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Algal bloom—critical to designing SWRO pretreatment and pretreatment as built in Shuwaikh, Kuwait SWRO by Doosan

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ABSTRACT

The growing demand for fresh water in many areas in the world is due to drought, water shortages, population increases, and the desire for high- quality drinking water. The reverse osmosis (RO) process is pressure-driven and filtered seawater is pressurized beyond the osmotic pressure the solution to overcome the permeation barrier of membrane and the water molecules in the seawater able to pass through the membranes. In recent years, the number and size of these water projects have increased noticeably. RO membranes are expensive and susceptible to fouling due to contamination in the feed water; hence, it is utmost important to care for particular feed water treatment in maintaining ongoing performance and avoiding significant problems in downstream process equipments. In recent, days the additional risks are due to naturally occurring events like algal blooms or red tide, due to ingress of marine algae, planktonic bloom with small particles and colloidal material released from algae cause for pretreatment failure almost regularly. As algal bloom life cycle peaks and decays, a significant amount of organic material is released upon cell death. Also, bacteria feed on the decaying material and release their own extracellular polymeric substance (EPS) that has the potential to escape out pretreatment and foul RO membranes. There are many pretreatment procedures for seawater reverse osmosis (SWRO) plant, and the basis of selection of right system depends on seawater quality and the price. Doosan built facility in Shuwaikh in Kuwait is having the pretreatment configuration with combination of dissolved air flotation and ultrafiltration to take care of difficult water condition with highly suspended solid value arise for various reasons. Pretreatment combination is found to be working well in providing plant availability and quality. But the main concern is that it is impossible to avoid deposition of EPS on SWRO membrane surface with present pretreatment technology—it may happen in future with new generation of technology, it will be possible to overcome the situation at added cost.

Keywords: Seawater reverse osmosis; Permeation; Osmotic pressure; Algal bloom; Pretreatment; Red tide; Dissolved air flotation; Ultrafiltration; Extracellular polymeric substance

1. Introduction

Middle East region is deprived of freshwater supply and desalination is the only source of freshwater to meet the demand of population growth, industrial growth, civilization, and agricultural demand. Fortunately, this region is enriched in nonrenewable energy source and thermal desalination was the practice over the years. As the thermal

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desalination process is the simplest procedure of desalination by phase separation of water at boiling point at very low pressure, and hence, the product quality is practically independent of impurities in seawater. Thus, thermal desalination is the common practice with the most difficult water of the region in Kuwait, Bahrain, etc. situated at the stagnant end of Persian Gulf. With the increase in price of oil and natural gas, familiar desalination process in today's world is seawater reverse osmosis (SWRO) utilizes semi-permeable membranes to remove salts while allowing pure water to pass through. Water production cost for desalination still remains high as the reverse osmosis (RO) process is pressure-driven, and electrical energy is used for pumping water at high pressure. The filtered seawater would be pressurized high so that the osmotic pressure of the solution can overcome the permeation barrier of membrane and water molecules in the seawater preferentially pass through the membranes to produce pure water on other side of membrane leaving concentrated seawater at the feed side of membrane. Although not simple like thermal desalination still SWRO is robust, reliable, and widely practiced desalination technique for augmenting drinking water supplies worldwide. In recent years, the number and size of these water projects have increased noticeably. Through many years of plant operations, it has been learned that the key to any successful RO process is the pretreatment. Doosan built the first operating SWRO plant in Kuwait with most difficult seawater using novel technique of dissolved air floatation (DAF) and ultra-filtration (UF) as combination of pretreatment for the first time in large commercial plant to tackle extreme quality of seawater of Persian Gulf. Although many conventional pretreatment techniques are suppose to remove algogenic organic carbon, it is difficult to control the amount. Algogenic organic material (AOM) is not bio-degraded nor can be chemically fragmented. Algal blooms of blue-green algae or diatoms cause difficulties in controlling dissolved organic carbon (DOC) because of the release of extracellular organic matter (EOM) and intracellular organic matter into the water by cell fragmentation [1].

2. Problem

RO membranes are expensive and susceptible to fouling due to contamination in the feed water; hence, it is utmost important to care for particular feed water treatment in maintaining ongoing performance and avoiding significant problems in downstream process equipments. Seawater must be conditioned to ensure that it is of suitably high quality for use in the RO plant. The key objectives of the pretreatment are to remove turbidity and suspended solids, manage risks from human activities like oil leaks from shipping, etc. Nowadays, the additional risks that is being asked to cover by SWRO plant supplier is from naturally occurring events such as algal blooms.

Desalination by SWRO using semi-permeable membranes to remove salts while allowing water to pass through is considered as a simple commercial process. At present, membrane desalination technology for fresh water production process is used in seldom. In large commercial plant, the process is now complicated one due to the presence of large variety of organic contamination in addition to inorganic salts and silts. In marine topology, there are wide natural variations in the number of bacteria because many factors make their numbers change constantly, such as light, temperature, tide, currents, turbidity, and nutrients. Also, it is uncertain that when the bloom will appear or disappear, and how severe it will be; therefore, based on all these factors, the performance of membrane is very irregular and frequent maintenance is required like clean-in-place frequency, membrane replacement, etc.

The RO membranes are sensitive to feed water quality and membrane gets fouled with contaminated feed water. Small particles and colloidal material released from algae are more detrimental to filtration than the whole algal cells. Small particles and colloids are likely to produce greater flux decline because of enhanced pore blocking and a less porous cake layer. Such a phenomenon has been seen in membrane fouling studies using bacterial organic matter [2]. Similarly, studies have shown that coagulants forming more compact bacterial flock structures result in more dramatic cake-layer resistance than less-dense flock formations [2]. Fouling could also be exacerbated with shear due to increased availability of dissolved and colloidal organic material that fouls by an adsorption mechanism. The incidents of planktonic bloom, influx of invasive organisms like jellyfish and macro-fouling organisms and ingress of marine algae are cause for pretreatment failure almost regularly. Influx of jellyfish, noticed during the summer, was not found to cause havoc in plant operations. Data on plankton showed the presence of many phyto and zooplankton organism in water of biofouling potential that can have detrimental effect on the RO plant operations. Total suspended solids indicated the possibility of the intake bay becoming a source of elevated Silt Density Index (SDI) for the new SWRO plant.

