ECOLOGY

UDC 628.161.1
DOI: 10.15587/1729-4061.2023.277491

PRODUCTION OF PHYSIOLOGICALLY COMPLETE DRINKING WATER USING MODIFIED REVERSE OSMOSIS MEMBRANE ELEMENTS

Artem Tyvonenko
Postgraduate Student*
Tetiana Mitchenko
Doctor of Technical Sciences, Professor*
Oleksii Homaniuk
Engineer
Ukrainian Water Society WaterNet
Saksaganskogo str., 123, Kyiv, Ukraine, 01032
Sergey Vasilyuk
PhD, Senior Researcher
Laboratory of Ion Exchange and Adsorption**
Iryna Kosogina
Corresponding author
PhD, Associate Professor*
E-mail: kosoginairyna@gmail.com
Rostyslav Mudryk
Director
Department of Business Development
ECOSOFT SPC LTD
Pokrovska str., 1st, Irpin, Ukraine, 08200
*Department of Technology of Inorganic Substances, Water Treatment and General Chemical Technology**
**National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"
Peremohy ave., 37, Kyiv, Ukraine, 03056

Drinking water prepared using the most effective and popular reverse osmosis method is absolutely safe but for the most part does not meet the requirements for physiologically complete water. The latter must meet, in addition to the basic requirements, the following requirements: salt content, at least 100, and not more than 1000 mg/dm^3; total hardness; in the range of 1–7.0 mmol/dm^3. Now, to fulfill these requirements, the stage after desalting employs various methods of domineralization of reverse osmosis water, each of which has certain disadvantages.

This paper considers the task of obtaining safe physiologically complete water immediately after the stage of membrane desalting by using modified reverse osmosis membrane elements with the predefined selectivity. The study object was the process of obtaining reverse osmosis membrane elements with the predefined selectivity by modifying them with sodium hypochlorite solution for use in the process of obtaining physiologically complete drinking water.

The required level of selectivity of modified elements was calculated to obtain safe physiologically complete water from starting water, depending on its salt content. Thus, for the starting water with a salt content of 200–300 mg/dm^3, the specified selectivity of the membrane element should be no more than 60 % at a temperature of 25 °C. Rational conditions for conducting the modification process for obtaining a membrane element with such exact selectivity have been established. The nature of the influence of changes in water temperature on the selectivity of the modified element was studied.

A prototype of the modified element was tested in a vending machine for bottling water, which purified tap water in the city of Kyiv, with a salt content of 230 mg/dm^3 at a temperature of 8–12 °C. The test results showed the possibility of one-stage obtaining safe physiologically complete water by reverse osmosis using a modified membrane element with the predefined selectivity of 50 %

Keywords: reverse osmosis, modified membrane elements, predefined selectivity, physiologically complete water

Received date 10.02.2023
Accepted date 14.04.2023
Published date 30.04.2023

***How to Cite:** Tyvonenko, A., Mitchenko, T., Homaniuk, O., Vasilyuk, S., Kosogina, I., Mudryk, R. (2023). Production of physiologically complete drinking water using modified reverse osmosis membrane elements. Eastern-European Journal of Enterprise Technologies, 2 (10 (122)), 6–13. doi: https://doi.org/10.15587/1729-4061.2023.277491*

1. Introduction

The quality of drinking water must meet the established requirements of a certain regulatory document, which regulates the content in water of up to 100 or more substances according to sanitary-bacteriological and sanitary-chemical indicators. There are many such documents in the world, both international and regional [1–4]. In most of them, in addition to safety requirements, there are recommendations for the composition of physiologically complete water, which should have a total salt content of at least 100 mg/dm^3 and not more than 1000 mg/dm^3, and a total hardness, the value of which should be in the range of 1–7.0 mmol/dm^3. This means that desalinated water, the salt content of which is less than 100 mg/dm^3, and the hardness is less than 1 mmol/dm^3, must necessarily be subject to mineralization to the level of requirements. First of all, it concerns drinking water purified by reverse osmotic method. The salt content of such water, as a rule, does not exceed 10–15 mg/dm^3, and the content of hardness ions – 0.1 mmol/dm^3 [5].

Typically, to meet the requirements for physiologically complete water after reverse osmosis treatment of water, another stage is carried out – domineralization of desalinated water (permeate). To this end, the following methods are used:

– passing permeate through cartridges containing the natural minerals calcium and magnesium;

– dosing in permeate of saline containing the necessary chemical compounds;

– admixture of source water to permeate (bypass).

Many years of experience in the operation of two-stage reverse osmosis systems with the stage of premineralization showed the presence of significant drawbacks of this method, namely the impossibility of achieving stable salt content of treated water, reliable provision of its microbiological purity, and technical difficulties in servicing plants. Designing single-stage membrane systems for obtaining drinking water, which would meet all regulatory requirements both in terms of safety and physiological usefulness, is very relevant. This is especially true of commercial reverse osmosis plants, in particular, vending machines for bottling drinking water, which are characterized by a high level of autonomy and digitalization [6].

