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CCD series no-20: high-flux low-energy upgrade of municipal water supplies with 96% recovery for boiler-feed and related applications

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ABSTRACT

This study describes the application of closed circuit desalination (CCD) as a first pass for boiler-feed supplies with high recovery (96%) and low energy (0.34 kWh/m^3) from a municipal source (553 µS/cm) comprising the scaling constituents Ca (65 ppm), SO_4 (180 ppm), SiO_2 (32 ppm), F (1.2 ppm), Ba (0.022 ppm), and Sr (0.295 ppm) in addition to modest amounts of Na (65 ppm) and Cl (18.8 ppm). The 96% recovery trials were performed using a pilot comprised of a single module (8´´) with three elements (ESPA2-MAX) under fixed flow and variable pressure consecutive sequential CCD conditions at flux of 27.5 lmh and feed temperature of 20.7˚C. Under the specified trial conditions, average permeates of 13 µS/cm electric conductivity (~6.5 ppm) are produced with energy consumption of 0.59 kWh/m^3 which translates 0.34 kWh/m^3 at 25˚C and pressurizing means efficiency of 75%. The process proceeds at pH 5.0 in the presence of an antiscalant (Hydrex-4192 and 4102) with recycled concentrates of high super-saturated silica (max. 800 ppm) without any signs of scaling and/or fouling. The module performance results of this study are scalable to larger CCD systems of similar process design.

Keywords: RO; Closed circuit desalination (CCD); High recovery; Low energy; Upgrade of municipal water; High silica feed; High silica super-saturation; Boiler-feed supplies

1. Introduction

Less than one percent of the water on earth is found as fresh water (FW) and the declined availability and/or quality of such natural ground and/or surface sources as results of depletion and/or deterioration created the growing needs for water treatment and recycling. This takes place mainly by RO membrane techniques [1–4], the most widely practiced RO today to upgrade FW sources for domestic and/or industrial applications. Rising costs of FW treatment normally as results of declined quality of natural sources provide growing incentives of waste water recycling for reuse. A relatively smaller RO application today relates to seawater desalination [5,6] in order to create new FW supplements as replacements for depleted FW sources and/or due to increased demand by a growing population. The global trends regarding FW supplies dictate the need for advanced water treatment and water recycling techniques with RO of higher recovery, lower energy consumption, and greater cost effectiveness.

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Common industrial technologies used today for water treatment are based on conventional RO designs [7] of 2–3 staged modules (e.g. six elements per module), with/without inter-stage boosters or turbo chargers, for 70–85% desalination recovery depending on the compositions of the water source; wherein, recovery is a function of the number of lined elements in the design and low energy consumption determined by the ability to recover power from the disposed flow of pressurized brine. A recently reported innovation of closed circuit desalination (CCD) on the basis of different operational principles compared with conventional RO revealed the ability to reach high recovery without the need for staged modules designs, irrespective of the number of elements per module, with near absolute energy conversion efficiency, and without the need for energy recovery. The new approach was demonstrated for brackish water desalination [8–11], rejection of nitrates from drinking water [12], and desalination of clean domestic effluents [13]. This technology also applies to seawater desalination and demonstrated [14,15,16] low energy consumption without need for an energy recovery device.

The present study describes the application of a single-module CCD pilot with three elements for high recovery (96%) and low energy (0.574 kWh/m^3—50% feed pressurizing means efficiency) production of boiler feed at the Veolia-Energy site in Kansas City (VE-KC) from domestic water supplies (553 μS/cm) with the scaling constituents Ca (65 ppm), SO_4 (180 ppm), SiO_2 (32 ppm), F (1.2 ppm), Ba (0.022 ppm), and Sr (0.295 ppm) in addition to Na (65 ppm) and Cl (18.8 ppm). The term module hereafter refers to a pressure vessel with a defined number of elements connected in line. Treatment of domestic supplies for boiler feed is a common industrial application worldwide and the incentive for the trial at VE-KC site originated from the high domestic FW supplies costs ($10.56/1,000 gallon—2.98 $/m^3) which accounted for ~25% of the plant's operational expenses.

2. CCD pilot unit design and operational modes

The CCD pilot used for the municipal VE-KC water treatment of the schematic design displayed in Fig. 1 is of the ME3 configuration made of a single 8´´ pressure vessel with three elements (E = ESPA2-MAX [13]) and a spacer in front of the elements in order to expand the intrinsic volume of the closed circuit. The low-pressure VE-KC feed was passed through a multimedia filter (MF) and then modified before inlet to HP with hydrochloric acid, anitscalant, and sodium bisulfite solutions through the respective ASP, ASDP, and SBDP dosing pumps. Pressurized feed flow (Q_{hp}) inside the pilot is created by means of a high pressure pump (HP) and cross flow (Q_{cp}) by means of a circulation pump (CP) and both pumps equipped with variable frequency derive (vfd) to enable control of flow rates. Monitoring means of the pilot include electric conductivity (EC) of feed (CM_f), permeate (CM_p), and recycled concentrates (CM_c); flow-volume of feed (FM_f), permeate (FMp) and recycled concentrates (FM_c); pressure at module inlet (PMi) and outlet (PMo); and pH of feed. The monitored EC of recycled concentrate (FM_c) takes place by bleed through an external EC cell. Flow-volume data of permeates (Q_p–V_p) in the pilot are provided by the FM_p monitoring means. The conducting lines in the Pilot are made of SS316 of 300 psi rating with connection to actuated valve (AV), manual (MV), and check valve means (CV) at the locations cited in Fig. 1.

