Development of Water Softening Method of Intake in Magnitogorsk

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Abstract. This article contains an appraisal of the drinking water quality of Magnitogorsk intake. A water analysis was made which led to the conclusion that the standard for general water hardness was exceeded. As a result, it became necessary to develop a number of measures to reduce water hardness. To solve this problem all the necessary studies of the factors affecting the value of increased water hardness were carried out and the water softening method by using an ion exchange filter was proposed. The calculation of the cation-exchanger filling volume of the proposed filter is given in the article, its overall dimensions are chosen. The obtained calculations were confirmed by the results of laboratory studies by using the test installation. The research and laboratory tests results make the authors conclude that the proposed method should be used to obtain softened water for the requirements of SanPin.

1. Introduction

In the actual centralized domestic water supply system of Magnitogorsk water comes from three underground water supplies. According to the results of realized studies, from the wells of the water intake investigated in this work water is supplied with hardness that exceeds the requirements of SanPin [1].

To ensure the further standard exploitation of this water intake, it is necessary to develop measures for softening the extracted ground water.

2. Chemical constitution and ground-water quality

The laboratory tests on organoleptical, generalized, microbial attributes, as well as on inorganic substances were conducted to analyze the water quality of Magnitogorsk intake. A complete chemical analysis was carried out during 2012-2016 quarterly on each of 8 wells at the water intake.

The received data showed that the ground water of investigated deposit on the chemical constitution is chloride-sulfate-hydrocarbonate magnesium-sodium-calcium with a dry residues of 0,5-0,7 g/dm³, with sulfates content of 94-339 mg/dm³, with chlorides content of 32-155 mg/dm³.

In samples from all wells in 58-83% of cases the excess of standard of general water hardness is 7,0-9,3°dH, in unit samples of ferrum up to 3,08 mg/dm³ and of manganese up to 0,29 mg/dm³. It is interesting to note that this excess is increasing during the investigated period (figure 1).
In a mixture of ground water from all wells of water intake at the station of the 2nd rise in 79% of samples the excess of MPC of ferrum is up to 8.1°dH, when the average value is 7.4°dH; the content of ferrum and manganese is normalized. Ammonia, nitrates and nitrites are in trace amount.

The water quality in the investigated underground source does not create restrictions to use it as a productive aquifer. The forecast of water quality under conditions of stable chemical constitution is profitable, provided that the actual aquicultural situation is maintained within the collecting area of deposit and in the basin.

The ground waters of investigated deposit are classified as natural unqualified ground waters in terms of general hardness, therefore the water softening must be included in the water treatment complex [2].

3. Current position

General ferrum, general hardness and dustiness have double standards in the reference documents of water quality in Russian Federation – nationwide and local. The MPC can be set by the Chief State Medical Officer of relevant territory and for particular water supply system [3]. The nationwide standards comprise of ferrum 0.3 mg/l, dustiness 1.5 mg/l, hardness 7 mg-eq/l. In Magnitogorsk the MPC for hardness is carried at the regional level, it equals to 9 mg-eq/l. The temporary limit of MPC for Magnitogorsk is valid until the end of 2017 [4].

The problem of increased hardness is solved currently by mixing domestic potable water, coming from all three intakes of the city, in water supply ring-net. In this case hardness decrease is achieved due to a lower water hardness index delivered from others underground water supplies of Magnitogorsk.

As a result of data processing on exploitation of investigated water intake, it was revealed that the actual daily average water extraction from wells from 2007 to 2016 decreased 2.4 times. This fact caused by an increase of water hardness index. The schedule of changes of water extraction from investigated underground water supply is shown in Figure 2.

Figure 1. The dynamics of change of general water hardness in 8 wells of Magnitogorsk in 2012-2016.
The tendency of increase of water hardness index with its chaotic short decrease was noted according to results of the analysis of chemical constitution of ground water in investigated intake.

In this case, it is interesting to identify factors that affect the value of ground water hardness [5]. In the capacity of such factors were accepted:

- influence of atmospheric condensation;
- influence of quantity of water taken from the wells.

In order to check the possible influence of atmospheric condensation on ground water hardness, a comparative data analysis on water hardness in wells and precipitation depth was carried out. The results of the August 2015 analysis are shown in Figure 3.

The received data indicate that the ground water hardness of investigated intake does not depend on the precipitation depth.

The quantity of water extraction from wells was considered as the second factor affecting the hardness index. The comparative data analysis on water hardness and quantity of water taken from the wells established that the concentration of hardness salts in the given well increases when the water extraction decreases.