3. Algal bloom and filtration

SWRO tends to be more sensitive to source water conditions than thermal desalination. Algal blooms increase the organic load of the source water, which accelerates the biofouling of RO membranes and adversely impacts the performance and efficiency of the plant. Poorest quality of water has been observed during red tide event and pretreatment has been the single biggest variable in determining an installation's success and thus plays a vital role in terms of assuring consistent water quality prior to the RO stage. In fact, during recent past, it was found that red tide is growing phenomenon that shakes the availability of membrane-based desalination plant along the coast of Arabian Gulf and Persian Gulf. Plants are being shut down when their pretreatment systems were overwhelmed by the extreme intensity and duration of algal blooms. One of the most critical situations was observed for quite long time period from August 2008 to May 2009 over large area of Arabian Gulf can easily be detected by the presence of chlorophyll from NASA MODIS picture as shown in Fig. 1.

In marine environment, phytoplankton specimens are mostly diatoms around 90% of size around 2 μm–2 mm available in eutrophic areas with external silicate envelop, second group is dinoflagellate species of size 50–500 μm predominant in tropical and subtropical oceans can also be present in temperature and rest are identified as Chromophyta, Chlorophyta, and Cyanophyta in size range of 2–10 μm present almost everywhere. Blooming species are in a size range (10–50 μm) that would easily pass through inlet screens. Their neutral buoyancy and ability to swim also make settling chamber removal impractical, though certain types of coagulation/flocculation or floatation-based methods may be worth considering. Dinoflagellates are easily rejected by microfiltration (MF) and UF membranes, but a bloom with high cell concentration (on the order of 10^5 cells per ml) will quickly form a thick cake layer and impede water passage. If cells are

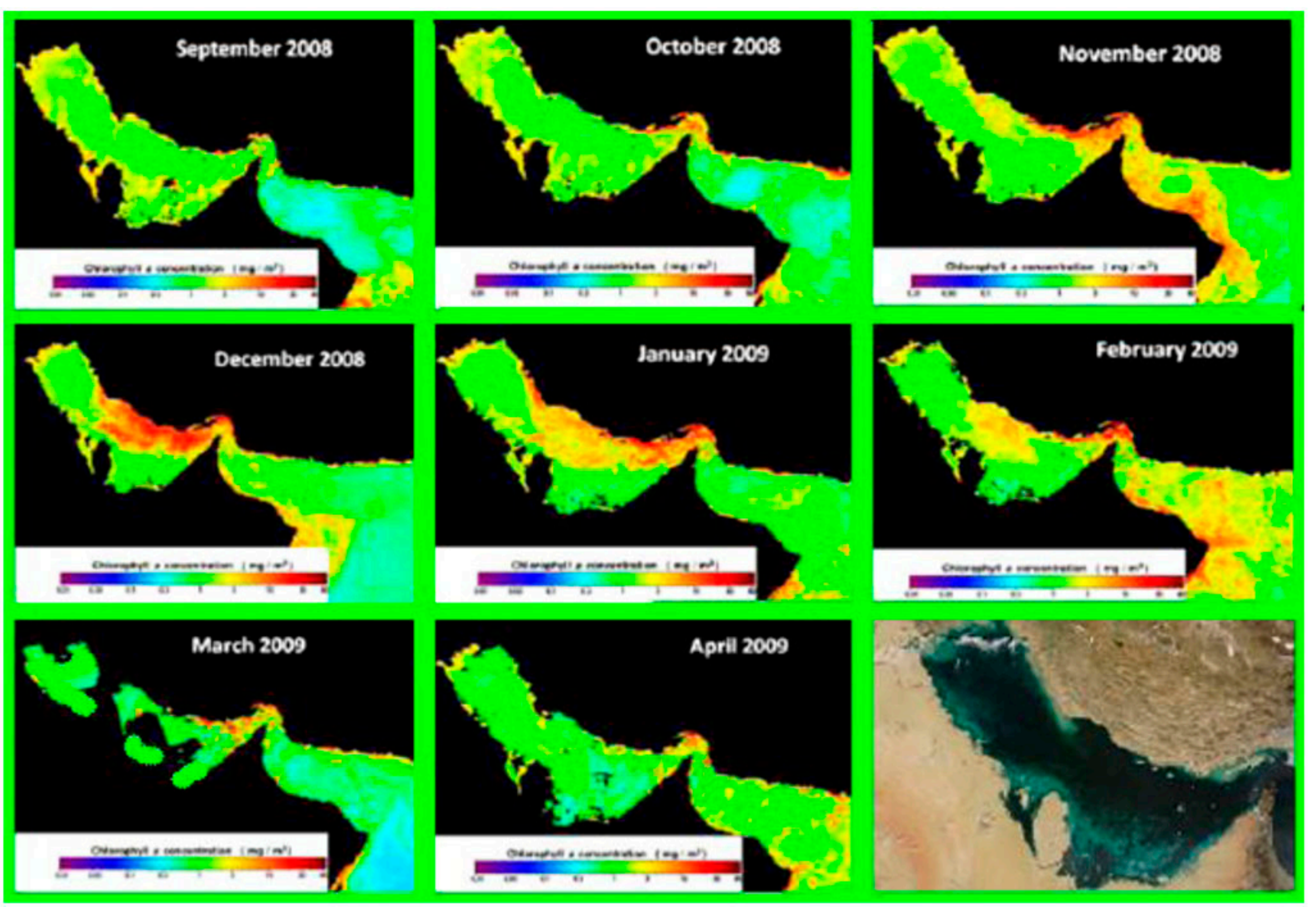

Fig. 1. One of the longest event of red tide in between August 2008 and May 2009 on Arabian coast affected many RO plant operations.

damaged, either through natural death cycles, or through shear in the pumping system, they may release organic matter that passes through the pretreatment system to the RO membranes. Organic matter can directly foul the RO membrane and/or serve as substrate for bacterial species in biofouling. Unlike other biological species algae also follow a life cycle and during blooming due to deficiency in oxygen there involves a long lag phase with rapid increase in phytoplankton cell number leading to rapid increase in bacterial cell number. During this phase, seawater composition changes their extreme from prebloom background material to algal cells and finally high in bacterial organic matter. This makes the situation challenging for water treatment plant operator due to large-scale scum formation during flocculation and accumulation on the surface of media filter. Also, the small quantity of water has changed to generate a filthy smell. For seawater desalination facilities, this is detrimental as feed water that changes greatly from day to day in terms of organic matter and microbiological concentration, and composition. Organic matter from the algal bloom was then available for the bacterial bloom that began about one week later. As an algal bloom life cycle peaks and decays, a significant amount of organic material is released upon cell death. Also, bacteria feed on the decaying material and release their own extracellular polymeric substance (EPS) that has the potential to foul pretreatment and RO membranes. It is possible that the material from decomposition could have more impact on membrane fouling than the algal cells themselves.

