Located on the southwestern coast of Saudi Arabia, the Shuqaiq Phase-II Independent Water and Power Project supplies water and power to the cities of Abha and Jizan and the surrounding area. The region has been subject to recent water and power shortages. The 1,020-MW power plant consists of three 340-MW steam turbines and heavy crude oil-fired boilers and generators. The seawater reverse osmosis (SWRO) plant, one of Saudi Arabia's largest, has the capacity to produce 212,000-m$^3$/day of desalinated drinking water and achieves 14 mg/L of chloride ion and 0.5 mg/L of boron for product water quality. The Shuqaiq plant will use a two-pass desalting process that uses SWRO and brackish-water RO. This article summarizes the plant's commissioning and commercial operation, including membrane oxidation and scaling at high pH.

# SWRO Drinking Water Project in Shuqaiq: Advanced BWRO, Membrane Oxidation, and Scaling

Nabil Nada, Tony Attenborough, Yoshiaki Ito, Yasushi Maeda, Kiichi Tokunaga, and Hideo Iwahashi

Located on the southwestern coast of Saudi Arabia, the Shuqaiq Phase-II Independent Water and Power Project (IWPP) supplies water and power to the cities of Abha and Jizan, as well as the surrounding area (Figure 1). The power plant consists of three 340-MW extraction condensing steam turbines, heavy crude oil-fired boilers, and generators. The seawater reverse osmosis (SWRO) plant can produce 212,000 m$^3$/day of desalinated drinking

water. The plant was constructed adjacent to Shuqaiq Phase-I, also a power and desalination plant. In Phase-I, the desalination plant uses multistage flash technology (Fakih, 2005). The Phase-II plant commenced commercial operation in late May 2010.

The Power Water Purchase Agreement specifies a maximum permeate, chloride concentration had to be reduced to less than 14 mg/L to prevent pipe corrosion, and boron concentration had to be reduced to no more than 0.5 mg/L to comply with World Health Organization guidelines. Although achieving these values is challenging for an SWRO desalination plant, the authors proposed an advanced two-pass RO process in which part of the second-pass permeate—the brackish-water RO (BWRO) process—would be recirculated. Now the plant has been in commercial operation for more than 1 year. This article reports some of the experiences during commissioning and early operation.

## Desalination Processes

The Shuqaiq IWPP desalination plant (Figures 2 and 3) consists of the following processes:

- Seawater intake
- Pretreatment
- RO, including SWRO and BWRO
- Potabilization

**Figure 1. Location of Shuqaiq IWPP**

KUWAIT

SAUDI ARABIA

Al-Khobar    QATAR

Riyadh

Jeddah    UAE

OMAN

Shuqaiq

YEMEN

Membrane performance was evaluated
by conducting an ion analysis of the
feedwater samples in September 2010.

These processes are designed to produce 212,000 m³/day of drinking water from 600,000 m³/day of seawater during the plant's 20-year life cycle.
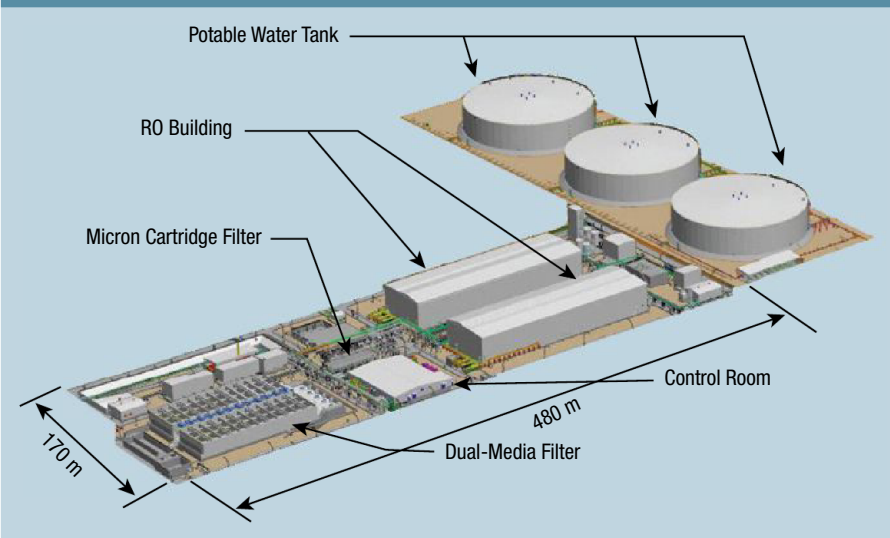
**Seawater Intake System.** Seawater is drawn 1.3 km offshore from a depth of approximately 5 m and diverted to the raw intake pond. The seawater is chlorinated at two points—the intake channel inlet and the seawater pump suction. The dosing rate is calculated to achieve suitable chlorine residual at the outlet of a dual-media filter.

**Pretreatment.** Pretreatment is necessary to remove silts, suspended solids, and organic materials and to achieve required feedwater quality.

The plant's pretreatment unit is conventional gravity filtration. Dual-media filtration (DMF) with pH adjustment and in-line coagulation are provided to ensure pretreatment performance. After coagulant dosing, sulfuric acid is injected to adjust pH to 6.5. Both chemical injections were optimized by pilot testing.

DMF consists of sand and anthracite media with a gravel support layer. The media are backwashed with RO process brine and covered by a roof to prevent algae bloom. For further protection of high-pressure pumps

and RO elements, filtered water from DMF is passed through an array of 10-µm mesh microcartridge filters, which can be replaced without loss of production.

