DETERMINATION OF PHYSICAL AND CHEMICAL PARAMETERS OF WATER BEFORE AND AFTER ION EXCHANGE TREATMENT

ORIGINAL SCIENTIFIC PAPER

Indira Šestan, Sabina Begić, Melisa Ahmetović✉, Husejin Keran, Erna Begić, Dženana Mehmedović, Vanja Srebro

DOI: 10.51558/2232-7568.2023.16.2.67

RECEIVED 2023-12-15 **ACCEPTED** 2024-04-15

Faculty of Technology, University of Tuzla, Urfeta Vejzagića 8, Tuzla, Bosnia and Herzegovina

✉ melisa.ahmetovic@untz.ba

ABSTRACT:
In accordance with consumer requirements, the water must be adequately purified, and the corresponding parameters within the defined values. Various methods are used for this purpose, of which the ion exchange method can be highlighted as the simplest, most efficient and economically profitable. Ion exchange is a reversible process of ion exchange between a solid phase and an electrolyte solution. The ion exchanger is a macromolecular insoluble material that has chemically bound electrified groups and mobile, oppositely charged ions that compensate for this electrification. Ion exchangers are usually used in the form of compact or granular beds that fill the column through which the solution with the ions to be exchanged flows. They usually contain phenolic, carboxylic, sulfonic amino and other groups, which is why the treatment also results in decarbonization, softening, demineralization and denitrification of water. As the assessment of water quality is based on the most significant physico-chemical parameters, the aim of the work is the analysis of drinking water before and after treatment with an ion exchanger. For this purpose, organoleptic parameters such as smell, taste and color were first analyzed. After that, physico-chemical parameters were analyzed: pH values, electrical conductivity, m-alkalinity, p-alkalinity, water hardness, organic matter content, chloride content, iron and manganese content. An ion exchanger based on resin was used, which after use was regenerated by washing with NaCl solution. The analysis of the water sample, before and after the ion exchange treatment, showed that the treatment process was effective and that the decarbonization and softening of the water was carried out, whereby the water was categorized as soft water (water <9 ^{0}dH). The analyzed water is tasteless, odorless and colorless before and after treatment. The results of the analysis showed that all the values of the analyzed physico-chemical parameters are in accordance with the Rulebook on the Healthiness of Drinking Water (Official Gazette of Federation of Bosnia and Herzegovina No. 40/10) are below the maximum allowed values.

KEYWORDS: water, ion exchange, physical-chemical parameters; water treatment

INTRODUCTION

Water is one of the most important substances in nature and an irreplaceable resource for households, agriculture, industry, etc. [1]. The exponential growth of humanity is paralleled by the exponential growth of water consumption, whereby the importance of natural sources of quality water is increasing. Following consumer requirements, the water quality parameters should have suitable values. Therefore, different types of water can be treated with the same technologies, and most often combinations of different treatment processes are applied in water technology. One of the simplest and most effective methods is ion exchange, that is, the membrane method with ion exchange.

Namely, the process of ion exchange results in the exchange of mobile ions in a stoichiometrically equivalent amount with the corresponding ion charge from the solution. The management of the process itself is simple, and the installation of the ion exchanger does not require significant reconstruction, and the desired water quality can easily be achieved by combining certain types of ion exchangers. Ion exchange is carried out in a column filled with an ion exchanger, and after the saturation of active groups, the ion exchanger is regenerated with a solution of an elution agent, which converts the exchanger back into its initial ionic form. Ion exchangers are insoluble macromolecular polyelectrolytes that show the ability to exchange ions. Each exchanger consists of a skeleton or lattice, which is held together by covalent bonds to which active groups that dissociate in water are firmly attached and are therefore electrically charged, so the exchange is carried out at exactly fixed places within the lattice. If those groups are acidic, the lattice is externally charged with a negative charge, and if they are basic, it is charged with a positive charge. This charge is compensated by a moving ion of the opposite charge so that each particle of the exchanger is electrically neutral to the outside [2,3].

