TEP and biofilm fouling on membranes

Tom Berman[1]

Marina Holenberg[2]

[1]Yigal Alon Kinneret Limnological Laboratory,
Israel Oceanographic and Limnological Research,
P.O.Box 447
Migdal 14 950
Israel
e-mail: tberman@ocean.org.il

[2]Amiad Filtration Systems
Kibbutz Amiad
Galil Elyon 12335
Israel
e-mail: marinah@amiad.com

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About the authors:

Research Professor (Emeritus) Tom Berman is an aquatic microbiologist at the Kinneret Limnological Laboratory (Israel Oceanographic and Limnological Research), Israel. Over the past 35 years, he has been following the antics of algae, bacteria and other "wee beasties" in various lakes and seas. From 1999 to 2003, he made the first detailed study of TEP in a freshwater lake.

Dr.Marina Holenberg is with the R&D Division of Amiad Filtration Systems, Amiad, Israel , and has a PhD in Chemical and Filtration Technology from the Polytechnical University at Tomsk, Russia.

Contact Information

Tom Berman
Kinneret Limnological Laboratory
Israel Oceanographic and Limnological Research
P.O.Box 447
Migdal 14 950
Israel
e-mail: tberman@ocean.org.il

Marina Holenberg
Amiad Filtration Systems
Galil Elyon 12335
Israel
e-mail: marinah@amiad.com

Article Heading/Summary

Biological fouling on membranes is a major problem in desalination and water purification plants. Oceanographers and limnologists have found that most marine and fresh waters are full of microscopic Transparent Exopolymer Particles, otherwise known as TEP. In this article, aquatic microbiologist Tom Berman and Filtration Specialist Marina Holenberg (Amiad Filtration Systems, Amiad, Israel) propose that TEP in source waters is a prime factor leading to biofilm growth on membrane surfaces. Because TEP levels can be lowered by appropriate pre-filtration, they suggest measuring TEP concentrations to determine the efficiency of pre-filtration arrays upstream from membranes.

Biological fouling caused by the growth of biofilm on RO and NF membranes can be a major problem in desalination and water purification plants. Biofilm development lowers filtration efficiency and eventually the membranes must be replaced. Biofilm is usually made up of layers assorted microbial populations, mostly bacteria, held together in a sticky matrix of extracellular polymeric substances, **EPS**. These substances are largely muco-polysaccharides, long-chain polymers of amino-sugars.

It is generally accepted that the growth of biofilm on membranes is fueled by dissolved organic material, **DOM**, in the input water. Current thinking is that much of the DOM used by biofilm microorganisms derives from the cells of algae and other plankton that are mechanically disrupted or damaged as a result of pre-filtration upstream of the membranes. As a result, these organisms leak their cellular contents of DOM into the water that flows over the membranes and thus provide readily available nutrition for the biofilm bacteria and their associates. Bits and pieces of cells and other detritus that also stick to the membrane surface may spur further biofilm development.

We doubt that the above scenario accurately or adequately explains how biofilm fouling gets its start and grows on membrane surfaces. Most input waters to desalination or water purification plants have naturally high DOM levels. For example, in many marine coastal waters, about 80% of all the nitrogen content (apart from gaseous nitrogen) is in the form of dissolved *organic* nitrogen, while only about 10% consists of dissolved *inorganic* nitrogen (nitrate and ammonia). The remaining 10% of nitrogen is in particle form, mostly within the cells of algae, bacteria and zooplankton and in detritus. In a freshwater example, (Lake Kinneret, the Biblical Sea of Galilee, Israel) between 40 and 65% of total nitrogen is dissolved organic nitrogen, about 8 to 10% is dissolved inorganic nitrogen and the remainder is particulate N.

Not all of the large DOM pool is readily used by microorganisms. Nevertheless we stress that most source waters used for desalination or water treatment have initially high concentrations of DOM, even prior to any addition resulting from pre-filtration. **But, even more significantly, most input waters carry high loads of TEP.**

What is TEP?

In 1993, an American oceanographer, Alice Alldredge and her colleagues stained seawater with Alcian Blue, a dye specific for acid mucopolysaccharides and discovered that their samples were full of hitherto undetected, transparent micro-particles. These particles ranged in size from about 2 to 100-200 microns and were dubbed **TEP,** an easy acronym for **Transparent Exopolymer Particles**. Over the next few years, researchers found TEP in high concentrations in most marine and freshwater environments. For example, in near-surface ocean waters the numbers of TEP range from 3000 to 40000 TEP/ml, in freshwater Lake Kinneret, an annual average of 20000 TEP/ml was observed. Although TEP are mostly made up of the muco-polysaccharides that take up the Alcian Blue dye, other organic compounds such as proteins may also be incorporated into these particles.

