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ECONOMIC AND ENVIRONMENTAL BENEFITS OF NACL BRINE REUSE BY NEW MEMBRANE TECHNOLOGY

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Cation exchange water softening is one of the most widely used technologies of water treatment. However, its environmental impact related to discharge of highly concentrated regeneration brine draws more attention as overall quality and availability of water resources decreases. Bearing in mind high levels of reusable NaCl in brine discharge, technology that will reduce the environmental impact and help reuse brine is required. To develop such technology composition of spent brine solution from Na-cation exchanger was investigated and conditioning of such solution with use of nanofiltration membranes of different types under different temperatures, pressures and recovery values was tested. Results show that optimal conditions for NaCl recovery include usage of Dow Filmtec Fortilife XC-N membrane elements at temperature 23–27 °C, pressure of 23–25 bar and recovery of 55–60%. Under these conditions purity of NaCl in permeate over 90% and NaCl yield of 13,1 kg/h were achieved. Principal technological scheme of the process of membrane conditioning of the spent regeneration solution was proposed that allows achieving reduction of NaCl consumption by 40% and reduction of NaCl discharge into sewage by 72% with corresponding economic and environmental benefits.

Keywords: *membrane technology; softening; brine; nanofiltration.*

1. Introduction

Water softening with Na-cationite resins is very widespread technology. Based on data for 2016, total world production of ion exchange resins (IER) could be estimated as 625000 m^3, with Na-cationites for water softening are nearly 50% of them, or 312000 m^3. Total world consumption of NaCl in 2016 reached 270 million tons [1], and authors estimate the amount of salt used for regeneration of Na-cationite softeners to be 11, 4–18, 3 million tons. Regarding the efficiency of regeneration [2], conclusion could be done that only 6, 6 million tons were spent for regeneration and 4, 8–11, 7 million tons of NaCl depending on the regeneration ratio was directly discharged into wastewater as spent regenerant solution (SRS).

Considered as low volume discharge [3], this wastewater is characterized by high levels of salinity and mostly NaCl and thus becomes serious environmental problem. There are several negative effects of excess of Na^+ including soil salinization and decrease of efficiency of wastewater treatment plants
[4–6].

Special attention is paid to small softeners used worldwide at private houses. These point-of-use units produce small amounts of wastewater but are very widespread thus resulting in noticeable amounts of saline discharge [7]. Locally discharged wastewater causes beforementioned problems with local wastewater treatment facilities.

Also, high levels of sodium are known to decrease the permeability of soil for water thus leading to problems with drainage of treated wastewater. Another environmental hazard of sodium is linked with its ability to promote uptake of phosphorus by algae leading to more intense algae blooming of water bodies [4,5].

Possible ways of reduction of these environmental issues include replacement of sodium chloride with potassium chloride that has no effect on algae and is not harmful for soil. Yet such replacement would increase cost of water softening up since potassium chloride is nearly twice as expensive as sodium chloride [4]. In addition, potassium causes problems with water drainage as well [5].

Another issue is that the excess of NaCl is paid for and then just discharged to sewage being an excess over stoichiometric quantity required for efficient regeneration [2]. More is added to the economical part of the problem, as we must consider the environment taxes and fines paid for discharging saline wastewater in most of countries.

Regarding the environmental and economic benefits of reuse of spent brines, several attempts to propose the solution were made. Some of proposed solutions includes chemical precipitation of calcium and magnesium with different reagents from brine with further filtration of residual NaCl solution.

Disadvantages of such technologies are usage of high amounts of expensive reagents (Na_2CO_3, NaOH), need in additional equipment and high amounts of wet solid waste.

Another method includes nanofiltration treatment of brine solution with added H_2SO_4 to achieve pH of solution as low as 2, 0 in order to promote permeation of monovalent ions including Na^+ and Cl^- to permeate and retention of ions of hardness in concentrate [8]. Being relatively efficient, such solution results in production of aggressive acidic waste which is more harmful and difficult to treat than the initial spent brine solution.

Several attempts were made to reduce usage of NaCl by tuning of ion exchange parameters itself including more efficient counterflow regeneration. As an example, UPCORE technology introduced by Dow Chemical could be mentioned.

The UPCORE system uses a simple countercurrent design, resulting in lower capital costs [9]. UPCORE countercurrent regeneration system uses downflow for the service cycle. At the end of the UPCORE system service cycle the resin bed is compacted with water in an upflow direction against a layer of floating inert resin at the top of the vessel. The resin regeneration and rinse are then carried out in an upflow direction, which is the most common practice among counter-current regeneration processes. Implementation of UPCORE technology results in a chemical savings of 5–25% compared to reverse flow regeneration systems using standard resins [9].

Considering all mentioned above, need for technology of recovery of NaCl from regeneration wastewater free of said disadvantages is obvious. The aim of this study was to develop technology for conditioning of spent regeneration solution from Na-cation exchanger with new generation of nanofiltration membranes for partial recovery of NaCl and reduction of environmental damage and cost of softening of water.

2. Materials and Methods

2.1.Spent regeneration solution of Na-cation exchanger

The object of the research in this work is spent regeneration solution (SRS) that is produced at the stage of regeneration of ion exchange resin. In order to find out the composition of actual SRS and distribution of its constituents in time of regeneration and to prepare the model solution for further tests samples of SRS from regeneration of industrial UPCORE Na-cation exchanger with capacity of 200 m^3/h and regeneration every 30 hours were taken. Industrial scale system was chosen due to higher environmental impact of such system because of higher volumes of discharge and bigger amounts of NaCl used per each regeneration.