The pilot under review is programmed to operate a two-step consecutive sequential desalination process with CCD experienced most of the time (>90%) and brief plug flow desalination (PFD) steps in between for brine replacement form the closed circuit by fresh feed when the desired recovery is attained. The CCD steps proceed under fixed flow and variable pressure conditions, with same flow rates of pressurized feed and permeate ($Q_{hp} = Q_p$), and module recovery (MR) expressed by $Q_p/(Q_p + Q_{cp}) = Q_{hp}/(Q_{hp} + Q_{cp})$ with an instantaneous batch recovery of 100%; whereas, the PFD steps proceed with brine flow (Q_b) rejection according to the flow balance equation $Q_{hp} = Q_p + Q_b$ or $Q_{hp} = Q_p + Q_{cp}$ with recovery expressed by Q_p/Q_{hp} or $Q_p/(Q_p + Q_{cp})$, since at this step $Q_b = Q_{cp}$.

The pilot is controlled by operational set points (SPs) of constant flow rates for HP, under CCD ($SP_{hp\text{-}CCD}$) and PFD ($SP_{hp\text{-}PFD}$) conditions, and CP (SP_{cp}), as well as of batch recovery (SP_R), or instead of maximum applied pressure (p_{max}) during CCD. Operational SPs provide an infinite number of combinations, which may be changed on line, with enormous performance flexibility and versatility and the choice of flow rates dictates the MR and cross flow irrespective of selected recovery. The only manual control in the system is that of minimum pressure experienced during PFD and this is achieved by the degree of opening setup of the MV. The actuation signal of the consecutive sequential process include the termination of CCD and initiation of PFD when the cumulative feed volume (ΣV_{hp}) per desired batch recovery (R) is reached, and the termination of PFD and initiation of CCD when the cumulative cross flow volume (ΣV_{cp}) is that of the intrinsic volume of the closed circuit, or little greater to insure effective replacement of brine by fresh feed without mixing. The unique features of the CCD technology account for the attainment of any

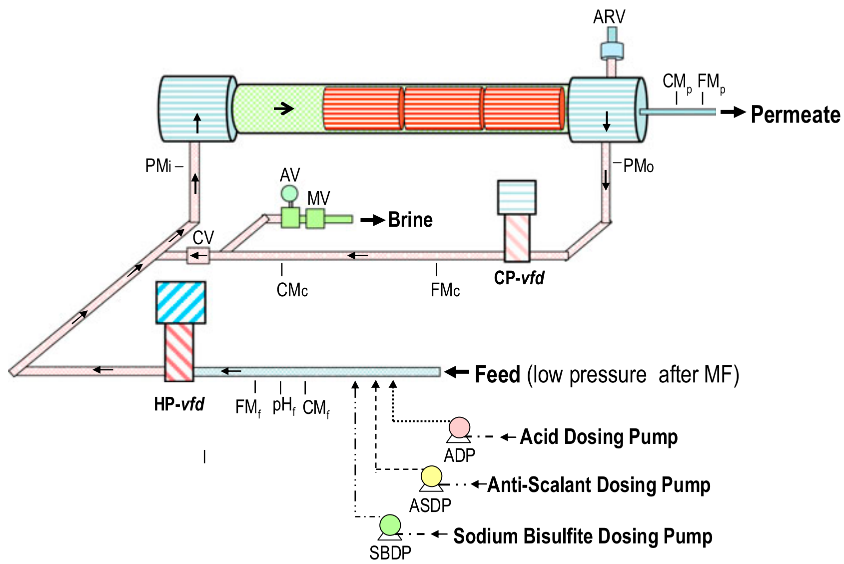

Fig. 1. Schematic design of the CCD pilot used for the treatment of the KC municipal water supplies with 96% desalination recovery.

desired recovery irrespective of the number of elements per module and/or MR selection and/or cross flow selection and/or flux selection, thereby allowing maximum optimization means of the desalination process for a specific feed source.

3. Selected conditions of the CCD trials of 96% recovery

The analytical data of the municipal VE-KC feed source used in the 96% recovery trials revealed the following composition: Ca: 33.0 ppm; Mg: 5.8 ppm; Na: 65.0 ppm; K: 5.5 ppm; Ba: 0.022 ppm; Sr: 0.25 ppm; Fe: 0.005 ppm; Al: 0.295 ppm; SO_4: 180 ppm; Cl: 18.8 ppm; F: 1.2 ppm; HCO_3: 18.43 ppm; NO_3: 7.6 ppm; P: 0.292 ppm; SiO_2: 32 ppm; EC: 553 μS/cm, and pH 9.69. Most obviously, the analytical data revealed a non-typical municipal feed source of low NaCl content and relatively high calcium, sulfate, and silica and therefore, special attention was given to selection of the antiscalant and the pH conditions to enable the attainment of the highest desired high recovery during trials.

