Membrane techniques in groundwater treatment

Alexei Pervov, Roman Efremov
Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia
E-mail: ale-pervov@yandex.ru

Abstract. The present work is aimed at development of a new approach to reduce RO concentrate flow and to increase recovery. The described techniques enable us to remove calcium carbonate from RO concentrate by means of "seed" crystallization. These proposed techniques use "open channel" spiral wound membrane modules that can directly treat water with high scaling and fouling potentials without pretreatment. The experimental procedure is described and experimental plots are presented that describe precipitation kinetics. The test membrane unit was operated in circulation mode and recovery values reach 95% or higher. RO concentrate constantly passed through the precipitation reactor where seed crystals were contained. Seed crystal formation was initiated by injecting caustic solution to RO concentrate. The driving force for crystal growth was constantly created by RO process due to increase of calcium and carbonate ion concentration values. Fouling control is achieved by providing sufficient cross flow velocities, flushings and cleanings. Coagulated suspended matter after membrane flushes is collected, sedimented and finally dewatered. The concentrated solution that contains rejected salts and impurities constitutes no more than 1 per cent of initial feed water volume and can be withdrawn together with wet sludge as a sludge moisture. The described technical procedure enables us to completely utilize concentrate and produce quality product water, softened water and sludge.

Keywords: groundwater; hardness; softening; reverse osmosis concentrate, concentrate utilization; calcium carbonate precipitation; seed crystallization

1. Introduction

Two main economic factors that influence successful RO industrial application are: operational costs to ensure pretreatment and the handling of concentrate disposal [1, 2]. Both of these problems and their solutions are closely connected: the necessity of adequate pretreatment is attributed to the fouling and scaling hazard as suspended particles, organics, and sparingly soluble salts can form sediments on membrane surfaces and decrease membrane product flow and rejection values. To increase recoveries, a number of techniques are being developed such as withdrawal of calcium sulphate from concentrate by precipitation on the seeds in reactor [3], lime softening to withdraw carbonate [4], to apply air stripping to increase pH values [5]. A Zero Liquid Discharge tools are being implemented by increasing recoveries [3-5] and reduction of concentrate volume followed by evaporation [3].

Control of scale formation in membrane channels can also be implemented by means of "seed" precipitation described in [6]. In these experiments tubular membrane modules were used. The "open" membrane channel of tubular modules provided safe operation of the pilot unit without the fear of seed particle "trapping" by a spacer mesh and fouling that exists when spiral wound membranes are used. Also recovery can be increased using a "contact stabilization" process [7] where RO concentrate passes through a "contact" mass filter bed and calcium carbonate is precipitated on the "contact mass".
This article offers a new approach to solving pretreatment and concentrate disposal problems, based on the understanding of fouling mechanisms in membrane channels and the introduction of new "open channel" membrane modules with decreased fouling potential as a tool to simplify pretreatment and increase recoveries.

High values of concentrate flow are mainly attributed to the "fear" of exceeding the solubility limits of main sparingly soluble constituents such as calcium sulphate and calcium carbonate in RO concentrate, as it is recognized as subversive to membrane performance. As it was shown in a number of previous publications, fouling and scaling in commercial RO modules are attributed to the module design and channel geometries [8, 9].

The main disadvantages of spiral wound modules are attributed to the presence of separation spacer mesh in the feed channel as it traps fouling particles and increases cross-flow channel resistance. The places (spots) where the mesh connects to the membrane surface provide "dead areas" without cross-flow that result in high concentration increase at the membrane surface, initiating the formation of crystals. Organic and colloidal matter coagulates and sediments within "dead areas", promoting expansion of the foulant layer around the "dead area". The accumulation of foulant around mesh bundles increases flow resistance – an increase that follows the filtration theory mechanism.

