

EFFECT OF DECHLORINATION POINT LOCATION AND RESIDUAL CHLORINE ON BIOFOULING IN A SEAWATER REVERSE OSMOSIS PLANT¹

Mohamed O. Saeed

Saline Water Conversion Corporation
P.O.Box 8328, Al-Jubail -31951, Saudi Arabia
Tel: + 966-3-343 0012, Fax: + 966-3-343 1615
Email: rdc@swcc.gov.sa

ABSTRACT

Experiments were carried out to test the effect of dechlorination dosing point location and the concentration of residual chlorine on bacterial growth and biofouling in a seawater reverse osmosis (SWRO) plant. The plant is located in Al-Birk on the Red Sea coast, Southern Saudi Arabia. The plant was routinely operated with injection of chlorine as a biocide in the intake chamber in the open sea and with the injection of sodium metabisulfite (SBS) to remove chlorine after the dual media filter (DMF). During the experiments, the SBS dosing point was shifted to two locations after the micron cartridge filter (MCF). First, to a point 13m ahead of the high pressure pump (HPP) and second, to a point just ahead (< 1 m) of the HPP. Due to fluctuations in residual chlorine resulting from certain operational and physical circumstances, it was possible to assess biofouling potential when free chlorine is regarded as high (≥ 0.5 mg/l) or low (<0.5 mg/l) within a maximum of 1 mg/l. Bacterial generation (doubling) time was used to evaluate biofouling. Generation time was higher (lower multiplication capacity) when the SBS dosing point was before the MCF (after DMF). It decreased significantly, reflecting higher multiplication capacity and higher biofouling potential, when the SBS dosing point was moved to after the MCF. Generation times in high-pressure RO feed water were similar when the SBS dosing point was moved to two locations after the MCF. This indicated minimal contribution of the low-pressure pipe, between the MCF and the HPP, to biofouling. In general, biofouling increased as the SBS dosing point was moved forward along the pretreatment line, closer to the RO membranes. Generation times were similar when

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residual chlorine was less or more than 0.5 mg/l. Bacteria were capable of biofilm formation in the chlorinated section of the plant.

Key words: Chlorination; Biofouling; Biofilm; Bacteria; Generation time.

1. INTRODUCTION

Biofouling of reverse osmosis (RO) membranes is a major cause of operational problems in RO plants in all regions of the world. The Al-Birk SWRO plant, in the southern region of Saudi Arabia is more prone to biofouling because it is situated in a hot climate which is more conducive to microbial growth and biofilm formation. The outstanding manifestation of biofouling in this plant is the phenomenal rate of increase of ΔP across the RO membranes. Other impeding performance features include flux decline and filters choking.

To control biofouling in this plant chlorination is used. Later, chlorine is reported to enhance biofouling [1] and running the plant without chlorine had been tried but with limited success [2]. The plant is normally operated with sodium metabisulfite (SBS) dosing after the dual media filter (DMF) and before the micron cartridge filter (MCF). With this arrangement clogging of the micron cartridge filter reached alarming rates. It was thought that shifting of the SBS dosing point to a location after the MCF would limit biofilm formation, thus prolonging the life of the MCF filter. Shifting of the SBS dosing point to after the MCF would also provide the opportunity to test the effect of this shift on biofouling on RO membranes. It also provide an opportunity to compare the biofouling in the RO membranes with different locations of the SBS dosing point.

It is interesting to study the relationship between the concentration of the residual chlorine and biofouling because chlorine is known to enhance biofouling.

This experiment was carried out to investigate the effect of varying the dechlorination dosing point location and the concentration of residual chlorine at the dechlorination point on biofouling of the above-mentioned plant.

2. MATERIALS AND METHODS

Bacterial generation time and biofilm attachment studies were used to evaluate biofouling with SBS dosing shifts and with variable residual chlorine concentrations.

