

New spatial-globular structure polymer for pre-treatment in reverse osmosis membrane filtration

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ABSTRACT

Kazakhstan is facing increasing water scarcity due to climate change and transboundary international water diversions. For this reason, low-quality water with high mineral content needs to be increasingly used in the future. A way to improve water quality for consumptive use is membrane treatment technology. In view of this, we investigated a new type of synthetic spatial-globular structure (SGS) polymers as a pre-treatment to reverse osmosis membrane filtration to increase its efficiency and service life. SGS polymer filters can be used as a pretreatment unit before ultrafiltration and reverse osmosis, providing filtration, suspended solids retention, and water softening. The investigated SGS polymer reduced the Ca content in the source water from 390 to about 1 mg/L with a purification effect of 99.7 %. The treatment as indicated by the contamination index Φ of the filters showed that the overall cleaning effect was 90 % or more. Thus, the use of the new pre-filtering SGS material with ion-exchange and sorption properties displayed good improvement for drinking water treatment and it can be used to increase the life of membrane devices.

1. Introduction

Providing drinking water to the population is not only an investment but also a scientific and technical task [1]. Global warming and continuous contamination of surface and groundwater cause increasing problems for safe water supply. Increasing mineral and pollutant contents in surface waters induce problems as well for industry and agriculture, which inevitably cause negative socioeconomic effects [2]. The advantage of membrane technologies such as reverse osmosis and ultrafiltration is their versatility, i.e., the ability to purify water from impurities of different compositions and concentrations [3]. However, to ensure long-term and stable operation of various types of membrane filters usually necessitates various kinds of pre-treatment. The tasks of water pretreatment include both the mechanical removal of impurities from filters and membranes and the creation of conditions that prevent filter and membrane contamination [4].

In recent years, new separation processes based on the use of synthetic materials for specific purposes (selective ion exchange resins and membranes, porous polymer materials, coalescent nozzles, new types of

filter fabrics, highly effective extractants, coagulants, flocculants, and defoamers) have been introduced into the practice of water treatment. New synthetic materials largely determine the technical progress in the field of water treatment [5,6]. Among these materials, highly porous polymers are of great importance and are being developed in many countries, e.g., microporous polypropylene is the basis for the global life science industry of the Merck Millipore. These materials are characterized by high efficiency and retention capacity in treatment. The inert nature of polymers makes it possible to carry out sorption and coalescence separation processes on their bases.

A fundamentally new type of polymer material of the type of spatially globular structure (SGS) has recently been synthesized at the National Centre for Complex Processing of Mineral Raw Materials, Almaty, Kazakhstan. The chemical composition and structure of the SGS is like generally used polymers such as phenol-formaldehyde, urea-formaldehyde, melamine-formaldehyde plastics, polystyrene, polyvinyl pyridines, polyacrylates, etc. The SGS polymers are distinguished by a special physical structure and consist of many globular particles of spherical shape, contact-linked to form a continuous spatial framework.

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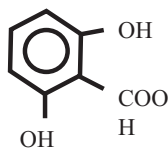
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Thus, they can maintain their geometric shape under the influence of physical exertion. SGS polymers are porous, highly permeable materials. Their porous structure is determined by 1) size of the globules; 2) structure of the globules; 3) deviation of the size of the globules from the average value. The globular structure of SGS polymers with a micro globule size of 0.5 μm and above is clearly visible in an optical microscope. The specific surface area of micropores with their size of about 50 Å (angstrom) is about 300 m^2/g . Thus, the general properties SGS polymers are a large, expanded surface, a narrow range of pore size distribution, and a wide variety of chemical and physicochemical properties that gives these materials valuable technological properties. The SGS porosity ranges from tens of angstroms to tens of microns [7,8]. SGS polymers can be effectively used in separation processes such as micro- and ultrafiltration, hyperfiltration, sorption, ion exchange, coalescence, and extraction. With the emergence of new types of SGS polymers and the study of their filtration, sorption, and ion exchange properties, the possibility and prospect of creating new, effective separation processes arise [9,10]. They are also used in pre-treatment processes before membrane apparatuses, providing at the same time the processes of filtration, retention of suspended substances, and water softening. Due to their ability to remove suspended particle contamination and high sorption and ion exchange properties, the use of SGS filters also increases the service lifetime of membrane devices.

The complex SGS polymers based on oxyacids, oxyquinolines, and hydroxymethylphenols can be used in ion exchange processes. These polymers form stable claw-like complexes with calcium, magnesium, zinc, germanium, boron, and several other elements at strictly defined pH values. A feature of such complexes is a gradual decrease in stability as the concentration of monovalent cations present in solution (sodium, potassium, and ammonium) increases due to the salt formation of carboxyl and methoxy groups at an ionic strength of about 1–2 M. Practically, this is expressed in the fact that for a moderate content of 5–10 g/L of sulfate or chloride, effective binding of complexing ions by the corresponding SGS ions occurs. Thus, 1–2 M solution of salts (sodium sulfate, sodium chloride) can be used as reagent. This is an extremely valuable and practically important property of this class of SGS polymers, which allows in some cases to develop a waste-free ion exchange process. This type of SGS ionites is solid insoluble substances capable of exchanging their ions for ions from the surrounding solution that usually form a synthetic organic resin.

The spatially globular sorbents are characterized by high sorption rates (about 1000–2000 specific volume/h; specific volume is defined as volume occupied by a kg of filter material), high selectivity, and separating ability. The advantages of SGS polymer technology are: 1) ultra-high-speed mode of sorption and elution; 2) waste-free process (there are no liquid products, such as eluates, wastewater, etc.) due to recycling of the eluent (the eluent is a liquid saturated with air to maintain a saturated solution of calcium and magnesium in equilibrium); 3) consumption of salts for elution is close to the theoretically consumed amount; and 4) clarification of the source water is not required since sorption occurs simultaneously with filtration. This provides highly selective and high-speed extraction of hardness cations from aqueous solutions. The affinity of the ion-exchanger for calcium and magnesium increases with an increase in the pH of the solution (Fig. 1). In the pH range of 6–8, complexes can be destroyed by the action of a large excess of monovalent cations. This is since ionites usually are synthetic organic resins that also exhibit some affinity with them. This makes it possible to develop effective technology for low-waste ion exchange softening.



