FILTRATION AND FOULING PROBLEMS IN A SWRO PLANT ON THE GULF COAST[1]

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ABSTRACT

A 24-mgd commercial seawater RO plant in Al-Jubail, Gulf coast of Saudi Arabia was recently commissioned. At certain periods, the pretreatment fails to attain desired silt density index (SDI) levels and recently the plant also experienced high ΔP levels across the membranes that were thought to stem from biofouling. Measurements of total suspended solids (TSS), bacterial attachment and growth rates and SDI levels were carried out and correlated with filtration efficacy and membrane performance. Comparisons were made with measurements from a pilot SWRO plant fed from the same intake bay of the commercial plant, but with a different pretreatment regime. Filtration efficacy of the dual media filter (DMF) fluctuated widely. The plant experienced higher SDI values than the pilot plant, even when the TSS loads were similar. High SDI values in the 24-mgd SWRO plant were attributed to chlorination of source water. This chlorination breaks down organic matter (mainly algae) into small fractions that pass the DMF along with naturally occurring colloids. Bacterial attachment and dissolved sugars and proteins were recorded as being higher in source water at the plant's intake bay than in the open seawater. Also, high bacterial growth rates were recorded in RO feed water following the micron cartridge filters. This has led to biofilm formation on the membranes. Difficulties in filtration and membrane performance stem from unstable source water quality. Recommendations were offered to manipulate chemical pretreatment and to check suitability of grain size and bulk density of DMF beds as a means to attain desired SDI and ΔP levels. Open coastal intake design for SWRO plants is something to be considered seriously.

***Key words*:** Silt Density Index, Total Suspended Solids, Source Water Quality, Chemical Pretreatment, Bacterial Growth Rate, Biofilm Formation.

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.1. INTRODUCTION

Although RO technology may appear to be a simple technique of filtration under pressure, in practice it is fraught with problems. The difficulty in membrane filtration arises from the need of the purest possible feed water. Therefore, source water for membrane desalination is pretreated physically and chemically to attain the desired level of purity. The pretreatment is particularly needed in seawater RO plants with open coast water as source water. The need for pretreatment becomes a must in plants along the shoreline of the Arabian Gulf. The hot climate makes water temperature conducive to biological growth and membrane fouling. The sea is also very shallow, with abundant sunlight; and this promotes biological productivity. Shallowness also allows the water column to become easily disturbed. The combination of high biological productivity and easy disturbance of the water column makes total suspended solids (TSS) vary in concentration to a great extent. At times, elevation of TSS creates filtration problems and plants may need to be totally shut down until SDI values normalize. This problem occurs in many plants along the Red Sea and Gulf coasts.

Problems in SWRO operation are not unique and information gathered from solving a problem at one location seldom becomes useful at another. This is because SWRO operational problems are site specific. This has led to diversity in pretreatment process design, operation techniques and troubleshooting responses. Localized procedures, therefore, have to be developed and practiced until they become an established technique for a given location.

The recently commissioned 24 mgd Jubail SWRO plant is fed from an intake lagoon with a water depth of about 5m. The lagoon is separated from the sea by cemented break water walls with an opening to the open sea. The plant intake pit is situated in the far dead end of the lagoon, about 4 km from the mouth to the open sea. Feed water is chlorinated in the intake chamber and again further down the feed pipe before the DMF. The water is filtered through a single dual media filter (DMF) of gravel, sand and anthracite (from bottom to top). Following chlorination, further chemical treatment includes addition of (in sequence): sulfuric acid, ferric chloride and a cationic coagulant aid all before the DMF. Frequent higher than normal SDI interrupt the plant operation. Membrane fouling has also started to show recently.

These kinds of nagging operational problems pose serious challenges for seawater membrane desalination in the region. At times, viability of this technology comes under question when applied to open sea intake systems. This is particularly true when the situation is contrasted with thermal desalination in the region, which has a relatively trouble free operation. However, with recent developments in SWRO energy saving devices, the cost of SWRO desalted water production is likely to drop considerably. This will boost interest in SWRO technology, therefore every effort is going to be made in solving problems in such areas as intake design, efficacy of pretreatment, and membrane fouling.

