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Boifouling Potential In Open Sea And Adjacent Beach Well Intake Systems

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Abstract

Intense solar radiation and elevated water temperature are characteristics of the Red Sea particularly in the southern part. These factors make coast water conducive to biological growth. Consequently, seawater reverse osmosis (SWRO) desalination plants sourced from open sea intake systems are subject to membrane fouling. Chronic membrane fouling in one such plant on the southwestern Red Sea coast of Saudi Arabia has necessitated the search for an alternative beachwell intake system. The beachwell system consists of three wells located within a distance of 20–30m from coast line and spaced about 75m from each other. Measurements of bacterial growth rates, bacterial biofilm formation, organic and inorganic nutrients were carried out in the beachwell water and compared to those of adjacent coastal seawater. Beachwells showed significantly higher bacterial growth rates and increased inorganic nutrient concentrations, but significantly lower biofilm formation and decreased organic nutrient concentrations than seawater. Therefore, presence of organic nutrients is a determinative factor in biofilm formation and subsequent membrane fouling. The present data indicate that feed water for the plant can be sourced directly from beachwells without significant fouling problems. On the other hand, well water also possesses characteristics which promote improved plant operation. These include reduced silt density index (SDI) values of less than one and a constant, favorable temperature of about 33 °C.

Keywords*:* Open sea intake, Beachwell intake, Biofouling, Nutrients

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Introduction

Maintaining acceptable water quality for membrane desalination is essential for successful operation of reverse osmosis plants. Questionable source water quality results in operational problems for many reverse osmosis (RO) plants. Such problems are magnified in plants with surface intake, particularly in tropical and sub-tropical regions. In such regions, the hot climate promotes biological growth and membrane fouling. The feed water withdrawal pipes are usually located at shallow depths. Such a location allows the water column to become easily disturbed. This results in elevated concentrations of total suspended solids (TSS). At times, elevated levels of TSS create filtration problems, and plants may need to be totally shut down until silt density index (SDI) values normalize. The combination of bacterial fouling and high SDI are particularly manifested at the Saline Water Conversion Corporation (SWCC) Seawater Reverse Osmosis (SWRO) plant at Al-Birk. The fouling and filtration problems at this plant arise from unfavorable feed water drawn from an open sea intake system. This is already well documented [1,2,3].

Efforts to control fouling and pretreatment problems at this plant included operation without chlorination/dechlorination [2] and operation with a chlorine-tolerant membrane [3]. None of these measures alleviated operational problems. They failed because of fluctuating seawater quality and particularly seasonal encounters of high silt load. Therefore, the marine environment does affect the operation and maintenance of coastal desalination and power plants. Consequently, high quality source water is a prerequisite for the successful operation of such plants. The adverse prevailing marine conditions on both the Gulf and Red Sea coasts require complex pretreatment. Such pretreatment is not yet available let alone economically feasible.

None the less, an immediate and attractive alternative to an open sea intake exists in the form of subsurface intake system of beachwells. Preliminary hydrogeologic studies at Al-Birk SWRO plant using bore holes revealed SDI and water characteristics which make the development of beachwells feasible. Subsequently, three beachwells were excavated about 20-30 m from the coast line and spaced about 75 m from each other. Elemental and chemical analyses showed beachwell water to be comparable with or superior to nearby seawater. Trace metal concentrations were within WHO standards [4]. The beachwell water turbidity is quite low thus, no further filtration may be required prior to sending this water for RO. Although both chemical and physical compositions of beachwell water are optimal for successful RO operation, it is still not yet known whether bacterial growth rates would be elevated enough to pose a potential source of fouling and thus prohibit successful desalination.

This paper reports on bacteriological and nutrient analyses conducted as part of a feasibility study of beachwells as a potential source of feed water for the Al-Birk SWRO plant.

Materials And Methods

Bacteriological analyses complemented operational parameters in water quality assessment of beachwells and their feasibility as source of feed water for the Al-Birk SWRO plant (Figure 1).

First, bacteriological growth rates and biofilm attachment studies evaluated the biofouling potential of beachwells. Then nutrient analyses sought to explain any variation in bacterial growth rates and attachment.

