# Pushing the Limits: Optimizing Membrane Plants Via Correlating Fouling With Critical Flux

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## Abstract

The concept of establishing direct correlations between the operating flux, represented by the conversion, and fouling potential of membrane systems has always been of tremendous interest to membrane technology researchers, plant end-users and membrane manufacturers since the advent of membrane technology's commercial applications worldwide some forty years ago. Several attempts were made to effectively control biological and colloidal fouling in particular, as a means of optimizing plant design, operation and performance, by limiting the operating system conversion or flux below "safe" or "critical" values. However, such attempts resulted in designing plants that are not economically feasible to operate. Moreover, the concept of critical recovery or flux did not in reality allow for the implementation and utilization of new, innovative technologies, processes and equipment that continually optimize the operating and performance efficiencies and competitiveness of membrane processes. On the other hand, cost benefits resulting from increasing the conversion and flux can be prove critical in end-users' ultimate decision to adopt membrane processes as the technology of choice for meeting the demand for reliable and cost-effective desalinated water. A more realistic and practical approach to correlate the fouling potential with operating recoveries and fluxes was therefore critically needed in the industry to achieve that goal.

This paper directly addresses this dilemma by utilizing a new technology, known as the *Silent Alarm*, that measures and monitors the onset of fouling development or potential in membrane desalination systems in real-time, not as a long-term trend. A quantitative and early-warning parameter known as the "Fouling Monitor (FM)" has been employed to correlate the fouling potential of representative membrane desalination plants around the world as a function of plant operating conversion and flux based on actual system design parameters, operating history and maintenance requirements.

The results of this evaluation show conclusively how to maximize site-specific operating conversion and flux of desalination plants incorporating RO and NF membrane processes, to much more practical and cost-effective values not attainable before, via real-time monitoring of the FM. More realistic on-site optimization of such values are now possible with the new approach. Potential future applications extend even farther to UF and MF membrane processes, especially when used to replace conventional pre-treatment at RO and NF plants. The tide has just turned in the eternal quest to achieve, implement and maintain the most optimum plant design and operating conditions of membrane desalination plants, resulting in delivering superior performance, maximum operating efficiency, maximum conservation and lowest total cost of water.

## I. BACKGROUND

Since the advent of commercial membrane technology applications for water desalination and purification some forty years ago, industry researchers, plant end-users, and membrane manufacturers have been intrigued by the concept of direct relationships between membrane system flux, conversion and fouling potential. Several attempts, both empirical and theoretical, were made to correlate these two dynamic parameters and account for, as well as predict, the possible effect on membrane fouling development. The purpose of these correlations was to better predict and therefore optimize system design, operation and performance, with an obvious direct and significant impact on overall plant operating and maintenance costs. Most attempts focused on large-scale seawater RO plants as the process of choice for producing good-quality drinking water especially in water-scare countries. Proponents of earlier work advocated limiting the effective overall system conversion below a "safe" or "critical" ratio, above which membrane fouling, such as biofouling or colloidal fouling, was thought to promulgate uncontrollably regardless of any design configuration, operating procedures or maintenance regimes. However, these limiting conversion ratios were set at such low levels, ranging between under 20 for hollow-fine fiber membrane systems and 37% for spiral membrane systems employed at seawater RO desalination plants, that rendered the entire membrane process neither practical nor feasible from an economic or cost-worthiness point of view. On the other hand, cost benefits resulting from increasing the conversion and flux can be significant and prove critical in end-users' ultimate decision to adopt membrane processes as the technology of choice for meeting the ever-increasing demand for reliable and cost-effective desalinated water. For example, cost savings resulting from increasing the conversion from 35%-45% for a 37,900 $m^3/d$ (10 MGD) Arabian-Gulf surface seawater RO plant, are estimated at \$1.8-\$2.0 million a year. Moreover, the idea that a single parameter, such as the critical flux or conversion, must be set at a certain value regardless of other design and operational considerations in order to prevent fouling, created a major obstacle to the development and utilization of new technologies and innovations, in both process and equipment, that allow the continual optimization of the operation, competitiveness and cost-effectiveness of membrane processes. The overall effect is to hamper serious water conservation efforts, which are largely driven by maximizing the attainable conversions of large-scale water desalination plants in order to minimize feed intake. A more realistic and reliable approach to correlate the fouling potential with operating recoveries and fluxes was therefore critically needed in the industry to achieve that goal.