Understanding of scaling mechanism in membrane modules was based on results of observations of membrane surface after autopsies of membrane modules used to treat groundwater [8, 9]. The boundary membrane layer where the concentration polarization effect occurs can be considered a "chemical reactor", where flocculation of the suspended, colloidal and organic matter, as well as calcium carbonate crystal nucleation processes take place. This idea to use membrane concentration process as a driving force to remove iron turbidity and colour as well as hardness seems very attractive, as no reagent is required. Foulants that sediment on the membrane surface are easily removed using hydraulic flushes.

Application of spiral wound membranes substantially reduces operating costs due to lower required cross-flow values as compared to the use of tubular configuration. This technique uses "open channel" spiral wound membranes where turbulation mesh and its influence on flow resistance is eliminated and hydraulic conditions are similar to those of the tubular configuration. The open channel configuration and technical considerations to improve membrane channel geometry and avoid formation of "dead areas" are described in [8].

Application of the developed "open channel" membrane modules in RO facilities that treat surface water and well water can exclude pretreatment. This, in turn, can significantly reduce start-up and operational costs of building pretreatment [8]. Elimination of the spacer mesh from the feed channel in spiral wound modules eliminates "dead" regions that provide scaling and fouling conditions. This novel concept of spiral wound module with an "open channel" configuration offers a new way to prevent scaling and fouling, and develop a new to treat water with high fouling potential. The risk of sparingly soluble salts precipitation (calcium carbonate, etc.) is minimized by the strong stability of calcium carbonate solutions. Introduction of the "open channel" configuration also helps to exclude measures that control scaling – such as antiscalant dosing, softening, acid addition and timely cleanings. As it was already mentioned [8], fouling control is achieved by providing sufficient cross flow velocities, flushes and cleanings.

As it was discussed above, elimination of the spacer mesh from the feed channels of spiral wound modules eliminates "dead" regions that provide scaling and fouling conditions while also reducing the risk of particle trapping and associated dramatic increase of cross flow resistance. To control colloidal fouling, automatic flushes are applied by opening of solenoid valves located on the concentrate line at the outlet of the module. Hydraulic flushes destroy fouling layers and withdraw foulants from membrane surface due to cross-flow velocity increase and water hammer initiation through rapid pressure drop. Flush modes (time intervals between flushes and flush durations) are very important to maintaining fouling control and flow velocities on the desired level.

To avoid pretreatment and remove iron hydroxide from membrane surface "open channel" modules and built-in flushing system are used [8]. Feed water is pressurized by a centrifugal pump and is
forwarded to membrane module and small pressurized accumulation tank. When the solenoid flush valve is open, flow pressure drops and cross-flow velocity increases. To ensure high cross flow velocity value, pressurized feedwater tank is used.

Figure 1. Flow diagram of membrane system with a reduced concentrate disposal; 1 – 100 micron prefILTER; 2 – solid state antiscalant cartridge; 3 – centrifugal pump; 4 – first stage membrane modules; 5 – second stage membrane module for concentrate flow reduction; 6 – pressure switch; 7 – solenoid valve; 8 – pressure gauge; 9 – product water counter; 10 – conductivity meter sensor; 11 – permeate flow meter; 12 – bypass flow meter; 13 – concentrate flow meter; 14 – control valves.

Figure 2. A flow diagram of 20 cubic meter per hour membrane unit with decreased concentrate flow.

Application of the open channel modules provides safe operation without scaling problems when well water is treated. As it was already discussed earlier [8, 13], calcium carbonate solutions are stable and it is possible to operate membrane units with high recoveries beyond calcium carbonate solubility limits in concentrate. As an example of RO unit with decreased concentrate discharge, a membrane system with product water capacity of 20 cubic meters per hour to remove hardness, fluoride and strontium from the well water is shown on Figures 1, 2 and 3. A low concentrate flow value is reached through the use of membrane modules on the second stage to further decrease concentrate flow.
Figure 1 shows the process flow diagram. Feedwater is pumped into nanofiltration modules (in the first stage) where it is separated into product flow and first stage concentrate flow. First stage product flow is forwarded to the product water tank and first stage concentrate enters the second stage nanofiltration modules where it is further concentrated and separated into second stage product water and second stage concentrate. The second stage product is added to the feedwater and concentrate is discharged into the sewer. Figure 2 shows flow diagram of described process to produce 20 cubic meter per hour unit where mass balance is presented. Concentrate flow is 1 cubic meter per hour. The 20 cubic per hour unit consists of four 5 cubic meter lines connected in parallel. Figure 3 shows a membrane treatment station that includes a well water treatment pavilion, membrane unit located in container and the product water tank. The interior of container is shown on Figure 3(a) and the general view of the station is shown on Figure 3(b).