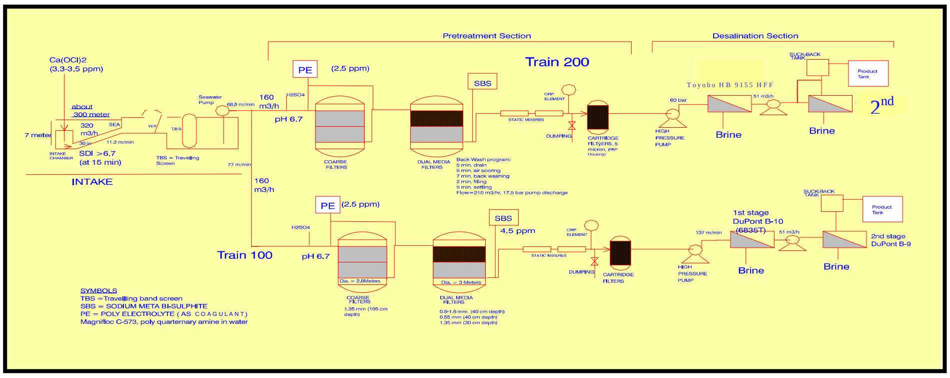

Figure 1. Schematic flow diagram of Al-Birk SWRO plant (Train 100 uses DuPont and Train 200 uses Toyobo membrane)

1. Bacterial Growth Rates

Water samples were taken aseptically from a side valve in the discharge pipe of each well. Bacteria were counted immediately after sampling and this count was designated 0-h count. Further counting was carried out after 24 (24-h count) and 48 h (48-h count), following the incubation of samples at a temperature of 30^{o}C in a thermostatically controlled incubator. The samples were first thoroughly mixed on a vortex mixer, and then a pour plate count in marine agar was employed to reveal the colony-forming units (CFU). The CFU were counted after 96 h of incubation.

Zero-hour counts were used as a base to calculate the generation time for 24 and 48h of incubation as per the formula [5]:

$$\text{Generation time (h)} = \Delta t \cdot k/(\ln Nt - \ln Nt_0)$$

Where : Δt = 24 for 24-h generation time and 48 for 48-h generation time, k = ln 2 = 0.693, Nt bacterial count, after 24 or 48-h incubation, and Nt_0 initial bacterial count

The generation time reflects the speed of bacterial multiplication and is more homogeneous than bacterial counts for statistical analysis.

2. Biofilm Bacteria

A pilot test was carried out to assess the performance of a seawater RO membrane when sourced from beachwell water. The membrane was a hollow fine fiber

(HFF) of cellulose triacetate (CTA) composition. The same membrane type (Toyobo HB 9155) is used in one of two desalination trains (train 200) that compose the Al-Birk SWRO plant (Figure 1). The second train (train 100) is operated on a HFF membrane of polyamide (PA) composition (DuPont B-10). Pilot test conditions were similar to those of the commercial membrane of the Al-Birk plant a part from the omission of coagulation, chlorination and media filtration pretreatment regiment. Feed water from beachwells was acidified (H_2SO_4) to reduce the pH from 7 to 6 and a micron cartridge filter (0.5 μm) was used before the high pressure pump.

Biofilm samplers were installed in the feed from each well as well as in the brine reject of the SWRO test membrane of the well's water. For comparison, biofilm formation was also studied in coastal raw seawater and in brine reject of the two membrane types that are used in Al-Birk SWRO plant.

Each sampling unit contained six holders with a stud (coupon) of glass slide measuring approximately 2.5 x 2.2 cm. For each sampler, water was diverted to flow through at a rate of 10 l/min. After 15 days the slides were retrieved and the attached biofilm was aseptically scraped off for enumeration of its bacteria. Following 96h of incubation at 30^oC, the number of bacteria was obtained and expressed as CFU/cm^2.

3 Nutrient Analyses

The inorganic (total ammonia, NO_2, NO_3, & PO_4) and organic (dissolved proteins and carbohydrates) nutrients were determined following a seawater analysis manual [6]. The indophenol method was used to determine total ammonia. Total organic carbon (TOC) was also determined by measuring the CO_2 released by the catalytic combustion of organic carbon in the samples. This was performed by using a non-dispersive infrared detector after the samples were acidified to purge off total inorganic carbon [7].