2.1 *Planktonic Bacteria*

Water samples were taken from 4 sampling stations: (1) After the dual media filter, (2) After the micron cartridge filter, (3) Ahead of the membranes, (4) The brine reject. In the chlorinated sampling stations, water samples were taken in sterile plastic sampling bags containing sodium thiosulfate as dechlorinator, while plain sterile bags without the dechlorinator were used to collect water samples from dechlorinated sampling stations. Bacteria were counted immediately after sampling and this count was designated 0-h count. Further counting was carried out after 24h (24-h count) and 72h (72-h count) following the incubation of samples at a temperature of 30°C in a thermostatically controlled incubator. The samples were first mixed well on a vortex mixer, and 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 24h and 72h of incubation as per the following formula [3].

$$\begin{aligned} \text{Generation time (h)} &= \Delta t K / (\ln N_t - \ln N_{t_0}), \text{ where :} \\ \Delta t &= 24 \text{ for 24h - generation time and } 72 \text{ for 72h -} \\ &\quad \text{generation time,} \\ K &= 0.693 \\ N_t &= \text{count at 24 or 72h and } N_{t_0} = \text{count at 0h.} \end{aligned}$$

The generation time reflects the speed of bacterial multiplication and was used as an index of nutrient load of water samples.

2.2 *Biofilm Bacteria*

In order to assess the effect of SBS doing point location on biofilm formation, biofilm samplers were installed in two locations after the micron cartridge filter namely :

- (1) After the micron cartridge filter and 13 m ahead of the high pressure pump,
- (2) The brine reject.

Each sampling unit contained six holders with a stud (coupon) of glass slide measuring 2.5 x 2.2 cm. In each sampling station, water was diverted to flow through the sampler at a rate of 10 l/min. After 15 days the slides were retrieved and the biofilm attached was aseptically scraped off for enumeration of attached bacteria. Following 96h of incubation at 30°C the number of bacteria was obtained and expressed as CFU/cm². A scanning electron microscope (JEOL Model JSM-5300 LV with JEOL-1100E ion sputtering device) was used to photograph the biofilm bacteria [2].

2.3 Analysis of Data

Data were compared using an analysis of variance to reveal differences between means and LSD and t- test to distinguish differing means.

3. RESULTS

3.1 Planktonic Bacteria

Bacterial density (CFU/ml) and generation time (h) for each sampling station where the plant was operating with the SBS dosing point at 3 different locations are given in Table 1.

It can be seen that the time needed for bacterial cells to divide (generation time) decreased significantly when the SBS dosing point was shifted from its original location, before the MCF, to after the MCF. There is no significant difference between generation times when the SBS dosing point was shifted to two locations after the MCF except for the brine reject.

Table 2 shows a comparison of generation time when the SBS dosing point was at two different locations each when free residual chlorine at the dechlorination point was high (≥ 0.5 mg/l) or low (< 0.5 mg/l). In the vast majority of values, and for the same sampling station and generation time there was no significant difference between generation times in samples with low and high residual chlorine.

3.2 *Biofilm Formation*

The density of bacteria attached to biofilm slides is given in Table 3. When the SBS dosing point was before the MCF, biofilm formation after the MCF was extensive (1.16 ± 0.5) $\times 10^6$ CFU/cm². When the SBS dosing point was shifted to after the MCF, the sampling station became chlorinated and biofilm was still forming in the chlorinated stream but to a lesser extent (5.85 ± 0.43) $\times 10^3$ CFU/cm². With the SBS dosing point after the MCF, the number of attached bacteria in the brine increased more significantly than when the SBS dosing point was before the MCF ($1.29 \pm 0.08 \times 10^6$ compared to $2.47 \pm 0.15 \times 10^5$ CFU/cm², respectively).

Figure 1 shows two scanning electron micrographs from biofilm slides placed in the brine reject when the SBS dosing point was either before or after the MCF. It was seen that bacterial cells were healthy and stout when the SBS dosing point was after the MCF i.e., closer to the membranes.

3.3 *Practical Manifestation*

When the SBS dosing point was shifted to after the MCF, ΔP across the MCF stabilized with less frequent clogging and filter replacement. This beneficial effect was noticed with a residual chlorine of ≥ 0.5 mg/l. When residual chlorine dropped to <0.5 mg/l, an immediate rise in ΔP across the MCF was noticed.