SRS consists of diluted initial NaCl brine (ca. 8%) with sodium partially replaced by calcium and magnesium during the regeneration process. The composition of the initial regeneration solution is given in table 1.

Table 1. Composition of the initial regeneration solution

Parameter	Units	Value
Chlorides	meq/l	1470
Sodium	meq/l	1452
Total hardness	meq/l	18
Calcium	meq/l	16,6
Magnesium	meq/l	1,4
Total iron	mg/l	1,47
Manganese	mg/l	0,115
Total dissolved solids	g/l	85,3

2.2.Nanofiltration membrane elements

Experiments were done with 3 types of nanofiltration membrane elements with different parameters as shown in Table 2. Membrane elements used for tests have different permeate flow rate, stabilized rejection and purpose.

Table 2. Parameters of test membrane elements

Parameter/Item	FILMTEC NF270	FILMTEC NF90	FORTILIFE XC-N
Type and size	Spiral wound membrane element, 4” × 40”		
Operating Pressure, bar	4,8	4,8	4,8
Maximum Operating Pressure, bar	41	41	41
Target Permeate Flow Rate, m^3/d	3,2	2,6	3,2
Operating Temperature Limit, ° C	45	45	45
pH Range	2–11	2–11	3–10
Stabilized Rejection, %	> 97	98,7	99

2.3.Pilot nanofiltration plant

Pilot plant with the scheme shown on figure 1 was used. Constant operation in recycling mode was chosen due to limited availability of feed stream that was prepared in batches for every test.

Model brine solution is stored in the tank 1. By means of feed pump 2, the initial solution is pumped to the next stage — removal of mechanical impurities able to damage the membrane elements by the PP cartridge filter 3.

Further, model solution is pumped by high pressure pump 4 to the rack of pressure vessels with nanofiltration membrane elements 5. As model solution contained significant levels of chlorides, vertical centrifugal pump with titanium housing and working parts was used. As membrane separation took place, flows of permeate and concentrate occurred which were passed back to the tank 1. To achieve higher recovery for the system keeping recovery per element as low as the allowed limit concentrate recycle was implemented and part of concentrate stream leaving the membrane rack is sent back to the inlet of high pressure pump.

Flow rates and pressures of each stream were measured with flow meters and pressure gauges 8 respectively and controlled by adjusting the flow of recycle and concentrate with valves. Temperature of feed solution was measured by thermometer and controlled by heating up the solution via recirculation with feed pump 2.

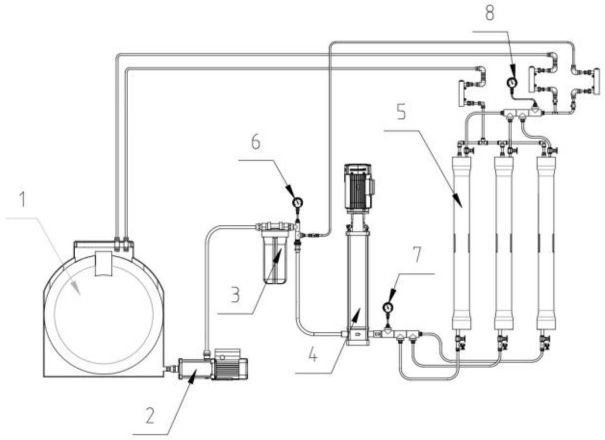

Figure 1. Principal technological scheme of conditioning of the spent regeneration solution: 1 - tank for regeneration solution; 2 - centrifugal pump; 3 - mechanical filter; 4 - pump; 5 - rack of nanofiltration membranes; 6, 7, 8 - pressure gauges

2.4.Comparison criteria

In order to select the most suitable membrane element and find the best conditions for recovery of NaCl from model solution several tests were done for all 3 membrane elements to investigate the effect of the main parameters of the process: temperature, recovery and pressure. The comparison criteria for choosing the most effective membrane element were the values that characterize the purity of NaCl in permeate (α) and the NaCl yield in the permeate (β) calculated by the following equations:

$$\alpha = \frac{C_{Na^+}}{C_{Cl^-}} \qquad (1)$$

where α is the purity of the permeate by NaCl, %; C_{Na^+} — concentration of sodium ions in permeate, meq/l; C_{Cl^-} — concentration of chloride ions in permeate, meq/l; and

$$\beta = \omega \cdot C_{NaCl} \qquad (2)$$

where β is NaCl yield in permeate, kg/hour; ω — permeate production, l/hour; NaCl — concentration of NaCl in permeate, kg/l.

2.5.Method of estimation of economic and environmental efficiency

To estimate environmental and economic efficiency of the proposed technology absolute (Δ) and relative (R) indices of reduction of consumption and discharge of NaCl were calculated:

$$\Delta = a - b \qquad (3)$$

where Δ is absolute value of reduction of cost and discharge of NaCl, units; a — value of the parameter after the Na-cation exchange filter with the UPCORE technology (without brine reuse); b — value of the parameter achieved with usage of the proposed technology, and

$$R = \frac{\Delta}{\alpha} \qquad (4)$$

where R is relative value of reduction of cost and discharge of NaCl, %.