To solve this problem, it is necessary to investigate the processes of obtaining modified reverse osmosis membrane elements with the predefined selectivity and their use to obtain safe physiologically complete drinking water in one stage. The results will make it possible to design a reliable and easy-to-use reverse osmosis system for obtaining drinking water, the quality of which meets all established standards.

2. Literature review and problem statement

As shown in [7], one of the most popular methods of postmineralization is the passage of permeate through a mixture of natural minerals containing calcium and magnesium (for example, Calcite and Corosex [8]). However, the result, in this case, is significantly dependent on the pH and temperature of the permeate, which may fluctuate according to seasonal changes. Because of these fluctuations, the solubility of minerals in water and, accordingly, its salt content and pH change uncontrollably.

Postmineralization by dosing a concentrated solution of salts (calcium, sodium, magnesium, fluorine, and others) into desalinated water is a fairly effective method in which you can easily adjust the salt content of drinking water [6, 9]. As shown in [6], its implementation requires additional equipment (dosing pump), which must be regularly configured and monitored. In this regard, for example, one of the advantages of vending machines, autonomy, suffers. There is also a high probability of repeated microbiological contamination of treated water in case of insufficient purity of saline solution [9].

To obtain physiologically complete water by mixing permeate with the original tap water, the latter must be cleaned. In [10], it is proposed to apply micro- or ultrafiltration methods to ensure its microbiological purity. It is noted that the disadvantage of this method is the need for constant monitoring and regulation of the ratio of mixed flows in accordance with seasonal changes in the composition of tap water.

Thus, producing absolutely safe physiologically complete drinking water, which today is implemented in two stages, water treatment by reverse osmosis and subsequent adjustment of mineral composition, is associated with certain problems. More rational is the organization of a one-stage process for producing drinking water using membrane elements with predefined selectivity.

In [11], information is provided on the possibility of producing membrane elements with predefined selectivity and productivity by modifying reverse osmosis membranes based on polyamide. The essence of the modification is to process the membrane element or membrane fabric with various oxidizing agents. In [12], a solution of potassium permanganate was used to oxidize the polyamide layer and process membranes into microfiltration membranes. However, when using this modification method, it is difficult to control the degree of influence of the oxidizer to obtain modified membrane elements with the predefined selectivity. When using ozone [13], the desired modification effect can be achieved but difficulties arise with the constant maintenance of ozone concentration at the same level (especially when processed under passive conditions). As shown in [14], it is possible to use hydrogen peroxide as an oxidizing agent, but its disadvantage is too long processing time of the membrane element. In [15], to correct the permeability of membranes, it is recommended to use compounds of active chlorine and it is noted that this method is the most effective and controlled. The authors of [16] note that, unlike nanofiltration, modified reverse osmosis membranes with controlled pore size can pass not only single-charge ions but also multi-charged ones. This makes it possible in purified water to ensure, at the established level, not only salt content but also the presence of hardness ions.

It should be noted that the objects of research in most studies into this area were used membrane elements of the industrial range, the modification of which was carried out for the purpose of further utilization in wastewater treatment processes. Information on the modification of standard reverse osmosis elements for their use in the processes of producing safe physiologically complete water on installations of the commercial series was not found in the literature. However, in this case, the level of selectivity of the modified elements should ensure not only physiological usefulness but also the safety of the purified water. That is, the modified elements must trap the main pollutants at the same level as standard ones.

3. The aim and objectives of the study

The aim of this study is to establish rational conditions for producing modified reverse osmosis membrane elements with the predefined selectivity and their use in a one-stage process of producing safe physiologically complete drinking water.

To accomplish the aim, the following tasks have been set:

– to formulate requirements for the selectivity of modified reverse osmosis membrane elements depending on the salt content of the source water;

– to establish a rational mode of the process of modification of reverse osmosis membranes to achieve the predefined level of their selectivity;

– to conduct pilot tests of the process of producing physiologically complete water using modified reverse osmosis elements with the predefined selectivity in vending machines for bottling water;

– to confirm the possibility of producing safe and physiologically complete water by reverse osmosis without the stage of postmineralization using modified reverse osmosis membrane elements with the predefined selectivity.

4. The study materials and methods

4. 1. Materials

The hypothesis of the study assumed the possibility of producing membrane elements with the predefined selectivity by modifying the starting elements with sodium hypochlorite solution for their use in the process of producing safe physiologically complete water.

The objects of research were the original reverse osmosis (RO) elements CSV-3012-500 ("Ecosoft-BWT", Ukraine) with a membrane sheet TU-14 (Source Water, China), and modified membrane elements with the predefined selectivity.

To modify the RO elements, a 4 % sodium hypochlorite solution was used (Milam, Ukraine). To stabilize the modified membrane elements, solutions of sodium metabisulfite (1 %) (CHEMICO GROUP, China) and glycerol (5 %) (Miranda-S, Ukraine) were used [17]. Reverse osmosis water was used to prepare solutions.

The starting characteristics of the elements, given in Table 1, were determined at the original installation, the description of which is provided below.