**Figure 3.** Water treatment station mounted inside the container: a) interior of the container; b) outside view of container attached to water intake.

Calcium carbonate scaling hazard is recognized as a main factor that disturbs multiplied concentration of the feed water in membrane modules. The use of "open-channel" modules enables us to concentrate solutions that are supersaturated by calcium carbonate and calcium sulphate, and to develop a reagent-free technique to remove calcium carbonate water.

The present report aims to investigate the possibilities of decreasing concentrate discharge (to increase recovery) and reducing pretreatment expenses mainly connected with the use of chemicals and facilities to initiate flocculation and to predict calcium precipitation. To increase recovery values, a new process is developed that uses continuous crystallization of calcium carbonate at a constant supersaturation level provided by a constant raise of concentrate TDS while RO is operated in circulation mode.

The investigations of scaling mechanisms on membrane surfaces enables us to simulate it, implement it "outside" the membrane module, and withdraw calcium and bicarbonate ions from the concentrate stream.

In majority cases, when drinking water is produced by RO unit, only partial removal of hardness, fluoride, ammonia, strontium is required. Thus, the largest part of concentrate flow can be blended with the product flow. The described approach enables us to utilize the concentrate by separating the feed water into product water flow and sedimented sludge flow.

The principles of RO concentrating of solutions containing sparingly soluble salts and recovery increase are described in [8, 9] in respect to calcium sulphate. The supersaturated solution (concentrate) after RO unit enters sedimentation tank where excessive calcium carbonate is
precipitated and sedimeted. Concentrate after calcium sulphate separation is forwarded back to RO unit where it is further concentrated. Thus concentrate amount can be substantially diminished. Calcium carbonate system has a different nature and cannot be withdrawn the same way [11, 12]. To initiate calcium carbonate precipitation, a constant "driving force" should be applied to maintain constant supersaturation level. This was implemented by caustic addition [12] and by air-stripping [5] that increased pH in RO concentrate.

The present work aims to develop a new approach to concentrate utilization: seed mass is added to RO concentrate and excessive calcium carbonate is precipitated on the seed mass, then softened concentrate is blended with RO product water. Thus, softened water is produced that can be used either for drinking or technical purposes (such as boiler feed or cooling water). The described water softening method does not require chemicals (such as lime and soda), does not produce brines like sodium-cationite regeneration solution or RO concentrate to be discharged.

The main challenge to initiate calcium carbonate precipitation on the seed crystals is to create a "driving force" for crystal growth – to maintain high supersaturation levels. Calcium carbonate supersaturation depends on calcium and carbonate ion concentration values. Carbonate concentration depends on pH values. As was shown previously in [11, 12], the addition of seed crystals to calcium carbonate supersaturated solution does not initiate crystal growth as the reduction of carbonate ions decrease the pH value and thus decrease the supersaturation level.

A main aim of research described in this article was to develop a new approach to treat groundwater with nanofiltration and reverse osmosis membranes: to efficiently remove iron, hardness and fluoride and avoid discharge of concentrate streams.

2. Materials and methods

During RO system operation, calcium and bicarbonate concentration values in RO concentrate constantly increase, providing a driving force for calcium carbonate crystal growth. The present article shows the experimental results of precipitation kinetics study that are influenced by various factors (such as seed concentration, supersaturation, crystal age, etc.).