Calculations of savings on environmental payments were done based on estimation of cost of discharge of wastewater with excess of concentration of different compounds used by Ukrainian government [10]. Estimation is performed by calculation of excess of concentration of a component:

$$EC = \frac{C_p - L_p}{L_p} \qquad (5)$$

where EC is excess of concentration, %; Cp — actual concentration of a component; Lp — limit of concentration for a component in wastewater allowed to be discharged into municipal sewage system (stated by government). It should be noted if value calculated by (5) is bigger than 10, EC is taken to be 10 [10]. Then payment for discharge is calculated as follows:

$$P_{tot} = V_D \cdot EC \cdot T \cdot F_{EC} + T \cdot V_D \quad (6)$$

where P_{tot} is total payment for discharge; V_D — volume of discharge of wastewater; EC — excess of concentration; T — tariff for discharge per 1 m^3 of wastewater; F_{EC} — coefficient of increase of tariff for excess of concentration (stated as 59% [10]).

Then total annual payments were calculated for cases without technology of brine reuse based on 292 regenerations of softener per year (operational data from plant) and with proposed technology and savings were found. Payback period was calculated by following equation:

$$PP = \frac{CapEx}{S_{NaCl} - \Sigma OpEx + S_{env}} \quad (7)$$

where PP is payback period in months; $CapEx$ — total capital expenses for implementation of proposed technology; S_{NaCl} — annual savings on cost of NaCl by its reuse; $\Sigma OpEx$ — total amount of operational expenses for proposed technology (power cost, maintenance, consumables etc.); S_{env} — savings of environmental payments due to decrease of wastewater volume discharge.

3. Results

3.1. Analysis of SRS from industrial Na-cation exchanger and determination of composition of the model solution

In order to prepare the model solution for further tests of the process of conditioning of SRS analysis of the spent regeneration solution discharged during the regeneration stage of the Na-cation exchanger. In order to determine the amount of wastewater that is appropriate for averaging and subsequent conditioning, an initial concentration profile for the Na-cationite filter regeneration process, shown in figure 2, was obtained.

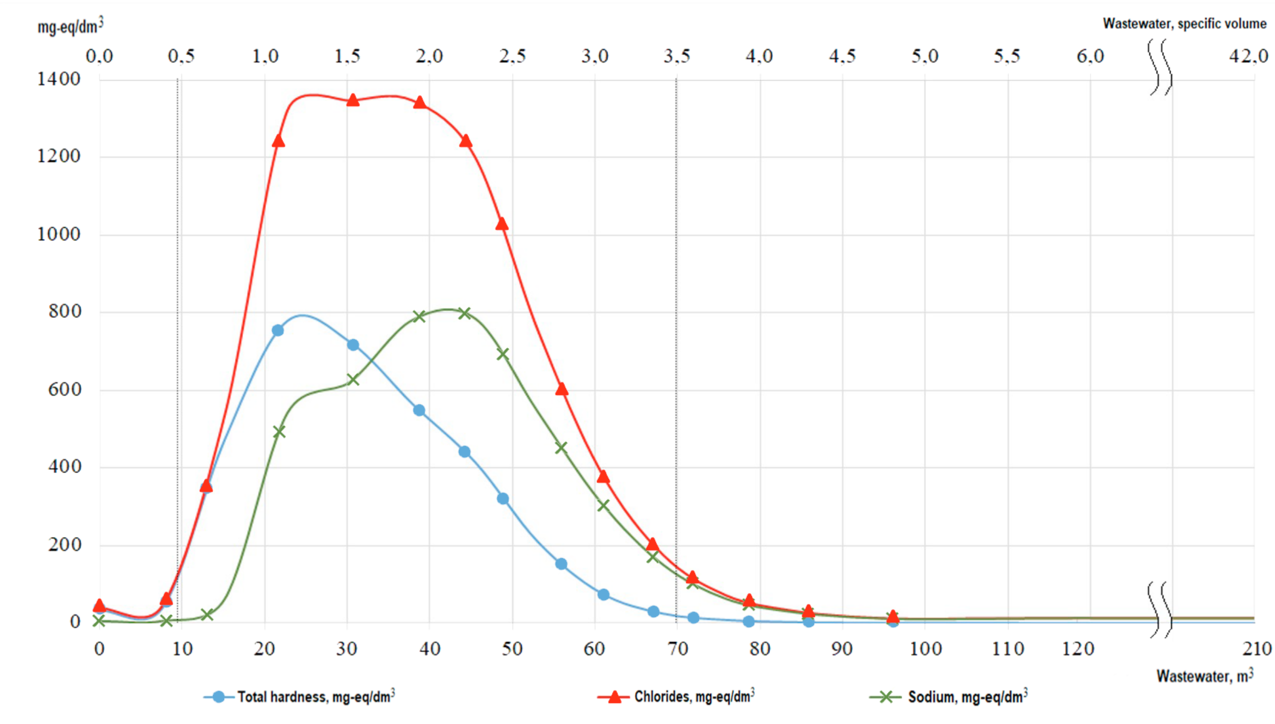

Figure 2. Initial concentration profile of the cation exchange regeneration process: concentrations of main species vs discharged volume

As it could be seen from the concentration profile of regeneration, main quantity of the target species — Na^+ — appears in the discharge between 10 and 70 m^3 of wastewater. For the regeneration of the ion exchange resin in the Na-cation exchanger 31 m^3 of 8% solution of NaCl is used. Consequently, in order to obtain the required volume of solution provided nearly 50% of recovery of membrane plant, it is necessary to take and condition 60 m^3 of SRS. Estimation could be done that wastewater between 10 and 70 m^3 of regeneration discharge should be collected for reuse and to obtain the required amount of NaCl its reuse should be at least 80%. After averaging this volume, the average value of the TDS of 56 g/l is achieved.

Regarding the mentioned above, the composition of model solution for tests was calculated to correspond to the average discharge of the industrial Na-cation exchanger. The composition of the model solution is shown in table 3.

