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| **Operation of DMFs as Biofilters to Reduce SWRO Biofouling** |

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# Introduction and Purpose

## The Mechanisms of Biofouling

Biofouling is the most common type of fouling that is encountered when operating an RO process. It is ubiquitous in water treatment membrane systems and although it cannot be eliminated, it can be managed so that its effects can be tolerated within accepted norms. As outlined by Nguyen et al (2012)[[1]](#footnote-1) in their published technical review paper on the underlying causes, monitoring techniques and control measures for biofouling of water treatment membranes “*We now know for instance that the process of biofouling occurs at very low nutrient concentrations and will always be part of the membrane filtration process… but there is still a need for applied scientific research at plant sites to demonstrate the effectiveness of the developed control strategy*”. From the first wetting of a membrane whether it be on a potable, brackish, seawater or sewerage water plant, biogrowth starts and the art is to control it.

The fouling is caused by bacteria which grow on the membrane surface. A single bacterium is required to seed the membrane surface, and this initial seed then reproduces exponentially, using organic and inorganic nutrients (organic carbon, nitrogen and phosphorous) in the seawater. The bacteria produce an extracellular polymeric (gel like) substance, which is used to both stick to the membrane surface and to provide a protective barrier between themselves and the seawater. This extracellular polymeric substance appears like a brown-orange jelly which covers the surface of the piping and collects in the membrane feed spacers. It is actually this extracellular polymeric substance which blocks the membrane feed spacers and increases the differential pressure (DP). In addition to increasing DP, biofouling membrane fouling may increase energy consumption, chemical consumption and reduce plant availability. An example of the extracellular polymeric substance is shown below in Figure 1.

Graphical user interface, application

Description automatically generated

Figure 1 Membrane Feed Spacer with Biofouling

Figure 2 shows the biofilm formation stages, indicating how a single bacterium attaches to the membrane surface and then starts to reproduce and produce extracellular polymeric substance (EPS). This matrix of bacteria and EPS continues to grow, and the final stage of formation is dispersion where the biofilm is established and may only change its shape and size by spreading and attaching to more surfaces. It is therefore possible for a single seed bacterium to completely colonise a particular surface (ie. all the RO membranes in a vessel), given sufficient time and sufficient conditions for growth. The key to managing biofouling in RO plants is to manage the conditions in which the bacteria are growing such that the time over which they grow is within acceptable limits. It is unrealistic to expect that biofouling can be eliminated, but it can be managed.

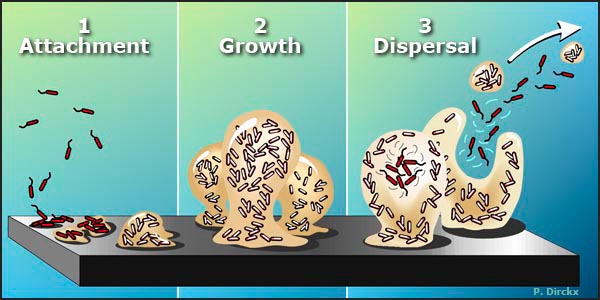


Figure 2 Biofilm Formation

## How Does Biofouling Occur and How Can It Be Controlled?

There are 5 essential ingredients required for biofouling to occur:

* Bacteria
* Carbon (C)
* Nitrogen (N)
* Phosphorous (P)
* Energy (Normally Oxygen (O))

There are essentially two strategies which can be used to control biofouling: poison (disinfection) and starvation.

The most common poison used for biofouling control is chlorine, which is a very effective disinfectant. Unfortunately, RO membranes cannot tolerate chlorine, so disinfection with chlorine is not possible. RO membranes have some tolerance of chloramines, which are used to control biofouling in wastewater reclamation RO membrane systems. However, the chloramine oxidises bromide in the seawater to hypobromous acid, which oxidises RO membranes, so chloramine disinfection does not work for SWRO. DBNPA is a non-oxidising biocide which can be used to control biofouling in RO membranes without destroying the membrane’s active layer. However, DBNPA is not normally used in potable water SWRO systems due to concerns over its toxicity (although DBNPA is regulated by NSF/ANSI 60[[2]](#footnote-2) with a TAC of 0.4 mg/l, SPAC of 0.09 mg/l and STEL of 2 mg/l – with removal achieved by RO and dosing to only one of multiple trains, it should be possible to comply with these limits with on-line DBNPA dosing).