The selected operational conditions of the high recovery trials are as follows: $SP_R = 96\%$; $SP_{hp\text{-}CCD} = 3.4\ m^3/h$; $SP_{hp\text{-}PFD} = 4.6\ m^3/h$; $SP_{cp} = 6.4\ m^3/h$. Hydrochloride acid dosing rate through ADP adjusted to maintain pH 5.0. Antiscalants dosing rate through ASDP adjusted to 1.0 mg/l Hydrex-4192 [17] and to 2.0 mg/l Hydrex-4104 [17]; and sodium bisulfite dosing rate through BSDP adjusted to 7.3 mg/l. Hydrex-4192 is a common scale preventive antiscalant, whereas, Hydrex-4104 is more specifically effective for silica scale prevention. Sodium bisulfite is added to the feed in order to neutralize the free chlorine used to disinfect municipal drinking water supplies and to avoid damage to the membranes. The specified selections of flow rates implied trial conditions of CCD-MR = 34.7% at flux of ~27.5 lmh with the cited (parentheses) efficiency of the HP (~50%) and CP (~40%) pumps.

Three high recovery 96% trials, each of 8 h duration, were performed on successive days during October 11–13, 2014 with feed-supplied temperature range of 67.4–69.4˚F and the specific trial illustrated hereinafter was carried out at 69.4˚F (20.7˚C). Prior to the 96% trials, the pilot was operated smoothly for several weeks at 94% recovery and neither fouling nor scaling encountered in any of the trials.

CCD is a consecutive sequential batch desalination technology and its performance is best illustrated by the follow-up parameters on the time scale. Accordingly, the results of the 96% recovery trials are illustrated by actual online data collected over a 5-h time interval on 13 October 2014 (08:16–13:16) at temperature of 20.7˚C.

4. Online results of a 96% recovery CCD trial

Results of the CCD experimental trial of 96% recovery with VE-KC municipal supplies presented hereinafter are the online monitored data over the specified time interval of the process. Flow rates displayed in Fig. 2 and pressures in Fig. 3 reveal a highly consistent two-step consecutive process pattern of long sequences (~47 min) during which CCD is experienced ~96.2% of the time with 100% recovery ($Q_{hp} = Q_p$) and brief (~1.8 min) PFD steps in between during the rest of time for replacement of brine with fresh feed while desalination is continued with low recovery. The flow rates are consistent with the control SPs with minor variations hardly noticed including with respect to HP flow rate increase during the brine flush out step of shapely reduced recovery during which period CP is temporally stopped. Fig. 3 reveals consecutive sequential applied pressure variations during the CCD cycles of minor pressure difference changes (Δp ~ 9.5 psi or 0.66 bar) as expected by a constant net driving pressure (NDP) operation under the fixed flow conditions of the process. Constant NDP during CCD implies that forces on membrane surfaces remain essentially unchanged suggesting motionless membrane surfaces. According to Fig. 3, a drop in HP feed pressure from ~2.3 to ~1.0 bar takes place briefly on change from CCD to PFD due to the increased feed flow and declined permeation during the brine flow release out of the closed circuit. The average CCD module inlet pressure (~7.25 bar) displayed in Fig. 3 is also the average specific energy contribution of HP expressed in atm-m^3 units (0.403 kWh/m^3) at the performance efficiency level (~50%) of said pump, since $Q_{hp} = Q_p$. The features displayed in Fig. 4 are noteworthy, since high recovery (96%) and high flux (~27.5 lmh) operation with difficult feed sources, such as high silica and sulfate, with conventional PFD techniques will most probably induce enhanced scaling; whereas, in the current study, at pH 5.0, the unchanged module pressure

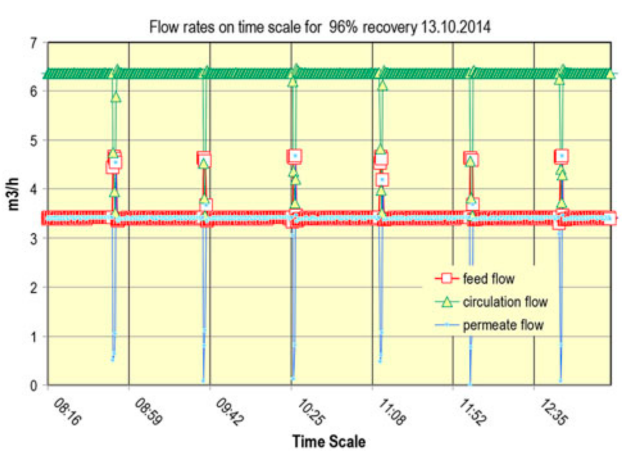

Fig. 2. Flow rates of feed, permeate, and cross flow over the indicated 5-h interval of the 96% recovery trial with VE-KC feed.