Table 3. Composition of the model solution

Parameter	Units of measurement	Value
TDS	mg/L	56650
pH	units	7,14
Chlorides	meq/L	806,9
Calcium	meq/L	282,5
Magnesium	meq/L	87,5
Total hardness	meq/L	370
Sodium	meq/L	437

3.2.Selection of the most suitable membrane element for the separation of NaCl from SRS

To select the most suitable membrane element, three different membrane elements were tested. Choice of the membrane element was carried out at constant temperature and pressure. Table 4 shows parameters and results of the test runs. Characteristics of permeate and concentrate obtained during tests are given in table 5.

Table 4. Parameters and results of the tests of membrane elements

Membrane element	Conditions		Results		
	Pressure, bar	Temperature of solution, °C	Flow rate, l/h		Recovery, %
			Permeate	Concentrate	
FILMTEC NF270	25,0	23	330	300	52%
FILMTEC NF90	25,0	23	60	300	17%
FORTILIFE XC-N	24,0	23	300	300	50%

Table 5. Composition of permeate and concentrate obtained from various membrane elements

Membrane element	**Sample**	**TDS, mg/l**	**pH**	**Cl^-, meq/l**	**Ca^{2+} + Mg^{2+}, meq/l**	**Na^+, meq/l**
FILMTEC NF270	Permeate	33050	6,86	465	95	370
	Concentrate	65200	7	850	515	335
FILMTEC NF90	Permeate	14500	6,54	210	19	191
	Concentrate	53200	7,18	740	395	345
FORTILIFE XC-N	Permeate	29750	7,04	410	35	375
	Concentrate	60500	7,08	795	415	380

Results of the experiment as comparison criteria are shown at the figure 3.

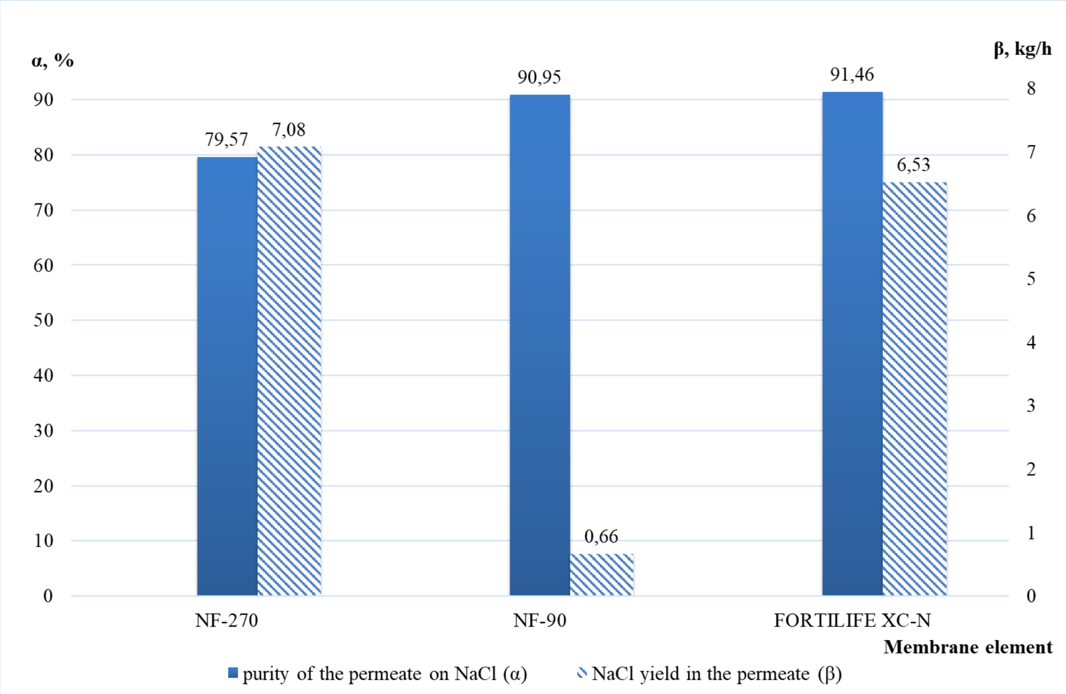

Figure 3. Dependence of the purity of NaCl in permeate (α) and NaCl yield in permeate (β) on the type of membrane element

Analysis of the obtained results shows that the largest NaCl yield in permeate (7,08 kg/h) is observed for NF-270 but its purity is 79,57%. On the other hand, for NF-90 NaCl yield in permeate is the lowest — 0,66 kg/h, but the purity of NaCl in permeate is 90,95%. FORTILIFE XC-N element was the most effective for the separation of NaCl from SRS, showing high NaCl yield in permeate (6,53 kg/h) combined with high purity (91,46%). Regarding these results, FORTILIFE XC-N was selected for further research.

3.3. Choosing the optimal conditions for process of conditioning of SRS

To determine the optimal conditions for SRS conditioning process on FORTILIFE XC-N membrane element, a study was made of the effect of the main parameters of the separation process — temperature, recovery and pressure.

To investigate the influence of temperature, range from 20 °C to 30 °C was chosen as easy to achieve and control and corresponding to typical temperatures of pressure driven membrane separation processes. Parameters of the process and the results of the study of temperature influence are given in tables 6 and 7 respectively.