**RO Process.** The RO process, which removes dissolved solids from seawater, is a crucial part of the desalination plant. In this project, desalination must achieve levels of 14 mg/L of chloride ion and 0.5 mg/L of boron. To achieve this requirement, a full two-pass RO process—which means all of the SWRO permeate is desalted by BWRO—is provided. The designed total recovery of this process is 36 percent, and the RO process consists of 16 trains. The RO process is depicted in Figures 4 and 5.

**Figure 2. A bird's-eye view of the RO desalination plant in Shuqaiq IWPP**



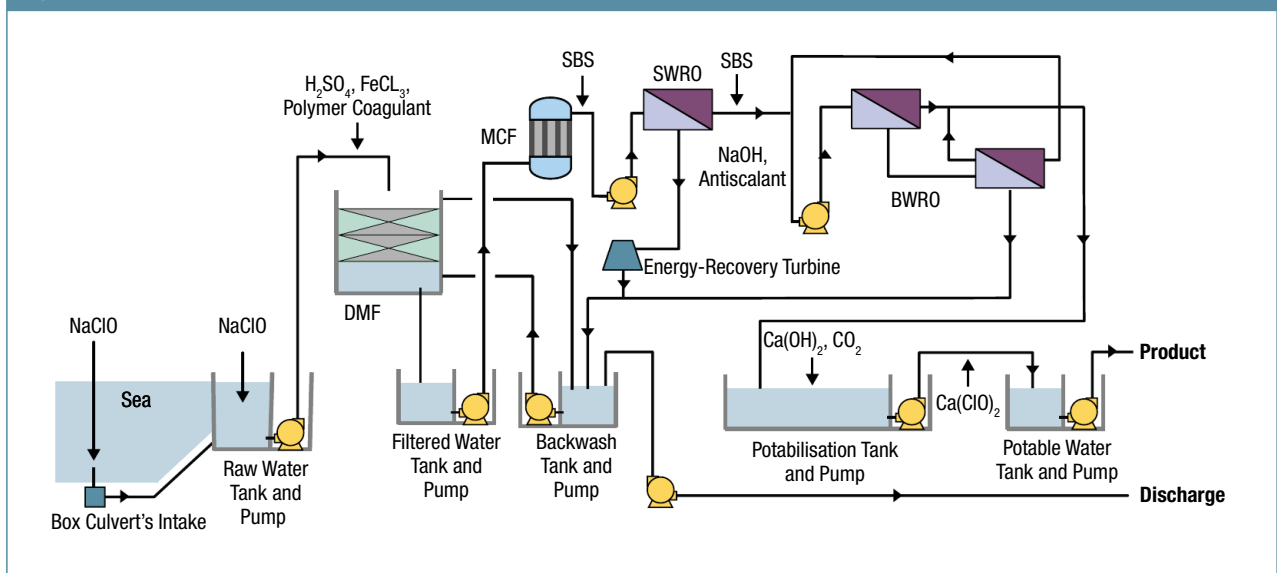**Figure 3. Process flow of the Shuqaiq IWPP RO desalination plant**

**Figure 4. First RO membrane bank**



**Figure 5. Second RO membrane bank**

*SWRO.* Pretreated feed seawater is dechlorinated by sodium bisulfite (SBS) and pressurized to about 7 MPa before it is sent to cellulose triacetate hollow fiber-type SWRO modules[1]. Because the SWRO membrane has a unique chlorine tolerance, an intermittent chlorine injection eliminates membrane biofouling (Kumano et al, 2003). The operation injects chlorine for 3 hours/day without SBS injection to filtered water. Designed SWRO recovery is set at 40 percent; the process removes 98–99 percent of dissolved materials. Before the brine is sent to the backwash tank, SWRO brine energy is recovered by a Pelton wheel.

*BWRO.* All SWRO process permeate is dechlorinated by SBS, and pH is adjusted to about 10 with caustic soda. High pH feedwater is required for effective boron removal (Busch et al, 2003; Redondo et al, 2003). In addition, antiscalant is injected to prevent scaling. Next, the feed is supplied to the BWRO process. The permeate circulation process is adapted to this process, which is effective when a high rejection of dissolved substances is required.

The BWRO elements are polyamide spiral-wound membranes[2]. Permeate quality is required to be less than 14 mg/L chloride and less than 0.5 mg/L boron. BWRO recovery is designed for 90 percent. Brine is sent to a backwash tank, similar to that used in the SWRO process.

**Potabilization**. This process aims to potabilize the RO permeate to reach the required water quality. The process includes two stages—hydrate lime dosing and carbon dioxide dosing. Hydrate lime and carbon dioxide are injected to increase hardness and alkalinity, respectively. Required pH and Langelier saturation index after potabilization range from 8.3 to 8.6 and +0.1 to +0.3, respectively, for drinking water. The adjusted drinking water is stored in a potable water tank and delivered to end users by a private company[3].

## Advanced BWRO Process

The 14-mg/L chloride and 0.5-mg/L boron targets are tight values for an SWRO plant. To achieve these values, the advanced BWRO process—called the permeate circulation process (PCP)—is used (Figure 6). This process has two BWRO stages and a line for part of the second-stage permeate to circulate into the pump inlet. In the second stage, the desalinated water permeate is taken from the permeate port at the front end of the modules and that for circulation is taken from



