ELSEVIER

Desalination 165 (2004) 183–191

DESALINATION

www.elsevier.com/locate/desal

Early discovery of RO membrane fouling and real-time monitoring of plant performance for optimizing cost of water

Mohamad Amin Saad

MASAR Technologies, Inc., 1688 Lost Moon Court, Tuscon, AZ 85737, USA
Tel. +1 (520) 797 4311; Fax +1 (520) 297 7242; email: mas@masar.com

Received 17 February 2004; accepted 25 February 2004

Abstract

RO plant operators, end-users, membrane manufacturers and system suppliers have been facing two major problems since the advent of commercial membrane technology applications for water desalination utilizing reverse osmosis (RO) and other membrane processes: how to reliably monitor their membrane system performance and how to detect membrane fouling and scaling development in real time and before significant or irreversible loss of performance efficiency occurs, resulting in lower plant availability and significantly higher O&M costs. The current industry-standard performance analysis and evaluation technique is based on trending RO flux decline characteristics of membranes via normalizing system operating data in accordance with ASTM D-4516 standard method. This paper discusses the shortfalls of this technique, and introduces a practical new technology for measuring and monitoring membrane fouling and flux performance in real-time. The new Silent Alarm™ technology, designed as an early-warning system, allows the discovery of any fouling or scaling development on the RO membranes in the very early stages, thus providing a valuable tool for the plant operator to take immediate corrective measures before it is too late. Two major brackish and seawater Arabian Gulf RO plant case studies with and without a fouling history are discussed. This proven capability to monitor RO plant performance in real-time and measure the actual development of any membrane fouling or scaling very early on has a direct and dramatic positive impact on optimizing the total cost of desalinated water.

Keywords: RO membrane; Fouling; Monitoring; Operation; Performance; Normalization; ASTM; Early warning; Alarms; Cost of water

Presented at the EuroMed 2004 conference on Desalination Strategies in South Mediterranean Countries: Cooperation between Mediterranean Countries of Europe and the Southern Rim of the Mediterranean. Sponsored by the European Desalination Society and Office National de l'Eau Potable, Marrakech, Morocco, 30 May–2 June, 2004.

0011-9164/04/$– See front matter

1. ASTM D-4516 – performance trending, not monitoring

Industry-standard ASTM D-4516 method is an analytical technique that was originally developed by the membrane manufacturing industry's pioneer and early leader, DuPont, and can only represents the membrane manufacturer's view of membrane performance trend, in terms of its normalized system flux decline charac-teristics, based on limited in-house testing of synthetic feed water under laboratory conditions, not representative of real-life site-specific plant design, operating parameters and other dynamics. By definition, trending requires a statistically valid, and reasonably large amount of operating data records plotted over a long period of time to establish a definite trend. Field experience at a large variety of membrane plants around the world in the past 20 years shows that it is virtually impossible to detect the early development of membrane fouling in a system simply by monitoring a long-term trending curve that is often ambiguous and contradicting. By the time conclusions can be reliably drawn, fouling development practically becomes too severe (i.e., uncleanable) and often causing irreversible loss in performance and element damage. This is largely due to the fact that fouling is cumulative in nature and builds up over a long period of time, unless it is already too severe from the start, before it starts noticeably exhibiting its physical effects at the plant. The other extreme where ASTM D-4516 trending method works reasonably well is when the membrane system performs well, with virtually no significant fouling, exactly as it was originally designed by the membrane manufacturer.

2. What is an early-warning alarm system?

In order for any technical system (i.e., analytical technique software program, device, etc.) to be reliably considered as an early-warning alarm system, it must be:

1. Functional (i.e., capable of providing a meaningful warning in sufficient time for proper corrective action).
2. Affordable (i.e., cost-effective).
3. Verifiable (i.e., produces similar results under different conditions).
4. Reproducible (i.e., produces similar results under similar conditions).
5. Reliable (i.e., produces minimum false positive or negative alarms).
6. Simple (i.e., requires low or minimum operator understanding and training).
7. Comprehensive (i.e., covers all potential threats and possibilities).
8. Universal (i.e., applicable to most situations in a specific industry).
9. Robust (i.e., capable of remote operation year-round).