Table 6. Conditions and results for the process of choosing the optimal temperature

Conditions		**Results**		
Pressure, bar	Temperature of solution, °C	Flow rate, l/h		Recovery, %
		Permeate	Concentrat	
24,0	20	390	240	62%
24,0	23	420	264	62%
24,0	25	435	270	62%
24,0	27	450	276	62%
24,1	30	468	288	62%
24,0	32	480	300	62%

Table 7. Composition of permeate and concentrate obtained at different temperatures

t, °C	Sample	TDS, mg/l	pH	Cl^{-}, meq/l	$Ca^{2+} + Mg^{2+}$, meq/l	Na^{+}, meq/l	*α*, %	*β*, kg/h
—	Model solution	53050	6,94	812	367,5	445	—	—
20	Permeate	37300	6,89	553	69	484	87,53	10,95
	Concentrate	71450	6,89	1091	715	376	—	—
23	Permeate	41150	6,76	560	70	490	87,51	11,94
	Concentrate	76550	7,04	1091	685	406	—	—
25	Permeate	37600	7,12	545	71	474	86,97	11,96
	Concentrate	75150	6,90	1117	715	402	—	—
27	Permeate	39400	6,89	572	74	498	87,07	13,01
	Concentrate	77350	7,06	1091	710	381	—	—
30	Permeate	38275	6,91	559	82	477	85,34	12,95
	Concentrate	72450	7,00	1091	720	371	—	—

Figure 4 shows dependence of the yield of NaCl in permeate (*β*), as well as its purity (*α*) on the operating temperature.

Results of the study show that temperature significantly affects purity of NaCl in permeate while having less impact on the yield. Consequently, with increasing temperature it is possible to obtain a slightly larger amount of sodium chloride in permeate, but the purity t will be significantly lower. Rational point is at 24 °C, which provides purity of salt of 87,5% with a relatively high yield in permeate (12 kg/h).

It was determined that the optimal temperature for the process of purifying the SRS can be considered as a range of 23–27 °C, where average values of comparison criteria are: *α* = 87,2%, *β* = 12,3 kg/h.

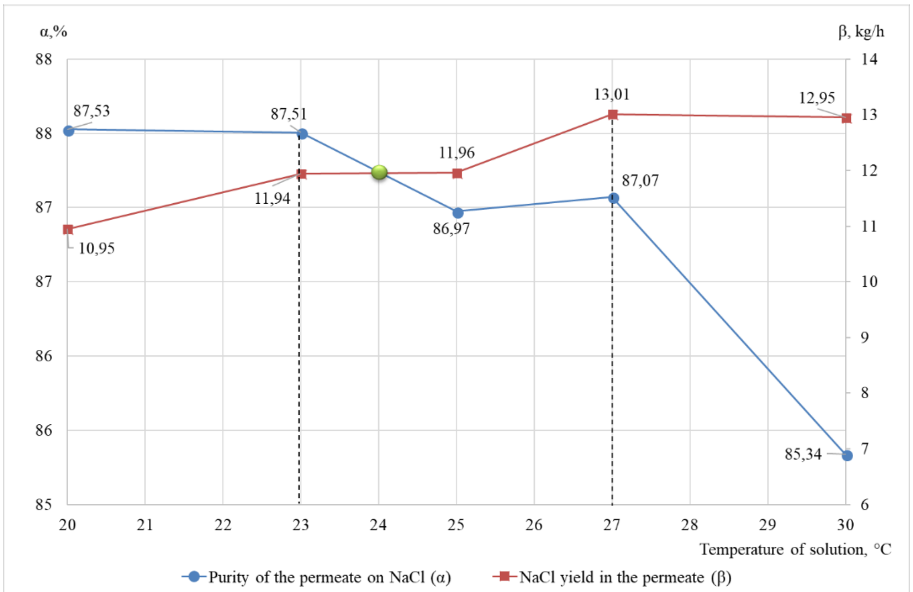

Figure 4. Dependence of the purity of NaCl in permeate (*α*) and NaCl yield in permeate (*β*) on operating temperature

Following experiments were carried out to study the influence of recovery on the process of conditioning of SRS. Parameters of the process and results are shown in tables 8 and 9 respectively.

Table 8. Conditions and results for the process of choosing the optimal recovery

Conditions		Results		
Pressure, bar	Temperature of solution, °C	Flow rate, l/h		Recovery, %
		Permeate	Concentrat	
23,0	26	465	450	50,8%
23,5	26	480	324	59,7%
24,3	26	438	216	67,0%

Table 9. Composition of permeate and concentrate obtained for different recovery

t, °C	Sample	TDS, mg/l	pH	Cl^{-}, meq/l	$Ca^{2+} + Mg^{2+}$, meq/l	Na^{+}, meq/l	*α*, %	*β*, kg/h
—	Model solution	56650	7,14	806,9	437	370	—	—
50,8	Permeate	40700	6,81	532,9	469	64	87,99	12,65
	Concentrate	74500	7,01	1015,0	505	510	—	—
59,7	Permeate	39825	6,74	576,5	504	73	87,34	14,02
	Concentrate	77200	6,88	1116,5	417	700	—	—
67,0	Permeate	42175	6,67	578,6	491	88	84,79	12,46
	Concentrate	78150	6,76	1167,2	407	760	—	—

Figure 5 shows dependence of comparison criteria on recovery. It could be concluded that with the growth of recovery there is a significant decrease in quality of the obtained solution of NaCl, and the effect on NaCl yield in permeate is best described by a parabolic curve. Increase in recovery leads to increase in the average concentration of dissolved substances, and in addition, increases the intensity of the concentration polarization — concentration of salts near the surface of the membrane. All this leads to a drop of rejection and flowrate.