Spatial-globular structure (SGS) polymer that can form complex compounds with magnesium of the type:

However, SGS polymers have not yet been sufficiently studied for the use in different separation processes [13–15]. Preliminary studies have shown that the combination of the directed synthesis of SGS polymers with technological tests can lead to the development of highly innovative and efficient processing solutions, suspensions, and emulsions [16–22]. In this paper, the possibility of using new types of commercial SGS polymers was investigated for their use in ion exchange softening of water, and the extraction of individual components from salt water and other complex solutions. The purpose of the study was to test new types of synthetic SGS filters to increase the efficiency of membrane processes and the service life of membranes using polymer ion exchange filters. The novelty of the work lies in the preparation of high-quality drinking water using SGS filters in high-speed mode. A partial objective was to study the efficiency of the commercial FEL-80 filter as a preprocessing technique in reverse osmotic desalination of natural water. The FEL-80 filter is a product of the Geyser Company (RK) under patents 2,203,721 dated 07/04/2001, 2,261,843 dated 05/26/2004, as well as patent 2864 dated 12/15/1995. Since 2000, the FEL-80 SGS polymer filters have been used for water treatment, providing a high level of water purification from mechanical, organic impurities, bacteria and viruses, and heavy metals [38,39]. Our research concerned the softening and sorption properties in the process of filtering polymers through the SGS filter and using them in desalination technology as a pre-treatment. The main objective of the study was to establish ion exchange and high-speed extraction of hardness cations from aqueous solutions with simultaneous sorption and filtration. Thus, a main contribution of the study was to use the FEL-80 with a pore size of 5 μm for solution purification as preprocessing treatment before reverse osmosis. The decrease in performance of the FEL-80 was determined due to the reduction in membrane performance. As well, we tested the FEL-80 polymers for softening technology, in ultra-high-speed mode (transmission rate up to 2000 specific volumes/h).

2. Materials and methods

In all experiments with ultrafiltration separation, an inert commercial filtering element named FEL-80 (Fig. 2) was used (National Center for Integrated Processing of Mineral Raw Materials and Satbayev University, Kazakhstan). Coalescent separation of emulsions was used in the oleophilic SGS polymers. The experiments were performed as semi-industrial laboratory experiments and water desalination tests. The FEL-80 filter elements have a size of 120x18x8 mm and come in pore sizes of 2–5 μm . An FEL-80 filter with a pore size of 5 μm was used in the below experiments.

The SGS polymer has a special physical structure that consists of many globular particles of spherical shape, which are interconnected in contact with each other to form a continuous spatial framework. The globular structure of SGS polymers with a micro globule size of 0.5 μm and above is clearly visible in an optical microscope. Fig. 3 shows the structure of some of the most typical polymers A, B, and C consisting of monodisperse globules. Structure A represents the densest arrangement of micro globules. The estimated porosity of such a structure is 25.9 %. Structure B represents a less dense packing of micro globules compared to structure A. Here, the estimated porosity is 47.6 %. In structure C, porosity can reach 80–85 % or higher. The porous structure of SGS polymers has been studied in detail by mercury porosimetry, sorption measurements and density measurements. Polymer filter elements having a spatially globular SGS structure are characterized by a very uniform porous structure and a narrow pore size distribution of 10 %. Filter elements with a pore size from 5 to 20 μm and a porosity of 35–60 % operate in microfiltration mode.

Semi-industrial laboratory experiments were carried out for a single-flow FEL-80 module with a size of 250x70x40 mm. The installation was

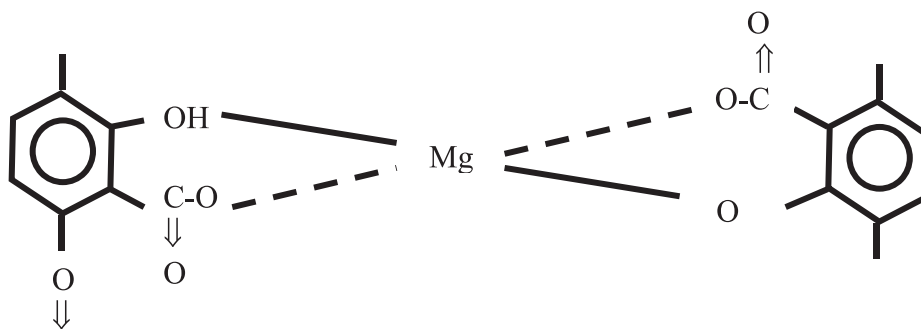


Fig. 1. Chemical structure of a complex-forming spatial-globular structure (SGS) polymer filter used for softening of water.



Fig. 2. Appearance and structure of the FEL-80 with SGS polymer filter.

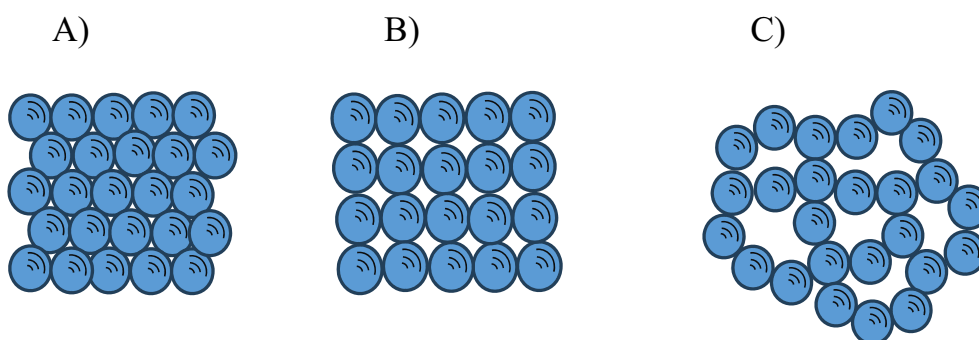


Fig. 3. Structure of typical polymers of monodisperse globules.

assembled in accordance with Fig. 4 in a plexiglass single cartridge module where 1) ion exchange module, 2) filter element FEL-80, reinforced with a polypropylene frame and needle-punched filter cloth, and equipped with threaded connections. The volume of the element was 650 mL.