Now as seen during red tide period of 2008–09, the phytoplankton species were *cochlodinium polykrikoide* and are of *dinoflagellates* group of around 10–50 μ. Hence, due to the presence of these algae and size-related issue should not be a concern, in general, when speaks about algal bloom for filtration-related problem in marine water [3]. As they can be efficiently filtered through conventional filters, product water is supposed to be free from suspended impurities that can create fouling problem to RO membrane. But the problem then lies with small particles and colloidal material released from algae could be more detrimental to filtration than the whole algal cells. During blooming, algal life cycle can release significant amount of organic materials upon cell death [2]. Also, bacteria feed on the decaying material and release their own EPS that has the potential to escape out pretreatment and foul RO membranes [2]. As observed in one of the large SWRO plant with conventional pretreatment system with flocculation and media filter, there were two issues related to media filtration.

Firstly, premature exhaustion of dual media filter (DMF) due to thick floating sludge or scum accumulation on top of DMF during red tide, it stops filtration within 10–12 h.

Water filtration capacity was reduced by accelerated and incomplete backwash for 30–40 min. Filtered water tank level dropped to 80% in some occasions. RO production was lost due to the unavailability of RO feed water. This is detrimental to plant availability but generally speaking no adverse effect on membranes.

The severe incident occur when the decayed organic and bacterial population increased these contaminant often passed through DMF causing the SDI value at both inlet and outlet of cartridge filter higher than 5. Cartridge filter absolute rating was 5 μm indicate that the particle size in water were less than 5 μm. As the limit SDI value set by membrane manufacture to run RO plant is <5, the RO production was forced to stop completely. The RO downtime was more than 40% in second case indicate existence of decay and bacterial formation for longer duration in life cycle of algal bloom. Situations were represented in Fig. 2 in form of photograph and Fig. 3 in form of graph.

Colloids, particles in the 1 nm–1 μ size range, are macromolecules and molecular assemblies. They include organic (e.g. primarily humic substances (HS) and fibrillar material, usually protein and polysaccharide exudates from microbes) and inorganic matter (e.g. Fe, Mn, Al, and Si oxides, and thus, analogous to manufactured metal oxide nanoparticles), and also biological material (e.g. bacteria). Colloidal fate and behavior are determined by aggregation. Colloids tend to aggregate to particles (>1 μ), and their transport depends on the first one, being denominated sedimentation. In case of RO process the fate of foulants tended to deposit in a pattern created by the feed spacer, suggesting that dead or low-flow zones were present [4]. Thus, it has been observed in SWRO plant during autopsy visual observation that feed spacer accumulating fouling materials in spiral wound membrane (Fig. 4).

4. Selection of pretreatment

For SWRO plant seawater must be treated to ensure high standard of feed water quality—appropriate raw water treatment is vital in maintaining ongoing performance and avoiding significant problems. Some major desalination projects have experienced problems those are related to pre-treatment failure or improper pre-treatment design.

Fig. 2. Thick floating sludge or scum accumulated on top of DMF (right side photograph) during red tide period as compared to clean surface during normal operations (left side photograph) in an operating plant in UAE.

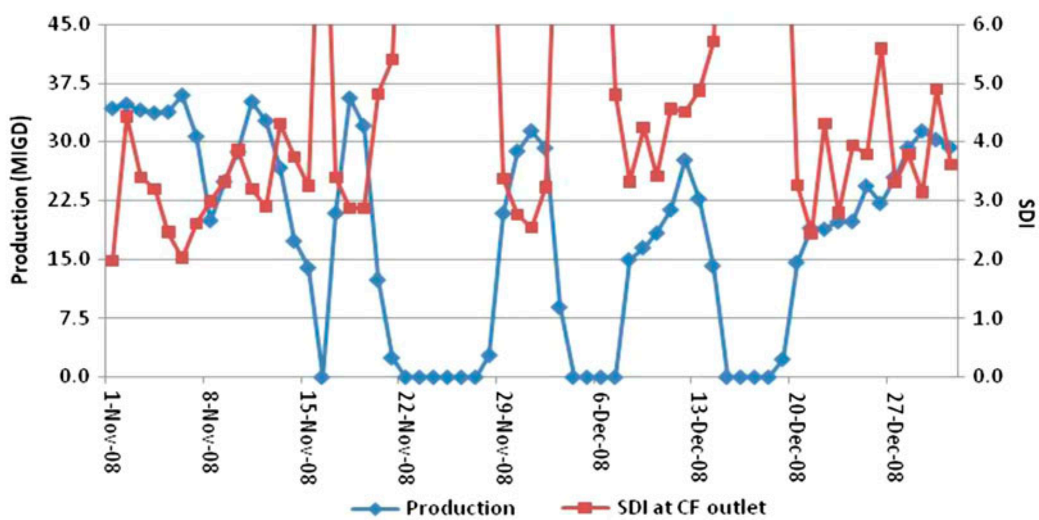

Fig. 3. Graph from one of the running plant in UAE coast depicting shutdown of plant due to high SDI value at the outlet of Cartridge filter during red tide condition with conventional treatment of flocculation and media filtration.

The key objectives of pretreatments are:

(1) To remove turbidity and solids
(2) Manage risks from activities like oil leak or shipping
(3) Manage risks from natural events like algal bloom, etc.

Generally, the smaller the filter, the more pressure is needed to push the water through it and higher pressure means a high cost, and so filters that remove very small particles are the most expensive to use. To be cost-effective, filtration is usually done as a multi-step process. Bigger contaminants are first removed using large-pore (and thus less expensive) filters, and then, filters with decreasing pore sizes are used to remove smaller and smaller particles. Using a sequence of filters also keeps the small-pore filters from getting clogged up with the large contaminants. This clogging of filters is also termed as "fouling." Filters must be cleaned regularly to remain usable.

There are many pretreatment procedures for SWRO plant and the basis of selection of right system depends on seawater quality and the price. It might be true that there are scientific techniques to contain the membrane fouling forming contaminants in majority at pretreatment stage. A table for the effectiveness of different pretreatment facility and cost is compared in Fig. 5.

