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Removal of Iron Compounds from Mechanical Filters of Household Reverse Osmosis Systems Water Purification

Iaroslav Radovenchyk[1], Olena Ivanenko[1], Margaryta Karpenko Victorivna[1*],
Vyacheslav Radovenchyk[1]

[1] Department of Ecology and Technology of Plant Polymers, Faculty of Chemical Engineering, Igor Sikorsky Kyiv Polytechnic Institute, Peremogy Avenu 37/4, 03056 Kyiv, Ukraine

* Corresponding author's e-mail: history1991@ukr.net

ABSTRACT

Today, the most convenient and widespread option for cleaning and purifying drinking water is to install reverse osmosis systems directly at the water intake points. When operating reverse osmosis systems, most owners are not concerned about the negative consequences of using such systems. After 3–6 months of using mechanical filters in the first stage of water treatment, such filters are thrown out together with other household waste. They pose a significant threat to the environment. Currently, companies in Ukraine would not collect and dispose of such filters. This direction is undeveloped. There are no corresponding data in the scientific literature. According to authors' calculations, about 20,000 household reverse osmosis systems are operated per 1 million people today, so it is easy to calculate that 44,000 cartridges with a total polypropylene volume of 26 m^3 enter the environment during the year. It is difficult to imagine the real environmental damage from the cartridges of even one city. Therefore, the regeneration of mechanical filters of reverse osmosis systems is quite relevant and essential today. This work aimed to develop an environmentally safe technology for regenerating mechanical filters with the possibility of repeated use. Filter lifespan can be prolonged by special cleaning with sulfuric acid with a fixed pH level. This article highlights the research results on the regeneration the mechanical filters, describes the characteristics of the cleaning process using sulfuric acid and shows the options for environmentally safe waste processing from such regeneration.

Keywords: desalination, reverse osmosis, end-of-life filters, cartridge lifespan, regeneration, waste management.

INTRODUCTION

Global environmental problems of humanity, such as warming, increasing the level of the world's oceans, shortage of fresh water, artificial pollution of the ecosphere, etc., lead to a catastrophic lack of the primary source of life on Earth – drinking water. Intensive pollution of surface and underground waters due to anthropogenic activity reduces the water suitable for consumption every year. Ensuring adequate water quantity and quality globally is of great impertinence and affects most countries. Water use in most world countries is mainly irrational: unproductive water consumption increases and pollution and depletion decrease the volume of water resources suitable for consumption (Remeshevska I. et al. 2021; Trus I. et al. 2019; Trus I. and Gomelya M. 2021). That is why the water that comes to the user through centralized water supply systems needs additional purification. Therefore, before using such water, it is necessary to disinfect it centrally. However, even in this case, it is impossible to guarantee the required quality of drinking water at the water collection points since, in the process of preliminary water treatment, its re-contamination with chemical reagents and chlorine occurs. An extended water stay in old, slightly worn water supplies leads to the transition of iron compounds and various biological objects into the water (Nirmala K. et al. 2023; Wang H. et al. 2021). Therefore, in most countries, the most acceptable option to bring drinking water quality to the requirements of current regulatory documents is to purify it directly at the points of water use, i.e. apartments, houses, and offices (Radovenchik Y. and Gomelya, M. 2016). The experience of recent years shows that the most convenient and widespread option for drinking water purification and purification is installing reverse osmosis systems directly at the water intake points (Malaeb L. and Ayoub G. 2011; Giraldo-Mejıa H. et al. 2022; Amimul A. and Monzur I. 2019; Melliti, E. et al. 2023).

The phenomenon of osmosis occurs without phase transformations. A semi-permeable membrane for installing reverse osmosis is a composite polymer material of uneven density (Tanioka K.S.A. et al. 2012). This polymer is formed from several layers that are inextricably linked. The membrane acts as a barrier to all dissolved salts, and organic and inorganic molecules with a molecular weight greater than 100, but water molecules pass freely through it, creating a flow. The degree of retention of dissolved salts on reverse osmosis membranes is 95–99%, which allows the highest quality water purification from mechanical and organic pollution, bacteria and viruses, radionuclides, pesticides and metals (Trus I. et al. 2020; Trus[a] I. et al. 2022; Zhou J. et al. 2011).

When operating a reverse osmosis system, owners are not concerned about the negative consequences of using such techniques. There are no corresponding data in the scientific literature. Therefore, considering the widespread distribution of such systems, research in this direction is relevant and timely. Moreover, with appropriate research, it is easier to identify which methods cause environmental damage – industrial or household and office. In addition, industrial systems have yet to acquire such use. During their operation, it is possible to introduce the technologies to regenerate system elements, wash membranes and filters, and decontaminate concentrates, after which all this is localized in a small area (Trus[b] I. et al. 2022; Trus I. and Gomelya M. 2023; Gomelya M. et al. 2014; Siyuan L. et al. 2021; Giagnorio M. et al. 2022). In the case of household and office systems, such opportunities do not exist. Any practical actions in this service require a wide range of specialist knowledge and skills from users. Therefore, all waste using such a system is dumped into the environment.

A typical modern reverse osmosis system can count up to 9 stages of water treatment today (Fathizadeh M. et al. 2011). At the same time, each step is designed to remove specific impurities or treat water to improve its quality.

The effectiveness of the reverse osmosis process regarding various impurities and dissolved substances depends on several factors. Pressure, temperature, pH level, membrane material and chemical composition of the incoming water affect the efficiency of the reverse osmosis system (Dong X. et al. 2022; Jiang J-Q. and Graham, N.J.D. 1998; Song, M. et al. 2020).