There is another disadvantage of using chlorine in the pre-treatment system before RO. Chlorine acts as an oxidant to break down large, complex organic molecules which are not very biodegradable into smaller, far more biodegradable organic molecules. The organic molecules are the food which feed the biological growth and the act of chlorination – dechlorination (essential before RO membranes to prevent oxidation) is like cooking the organic molecules so that they are far more digestible and increase the rate of biofouling. It is widely recognised within the RO industry that continuous chlorination of feed water before RO has a very serious, detrimental impact on RO biofouling.

If it is not possible to control biofouling by disinfectant, then removal of any one of the above 5 essential ingredients will stop biofouling from occurring.

As previously discussed, it is not possible to completely eliminate bacteria and there will always be at least one bacterium which can act as a seed bacterium no matter what precautions are taken.

Therefore, control of the nutrients (C, N and P) is far more effective than attempting to kill the bacteria. It is now recognised that the best strategy for controlling bio fouling in RO plants is to eliminate continuous chlorination so as not to increase the availability of carbon nutrient, and to reduce the nutrient content of the feed water. Continuing with the food analogy, control of nutrients is like starving the bacteria, which will grow much more slowly when their food supply is limited.

## DMF as Biofilter

As discussed above, biofouling is not caused by material which is already present in the seawater in particulate or colloidal form. Rather, it is caused by bacteria growing within the RO membrane using nutrients in the seawater as their food source.

The best nutrients for biofouling are small organic molecules – eg. adding a couple of ppm of vinegar (acetic acid) to the feed of an RO system will result in extremely fast biofouling. These small organic molecules are much, much smaller than the pore size of all filtration systems, including ultrafiltration, and certainly, much, much smaller than the interstitial spaces between the filter media granules.

Therefore, biofouling cannot be reduced during pre-treatment by a physical, size-exclusion, filtration process. The best strategy for reducing the rate of biofouling is to remove as much as possible of the food source (nutrients) which feed biofouling.

One of the most effective methods of removing biological nutrients is to provide a high concentration of bacteria to digest those nutrients. This should preferably be achieved in an environment where it can be easily managed. RO membranes are effective at biologically reducing the nutrient level in seawater, but unfortunately, the consequences of the biological growth are very difficult to manage. The filter media in the DMFs also provides an ideal location for biological growth to occur. The bacteria grow and attach to the filter media and consume the nutrients in the seawater as it passes through the filter. The excess growth can then be removed from the media by the normal backwash process, making it a much more manageable location for biological growth to occur.

Essentially, biological growth will occur, it cannot be prevented with acceptable disinfectants. The question therefore becomes whether it is preferable for the majority of that growth to occur within the DMFs or within the RO membranes. On the basis that it is far easier to manage biological growth in the DMFs than in the RO membranes, It is recommended that the DMFs should be configured to encourage the maximum biological growth to occur within the filters.

If biological growth is encouraged to occur within the DMF filter media, it will use nutrients (food) which are then not available for biological growth in the RO membranes. The bacteria within the DMF will take the most readily biodegradable nutrients from the feed water, such that the remaining nutrient material is less biodegradable and the rate of biofouling in the RO membranes will be reduced.

The biological growth on the DMF filter media will increase the solids loading to be removed by the DMFs and will cause a small increase in the rate of headloss development. It is possible that the DMFs might need backwashing slightly more frequently as a result.

The site has reported problems with mud-balls occurring in the DMFs. It is possible that the EPS secreted by biological growth on the DMF media will increase the rate of mud-ball formation. However, it is also possible that the majority of the EPS is produced during the shock chlorination events, since it is known that bacteria increase the rate of EPS secretion when they are under adverse conditions (such as presence of chlorine). There has also been a suggestion that the mud-balling is the result of calcium carbonate scale, in which case, dosing SBS prior to the DMFs will be slightly beneficial, since SBS reduces pH. The Operator has already identified routine chlorine soaking of the DMF filter media as a way to manage the mud-ball problem – it is recommended that this is continued on a routine basis as required to keep mud-balls in control. However, if it is proven that calcium carbonate scale is the cause of mud-balling, then soak chlorination should not be used. Instead, coagulation pH should be reduced and acid soaking should be used to recover the media.

In conclusion, biofouling will occur and it is preferable to encourage it to occur in the DMFs instead of the RO membranes because it is easier to manage in the DMFs.