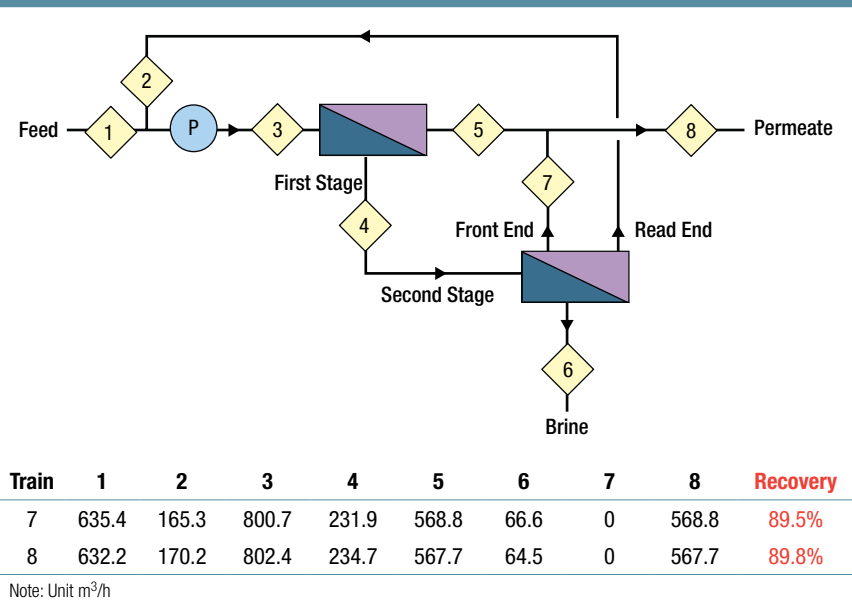**Figure 6. Schematic of BWRO process at Shuqaiq IWPP**
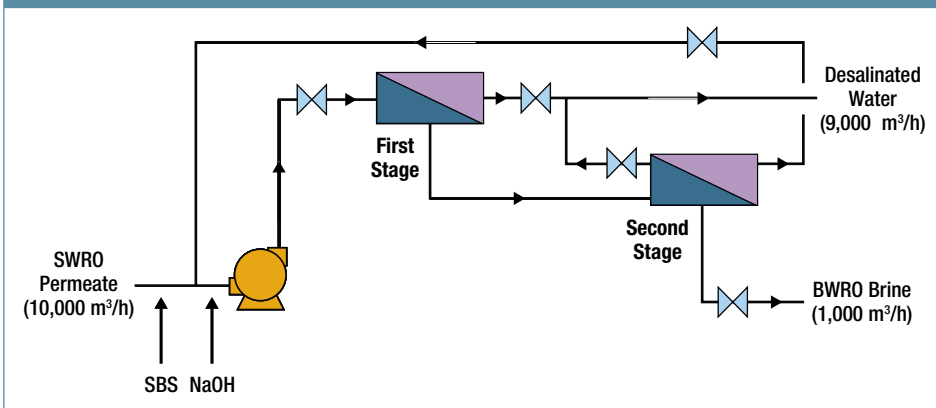
the rear end. This strategy can further improve process performance. Chloride of 97 percent and boron of 85 percent in the SWRO permeate can be removed with 90 percent recovery in the plant's designed BWRO process (Nagai et al, 2004; Hirai et al, 2007).

Membrane performance was evaluated by conducting an ion analysis of the feedwater samples in September 2010. The water samples were taken from the first- and second-stage RO permeate and second-stage RO circulation lines of Trains 7 and 8, respectively. The mass balance at the time of sampling and the results of ion analysis are shown in Figure 7 and Table 1. These results showed that the process can achieve around 90 percent recovery and more than 85 percent boron rejection simultaneously by adopting PCP with a feed pH of about 10. These results were compared with software analysis[4] calculations (Table 2), which demonstrated that the software can accurately predict membrane performance and that PCP has been successfully operated in the Shuqaiq plant according to the design philosophy.

## BWRO Membrane Oxidation

**Plant Operation.** During the commissioning stage, the Shuqaiq desalination plant's BWRO membranes experienced severe performance degradation. Figure 8 shows typical data acquired from Train 3. Permeate conductivity increased sharply for one week, and membranes completely lost their salt-rejection properties. Concurrently, on-line oxidation–reduction potential (ORP) values upstream of the BWRO membrane that were analyzed by two ORP meters increased gradually. This is a characteristic trend of this phenomenon. However, ORP values were less than 300 mV, which is set as the upper limit for polyamide BWRO membranes to prevent chlorine oxidation. The complete absence of chlorine is assured as long as the ORP value is maintained below 300 mV.

**Autopsy Analysis of Damaged Membrane.** Autopsy analysis of the deteriorated membrane was subsequently conducted. First, electron spectroscopy for chemical analysis (ESCA) was applied to evaluate the membrane surface's elemental composition. Analysis results of Train 3's element, where the most severe degradation occurred, are shown in Table 3. No Cl and Br halogen atoms were detected, so halogen oxidation did not occur. This is consistent with plant data that ORP values were less than 300 mV. In addition, the analysis revealed that the O/C value is greater than 30 percent, which is greater than for a normal membrane, suggesting that deterioration occurred because of an oxidation reaction.

In addition, inorganic foulants were analyzed within inductively coupled plasma (ICP). Analysis of Train 3's

**Figure 7. Result of mass balance**

| Train | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Recovery |
|---|---|---|---|---|---|---|---|---|---|
| 7 | 635.4 | 165.3 | 800.7 | 231.9 | 568.8 | 66.6 | 0 | 568.8 | 89.5% |
| 8 | 632.2 | 170.2 | 802.4 | 234.7 | 567.7 | 64.5 | 0 | 567.7 | 89.8% |