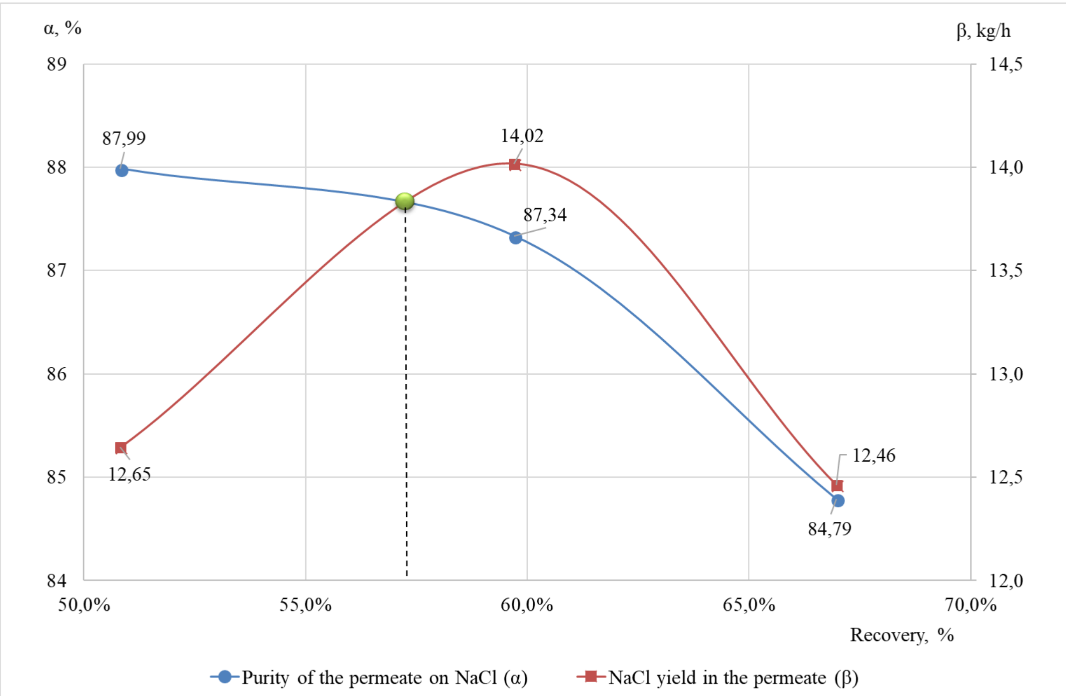

Figure 5. Dependence of the purity of NaCl in permeate (*α*) and NaCl yield in permeate (*β*) on recovery

Thus, from the analysis of the obtained dependence, we can conclude that the optimal values of the recovery for these conditions will be 57%. Next, a study was conducted to determine the efficiency of the separation of NaCl from SRS at different feed pressure values. Conditions and results of the process are shown in the table 10. Characteristics of samples of permeate and concentrate obtained at different pressure values are given in Table 11.

Table 10. Conditions and results for the process of choosing the optimal pressure

Conditions		Results		
Pressure, bar	Temperature of solution, °C	Flow rate, l/h		Recovery, %
		Permeate	Concentrat	
20,2	27	425	321	57%
22,0	27	441	333	57%
23,5	27	448	337	57%
24,3	27	457	345	57%
25,1	27	467	353	57%

Table 11. Composition of permeate and concentrate obtained at different pressures

t, °C	Sample	TDS, mg/l	pH	Cl^-, meq/l	Ca^{2+} + Mg^{2+}, meq/l	Na^+, meq/l	*α*, %	*β*, kg/h
20,1	Permeate	35554	6,71	496	439	62	88,58	11,36
	Concentrate	66577	6,98	968	507	512	—	—
22,0	Permeate	40700	6,81	540	469	64	86,75	12,32
	Concentrate	74500	7,01	1029	505	510	—	—
23,5	Permeate	39825	6,74	585	504	73	86,11	13,46
	Concentrate	77200	6,88	1132	417	700	—	—
24,3	Permeate	42175	6,67	587	491	88	83,60	13,49
	Concentrate	78150	6,76	1184	407	760	—	—
25,1	Permeate	44178	6,89	616	499	89	81,03	13,89

From the obtained dependence figure 6) conclusion could be done that with increase of pressure there is a gradual increase in NaCl content in permeate (*β*), but the purity of the permeate by NaCl (*α*) is described by the inverse response.