Although Fig. 5 is a notional indication of Capex (onetime expenses to acquire assets are capital in nature) and Opex (expenses incurred for day to day

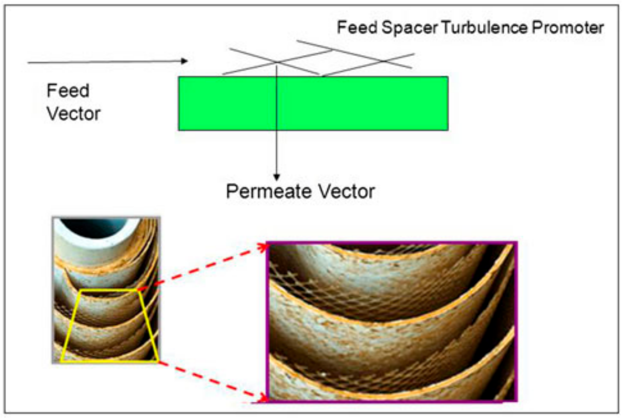

Fig. 4. Fate of colloids and particle—spacer induced deposition on membrane surface.

operation) price, it is necessary to describe the efficient pretreatment option that is described as MF/UF filtration without chemical dozing with sufficient spare stream to take care of extreme seawater condition. The algal biomass and the associated organic load cause significant desalination operational issues, impacting the pretreatment system and possibly forcing the treatment plant to be taken off-line. A variety of pretreatment procedures have been considered to address the difficult source water quality associated with algal blooms, where the organic and biomass load increased dramatically. Benchmark work is required to establish the effectiveness of the SWRO process in dealing with phytoplankton-derived substances. Even if advanced pretreatment technologies such as MF is implemented upstream of the RO process, passage of transparent extracellular material produced by the algal bloom may affect RO membrane performance. Additionally, the physical durability of phytoplankton varies greatly and the pretreatment process might disrupt cells and create significantly higher concentrations of dissolved organic substances, including toxins, that were originally present in the source water. Therefore, it is important that the international desalination community carefully characterize these potential contaminants and their removal to improve treatment approaches in seawater desalination.

5. Shuwaikh Kuwait SWRO plant

General configuration of the plant is shown in Fig. 6 below [5]. Doosan built facility in Shuwaikh in Kuwait is having the pretreatment configuration with combination of DAF and UF to take care of difficult water condition with high Total Suspended Solids value arises for reasons like algal bloom, torrential rain that carry down muddy stream to ocean and sea sediment churned by propeller of a ship.

The high rate DAF clarification process suppose to provide best membrane pretreatment alternatives by removing color, organics, soluble metals or colloidal

1	Simple Flocculator	Dual Media Filter (G)	Cartridge Filter
2	Simple Flocculator	Dual Media Filter (P)	Cartridge Filter
3	Simple Flocculator	Dual Media Filter (G+P)	Cartridge Filter
4	Simple Flocculator	Dual Media Filter (P+P)	Cartridge Filter
5	Dissolved Air Floatation	Auto Strainer	Ultra Filtration
6	Dissolved Air Floatation	Dual Media Filter (G or F)	Cartridge Filter
7	Dissolved Air Floatation	Microdrum Concrete Filter	DMF (G) + CF
8	Dissolved Air Floatation	Candle Auto Strainer	DMF (G) + CF
9	Simple Flocculator	Microdrum Concrete Filter	Turbo-disc Filter
10	Simple Flocculator	Candle Auto Strainer	Turbo-disc Filter
11	Simple Flocculator	Microdrum Concrete Filter	Spruce Filter
12	Simple Flocculator	Candle Auto Strainer	Spruce Filter
13	No Chemical Dozing	Auto Strainer	Membrane Filtration with Sufficient Standby

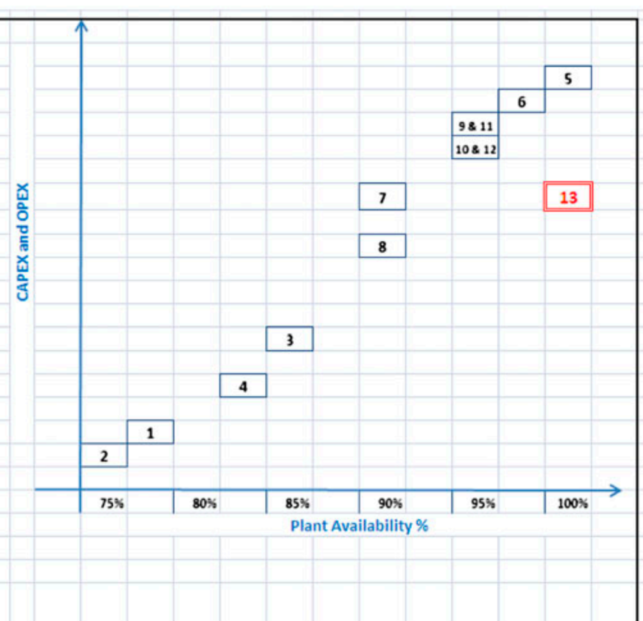

Fig. 5. Comparative table for CAPEX and OPEX vs. different combination of Pretreatment for SWRO (Graph is just a comparison and arbitrary, doesn't reflect real value).