Table 1

Specifications of the reverse osmosis element CSV-3012-500

Characteristic	Dimensionality	CSV500-3012-
Permeate consumption	dm^3/h	75
Efficiency	%	50
Selectivity (S_{RO})	%	97.1

Pilot tests of membrane elements were carried out using a vending machine for bottling water KA 60 ("Ecosoft-BWT", Ukraine).

4. 2. Modification process

To modify the RO element, sodium hypochlorite solution with an active chlorine concentration of 1250 mg/dm^3 and pH 10 was used, which was prepared by dilution of commercial NaClO until the required concentration was reached.

The modification process was carried out under passive or active conditions [18] to obtain a membrane element of the predefined selectivity, which is determined by the composition of the source water and is calculated by (1):

$$S_{mod} = \frac{TDS_{in} - 100}{TDS_{in}} * S_{RO}, \quad (1)$$

where S_{mod} is the specified selectivity of the modified RO membrane element, %;

S_{RO} – selectivity of the membrane element, %;

TDS_{in} – salt content of source water, mg/dm^3;

100 – salt content of permeate that meets the requirements for physiologically complete water, mg/dm^3.

The process of passive modification involves immersion for a certain time of the membrane element in a sealed container with a solution of active chlorine, until the membrane element reaches the predefined selectivity. The process of active modification involves the constant passing through the membrane element of a solution of active chlorine under a pressure of 1 bar.

The dose of active chlorine acting on the membrane element was determined by formula (2):

$$N = C_{Cl} * \tau, \quad (2)$$

where N is the dose of active chlorine, ppm*h;

C_{Cl} – concentration of active chlorine, mg/dm^3;

τ – contact time, hour.

The concentration of active chlorine in solutions for modification was constantly monitored according to the procedure set out by DSanPiN 2.2.4-171-10 [1] and adjusted to keep at a constant level.

After modification, membrane elements were washed from the active chlorine solution by passing reverse osmosis water through membrane elements for at least 30 minutes until no reaction to active chlorine in permeate and concentrate was achieved. After washing, the elements were kept in a stabilization solution containing 1 % metabisulfite and 5 % glycerol [17].

4. 3. Testing the starting characteristics of membrane elements

Testing of both initial and modified membrane elements was carried out at a special installation, which is shown in Fig. 1.

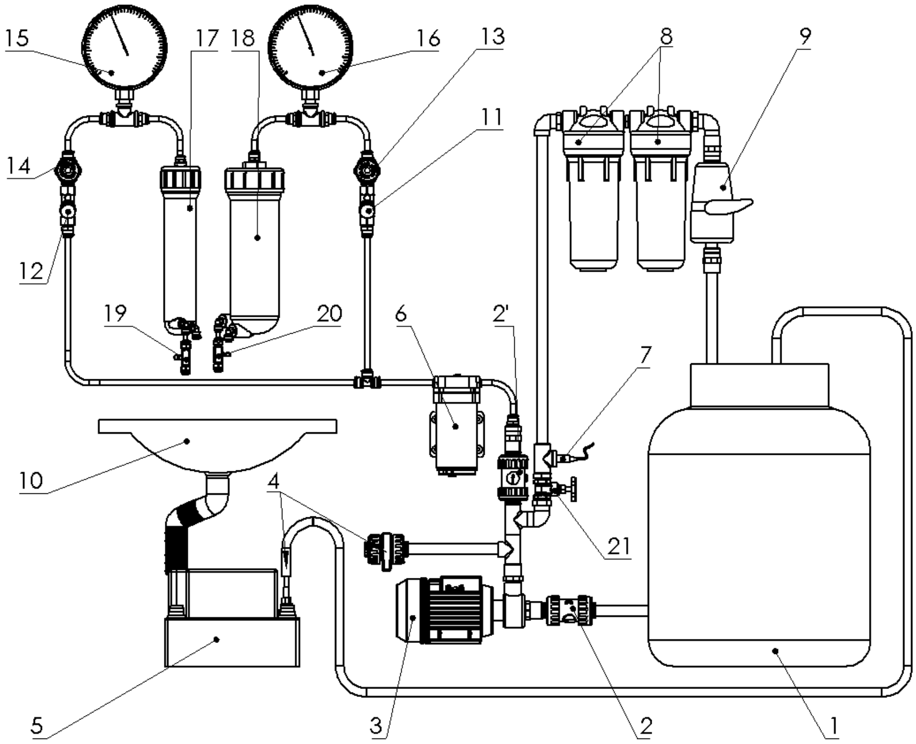

Fig. 1. Schematic diagram of the installation for testing membrane elements: 1 — tank with solution; 2 — check valve; 3 — vortex pump; 4 — discharge valve; 5 — Conlift pump; 6 — booster pump; 7 — temperature sensor; 8 — filters; 9 — flow heater; 10 — flow solution collector; 11, 12 — pressure regulator; 13, 14 — control valve; 15, 16 — pressure gauge; 17, 18 — membrane holder 1812 and/or 3012; 19, 20 — flow limiter; 21 — control valve

At this installation, it is possible to maintain the set pressure and temperature for a long time. Determination of membrane elements characteristics was carried out using a model solution containing TDS – 245 mg/dm^3; hardness – 2.38 mmol/dm^3; pH – 8.4, at a pressure of 4.8 bar, and water temperature of 7–25 °C. The concentrate flow was constantly maintained at 7.2 l/h, using a standard flow limiter.