Spiral wound modules of 1812 standard (12” length and 1,8” in diameter) tailored with low pressure RO membranes (BLN-type) manufactured by CSM (Korea) were used in experimental studies for comparison with newly developed modules. New "open channel" spiral wound modules were manufactured using the same flat sheet membranes, having the same dimensions and fitting the same size pressure vessel. Modules were manufactured in accordance with configuration described in [8, 9] using rolling machine "Model № RS 4040A" supplied by "Hydrocomponents and Technologies", CA.

A test unit flow diagram is shown on Figure 4. Feedwater was pumped from feedwater tank 1 into membrane module 3 using centrifugal pump 2. The working pressure value was 8 Bars. In RO module feedwater stream was separated into two streams: product and concentrate. Product is forwarded to product tank 4 while concentrate is retuned back to feedwater tank 1. Feedwater was concentrated by 6 times throughout the test run. Feedwater tank volume was 60 liters. By the end of each test run concentrate volume equaled 10 liters.

During test runs samples were withdrawn from feed water tank 1 and product water tank. In all samples temperature, TDS (conductivity), pH, total hardness, alkalinity, calcium were determined. Conductivity and temperature were controlled by a laboratory conductivity meter Cond 730 (WTW inoLab), pH values were determined using laboratory pH meter HI 2215 (Hanna Instruments), total alkalinity – by titration with HCl, total hardness – by complexometric EDTA titration.

Natural water (surface and groundwater) was used as test solutions in experiments. To increase fouling and scaling potential of the test solution (to increase hardness, colour or turbidity), natural water was preconcentrated using RO modules.

To initiate calcium carbonate scaling, a test procedure should provide supersaturation conditions as a driving force for crystallization [8, 9, 11, 12]. In described experiments high scaling potential
(supersaturation) was constantly arranged due to operation of the test unit in concentration mode where product water was withdrawn.

![Flow diagram](Image)

**Figure 4.** A flow diagram of experimental process using seed crystals:
1 – feed water tank; 2 – pump; 3 – membrane module; 4 – product water tank; 5 – flush water sedimentation tank; 6 – control valve; 7 – valve for flushing

The feedwater is constantly concentrated as the product is constantly withdrawn. "Seed" crystals were produced by addition of caustic solution to RO concentrate. In our experiments feed water (well water) was preconcentrated 6 times by volume and stoichiometric amount of 1 N caustic solution was added to concentrate collected in flush water tank 5 to form calcium carbonate. After nucleation occurred and crystal formation phase is finished, the crystals are sedimented during 3-4 hours, collected and added to the feed water tank 1. Throughout the test run feed water is constantly concentrated and samples are collected that correspond to concentration factor values 2, 3, 4, 6. Calcium and bicarbonate ionic concentrations are determined in these samples. In the end of each test run membrane "flushings" are applied that last 5-6 seconds. Concentrate (flush water) is collected in the tank 5. Crystals that are suspended in concentrate and removed from membrane surface are sedimented in tank 5 during 4-6 hours and then used in the next experimental cycle.

Thus, calcium carbonate is constantly withdrawn from the circulating solution as supersaturation constantly provides a driving force for crystal growth. Small crystals sediment on membrane surface during membrane operation and are easily flushed from the membrane surface by applying "flushings".

3. Results and discussion
Figures 5 and 6 show dependencies of calcium and bicarbonate ion concentrations in the circulating feed water solution on the concentration ratio, which is determined as a ratio of feed water volume to concentrate volume, during a test run. Figure 5 shows calcium and bicarbonate concentrations versus concentration factor for two cases: without seed crystals addition and in the presence of seed crystals. The amount of the added calcium carbonate was 10 grams (250 mEq). Figure 6 shows the influence of the seed mass and cross-flow value on the seed crystal growth rate. Addition of the double amount of seed crystals (20 grams) decrease concentrations of calcium during the test run as compared to
experimental curve that corresponds to addition of 10 grams. Decrease of cross flow value also decreases concentrations of calcium in the samples collected throughout test run that indicates that calcium carbonate growth intensiveness increases. The curves 2 and 4 shown on figure 15 correspond to cross-flow rates 100 and 25 liters per hour respectively.