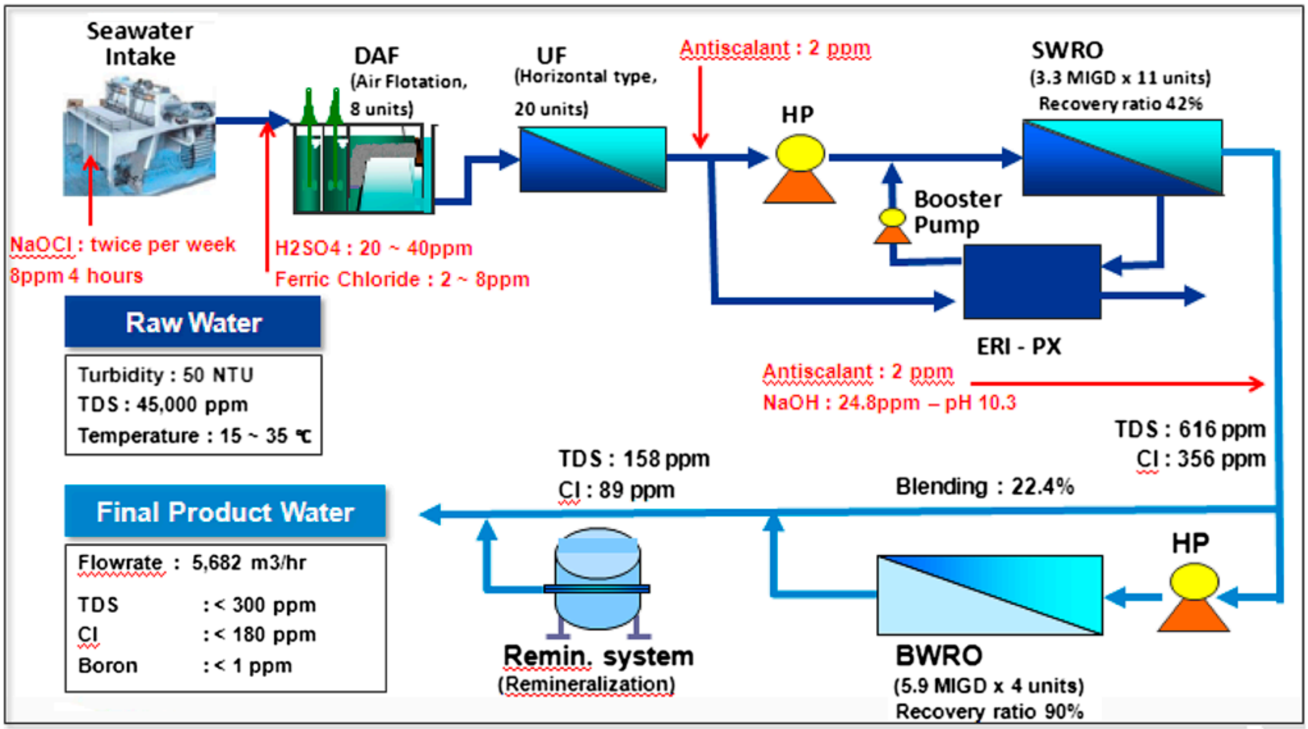

Fig. 6. General configuration of Shuwaikh SWRO plant in Kuwait built and operated by Doosan.

solids that are removed by adding aluminum or iron hydroxide low density flock. Generally speaking solids with hundreds of microns in size can settle naturally if retention time is provided, while particles of tens of microns in size are floating naturally. It is well documented that algae in the source water can best be removed by taking advantage of algae buoyancy and flotation technology in DAF.

In the DAF process, introduction of micron-sized air bubbles through diffusers combines with raw water particles and allow them to flocculate and separate out of the water by floating them to the surface rather than settling them to the bottom of the basin [6]. So far DAF is functioning well as is found by the turbidity analysis of intake water and DAF effluent. Results are plotted in a graph as shown in Fig. 7.

ITT Water and Wastewater Leopold conducted a pilot plant study reveal that the benefits of providing high rate DAF for pretreatment are: (i) to increase the membrane flux rate (ii) to reduce backwashing and chemical cleaning of the membranes and (iii) to prolong the membrane life and increase the time between membrane replacements [6]. Pretreatment combination found working well in providing plant availability and quality—SDI and turbidity values are plotted during the month of August 2012 are plotted in graph in Fig. 8.

The seawater organic matter composition changes radically from prebloom background material to algal cells and AOM to bacterial cells and finally bacterial organic matter. This makes a challenging chemistry when pre-treatment strategies are being considered for seawater desalination facilities; with the wide variation of raw water quality that changes greatly from day to day and fluctuate from day to night in terms of organic matter and microbiological concentration and composition, plant operators need to pay special attention to maintain maximum output from the plant [2].

Most important side of UF/MF system installation depends on effective on-line integrity monitoring method for MF and UF membrane systems is essential to guarantee the total suspended solids removal. A lot of works on low-pressure membrane integrity tests have been conducted by many researchers including direct and indirect methods. Direct methods are pressure-based tests, acoustic sensor test, liquid porosimetry, etc., and indirect methods are particle counting, particle monitoring, and turbidity monitoring surrogate challenge tests. ASTM D 6908 can be consulted further as guideline.

For maintenance of all time performance, it is essential to envisage membrane filtration streams in right number maintain proper transmembrane

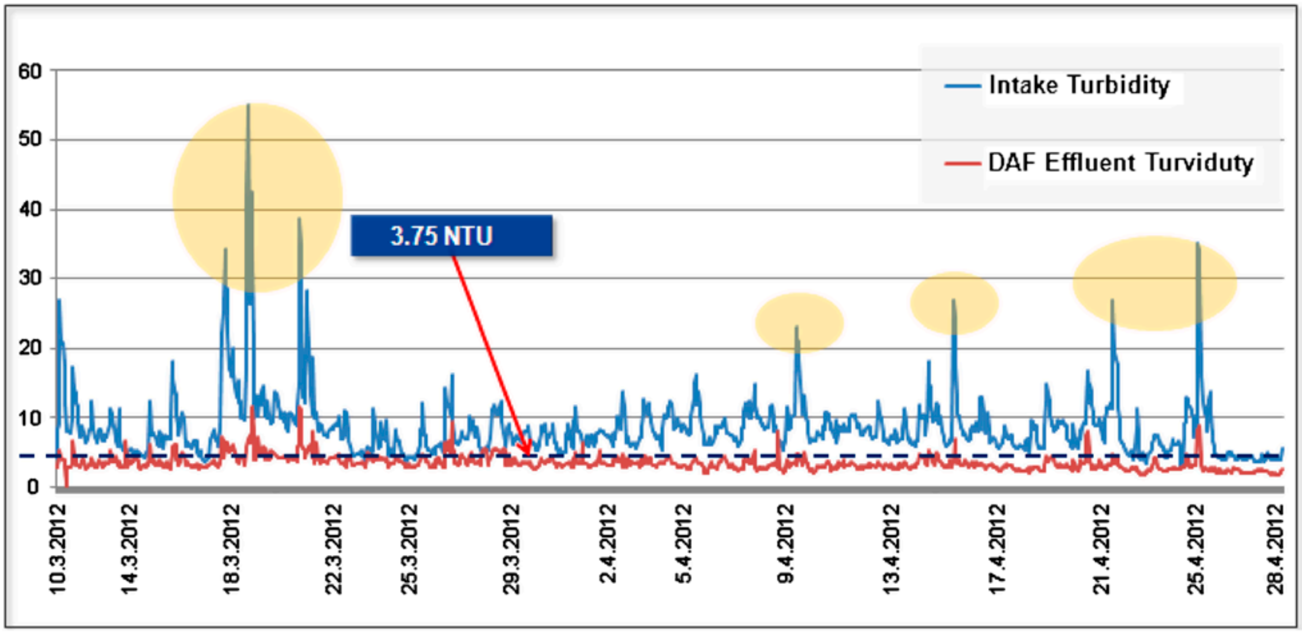

Fig. 7. Turbidity peak has been detected during ship movement, torrential rain and low tide with strong wind condition.

