can name the heavy metal ions and their compounds, which are in abundance in the industrial enterprise sewages [1, 2].

It is known that the industrial activity of the ore mining and processing enterprises results in the annual discharge of more than 45000000 ton of solid substance into atmosphere and roughly 2.5 billion m^3 of polluted waste waters entry into water bodies.

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Inhabitance in close proximity to mining enterprises leads to deterioration of population health and development of ecology-related illnesses, since heavy metals make problems for water and soil quality, for plants, animals and human life.

Environment protection and analytical review of waste waters are among the basic measures taken across a globe.

Regarding all the above mentioned, in order to remove heavy metal ions from the industrial waste waters there are used many new methods, including modern, conventional and unconventional ones, such as: chemical precipitation, extraction using solvents, ion exchange, phytoextraction, reverse osmosis, electrodialysis, adsorption etc. [3, 4].

Iron is the most widespread element next to aluminum among the heavy metals, and its quantity equals to 4% of the earth crust. Iron can entry the water both upon contact with the minerals of the ground and resulted in engineering processes taking place at the enterprises.

Iron is an important microelement participating in the process of hematogenesis, acts a serious role in the thyroid gland functioning and takes part in enzyme formation. Therefore an iron shortage in the organism is harmful for a human, and its elevated level (>0,3mg/l) causes side effects: has an effect on blood composition, promotes gastrointestinal tract disorders, causes allergic reaction, mental deficiency and may even cause visceral injuries.

The maximum permissible iron concentration in the drinkable water has to be within the limits of 0,2-0,3mg/l. In this regard, the investigation and development of simple technologies of waste waters purification from iron ions is quite relevant. Iron is presented in the water as Fe^{2+} and Fe^{3+} ions. Therefore, the adsorption method, which makes it possible to effectively and economically solve the environmental problems is one of the most prospective and interesting methods of sewage treatment [5].

The most attention is paid to sorption systems, which adsorbents are distinguished by local accessibility, high adsorptive capacity and economic efficiency. Cheap and effective natural alumosilicates and minerals of different structure are usually used as sorbents [6-7].

In this work, we have used perlite – a natural mineral of Georgian deposit. 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-times bulking compared to its initial volume and with 70-90% porosity. Detailed data on Georgian perlite deposits, its mining and processing, as well as on its chemical and physical properties were given in our previous works [5, 7].

The present work has been aimed to investigation of adsorptive capacity of Georgian expanded perlite in the process of Fe^{3+} ions removal from the aqueous solution. The effect of medium pH, adsorbent dosage, contact time and adsorbate concentration on the Fe^{3+} 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 Fe^{3+} adsorption. The volume of the Georgian perlite has been increased 30 times when heated up to 900-1100°C. Physical data and chemical composition of the Georgian perlite are given in the work [7].

For preparation of the standard solution containing Fe^{3+} ions ferrous ammonium sulfates have been dissolved in the distilled water taking the given concentration (100 mg/l) into account.

2.2. Experimental part

Experiments on iron ions adsorption on the expanded perlite at the given values of pH, contact time, adsorbent dosage and adsorbate concentration have been conducted. In order to determine the optimum quantity of expanded perlite in regard to Fe^{3+} adsorption, different quantities (1-7 g) of adsorbent have been placed in the container, poured with 100ml of the iron solution under study, then containers have been closed, shaken up for 1 hour and filtered, analyzed and the optimum quantity of adsorbent equal to 5g has been chosen.

In order to establish the optimum shaking time, 5g of adsorbent have been placed in containers, poured with 100ml of standard Fe^{3+} solution and shaken. Samples have been collected after 30, 60, 120, 180 minutes and the optimum contact time has been defined, which was equal to 60 minutes.

The effect of adsorbate concentrations in the process of Fe^{3+} cations adsorption on the investigated sorbent has been studied using the method of permanent sample weights and alternate concentrations, which have been varied within 20-300mg/l.