![Figure 5](image1.png)

**Figure 5.** Experimental results of calcium carbonate growth on seed crystals. Concentrations of calcium and bicarbonate ions in circulation solution versus concentration factor (initial volume / final volume): 1 – calcium ion (well water, without seed addition); 2 – calcium ion (well water, after addition of 250 mEq of calcium carbonate); 3 – bicarbonate ion (well water, without seed addition); 4 – bicarbonate ion (well water, after addition of 250 mEq of calcium carbonate).

![Figure 6](image2.png)

**Figure 6.** Investigation of the influence of the mass of added seeds and cross-low rate on the rate of calcium carbonate growth on seed crystals. Calcium ion concentrations in circulating solution versus concentration factor: 1 – well water, without seed addition; 2 – well water, after addition of 250 mEq of calcium carbonate, cross flow rate – 100 liter per hour; 3 – well water, after addition of 500 mEq of calcium carbonate, cross flow rate – 100 liter per hour; 4 – well water, after addition of 250 mEq, cross flow – 25 liters per hour.

Figure 7 shows results of experiments conducted to understand the influence of the mass of precipitated calcium carbonate mass on the scaling rate of the seed crystals. Dependencies of calcium concentrations versus concentration ratio throughout 10 test runs are presented. Seed crystals after each test run were sedimented, collected and added to the feed water tank 1 for the next test run.

Figure 8 and 9 present results of calcium carbonate growth rate determination. Amounts of precipitated calcium carbonate as a function of time are shown on Figure 8. Amounts of precipitated calcium carbonate were determined by means of calcium mass balance as a difference between calcium contained in the feed water and concentrate. Calcium carbonate scaling rate values are plotted versus concentration factor (figure 9). Scaling rates are determined as tangents of the slope of the plots shown on figure 9.
Figure 7. The influence of the mass of precipitated calcium carbonate on crystal growth rate. Calcium ion concentrations versus concentration factor at different stages of crystal growth: 1 – well water, without seed addition; 2 – well water with addition of 250 mEq of calcium carbonate, first cycle; 3 – well water with addition of seed crystals after 2 cycles; 4 – well water with addition of seed crystals after 5 cycles; 5 – well water with addition of seed crystals after 10 cycles.

Figure 8. Mass of calcium carbonate accumulated on the seed throughout test run versus concentration factor at different stages of crystal growth: 1 – well water, without seed addition; 2 – well water with addition of 250 mEq of calcium carbonate, first cycle; 3 – well water with addition of seed crystals after 2 cycles; 4 – well water with addition of seed crystals after 5 cycles; 5 – well water with addition of seed crystals after 10 cycles.

Figure 9. Determined calcium precipitation rates values versus concentration factor: 1 – well water with addition of 250 mEq of calcium carbonate, first cycle; 2 – well water with addition of seed crystals after 2 cycles; 3 – well water with addition of seed crystals after 5 cycles; 4 – well water with addition of seed crystals after 10 cycles.

Figure 9 confirms that calcium precipitation rate does not decrease after 10 cycles of test runs while seed crystals grow and their weight and size increase. Seed crystals should be replaced after their size increase to avoid their sedimentation on membrane surface. Observations of seed crystals
sedimentation revealed that it took from 1 to 4 hours to sediment calcium carbonate crystals collected after flush cycle. About 30% of all crystals collected after 10-th test run sediment during one hour. Figure 10 shows microphotographs of crystals at different growth stages.