Note: Unit m³/h

**Table 1. Ion analysis results**

| Train | | Na (mg/l) | K (mg/l) | Ca (mg/l) | Mg (mg/l) | Cl (mg/l) | SO4 (mg/l) | Boron (mg/l) |
|---|---|---|---|---|---|---|---|---|
| 7 (pH 10.0) | First RO Permeate | 34.3 | 1.5 | .075 | 2.21 | 56 | 3.2 | 3.2 |
| | Second RO Permeate | 2.1 | < 0.1 | < 0.01 | < 0.01 | 0.2 | < 0.1 | 0.37 |
| | Rejection | – | – | – | – | 99.6% | – | 88.4% |
| 8 (pH 9.9) | First RO Permeate | 27.7 | 1.3 | 0.53 | 1.64 | 46 | 1.9 | 3.1 |
| | First RO Permeate | 2.0 | < 0.1 | 0.02 | < 0.01 | 0.2 | < 0.1 | 0.41 |
| | Rejection | – | – | – | – | 99.6% | – | 86.8% |

### Figure 8. Operation data of degradation (Train 3)
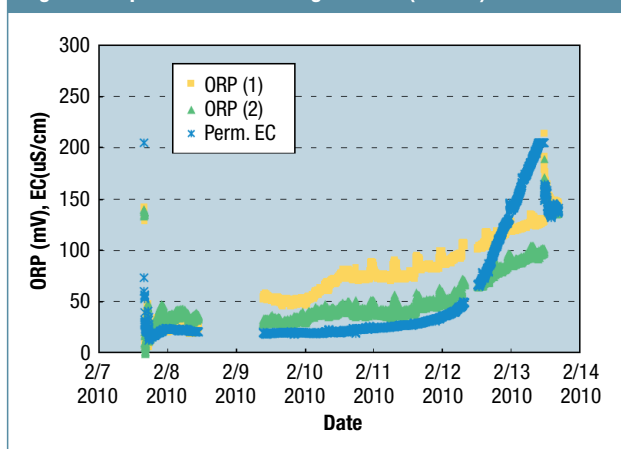


element revealed that heavy inorganic foulants were detected on the membrane surface (Table 4). A major foulant was iron, with a volume of 53 mg/m², which is greater than the usual range within 10 mg/m². Also, copper, nickel, manganese, and zinc were detected as transition metals.

The authors hypothesized that membrane deterioration by the SBS-originated oxidant was the root cause of membrane degradation. The hypothesis was based on the following facts:

- In the Shuqaiq desalination plant, SBS is injected between SWRO and BWRO, because chlorine is injected in front of SWRO for disinfection and must be eliminated to prevent BWRO deterioration from chlorine oxidation. This is the specific process of combining cellulose triacetate SWRO with polyamide BWRO.
- ESCA analysis of an autopsied membrane suggested that deterioration was caused by oxidation reaction, not by halogen oxidation.
- ICP analysis reveals heavy inorganic foulants remain on the membrane surface. This means the membrane surface has high potential to cause oxidation reaction, because heavy metals work as a catalyst.

In addition, a literature review revealed that sulfite auto-oxidation investigated in other technical fields—such as polymerization catalysis and solubilization of organics—found this reaction was subject to initiation in the presence of heavy metals (Brandt et al, 1995; Neta et al, 1985; Kuo et al, 2006). Lessons learned from Kawanishi et al (1989) suggest:

- Sulfite caused DNA damage in the presence of $Co^{2+}$, $Cu^{2+}$, and $Mn^{2+}$, although sulfite or metal ion alone did not.
- The addition of Cu(II) at concentrations ranging from $6.67 \times 10^{-4}$ to $3.33 \times 10^{-3}$ M to DNA–$SO_3^{2-}$ binary systems increased the reaction constant of $SO_3^{2-}$ with DNA 41–115 fold at a low concentration of $SO_3^{2-}$ ($10^{-3}$ M).
- The order of inducing effect on sulfite-dependent DNA damage is $Co^{2+} \gg Cu^{2+} > Mn^{2+} > Fe^{3+}$.
- The DNA damage induced by sulfite plus $Co^{2+}$ was inhibited by 3,5-dibromo-4-nitrobenzenesulfonate, primary and secondary alcohols.
- Sulfite is rapidly auto-oxidized in the presence of $Co^{2+}$ to produce $SO^{4-}$ radical, causing site-specific DNA damage.

From this information, an image of membrane degradation by sulfite auto-oxidation emerged (Figure 9). To verify the hypothesis, two experiments—a beaker test and flow-cell test—were conducted.

*Verification Test 1, Beaker Test.* The simulated condition of membrane degradation was prepared in a beaker and ORP was measured. The test was conducted according to the following procedure:

- The simulated BWRO feedwater was prepared in a beaker, the temperature of which was a constant 35°C. The simulated feedwater was composed of NaCl of 1,000 mg/L, NaHCO₃ of 60 mg/L, CaCl₂ of 10 mg/L as Ca, and MgCl₂ of 30 mg/L as Mg.
- Additionally, SBS, heavy metal ($Fe^{3+}$ and $Cu^{2+}$) and chelate agent (Na₄-EDTA and antiscalant) were injected to simulate water with the noted concentrations. An antiscalant[5] was applied.
- Simulated water pH was adjusted to 5 by HCl, which was the same as the SWRO permeate.
- Simulated water pH was adjusted to 10 by NaOH, which is same as BWRO feed.
- ORP was measured for 30 minutes.

At first, the effect of heavy metal was studied by simulated water with SBS of 10 mg/L and without the chelate agent. The three conditions of heavy metal injection—$Fe^{3+}$ of 1 mg/L and with $Cu^{2+}$ of 0.1 mg/L—were prepared and tested. Figure 10 shows the results. Without heavy metal, the ORP value became steady around 200 mV. When

### Table 2. Software analysis comparison

| Train | | Feed Pressure [bar] | Permeate Chloride Concentration (mg/L) | Permeate Boron Concentration (mg/L) |
|---|---|---|---|---|
| 7 | Operation Data | 10.8 | 0.2 | 0.37 |
| | Software | 10.6 | 0.47 | 0.35 |
| 8 | Operation Data | 10.3 | 0.2 | 0.41 |
| | Software | 10.7 | 0.36 | 0.39 |

$Fe^{3+}$ of 10 mg/L was injected, the ORP value also became steady, as was the case without heavy metal. However, when $Cu^{2+}$ of 0.1 mg/L was injected, a steep increase was observed, although $Cu^{2+}$ concentration was one-hundredth of the $Fe^{3+}$ injection. These results indicate the oxidation reaction initiated in the presence of $Cu^{2+}$ of 0.1 mg/L and suggested that the $Cu^{2+}$ should be a much stronger catalyst than $Fe^{3+}$.