# Biofilters

Biofilters include any deep media filter where biomass is allowed / encouraged to grow on the surface of the filter media with the consequence that the biological growth consumes nutrients from the seawater thereby reducing the concentration of biological nutrients in the filtrate.

Deep media filters that are designed with biofiltration in mind from the initial design concept look exactly the same as conventional DMFs or pressure filters using sand / anthracite filter media, except that they normally replace the anthracite (and sometimes the sand) with a porous filter media such as pumice, expanded clay or Granular Activated Carbon (GAC). The purpose of the porous filter media is to increase the concentration of biomass that can be held by the filter media, thereby increasing the rate at which nutrients can be consumed.

However, given the right environment, biological growth can occur on the surface of anthracite and sand media, which means that a conventional sand / anthracite DMF or pressure filter can be converted in to a biofilter simply by allowing biological growth to occur on the media surface.

This can be achieved by neutralising any chlorine used for intake disinfection before the feed water enters the filter.

# Reference Material

The FilmTec Design Manual[[3]](#footnote-3) includes a section (2.6) dedicated to Biological Fouling Prevention. In this section, it states,

*“The most successful approach* (to Biological Fouling Prevention) *is the limitation or removal of nutrients for microorganisms from the water in order to limit biological growth. This can be achieved with biofiltration - see Section 2.6.8”*

A biofilter is any deep media filter where biological growth is allowed to grow on the filter media. Because the filter media has a high surface area, a large contact area is presented between the bacteria attached to the filter and the water flowing through the filter. Ideally, a biofilter should employ a porous filter media, such as pumice, expanded clay or granular activated carbon (GAC), because the porous structure provides an excellent habitat for the biological growth.

The FilmTec Design Manual Section 2.6.8 on Biofiltration states,

*“When such filters are operated at sufficiently low filter velocities (1 – 4 gpm/ft2 or 2 – 10 m/h) and with sufficiently high beds (6.5 – 10 ft or 2 – 3 m), most of the biolife activity takes place in the upper region of the filter bed, and the filtered water is almost free of bacteria and nutrients.*

*Using biofiltration to prevent biofouling of RO/NF membrane systems has been demonstrated and advocated as a suitable pretreatment method by several authors /29[[4]](#footnote-4), 30[[5]](#footnote-5), 36[[6]](#footnote-6), 37[[7]](#footnote-7)/”*

Abushaban et al[[8]](#footnote-8) monitored the performance of 2-stage DMF and DAF + 2-stage DMF at two different, full-scale SWRO plants in the Middle East (location not specified). They performed analysis of biological growth indicators (microbial ATP (Adensine Tri Phosphate) and BGP (Biological Growth Potential) at various points in the process. Some of the significant findings were:

*“When chlorination was applied (day 4), higher microbial ATP levels were measured after the first stage of DMF compared to the microbial ATP in the seawater intake and after the first stage of DMF in the absence of chlorine, which might be due to the breakdown of the biofilm present on the media of DMF”*

*“The low removal of organic/biological fouling potential through the SWRO pretreatment system could be attributed to a low level of biological activity in the media filters. This could have been caused by operational practice such as (i) frequent chlorination of the intake and de-chlorination after the media filtration units, (ii) overly short empty bed contact times in the filter media or (iii) applying backwashing conditions that remove/wash out biofilm layers on filter media, which are required to degrade organic matter (nutrients), preventing further bacterial growth in the downstream SWRO membranes.”*

*“Thus, to further reduce the BGP of SWRO feed water, priority should be given to (i) reducing the frequency of chlorination in intakes and/or (ii) performing the neutralization step before media filtration, and not after”*

This paper is very strong in its conclusion that allowing intake shock chlorination to reach the DMFs has a significantly adverse impact on the ability of the DMFs to reduce biological growth potential in the filtered water.

Miyakawa et al[[9]](#footnote-9) evaluated the performance of a SWRO pilot plant operating at Jubail on Gulf Sea water with very high recovery and where no chlorine was applied prior to filtration by DMF. Daily shock acid dosing was used to control marine growth. Some of the key points to note are:

The normalised feed-brine pressure drop increased from about 0.55 Bar to about 0.65 Bar over a period of 120 days. This is excellent for Gulf Sea water.