At the first stages of processing with a stream, solid particles up to 1–20 microns in size are removed, regardless of the initial composition of the water. For this purpose, polypropylene cartridges with the appropriate pore size are preferred. During operation, particles of sand, clay, rust, metal hydroxides, and organic objects are deposited in the pores and on the surface of the cartridge. Over time, the hydraulic resistance of the cartridge as a result of filling the port and

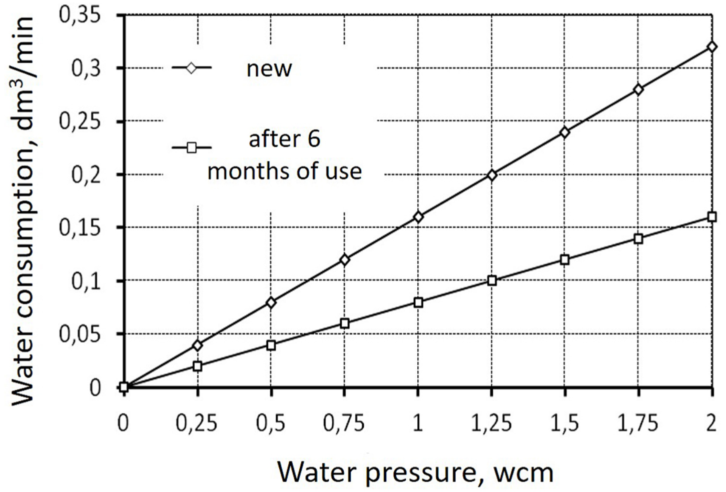

Figure 1. Change in throughput of a polypropylene cartridge during operation

the formation of a layer of impurities on the surface becomes quite significant, which requires an increase in energy consumption for a system with an additional pump or is accompanied by a decrease in the performance of after treatment equipment for systems connected to a centralized water supply network. As it was shown in the authors' research (Fig. 1), the difference between a new cartridge and a cartridge with an exhausted resource is quite significant, even with small pressures. The characteristics of the cartridge are reduced by more than two times in 6 months. A cartridge that has exhausted its resource needs to be replaced. It is dismantled and replaced with a new one. The end-of-life cartridges and retained impurities replenish the volume of solid household waste.

The main objective of the research was to find practical and environmentally safe ways to clean the mechanical filters of the reverse osmosis system. The method of this work was developing an environmentally safe technology for the regeneration of mechanical filters with the possibility of their repeated use.

MATERIALS AND METHODS

The method of work consisted of the precipitation of $FeCl_3 \cdot 6H_2O$ solutions of different concentrations with NaOH and $Ca(OH)_2$ solutions, the study of the intensity of dissolution of the obtained precipitates with sulfuric acid solutions of different concentrations as well as determining the intensity of illumination and filtering of the obtained suspensions.

The mechanical filter of a typical household ten-inch reverse osmosis system is a cartridge in the form of a hollow cylinder made of porous polypropylene with an outer diameter of 6.35 cm, an inner diameter of 3 cm, and a length of 25.4 cm (Fig. 2).

The cartridge can be formed from a foamed polypropylene mass or wound with polypropylene fiber. Cartridges are manufactured with a pore size of 1, 5, 10 and 20 microns.

RESULTS AND DISCUSSION

The cost of cartridges starts from 1 euro per piece in the territory of the European Union. For example, in Poland, three cartridges cost 7 to 20 € and more (GW-SET-RO5-MINI, Global water, Czeladz, Poland; KW-RO-HS, Set of pre-fills, Warsaw, Poland). In Germany, the average cost of a mechanical filter is 8–9 € (PP-20A-1, Naturewater, Koenigsbenden, Germany; Foam cartridges, Wasserfilter, Germany). In Spain, a standard set of three replaceable filters for a reverse osmosis system costs 21 € (Domestic reverse osmosis consumables IDRAPURE 9¾" from Idrania, Turiego, Spain; Set of 3×1¼" spigot filters, Gedar Chauchina, Spain). In Ukraine, the cost of one cartridge starts from 1 € and rises to 7 € (1-2-3 Cartridge Kit for Reverse Osmosis Filters CHV3ECO, Ecosoft, Kyiv, Ukraine; Polypropylene cartridge PP-20L BigBlue, Bio+ systems, Kyiv, Ukraine). The price depends on the presence of an antibacterial coating, surface treatment with special reagents and the type of material. A more critical parameter is the frequency of cartridge replacement. Unfortunately, today there is no single approach in this matter.

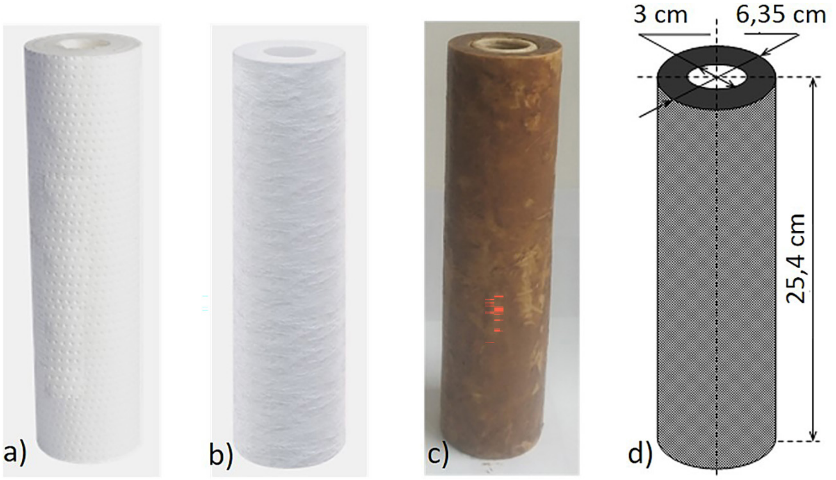

Figure 2. Appearance and dimensions of a typical 10" polypropylene cartridge: a – pressed; b – from polypropylene thread; c – after six months of operation; d – main dimensions