3. Fouling measuring and monitoring – the Silent Alarm™ approach

To address the critical need of RO, NF and other membrane plant operators and owners to detect and measure membrane fouling or scaling development as early as it starts to occur and to monitor the real performance of their membrane systems in real-time, MASAR Technologies, Inc., has developed an innovative and practical new technology – the Silent Alarm™. The new approach was discovered after many years of closely monitoring and trending the flux decline performance of a large RO plant in the Middle East with a biofouling history that exhibited itself suddenly after the first 2 years of operation, as was the cased in many other desalination plants, too late for any meaningful corrective action.

Many plants which are prone to fouling typically start exhibiting significant and sudden losses in productivity and/or deterioration in product quality when the ASTM-normalized "trend" in flux decline or salt passage has matured, at which point it is almost always too late to save the plant. Significant losses in the plant's performance, availability and consequently O&M costs result. This new technology is capable of detecting or discovering fouling or scaling development at the onset and quantitatively measuring it via a parameter known as the Fouling Monitorä (FM), representing the percentage differential between the industry-standard ASTM-normalized flow and the corrected-normalized flow of each data point using the new approach, as indicated by the yellow area on the graph (Fig. 1). The new monitoring system acts as an early-warning alarm system and benefits plant owners and end-users in minimizing the total cost of produced water.

4. Arabian Gulf plant performance history

4.1. Case study 1

Fig. 1 shows a typical normalized flux decline graph of a large brackish RO plant located on the Arabian Gulf with hollow-fine fiber polyamide membranes.

The plant witnessed a biofouling event that started to be physically exhibited on site at the end of the second year of operation (about 17,500 h of operation), as a case of severe fouling "trend". However, using the same operating data, the Silent Alarm™ shows that a rising FM values at the very early stages of fouling development, almost 9 months earlier (manifested in the beginning of the split between the two red and blue normalized flux decline curves). Because the plant was apparently performing so well in terms of productivity and quality throughout the entire first two years of operation, the biofouling event went undetected until the flux suffered a sudden drop (at about 17,500 h). Subsequent frantic cleanings proved ineffective and a large number of membranes had to be replaced at a great cost, coupled with critical loss of plant availability and much lower productivity, as the plant provides a major portion of desalinated drinking water.

Fig. 2 shows the normalized flux decline history of the same plant (both by the ASTM and Silent Alarm™ methods), after membrane replacements, system refurbishment and operation optimization, and other process and operational changes that resulted in sustaining excellent, non-fouling performance, as exhibited in achieving optimum

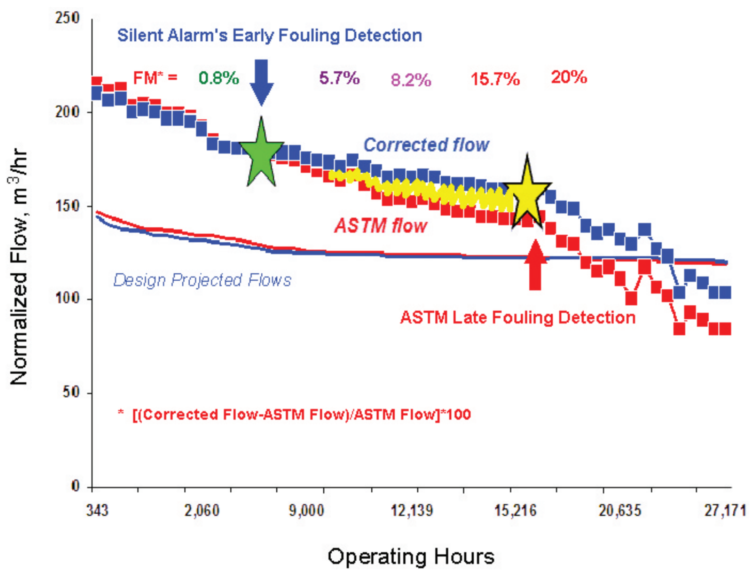

Fig. 1. Flux decline history — brackish RO plant.