Optimum quantity, 5g of adsorbent has been placed in containers, poured with 100ml of standard solution and the sorbent-sorbate system has been shaken for an hour at 20°C temperature, filtered and analyzed.

It is known that solution pH is one of the important parameters of the adsorption process. With the purpose of determination of medium pH effect on iron adsorption, pH has been varied within 2 - 6 via addition of salt acid (hydrochloric acid). The solution with the given pH has been poured into containers with 5g of expanded perlite already placed there, substances have been stirred, then the contents have been filtered and the filtrate has been analyzed for iron ions content.

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

The amount of iron adsorbed per unit weight of adsorbent surface (adsorption capacity) A mg/g, and Fe^{3+} 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/dm³;
C — aposteriori (after the test) concentration;
m — Sorbent weight, g;
V — Volume of purified solution, dm³.

3. Results and discussion

The regularities of water solution treatment from Fe^{3+} ions through adsorption method using the local mineral – perlite have been investigated.

It is known that perlite mainly consists of silica in the form of SiO_2 (72-76%) and alumina, 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 other oxide groups.

Silicon atoms form silanol groups at the surface of perlite, namely: silanol – SiOH, silanediol – Si $(OH)_2$ and silanetriol – $Si(OH)_3$ groups; hydroxyl groups of aluminum hydroxide Al(OH) or are formed $Al(OH)_3$ as well. The mentioned groups promote adsorptive capacity of metal oxide aqueous solutions and this way predetermine the adsorptive nature of perlite [8].

The effect of sorbate dosage, contact time, adsorbent quantity and medium pH on the adsorptive capacity of the expanded perlite is studied in the work.

Adsorbent quantity is one of the most important parameters of adsorption processes. Ion exchange capacity and the adsorption percentage to the large extent depends on specific surface area available for dissolved substance interaction with the surface. Therefore it is assumed that ion-exchange capacity increases with the extension of adsorbent surface area [7-10].
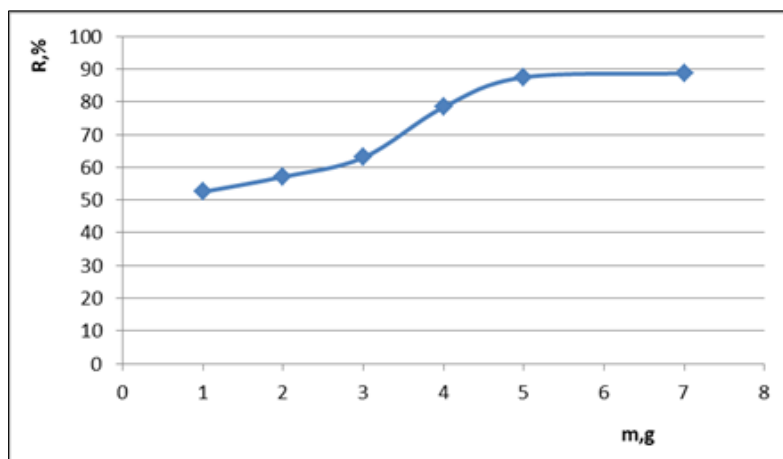
Figure 1 Adsorbent dosage (m, g) impact on Fe^{3+} adsorption degree (R, %). pH =2,6, τ=1h, t = 20°C, $C_{Fe^{3+}}$ =100mg/l

In Fig. 1 there is shown the dependence of Fe^{3+} ions adsorption percentage from adsorbent quantity. It is seen from the diagram that adsorption degree increases with the growth of adsorbent quantity from 53,8 to 88%, while adsorptive capacity rises from 0,17 to 4,45mg/g, since the bigger adsorbent surface becomes available for adsorption of the dissolved substance.