Several companies declare that cartridge lifespan is six months (Gedar Ecosoft, Naturewater), while others indicate its resource in the characteristics, for example, 10,000 dm^3 of water (Bio+ systems; Idrania, Gedar). However, the problem is that most household systems are not equipped with treated water meters, so it is almost impossible to record the moment when the resource is exhausted. Replacing the cartridge every six months is also a subjective procedure, since it does not consider the quality of water, the intensity of its consumption, the operating conditions of the system, etc.

On the basis of the above, as a result of the operation of the household reverse osmosis system, two polypropylene cartridges are replaced during the year. Several companies, when replacing cartridges, take used ones for disposal (45), but the authors needed to familiarize themselves with the actual technology of this procedure. Moreover, it is possible to justify this fact from an economic point of view since the cost of cartridges is relatively low. In that case, the environmental aspects will become more acute yearly (Elsaid M., et al. 2020; Chen Z. et al. 2021). Calculating that each cartridge holds about 625 cm^3 of foamed polypropylene or polypropylene thread is easy. Today, 60% of all desalinated water in the world is produced using reverse osmosis (Grossi L. et al. 2021). During operation, the cartridge does not undergo any changes that prevent its reuse. Since the cartridge is made of porous polypropylene, these products become sources of microplastic particles in the environment. In the stream of household waste, where cartridges mostly end up today, due to repeated overloading and transportation, such porous elements are destroyed to the greatest extent. At the same time, 625 cm^3 of polypropylene is guaranteed to retain some volume of hydrocarbons – all of the above points to the benefit of the regeneration of polypropylene cartridges and their reuse. Let us assume that according to calculations, around 88,000 domestic reverse osmosis systems are in operation today in Kyiv (Ukraine) alone. In that case, it is easy to calculate that 176,000 cartridges with a total polypropylene volume of 105 m^3 enter the environment during the year. It is difficult to imagine the total environmental damage from the cartridges of even one city. On the other hand, most owners of reverse osmosis systems use the services of specialized companies to replace cartridges, so collecting spent cartridges and locating them in one place is fine.

Since the environmental aspect is the primary goal of this research, it is evident that the regeneration technology of polypropylene cartridges should be environmentally safe. This technology was developed from this point of view.

The conducted research showed that the bulk of the solid particles trapped by the cartridge comprise iron (III) oxides and hydroxides (Fig. 3). Research was conducted for the cartridges used to purify water from the underground horizon.

When the water of the centralized water supply is purified, the sediment composition will be diverse (Sophonsiri C. and Morgenroth E. 2004). To clean the cartridge from such impurities, it seems most appropriate to use acids of the appropriate concentration, since it is practically impossible to effectively remove solid particles from the pores of the cartridge without dissolving them. The study of the features of using such cartridges showed that during their long-term operation or with a significant concentration of iron compounds, a washing layer of impurities is formed on the surface of the cartridge, which is destroyed when the cartridge is removed from the water environment. Thus, the first stage of cartridge regeneration occurs already at the stage of its dismantling. The next step should be carried out with sulfuric acid solutions. At the same time, oxides and hydroxides of iron (III) go into the solution and release the pores of the cartridge:

$$2Fe(OH)_3 + 3H_2SO_4 \rightarrow Fe_2(SO_4)_3 + 3H_2O \quad (1)$$

Since a significant excess of acid requires significant consumption of reagents during subsequent neutralization, the rate of dissolution of

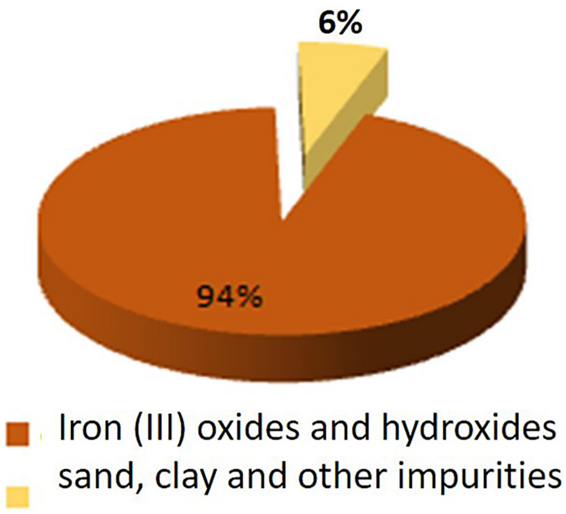

Figure 3. Composition of sediments on polypropylene filters

iron (III) hydroxide in sulfuric acid solutions was investigated (Fig. 4). It was established that during contact with the acid solution for 30 min. a different degree of dissolution of pre-precipitated iron hydroxide (III) is achieved. As it can be seen from Figure 4, while maintaining the pH at 1.5, the entire sediment turns into an acid solution during the specified time. At the same time, it is advisable to add acid as the pH increases. As the experience of working with used mechanical cleaning cartridges shows, they all have different levels of contamination, so it is difficult to determine in advance the concentration and the required volume of acid for their regeneration. When the pH of the regenerating solution is 2.0, the dissolution time of iron (III) hydroxides increases by 1.5–2.0 times, but this requires less consumption of reagents for its subsequent neutralization. Since recording the pH of solutions today does not cause technical difficulties, maintaining the required pH should be entrusted to an automated system for measuring and dosing the acid solution.