The technology of water treatment using ion exchangers is most often used for the purpose of water decarbonization (dealkalization), water softening, water softening with prior decarbonation, water demineralization, and removal of nitrites (denitrification) and organic substances from water [4,5].

Water quality is determined by various regulations and must be followed. Therefore, water analysis is one of the main measures to prevent and control infectious diseases. It is determined by the size of certain indicators (chemical, physical and biological) that speak about the composition, concentration and properties of certain substances present in the water. The goal of this work is to determine the physico-chemical and organoleptic properties before and after treatment in order to define the water quality and determine the concentrations of the analyzed parameters.

MATERIALS AND METHODS

A water sample from the tap, which is fed from the source of Cerik, Tuzla, was used for analysis before and after treatment with an ion exchanger. Physico-chemical parameters (pH values, electrical conductivity, m-alkalinity, p-alkalinity, water hardness, organic matter content, chloride content, iron and manganese content) as well as organoleptic parameters (odor, taste and color) of tap water sample were analyzed. In accordance with standard methods (APHA, 2000 and the Law on Water Official Gazette of the Federation of Bosnia and Herzegovina No. 70/06), a water sample was analyzed for the analysis of physical and chemical parameters, after which the water was subjected to treatment with an ion exchange device (ion exchange resins). The ion exchange device is used for softening, decarbonizing and demineralizing water. After the treatment, the analysis of the mentioned parameters was repeated. A column of the Italian brand Monostand M-100 was used - Resinex Kw-8 type of ion exchange resin, with a capacity of 5 m^3/h, which is filled with resin based on sodium ions with the possibility of regeneration.

Water analysis before and after treatment was done at the Faculty of Technology of the University of Tuzla. Analytical methods and detection limits for all tested parameters are shown in table 2, and more detailed descriptions of the applied analytical method itself and a discussion of the results are shown below the table. The obtained values were compared according to the Rulebook on the Healthiness of Drinking Water (Official Gazette of the Federation of Bosnia and Herzegovina No. 40/10)

PHYSICAL PARAMETERS OF WATER QUALITY

Temperature is a physical indicator of drinking water quality. In ideal cases, the water temperature is constant or with small deformations (8-14ºC). Increased water temperature values are a consequence of thermal pollution, and it depends on the depth, thermal conductivity of the rocks, the lithological structure of the rocks and the proximity of magmatic bodies [6]. Water temperature before and after treatment was measured with a thermometer (in ºC).
Electrical conductivity represents the total amount of dissolved salts or ions in water and depends on the ions present in the water, concentration, mobility and charge of ions, temperature, etc. It is carried out with the aim of determining the degree of water mineralization and filtration residue (total soluble matter in the water sample), and was carried out by measuring on a Mettler Toledo conductometer. The device was first calibrated using standard calibration solutions (conductivity of 814 μS/cm and 1413 μS/cm), and then the measurement was performed [7-10].

ORGANOLEPTIC PARAMETERS

Table 1. Scoring system for intensity of taste and smell of water [11]

Number of points	The strength of the smell	Description
0	Without	Absence of smell, it cannot be noticed
1	Very weak	The smell can be determined by a specially trained person
2	Weak	Odors do not attract the attention of water users. But it can be noticed if it is pointed at.
3	Noticeable	The smell is easy to detect and causes hesitation to use water
4	Significantly	The smell that is immediately felt and causes attention, and makes the water unsuitable for drinking.
5	Very strong	The smell is so strong that it makes the water unsuitable for drinking

The smell and taste of water originate from the presence of organic and inorganic contaminants, from biological sources and processes, contamination with synthetic chemicals, corrosion or as a result of water treatment. The smell of water was determined organoleptically at room temperature and at 40 ºC, and was defined descriptively according to the table provided by the author [11]. The taste test was performed by heating the sample to 40°C and holding it in the mouth for several seconds in order to come into contact with the receptors in the mouth.