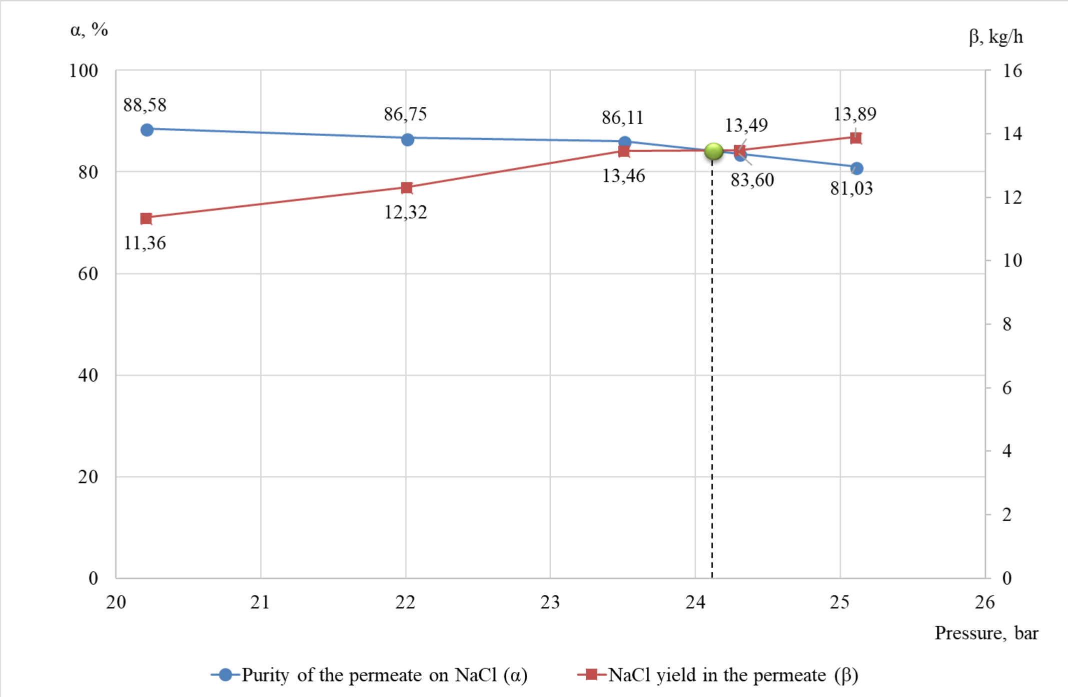

Figure 6. Dependence of the purity of NaCl in permeate (α) and NaCl yield in permeate (β) on pressure

Obtained results allow to formulate optimal conditions for the process of conditioning of SRS:

- membrane element — FORTILIFE XC-N;
- temperature — 23–27 °C;
- recovery — 57%;
- pressure — 24,1 bar.

Subsequently, under these conditions, the efficiency of the process of conditioning on the pilot unit was evaluated.

3.4.Estimation of efficiency of the conditioning process under optimum conditions at the pilot unit

Test was carried out to determine the efficiency of the separation of NaCl from SRS under optimum conditions at the pilot plant, given in table 12. Results of test are given in table 13.

Table 12. Conditions for conducting the process of conditioning on the pilot plant

Conditions		**Results**		
Pressure, bar	Temperature of solution, °C	Flow rate, l/h		Recovery, %
		Permeate	Concentrat	
24,0	24	480	360	57,1%

Table 13. Composition of permeate and concentrate obtained under optimal conditions

Sample	TDS, mg/l	pH	Cl^-, meq/l	$Ca^{2+} + Mg^{2+}$, meq/l	Na^+, meq/l	α, %	β, kg/h
Model solution	57850	7,07	912,5	367,5	445	—	—
Permeate	41173	6,84	516,6	45	472	91,4	13,1
Concentrate	81131	7,15	984,6	585	400	—	—

3.5.Principal technological scheme of conditioning of SRS

Obtained results of the experiment of the process of conditioning of the SRS allow offering the single stage scheme for increasing the economic feasibility and environmental safety of the Na-cationite softening process, shown in Fig. 7.

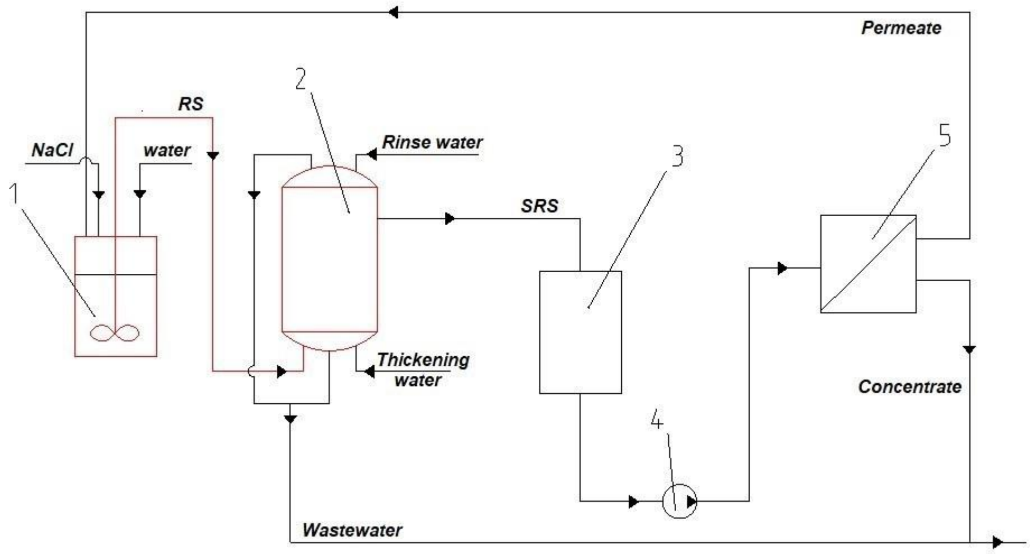

Figure 7. Principal single stage scheme of the process of conditioning of SRS: 1 - tank with regeneration solution; 2 - Na-cation exchanger; 3 - storage tank for SRS; 4 - SRS feed pump; 5 - nanofiltration unit.

At the end of the operational cycle of the Na-cation exchanger 2, the process of regeneration starts, beginning with pressing the resin up to the inert media with the ascending stream of water.

After resin layer has been clamped, regeneration solution is fed through the bottom distributors so that the ion exchange resin remains pressed upwards. 8% solution of NaCl is used. Solution is prepared and stored in the tank of regeneration solution 1. With the help of pumps, NaCl solution is fed into the water softening filter, after which all the washing water and part of SRS are directed to the sewage system, and the greater part the actual SRS from the regeneration stage (60 m^3), as described earlier, is passed into the storage tank 3. At this stage, the SRS composition is averaged before further conditioning.

Then, with the help of SRS pump, solution is supplied to the SRS conditioning unit 5, which includes PP cartridge filter, high pressure pump and pressure vessels rack with membrane elements. Permeate is sent to a tank with regenerant solution 1 for saturation with NaCl to the required concentration and then is used for the next regeneration.