## II. FOULING & PERFORMANCE TRENDING

To date, the only available performance evaluation of membrane systems is based on normalizing operating data and flux-decline trending. This technique, known as ASTM D-4516 standard method, was originally developed by a leading membrane manufacturer based on in-house standards and tests, and not on real-life and site-specific plant dynamics including feed water quality, process design, operation and maintenance. Long-term trending, by both definition and practice, does not allow for discovering the development of membrane fouling or scaling until it results in significant loss of performance characteristics such as product flow and salt passage. The technique works, however, in cases where the plant performs as designed (i.e. no fouling or scaling), or when fouling or scaling is very severe from the onset. In reality, such cases are rather the exception than the rule. This is simply due to the fact that RO or nanofiltration membrane system design does not, and cannot, allow for fouling. The so-called Fouling Factor is simply a design "safety" factor that is incorporated in plant design projections by membrane manufacturers for commercial warranty reasons rather than technical ones.

The late discovery in these plants of the onset of fouling, especially biological and colloidal fouling, presented a serious technical and economical challenge to the commercial application of the newly-developed membrane process as a reliable and competitive alternative to thermal desalination. Field experience shows that the problem actually emanates from the lack of adequate and effective system performance evaluation and monitoring rather than from technical limitations of the technology or process itself.

## 2.1 Critical Flux, Conversion & Fouling

The new approach directly addresses this dilemma by utilizing a new technology, known as the *Silent Alarm*, that measures and monitors the onset of fouling development or potential in membrane desalination systems in real-time, not as a long-term trend. This is achieved by comparing the membrane system flux decline performance in terms of its design using the standard normalization method, and a corrected flux decline performance that accounts for plant dynamics and site-specific parameters. Under ideal design and operating conditions, or non-fouling conditions, the difference between the two fluxes is minimal. As soon as fouling or scaling starts to develop on the membrane surface, the real performance starts to deviate from design, and a split between the two curves starts to be exhibited indicating the onset of fouling (*Fig. 1*).