4. Ion-exchange water softening

In the result of analysis of actual studies devoted to decrease of drinking water hardness [6,7,8], it was found that the ion-exchange is the most acceptable method to solve this problem.

The ion-exchange softening is carried out with the passing of hard water through cation exchangers [9,10]. Moreover, to obtain domestic potable water of the required hardness as a rule some of it is softened with the following mixing in the general volume [11]. Then the quantity of softened water $Q_s$ (in percent) is determined by the formula:
\[ Q_s = \frac{H_{t,s} - H_{t,n}}{H_{t,n} - H_{t,sof}} \times 100\% = 16\% \]  

where \( H_{t,s} \) – total hardness of source water, mg-eq/l; \( H_{t,n} \) – total hardness of water entering the net, mg-eq/l; \( H_{t,sof} \) – total hardness of softened water, mg-eq/l.

The softened water discharge \( q_s \), m³/h, is determined by the formula:

\[ q_s = Q_s \frac{G}{100} = 142.72 \]  

where \( G \) – actual water extraction from intake.

A single-stage ion-exchange scheme based on technical-and-economic indexes and required indexes of renovated water was chosen to soften water on the investigated intake [11]. Also the cation resin of home manufacture CU-2-8CHS was adopted as a filter filling on the ground of technical-and-economic compare [13-15].

The physicochemical cationite parameters CU-2-8CHS according to GOST are shown in the table 1 [13].

| Index name                               | Nameplate CU-2-8CHS |
|------------------------------------------|---------------------|
| Grain size, mm                           | 0.4-1.25            |
| Total static exchange capacity, m eq/sm³ | 1.8                 |
| Dynamic exchange capacity, g eq/m³ minimum | 1700               |
| Residual hardness after the first stage, g eq/m³ | 0.05               |

The volume of filling and the sizes of filters are calculated for actual capacity of investigated intake. According to the calculation procedure given in SP [11], the volume of cationite \( W_c \), m³/h, is in the filters of the first stage:

\[ W_c = \frac{24 \cdot q_s \cdot H_{t,s}}{n \cdot C_{op}} = 10.85 \]  

where \( q_s \) – softened water discharge, m³/h; \( H_{t,s} \) – total hardness of source water, g-eq/m³; \( C_{op} \) – operating cation exchange capacity, g-eq/m³; \( n \) – number of regenerations of each filter per day taken in the range from one to three.

The operating cation exchange capacity, g-eq/m³, was determined by the formula:

\[ C_{op} = \alpha_{Na} \cdot b_{Na} \cdot C_{com} - 0.5q_{op} \cdot H_{t,s} = 1262.6 \]  

where \( \alpha_{Na} \) – efficiency coefficient of cationite regeneration (considering the incompleteness of cationite regeneration receivable from 0.62 to 0.9 depending on the solution consumption for regeneration); \( b_{Na} \) – coefficient considering the decrease of cation exchange capacity of Ca²⁺ and Mg²⁺ because of the partial retention of cationites Na⁺ receivable to [11]; \( C_{com} \) – complete cation exchange capacity, g-eq/m³; \( q_{op} \) – specific discharge of water to washing cationite, m³ per 1m³, receivable to [8].

The area of cation exchangers of the first stage \( F_c \), m², was determined by the formula:
where \( H_c \) — highness of cation bed in the filter, receivable from 2 to 2.5 m.

The cation exchanger is structurally a seal tank or a balloon that is full of ion resin [16,17].

The number of cation exchangers of the first stage is accepted: working – at least two, reserve – one [11].

To clarify the overall dimensions of the filter, the diameter of the tank \( D_i \), m, was determined by the formula:

\[
D_i = 4 \frac{F_c}{\pi \cdot k} = 2.76
\]

where \( k \) — number of filters, pcs, (from 2pcs is taken in view of the maximum universal filter diameter (3400 mm)) [12].

According to the data [12], the overall dimensions of cation exchanger are: the diameter of tank is 3000 mm, the height of tank is 5645 mm [19,20].

Thus, in the result of calculation, the cation exchangers are chosen to solve this problem, especially to decrease the ground water hardness on the investigated intake to standardized value.

5. Experiment

To confirm the results received due to calculation, experimental studies of the efficiency of ion-exchange water softening in the investigated intake were carried out. An experimental model of cation exchanger, on which the studies were carried out in laboratory conditions, was created on the basis of calculation results. The filter was filled with cation resin of home manufacture CU-2-8CHS. After ion-exchange water softening its hardness was determined on experimental model. The water analysis was conducted by the method of alkalimetric test by trilon B [20].

For the study the water samples were taken from the reservoir of the investigated intake with an average hardness. Water was taken in the volume of 5 l.