The objectives of the present work are to ascertain relationships between TSS, SDI, efficacy of filtration and effects of water quality and chemical treatment. Bacterial growth and attachment will be measured in relation to pretreatment and membrane performance. Comparisons will be made between an SWRO pilot plant fed from the same intake bay of the commercial SWRO plant under investigation, but with a different pretreatment regime.

2. MATERIALS AND METHODS

2.1 Total Suspended Solids (TSS)

TSS were measured in 3 locations:

(i) Chlorinated source seawater before coagulant and acid dosing.

(ii) Acid and coagulant dosed water before dual media filter.

(iii) After dual media filter

The procedure of TSS determination was as described in [1,2]. The filtration was carried out within 10 minutes in a filter manifold under a vacuum of 15 lb/in^2. For comparison, TSS were also determined in the above-mentioned SWRO pilot plant which is fed from the same intake bay but with a different pretreatment regime.

2.2 Silt Density Index (SDI)

Measured by collection of two 500-ml volumes separated by 15 minutes draining at a pressure of 30 psi. For comparison, SDI was also determined in the SWRO pilot plant.

2.3 Bacteria

Samples were taken from 3 locations:
(i) Before dual media filter (DMF) (ii) After DMF (iii) After micron cartridge filter (MCF).

Samples were collected in sterile plastic sampling bags containing sodium metabisulfite (SBS) as dechlorinator. The samples contained residual chlorine of about 2.5 mg/l. Pour plate count in marine agar was employed to determine the density of bacteria at 0h (initial count), 24h and 48h following 96-h incubation at 30^{o}C [3]. Bacterial multiplication/generation time was determined using initial and subsequent bacterial counts [3].

2.4 Sugar and Protein Content

These were measured in water samples from the intake bay of the plant and also from the open sea. Samples from each location were divided each into two parts. One part was filtered (0.3 mm nylon mesh followed by 1.0 μm membrane) and sugars and proteins determined in the filtrate. The other part was chlorinated to residual chlorine of 0.5 mg/l for 20 min after which chlorine was removed by the addition of SBS. In this way, the effect of filtration and chlorination on these nutrients content could be ascertained. Sugars were determined following acid (HCl) hydrolysis [4] and proteins were determined using the Folin reaction [5].

2.5 Biofilm Formation

Biofilm formation was studied in the membranes, as well as at the intake site of the plant. In the membranes, bacterial density and sugar and protein content were used to evaluate the extent of biofilm formation. In the intake site, the density and visual biofilm formation was compared with that of the neighboring open sea. A hollow fine fiber membrane of higher than normal ΔP was taken fresh off the desalination racks and was dissected immediately. Upon visual examination, it was possible to distinguish the inner muddy layers of fibers from the relatively clean outer ones. Density of attached bacteria and concentrations of sugars and proteins were determined for the inner and outer layers of the membrane. A sample of fibers from each layer was suspended in sterile (0.2 μm filtration and autoclaving) seawater in a test tube. The loosely attached material was removed by gentle shaking and then decanted. The fibers were then resuspended in sterile seawater and vortexed vigoursly to remove attached bacteria. Following appropriate dilutions, the density of attached bacteria was determined employing pour plate in marine agar [3]. For the determination of sugar and protein, fresh membrane fiber samples were suspended in distilled water and shaken vigoursly on a vortex mixer. The mixures were filtered (1.0 μm) and the sugar and protein content determined in the filtrate. Values were expressed as per gram of dry fiber after drying of fiber samples to constant weight. Biofilm samplers with rectangular glass slides were used to study the bacterial attachment in the source water. The samplers were immersed in the commercial SWRO as well as the pilot plant intake and in the open sea outside the intake bay mouth for 15d. Biofilm density of the slides was calculated per square centimeter. Electron micrographs of the slides from the two locations were then compared [3].