It is most expedient to treat spent iron solutions with lime. At the same time, iron (III) ions will hydrolyze into sparingly soluble $Fe(OH)_3$, and calcium with sulfates will form gypsum particles:

$$\begin{aligned} &Fe_2(SO_4)_3 + 3Ca(OH)_2 \rightarrow \\ &\rightarrow 2Fe(OH)_3\downarrow + 3CaSO_4\downarrow \end{aligned} \tag{2}$$

When accumulated in sufficient quantity, the filtered solid phase from a mixture of iron hydroxide and gypsum can be used in the technologies for obtaining building materials and structures. The filtered mother solution containing calcium sulfate at the solubility level (2.0 g/dm^3 (Goronovsky I. et al. 1962) is used to prepare the next dose of regeneration solution by dosing the appropriate amount of sulfuric acid. A series of

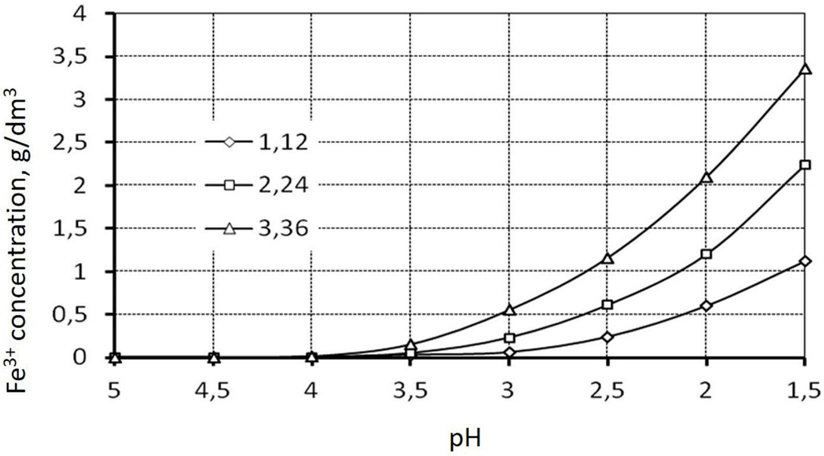

Figure 4. Dependence of the concentration of iron (III) ions in sulfuric acid solution on value from hydrogen index at different initial concentrations of iron ions (g/dm^3)

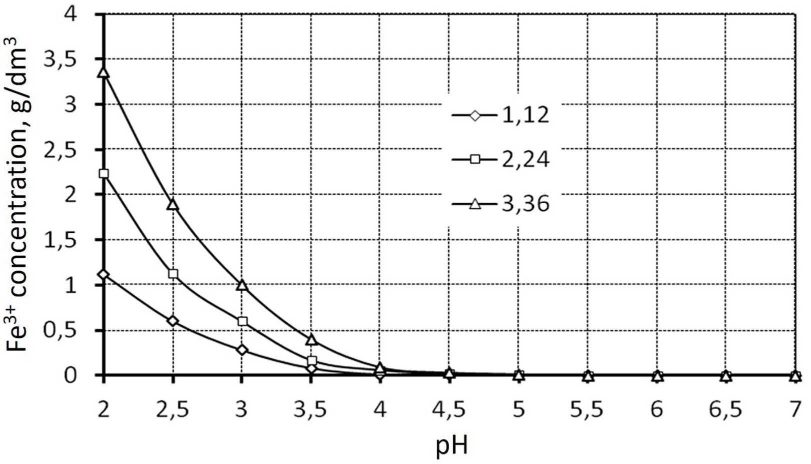

Figure 5. Dependence of the residual concentrations of iron (III) ions in the clarified solution on the value of the hydrogen index at different initial concentrations of iron ions (g/dm^3)

experiments was conducted to establish the minimum residual concentration of iron in the mother liquor. It was established (Fig. 5) that pH 4.0–4.5 can be considered optimal, at which the content of iron ions is at the level of their content in drinking water.

The problem of separating solid and liquid phases is essential. Filtering can be considered the most acceptable, considering the volume of the suspension. The settlement, in this case, does not allow obtaining a completed process, and the suspension settles too slowly. For example, when the concentration of iron ions in the initial solution is 5.6 g/dm^3 and the pH is adjusted to 4.03 with a sodium hydroxide solution, only 5 cm^3 of the suspension is clarified in 3 hours. Filtering turned out to be more acceptable. In this case, the hydrogen indicator of the suspension was decisive (Fig. 6). At pH 2.6, the mother liquor is filtered very quickly due to the absence of a solid phase, which begins to form only after pH > 3. However, at such pH, a jelly-like precipitate forms, which blocks the filter pores and slows down the filtration process. The best results are obtained at pH = 4.5 when the hydroxide particles are fully formed, giving off moisture well, so if at pH = 4.03, only 28% of the initial volume of the suspension is filtered out of the liquid phase in two hours, then at pH = 4.5, already 89%, and within 50 minutes.