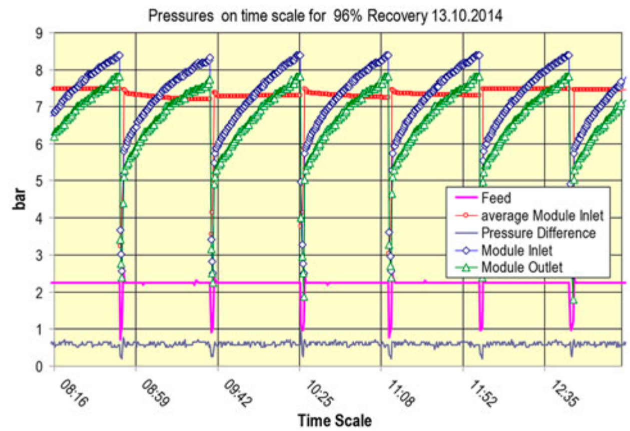

Fig. 3. Pressures on a time scale over the indicated 5-h interval of the 96% recovery trial with VE-KC feed.

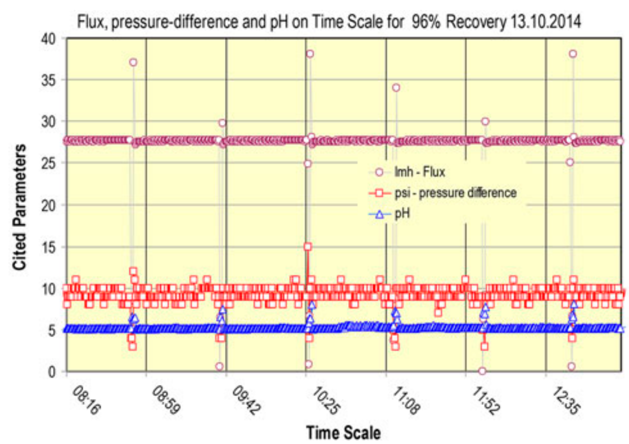

Fig. 4. Flux, pressure difference, and pH on a time scale over the indicated 5-h interval of the 96% recovery trial with VE-KC feed.

difference (~9.5 psi) reveals no signs of any scaling under the CCD conditions despite the very high batch recovery. The same consecutive sequential pattern on the time scale displayed in Figs. 2–4, as well as in the other results figures described hereafter, distinguishes CCD from conventional PFD techniques which operate on the basis of different principles.

Monitored electric conductivity (EC) information during the exemplified trail provides the means to follow-up concentrations, since the relative concentrations of constituents in feed and recycled concentrates do not change significantly, while their absolute concentrations are reflected by the EC data.

Online EC data on the time scale displayed in Fig. 5 reveal large salinity variations associated with recycled concentrates in reference to near constant feed and average permeates values. Recycled concentrates of increased salinity create the same salinity pattern of produced permeates manifested by the EC data displayed in Fig. 6 with a sequential permeate average at 96% recovery of ~13 μS/cm (~6.5 ppm). Despite high salinity recycled concentrates during the CCD sequences of 96% recovery, the quality of produced permeates is relatively high (Fig. 6) and manifests the high flux (27.5 lmh) effect and the good salt rejection characteristics of the membrane elements. The average salt rejection during the trial (>99.6%) on the basis of online monitored EC data displayed in Fig. 7 also comprise fine structure variations due to the slight decline in the EC/concentration ratio with increased salinity, and this implies that the true average salt rejection is around 99.7%. The salt diffusion coefficient of the membrane during the high recovery trial displayed in Fig. 8 is another noteworthy parameter derived from online EC information together with the appropriate terms of flux and concentration–polarization based on experienced MR. Information displayed in Fig. 8 reveals fine structure due to small changes in the EC/concentration ratio, as already pointed out, as well as high stability membrane performance with a near constant diffusion coefficient of around 0.08 lmh despite the large pressure variations.

Online monitored data every 16 s average over the 5-h trial interval revealed the average feed and permeate rates of 3.44 and 3.33 m^3/h, respectively, thereby suggesting an over recovery of 96.8% (3.33/3.44). Correction for the concentrate release from the closed circuit through the external EC cell at an estimated rate of 0.4 L/min does confirm the attainment of 96% volumetric recovery during said trial. The recovery information displayed in Fig. 9 reveals a fixed

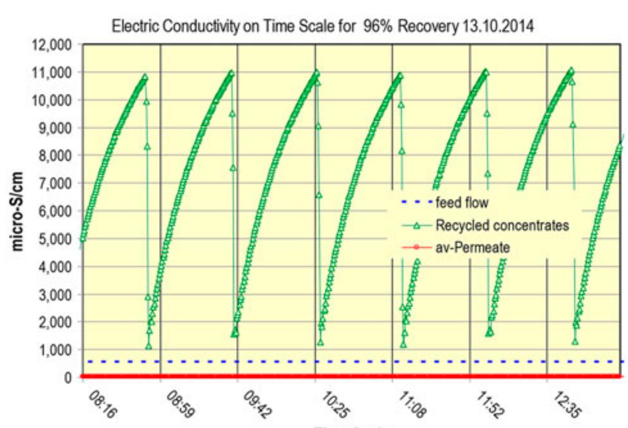

Fig. 5. EC online data on a time scale over the indicated 5-h interval of the 96% recovery trial with VE-KC feed.