TEP appear in many forms; amorphous blobs, clouds, sheets, filaments or clumps, sometimes recognisable as debris from broken plankton (Fig. 1). In the sea, much of TEP seems to form abiotically from DOM by coagulation, aggregation or by bubble adsorption. Some TEP can also be produced from the gelatinous, mucous envelopes surrounding bacterial cells, diatoms and various other algae. Many TEP are intensely colonized by bacteria that find them both a convenient and a nutritional platform on which to grow.

The role of TEP in natural waters

It turns out that TEP is an important ecosystem player in both marine and freshwaters. TEP adsorb trace metals and dissolved organic compounds. They are often loaded with bacteria and other microbes. In this way, TEP become “hot spots” of intense microbial activity and chemical transformations within the water mass. Together with their associated flora and fauna of microorganisms, TEP serve as “food packages” for all kinds of small plankton and even for larval fish. Additionally TEP can aggregate with each other or with other small bits and pieces of detritus to form larger (>300 micron to 1-2 mm) particles called marine or lake “snow”. Some of the TEP and “snow” sinks out of the upper water column and transports large amounts of organic matter and microorganisms to deeper water and sediments. Recently oceanographers discovered that the levels of TEP could determine the composition of the microbial populations in ocean water. In closed water supply systems, TEP may be an important factor in stimulating “bacterial regrowth”. A comprehensive review of TEP and its role in aquatic environments has been published recently in “Progress in Oceanography” (Vol. 55, 287-333, 2002) by Uta Passow, one of the scientists who first described these particles.

TEP and the formation of biofilm on membranes

We propose that TEP are the major initiators of biofilm on membranes. As noted above, these negatively charged, polysaccharide particles are very numerous in most source waters, they are small and sticky, and many of them already carry resident bacterial populations. Once TEP adhere to the membrane surface, they can provide a nutritious substrate for microbial growth and establishment of biofilm. It almost looks like TEP were specially designed to stick efficiently to membranes or other surfaces forming a “task force” that jump-starts biofilm growth. Further fouling is then stimulated by the continuous stream of TEP being trapped at the biofilm surface, in addition to DOM in the input water (Fig.2). However, although biofilm nutrition may indeed be supplemented by some DOM and organic detritus released from microorganisms damaged by pre-filtration, these are not likely to be the main sources for the buildup of biofilm on membranes. We also suspect that at least some of the EPS matrix observed in biofilm (see above) is, in fact, TEP or derived from TEP.

Measuring TEP as a criterion of pre-filtration efficiency

The above scenario for TEP involvement with biofilm implies that the rate at which biological fouling develops is affected to large extent by the amounts of TEP in the water reaching the membrane surface. So measuring the concentration of TEP in inflow water could be useful in estimating the potential for biofilm development. (In practice, TEP concentrations in water can be easily measured with a simple colorimetric assay). Moreover, it is important to determine the extent to which various pre-filtration arrays can lower the amounts of TEP reaching the membrane surface.

We ran some very preliminary tests using 2 kinds of filtration systems to determine their effects on TEP levels occurring in water taken from Lake Kinneret. In 4 trials we found that a filament-wound cassette filter nominally rated at 3.0 micron (Filtomat from Amiad Filtration Systems, Israel) and a conventional sand filter reduced TEP concentrations on average by 44% and 12%, respectively.

These tests are hardly definitive but they do show that the levels of TEP reaching membrane surfaces can indeed be lowered by effective pre-filtration. Therefore, we advocate measuring TEP concentrations before and after pre-filtration as a criterion of filtration efficiency, in addition to determinations of commonly used parameters such as Total Suspended Solids, Turbidity (NTU) and Silt Density Index (S.D.I.). Probably, due to their small size and relative fragility, only relatively fine filtration (1-10 micron) will be effective in removing significant amounts of naturally occurring TEP in many source waters.

By now there are several hundred papers in the scientific literature about TEP but to the best of our knowledge, people in the filtration industry are as yet largely unaware of these particles. Because large amounts of TEP are found in most natural waters, it is likely that these hitherto neglected particles will turn out to have important implications for biological fouling in many other filtration applications, in addition to biofilm development on membranes.