The formation of a significant amount of specific solid waste contributes to the increase of microplastic particles in the environment. The main components of deposits on mechanical filters are iron (III) compounds. An ecologically safe technology for the regeneration of polypropylene filters of the stage of mechanical water purification of reverse osmosis systems is proposed. The technology involves treating used cartridges with a solution of sulfuric acid at a pH of 1.5–2.0, then neutralizing the resulting solution with calcium hydroxide to a pH of 4.0–4.5 to form a mixture of iron (III) hydroxide and gypsum in the mother solution. The solid phase is separated from the mother liquor by filtration and used in the building materials industry, whereas the filtrate is corrected with acid and reused in the process. Thus, the conducted analysis allows stating that a significant negative impact accompanies the operation of domestic and office reverse osmosis systems on the environment.

On the basis of the above, one of the variants of a possible technological scheme for the regeneration of polypropylene cartridges of reverse osmosis systems may have the following form (Fig. 7). The basis of the equipment for the implementation of the technology consists of three housings for 10" filters 1, 2, 3, in which used cartridges 4 are placed. Each cartridge has been equipped with lower five and upper six plugs. In addition, the equipment includes pump 15, faucets 7–14, buffer tank 16, mixer 17 and tank 18 with bag filter 19.

The scheme works as follows. At the beginning of work, all taps are closed. The required amount of water and acid to prepare a solution with a concentration of % is poured into the buffer tank 16. Next, taps 7, 11 and 14 are opened, and the resulting solution is pumped through the cartridges with pump 15.

The volume of the buffer tank is selected from the condition of the content of the volume of acid solution necessary to fill all three filter housings with cartridges, adding another 10% to it. The acid solution passes through all the cartridges

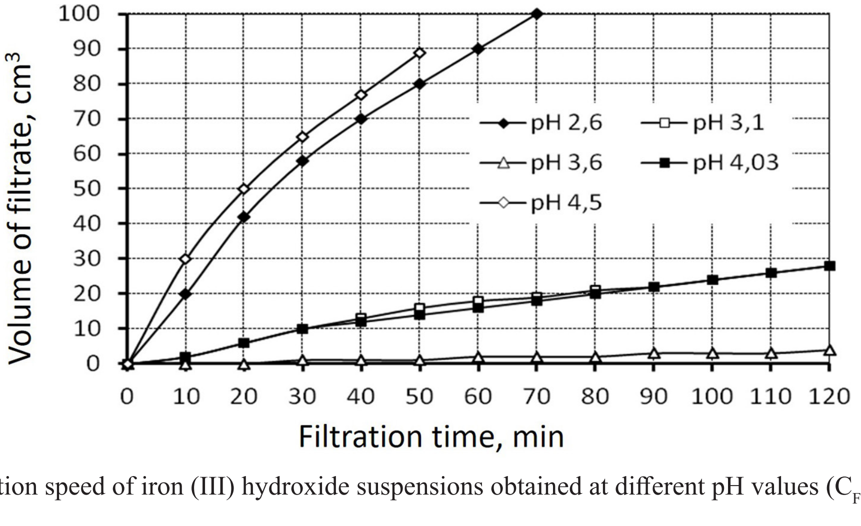

Figure 6. Filtration speed of iron (III) hydroxide suspensions obtained at different pH values (C_{Fe3+} = 5.6 g/dm^3)

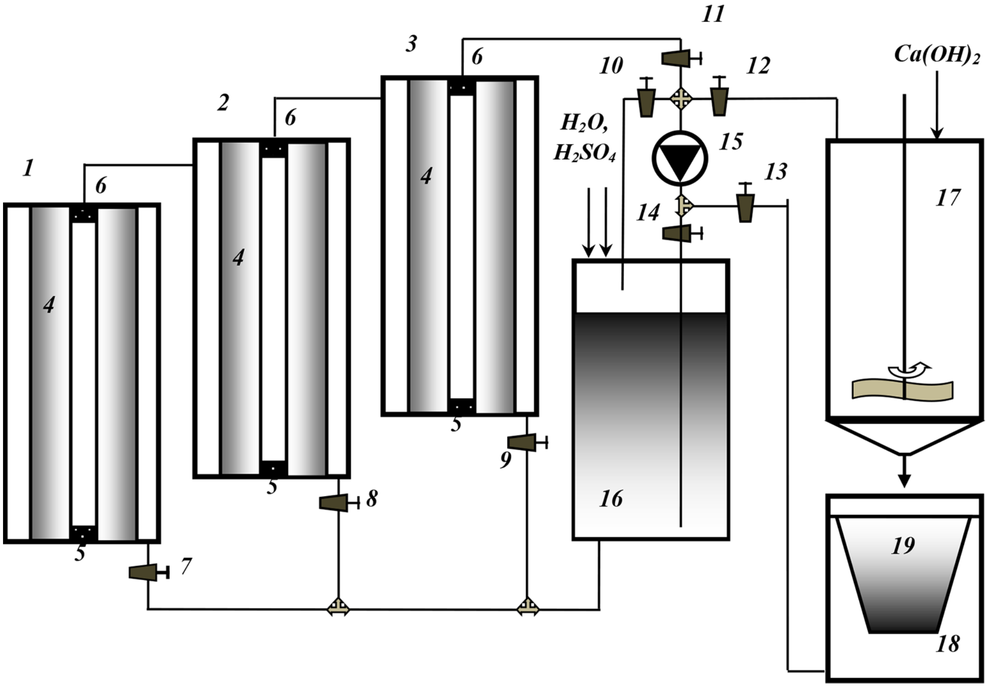

Figure 7. Technological scheme of regeneration of polypropylene filters (explanation in the text)

sequentially in the direction opposite to the working direction, dissolving the precipitated iron (III) hydroxide. The concentration of the acid solution is selected so that it is sufficient to wash all three cartridges. After the solution is saturated with iron (III) ions, taps 8, 9, and 12 are opened, tap 11 is closed, and the solution is pumped into mixer 17, equipped with a stirrer. With the stirrer turned on, a specified CaO or $Ca(OH)_2$ is added to the mixer and mixed for a minute. After forming a solid phase in the mixer, it is poured into container 18 through a bag filter 19. After the filtering process, the bag filter is removed to dry and remove the hydroxide mixture of iron (III), and gypsum. After closing all taps, except 10 and 14, the liquid phase is pumped by pump 15 into buffer tank 16. The required amount of water and acid are added there, the cartridges in housings 1–3 are replaced, and the regeneration cycle is repeated. The regenerated cartridges are washed in a separate line, dried in the air, disinfected with ultraviolet light and packaged for delivery to consumers.