Subsequently, the effect of the presence of SBS and the chelate agent was investigated with $Cu^{2+}$ of 0.1 mg/L as a catalyst. The four experiments were conducted under different conditions of SBS and chelate injection. Figure 11 shows the results. In the condition without SBS, an ORP increase was not observed, indicating that the presence of SBS is related to the ORP increase in the case of $Cu^{2+}$ being present, and SBS-originated oxidant can be formed in the simulated water with $Cu^{2+}$ as a catalyst. In addition, in the test in which $Na_4$-EDTA or the antiscalant as chelate agent was injected to simulate water with SBS and $Cu^{2+}$, ORP increase was inhibited. These results revealed that the chelate agent can prevent SBS oxidation. This seems to indicate the chelate agent masked heavy metal and inactivated the catalyst action.

From these results, it was concluded that SBS-originated oxidant could be generated on a BWRO membrane surface by the catalysis reaction shown in Figure 9, if heavy metal on the membrane surface was the catalyst. Moreover, it was suggested that chelate agent injection can effectively inhibit this kind of oxidation reaction.

*Verification Test 2, Flow-Cell Test.* The flow-cell test was conducted with simulated BWRO feedwater to demonstrate that SBS-originated oxidant deteriorates BWRO membranes. Figure 12 shows a flow diagram of test equipment. The 75-mm-diameter flat-sheet BWRO membranes were soaked in the flow cell, which consisted of a 500-mg/L glass bottle and stirrer. Each flow cell contains three membranes. The degree of membrane deterioration was evaluated by averaging the performance of the three membranes. This equipment has four lines, and three chemicals can be injected for each line. They were used for SBS, chelate agent ($Na_4$-EDTA), antiscalant, and NaOH, respectively. The test was conducted according to the following procedure:

■ The simulated BWRO feedwater was prepared in the feed tank, the temperature of which was maintained around 35°C. The compositions of the simulated feedwater were NaCl of 1,000 mg/L, $NaHCO_3$ of 60 mg/L, $CaCl_2$ of 10 mg/L as Ca, $MgCl_2$ of 30 mg/L as Mg, and $Cu(NO_3)_2$ of 0.02 mg/L as Cu. After mixing, pH was adjusted to 10 by NaOH.

| Table 3. ESCA analysis results | | | | | | | |
|---|---|---|---|---|---|---|---|
| (C) | (O) | (N) | (Cl) | (Br) | (Fe) | (S) | (O)/(C) |
| 67.7% | 21.4% | 9.6% | N/D | N/D | 1.0% | 0.3% | 0.316 |

| Table 4. Inorganic foulant amount analyzed by ICP | | | | | | |
|---|---|---|---|---|---|---|
| Al | Ba | Ca | Cu | Fe | Mg | Mn |
| 0.987 | 0.04 | 2.61 | 0.879 | 53 | 0.925 | 0.416 |
| Ni | P | K | Na | Sr | Zn | Si |
| 0.576 | 1.41 | 1.18 | 8.40 | N/D | 3.31 | 3.41 |

Unit: $mg/m^2$

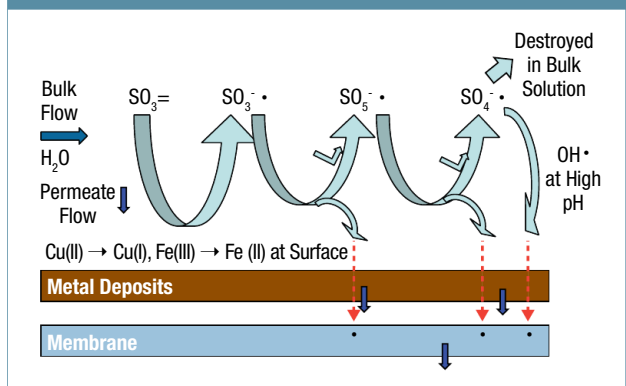**Figure 9. Membrane degradation by sulfite auto-oxidation**