THE COLOR OF THE WATER

The color of water is an optical property, and it is the result of the absorption and reflection of light of a certain wavelength. Water color is a parameter that is not always related to toxicity or pathogen contamination, but it is on the list of aesthetic parameters and the recommended value in water is 15 color units.

CHEMICAL PARAMETERS OF WATER QUALITY

pH value

The pH value is a very important indicator of water quality because a large number of water cleaning procedures depend on the pH value. The required optimal pH value of the water varies in different sources according to the composition of the water, but it is most often from 6.5 to 8.0. It is necessary that the pH value of drinking water be neutral to slightly alkaline (pH=7.0-7.4) because acidic waters corrode water pipes, while alkaline waters create sediment [11]. The pH value before and after the ion exchange treatment was determined using a pH meter Mettler Toledo 220.

Alkalinity of water

Alkalinity of water is a factor of the capacity of water to receive H+ ions. It is determined by acid titration of the sample and is expressed as total alkalinity (m-alkalinity) determined with methyl orange as an indicator that induces a change at pH 4.3, and phenolphthalein alkalinity (p-alkalinity) as a quantitative measure of alkalinity up to pH 8.3.

$$MA = 10 \cdot m \quad (1)$$
$$PA = 10 \cdot p \quad (2)$$

where is:
m- volume of HCl (ml) used for titration with methyl orange as an indicator;
p- volume of HCl (ml) used for titration with phenolphthalein as an indicator.

Water hardness

Water hardness represents the total concentration of calcium and magnesium ions expressed as $CaCO_3$. It is determined according to the amount of calcium and magnesium ions, by titration with EDTA with the indicator erichrome black, d.s. Considering the total hardness of the water, it can be divided into: soft water (up to 9 ºnj), moderately hard water (9 - 18 ºnj), hard water (18 - 26 ºnj), very hard water (above 26ºnj) [2].

$$\mathrm{UT} = \frac{V_{EDTA} \cdot c_{EDTA} \cdot M_{CaO}}{V_{sample}} \cdot 1000 \qquad \left(\mathrm{mg}\frac{\mathrm{CaO}}{\mathrm{L}}\right) \quad (3)$$

where is:
V_{EDTA}- volume of EDTA (ml) used for sample titration;
C_{EDTA}-concentration of EDTA;
M_{CaO}-molar mass of CaO;
V_{sample}- volume of sample.

The content of organic matter

The content of organic matter in water was determined by the Kubel-Tiemann method, i.e. by titration with a standard solution of $KMnO_4$ in an acidic medium. Based on the $KMnO_4$ content, the oxygen content in the water was also determined [12].

The chloride content

The chloride content was determined by titration with a standard $AgNO_3$ solution in the presence of potassium chromate as an indicator [2].

The content of Iron and Manganese

Iron content was determined spectrophoto-metrically using a JENWAY model 7300 spectrophotometer, while manganese content was determined using a Perkin Elmer AAnalyst 200 atomic absorption spectrophotometre.

RESULTS AND DISCUSSION

The analyzed values of physical and chemical parameters of the sample before and after treatment are given in the Table 2

Table 2. Values of physical and chemical parameters before and after ion exchange treatment

Parameters		The value before treatment	The value after treatment	Limit values	Analytical method
Color		Clear	Clear	-	Organoleptic
Smell and taste		Acceptable to consumers	Acceptable to consumers	-	Organoleptic
Temperature		19ºC	15ºC	-	
pH value		6.77	6.59	≥6.5 – ≤9.5	Potentiometric,ISE
Electrical conductivity		266.333 µS/cm	253.33 µS/cm	2500 µS/cm na 20ºC	Conductometric
Alkalinity	p-alkalinity	0	0	-	Titration with HCl
	m-alkalinity	28	25	-	
Water hardness		25.2 mg/L 2.5 ºnj	2.8 mg/L 0.28 ºnj		Titration with EDTA
The content of organic matter		1.89 mg/L	2.212 mg/L	5 mg O_2/L	Consumption of $KMnO_4$, by cooking in an acidic medium; Titration according to Kubel-Tiemann
The content of O_2		0.472	0.553		
The chloride content		7.1 mg/L	21.3 mg/L	250mg/L	Titration with $AgNO_3$
The content of Iron		0.002 mg/L	0.003 mg/L	200 µg/L	Spectrophotometrically
The content of Manganese		0	0	50 µg/L	Atomic absorption spectrophotometry