The figure shows that adsorption percentage becomes almost constant, when adsorbent weight is $\geq$ 5g. Based on this fact, 5g have been taken for subsequent experiments.
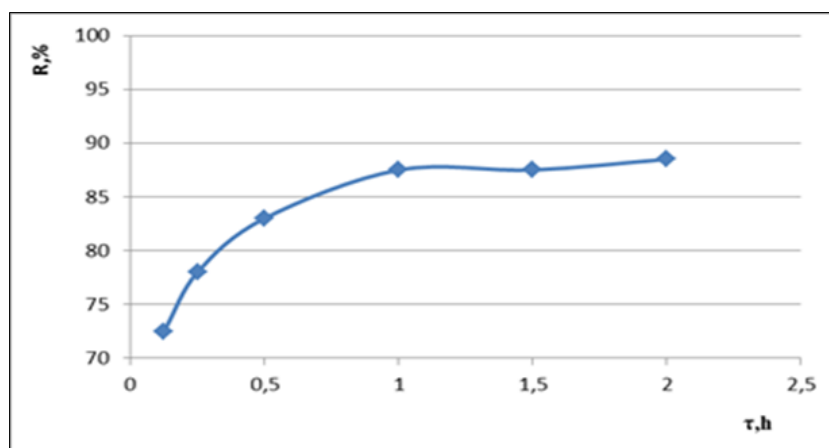

Figure 2 Contact time impact on Fe^{3+} adsorption degree. pH =2, 6, m=5g, t=20°C, $C_{Fe^{3+}}$ =100mg/l

Figure 2 shows the effect of contact time on adsorptive capacity of Fe^{3+}. As is seen, the Fe^{3+} concentration in aqueous solution rapidly decreases for the first 30 minutes, adsorption percentage rises correspondingly and reaches the maximum 88% when t=60 minutes, after which it remains almost constant. That's why 60 minutes have been selected as the optimum contact time.

The effect of Fe^{3+} ions initial concentration on the adsorption capacity of the expanded perlite has been studied as well. Experiments have been conducted within wider range of adsorbate (standard solution) concentrations from 25 to 300mg/l. In order to obtain the given adsorbate concentrations a standard solution has been diluted with respective amounts of distilled water.

It is known that adsorption heavily depends on initial concentration of adsorbate and almost linearly increases with the increase of initial metal concentrations. Input concentration provides the necessary driving force for overcoming all kinds of resistance to metal mass exchange between aqueous and solid phase [11].
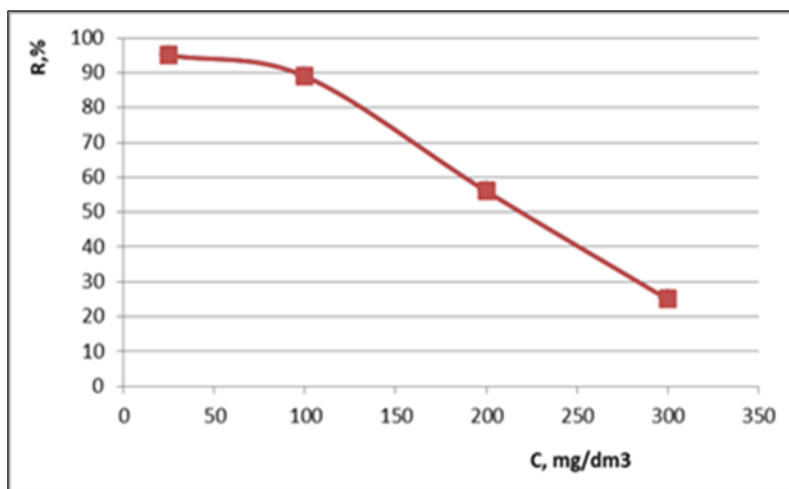
Figure 3 The effect of the solution concentration on Fe^{3+} adsorption degree. pH =2,6, m=5g, t=20°C, τ=1h

Worth noticing the amazing fact that almost in all tests the increase of initial iron concentrations leads to decrease of Fe^{3+} adsorption (Fig. 3). As is seen from the figure, the maximum adsorption percentage is reached, if concentration equals to 25 mg/l, falls at higher concentration and becomes equal to 20%, when concentration is 300 mg/l. It should be mentioned that dissolved salt (which has been used for preparation of standard solution) makes a significant contribution to ionic strength of the adsorbate and in case of Fe^{3+} concentration increase it falls out as precipitate $Fe(OH)_3$, so the adsorption percentage (and adsorption capacity, respectively) is getting smaller. It seems that Fe^{3+} hydrolysis takes place, which has an effect on adsorption mechanism. It is known that such groups as OH^- and SO_4^{2-} weaken the adsorption capacity [13].