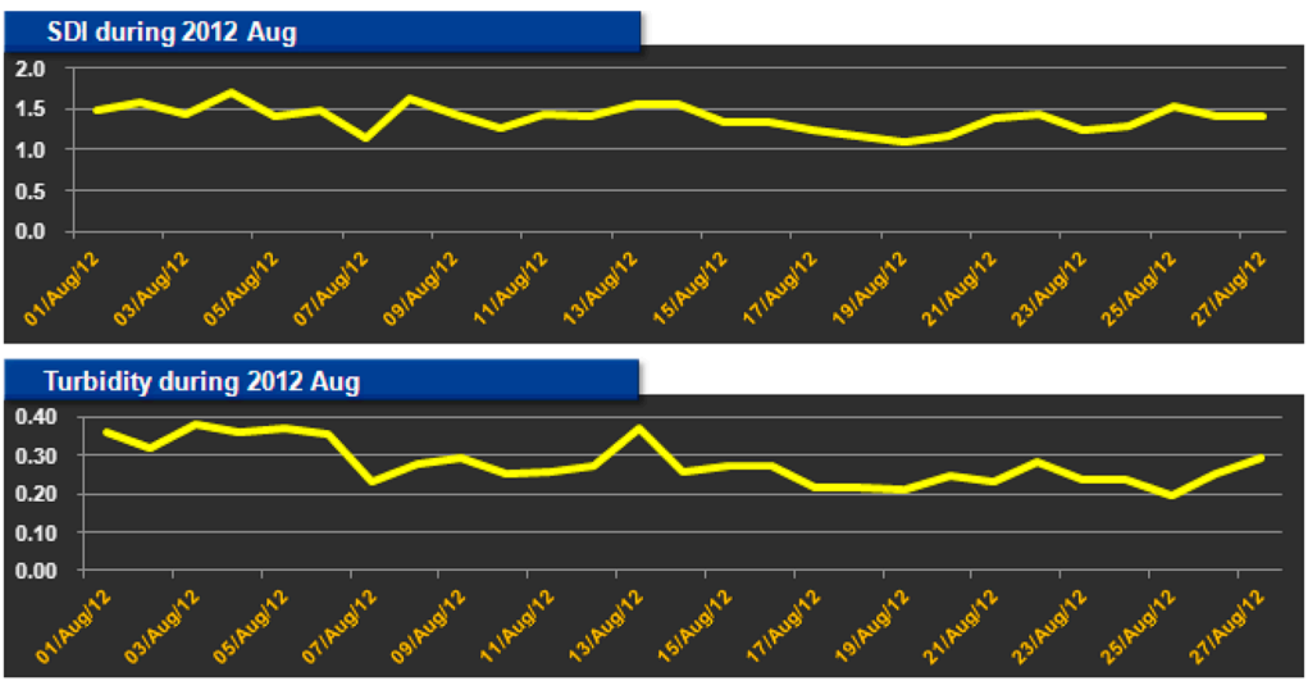

Fig. 8. SDI and turbidity values meet the specification requirement.

pressure (TMP) selected for backwashing and chemically enhanced backwash (CEB) cycle without piling up of backwash and CEB sequence. A cheaper option need verification can be installation of 10–20% bypass stream with cartridge filter that can be used during extreme condition can be defined as quick increase in TMP value.

Small particles and colloidal material released from algae could be more detrimental to filtration than the whole algal cells. Small particles and colloids are likely to produce greater flux decline because of enhanced pore blocking and a less porous cake layer. Such a phenomenon has been seen in membrane fouling studies using bacterial organic matter [2].

Similarly, studies have shown that coagulants forming more compact bacterial flock structures result in more dramatic cake-layer resistance than less-dense flock formations [2]. Fouling could also be exacerbated with shear due to increased availability of dissolved and colloidal organic material that fouls by an adsorption mechanism. In MF and UF filtration of fresh surface waters, it has been shown that the small dissolved colloidal fraction is the most important foulant due to its specific adsorptive interaction. Some size fraction of algal organic matter could also have a specific interaction with membranes and be the principal foulant.

6. Membrane autopsy discussion

Now, we discuss some of the autopsy analysis of used membrane from large SWRO plant with different RO configuration. Important information obtained when we compare FTIR spectrogram. EOM and AOM fouling layers displayed the presence of protein- and polysaccharide-like compounds. The broad OH band around 3,400 cm^{-1} and peaks near 1,000–1,120 cm^{-1} suggest the presence of polysaccharide-like compounds. N–H peaks at 3,278 and 1,550 cm^{-1}, together with amide connected C=O stretching at 1,650 cm^{-1} suggest the presence of peptide groups.

First, we see the graph from Shuaibah plant in Saudi Arabia in Fig. 9, plant is having the configuration of conventional dual media filtration followed by SWRO plant as first pass. Foulng material contain peak for both protein and polysaccharides, whereas similarly graph from Shuwaikh plant showing the peaks of protein compounds only as shown in Fig. 10. Plant configuration here is DAF and UF followed by first pass SWRO.

The protein data show that more proteinaceous material was collected as the pore size decreased. This indicated that proteinaceous material existed in a distribution of size classes; some was large enough to be