Results And Discussion

Bacterial counts and growth rates are presented in Table 1. Initial bacterial density in the well water was one order of magnitude lower than the bacteria in raw seawater (10^2 and 10^3 for the two types of waters, respectively). The 24 and 48-h bacterial counts in the beachwells and the seawater were of the same order of magnitude (10^5). Since beachwells contained lower bacterial concentration than seawater at 0h and similar to seawater concentration at 24 and 48h, this reflects faster growth rates in beachwells than in seawater. In spite of accelerated growth in beachwell water samples, the biofilm formation in beachwell water was appreciably lower than it was in either the raw seawater or in the brine reject of trains 100 and 200 (Table 2). Note that the biofilm formation is appreciable in the brine of train 200 even though the membranes of this train are chlorinated. Thus, we can conclude that chlorination is not a solution to the problem of membrane fouling. The accelerated bacterial growth in the beachwells is due to the presence in them of significant concentration of inorganic nutrients as compared with the seawater (Table 3). However, negligible concentrations of organic nutrients in the beachwells (Table 3), retarded biofilm formation. It is known that organic molecules condition surfaces for bacterial attachment and, therefore, enhance biofilm formation. Higher concentrations of organic material also induce organic fouling. This is brought about through the precipitation of soluble organics by the in-line cataionic polyelectrolyte coagulants which were not removed by media and cartridge filtration [8]; a cataionic coagulant which is a solution of polyquaternary amine in water, (Magnifloc C-573), is used at al-Birk SWRO plant. The beachwell water is characterized by very low TSS concentrations, as indicated by the reduced SDI values (<1) in contrast to the fluctuating, high TSS values of the open seawater that require intensive pretreatment (disinfection, coagulation and filtration). As such, no coagulation is needed; and the aforementioned organic fouling should not exist. There are cases of beachwells containing higher bacterial concentration than adjacent sea. They also have high concentrations of soluble organics in the range of 40-80 mg/l. SWRO plants fed such water have experienced fouling [8]. In comparison, the present beachwells have exceptional water quality. The outstanding water quality of beachwell water reflected well on pilot test parameters. Pilot testing showed that product recovery, product total dissolved solids (TDS) and differential pressure (ΔP) across test membrane and cartridge filter all remained steady during six months of operation, with no signs of membrane fouling. Beachwell water temperature was stable at 32 - 33^{o}C. The stability of water temperature is an asset to successful plant operation. This is in contrast to the fluctuating temperature of the open sea intake.

One useful practical application of the nutrient analyses is to spike or shock dose the beachwells with chlorine, if needed, without promoting biofouling. This is contrary to what occurs with chlorinated seawater. Because seawater contains organic nutrients, the chlorine usually breaks down these nutrients into molecules that can be assimilated by bacteria. Thus, chlorine promotes accelerated growth and an increased very apparent biofilm formation in seawater. This scenario is not applicable in beachwell water. Table 2 shows extensive biofilm formation in brine rejects from Al-Birk plant membranes which have been fed pretreated open sea water.

Conclusions

Bacteriological and nutrient analyses reveal that beachwell water is superior to coastal seawater and is not likely to cause filter clogging or membrane fouling. The pilot testing could be extended to the commercial plant without any expected biofouling.

Recommendations

1. That the SWRO plant be sourced from beachwell water with no membrane fouling expected.
2. That beachwells be monitored periodically for detection of any changes in present water quality.
3. That bacterial growth rates and biofilm formation studies be included in any feasibility studies of beachwell use for RO operation.

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Table 1. Comparison of bacterial counts and generation times in three beachwells and open sea at the SWCC Al-Birk SWRO Plant, (n = 4)

Parameter	Beachwell # 1	Beachwell # 2	Beachwell # 3	Raw Seawater
O-h bacterial count[1]	$(2.28 \pm 1.94)^{a} \times 10^{2}$	$(1.23 \pm 0.39)^{a} \times 10^{2}$	$(2.63 \pm 1.87)^{a} \times 10^{2}$	$(2.96 \pm 1.28)^{b} \times 10^{3}$
24-h bacterial count	$(5.59 \pm 0.28)^{a} \times 10^{5}$	$(4.50 \pm 3.49)^{a} \times 10^{5}$	$(12.36 \pm 3.56)^{b} \times 10^{5}$	$(2.87 \pm 3.06)^{a} \times 10^{5}$
48-h bacterial count	$(7.41 \pm 0.74)^{ab} \times 10^{5}$	$(5.49 \pm 4.88)^{ab} \times 10^{5}$	$(9.61 \pm 4.94)^{a} \times 10^{5}$	$(4.26 \pm 3.01)^{b} \times 10^{5}$
24-h generation time (h)[2]	2.06 ± 0.17^{a}	2.05 ± 0.16^{a}	1.96 ± 0.11^{a}	3.92 ± 0.88^{b}
48-h generation time (h)	4.07 ± 0.44^{a}	4.02 ± 0.40^{a}	3.81 ± 0.63^{a}	5.77 ± 0.74^{b}