All experiments were carried out using Almaty tap water, while the content of calcium and magnesium was controlled. Tap water was passed through the FEL-80 with a volume of 25 mL at a pressure of 0.015 MPa. The transmission rate was recorded with the selection of 2 L of filtrate, in which the contents of calcium, magnesium, and pH were determined. Then the ion-exchange filter element was purged with compressed air, and the circulating effluent (10 specific volumes) was

passed under the same pressure, again purged with compressed air, and sorption-elution cycles were repeated. The transmission rates during the first 1200 sorption-elution cycles were 1700–2000 specific volumes (depending on the fluctuation of gases dispersed in water).

The circulating effluent was created during the first 150–200 sorption-elution cycles as follows: 10 L of a 10 % sodium sulfate solution were prepared, which was then poured into 5 containers of 2 L each. Every day for 5 days, the solution in each container was alternately used as a circulating eluate with 30 sorption-elution cycles. At the same time, a white crystalline precipitate was formed with the completion of sedimentation within 10–12 min. During this time, the solution was completely clarified, and precipitation occurred.

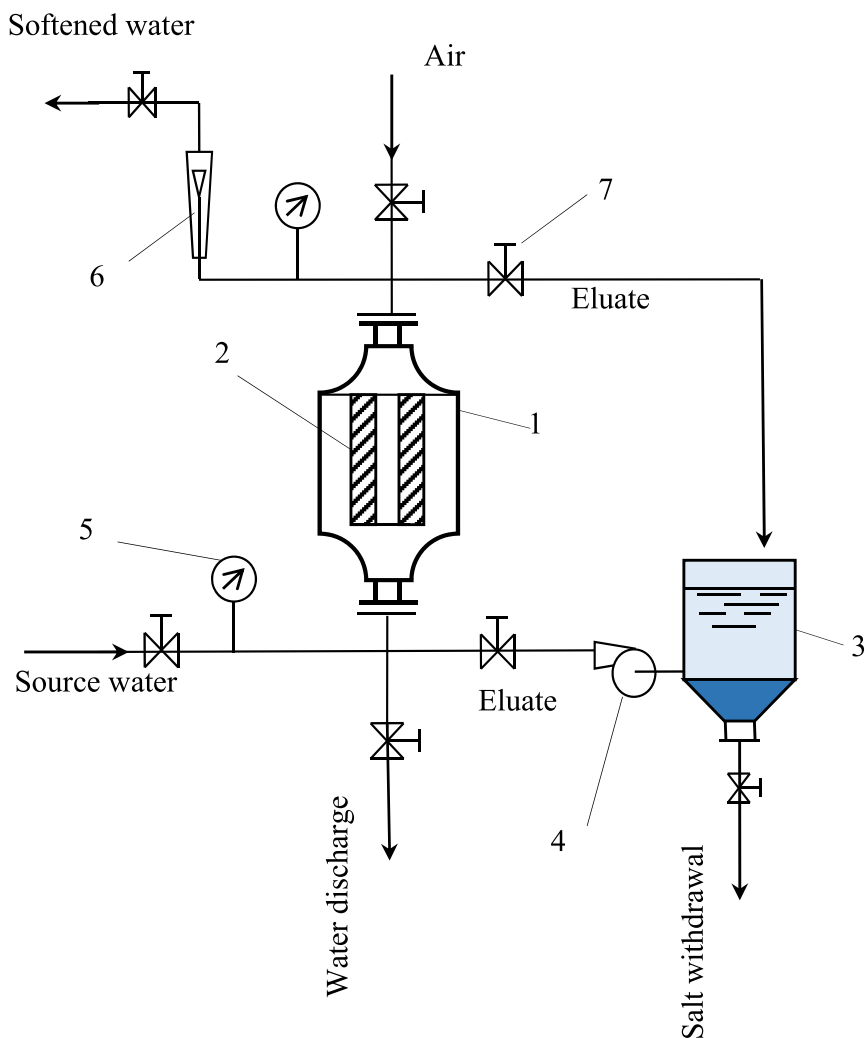


Fig. 4. Semi-industrial laboratory experiments for water-softening plant based using the SGS-filter FEL-80 with a volume of 650 mL with 1) single-cartridge module, 2) polymer filter element FEL-80, 3) two-chamber tank, 4) circulation pump, 5) pressure gauge, 6) rotameter, and 7) valve.

Further, solutions in pressure tanks were used daily in the appropriate order. After the 200th cycle, a solution was formed in each pressure vessel in equilibrium with the sediment containing 400–720 mg/L of calcium and 120–870 mg/L of magnesium (depending on the concentration of sodium sulfate in it). Periodically, the circulating

eluates were adjusted for sodium sulfate (approximately every 250–300 sorption–elution cycles), maintaining an effluent density of 1.05–1.10 (density of 10 % Na_2SO_4 solution at 200 °C: 1.105 t/m³, pH 4.8–5.4).

In the circulating effluent, the pH value was set in the range of 7.35–7.65. About 1500 sorption–elution cycles were performed in this

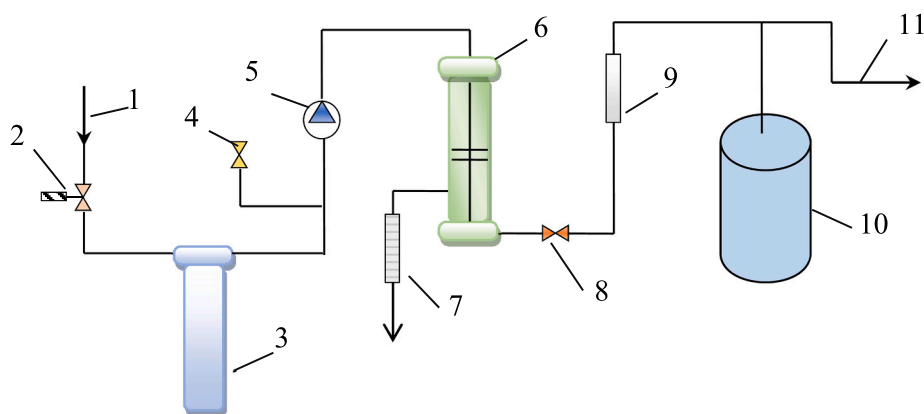


Fig. 5. Experimental water desalination plant with FEL-80 cartridge filters; 1) feed water supply pipeline, 2) inlet valve, 3) filter element FEL-80, with pore sizes of 5 μm , 4) pressure sensor, 5) pump ND-63/100, 6) reverse osmosis module, 7) concentrate outlet, 8) check valve, 9) filtrate quality sensor, 10) container for collecting filtrate, and 11) transport to the autoclave.