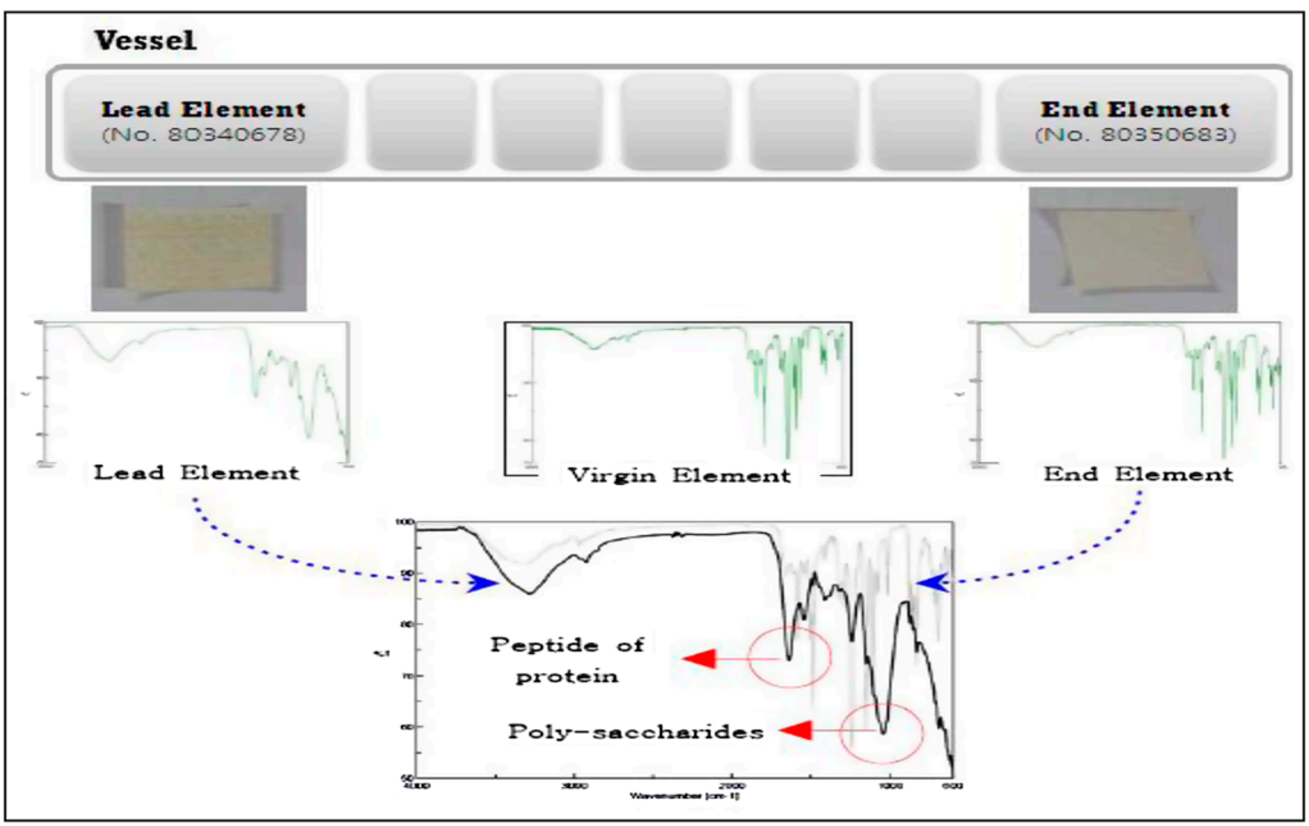

Fig. 9. FTIR spectrogram for the foulant material collected from used membrane of Shaubah SWRO plant in Saudi Arabia, autopsied in Korea University, Department of Water Engineering Environment Laboratory by Prof. Seungkwan Hong group.

retained on loose membranes, while other material could only be retained by tighter membranes. The sheared samples had significantly higher protein levels than the nonsheared sample, indicating that proteins were able to pass through the glass-fiber filter after shear more readily than before shear. The data are suspect because the bacterial concentration was elevated in the sheared sample; it could be thought that this was a measurement of the protein in the bacteria. However, if the measurement were dominated by bacteria, the concentrations would all be similar because bacteria were almost completely rejected by all membranes.

UF membranes, especially, are able to remove many organic constituents released by phyto-planktonic organisms. There are studies even UF pretreatment did not prevent RO fouling at high flux. It was assumed that the foulant was organic material small enough to pass through the UF membrane. From oceanographic studies, it is known that there exists a large fraction of seawater DOC smaller than the molecular-weight-cutoffs of UF membranes [7].

Algae and bacteria are members of the particulate size class, operationally defined as greater than 0.45 μm in size. Fouling certainly correlates with that size fraction, but the question remains whether fouling also correlates with the dissolved material. Particularly, dissolved biopolymers and small colloidal material would be suspect as foulants.

Natural waters caused very little organic fouling of RO membranes in the bench-scale results of the previous chapter, though some organic matter did deposit on the membranes. A question arose, then, as to whether situations could occur when sufficient organic matter was present to cause measurable flux

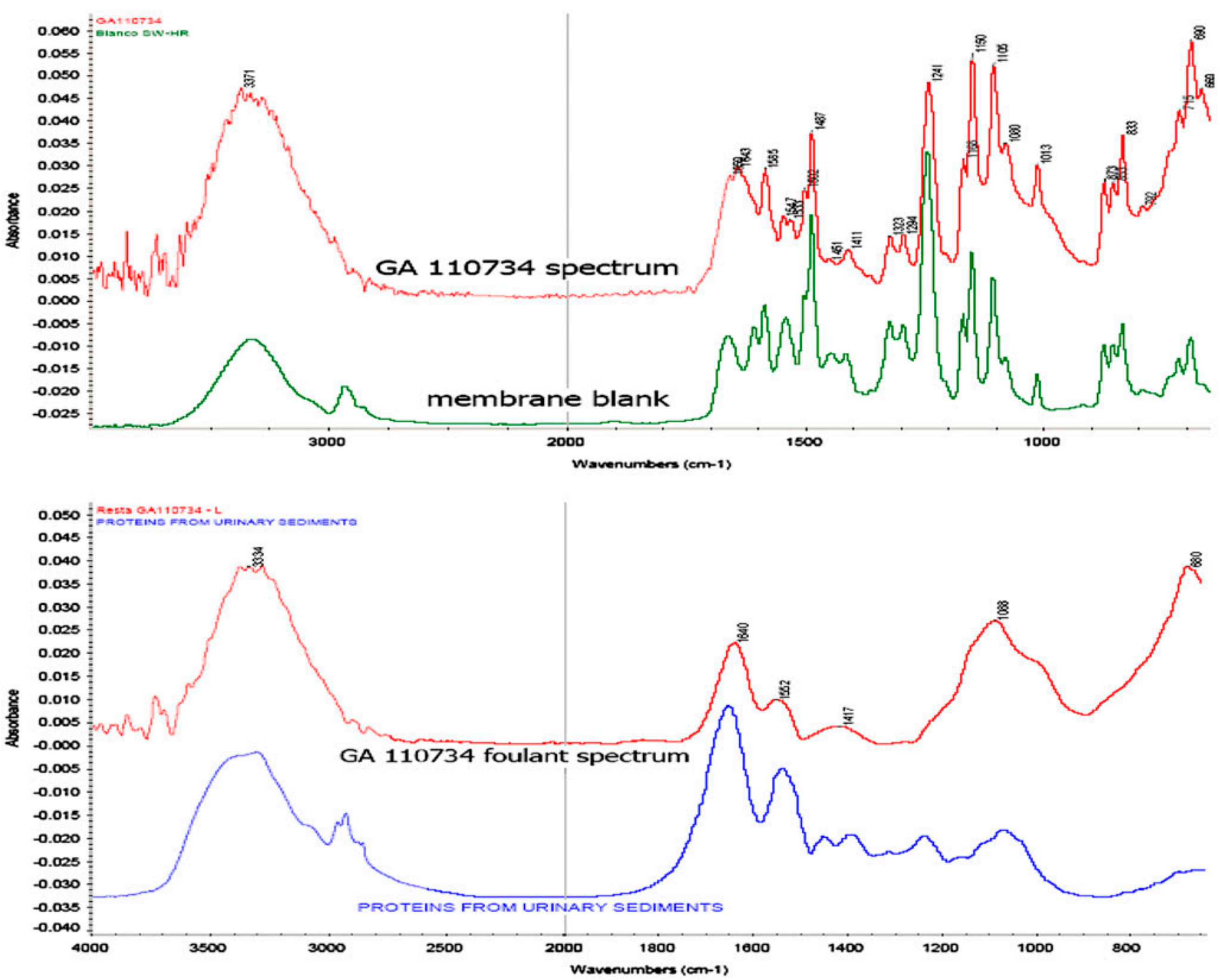

Fig. 10. FTIR spectrogram for the foulant material collected from used membrane of Shuwaikh SWRO plant in Kuwait, autopsied in Genesys Membrane Product Laboratory in Madrid, Spain.