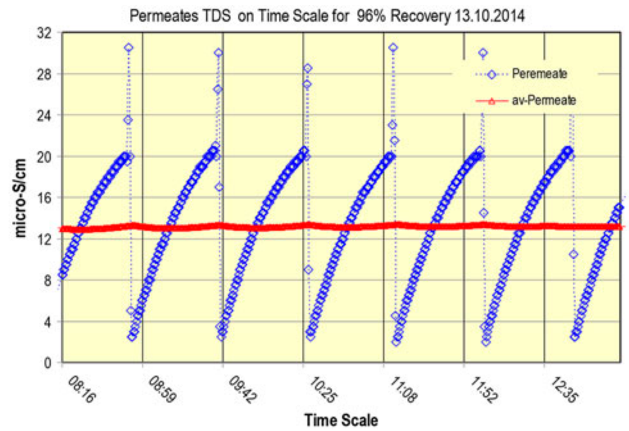

Fig. 6. EC online data of permeate on a time scale over the indicated 5-h interval of the 96% recovery trial with VE-KC feed.

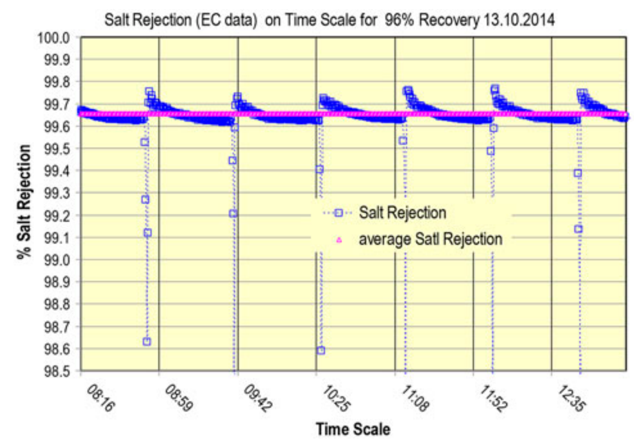

Fig. 7. Salt rejection derived from online EC data on a time scale over the indicated 5-h interval of the 96% recovery trial with VE-KC feed.

CCD-MR of ~35% based on monitored flow data as well as batch recovery build-up during the consecutive sequences with maximum (>99.5%) manifesting the average trial recovery of monitored EC data. Accounting for the slight decline in the EC/concentrate ratio with increased salinity brings the effective trial recovery to 96% in agreement with the volumetric result. In this context, it is noteworthy that production of permeates with 100% recovery takes place during CCD with $Qh_p = Q_p$ over 96.2% of the sequence time. This numerical figure (~96) also manifests the average process recovery, since the low production of permeates (<1.0 m^3/h) during the brief PFD brine flushing steps is compensated by the lost permeate production as results recycled concentrate leakage through the external EC cell.

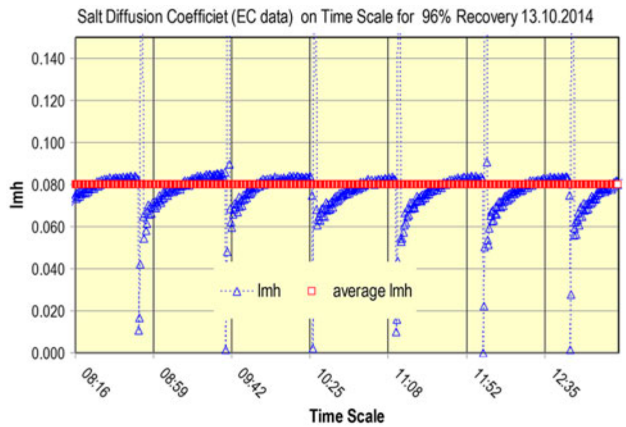

Fig. 8. Salt diffusion coefficient of membranes derived from online EC data on a time scale over the indicated 5-h interval of the 96% recovery trial with VE-KC feed.

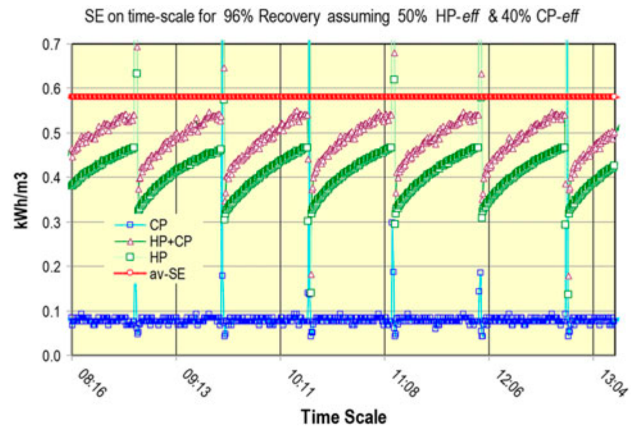

Fig. 10a. Specific energy derived from online pressure-flow data over the cited 5-h interval trial on 13 October 2014 of 96% recovery at 20.7˚C with assumed efficiencies of 50% HP and 40% CP and with monitored (ΣkWh/ΣV_{p}) average of 0.59 kWh/m^3.