The filter washing system after regeneration consists of a separate line of three containers with a volume of 2.25 dm^3 and a height of more than 26 cm each (Fig. 8). The tanks are installed in a

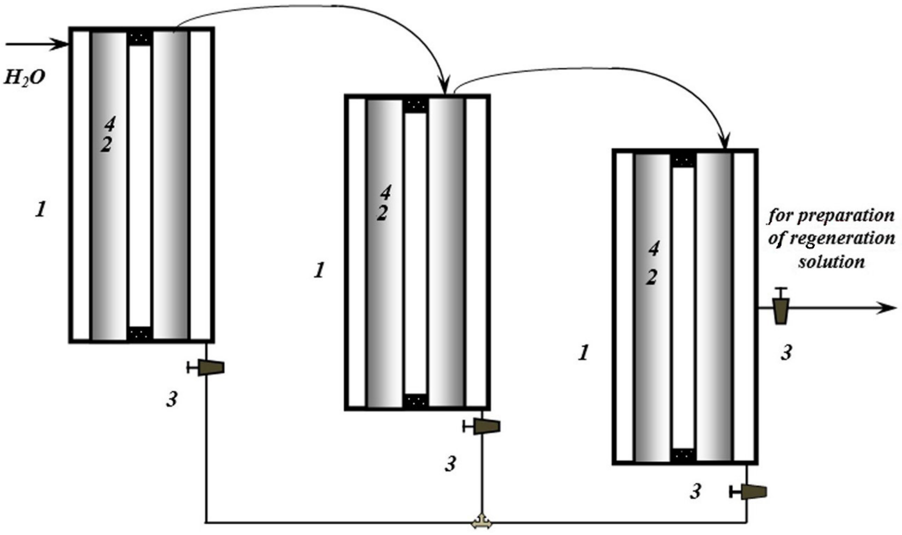

Figure 8. Technological scheme of washing regenerated polypropylene filters (explanation in the text)

cascade in such a way that when the taps three are opened, 262 cm^3 of washing water flows from one tank to another. This volume of the liquid phase is lost during reagent neutralization of regeneration solutions per 1 dm^3 of solution. Thus, the flushing system works according to the following scheme.

All three containers (1) are filled with clean water in the amount of 1.85 dm^3 each. The regenerated polypropylene filter is immersed in the highest container and remains for 20 minutes. Next, the filter is removed from the container, and after the liquid has stopped scavenging, it is placed in the next container. After the third capacity, the filter is dried, disinfected and packaged for delivery to the service department. From the third tank, 262 cm^3 of washing water is used to prepare acid solutions in the buffer tank 16 (Fig. 7). The same volume of clean water is poured into the first container, and the washing cycle is repeated. As it was shown in the conducted experiments, the washing water after the third tank has a pH of 6.36 and contains 0.2 mg/dm^3 of iron (III) ions.

CONCLUSIONS

Baromembrane water purification systems remain today the most popular and safest method of water purification for drinking purposes. However, the presence of waste generated as a result of the operation of such systems causes significant damage to the environment. Spent mechanical filters of the first stage of purification can be regenerated and reused in reverse osmosis installations. The study of the features of using such cartridges showed that during their long-term operation or with a significant concentration of iron compounds, a washing layer of impurities is formed on the surface of the cartridge, which is destroyed when the cartridge is removed from the water environment. Thus, the first stage of cartridge regeneration occurs already at the stage of its dismantling. At the same time, oxides and hydroxides of iron (III) go into the solution and free the pores of the cartridge. The next stage should be carried out with sulfuric acid solutions.

Regeneration technology involves the use of a sulfuric acid solution. When the pH is maintained at 1.5, the entire sediment from the polluted pores of the filter turns into an acid solution within half an hour. At the same time, it is advisable to add acid as the pH increases. Treating spent iron solutions with lime followed by filtering is the most expedient. The filtered mother solution containing calcium sulfate at the solubility level is used to prepare the next dose of regeneration solution by dosing the appropriate amount of sulfuric acid and washing water. When accumulated in sufficient quantity, the filtered solid phase from a mixture of iron hydroxide and gypsum can be used in technologies for obtaining building materials and structures.

The technological schemes for regenerating and washing polypropylene filters of reverse osmosis systems were also offered.