decline. One situation where high levels of organic matter would be present is during an algal bloom. As noted in the literature review, fouling by marine algae and AOM is a cause of concern for desalination facilities[2]. Red tide events have severely damaged pilot MF/RO systems and full-scale RO systems with dual media filtration pretreatment. In these reports, little information was collected as to the extent to which AOM fouling occurred. The laboratory experiments described in this chapter elucidate the magnitude of fouling by AOM on RO membranes.

During bubble test of to confirm integrity of UF membrane at SWRO plant in Shuwaikh, Kuwait many foreign materials were found released from capillaries of UF fiber. They were worm-like material, sometimes they are brown color material and sometimes they are translucent like plastic. This clearly indicates that UF is working and quite efficient in removing seawater contaminants mostly polysaccharide in nature. This is shown in Fig. 11. Also, it is indicating that in Shuwaikh region seawater polysaccharides molecular sizes are big enough to retain on UF membranes, whereas protein molecules pass through UF membranes and foul RO membranes. Foreign materials were found released from capillaries of UF fiber. They were worm-like material, sometimes they are brown color material and some time they are translucent like plastic. These are formed due to transparent exopolymer particles, gel-like substances in aquatic systems in seawater and they are identified as mainly made up of acidic polysaccharides from phytoplanktons and bacterioplanktons [8].

Several literature reports [2,9] discuss fouling by colloids and natural organic matter on RO membranes and high concentrations of colloids and organic matter are present in an algal bloom scenario. Dissolved AOM is the material most relevant to a full-scale RO process because it can pass through many pretreatment processes. A gel-layer forms at the membrane surface as the concentration of constituents increases and they form weak intermolecular and ionic bonds. The reversible gel-layer increases permeate resistance resulting in a decline in flux and the cross-membrane passage of small contaminants. As a consequence, the feed water pressure is increased to maintain a consistent flux rate. High pressures result in aggregation of constituents (colloidal, macromolecular, and micromolecular organic compounds) at the membrane surface forming a cake-layer. At this point the fouling layer becomes strongly adhered to the membrane surface and some foulants remain and the rate of flux decline increases after each cleaning process. Subsequent flux reduction leads to increased feed pressure, further compaction of the cake-layer and an irreversibly bound fouling layer; when the critical flux was exceeded, the loosely held cake-layer (or gel-layer) forms a consolidated cake structure that is irreversible.

Last fraction of analysis using UV254 between 77 and 110 min are the smallest molecular-weight compounds and represent greatest fraction around 40–50% as compared with higher molecular-weight polysaccharides present in 30–50 min on the graph shown below as Fig. 12. Also, pretreatment like media filtration or cartridge filtration do not impact NOM noticeably [10]. Practically, it has been observed that they don't even removal by MF/UF treatment also—and it is inevitable that in spite of severe hardship and cost avoidance of membrane fouling is beyond the scope of present technology.

Fig. 11. Foreign materials were found released from capillaries of UF fiber. They were worm like material, sometime they are brown color material and some time they are translucent like plastic.

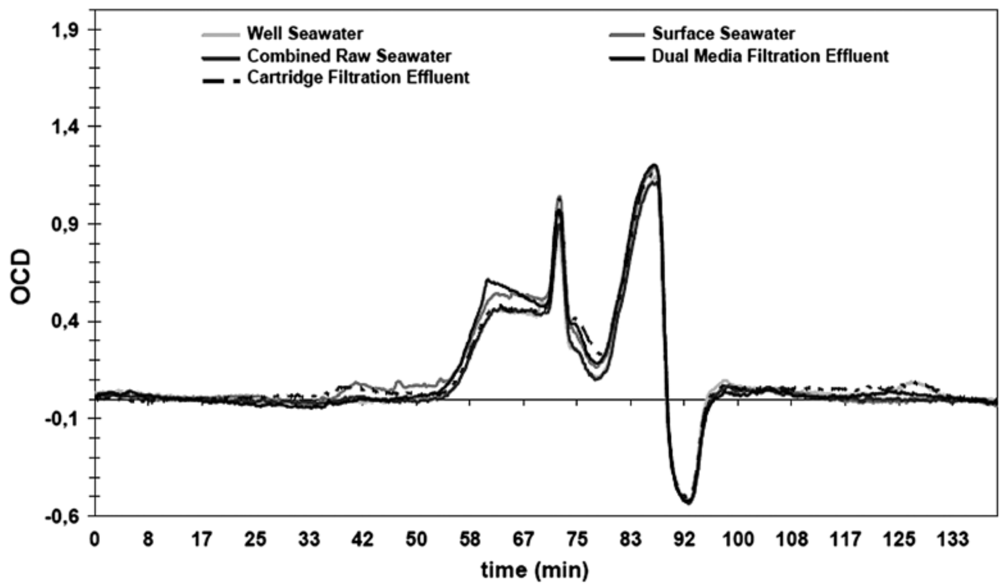

Fig. 12. LC—OCD graph for various samples drawn from SWRO plant to show the types of organic material present.

7. Conclusion

With so many combination and changes in configuration, it is impossible to get SDI value at the outlet of pretreatment stage below 2.5 during good seawater condition and around 3.0–3.5 during deteriorated water conditions. As discussed above, this is because of the organic content in marine water in varieties covering broad spectrum of size distribution. It is fact that water contains impurities in level of nano or subnano size range and none of the pretreatment established so far to contain them before reaching and affecting costly NF or RO membranes in form of fouling during course of desalination. SWRO technology is now waiting for new generation pretreatment to remove AOM to negligible amount that can cause any substantial deposition on membrane surface to trigger cleaning.

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