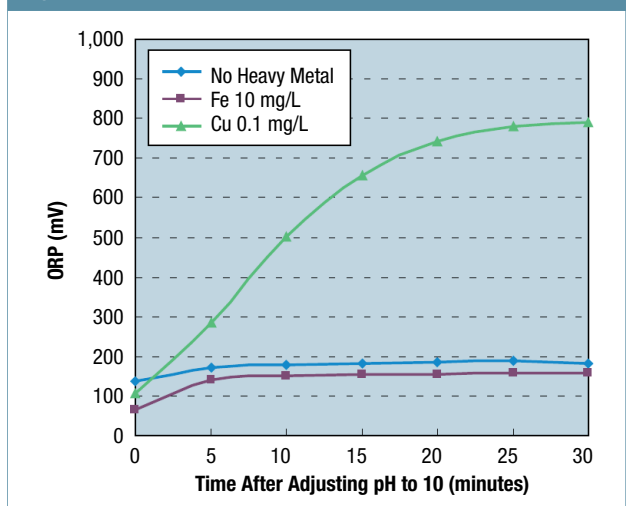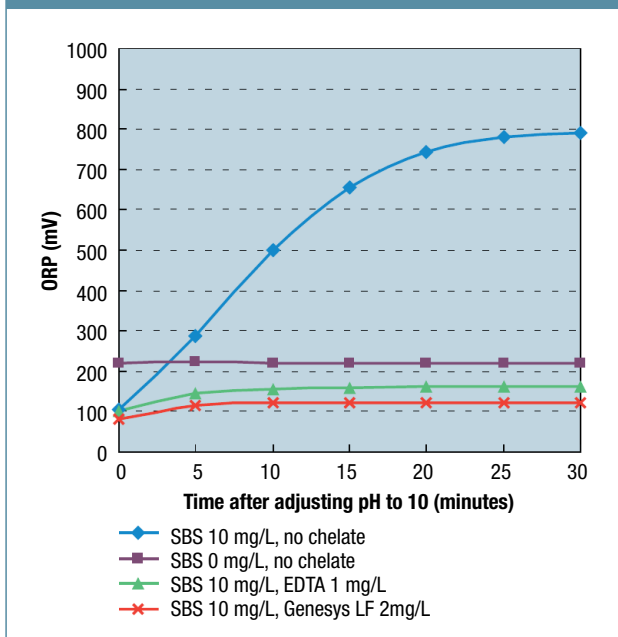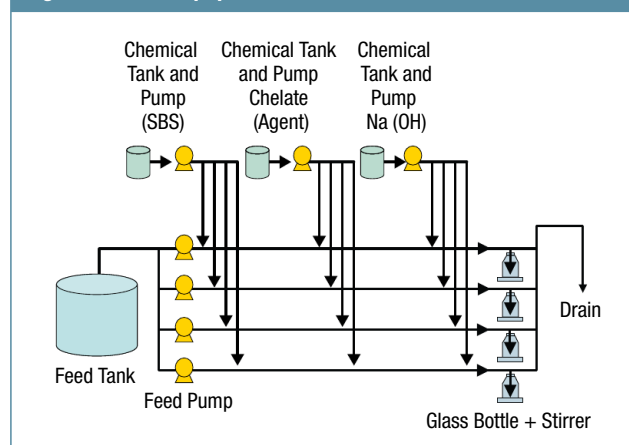**Figure 10. Effect of heavy metal**



■ New flat-sheet membranes of the same type used at the Shuqaiq plant were prepared. They were soaked in the $Cu^{2+}$ solution in advance to create a copper deposition on the membrane surface. Next, three prefouled membranes were set in each glass bottle.

## Figure 11. Effect of SBS and chelate agent



**Figure 11. Effect of SBS and chelate agent**

ORP (mV) vs Time after adjusting pH to 10 (minutes)

- ◆ SBS 10 mg/L, no chelate
- ■ SBS 0 mg/L, no chelate
- ▲ SBS 10 mg/L, EDTA 1 mg/L
- ✕ SBS 10 mg/L, Genesys LF 2mg/L

## Figure 12. Test equipment for flow-cell test



**Figure 12. Test equipment for flow-cell test**

Chemical Tank and Pump (SBS) · Chemical Tank and Pump Chelate (Agent) · Chemical Tank and Pump Na (OH) · Feed Tank · Feed Pump · Drain · Glass Bottle + Stirrer

■ Chemical tank concentration and the stroke of the chemical pumps were adjusted to inject the prescribed dose. NaOH was injected to adjust pH to 10 in all conditions. In addition, the feed pump stroke was set to run at a flow rate of around 40 mL/minute.

■ The feed pump and chemical pumps were started and continued operating for several days.

■ After continuous operation, flat-sheet membrane performance was measured.

First, the concentration dependence of SBS was investigated. The flat-sheet membrane was soaked in Cu solution consisting of NaCl of 100 mg/L, $NaHCO_3$ of 60 mg/L, $Cu(NO_3)_2$ of 1 mg/L as Cu, and NaOH to adjust pH to 10, for 4 hours in advance. The fouled volume of copper was analyzed by ICP, and the result

was 0.28 mg/m². After that, the fouled membranes were set in the flow cell, and the test was started. The range of SBS concentration was 0.75 mg/L to 75 mg/L. No chelate agent was used for the experiment. After testing for three days, membrane performance was evaluated as follows:

■ Test solution: 2,000 mg/L NaCl solution

■ Feed pressure: 15.5 bar
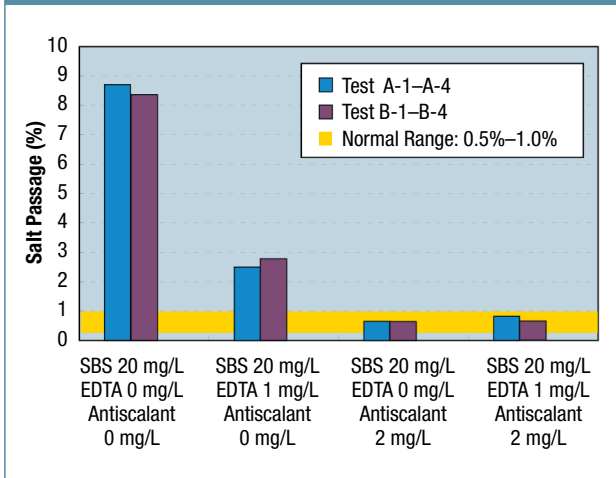
■ Test solution pH: 8

Test results (Figure 10) showed that salt passage was higher than normal performance when SBS concentration ranged from 7.5 mg/L to 50 mg/L. The results confirmed this test method can successfully duplicate the experienced phenomena in the Shuqaiq plant and that there is an appropriate SBS concentration range for SBS-originated oxidation to initiate. When degradation occurred in the Shuqaiq plant, SBS was overdosed as a result of several adjustments during commissioning. Test results suggested that deterioration would be inhibited if SBS dosing was well controlled and correctly adjusted to the design value of 0.75 mg/L.