REFERENCES

1. Remeshevska I., Trokhymenko G., Gurets N., Stepova O., Trus I., Akhmedova V. 2021. Study of the Ways and Methods of Searching Water Leaks in Water Supply Networks of the Settlements of Ukraine. Ecol. Eng. Environ. Technol., 22(4), 14–21. doi.org/10.12912/27197050/137874
2. Trus I., Gomelya M. 2021. Effectiveness nanofiltration during water purification from heavy metal ions. Journal of Chemical Technology and Metallurgy, 56(3), 615–620.
3. Trus I., Gomelya M., Skiba M., Pylypenko T., Krysenko T. 2022. Development of Resource-Saving Technologies in the Use of Sedimentation Inhibitors for Reverse Osmosis Installations. J. Ecol. Eng., 23(1), 206–215. https://doi.org/10.12911/22998993/144075
4. Trus I., Radovenchyk I., Halysh V., Skiba M., Vasylenko I., Vorobyova V., Hlushko O., Sirenko L. 2019. Innovative Approach in Creation of Integrated Technology of Desalination of Mineralized Water. Journal of Ecological Engineering, 20(8), 107–113. https://doi.org/10.12911/22998993/110767
5. Trus I., Gomelya N., Halysh V., Radovenchyk I., Stepova O., Levytska O. 2020. Technology of the comprehensive desalination of wastewater from mines. Eastern-European Journal of Enterprise Technologies, 3/6(105), 21–27. https://doi.org/10.15587/1729-4061.2020.206443
6. Trus I., Gomelya M. 2023. Applications of antiscalants in circulating water supply systems. Journal of Chemical Technology and Metallurgy, 58(2), 360–366.
7. Trus I., Gomelya M., Levytska O., Pylypenko T. 2022. Development of scaling reagent for waters of different mineralization. Ecological Engineering and Environmental Technology, 23(4), 81–87. https://doi.org/10.12912/27197050/150201
8. Gomelya M.D., Trus I.M., Radovenchyk I.V. 2014. Influence of stabilizing water treatment on weak

acid cation exchange resin in acidic form on quality of mine water nanofiltration desalination. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 5, 100–105.

9. Nirmala K., Rangasamy G., Ramya M., Uma Shankar V., Rajesh G. 2023. A critical review on recent research progress on microplastic pollutants in drinking water, Environmental Research, 222, 115–122. https://doi.org/10.1016/j.envres.2023.115312
10. Wang, H., Wang, Y., Han, X., Zhang, J., Tang, F. 2021. Monitoring DOM in drinking water supply systems using DOC, CODMn, UV and fluorescence measurements. Environmental Science: Water Research & Technology, 7(12), 107–120. https://doi.org/10.1039/D1EW00409C
11. Radovenchik, Y., Gomelya, M. 2016. Physicochemical methods of water purification. Condor Publishing House, 264.
12. Malaeb, L., Ayoub, G. 2011. Reverse osmosis technology for water treatment: State of the art review. Desalination, 1(267), 1–8. https://doi.org/10.1016/j.desal.2010.09.001
13. Giraldo-Mejıa, H., Toledo-Alarcón, J., Rodriguez, B., García, A. 2022. Direct recycling of discarded reverse osmosis membranes for domestic wastewater treatment with a focus on water reuse. Chemical Engineering Research and Design, 184, 473–487. https://doi.org/10.1016/j.cherd.2022.06.031
14. Amimul A., Monzur I. 2019. Nanofiltration Membrane Technology Providing Quality Drinking Water. Editor. Nanotechnology in Water and Wastewater Treatment, 14, 291–295. https://doi.org/10.1016/B978-0-12-813902-8.00014-9
15. Melliti, E., Van der Bruggen, B., Elfil, H. 2023. Chemical inhibition of combined gypsum and iron oxides membrane fouling during reverse osmosis desalination process: Prevention and regeneration of membranes. Desalination, 551. https://doi.org/10.1016/j.desal.2023.116414
16. Tanioka, K.S.A., Irie, M., Zaitsu, S., Sakai, H., Hayashi, H. 2012. Power generation by pressure retarded osmosis using concentrated brine from seawater desalination system and
17. treated sewage: review of experience with pilot plant in Japan. The 3rd Osmosis
18. Membrane SummitStatkraft, 4, 1–33. http://refhub.elsevier.com/S2214-9937(15)30010-5/rf1945
19. Zhou, J., Chang, V.W.-C., Fane, A.G. 2011. Environmental life cycle assessment of reverse osmosis desalination. The influence of different life cycle impact assessment methods on the characterization results, Desalination, 283, 227–236. https://doi.org/10.1016/j.desal.2011.04.066
20. Siyuan, L., Zhongyang, W., Han, M., Zhang, J. 2021. Embodied water consumption between typical desalination projects: Reverse osmosis versus low-temperature multi-effect distillation. Journal of Cleaner Production, 295. https://doi.org/10.1016/j.jclepro.2021.126340
21. Giagnorio, M., Morciano, M., Zhang, W., Hélix-Nielsen, C., Fasano, M., Tiraferri, A. 2022. Coupling of forward osmosis with desalination technologies: System-scale analysis at the water-energy nexus. Desalination, 543. https://doi.org/10.1016/j.desal.2022.116083
22. Fathizadeh, M., Aroujalian, A., Raisi, A. 2011. Effect of added NaX nano-zeolite into polyamide as a top thin layer of membrane on water flux and salt rejection in a reverse osmosis process. Journal of Membrane Science, 375(1–2), 88–95. https://doi.org/10.1016/j.memsci.2011.03.017
23. Dong, X., Wang, X., Xu, H., Huang, Y., Gao, C., Gao, X. 2022. Mesoporous hollow nanospheres with amino groups for reverse osmosis membranes with enhanced permeability. Journal of Membrane Science, 657. https://doi.org/10.1016/j.memsci.2022.120637
24. Jiang, J-Q., Graham, N.J.D. 1998. Observations of the comparative hydrolysis/precipitation behaviour of polyferric sulphate and ferric sulphate. Water Research, 32(3). https://doi.org/10.1016/S0043-1354(97)83364-7
25. Song, M., Ju Im, S., Jeong, D., Jang, A. 2020. Reduction of biofouling potential in cartridge filter by using chlorine dioxide for enhancing anti-biofouling of seawater reverse osmosis membrane. Environmental Research, 180. https://doi.org/10.1016/j.envres.2019.108866
26. Komplet wkładów do filtra RO5 Mini. URL: https://sklep.osmoza.pl/komplet-wkladow-gw-set-ro5-mini-p-1902.html
27. KW-RO-HS: Komplet wkładów wstępnych. URL: https://www.woda.com.pl/p1841,kw-ro-hs-komplet-wkladow-wstepnych.html
28. KW-RO-USTM: Komplet wkładów wstępnych, URL: https://www.woda.com.pl/p160,kw-ro-ustm--komplet-wkladow-wstepnych.html
29. Komplet wkładów do filtrów Klarwod do systemu odwróconej osmozy - Wkłady – Castorama. URL: https://www.castorama.pl/komplet-wkladow-do-filtrow-klarwod-do-systemu-odwroconej-osmozy-id-1058405
30. FCPS1 wkład piankowy polipropylenowy mechaniczny. URL: https://filtrowana.pl/pl/p/fcps1--wklad-piankowy-polipropylenowy-mechaniczny/1356
31. Naturewater 20 Inch – 508 mm 5µ Sediment Filter Insert PP-20A-1. https://www.naturewater.eu/Naturewater-20Zoll-508mm-5-Sedimentfilter-Einsatz-PP-20A-1/51184