mode. Starting from the 300th cycle, stable and well-reproducible results were obtained for the content of calcium and magnesium in the filtrate (in 80 specific volumes with calcium concentrations of 1.5–2.5 mg/L and magnesium concentrations of 1.5–2.3 mg/L). In the case of using fresh (10 % Na_2SO_4), the calcium content was no more than 1 mg/L, and no magnesium was detected.

During the first 1000 sorption-elution cycles, the transmission rates of solutions were stable in the range of 1200–1600 specific volume/h at a pressure of 0.015 MPa. During the next 500 cycles, the speed decreased slightly and amounted to about 1000 specific volume/h by the 1200th cycle and about 800 specific volume/h by the 1500th cycle.

The outline of water desalination tests with FEL-80 cartridge filters is shown in Fig. 5. In the conducted experimental study, the following tasks were investigated:

- identification of the barrier role of the cartridge element,
- calculating the increase in pressure losses during operation, and
- determining the filter cycle for various cartridge element performance.

In the experimental setup, a reverse osmosis apparatus was used, with cellulose acetate membranes at a pressure of $P = 5$ MPa, the number of working membranes was 14. The source water entered the working chambers, moving in parallel flows, part of the water under pressure was filtered through the membrane, and the rest through the hole in the guide plates was released as a concentrate. The filtrate was drained through the base plate and out from the apparatus.

In the experimental water desalination plant with FEL-80 cartridge filters (Fig. 5), the source water, before being supplied to the reverse osmosis unit, was supplied to the FEL-80 filter element. Then, the filtered water was supplied to the reverse osmosis module, the quality of the desalinated water permeate was controlled by water quality sensors, the calcium concentration was determined by titrimetric method, and the change in the performance of the reverse osmosis unit during the experiment, due to the formation of sediment on membranes, was determined by the contamination index. Methods used in the experiments to determine calcium and magnesium contents were titrimetric according to GOST 31954–2012 (ISO 6059; 1984 NEQ and ISO 7980; 1986 NEQ), and X-ray methods for the study of sediment.

3. Results

3.1. Semi-industrial laboratory experiments

During the semi-industrial experiments, approximately the same results were obtained in terms of treatment as in previous small-scale laboratory experiments (results not shown; a slightly greater purification of calcium and magnesium, on average 1 mg/L and 0.8 mg/L is explained by the greater wall thickness of the industrial-sized cartridge, 15 mm versus 5 mm for the laboratory cartridge). In total, about 50 m³ of tap water was treated to produce about 5 kg of sediment. The precipitate contained 94–95 % $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ and about 5 % $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, with a minor impurity (less than 1 % CaCO_3), according to X-ray spectral analysis. The content of calcium (in terms of CaO) was 32.4–32.7 % and magnesium (in terms of MgO) was 1.8–1.9 %.

Fig. 6 shows the output curves of calcium sorption from tap water of the FEL-80 at different transmission rates of 400, 800, and 1500 specific volumes/h (initial calcium content 390 mg/L). As seen from the figure, there are not large differences between the transmission rates in terms of sorbed calcium. After about 80 specific volumes through the filter most of the calcium has been sorbed. Sorbed calcium is almost the same independent of transmission rate. The highest transmission rate of 1500 specific volumes/h are similar to the 400 specific volumes/h. Further tests (data not shown) showed that the optimal transmission rates of solutions at a given concentration of calcium in a solution were 800–1000 specific volumes/h. This shows that the FEL-80 works well for high transmission rates in terms of sorbed calcium.

Fig. 7 shows the calcium sorption for a lower initial calcium content equal to 70 mg/L and depending on transmission rates between 200 and 1846 specific volumes/h. Also here the sorbed calcium content is almost constant independent of the transmission rates. After about 450 specific volumes through the filter most of the initial calcium has been sorbed. The highest transmission rate (1846 specific volumes/h) is similar to the lowest transmission rate (200 specific volumes/h) in terms of sorbed calcium showing the efficiency also for high transmission rates.

Fig. 8 shows the calcium sorption for different initial calcium contents in the solution (20 to 400 mg/L) for a constant high transmission rate (1500 specific volumes/h). As seen from the figure, the sorbed calcium in terms of the highest initial calcium content (400 mg/L) resulted in a 50 % decrease in calcium concentration after a transmission