3. RESULTS

3.1 Total Suspended Solids (TSS)

The TSS values varied considerably. Six samples showed the following range of values:

Chlorinated source water (no coagulant): 5.0 – 11.5 (average 7.6 mg/l)

Before dual media filter (with coagulant): 4.6 – 7.6 (average 6.3 mg/l)

After dual media filter: 1.0 – 4.6 (average 2.5 mg/l)

For comparison, TSS obtained from the SWRO Pilot Plant were as follows:

No-chlorine source water (no coagulant): 2.8 – 4.8 (average 4.5 mg/l)

After first dual media filter (with coagulant): 2.5 – 4.7 (average 3.1mg/l)

After second media filter: 0.9-2.1 (average 1.7 mg/l)

3.2 Silt Density Index (SDI)

SDI and TSS values on 3 sampling dates are given in Table 1. For comparison, SDI and corresponding TSS values from the pilot plant on the same sampling dates are presented in Table 2. It can be seen from comparing figures in the two tables that SDI values were above 3 in the plant even when TSS values corresponded to those in the pilot plant with SDI of below 3. Also, the feed water for the 24 mgd SWRO plant had higher concentrations of TSS. Table 3 shows variation in TSS and SDI in source water with and without chlorination.

3.3 Bacteria

Bacterial counts in colony forming units per milliliter (CFU/ml) of water are given in Table 4. The DMF was virtually free of bacteria and the bacterial count in the MCF was negligible. However, there was intense bacterial multiplication following MCF. This could be significant in terms of membrane fouling.

3.4 Sugar and Protein

Sugar and protein concentrations in source water are given in Table 5. Chlorination increased the contents of the two nutrients while filtration reduced them considerably.

3.5 Biofilm Formation

Bacterial density and sugar and protein content of the membrane and source water are presented in Table 6. Comparison of biofilm structure in the plant intake, the open sea and the pilot plant intake is shown in Figure 1. In the membrane, biofilm formation was noticeable in the innermost layers, as indicated by increased bacterial attachment and increased sugar and protein content. The outer layers were largely free of biofilm formation. The fouled inner layers had entrapped detritus with brown color as opposed to the white outer layers. The inner layers contained a black area, which was positive for sulfate reducing bacteria (Figure 2). The dominant bacterial foulant responsible for biofilm formation was a single species. On the nutrient agar (supplemented with 2% salt), the bacterium grew like fungus colonies with radiating hair resembling fungal hyphae. The colonies were very large and dull white in color. On the brain heart infusion agar (with 2% salt), the colonies were large and round in shape and beige in color. On both media, the colonies were very mucoid, watery and sticky. The fouling species stained gram negative with slender rod form.

4. DISCUSSION

4.1 TSS and SDI Values

When the TSS values in chlorinated source water (CSW) are compared to those after dual media filter (DMF), the average percentage removal of the TSS is 67% with a range of 44-91%. The TSS removal by the DMF in the reference pilot plant ranged between 55-68%. Only on two out of six sampling dates was the removal percentage less than 60%, and these instances were observed when the filter bed was loaded with suspended material and was about to be backwashed. Therefore, the TSS removal in the pilot plant is more stable than in the 24 mgd SWRO plant. This is because the pilot plant employs two DMF; the first filter protects the second one and passes to it a water of more uniform suspended matter. The above-mentioned removal values are for the second DMF. The TSS values from the first filter are always greater than the second DMF. Nevertheless, the SDI values after the first DMF are usually less than 3 and become consistently less than 3 following the second DMF. The TSS after the DMF of the 24 mgd SWRO plant ranged from 1.0-4.6 mg/l during the sampling period, as compared to 0.9–2.1 mg /l in the pilot plant. This overlap between the two ranges means that there are instances where the TSS values in the plant are equal to or less than the TSS in the pilot plant. Yet SDI values in the 24 mgd SWRO plant were higher than 3 during the sampling period. The SDI was 3.3 when the TSS were 1.0 mg/l, and 3.5 when the TSS were 2.0 mg/l (Table 1). Why then, does the SWRO plant face periods of high SDI encounters, which are not observed in the pilot plant, even though the efficacies of the DMF are at times similar? The causes for this could be source water quality, filter media, or chemical pretreatment.