The starting characteristics of membrane elements were determined after 30 minutes of operation of the membrane element at this installation. The calculation of performance, efficiency, and selectivity was carried out according to known formulas given in [13, 15, 19].

4. 4. Pilot tests of the process of producing physiologically complete water using membrane elements

The experimental procedure involved passing tap water from the city of Kyiv through a standard or modified membrane RO element installed in a vending water bottling machine. Water supply was carried out from a centralized water supply network.

Characteristics of the source tap water are given in Table 2.

Sampling for analysis was carried out every 100 dm^3 to 1000 dm^3 of purified water, and every 500 dm^3 to 3500 dm^3. In addition, before analyzing samples of the water passed through the membrane element, samples of the original tap water supplied for treatment were also taken. To assess the effectiveness of membrane elements, the following parameters were determined: permeate consumption, temperature, pH, salt content, total hardness, color, trihalogenmethane content, as well as microbiological parameters (Coli-index) in the source and purified water according to procedures given in [1, 2].

Schematic diagram of the vending machine used for pilot studies is described in [6, 9].

Table 2

Physical and chemical parameters of tap water in the city of Kyiv that entered membrane elements

Indicator	Units of measure	Value
pH	unit	7.7–8.4
Salt content (TDS_{in})	mg/dm^3	223–238
Hardness	mmol/dm^3	2.25–2.45
Chromaticity	degree	35.0–42.5
Trihalogenmethane content (THM)	μg/dm^3	35.0–38.0
Total microbial number	CFU/cm^3	0–2
Temperature	°C	8–12

5. Results of investigating the process of producing physiologically complete water using modified reverse osmosis membrane elements

5. 1. Requirements for the selectivity of modified reverse osmosis membrane elements depending on the salt content of the source water

Fig. 2 shows the dependence of the requirements for the value of selectivity of modified RO elements intended for producing physiologically complete water on the salt content of the source water.

The value of selectivity (S_{mod}) is calculated by (1).

Analysis of the data shown in Fig. 2 reveals that in order to obtain physiologically complete water from tap water in the city of Kyiv, the salt content of which is 250–300 mg/dm^3, it is necessary to use a membrane element with a selectivity of not more than 60 % at a temperature of 25 °C.

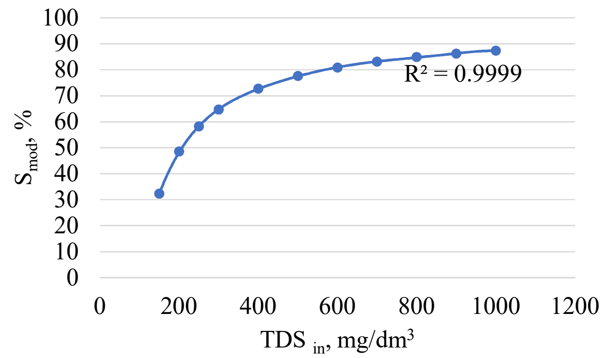

Fig. 2. Dependence on the salt content of the source water (TDS_{in}, mg/dm^3) of the selectivity requirements of modified reverse osmosis elements (S_{mod}, %) intended for producing physiologically complete water (at a temperature of 25 °C and selectivity of the original membrane element ($S_{RO)}$ 97.1 %)

5. 2. Establishment of a rational mode of the process of modification of reverse osmosis membranes to achieve the predefined level of selectivity

In the course of our work, the properties of standard RO and membrane elements modified under different conditions were investigated in the installation shown in Fig. 1. The starting characteristics of the elements, obtained at a temperature of 25 °C, are given in Table 3.

Analysis of the data in Table 3 shows that permeate after a standard RO membrane element with a selectivity of 97.1 % does not meet the requirements for physiologically complete water. It is characterized by too low salt content and concentration of hardness ions and high acidity. The selectivity of all investigated modified membrane elements did not exceed 60 %, and the water characteristics afterward met the requirements for physiologically complete water.

In addition, the permeate consumption increased on the modified elements, which is also a positive point since it may eliminate the need to use a storage tank in the technological scheme. This, in turn, will avoid problems with secondary bacteriological contamination of treated water.

As can be seen from the data in Table 3, the formulated requirements for reducing selectivity and increasing permeate consumption are met by the modified element No. 3.

Fig. 3 shows the dependence of the selectivity of the modified membrane element No. 3 on the temperature of the source water. The dependence is linear with a high degree of reliability.