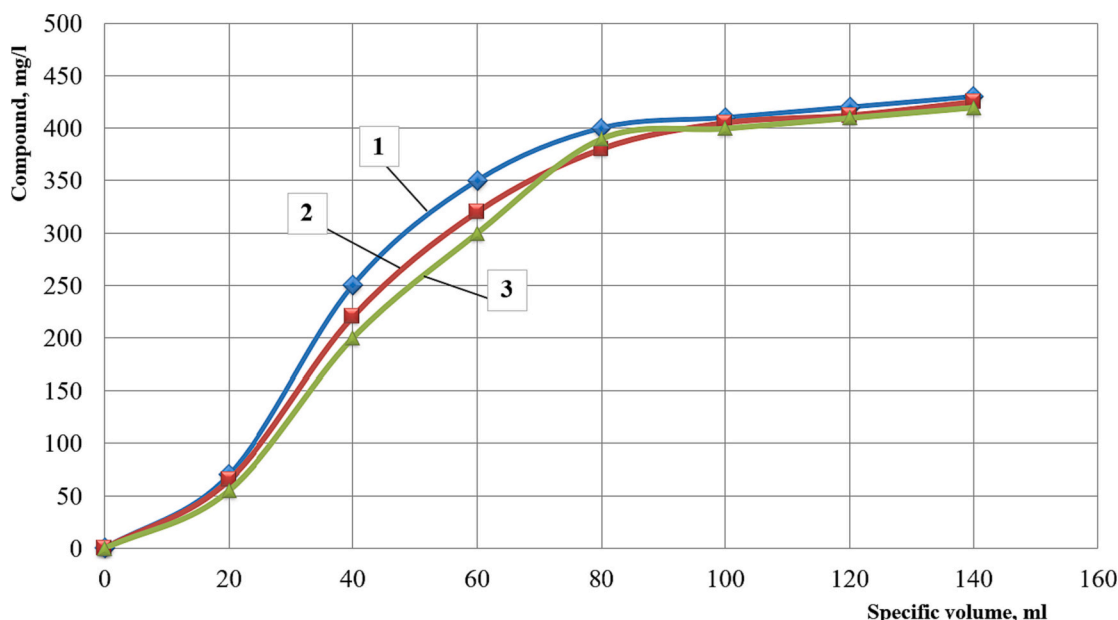


Fig. 6. Calcium sorption at an initial calcium content of 390 mg/L and transmission rates of 1) 400, 2) 800, and 3) 1500 specific volumes/h.

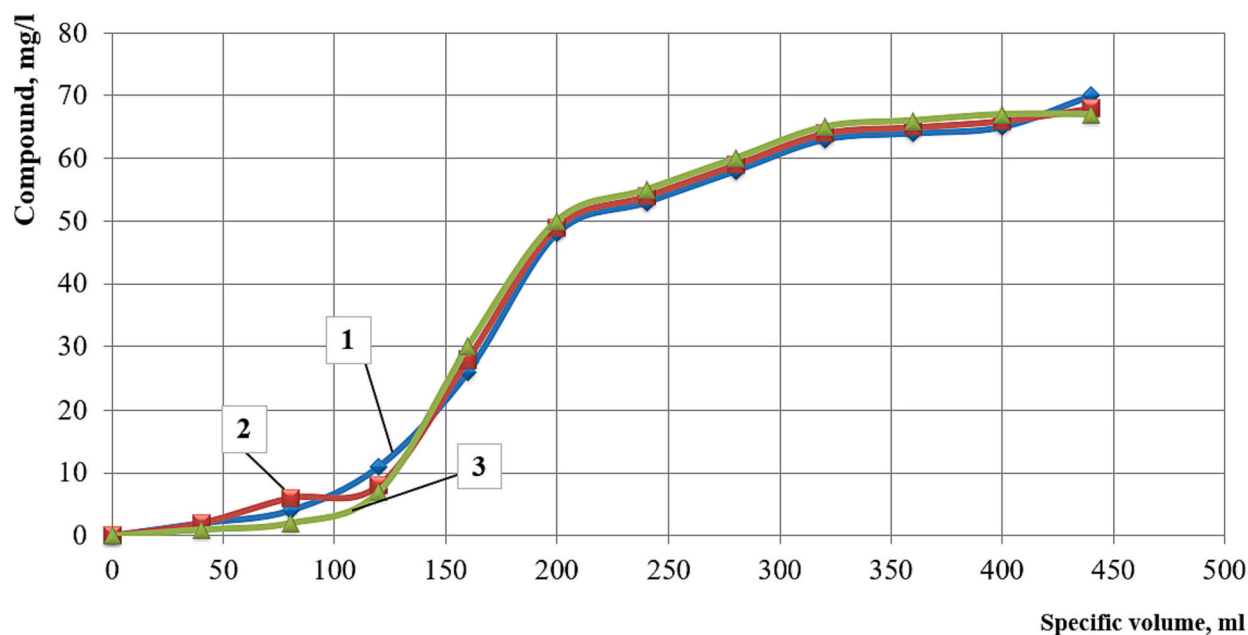


Fig. 7. Calcium sorption at an initial calcium content of 70 mg/L and transmission rates of 1) 200, 1500, and 1846 specific volumes/h.

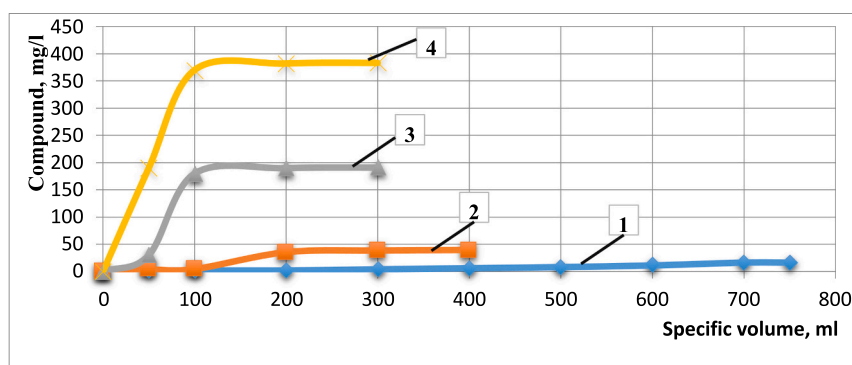


Fig. 8. Calcium sorption at a constant transmission rate equal to 1500 specific volumes/h and for different initial calcium contents 1) 20, 2) 70, 3) 200, 4) 400 mg/L.