4.1.1 Source Water Quality

There was noticeable algal growth on the biofilm attachment slides at the intake of the plant, as compared with the intake location of the pilot plant and the open sea (Fig. 1).

When algae enter the source water feed line, they are subjected to impingement and chemical degradation. Cellular debris can pass through the DMF and the MCF and settle on the SDI membrane filters. Picophytoplankton (both prokaryotic and eukaryotic) of less than 1μm size can also pass these filters. The algal debris and picophytoplankton can effectively clog SDI membrane filters. Since the water content of these organisms is high, they will have a very negligible weight upon drying the filters to determine the TSS. Thus, while phytoplankton may give rise to high SDI values, they contribute little to the TSS in terms of weight. Another source of filter clogging is colloidal particles. Colloidal particles are known to clog filters of 0.45 μm pore size. This is why during the TSS determination, filtration is recommended within

10 minutes in order to avoid filter clogging by colloidal particles [1]. The velocity of feed water through the DMF must be optimal for effective coagulation/filtration. In a pilot plant study designed for the SWRO plant under investigation, SDI of 3.2 (range 2.6-3.9) was obtained with a flow rate of 20 gpm. An SDI of 2.6, range (2.3-3.0), was obtained when the feed flow rate was reduced to 14 gpm [6]. Decreased flow rates allow formation of larger flocs. Operation velocity of 0.12 – 0.24 m/min across the DMF was reported as suitable, providing high quality feed water [7]. Filtration velocity across the DMF in this plant is 0.13 m/min, which is optimal; but during backwash, filtration velocity increases to 50 m/h, which is equivalent to 0.83 m/min. The stripped suspended particles and attached colloids and molecules from backwashing may reach the MCF and influence the SDI reading. Varying backwash velocity can be tried out and then correlated to the SDI measurements. Prolonged dumping of the first post-backwashing filtrate may be needed to obtain the desired filtrate purity.

4.1.2 Filter Media

The grain size utilized by the plant is 2.0-5.6 mm for coarse sand and gravel (2 coarse sand/gravel beds are used, a size range of 2.0-3.15 mm and a size range of 3.15-5.6 mm) with bulk density (specific gravity) of 1400 kg/m^3. The fine sand bed (0.63-1.0 mm) has the same density of 1400 kg/m^3, and for anthracite (1.4-2.5 mm) the bulk density is 730 kg/m^3. Specification for grain size and specific gravity for the DMF was reported as follows:

Gravel size 2.4-4.8 mm with specific gravity of 2,600-2650 kg/m^3, coarse sand grain size 1.4-2.8 mm and specific gravity of 2,600-2650, and for anthracite 0.85 – 1.70 mm with 1,400 – 1450 kg/m^3 specific gravity [7]. If these are the optimal specifications, then the grain size of the DMF of the plant does not meet these specifications.