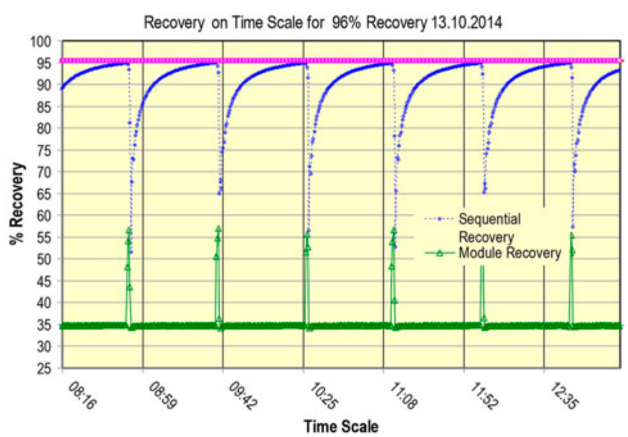

Fig. 9. Recovery parameters derived from online EC data on a time scale over the indicated 5-h interval of the 96% recovery trial with VE-KC feed.

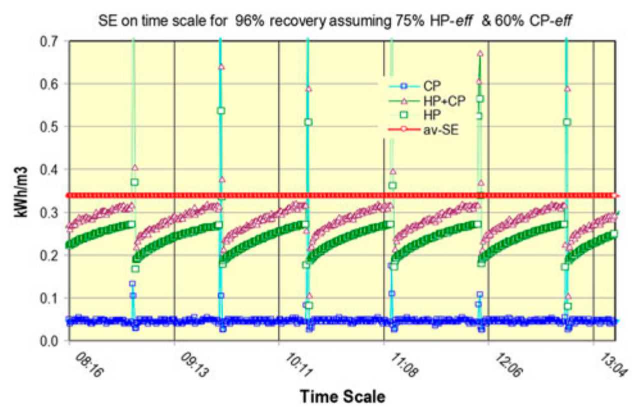

Fig. 10b. Specific energy projection derived from online pressure flow data over the cited 5-h interval trial on 13 October 2014 of 96% recovery at 20.7˚C with assumed efficiencies of 75% HP and 60% CP and with an estimated ΣkWh which combined with monitored ΣV_{p} yields av-SE of 0.34 h/m^3.

The energy aspects of the high recovery CCD trial under review are assessed from online monitored flow pressure data assuming efficiencies of pumps (50% HP and 40% CP) which are relatively low in light of their small size as well as from the monitored energy (ΣkWh) and volume of permeates (ΣV_{p}) during the trial period which provides an average energy count (av-SE). Fig. 10a displays the specific energy components of HP, CP, HP + CP, and sequence av-SP and reveals the following features:

(1) HP energy consumption is more than 80% of the total required energy.
(2) The energy consumption mode of HP takes place along the batch recovery progression of the consecutive sequential process.
(3) The average energy of the process is defined by av-SE = ΣkWh/ΣV_{p} and expresses cumulative monitored data.
(4) The energy consumption of CP is essentially constant and determined by its fixed flow rate and low pressure ($\Delta p \sim 9.0$ psi) of operation during the CCD steps of the process.
(5) The process average is found ~10% above the maximum HP + CP level and this reflects some overestimation of pumps' efficiencies as well as the expected increased energy demand of pumps during the CCD-PFD transformations.

Energy demand for the process with improved efficiency of pumps is projected in Fig. 10b for 75% HP and 60% CP instead of 50% HP and 40% CP. In this instance, ΣkWh reflects the increased efficiency of pumps, whereas, ΣV_p remains unchanged.

5. Discussion

Desalination of municipal supplies for high quality water production is widespread worldwide for many applications such as feed for boilers and electric power turbine generators as well as for many industrial processes including such associated with solid state, pharmaceuticals, cosmetics, and many more. Ordinary two-stage desalination of municipal supplies with 75–80% recovery by conventional PFD is commonly practiced worldwide and accompanied with 20–25% waste of water, a major economical issue in light of the increased costs of municipal supplies in many places, especially in advanced countries where strict regulations are implemented to insure the quality of drinking water. Minimizing loss of expensive municipal supplies requires high desalination recovery beyond the ordinary range offered by conventional RO techniques and this is a non-trivial issue with conventional methods. The present study demonstrates how near absolute recovery (96%) with excellent quality permeates could be obtained at high flux and low energy from a difficult municipal source by the newly conceived CCD technology.

The VE-KS supply source of ~553 μS/cm used as feed in the current study comprises high amounts of Ca (65 ppm), SO_4 (180 ppm) and SiO_2 (32 ppm), modest amounts of Na (65 ppm), and Cl (18.8 ppm), and small amounts F (1.2 ppm), Ba (0.022 ppm), and Sr (0.295 ppm). Such a source composition suggests the prospective scaling constituents of SiO_2, CaF_2, $CaSO_4$, $BaSO_4$, and $SrSO_4$ during high recovery desalination trails, and therefore, it is imperative to analyze the reported results with regards to such cited prospects scaling and/or fouling.