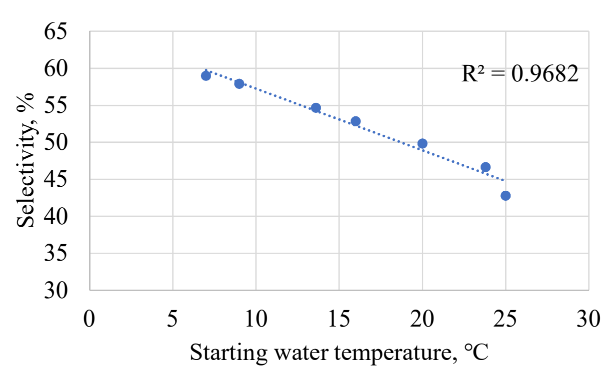

Fig. 3. Dependence of the selectivity of the modified membrane element No. 3 on the temperature of the source water

Table 3

Starting characteristics of standard RO and modified membrane elements at 25 °C

Membrane element	RO	No. 1	No. 2	No. 3
Method of modification	–	Passive	Active	Active
Oxidant dose, ppm*h	0	35500	24800	27900
Permeate consumption, dm^3/h	75	90.0	93.5	112.1
Efficiency, %	50	54.4	55.6	61.2
Selectivity, %	97.1	58.0	59.2	42.8
Salt content of permeate, ppm	7.1	103	100	140
Permeate hardness, $mmol/dm^3$	<0.02	0.92	0.92	1.27
pH	6.7	8.1	8.2	8.3

It has been established that with decreasing temperature, the selectivity of the modified element increases. At the same time, when the temperature changes within 7–25 °C, the specified requirements for the selectivity of the modified RO membrane element are met, not exceeding 60 % (Fig. 3).

5. 3. Testing the process of producing physiologically complete water using the modified reverse osmosis elements

To determine the optimal mode of modification of RO elements, studies were conducted on the effectiveness of their use under real conditions on a vending machine that was connected to the Kyiv water supply network.

Fig. 4, *a–c* shows changes in the current values of salt content, pH, and hardness of permeate after the initial and modified reverse osmotic elements, depending on its volume. Fig. 5 shows a comparison of the average values of salt content, pH, and hardness of permeate for all elements, as well as requirements for physiologically complete water.

Analysis of the data shown in Fig. 4 indicates stability of the results obtained during the work of all investigated membrane elements during the production of 3500 dm^3 of permeate. The confidence interval for the results is in the range of 0.04–0.15 for pH, 0.06–0.18 $mmol/dm^3$ for hardness, and 0.55–5.7 mg/dm^3 for water salt content.