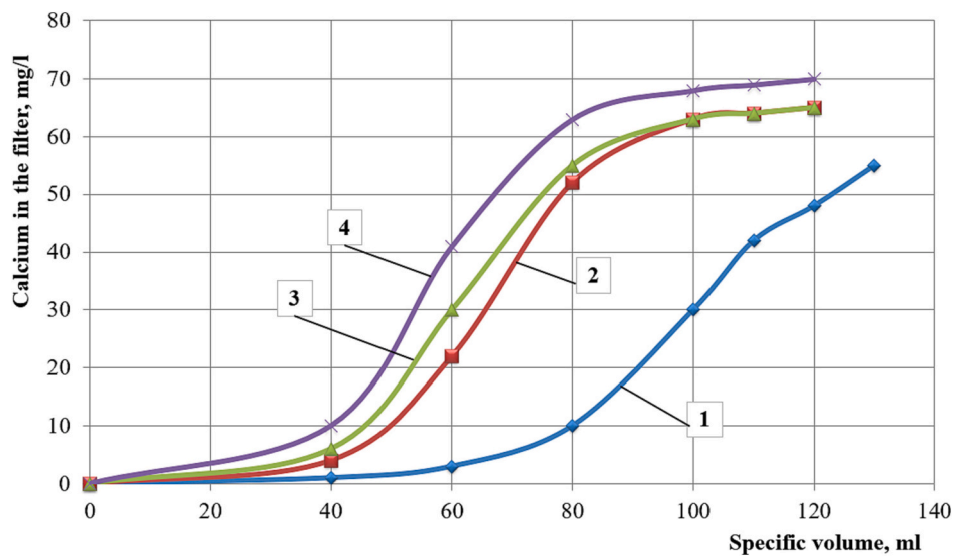


Fig. 9. Calcium sorption in tap water for an initial calcium content of 70 mg/L at pH 7.85 and different salt content 1) salt content 200 mg/L, 2) 5 g/L NaCl, 3) 5 g/L Na_2SO_4 , and 4) 5 g/L NaCl + 5 g/L Na_2SO_4 .

rate of about 50 specific volumes/h. The second highest initial calcium content (200 mg/L) decreased by 50 % after about 70 specific volumes/h. For these two highest initial calcium concentrations most of the calcium content was sorbed after about 100 specific volumes/h. Again, this shows the efficiency of the filter with high transmission rates. For the initial calcium content of 70 mg/L, about 50 % were sorbed after about 150 specific volumes/h and about 100 % after about 200 specific volumes/h.

Fig. 9 shows the calcium sorption from tap water with an initial calcium content of 70 mg/L at pH 7.85 and depending on the addition of various salts. As seen from the figure, addition of salts appears to lead to more efficient calcium sorption. A lower salt content (200 mg/L) means more specific volumes/h for the same treatment. Addition of NaCl and Na₂SO₄ results in more efficient calcium sorption. At 120 specific volumes/h most the calcium in the higher salt content tap water was sorbed. On the other hand, only about 50 mg/L calcium was sorbed in the low-saline tap water (200 mg/L) after about 120 specific volumes/h. The calcium sorption was most efficient in the tap water with 5 g/L NaCl + 5 g/L Na₂SO₄.

3.2. Water desalination experiments for purification before reverse osmotic desalination

Long-term successful operation of reverse osmosis desalination plants shows that in technological schemes of preliminary water treatment, final purification is usually carried out on cartridge filters with a pore size of 5–10 µm [23–26]. An increase in the degree of purification of water entering the membrane device can be achieved by using anthracite with quartz sand. However, the use of filter loadings does not guarantee the passage of sorbent particles through cracks in the drainage system, as well as from the passage of coarse impurities. This indicates the expediency of using cartridge elements as barrier elements.

Cartridge filters were designed for the treatment of natural and wastewater, as well as the retention of valuable components in the wastewater of non-ferrous metallurgy enterprises. The filter element is made using conversion technology from a unique material, which is a highly porous polymer product of a given geometric shape. All suspended and colloidal contaminants (sand, clay, iron oxides, algae) can be retained on the filter element's outer surface during the first stage of filtration. In the second stage, due to chemical binding by sorption-active micro globules, from which the filter is built, heavy metals, non-ferrous metals, hardness ions, radionuclides, petroleum products, phenols, pesticides, residual active chlorine, viruses, as well as substances that give water odors, flavors, and colors, are absorbed, and thereby removed from the water.

To predict potential drop in productivity, it is necessary to know how much contamination remains on the membrane after each filter cycle and how long it will take for an amount of contamination to accumulate that will cause a drop in productivity, which is the maximum allowable for this water purification system. The contamination of the source water and the water that has passed the FEL filter was assessed according depending on the F-pollution index [27–32]. The F-pollution index, determined in the concentrate, considers the phenomenon of salt concentration during the desalination of natural and waste waters containing organic substances in the pressure chambers of the reverse osmosis apparatus. This causes an increase in the concentration of electrolytes in comparison with the original water. This leads to precipitation of insoluble compounds or salting out of macromolecular substances in the form of a gel-like layer on the surface of the semi-permeable membrane. As initial water, an experimental solution was prepared with a calcium content of about 390 mg/L and HMW (high molecular weight substance) - protein solution - bovine albumin 5 % solution. The F-pollution index was determined on a microfiltration cell simulating the process of reverse osmosis by [33–35]:

$$F = \frac{P \cdot \Delta t}{q} \cdot \frac{\mu_{20}}{\mu} [\text{Pa} \cdot \text{s} \cdot \text{m}^{-2}] \quad (1)$$

where P denotes the process pressure (Pa); t is the difference in filtration time between two portions (s); q is the amount of water that has passed through the filtration surface unit (m/m); μ is dynamic viscosity of water at 20°C and the control temperature (Pa s);

The water supplied to the reverse osmosis apparatus was examined for content by using the F-pollution index. Fig. 10 shows the change in the F-pollution index of water that has and has not passed through the FEL-80 filter. The value of the F-pollution index for water that has passed the filter is much less than that of water that has not passed the FEL-80 filter, which indicates that the water that has passed the filter is much cleaner than water that has not passed the FEL-80 filter. Based on these results, it can be concluded that the FEL-80 cartridge element with a pore size of 5 µm has high barrier properties and can be used for technological schemes before reverse osmosis water treatment.