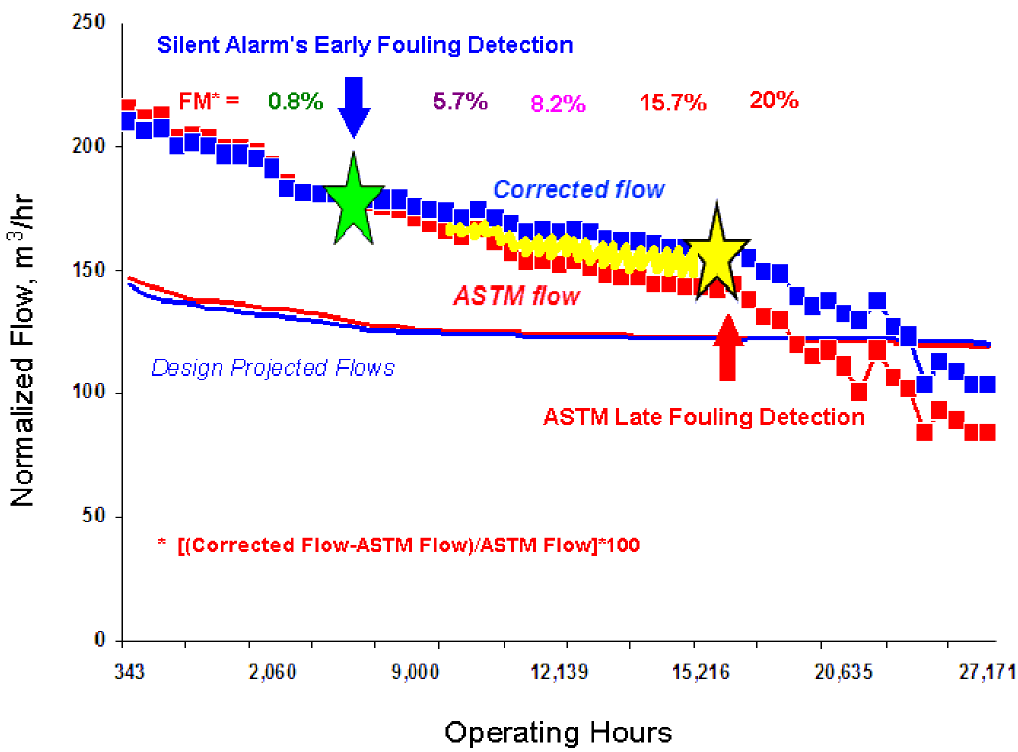


*Figure 1*

Such difference is a quantitative and early-warning parameter known as the "Fouling Monitor" or "FM". *Fig. 4* represents an actual Silent Alarm flux decline evaluation of a large non-fouling RO plant with seawater membranes over an 11-year period, and *Fig. 6* represents an actual Silent Alarm flux decline evaluation of a major SWRO plant with a history of organic fouling. Both plants are located in the Arabian Gulf region.

### 2.2 Methodology

The *Silent Alarm* technology was employed to directly correlate the fouling development or potential as a function of plant operating conversion and flux in real-time based on actual system design parameters and operating history. The FM, as an empirical and sensitive and reliable indicator of fouling, is used to determine the maximum flux and conversions rates that can be attained in a given plant while maintaining non-fouling conditions and the most optimum operational and cost parameters at the same time. Membrane pressure drop performance (*Fig. 3*), as well as the cleaning frequency, are used as supplementary indicators of the prevalence of fouling or non-fouling conditions during each period of interest.

### 2.3 Case Histories

Actual operating data from two major Arabian Gulf SWRO plants were utilized in this study. Train 6 at Plant A had no significant fouling history while Skid 4 at Plant B experienced organic fouling for the first few months of operation. *Table 1* summarizes plant conditions while *Table 2* summarizes and the results achieved from each of these five case studies. The five case histories discussed cover 3 phases at Plant A with incremental increases in conversion, and two phases at Plant B (Phase I when organic fouling was developing, and Phase II after it was identified and successfully resolved).

| CASE HISOTRY | OPERATING HOURS | MEMBRANE TYPE | CLEANING HISOTRY | FOULING HISTORY |
|---|---|---|---|---|
| **PLANT A Train 6-I** | 38,842 | Hollow-Fine Fiber | Annual routine cleaning. | No significant fouling. |
| **PLANT A Train 6-II** | 23,264 | Hollow-Fine Fiber | Annual routine cleaning. | Recovery ratio increased by adding membranes. |
| **PLANT A Train 6-III** | 13,762 | Hollow-Fine Fiber | Annual routine cleaning. | Recovery ratio increased by adding membranes. |
| **PLANT B Skid 4-I** | 5,261 | Spiral-Wound | Frequent cleaning (2-3 times a month). | Moderate to heavy organic fouling. |
| **PLANT B Skid 4-II** | 894 | Spiral-Wound | Cleaning once every 3 months | Fouling source stopped. |

*Table 1*

### 2.4 Discussion

The results of this evaluation show the correlation between operating flux, ASTM-normalized flux and Silent Alarm flux under two different conditions at seawater membrane systems:

A. Non-fouling conditions with variable conversions (*Fig. 2*).
B. Fouling conditions under constant conversions.

| CASE HISOTRY | OPER. CONVRN. % | FOULING MONITOR % | MEMB. DP bar | OPER. FLUX l.m-2.h | ASTM FLUX l.m-2.h | SILENT ALARM FLUX l.m-2.h |
|---|---|---|---|---|---|---|
| PLANT A6-I | 36.4 | 0.35 | 0.79 | 2.42 | 2.53 | 2.54 |
| PLANT A6-II | 38.8 | 0. 87 | 0.63 | 2.35 | 2.10 | 2.08 |
| PLANT A6-III | 42.2 | 1. 19 | 2.32 | 2.48 | 2.24 | 2.22 |
| PLANT B4-I | 35 | 12.6 | 1.23 | 15.30 | 17.59 | 15.37 |
| PLANT B4-II | 35 | 3.1 | 1.76 | 15.28 | 15.56 | 15.07 |

*Table 2*

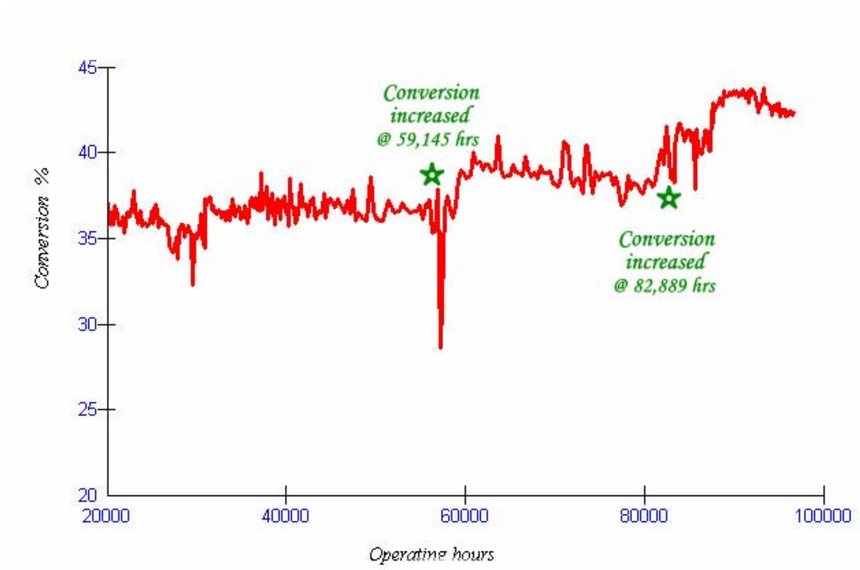


*Figure 2*

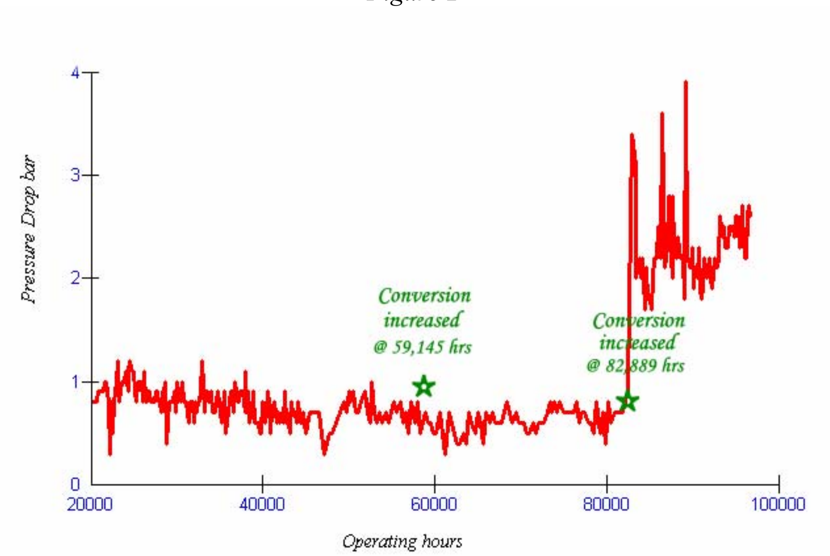


*Figure 3*

Under non-fouling conditions (case histories A6-I, A6-II & A6-III), the closer the ASTM flux and Silent Alarm flux are together, the lower the fouling potential is, as exhibited by the low average FM values (*Table 2*).