*“eliminate the use of chlorine and SBS, which can accelerate membrane fouling”*

*“the system was operated for longer than four months without membrane cleaning (clean in place; CIP) and the possibility of operation for seven months without CIP was confirmed by the extrapolation of the pressure values”*

*“In this study, H2SO4 shock dosing was used to prevent biofouling but the obtained mBFR values of DMF treated seawater suggest that the system could have been operated reliably enough without H2SO4 shock dosing”*

*“The advanced design system with No-Chlorine/No-SBS Dosing process can operate for more than 4 months and perhaps up to 7 months without any CIP, even in an area where there is high potential for membrane fouling in 55% recovery rate in the RO process”*

This paper demonstrates that low DP increase and long interval between CIPs can be achieved if no chlorine is added to DMFs filtering Gulf Sea water, and no issues with the performance of the DMFs are reported.

Flemming[[10]](#footnote-10) states,

*“If biofouling can be considered as a “biofilm reactor in the wrong place” as pointed out earlier, it is logical to use a “biofilm reactor in the right place.” The “right place” is ahead of any system to be protected. For the case of nutrients in water, this has been successfully implemented to prevent biofouling in membrane systems (Griebe and Flemming 1998, Table 2) and is increasingly applied now in membrane technology and also in the protection of heat exchangers against biofouling”*

Peterson[[11]](#footnote-11) states,

*“The solution to this dilemma is to grow microbes in biological filters ahead of the RO membranes. If a high quality filtration material, such as Filtralite® expanded clay, is used for microbial attachment, it is possible to effectively remove both microbial energy and nutrient compounds even at low temperatures (6°C). Pilot and full-scale plant experiences from the Canadian prairies using biological filtration have advanced these treatment processes from experimental to proven technologies and are currently being evaluated as potentially becoming “best available technology” in the treatment of extremely poor quality brackish groundwater. The first Integrated Biological and RO Treatment Plant was commissioned in December 2003, and after two years of full-scale testing, two more plants were commissioned in December 2005. At one of these plants, conventional manganese greensand treatment was followed by RO treatment resulting in frequent chemical RO cleanings as well as membrane replacements every eight months. Removing the manganese greensand in the existing filters and replacing them with Filtralite® material resulted in a rapid improvement of treated water quality and a literal stop to frequent RO cleanings. The biological filters need to be backwashed 36 times less than the manganese greensand filters (100 filter backwashes per year vs. 3,600). Backwash water use decreased to 0.4 million L from 23 million L and backwash labor decreased to 40 hours from 1,440 hours per year. Combining these savings with decreased RO cleanings, no need for frequent membrane replacements, and decreased chemical costs, it has been estimated that this water treatment plant serving 1,200 people will save more than $100,000 per year.”*

Wittmann et al[[12]](#footnote-12) present a case study from an 84 Ml/d plant in South Korea. Statements include,

*“Several modifications in 2006 have allowed operating the membranes with significantly reduced biofouling. The most important improvement has been removal of a major part of biodegradable organic matter in the pretreatment by operating the two filtration stages without the presence of free chlorine.”*

*“The major results of the significantly reduced biofouling are a membrane life that has more than doubled and a chemical cleaning frequency that has been reduced by a factor of 4.”*

# Existing Plant Operation

It is not easy to obtain information on existing plants, apart from information that is written up in the literature. Particularly on issues such as whether or not chlorine is allowed to enter the DMF feed. However, through various connections, I understand that the following plants operate with DMFs which receive non-chlorinated filter feed water:

* 120,000 m3/d Barka Phase 2, Oman (pressure DMF)
* 150 MIGD Umm Al Quwain (DAF + gravity DMF)
* 3, 6 & 7 MIGD plants at Zawra, Ajman (pressure DMF)
* I understand SIDEM operate a number of their desalination plants with DMFs as biofilters, but I don’t have the details

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2. NSF International Standard / American National Standard; NSF/ANSI 60 – 2016; Drinking Water Treatment Chemicals – Health Effects; 09/03/16 [↑](#footnote-ref-2)
3. [DuPont; FilmTec Reverse Osmosis Membranes Technical Manual; Form No. 45-D01504-en, Rev.16; February 2023.](https://www.dupont.com/content/dam/dupont/amer/us/en/water-solutions/public/documents/en/RO-NF-FilmTec-Manual-45-D01504-en.pdf) [↑](#footnote-ref-3)
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