4.1.3 Chemical Pretreatment

The SWRO plant uses four chemicals in the pretreatment process: chlorine as a biocide, ferric chloride as a coagulant, a cationic polyelectrolyte (Cynamid, superfloc 573-C®) as a coagulant aid, and sulfuric acid for adjustment of pH to an acidic level of 6.5. As mentioned above, chlorine could result in high SDI measurement due to breakage of organic materials and microorganisms into fractions that are caught on the SDI filter paper. Chlorinated seawater from the intake of this plant had an SDI which is higher by 1 unit over non- chlorinated seawater feed [6]. This is also true in the present experiment. While raw seawater has an average SDI value of 5.6, chlorinated water has an average SDI of 6.4 (Table 3). In contrast, the SDI of raw feed water in the reference SWRO pilot plant decreased from 5.6 in source water to 4.5 upon reaching the plant. This is possibly due to some naturally occurring organic matter that influences the SDI readings getting adsorbed in the lining of the feed water pipe of the pilot plant. Hence, while the use of chlorine increases the SDI the non-use of chlorine decreases the SDI. Chlorination has also resulted in a slight increase of the TSS, probably due to sloughing of material attached to feed water piping. The use of ferric chloride, although advantageous in removing suspended solids through coagulation, may have the problem of microfloc formation. Microflocs have been reported to form in acidified seawater (as the case in the SWRO plant) containing high concentrations of humic acids. If this is true, then the plant conditions are more favorable to microfloc formation, because sulfuric acid is dosed to acidify water before coagulant dosing. Microflocs are small and could pass through the DMF and 5 μm CF. A slightly higher SDI of Gulf water was recorded for water treated with $FeCl_3$ at a pH of 6.5 than for water treated at a pH of 8.0 [6]. In this plant, sulfuric acid is dosed before and after DMF. The first dosing is before the coagulant dosing. Addition of acid before the coagulant may promote formation of microflocs. In contrast, sulfuric acid in the reference pilot plant is only dosed following the DMF. The use of a cationic coagulant aid may be the cause of microfloc formation. The positively charged coagulant aid may compete with the positively charged iron (III) hydroxide (formed from the coagulant iron III chloride), resulting in microfloc that could seep through the DMF. One of the benefits of coagulant aids is that they save on the amount of coagulants used. This is not the case in this plant, as more $FeCl_3$ is now utilized. This results in the formation of more colloidal $Fe(OH)_3$. Operation without the coagulant aid should be tried out to see if it obtains the desired SDI levels. This assumes that other physical parameters such as well mixing of the coagulants and sufficient residence time for coagulation are optimal. There were instances when the TSS values were less before than after the addition of coagulant (Table 1), without any traces of coagulant on the filtering membrane paper. This implied the incomplete mixing of the coagulant. The coagulant aid dosing point is too close to the DMF, which allows for only a short residence time. It is recommended to shift back the coagulant aid dosing point and to introduce sufficient static mixers to ensure a proper mixing of both the coagulant and the coagulant aid.

4.2 Bacteria

Bacteriological analysis showed the DMF to be virtually free of bacteria. The count after MCF was also negligible (Table 4). Thus bacteria, or their slime do not contribute to SDI. Following chlorine removal and incubation in the laboratory, bacteria after MCF multiplied rapidly after 24-h incubation and continued to multiply at a similar pace flowing further incubation for 48-h. In nutrient deficient media, multiplication normally slows down after the first 24-h and the growth rate declines along the pretreatment line from before to after MCF [3]. Stable growth rates reflect the availability of nutrients in pretreated water at this plant. This is well known in chlorinated SWRO feed waters [3], and is evident from present analysis of dissolved sugars and proteins (Table 5). The water continued to be chlorinated in the clear well (storage tank) after MCF. Well-nourished bacteria are likely to reach the SWRO membranes and create membrane fouling. The aforementioned discussion points to two disadvantages of chlorination: elevation of SDI and high bacterial growth rates. Operation without chlorine is a good alternative to be tested in this plant, particularly when the reference pilot plant (which is fed from the same source water) performs without chlorine and without reports of high SDI or membrane fouling.