We also investigated the decrease in membrane performance over time according to:

$$V = V_0 \left(1 + 2 \frac{F}{P} V_0^2 t \right)^{-1/2} \quad (2)$$

where V is the specific performance of the reverse osmosis membrane, m³/m² s, V₀ is specific productivity at the initial moment of time, m³/m² s, P is process pressure, Pa, and t is duration of the membrane apparatus operation, s. The relative decrease in the performance of the reverse osmosis membranes (initial filtration capacity according to the manufacturer V₀ = 1.5 × 10⁻⁶ m³/m² s⁻¹) after an operating time of 1 month (2.6 × 10⁶ s) is thus estimated by:

$$\frac{V}{V_0} = \left(1 + 2 \frac{F_{orig}}{P} V_0^2 t \right)^{-1/2} \quad (3)$$

where the F-pollution index = 31.4 × 10⁸ Pa s m², measured in water that has passed the filter element according to:

$$\frac{V}{V_0} = \left(1 + 2 \frac{31.4 \cdot 10^8}{5 \cdot 10^6} (1.5 \cdot 10^{-6})^2 \cdot 2.6 \cdot 10^6 \right)^{-1/2} = 0.692$$

Similarly, the F-pollution index = 3200 × 10⁸ Pa s m² for water that has not passed the filter element:

$$\frac{V}{V_0} = \left(1 + 2 \frac{F_{fin}}{P} V_0^2 t \right)^{-1/2} \quad (4)$$

$$\frac{V}{V_0} = \left(1 + 2 \frac{3200 \cdot 10^8}{5 \cdot 10^6} (1.5 \cdot 10^{-6})^2 \cdot 2.6 \cdot 10^6 \right)^{-1/2} = 0.315$$

Thus, the relative error in the quantitative prediction of the effect of water pollution on reverse osmosis treatment is equal to:

$$\Delta = \frac{0.692 - 0.314}{0.692} = 54.6\%$$

Consequently, when using the filter elements in pretreatment for reverse osmosis desalination of water, the duration of membrane operation may be expected to increase (forecast of a decrease in membrane productivity is about 55 %). Accordingly, when desalination of water by reverse osmosis, the largest costs are the replacement of membranes, taking into account the results of the filter elements for pretreatment, costs will be reduced due to an increase in the service life of the membranes (Fig. 11). Fig. 11 shows the results of calculating a decrease in the performance of a reverse osmotic module over time operating on source water and water that has been pretreated by a FEL-80 filter and comparing these data with the theoretical performance (Eq. (2)). Water that has passed through the FEL-80 filter has a lower reduction in productivity compared to water that has not been filtered. Accordingly, the

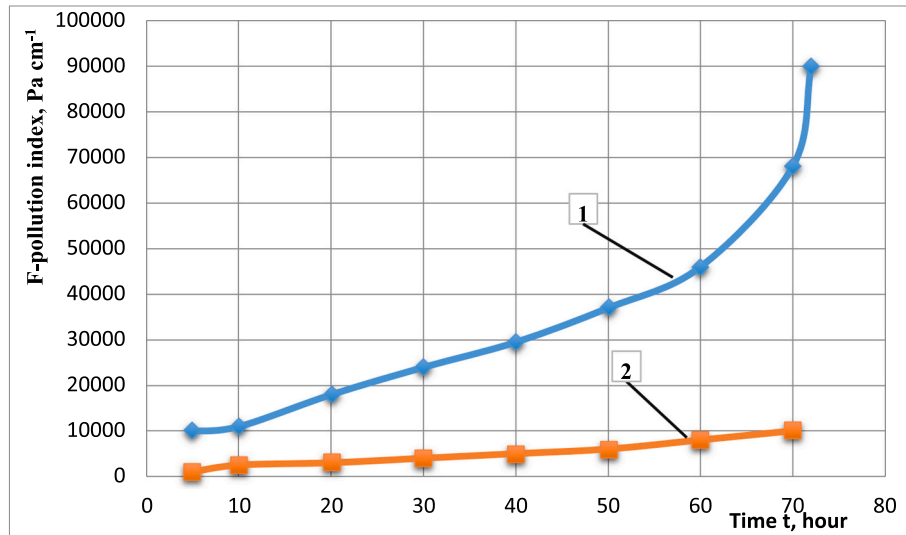


Fig. 10. F-pollution index of incoming water to the reverse osmosis module; 1) source water and 2) source water through the FEL-80.

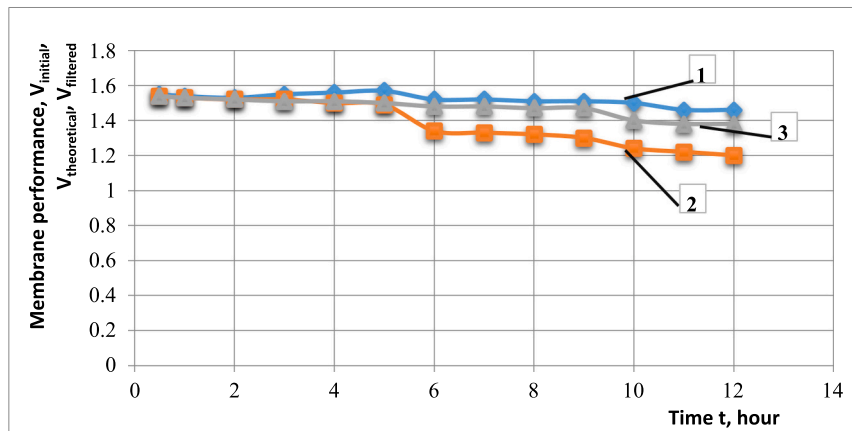


Fig. 11. Comparison of decrease in productivity of a reverse osmosis installation, calculated theoretically with the productivity of a device operating on source water and pretreated by a FEL-80 filter 1) filtered water, 2) source water, and 3) theoretical calculation.