4. DISCUSSION

It can be seen from Table 1 that in all sampling stations there is a significant difference between generation times when the SBS dosing point was at the original location (before MCF) and when it was at the first shift location (after MCF and 13m ahead of the high pressure pump “HPP”). The fouling potential of RO feed water is therefore greater with the SBS shift. The closer the SBS dosing point to the RO membranes, the greater is the chance of biofilm formation on the membranes. Because chlorine breaks down larger molecules into smaller ones, bringing the SBS dosing point forward, closer to the membranes, will furnish more nutrients to biofilm bacteria. This will lead to more biofilm build up on the membranes. More nutrients also become available in the brine reject. Consequently, the density of biofilm bacteria increased in the brine with

the SBS dosing shift, when compared to the original SBS dosing point location (Table 3). Another study has shown that movement of dechlorination point from a distance of 75m to a distance of 1m before the HPP at Ad-Durr Seawater RO plant in Bahrain, reduces biofouling and increases plant availability [4]. This is not the case in the present study and is contradictory to other reports on negative effects of chlorination [5,6].

When generation times of the two SBS dosing shift locations are compared, no significant difference is noticed in all sampling locations except the brine reject (Table 1). The second shift was carried out to ascertain the contribution of the 13m section of the low-pressure pipe before the HPP to biofouling. This section was left unchlorinated with the first SBS shift. The similarity of generation times in sampling stations before the RO membranes indicates the insignificant contribution of this piping section to biofouling potential of RO feed water. The decrease in generation time and increase in bacterial attachment in the brine with the SBS dosing shift, could be explained by the accumulation in the brine of dead bacteria which were sloughed off the low pressure pipe before the HPP. This accumulation provided additional nutrients for bacteria in the brine. Figure 1 shows the impact of the SBS dosing point shift on biofilm formation in the brine. The healthy and stout look of cells seen with the SBS dosing shift to after the MCF is indicative of nutrients availability. In comparison, cells were flaccid and starved when the SBS dosing was before the MCF, indicating less available nutrients in the brine.

The high and low residual chlorine have not resulted in appreciable variation in generation times. In 91% of the sampling stations, the 24-generation times do not show any difference between high and low residual chlorine. There is no difference between 72-h generation times in 73% of the sampling stations (Table 2). The organic matter which is decomposed by chlorination in this instance seems to be of less refractile nature than humic acid. Therefore, decomposition extent is similar for various chlorine concentrations. Degradation of humic acid by chlorine was said to be the cause of excessive bacterial growth and biofouling in seawater RO plants with open sea intakes, like this plant [1,5,6]. According to Applegate, et al. [1] when chlorine was added at a concentration of 1.0 mg/l to synthetic seawater containing 2.5 mg/l humic acid, about 16% of the acid was degraded following 10 min of exposure time at a pH of 8.0 and a temperature of 35 °C. The pH and temperature of source water for this plant are close to

these values. The residence time of water in the plant (about 12 min) is also close the exposure time of humic acid to chlorine (10 min). One would expect at the residual chlorine concentrations tested in this plant, and a 12-min exposure time, only a minor fraction of humic acid would be degraded. Other forms of readily degraded organic matter is, therefore, significant in the source water for this plant.

With the SBS dosing shift, the MCF became chlorinated. This resulted in stabilization of ΔP rise across the filter. It was, however, noticed that when residual chlorine after the MCF dropped below 0.5 mg/l, an immediate rise in ΔP was noticed. This is an indication that biofilm formation in the MCF is not suppressed by a residual chlorine of < 0.5 mg/l. A residual chlorine of ≥ 0.5 mg/l is required to prevent biofilm build-up in the MCF.

5. CONCLUSIONS

1. The closer the SBS dosing point location to the RO membranes, the greater is the biofouling potential and biofilm formation.
2. A residual chlorine of ≥ 0.5 mg/l results in an increase of biofouling potential over a residual chlorine of < 0.5 mg/l.
3. A residual chlorine of ≥ 0.5 mg/l is required to be maintained over the micron cartridge filter to control biofilm formation in the filter of this plant.

6. REFERENCES

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