4.3 Biofilm Formation

An autopsy of the membrane revealed that causes of high ΔP across the membranes stemmed from biofouling. For some structural or physical reason, detritus and bacteria were entrapped in the inner feed side of the membrane. The results point out that, although chlorination removed the bulk of bacteria, there is chlorine-resistant species which could survive chlorination and foul the membrane. The growth of bacteria on the membrane will be aided in particular by nutrients made available by chlorination, as mentioned above. One useful application of the results is that presence of sugars and proteins is a good indicator of biological growth on the membrane. These simple chemical procedures could be used as indicators to biofilm formation. The site of the plant intake location was found to be inferior to that of the pilot plant and the open sea. This is evident from denser bacterial and algal attachment (Table 6 and Fig. 1)

5. CONCLUSIONS

1. Source water quality and chemical pretreatment are the main causal agents of elevated SDI.
2. The major chemical in SDI and biofouling problems is chlorine.
3. Efficacy of coagulation agents and dosing needs to be reviewed.
4. Suitability of DMF material needs to be checked with response to grain size and bulk density.
5. Bacterial generation time of source water and concentration of sugars and proteins on the membrane are good indicators of biofilm formation.
6. The plant seems to operate under very tight guidelines for SDI and ΔP.

6. RECOMMENDATIONS

The plant is advised to:

1. Operate without chlorination; shock dose chlorination could be applied when needed to protect the intake structures from marine growth.
2. Test larger doses of coagulant and ensure that coagulant is well mixed (add static mixers) and with sufficient residence time before DMF.
3. Acidify only after DMF, not before.
4. Because the plant seems to operate under tight operation guidelines it is advantageous to ascertain the effect of RO feed water with higher than normal SDI and ΔP on membrane performance.
5. Because of fluctuating DMF efficacy, the DMF could be backwashed after a specified time frequency, irrespective of ΔP across the filter and with considerable dumping of the first filtrate.
6. Change DMF filter bed with materials of different grain size and specific gravity as indicated above.

Table 1. Silt density index (SDI) values from after MCF in Al-Jubail 24 MGD SWRO with corresponding TSS in 3 locations along the feed water line (3 samples, November 2001)

Sample	SDI[1]	Total Suspended Solids (mg/l)		
		CSW[2]	BDMF[3]	ADMF[4]
1	3.3	11.5	7.6	1.0
2	3.5	5.0	6.5	2.0
3	3.7	6.2	4.6	3.5

[1] Measured after micron cartridge filter (5µm)
[2] Chlorinated source water
[3] Before dual media filter
[4] After dual media filter

Table 2. TSS and corresponding SDI[1] values in the RDC SWRO Pilot Plant (3 samples, November 2001)

Sample	FSW[2]		After MF-1[3]		After MF-2[4]	
	TSS	SDI	TSS	SDI	TSS	SDI
1	2.8	3.56	2.7	2.45	0.9	1.58
2	3.1	4.40	3.3	2.40	1.7	2.10
3	4.6	4.65	4.7	3.79	2.1	1.87

[1] SDI after micron cartridge filter ranged from 1.89 – 2.14 for 3 samples
[2] Feed seawater ahead of filters without $FeCl_3$ coagulant and without chlorine
[3] Coarse sand filter with coagulant
[4] Fine sand filter

Table 3. Effect of chlorination on TSS (mg/l) and SDI (March 2002)

Raw source water feed				Chlorinated source water feed			
Intake bay		SWRO Pilot Plant[1]		Jubail SWRO Plant[2]		MSF Pilot Plant	
TSS	SDI	TSS	SDI	TSS	SDI	TSS	SDI
1.2	5.8	1.3	4.5	2.0	6.4	2.1	6.3
1.6	5.5	1.3	4.3	2.1	6.5	2.3	6.4
1.8	5.6	2.2	4.7	4.8	6.4	2.5	6.5
$\bar{X}$ 1.5	5.6	1.6	4.5	3.0	6.4	2.3	6.4

[1] Prior to any chemical addition
[2] Prior to acid and coagulant dosing

Table 4. Bacterial counts and multiplication (generation) time in 3 locations along the pretreatment line of the Al-Jubail 24 MGD SWRO plant (n = 3)