[1] CFU (colony-forming units per ml; pour plate in marine agar)

[2] Generation time (h) = $\Delta t \cdot k/(\ln Nt - \ln Nt_0)$ where Δt = 24 for 24-h generation time and 48 for 48-h generation time, k = ln 2 = 0.693, Nt bacterial count, after 24 or 48-h incubation, and Nt_0 initial bacterial count.

[abc] For the same parameter (horizontal rows), means that are followed by the same letter/letters superscripts are similar, while those followed by different ones are different; Analysis of Variance and Tukey Test ($P < 0.001$)

± 95% C.I.

Table 2. Biofilm density in three beachwell water when each was used to feed a seawater RO membrane (hollow fine fiber of cellulose triacetate; Toyobo HB 9155) in comparison with open coast seawater and brine rejects from two SWRO membranes operating from conventionally pretreated open coast seawater (n = 3)

	Biofilm Density (Colony-forming units/cm^2)					
Source	Well-1	Well-2	Well-3	Train 100*	Train 200*	Raw Seawater
Feed	$(1.97 \pm 0.46)^b \times 10^3$	$(6.21 \pm 0.92)^b \times 10^3$	$(1.46 \pm 0.23)^b \times 10^2$	$(9.00 \pm 1.00)^c \times 10^4$	$(9.00 \pm 1.00)^c \times 10^4$	$(9.00 \pm 1.00)^c \times 10^4$
Brine	$(4.64 \pm 1.68)^d \times 10^3$	$(5.23 \pm 0.87)^e \times 10^4$	$(2.02 \pm 0.74)^d \times 10^3$	$(6.81 \pm 1.40)^f \times 10^5$	$(1.30 \pm 0.53)^g \times 10^6$	Not applicable

*Train 100 operates on Polyamide HFF SWRO membrane (DuPont B-10) and train 200 operates on Cellulose Triacetate HFF SWRO membrane (Toyobo HB 9155)

[a,b,c,d,e,f,g] For the same source (feed or brine), means that are followed by the same letter superscript are similar, while those followed by different onces are different; Analysis of Variance and Tukey Test ($P < 0.001$).

Table 3. Nutrient analysis of beachwell and coastal seawater at the SWCC Al-Birk SWRO Plant (n = 3)

Source	PO_4 - P (μg/l)	Ammonia - N (μg/l)	NO_2 - N (μg/l)	NO_3 - N (μg/l)	Dissolved Protein (mg/l)	Dissolved Carbo-hydrates (mg/l)	Total Organic Carbon (mg/l)
Beachwell - 1	6.88 ± 1.95[a]	10.96 ± 0.56[a]	0.02 ± 0.00[a]	0.74 ± 0.08[a]	0.75 ± 0.15[a]	0.52 ± 0.14[a]	0.8 ± 0.3[a]
Beachwell - 2	11.26 ± 2.10[b]	11.45 ± 0.66[a]	0.05 ± 0.01[b]	1.57 ± 0.14[b]	Not detected[b]	0.77 ± 0.10[b]	0.8 ± 0.2[a]
Beachwell - 3	9.41 ± 1.76[c]	13.29 ± 1.78[b]	0.06 ± 0.02[b]	3.91 ± 0.44[c]	Not detected[b]	0.50 ± 0.14[a]	0.7 ± 0.2[a]
Raw Seawater	0.78 ± 0.11[b]	2.14 ± 0.80[c]	0.06 ± 0.01[b]	1.56 ± 0.16[b]	2.73± 0.78[c]	1.57 ± 0.23[C]	2.5 ± 0.3[b]

[a,b,c] For the same nutrient, means that are followed by the same letter superscript are similar and those followed by different ones are different; Analysis of Variance and Tukey Test ($P < 0.001$)

± 95% C.I.