The results of the analysis showed that all values are within the permitted limits defined by the Rulebook on the Healthiness of Drinking Water Official Gazette of Bosnia and Herzegovina No. 40/10.

The basic requirement of water quality is that it should be odorless, tasteless and colourless. The presence of an odor most often indicates a qualitative defect in the water because the odor comes from dissolved organic and inorganic substances in the water [13]. The taste of water is most often a sign of faulty water, and is determined by the mineral composition, gas content and temperature, while water turbidity is caused by suspended and colloidal particles in the water (clay, silt, fine, small organic and inorganic matter, dissolved, colored organic matter , microscopic living organisms and plankton), the presence of aquatic organisms and undissolved air bubbles and represents the optical property of water.

The color of the water is the result of the presence of colloidally dissolved substances of plant origin and is very difficult to remove. It originates from substances of different origins, and the intensity of the color (yellow or red) depends on the presence of oxygen. Most often, the color of water is affected by the content of organic matter (yellow color, tea color). Although color as a parameter does not belong to the toxic parameters, it is on the EPA (Environmental Protection Agency) list of secondary (aesthetic) parameters and affects the appearance and sometimes the smell of water [14]. When it comes to the analyzed water and parameters, it has been proven that the water before and after treatment meets the requirements of drinking water, i.e. it is odorless, tasteless and colourless.

The pH value in natural waters is regulated by the balance of carbon dioxide and carbonate and is between 4.5 and 8.5 [15]. The pH is affected by humus substances that change the carbonate balance, the biological activity of plants, and in some cases salts that can be hydrolyzed, which is why waste and polluted waters can have lower or higher pH values. The pH value before and after the treatment showed that it is natural water whose value depends on the content of CO_2, carbonates and hydrogen carbonates, and that the pH value before and after the treatment did not change significantly. The electrical conductivity value also showed that the water is of approximately natural spring water quality. The small difference in values before and after treatment is attributed to the relatively short treatment time. High consumption of oxygen, as an indicator of organic pollution, indicates a high content of compounds subject to oxidation. Analysis of the sample before and after treatment showed a small consumption of

$KMnO_4$, which indicates the absence of organic matter.

Water alkalinity, which is a factor of water's capacity to receive H^+ ions, showed 0 values for p-alkalinity, and 28 for m-alkalinity for the sample before treatment and 25 for the sample after water treatment, which clearly shows that carbonates and bicarbonates are present in the water. The analysis also showed that the total hardness was reduced from 25.2 mg CaO/L before the treatment to 2.8 mg CaO/L after the treatment, respectively from 2.5 ^{0}dH to 0.28 ^{0}dH, which further shows that the process of softening and decarbonization has been fully carried out and of the water classified as soft water (water <9 ^{0}dH).

Metals in water are formed as a result of soil leaching and mineral dissolution. The increased amounts are the result of the discharge of wastewater from various branches of industry, agriculture and households. Water containing iron is not suitable for technological processes in the textile industry, in the leather and paper industry, and also above the upper permissible values in the food industry as well as for drinking [19]. Iron and manganese reach the water by dissolving and passing through the layers of the soil in water poor in dissolved oxygen, and if a concentration higher than the permitted level is observed, measures of deferrization or demanganization are carried out. When it comes to these metals, the analysis of tap water before and after treatment showed minimal values of these metals in drinking water.