Sample Location[1]	0-h count	24-h count (CFU/ml)	24-h generation time[2]	48-h count	48-h generation time
Before DMF	4.3	867	3.13	86,317	3.35
After DMF	0.3	0	-	0	-
After MCF	3.3	350	3.56	159,000	3.03

[1] All samples are chlorinated
[2] Time (in hours) taken to multiply (to double existing number)

Table 5. Effect of chlorination and filtration on sugars and protein contents (mg/l) in water sample from the intakes of the Jubail and pilot SWRO plants compared to open sea

Sample Location	Treatment			
	Filtration[1]		Chlorination[2]	
	Proteins	Sugars	Proteins	Sugars
Open sea	0.2	0.8	0.5	2.0
SWRO pilot plant intake	2.1	1.5	7.5	5.0
Jubail SWRO plant intake	3.5	1.5	11.3	14.0

[1] Filtered through 0.3 mm mesh size nylon net followed by ignited glass fiber filter (pore size ca.1.0 μm)
[2] First filtered (nylon net 0.3 mm mesh size) then chlorinated to residual chlorine of 0.5 mg/l for 20 min.

Table 6. Biofilm density, proteins and sugar contents of membrane and source water

Sample	Biofilm density	Proteins	Sugars
Membrane:			
Membrane inner-most layers[1]	3.15 x 10^5 CFU/g*	1.60 mg/g*	3.18 mg/g*
Membrane outer layers[2]	Negligible	0.42	0.11
Source water:			
Jubail SWRO plant intake	6.10 x10^4 CFU/cm^2	3.50 mg/l	1.50 mg/l
Open sea	2.30 x 10^4CFU/cm^2	0.20 mg/l	0.80 mg/l

[1] Positive for sulfate reducing bacteria
[2] Negative for sulfate reducing bacteria
* On a dry matter base

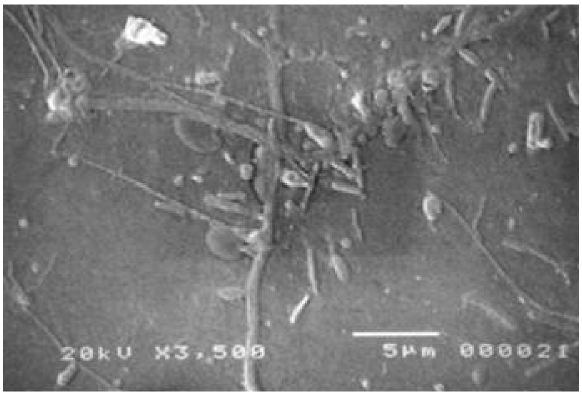

Fig. 1a. **A Scanning electron micrograph of a biofilm slide from the 24mgd SWRO plant intake. Note the formation of a network of filaments with entrapped debris and bacterial cells.**

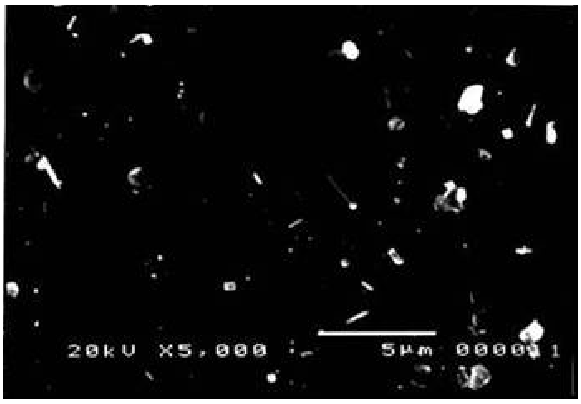

Fig. 1b. **A scanning electron micrograph of a biofilm slide from the open sea. Note the lack of a filamentous network and entrapped bacteria present in Fig. 1a above (the same applies to the pilot SWRO plant intake).**

Fig.2 **Photograph of the feed side of a HFF membrane. The interior black spot is due to Sulfate Reducing Bacteria and the brownish color is due to fouling**

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