The average hardness of the water samples on the basis of chemical analysis before the studies was 7.8 g-eq/m³.

After filtering a part of water in the experimental assembly through the layer of cationite CU-2-8CHS its hardness decreased to 0.04 g-eq/m³.

According to the calculations, a sample of source water in volume of 4 l was combined with 0.64 l (16%) of softened water. From the analysis the mixing hardness was 6.7 g-eq/m³.

Based on experience gained on the experimental model, the following results were received:
- the hardness of softened water filtered through the cationite CU-2-8CHS answers the specified requirements;
- the source water hardness after mixing with softened water is less than the MPC;
- the experimental model of cation exchanger, created due to calculation results, allowed to achieve the required standards of water hardness in investigated intake;
- the ion exchange is recommended for investigated intake as a method of ground water softening.

6. Conclusion

In this work, a chemical analysis of ground water quality of one of the intakes in Magnitogorsk was carried out. The results showed a hardness excess of MPC. To solve this problem, it was proposed to use the method of ion-exchange water softening.

To reduce the hardness, the ion-exchange filter with Na-cationite filling of resin CU-2-8CHS, which has all the qualitative adjectives necessary for water softening with the view of water drinking supply, was chosen.
According to results of calculation, two filters of 3.0 m in diameter with the cationite filling height of 2.5 m and one reserve filter were picked up for water softening in investigated intake.

An experimental model of ion-exchange filter was created with the calculation results to test the efficiency of the chosen method. The results of the experiment showed that because of filtering through chosen filter, the required hardness of investigated water can be achieved.

The ion exchange method is recommended to reduce the water hardness in investigated intake of Magnitogorsk to standard.

References
[1] ME Vodokanal Trust 2008 Water supply Retrieved from http://magvoda.ru
[2] Goldberg V M 1976 Hydrogeological forecasts of ground water quality in intake (Moscow: Mineral Resources) p 153
[3] 2010 Drinking water. Hygienic requirements to water quality of centralized drinking water supply systems. Quality control. Hygienic requirements to safety ensuring of hot water systems. Concerning the implementation of sanitary rules 2.1.4.1074-01
[4] Territorial Mineral Reserves Commission of the Chelyabinsk Region 2013 Minutes of the Meeting 438
[5] Zlobin V L 2002 Impact of atmospheric precipitation on acidification of groundwater p 336
[6] Frog B N and Levchenko A P 1996 Water reclamation (Moscow: MSU Publishing House) p 680
[7] Kozhinov V F 1971 Drinking water and process water treatment. Examples and calculations (Moscow: The Book on Demand) p 302
[8] Belikov S E 2007 Water reclamation: Reference book (Moscow: Aqua-Term) p 240
[9] Bolotova Y V, Kareлина K A and Nosikov S V 2015 Provision of minimum reagent costs, volume and cost of equipment and ion exchangers in water softening process Bulletin of the Perm National Research Polytechnic University. Applied ecology. Urbanistics 2 pp 128–45
[10] Amosov E G, Dolgopolov P I, Potapova N V, Malakhov D G and Zhuravlev S P 2003 Experience in applying countercurrent sodium cationing technology in boiler houses Sanitary engineering 2
[11] 2015 SP 31.13330.2012 Water supply. External networks and facilities. Revised edition of SNiP 2.04.02-84 (as amended 1, 2) (Moscow)
[12] Asonov A M 2007 Calculation of cation plants for water softening in industrial boiler-houses (Ekaterinburg: USURT) p 43
[13] 1976 GOST 20298-74 Ion-exchange resins. Cationites. Technical conditions (Moscow: PPC Publishing house of standards) p 15
[14] 2012 Ion exchange resins and their properties Retrieved from http://www.aqua-therm.ru/articles/articles_217.html
[15] Trading House Ural Chemical Company 2017 Production Retrieved from https://td-uhk.ru
[16] Byreniepro 2017 Filters for cleaning Retrieved from http://byreniepro.ru
[17] Information-reference catalog Water-preparation equipment. Filters Na-cation exchangers. Introduction is 1 p 5 Retrieved from http://water.sarzem.ru
[18] Sodium cation filters Retrieved from http://www.armatyra.org/tx_opis/fipa.html
[19] 2011 Water softening by sodium cationing COK 4 Retrieved from https://www.c-o-k.ru/articles/umyagchenie-vody-metodom-natriykationirovaniya
[20] Kharitonov Y Y, Jabarov D N and Grigorieva V Y 2012 Analytical chemistry. Quantity determination. Physicochemical methods of analysis (Moscow: GEOTAR-Media) p 368