![Microphotographs of crystals at different growth stages](image)

**Figure 10.** Microphotographs of crystals at different growth studies: a) crystals after nucleation, b), c) crystals after growth after 5 and 10 cycles

After contact with the "seed" mass, concentrate can be blended with product water to produce softened water with a decreased TDS value (by the value of withdrawn calcium carbonate). Table 1 shows the concentration of ionic species in the feed water, concentrate, product water and blended solution.

| Parameters          | Feedwater | Concentrate, recovery value 90% | Concentrate after contact with seed crystals, Recovery value 90% | Product water | Mixture (concentrate and product) |
|---------------------|-----------|----------------------------------|-----------------------------------------------------------------|--------------|----------------------------------|
| Calcium, mEq/l      | 4.6       | 38.6                             | 10.4                                                            | 0.32         | 1.3                              |
| Hardness, mEq/l     | 6.7       | 57.8                             | 33.4                                                            | 0.71         | 4.1                              |
| Alkalinity, mEq/l   | 6.1       | 47.6                             | 28.1                                                            | 1.4          | 4.1                              |
| Chlorides, mg/l     | 37.9      | 331                              | 326                                                             | 16.4         | 49.1                             |
| pH                  | 6.8       | 8.0                              | 7.9                                                             | 6.1          | 6.7                              |

Thus, the use of described techniques enables us to produce softened water without the use of reagents (as during lime and soda softening), high TDS brines (as during ion exchange softening), or RO concentrate flows.

The main disadvantage of described process is its "periodical" operational mode that limits practical application. For industrial application of results a "continuous" operational mode is developed. Figure 11 shows a flow diagram of the unit operated in "continuous" circulation mode with constant concentrate and precipitate discharge.

The unit is operated in circulation mode, main part of concentrate is circulated and the other part is discharged. Seed crystals are suspended in circulation solution. To avoid crystals sedimentation on membrane surface, high cross flow velocities are maintained in membrane channels. Flushings are arranged after 2-3 hours of operation. Flushing occurs after solenoid valve 3 is open and increased cross flow provides a shear force to remove sedimented crystals from membrane surface. Flush water is collected in the tank 4. Large and heavy crystals are sedimented in tank 4, smaller crystals flow into tank 5 and are pumped to the inlet of the unit. As a part of suspended seed crystals is sedimented in the
tank 4, it should be replaced by new crystals. Calcium carbonate seed crystals are obtained through addition of caustic solution in tank 5 where nucleation and precipitation occurs.

![Flow diagram of natural water treatment with reverse osmosis membranes without concentrate discharge](image)

**Figure 11.** A flow diagram of natural water treatment with reverse osmosis membranes without concentrate discharge: 1 – high pressure pump; 2 – membrane module; 3 – solenoid valve for flushing; 4 – flush water sedimentation tank; 5 – concentrate collection tank; 6 – concentrate return pump; 7 – concentrate bypass valve; 8 – pressure regulation valve; 9 – caustic dosing unit; 10 – feed water pressure tank; 11 – precipitate discharge valve.

The consumption of sodium hydroxide and required amount of calcium carbonate seed mass should be determined. As the unit is operated in continuous mode, the amount of calcium precipitated on the circulating seed mass during one hour should correspond to scaling rate value determined experimentally for the certain feed water and recovery conditions. Figure 9 shows calcium carbonate growth rate values versus recovery. For well water and recovery value 0.83 (concentration factor ≈ 6) scaling rate equals 21 mEq per hour (curve 4). The test run was conducted using spiral wound module with 0.5 square meter surface (1812 standard). Product rate throughout test run was 7-8 liters per hour. For a "model" membrane unit with 1000 liter per hour capacity, requires 60 square meters membrane surface, feed water calcium concentration and recovery value 0.83 we can calculate the amount of calcium carbonate precipitated on seed crystals and withdrawn from concentrate constitutes 2400 mEq per one hour. Therefore the amount of added seed crystals in the "model" unit should be 120 times more than the amount of seed crystals used during test runs. In 1000 liter per hour test unit the amount of seed crystals circulating in concentrate should be 30000 mEq of calcium carbonate, or 1200 grams.