## Table 5. Test condition with chelate agent

| Test | Membrane | SBS injection | Chelate injection | Test period |
|------|----------|---------------|-------------------|-------------|
| A-1 | Pre-fouled one (Solution) NaCl 100 mg/l + NaHCO₃ 60 mg/l + Cu 1 mg/l + pH 10 (Soaked time) 4 hours → Cu : 0.28 mg/m² | 20 mg/L | No chelate agent | 7 days |
| A-2 | | | Na₄-EDTA 1 mg/L | |
| A-3 | | | Anti-scalant 1mg/L | |
| A-4 | | | Na₄-EDTA 1 mg/L + Anti-scalant 1mg/L | |
| B-1 | Pre-fouled one (Solution) NaCl 100 mg/l + NaHCO₃ 60 mg/l + Cu 10 mg/l + pH 10 (Soaked time) 4 hours → Cu : 1.5 mg/m² | 20 mg/L | No chelate agent | 3 days |
| B-2 | | | Na₄-EDTA 1 mg/L | |
| B-3 | | | Anti-scalant 1mg/L | |
| B-4 | | | Na₄-EDTA 1 mg/L + Anti-scalant 1mg/L | |

**Figure 13. Result of test with and without chelate agent**



In addition, tests with chelate agent were planned to consider the operation method to inhibit membrane degradation. For this reason, other experiments were conducted (Table 5).

After the flow-cell test, membrane performance was evaluated by the same method that tested the concentration dependence of SBS. Figure 13 shows the results. Without a chelate agent, salt passage increased drastically in both cases. With a chelate agent, salt passage was less than the values observed without chelate agent in all cases. However, when only $Na_4$-EDTA of 1 mg/L was injected, degradation could not be prevented completely. In the case of only antiscalant of 1 mg/L and the combination $Na_4$-EDTA of 1 mg/L with antiscalant of 1 mg/L, membrane degradation was completely inhibited. The test proved that the injection of a chelate agent is an effective counter-measure to prevent BWRO membranes from being deteriorated by SBS-originated oxidation and antiscalant; that is, phosphonate compound is a more effective countermeasure than $Na_4$-EDTA.

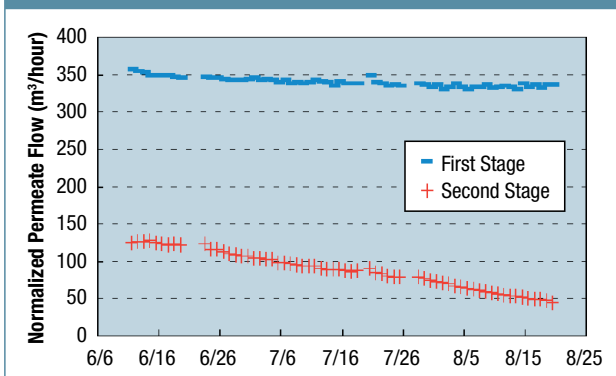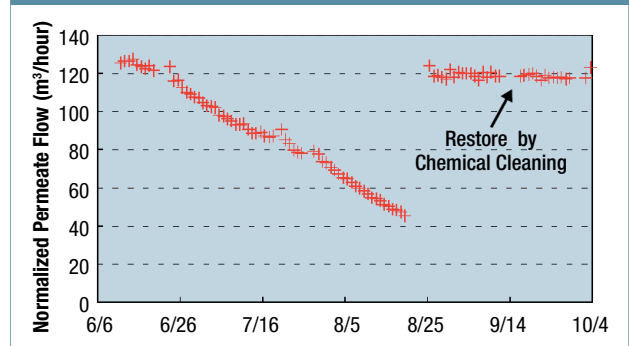**Figure 14. Operation data when scaling occurred**



**Figure 15. Effect of chemical cleaning**



Based on autopsy analysis, literature review, and verification tests, it was concluded that membrane deterioration caused by SBS-originated oxidant could be prevented by reducing SBS dosing to the design value and by injecting a chelate agent that can inactivate the catalyst action.

**BWRO Membrane Scaling.** The Shuqaiq desalination plant experienced severe scaling of BWRO membranes in all trains when scale control was insufficient. Scaling data during typical operation was acquired from Train 16 (Figure 14). The vertical axis is the normalized permeate flow rate calculated by the standard normalization program software. The second-stage normalized permeate flow rate declined rapidly to less than half of the original performance, even though the first-stage flow rate was comparatively stable. After second-stage performance declined, the vessels were opened to investigate the cause. Considerable scaling in the tail of the vessel was observed.