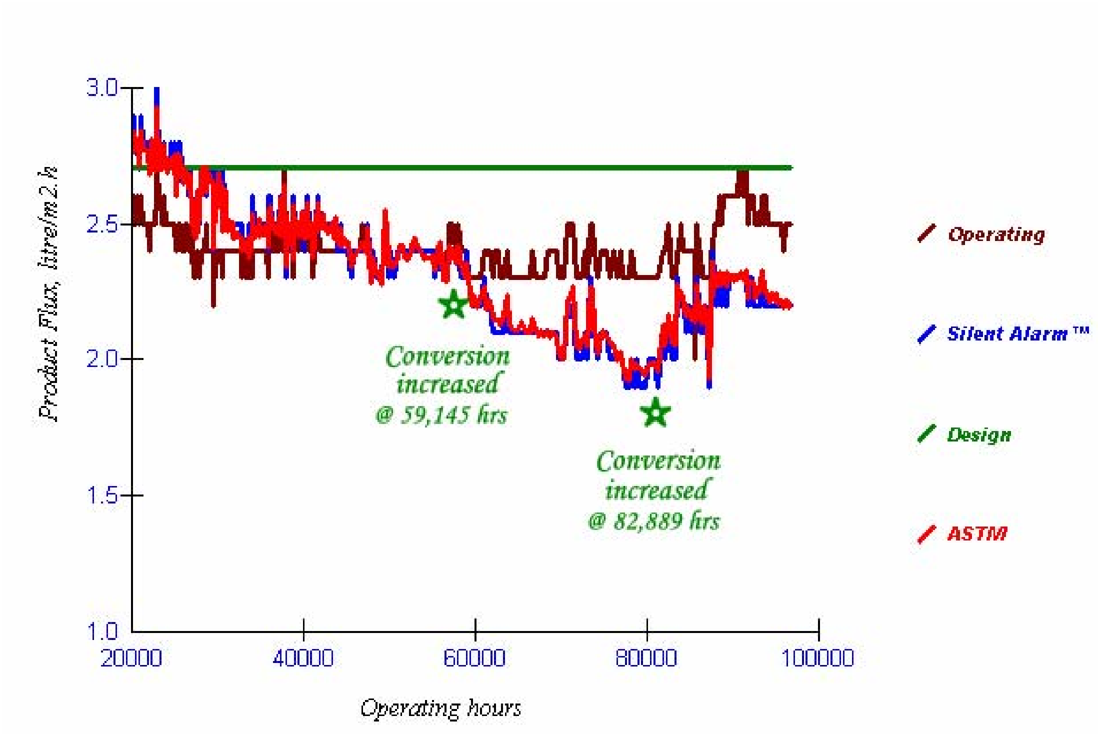


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*Figure 4*

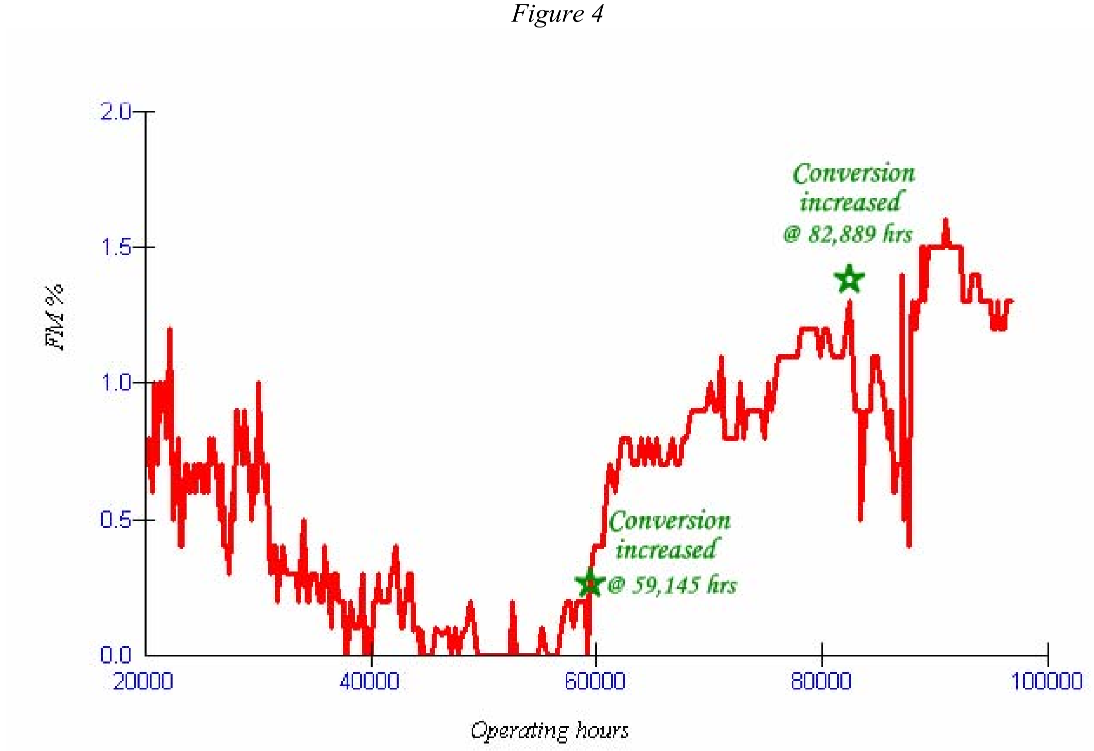


*Figure 5*

Field experience shows that when membrane plants operate at steady FM values under 3%-5%, non-fouling conditions prevail due to sound plant design, good operation and maintenance procedures, and lack of major fouling sources. However, , when the operating conversion was increased at Plant A from 36.4% to 38.8% then to 42.2% by adding new high-flux membranes at 59,145 and 82,889 hours of operation respectively, a remarkable corresponding increase in the fouling potential of the system was observed, as exhibited by the dramatic increase of the FM from 0.35% to 0.87%, a one-and-a-half fold relative increase, then further to 1.19%, a 37% relative increase. While the average membrane pressure drop hardly changed during the first phase of conversion increase, a more dramatic increase was exhibited during the second phase from 0.63 bar to 2.32 bar. Nevertheless, non-fouling condition still prevailed as the FM is still well below the average FM observed at fouling plants (i.e., less than 3%-5%). It may even be possible to further increase the conversion to 45% as long as the FM does not increase over 3-5% while maintaining the ASTM flux and Silent Alarm flux close to each other. The design flux for this plant was 2.71 l-m$^{-2}$.h at 36% conversion. Empirical optimization of the conversion and flux rates can be easily performed depending on site-specific design and operating conditions, as well as cost analyses and other considerations. Thus, monitoring the FM in real-time provides a unique tool allowing the optimization of the operating conversion and flux as long as the ASTM flux and Silent Alarm flux are kept close to each other, while maintaining acceptable membrane pressure drops and cleaning frequencies.

The same conclusions can also be drawn from the results of evaluating Plant B, which experienced an organic fouling problem due to overdosing of the organic polyelectrolyte coagulant-aid. In this case, the FM averaged 12.6% for the first 8 months of operation, indicating moderate to heavy fouling conditions based on field experience. The ASTM flux and the Silent Alarm flux were also remarkably different.