Figure legends

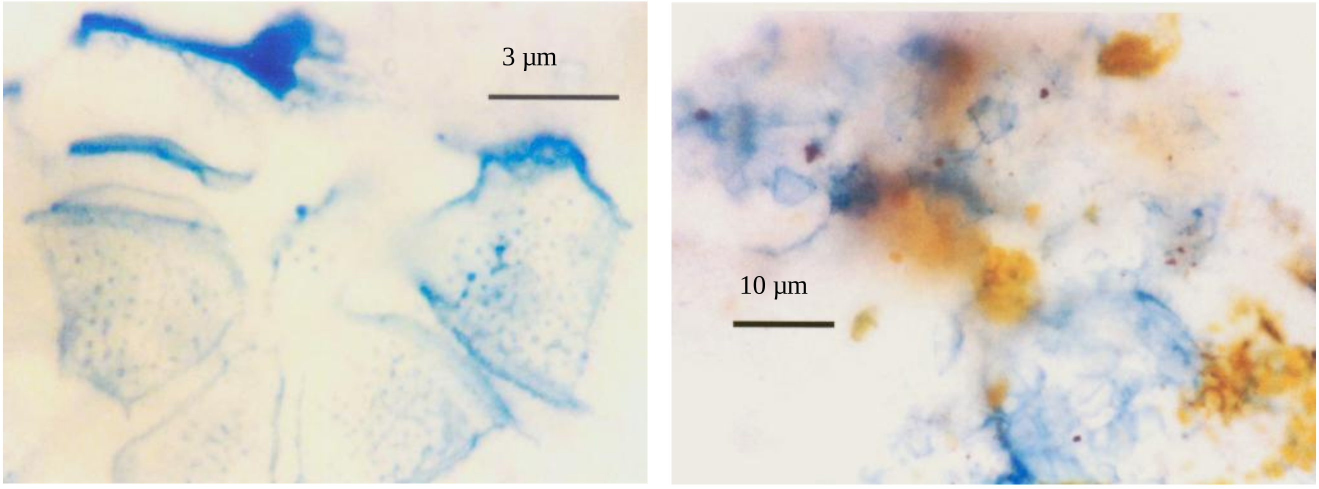

Fig 1. Examples of TEP in a freshwater lake (Lake Kinneret, Israel).
Top: TEP (blue colour), mostly from cell debris of an algal bloom in spring.
Bottom: TEP together with inorganic particles, in summer. Both samples taken from near-surface water. The black bar indicates scale in microns.

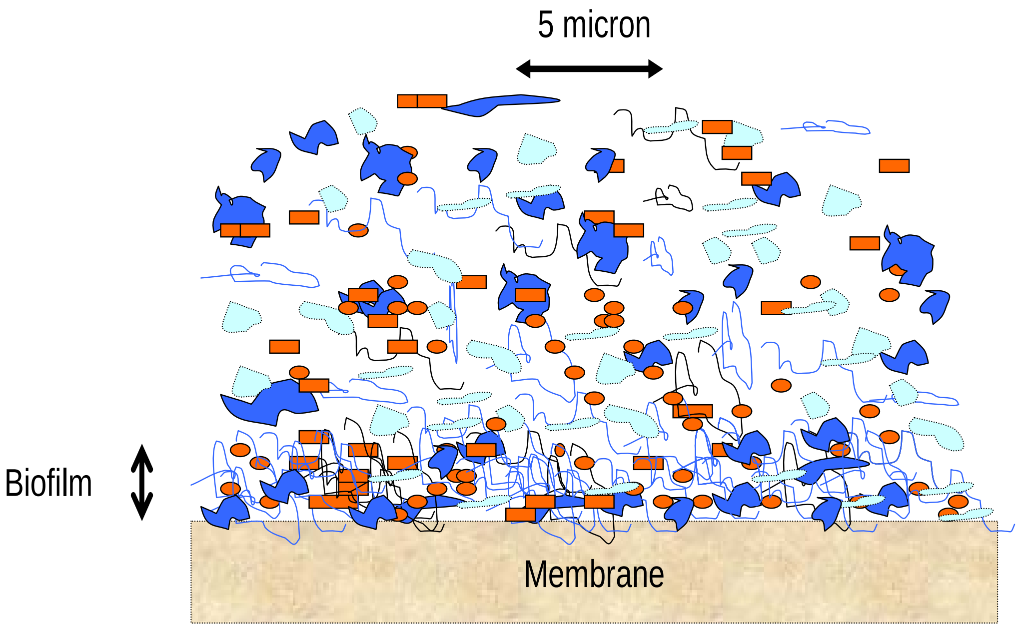

Fig 2. Schematic diagram of TEP involvement in biofilm development on a membrane surface.
Initially, a few TEP (dark blue), some carrying attached bacteria (red), stick to the membrane. Subsequently biofilm microorganisms (red) grow out; using dissolved organic matter, colloids (light blue) and additional TEP for nutrition, leading to the development of a layer of biofilm formed by bacteria within a matrix of extracellular polymeric substances, (EPS).