Next, acid cleaning by an HCl solution of pH 1

**Figure 16. Membrane surface**



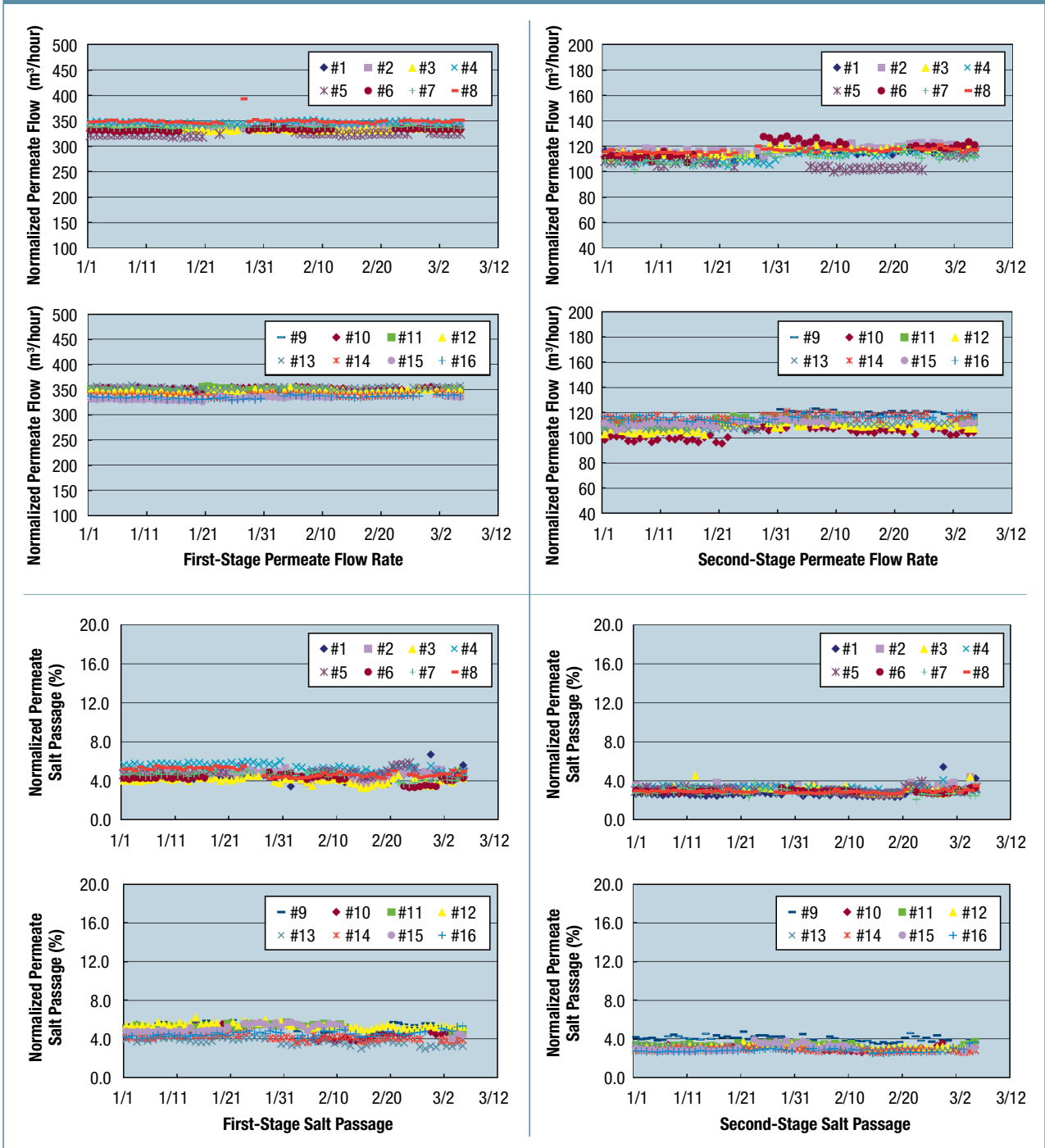**Figure 17. Membrane surface after acid was applied**



**Figure 18. Membrane surface after dye test**

Figure 19.  Operation data after counter-measures

for the second-stage membrane was conducted. Figure 15 shows operation data after acid cleaning. The normalized flow rate was almost completely restored.

However, the conductivity measurement of each vessel clarified that some vessels had low-salt rejection after cleaning. Therefore, one of the tail elements in the vessels where low-salt rejection was observed was autopsied for the analysis. At first, visual observation revealed heavy scale (Figure 16) remained on the membrane surface. In addition, when acid was applied to the surface, a bubble

was observed (Figure 17). This indicates the observed scale was $CaCO_3$ scaling. Moreover, a dye test would clarify whether the membrane was damaged. If damaged, the membrane would turn pink (Figure 18). Some dye stuck to the membrane surface and passed through to the backside. $CaCO_3$ scaling damaged the element and caused low salt rejection. Based on these investigations, the conductivity of all vessels was measured, and any element was replaced if conductivity was lower than originally noted. A lesson learned from this experience is that heavy scaling could be cleaned, but doing so could damage membrane surfaces. Chemical cleaning should be conducted before normalized flow rate declined more than 15 percent.

**Operation Data After Unexpected Experiences.** The following counter-measures were taken to prevent reoccurrence of membrane oxidation and scaling:

- The SBS dosing system was modified to prevent overdose.
- SBS was changed to food grade to minimize heavy-metal concentration.
- Scale control was corrected by antiscalant injection. Antiscalant application had two functions:
- To prevent $CaCO_3$ scaling
- To prevent membrane oxidation by inactivating the catalyst action of the heavy metal.

Figure 19 shows operation data after taking counter-measures in all 16 trains. Performance was stable, illustrating that the counter-measures were effective.

## Summary and Conclusion

In the advanced BWRO process, PCP was applied to achieve 14 mg/L chloride and 0.5 mg/L boron. Plant data analysis proved that the process could achieve target performance according to design philosophy. In addition, this plant had experienced two unexpected phenomena—membrane oxidation and scaling—during commissioning. Subsequent investigation counter-measures successfully inhibited the oxidation and scaling.

## About the Authors

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## Footnotes

[1] HOLLOSEP HU10255EI, Toyobo, Iwakuni, Yamaguchi, Japan.
[2] BW30-440i and LE-440i, Dow Water & Process Solutions, Edina, Minn.
[3] Saline Water Conversion Corp., Riyadh, Saudi Arabia.
[4] RO System Analysis (ROSA) software, Dow Water & Process Solutions, Edina, Minn.
[5] Genesys LF, Genesys International, Cheshire, United Kingdom.

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## Editor's Note