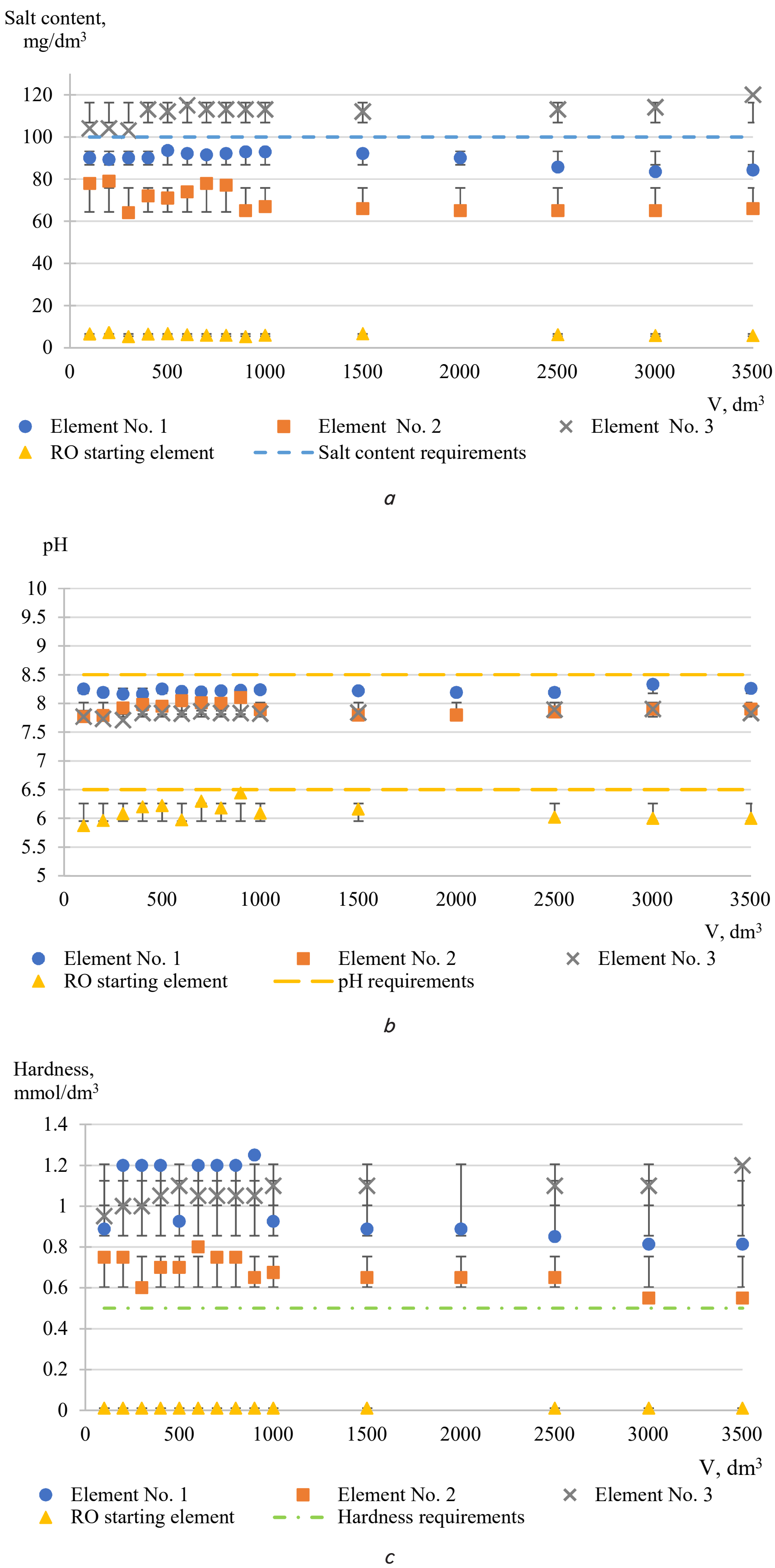

Fig. 4. Comparison of characteristics of permeate obtained by passing water through the initial and modified reverse osmosis elements No. 1–3, depending on the volume of permeate obtained: *a* – by salt content; *b* – by pH; *c* – by hardness

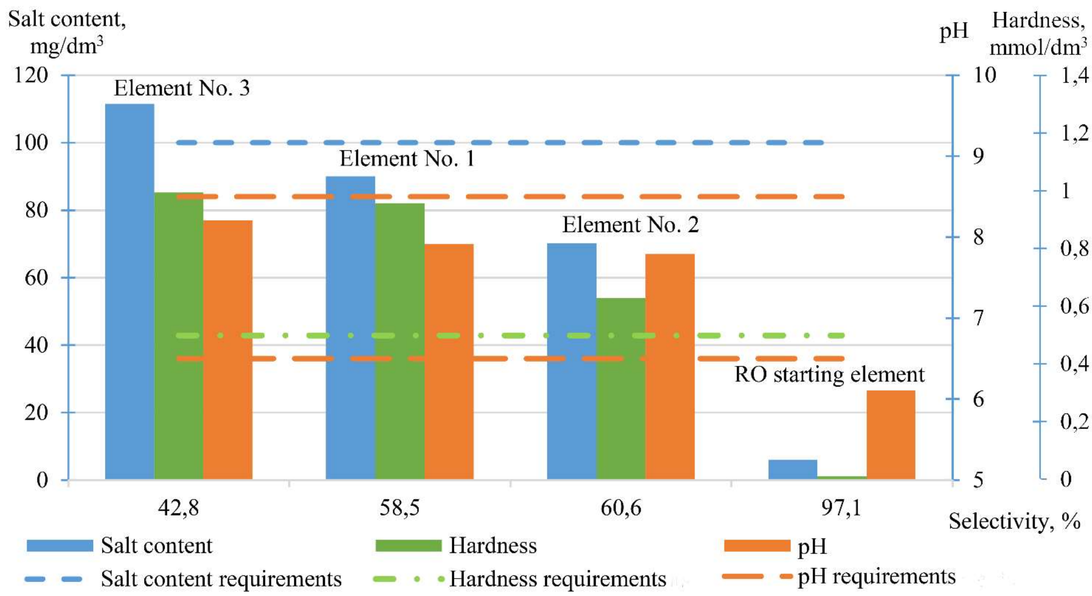

Fig. 5. Comparison of average values of salt content, pH, and hardness of permeate for elements with different selectivity

Analysis of the data shown in Fig. 5 reveals that the average pH and hardness values of permeate after passing tap water through all three modified membrane elements meet the requirements, unlike in the case of the original reverse osmosis element. However, a value of salt content that meets the requirements for physiological usefulness of water (≥100 mg/dm^3) is achieved only for peremeate after modified membrane element No. 3. This element was used during long-term pilot tests of the process of producing safe and physiologically complete water in a vending machine.

Table 4

Results of pilot tests of modified membrane element No. 3 in a vending machine for bottling water and the requirements given in [1] for safe physiologically complete water

Volume, dm^3	1000	2000	3000	4000	5000	6000	Averages	Standards from [1]
t, °C	12.6	11.3	10.7	8.6	8.3	11.3	10.5	–
Flow rate, dm^3/h	121.1	121.2	120	119	118.5	118.8	119.8	–
Selectivity, %	50.7	50.7	49.4	47.9	51	50.7	50.1	–
pH	7.82	7.89	7.83	7.9	7.94	7.89	7.9	6.5–8.5
Permeate salt content, mg/dm^3	113	113	120	124	119	113	117	≥100
Hardness, mmol/dm^3	1.1	1.1	1.2	1.2	1.2	1.1	1.2	≥1
Chromaticity, deg.	0	0	0	0	0	0	0	≤20
Trihalogen-methane (THM) content, µg/dm^3	≤5	≤5	≤5	≤5	≤5	≤5	≤5	≤100
Total microbial number, CFU/cm^3	2	1	2	1	2	2	1–2	≤50

5. 4. Establishing the possibility of producing safe and physiologically complete water by reverse osmosis method without postmineralization

Pilot tests were conducted to establish the possibility of organizing a stable process of producing safe physiologically complete water, which provides for its purification from the most characteristic pollutants for Kyiv tap water. These include compounds that give water color, organochlorine compounds (trihalogenmethanes), and microbiological pollutants.