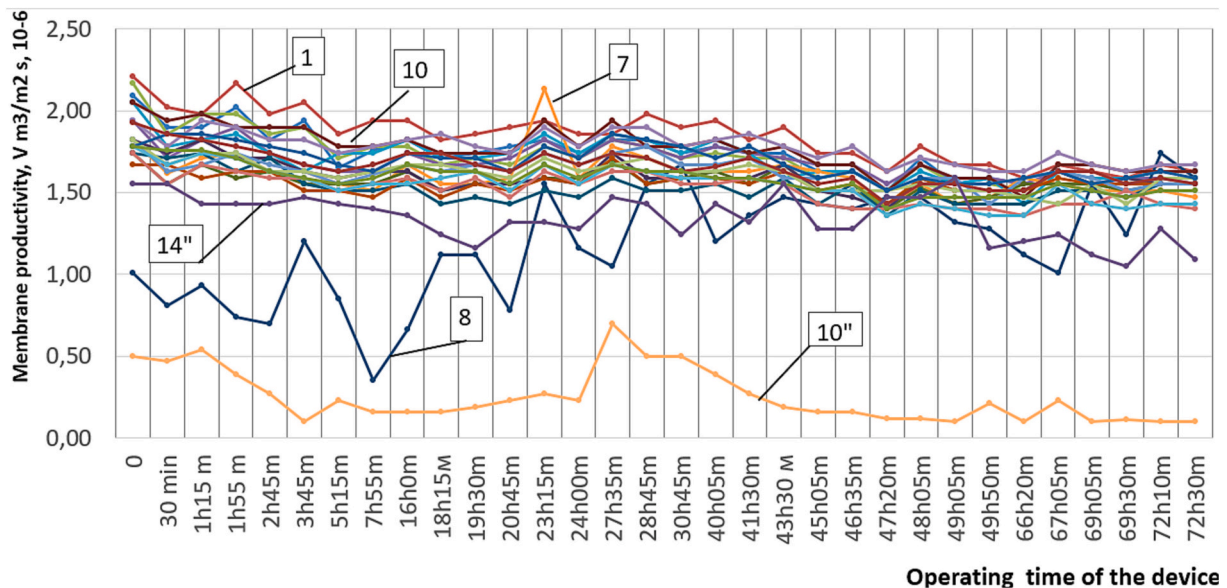


Fig. 12. Efficiency of reverse osmosis membranes for water filtered through 14 different FEL-80 filters over time.

source water and the water filtered through the FEL differs in the F-pollution index by more than 90 %.

Fig. 12 shows the capacity $V \text{ m}^3/\text{m}^2 \text{ s}^{-1}$, 10^{-6} for a total of 14 FEL-80 membranes. The membranes numbered 8 and 10 lost their efficiency during the installation. The other membranes worked well. Membrane performance was observed in graduated cylinders and continuously recorded.

Pollution affects performance, resulting in increased energy consumption, cleaning frequency and chemical consumption, membrane replacement and hence the cost of water treatment. Thus, it is very important to mitigate or prevent pollution to improve reverse osmosis technology. The purpose of monitoring is to provide information to limit the degree of pollution and prevent pressure loss [36]. To determine the increase in pressure losses during operation, studies were conducted on a single cartridge element (Fig. 13). Tap drinking water was used as the source water. Before use, the cartridge element was prepared by wetting with water followed by cleaning with compressed air for 20 min. This was done to wash off particles of organic substances present in the element during its manufacture. During the experiment, the flow rate varied between 25 and 175 L/h and the increase in pressure losses was measured. The pressure loss ranged from 0.1 to 0.7 m for this flow rate and the pressure loss was 0.1 m with every increase of 25 L/h.

Various kinds of polymers and polymer nanocomposites have been developed for various kinds of water and wastewater treatment [11–13]. The use of SGS polymers has also been used in different kinds of water treatment [40]. The specific use of SGS polymers as preprocessing for desalination of drinking water is to the authors' knowledge innovative. Since the SGS FEL-80 filter is a commercial product of the Geyser Company (RK) under various patents, the filter has been tested for various water treatments. The use of the FEL-80 specifically for preprocessing for desalination of drinking water has to the authors' knowledge not been done previously. Thus, it is difficult to compare the results with previous experiences. Regeneration of filter elements is normally provided by backwashing or backblowing with compressed air or a combination thereof, without the use of additional reagents. This technical solution makes it possible to significantly reduce the water consumption for flushing and restoring the filter's operability [37]. As well as the volumetric filtration rate of SGS polymers is 10–20 times higher than that of conventional granular ion exchange resins. This is an important advantage of SGS polymers [38,39].

4. Conclusions

The use of synthetic materials for special purposes determines the further development of the use of membranes and other methods in the preparation of drinking water. Thus, a decrease in soluble hardness salts, iron, and other salts and a decrease in color (due to water-soluble humic substances with a molecular weight of 2000 to 250,000) is not always possible by traditional methods. According to the results of sorption experiments on the content of calcium ions by ion exchange filters PGS FEL-80, the water purification efficiency for calcium was 99.7 %.

The use of new filtering materials with ion-exchange and sorption properties can improve the quality of drinking water and increase the life of membrane devices. Filters made of SGS polymers can be used as a pretreatment unit before ultrafiltration and reverse osmosis, providing filtration, suspended solids retention, and water softening all at the same time.

CRedit authorship contribution statement

N.V. Sidorova: Conceptualization, Formal analysis, Methodology, Software. **M.A. Imanbayev:** Conceptualization, Investigation, Methodology, Project administration, Supervision, Validation. **B. Khalkhabay:** Conceptualization, Investigation, Supervision, Visualization, Writing – original draft. **A.A. Zharmenov:** Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – original

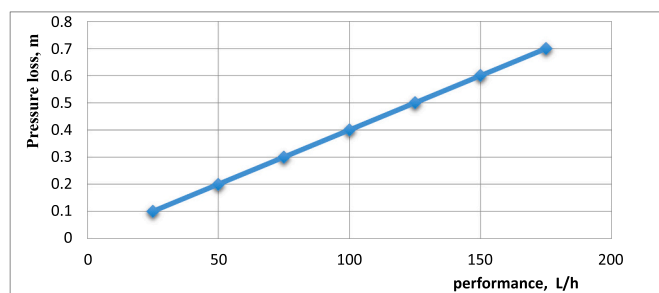


Fig. 13. Pressure loss as a function of flow rate for a single filter element FEL-80.

draft, Writing – review & editing. **Y.I. Kuldeev:** Conceptualization, Data curation, Formal analysis, Investigation, Writing – original draft. **S. Azat:** Formal analysis, Funding acquisition, Investigation, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing. **R. Berndtsson:** Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Data availability

Data will be made available on request.

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