Adsorbate solution pH is the most important parameter controlling metal ions sorption on the adsorbent. It is related to the fact that hydrogen ions are strong competing sorbates. At low pH, the positive charge (proton) increases at the adsorbent surface areas that leads to electrostatic repulsion of metal ions and reduction of their adsorption. Electrostatic repulsion reduces with increase of pH due to protons density decrease, as a result the surface becomes negatively charged that leads to metal ions adsorption increase [8, 14].

Fig. 4 shows the effect of pH on iron adsorption capacity: pH value has been varied within limits of 2-3,4, for this purpose the standard Fe^{3+} solution (pH=4) has been acidified though addition of HCl.
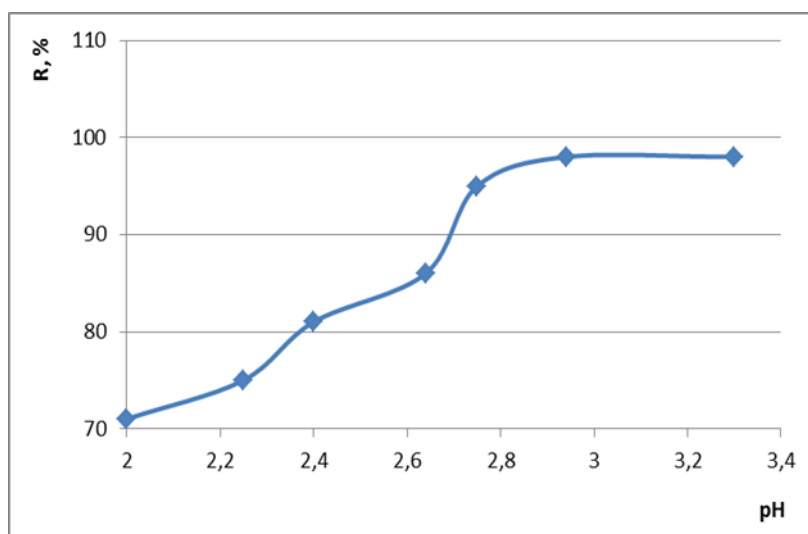

Figure 4 Impact of medium pH of solution under study on Fe3+ adsorption degree. m=5g, τ=1h, t=20°C, CFe3+ =100mg/l

As is seen from Fig. 4, degree of Fe^{3+} adsorption in case of pH value increase from 2,0 to 3,32 is getting bigger from 75% to 98% and becomes almost constant within the 2,8-3,32 limits. At pH values higher than 3,32, we were unable to vary the dependence between adsorption capacity and hydrogen index value. The reason is that the precipitation in the form of iron hydroxide took place that reduces adsorption rate as well as iron removal percentage from the solution.

4. Conclusion

In the presented work, for the first time there has been studied the applicability of Georgian expanded perlite as cheap and active adsorbent for reduction of environment pollution with Fe^{3+} ions. Adsorptive properties of expanded perlite in the process of Fe^{3+} adsorption in terms of adsorbent dosage, contact time, adsorbate concentration and solution pH values have been studied.

Optimum conditions for Fe^{3+} adsorption on the expanded perlite have been selected. Maximum efficiency has been reached when pH =3,32, adsorbent quantity – 5g, time contact –1 hour and adsorbate concentration – 100 mg/l. Under mentioned conditions, Fe^{3+} adsorption percentage on the expanded perlite was equal to 89%, while adsorption capacity was 4,45mg/g.

Compliance with ethical standards

Acknowledgments

Disclosure of conflict of interest

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

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