CONCLUSION

The quality of drinking water is determined by numerous rules and must be constantly monitored. In order to monitor, it is mandatory to carry out analyzes and compare them with the Rulebook on permitted values. The analysis showed that the ion exchange process was successfully carried out, i.e. that the decarbonization and softening of the water was carried out, whereby the water after treatment was classified as soft water (water <9 ^{0}dH).

The analyzed water is tasteless, odorless and colorless before and after treatment. The pH value and the electric value did not change significantly during treatment.

The analysis also showed that the content of chloride, as well as the content of iron and manganese in the water sample before and after treatment are below the maximum allowed values. The increase in the chloride value after the treatment compared to the analyzed sample before the ion exchange treatment can be attributed to the regeneration of the resin with NaCl ions.

REFERENCES

[1] Filković M., Primjena ionskih izmjenjivača u procesima obrade vode Završni rad, Sveučilište J.J Strossmayera u Osijeku, Prehrambeno-tehnološki fakultet u Osijeku,2016.

[2] Mijatović i Matošić, Tehnologija vode (Interna skripta), Prehrambeno – biotehnološki fakultet sveučilište u Zagrebu,2007

[3] Šestan I., A.Odobašić, H.Keran, M.Ahmetović, Kinetika i mehanizmi fizikalno-hemijskih procesa, Univerzitetski udžbenik,Tehnološki fakultet Tuzla, In scan, Tuzla,2022.

[4] Iličković Z., Membranski procesi , Tehnološki fakultet u Tuzli, 2007.

[5] J. Mallevialle, P. Odendaal, M. Wiesner, Water Treatment Membrane Processes. New York:McGraw-Hill,1996.

[6] I. Šaško, Analiza mikrobioloških pokazatelja kakvoće vode za kupanje, Diplomski rad,Geotehnički fakultet, Sveučilište u Zagrebu, str. 6, 8-14, 2017.

[7] Standard Methods 2510 B: Standard Methods for the Examination of Water and Wastewater, 21st edition, 2005.

[8] Standard Methods 4500-B+B: Standard Methods for the Examination of Water and Wastewater, 21st edition, 2005.

[9] Standard Methods 2320 B: Standard Methods for the Examination of Water and Wastewater, 21st edition, 2005.

[10] Standard Methods 4500-F-E: Standard Methods for the Examination of Water and Wastewater, 21st edition, 2005.

[11] Kuleš M.; Habuda – Stanić M., Analiza vode. Osijek: Sveučilište J. J. S. u Osijeku,2000.

[12] Kvalitet voda. Laboratorijski priručnik, Beograd: Građevinski fakultet; 2006.

[13] Rajković B. Miloš, Milojković S. Marjanović T., Antić M., Nikšić M., Stojanović M., Fizičko-hemijska i mikrobiološka ispravnost vode za piće u seoskim naseljima na teritoriji opštine Požarevac, Hrana i ishrana (Beograd), Vol.55. No. 1., 19-24,2014.

[14] Pravilnik o higijenskoj ispravnosti vode za piće. Službeni list SRJ, Beograd, 44: 1-28,1999.

[15] Knežević R., Kemijski parametri vode iz javnoopskrbnog sustava na području grada Požege u ožujku 2015.godine, Veleučilište u Požegi, Poljopriovredni odjel,2017.

[16] Šaško I., Analiza mikrobioloških pokazatelja kakvoće vode za kupanje,Diplomski rad, Geotehnički fakultet, Sveučilište u Zagrebu,2017.

[17] Guidelines for drinking-water quality, Incorporating the 1st addendum,World Health Organization, 4th edition, Geneva, 2017.

[18] N.Omerdić, Kloriranje vode, Hrvatske vode 29 (2021).

[19] Mijatović I. Tehnologija vode (interna skripta). Zagreb: Prehrambeno –biotehnološki fakultet sveučilišta u Zagrebu,1996.