Impaired membrane surfaces due to thin film deposition of organic and/or inorganic origin under CCD conditions of fixed recovery SP affect increased applied pressure at both ends of the range, since greater power is required to sustain fixed permeation flow of constant NDP. Moreover, such an event also leads to increased salts rejection manifested by higher quality permeates and a declined salt diffusion coefficient. Scaling formed by particular matter deposition in the concentrate side channels of membrane elements restricts the flow and, therefore, greater module pressure difference (Δp) is required in order to sustain the constant cross flow created by CP. Accordingly, scaling is normally associated with increased Δp whose value is a function of the degree of the partially blocked elements passages. The highly reproducible consecutive sequential CCD patterns of little variability displayed for applied pressure in Fig. 3, permeates TDS in Fig. 6, salt rejection in Fig. 7, salt diffusion coefficient in Fig. 8, and energy consumption in Fig. 9 appear to rule out any adverse effects on membrane surfaces during the high recovery trial under review. Moreover, the essentially unchanged Δp displayed in Figs. 3 and 4 suggests the absence of any signs of scaling in this trial. It should be pointed out that the 96% recovery trial for which data are provided pertains to the last of three such 8-h identical trials of unchanged patterns of consecutive sequential respective parameters. Apart from the 96% recovery trials, 94% recovery trails with the same feed source also revealed highly consistent reproducible results of similar types and the combined information of all the trials appears to rule out the possibility of esoteric observations.

All the high recovery (94–96%) trials with the VE-KC feed source were carried out without need for CIP which demonstrates the high effectiveness of the CCD technology for quality water production from municipal water supplies even when the feed comprises unfavorable constituents. The term unfavorable constituents in the case of the VE-KC source refers in particular to Ca (825 ppm), SO_4 (4,500 ppm), and SiO_2 (800 ppm) with respective maximum brine concentrations given in parentheses. The presence of high sulfate concentrations in the presence of Ca, Ba, and Sr is known to lead to extremely low solubility salts, and the saturation concentration of SiO_2 (120–140 ppm) is also considered low and prohibits high recovery under normal conditions by conventional RO techniques. Very high recovery in the presence of distinct scaling constituents implies the development of high supersaturation conditions and suggests the effectiveness of CCD for promoting such meta-stable supersaturation conditions. In contrast to single-pass conventional PFD techniques where the inlet feed to an element is the concentrate of the preceding element, the recycled concentrate in CCD is constantly diluted with fresh feed at module inlet with a declined tendency of scaling and increased propensity for supersaturation durable enough to allow high recovery prospects by this consecutive sequential batch desalination approach technology. Attainment of durable enough supersaturation conditions with CCD of high recovery prospects depends on the feed source composition, antiscalant, pH, temperature, and the selected operational parameters of flux and cross flow, independent of each other, whereby optimized conditions are created for maximum system recovery.

Development of supersaturation conditions during a batch CCD sequence is a progressive process influenced by the dilution effect with exponential dependence on batch recovery, and after reaching maximum allowed supersaturation conditions for a desired recovery level, brine is flush out of the closed circuit and all the fouling factors of previous batch sequence removed before a new sequence initiated. In the present study of 96% recovery with sequential periods of ~47 min during which CCD is experienced ~96.2% of the time, extreme supersaturation conditions are most probably developed towards the end of sequences with all adverse supersaturation effects completely removed during the PFD brine flush steps of the process PFD. In simple terms, extreme supersaturation conditions in the system under review will occur only over a relatively brief time interval toward the end of the batch sequence without left-over effects on the continued consecutive sequential process, if properly optimized.

While the results of the current study suggest high supersaturation preference under CCD conditions, operation under high supersaturation conditions with respect to silica is described in a recent US patent application [18] with an open circuit single-element module designed batch apparatus which was operated with 80–85% recovery under fixed cross flow of declined flux at low pH (3–5) in the presence of antiscalant with a silica-rich feed source (max-TDS > 10,000 ppm and max-silica > 124 ppm), and revealed maximum brine silica content just over 1,000 ppm. The reported [18] open circuit batch desalination with single-element module(s) under fixed cross flow and declined flux proceeds with exceptionally high energy consumption and low permeate productivity (high specific energy) using expensive apparatus therefore, less attractive for commercial applications compared with CCD. A recent theoretical study [19] which compared closed and opened circuit desalination of high silica feed sources under fixed pressure of declined flux conditions revealed that the former (CCD) proceeds with a much lower energy pathway and suggested the plausibility of CCD under fixed flow and variable pressure conditions as a better approach for such applications. The results of the current study confirm the ability to reach high recovery through high supersaturation of Silica (800 ppm) with module(s) of three elements under CCD conditions of fixed flow and variable pressure conditions of low-energy consumption and high permeates productivity. The findings of the current study appear to be consistent with the recently reported unreported results [20] of high recovery low energy desalination results obtained with other silica rich sources.