To develop the seeding process on industrial level, caustic solution consumption, caustic dosing mode and crystal sedimentation tank parameters should be determined. As it was already discussed, calcium carbonate seed crystal growth rate does not change significantly throughout the whole period of their growth in the circulation loop. Figure 8 shows that amount of calcium carbonate precipitated on seed crystals by the end of the first test run constitutes 136-140 mEq. Assuming that the mass of seed crystals added to circulating feed water was 250 mEq, the total mass of seed crystals after the 10-th test run equals 1610 mEq. To reach this amount, the unit should be operated in continuous flow mode about 80 hours. As it was already mentioned above, about 30% of all flushed crystals are sedimented in tank 4. The last 70 % of seed crystals enter tank 5 and are pumped to the inlet of the unit. During experimental test runs the added seed mass was 250 mEq. To replace 30% of the seed mass about 82 mEq of precipitated calcium carbonate is required. The amount of concentrate required for precipitation of this amount is 4.4 liters (for the test unit) and 528 liters for the 1000 liter per hour unit. The amount of sodium hydroxide added to concentrate is stoichiometric amount of required...
calcium carbonate. The caustic amount required to produce 30% of added seed crystals (250 mEq) equals 83 mEq. During 10 cycles of test runs 2000 mEq of calcium was removed that required 83 mEq of caustic, which is only 4% of required stoichiometric amount.

To utilize concentrate, a second stage nanofiltration unit can be used. Product water after nanofiltration unit is mixed with first stage RO product and concentrate is withdrawn together with precipitated calcium carbonate.

Through the use of the described "seed mass precipitation" techniques, softened water is obtained. The described approach does not require chemicals for calcium carbonate precipitation (as in case of lime and soda softening) or ion exchange bed regeneration (as in case of ion exchange softening).

To reach the required removal of dissolved impurities such as fluoride, ammonia, strontium, arsenic etc., part of the softened water is blended with the concentrate. The amount of blended flow is calculated using equilibrium equations.

The developed techniques provide a chemical-free method without waste water discharge (identified as "liquid discharge"). According to this technique, a part of the product water is blended with the "softened" concentrate after its contact with the "seed" mass. Thus, feed water is divided into 2 streams: deionized product water (used for steam production) and softened water with a TDS value that does not exceed the feed water TDS (used for heating or cooling). Low hardness values (0.005 mEq per liter) or low TDS values could be achieved by implementation of double stage RO.

Suspended and colloidal foulant contained in the feed water can be flushed out of the membrane module, sedimented, and dewatered. Growing seed mass can be withdrawn separately from the system and sedimented.

The described approach to utilize RO concentrate by calcium carbonate precipitation and withdrawing is distinguished by the use of RO process as a driving force to provide supersaturation and crystallization. Caustic solution is used not to maintain supersaturation values, as during conventional reagent softening, but to produce seed crystals (initiate homogenous crystallization). The required caustic amount is by 30-50 times lower than stoichiometric value required for conventional calcium carbonate precipitation.

4. Conclusions
Results of conducted studies could be used to introduce new water treatment techniques to directly treat natural water with high fouling and scaling potential using proposed "open-channel" spiral wound modules tailored by nanofiltration and reverse osmosis membranes. Elimination of the "dead areas" responsible for scale formation provides a new solution to increase recovery and utilize concentrate.

A new technique is described that enables us to increase recoveries and utilize RO concentrate that consists of calcium carbonate precipitation on the "seed" crystal mass, withdrawal of excessive calcium carbonate and further blending of softened concentrate with RO product water. As a result, softened water is obtained with lower TDS and hardness than of the initial feed water. The developed techniques do not require chemicals and do not discharge concentrated brines.

The increase of the seed mass increases precipitation rate. The obtained results indicate that even small amounts of seed crystals added to the feed water provide an efficient softening of the feed water. Calcium carbonate mass withdrawn from the feed water by 25-30 times exceeds the mass of seed crystals. After contact with seed mass concentrate can be blended with product water to produce softened water with a decreased TDS value (by the value of withdrawn calcium carbonate).

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