Testing of the modified membrane element No. 3 to obtain safe and physiologically complete water in the vending machine was carried out for more than two months. Sampling was carried out once a week. The results of pilot tests are given in Table 4.

Pilot tests confirmed the possibility of producing from Kyiv tap water (the composition is given in Table 2) of the safe and physiologically complete water by reverse osmosis without the stage of postminerization. During the tests, a modified reverse osmosis membrane element with a selectivity of 50 % at a temperature of 8.3–12.6 °C was used. The composition of the source water is shown in Table 2. The values of the quality indicators of the obtained permeate met the requirements [1] throughout the experiment.

6. Discussion of results of investigating the production of physiologically complete water by a reverse osmosis method using modified membrane elements

In the course of our work, the requirements for the selectivity of the modified RO elements were specified, depending on the salt content of the source water (Fig. 2). Thus, to obtain physiologically complete water from tap water in the city of Kyiv, the salt content of which is 200–300 mg/dm^3, in the temperature range from 7 °C to 25 °C, it is rational to use a modified membrane element with a selectivity of 40.0–60.0 % (Fig. 3).

Comparison of No. 1 and No. 2 membrane element modification conditions (Table 3) shows that the passive method takes longer than the active one to achieve the predefined selectivity within 58–59 % (28.4 and 19.8 hours, respectively), which correlates with data reported in [18]. This is due to the additional time under passive conditions for the diffusion of active chlorine into the middle of the membrane element. Comparison of the characteristics of elements No. 2 (selectivity, 59.2 %) and No. 3 (selectivity, 42.8 %), obtained by active modification, but at different doses of the oxidizer (24800 ppm h and 27900 ppm*h, respectively), confirms the ability to influence the selectivity and productivity of membrane elements by changing the dose of active chlorine (Table 3).

A rational mode of modification of the reverse osmosis element CSV-3012-500 has been established, which provides for its treatment with NaClO solution under active conditions at an oxidizer dose of 27900 ppm*h. The selectivity of the modified element decreases from 97 % to 42.8 % at a water temperature of 25 °C, and the consumption of permeate increases from 75 dm^3/h to 112 dm^3/h (Table 3). Using the modified element in the vending machine connected to Kyiv tap water made it possible to obtain physiologically complete water with salt content of 110 mg/dm^3, hardness 1.1 $mmol/dm^3$, and pH 8.4 (Fig. 5).

Pilot tests were conducted in a vending machine with an RO element modified in a rational mode, the selectivity of which at a water temperature of 10.5 °C was 50.1 %. The possibility of stable production of safe physiologically complete water from Kyiv tap water with the following average composition was proved: salt content, 117 mg/dm^3; hardness, 1.2 $mmol/dm^3$; pH, 7.9; chromaticity, 0 degrees, trihalogenmethane content≤5 $\mu g/dm^3$; and the total microbial number within 1–2 CFU/cm^3 (Table 4).

Purified water does not require adjustment of mineral composition, which will exclude the postmineralization units from the technological scheme and, thus, significantly simplify it and make it more reliable. At the same time, the stability of the process increases, which can significantly reduce the frequency of maintenance of machines.

Our results show the prospects of using the membrane element CSV-3012-500, modified with NaClO solution to the level of selectivity of 50 %, to obtain safe physiologically complete water from source water with a salt content of 200–300 mg/dm^3 by reverse osmosis method without the stage of postmineralization.

For the widespread introduction of this method, it is necessary to conduct research and mathematical modeling of the process of modifying the extended spectrum of reverse osmosis membrane elements. It is also necessary to establish rational conditions for their operation for the treatment of source water with a salt content of 200–1000 mg/dm^3.

7. Conclusions

1. We have proposed a formula for calculating the selectivity requirements of modified membrane elements for producing physiologically complete water depending on the salt content of the starting water. According to calculations, the selectivity of modified membrane elements for Kyiv tap water with a salt content of 200–300 mg/dm^3 should not exceed 60 % in the temperature range of 7–25 °C.

2. A rational mode of the modification process has been established, which includes active treatment of the original membrane element with sodium hypochlorite solution at a dose of active chlorine of 27900 ppm*h. This makes it possible to obtain a modified membrane element, the selectivity of which is 42.8–50 % at a temperature of 7–25 °C. Its use makes it possible to obtain tap drinking water from the city of Kyiv, the composition of which meets all the requirements for physiologically complete drinking water.

3. The results of the pilot tests showed the feasibility of using modified RO elements with a selectivity of 50 % in vending machines connected to a tap water network in the city of Kyiv to obtain safe physiologically complete drinking water.

4. The principal possibility of excluding the stage of postmineralization in the reverse osmosis process of producing safe physiologically complete water that meets all regulatory requirements is shown when using modified reverse osmosis membrane elements with the predefined selectivity. The use of the proposed method in vending machines for bottling water will significantly simplify the technology and make it more reliable, increase the stability of the process, and reduce the frequency of maintenance.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

Funding

The research was supported by TOV NVO ECOSOFT.