Concentrate currently is supposed to be discharged into the sewage because only single stage scheme was investigated but its further conditioning is possible and higher reduction of volume of liquid waste could be achieved.

Thus, the proposed scheme of SRS conditioning allows to reuse a large part of NaCl and reduces the discharge of salts and volumes of highly mineralized regeneration effluents to sewage.

3.6.Estimation of economic and environmental benefits of proposed technology

To estimate the environmental efficiency and economic feasibility of the proposed technology of conditioning of SRS from Na-cation exchanger, the material balances and efficiencies of proposed scheme were calculated. Table 14 shows the reduction of NaCl consumption and discharge achievable by installation of proposed technology.

Table 14. Reduction of NaCl consumption and discharge achievable with proposed technology

Parameter	Plants		Expenses reduction	
	Existing technology	With SRS conditioning	Δ, units	*R*, %
Usage of salt for 1 regeneration,	2,500	1,484	1,016	40,6
Consumption per year, t	730	433	297	
Total volume of wastewater per 1 regeneration, m^3	210	175,7	34,3	16,3
Wastewater volume per year, m^3	17520	7504	10016	57,2
NaCl discharge per 1	1,396	0,380	1,016	72,8
NaCl discharge per year, t	407,6	111	297	

Finally, economic efficiency of proposed technology could be estimated. Main parameters expressing the benefits from installation of the proposed conditioning plant are obtained annual savings as absolute value of economic efficiency and payback period as expression of time required for installation of proposed technology to become beneficial. Calculations are shown in table 15.

Table 15. Savings by environmental payments achieved with installation of technology of SRS conditioning

Parameter	Plants	
	Existing technology	With SRS conditioning
Excess of concentration:		
for TDS (limit 1000 ppm)	10,8	6,3
for chlorides (limit 240 ppm)	30,1	18,7
Payments per 1 regeneration discharge, $	358,2	299,7
Annual payments (292 regenerations), $	104588	87506
Capital expenses, $	—	54180
Annual operational expenses, $	—	4026
Annual savings on environmental payments, $	—	17083
Annual savings on NaCl, $	—	27154
Total annual savings, $	—	44236
Payback period, months	—	16

4. Conclusions

Process of conditioning of the spent regeneration solution from the UPCORE Na-cationite softener plant by nanofiltration was investigated.

Composition of the averaged spent regeneration solution of the industrial Na-cationite filter with the UPCORE design was determined and composition of the model solution for further tests was designed. As a result of a comparative study of various types of nanofiltration membrane elements the most efficient membrane element — Dow Filmtec Fortilife XC-N — was determined.

The optimal conditions for the use of Dow Filmtec Fortilife XC-N membrane element for conditioning of the spent regeneration solution were estimated.

Technological scheme of the process of nanofiltration conditioning of the spent regeneration solution has been developed. Application of such technology allows to achieve reduction of consumption of NaCl by 40% for the regeneration process, and 72% reduction of NaCl discharge. Economic efficiency of proposed technology could be expressed by achieving payback period of 16 months.

Further improvements of economic and environmental efficiency of the proposed technology could be achieved by investigation of possible methods of reuse of concentrate obtained from the proposed technology.

ЕКОНОМІЧНІ ТА ЕКОЛОГІЧНІ ПЕРЕВАГИ ПОВТОРНОГО ВИКОРИСТАННЯ ВІДПРАЦЬОВАНОГО РЕГЕНЕРАЦІЙНОГО РОЗЧИНУ NaCl НОВОЮ МЕМБРАННОЮ ТЕХНОЛОГІЄЮ

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Стаття присвячена проблемі повторного використання відпрацьованого регенераційного розчину промислових Na-катіонітних фільтрів та розробці технології для повторного використання із застосуванням мембранних технологій. Катіонообмінне пом'якшення води є однією з найбільш широко використовуваних технологій очищення води. Проте, його вплив на навколишнє середовище, пов'язаний зі скиданням висококонцентрованого регенераційного сольового розчину, привертає більше уваги у зв'язку зі скороченням доступних водних ресурсів та погіршенням якості води. Беручи до уваги високий вміст NaCl у відпрацьованому регенераційному розчині, потрібна технологія, яка зменшить вплив на навколишнє середовище та допоможе повторно використовувати NaCl із таких розчинів. З метою розробки такої технології досліджено склад відпрацьованого регенераційного розчину із промислової установки пом'якшення води та проведено дослідження кондиціонування такого розчину з використанням нанофільтраційних мембран різних типів за різних значень температури, тиску та виходу пермеату. Результати показують, що оптимальні умови для виділення NaCl включають застосування мембранних елементів Dow Filmtec Fortilife XC-N за температури 23–27 °C, тиску 23–25 бар та виходу пермеату 55–60%. За цих умов досягається чистота NaCl у пермеаті понад 90% і вихід NaCl 13,1 кг / год. Запропоновано основну технологічну схему процесу мембранного кондиціонування відпрацьованого регенераційного розчину, що дозволяє досягти зниження споживання NaCl установкою пом'якшення води на 40% та зменшити скидання NaCl зі стічними водами на 72%. Економічна ефективність запропонованої технології може бути виражена шляхом досягнення періоду окупності у 16 місяців.

Подальше поліпшення економічної та екологічної ефективності запропонованої технології може бути досягнуто шляхом дослідження можливих методів повторного використання концентрату, який утворюється при застосуванні запропонованої схеми.

Ключові слова: *мембранна технологія, пом'якшення, регенераційний розчин, нанофільтрація.*

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