The experimental results of the current study are far reaching beyond their immediate implication to the VE-KC specific feed source since improved quality municipal supplies represents genuine needs by many industries worldwide not only for quality water supplies for boilers. In this context, the high recovery (96%) demonstration without fouling of a difficult municipal feed source implies the ability to achieve even better results with common domestic supplies of lesser troublesome constituents. Saving of expensive municipal water supplies when their upgradation is warranted by a high recovery low-energy process using inexpensive CCD apparatus provides clear economical incentives. Moreover, the ability to reach exceptionally high recovery of low energy under high supersaturation conditions through CCD with difficult feed constituents in the absence of fouling may suggest the plausible application of this approach for the recycling of domestic and/or industrial effluents for reuse with high economical effectiveness. Attainment of a near absolute recovery under supersaturation conditions by means of optimized CCD processes provides a plausible route to near zero discharge with water saving, a noteworthy aspect of advanced water treatment technologies of growing environmental and economical importance.

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References

[1] P. Zhang, J. Hu, W. Li, H. Qi, Research progress of brackish water desalination by reverse osmosis, J. Water Resour. Prot. 5 (2013) 304–309.
[2] L.F. Greenlee, D.F. Lawler, B.D. Freedman, B. Marrot, P. Moulin, Reverse osmosis desalination: Water sources, technology and today's challenges, Water Res. 43 (2009) 317–2348.
[3] J.P. McHarg, Energy Optimization of Brackish Groundwater Reverse Osmosis Desalination, Final Report for Contract No. 0804830845, Texas Water Development Board, Austin, Texas 78711-3231, September 2011.
[4] Waterlines Report Series No 9, Emerging Trend in desalination: A review, UNESCO Centre for Membrane Science and Technology, University of New South Wales, Commissioned by the National Water Commission, Australian Government, October 2008.
[5] M. Elimelech, W.A. Phillip, The future of seawater desalination: Energy, technology, and the environment, Science 333 (2011) 712–717.

[6] A.D. Khawaji, I.K. Kutubkhanah, J.M. Wie, Advances in seawater desalination technologies, Desalination 221 (2008) 47–69.
[7] Dow Liquid Separation, FILMTEC™ Reverse Osmosis Membranes, Technical Manual, 2011. Available from: <http://msdssearch.dow.com>.
[8] A. Efraty, Closed circuit desalination series no-3: High recovery low energy desalination of brackish water by a new two-mode consecutive sequential method, Desalin. Water Treat. 42 (2012) 256–261.
[9] A. Efraty, Closed circuit desalination series no-4: High recovery low energy desalination of brackish water by a new single stage method without any loss of brine energy, Desalin. Water Treat. 42 (2012) 262–268.
[10] A. Efraty, Z. Gal, Closed circuit desalination series No 7: Retrofit design for improved performance of conventional BWRO system, Desalin. Water Treat. 41 (2012) 301–307.
[11] R.L. Stover, Industrial and brackish water treatment with closed circuit reverse osmosis, Desalin. Water Treat. 51 (2013) 1124–1130.
[12] A. Efraty, J. Septon, Closed circuit desalination series no-5: High recovery, reduced fouling and low energy nitrate decontamination by a cost-effective BWRO-CCD method, Desalin. Water Treat. 49 (2012) 384–389.
[13] J. Septon, A. Efraty, CCD series no-17: Application of the BWRO-CCD technology for high recovery low energy desalination of domestic effluents, Desalin. Water Treat., doi: 10.1080/19443994.2015.1035498.
[14] A. Efraty, R.N. Barak, Z. Gal, Closed circuit desalination—A new low energy high recovery technology without energy recovery, Desalin. Water Treat. 31 (2011) 95–101.
[15] A. Efraty, R.N. Barak, Z. Gal, Closed circuit desalination series no-2: New affordable technology for sea water desalination of low energy and high flux using short modules without need of energy recovery, Desalin. Water Treat. 42 (2012) 189–196.
[16] A. Efraty, Closed circuit desalination series no-6: Conventional RO compared with the conceptually different new closed circuit desalination technology, Desalin. Water Treat. 41 (2012) 279–295.
[17] The chemical use and dosage of Hydrex-4192 and Hydrex-4104 was verified by the on-site operator. Hydrex™ is the water treatment chemicals range of Veolia Water Technologies.
[18] A.J. Tarquin, Sea water reverse osmosis systems to reduce concentrate volume prior to disposal, US Patent Application, Pub. No.: US 2011/0036775 A1.
[19] A. Efraty, CCD series No-16: Opened versus closed circuit SWRO batch desalination for volume reduction of silica containing effluents under super-saturation conditions, Desalin. Water Treat., doi: 10.1080/19443994.2015.1035494.
[20] V. Sonera, J. Septon, A. Efraty, CCD series no-21: Illustration of high recovery (93.8%) of a silica containing (57 ppm) source by a powerful technology of volume reduction, Desalin. Water Treat., doi: 10.1080/19443994.2015.1126412.