32. Naturewater 20 Zoll – 508 mm 5µ Sedimentfilter Einsatz PP-20A-1. URL: https://www.naturewater.eu/Naturewater-20Zoll-508mm-5-Sedimentfilter--Einsatz-PP-20A-1/51184
33. Schaumkartuschen Sedimentersatz Haus Pumpe Umkehrosmoseset Wasserfilter Germany | eBay. URL: https://www.ebay.de/itm/266123327536?hash=item3df62fb830:g:InkAAOSwWxNY05xO-&var=565962149345
34. Consumibles osmosis inversa doméstica IDRAPURE 9¾" de Idrania. URL: https://www.turiego.es/consumibles-osmosis-inversa-domestica-idrapure-idrania.html#.Y_XjzLdc6Nw
35. Juego de 3 filtros de espiga en 1¼" GEDAR: Equipos y Productos para Agua. URL: https://www.gedar.es/tienda/400-juego-de-3-filtros-de-espiga--en-i-14.html
36. Cartridge polypropylene PP 10”. URL: https://www.aqua-ua.com/ua/product/kartridzh-polipropilenovyy-pp-10-1-mkm/
37. Improved set of Ecosoft 1-2-3 cartridges for reverse osmosis filters (CHV3ECO). URL: https://ecosoft.ua/ua/uluchshennyy-komplekt-kartridzhey-ecosoft-1-2-3-dlya-filtra-obratnogo-osmosa/
38. Set of 1-2-3 Ecosoft cartridges for reverse osmosis filters. URL: https://bt.rozetka.com.ua/dlya-sistem-obratnogo-osmosa/c196454/
39. Improved set of cartridges for reverse osmosis Aqualite Premium. URL: https://vodavdom.ua/ua/Product/2264
40. KP-RO5-HS: Komplet wkładów do filtrów RO5. URL: https://www.woda.com.pl/p1969,kp-ro5-hs--komplet-wkladow-do-filtrow-ro5.html
41. Cartridge polypropylene Bio+ systems PP-20L Big-Blue 20”. URL: https://mixer.km.ua/p1496888166--kartridzh-polipropilenovyj-bio.html
42. Cartridge polypropylene ПП 20” 5. URL: https://www.aqua-ua.com/ua/product/kartridzh-polipropilenovyy-pp-20-5-mkm/
43. How often to replace the cartridges in the reverse osmosis filter? URL: https://vodavdom.ua/ua/blog/kak-chasto-menyat-kartridzhi-v-filtre-obratnogo-osmosa/
44. Ordering filter installation or maintenance. URL: https://ecosoft.ua/ua/services/
45. Reverse osmosis service. URL: https://vencon.ua/ua/catalog/servis-obratnogo-osmosa
46. Elsaid, M., Kamil, M., Olabi, A. 2020. Environmental impact of desalination technologies: A review. Science of The Total Environment, 748. https://doi.org/10.1016/j.scitotenv.2020.141528
47. Chen, Z., Zhu, S., Ren, H. 2021. Occurrence of high-risk mcr-1 gene and blaNDM-1 positive superbug in the reverse osmosis filter cartridges of the household water purifiers. Journal of Hazardous Materials Letters, 2, 123–131. https://doi.org/10.1016/j.hazl.2020.100011
48. Grossi, L.B., da Silva, B.R.S., Neves, E.F.O., Lange, L.C., Amaral, M.C.S. 2021. Reverse osmosis elements waste assessment: Screening and forecasting of emerging waste in Brazil. Desalination, 517(1). https://doi.org/10.1016/j.desal.2021.115245
49. Sophonsiri, C., Morgenroth, E. 2004. Chemical composition associated with different particle size fractions in municipal, industrial, and agricultural wastewaters. Chemosphere, 55(5), 691–703. https://doi.org/10.1016/j.chemosphere.2003.11.032
50. Goronovsky, I., Nazarenko, Yu., Nekryach, E. 1962. Short reference book of chemistry. Institute of the Academy of Sciences of the Ukrainian SSR, 660.