Data availability

All data are available in the main text of the manuscript.

References

1. Pro zatverdzhennia Derzhavnykh sanitarnykh norm ta pravyl «Hihienichni vymohy do vody pytnoi, pryznachenoi dlia spozhyvannia liudynoiu». Nakaz No. 400 vid 12.05.2010. Ministerstvo Okhorony Zdorovia Ukrainy. Available at: https://zakon.rada.gov.ua/laws/show/z0452-10#Text
2. Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption (recast) (Text with EEA relevance). Available at: https://eur-lex.europa.eu/eli/dir/2020/2184/oj
3. National Primary Drinking Water Regulations. EPA 816-F-09-004 (2009). Available at: https://www.epa.gov/sites/default/files/2016-06/documents/npwdr_complete_table.pdf
4. Guidelines for Drinking-Water Quality (2017). World Health Organization. Available at: https://www.who.int/publications/i/item/9789241549950
5. Remineralizatsiya vody, ochyshchenoi systemoiu zvorotnoho osmosu. Smak vody ta zdorovyi hluzd. Available at: http://www.softwave.com.ua/remineralizatsiya-vodi-ukr/

6. Vseredyni akvaboksu chystoi vody. BWT Aqua. Available at: https://bwtaqua.com.ua/inside-bwt/
7. Mitchenko, T. Ye., Ponomarov, V. L., Svietlieisha, O. M., Makarova, N. V., Orestov, Ye. O., Maletskyi, Z. V. et al. (2019). Seriya vydan «Svit suchasnoi vodopidhotovky» Metody i materialy. Kyiv: VUVT WaterNet, 132.
8. Filter Media. Clack. Available at: https://www.clackcorp.com/water-treatment-ion-exchange-resin-filter-media/
9. Mitchenko, T. Ye., Ponomarov, V. L., Vasyliuk, S. L., Kuzminchuk, A. V., Poliakov, V. R., Stender, P. V. et al. (2021). Seriya vydan «Svit suchasnoi vodopidhotovky» Tekhnolohichni rishennia. Kyiv: VUVT WaterNet, 80.
10. Lesimple, A., Ahmed, F. E., Hilal, N. (2020). Remineralization of desalinated water: Methods and environmental impact. Desalination, 496, 114692. doi: https://doi.org/10.1016/j.desal.2020.114692
11. Tyvonenko, A., Mitchenko, T., Vasilyuk, S. (2022). Environmental problems caused by the use of reverse osmosis membrane elements, and ways to solve them. Water and water purification technologies. Scientific and technical news, 32 (1), 33–42. doi: https://doi.org/10.20535/2218-930012022259491
12. Khaless, K., Achiou, B., Boulif, R., Benhida, R. (2021). Recycling of Spent Reverse Osmosis Membranes for Second Use in the Clarification of Wet-Process Phosphoric Acid. Minerals, 11 (6), 637. doi: https://doi.org/10.3390/min11060637
13. Ouali, S., Loulergue, P., Biard, P.-F., Nasrallah, N., Szymczyk, A. (2021). Ozone compatibility with polymer nanofiltration membranes. Journal of Membrane Science, 618, 118656. doi: https://doi.org/10.1016/j.memsci.2020.118656
14. Ling, R., Yu, L., Pham, T. P. T., Shao, J., Chen, J. P., Reinhard, M. (2017). The tolerance of a thin-film composite polyamide reverse osmosis membrane to hydrogen peroxide exposure. Journal of Membrane Science, 524, 529–536. doi: https://doi.org/10.1016/j.memsci.2016.11.041
15. García-Pacheco, R., Landaburu-Aguirre, J., Lejarazu-Larrañaga, A., Rodríguez-Sáez, L., Molina, S., Ransome, T., García-Calvo, E. (2019). Free chlorine exposure dose (ppm·h) and its impact on RO membranes ageing and recycling potential. Desalination, 457, 133–143. doi: https://doi.org/10.1016/j.desal.2019.01.030
16. Govardhan, B., Fatima, S., Madhumala, M., Sridhar, S. (2020). Modification of used commercial reverse osmosis membranes to nanofiltration modules for the production of mineral-rich packaged drinking water. Applied Water Science, 10 (11). doi: https://doi.org/10.1007/s13201-020-01312-1
17. Maeda, Y. (2022). Roles of Sulfites in Reverse Osmosis (RO) Plants and Adverse Effects in RO Operation. Membranes, 12 (2), 170. doi: https://doi.org/10.3390/membranes12020170
18. Antony, A., Fudianto, R., Cox, S., Leslie, G. (2010). Assessing the oxidative degradation of polyamide reverse osmosis membrane – Accelerated ageing with hypochlorite exposure. Journal of Membrane Science, 347 (1-2), 159–164. doi: https://doi.org/10.1016/j.memsci.2009.10.018
19. FilmTecTM Reverse Osmosis Membranes Technical Manual. Water Solutions (2023). Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/water-solutions/public/documents/en/RO-NF-FilmTec-Manual-45-D01504-en.pdf