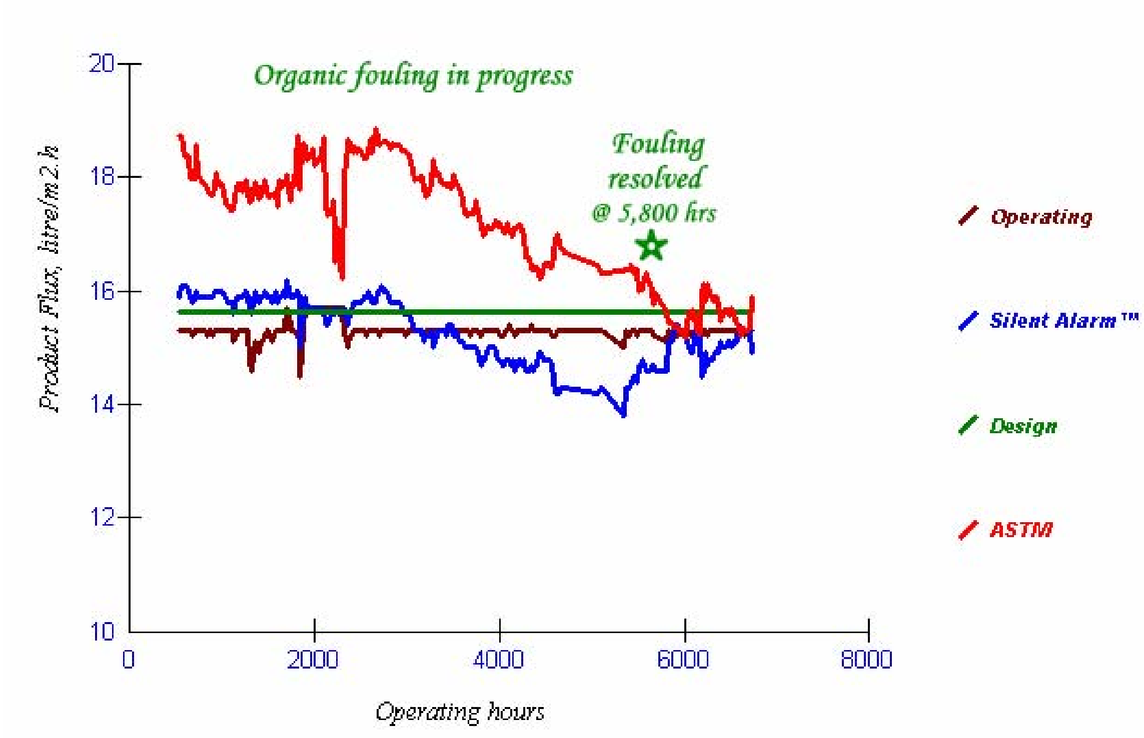


*Figure 6*

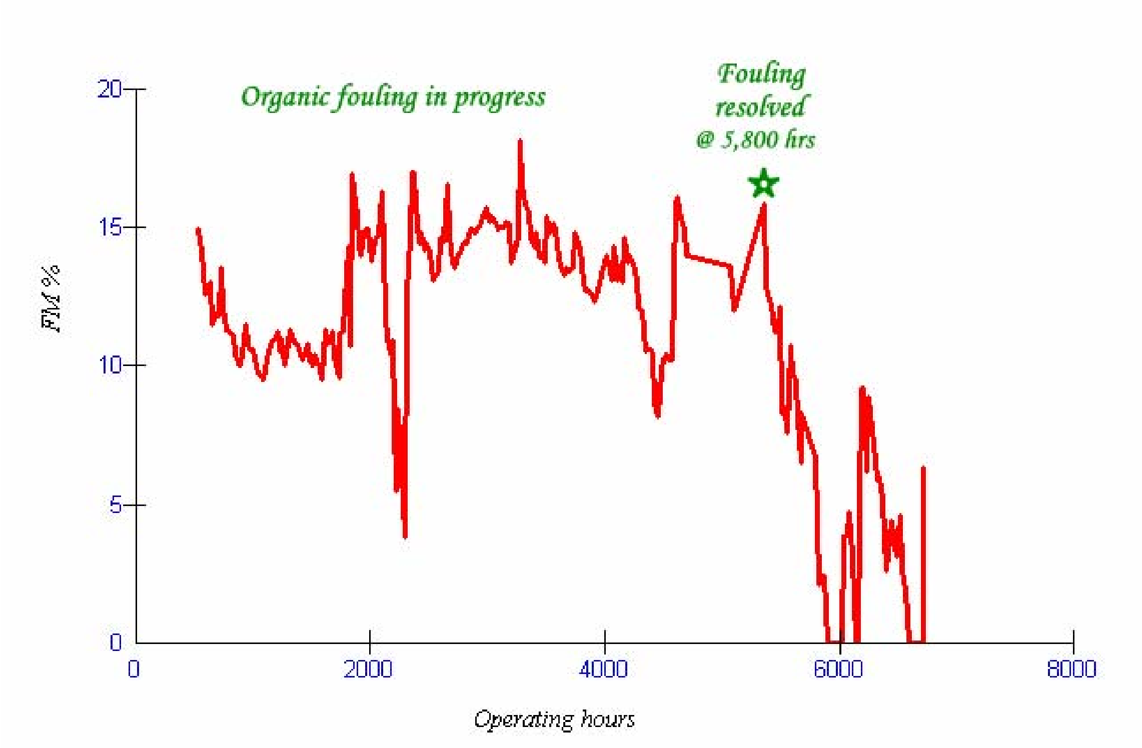


*Figure 7*

However, when the fouling source was stopped by optimizing the polyelectrolyte dosage, the average FM witnessed a dramatic dropped to 3.1% representing a relative decrease of 75%. This was coupled with a significant improvement in the cleaning frequency, typically dictated by rising membrane pressure drops, from 2-3 times a months to once every 3 months as well as a relative reduction and more stabilization of the SDI profile in the pretreatment system. Once non-fouling conditions have been established following the elimination of the organic fouling source, a conversion optimization phase can be initiated to achieve the maximum attainable values based on monitoring the FM and the corresponding fluxes, as well as the corresponding membrane pressure drops, cleaning frequencies and other operational considerations. The design flux for this plant was 15.63 $l\text{-}m^{-2}.h$ at 35% conversion.

The above results show conclusively how to maximize site-specific operating conversions and fluxes of desalination plants, as well as how to achieve non-fouling conditions as a first step to optimizing the operating parameters of such plants to much more practical and cost-effective values not attainable before, via real-time monitoring of the FM. Historical data from many more plants located around the world have been evaluated and similar conclusions to the ones discussed in this paper were reached

## III. CONCLUSIONS

1. The concept of pre-set critical flux limitation to prevent fouling of seawater membrane systems is neither practical nor cost-effective, besides it severely hinders technology innovation and largely ignores the impact of system and process design, as well operational and maintenance regimes on attaining non-fouling conditions.
2. The Silent Alarm technology, representing a more realistic and innovative approach, addresses the lack of adequate, real-time monitoring of the development of membrane fouling and allows the most

optimum determination of design and operational parameters to attain non-fouling and cost-effective conditions at the plant while promoting sound water conservation efforts.

## VI. APPLICATIONS - THE FUTURE

Potential future applications extend even farther to UF and MF membrane processes, especially when replacing conventional pre-treatment systems at RO and NF plants. Unlike RO and NF membranes, UF and MF are inherently designed to foul. Using the new Silent Alarm technology can allow not only designing and testing better performing membranes but also allows the optimization of the fouling regimes of such membranes via real-time measuring and monitoring of the fouling potential as related to operating fluxes and backwash frequencies, flow rates and other operational parameters. Other applications include more optimum and cost-effective membrane plant pilot systems, membrane selectivity and product development of water treatment chemicals, especially anti-scalants and disinfectants.

The tide has just turned in the eternal quest to achieve, implement and maintain the most optimum plant design and operating conditions of membrane desalination plants, resulting in delivering superior performance, maximum operating efficiency and lowest total cost of water.

***To request a free trial of the Silent Alarm software for your membrane desalination plant, click here:***
**http://www.masar.com/software/trial.html**

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