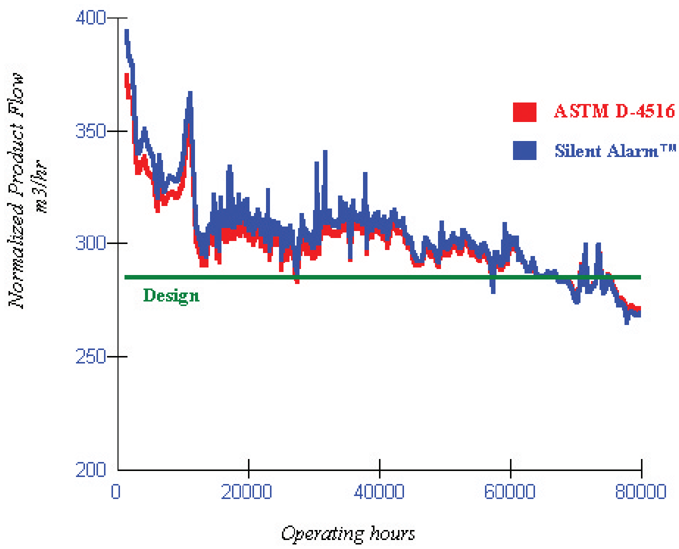

Fig. 2 ASTM and Silent Alarm™ normalized flux decline histories — brackish RO plant.

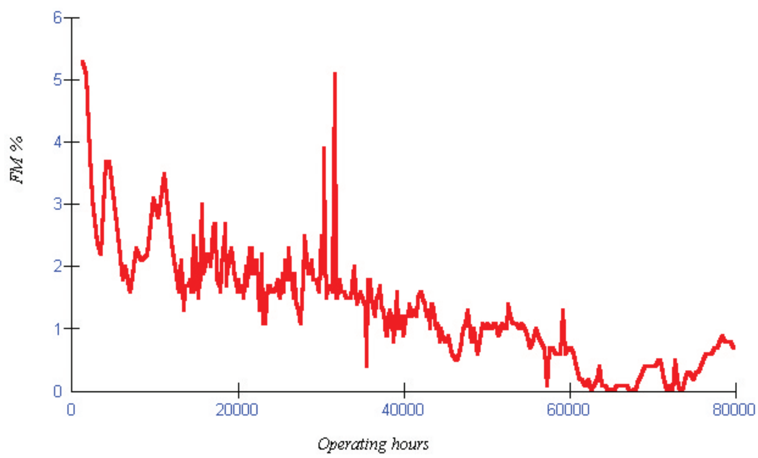

Fig. 3. Non-fouling Fouling Monitor™ (FM) history — brackish RO plant.

productivity, minimum maintenance and maximum plant availability for the next 7 years of operation. Fig. 3 shows the FM history for this period, averaging just 1.4% over about 80,000 h of operation.

4.1. Case study 2

Fig. 4 shows the ASTM-normalized flux decline trend performance of RO Train 4 at a large surface seawater RO desalination plant on the Arabian Gulf with spiral-wound polyamide membranes in its first year of operation (about 7,000 h of operation). As can be seen from the graph, it is very hard at any time during this monitoring process to conclude with any degree of certainty whether membrane fouling is occurring until the sudden drop observed at 2,000 h of operation. However, the plant was also being monitored by measuring the trans-membrane pressure drops on representative membranes on this train 3 times a week Fig. 5 shows the membrane pressure drop performance, indicating that an accelerated rising trend began to be observed shortly after the sudden flux drop observed at 2,000 h of operation. The

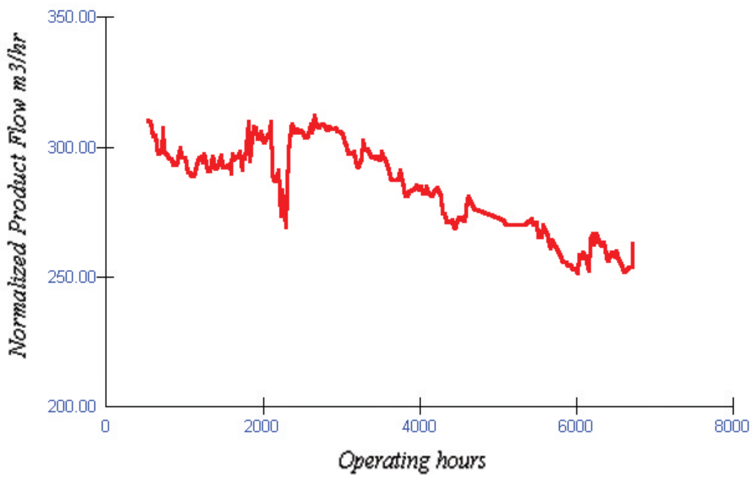

Fig. 4. ASTM-normalized flux decline trend — seawater RO plant.

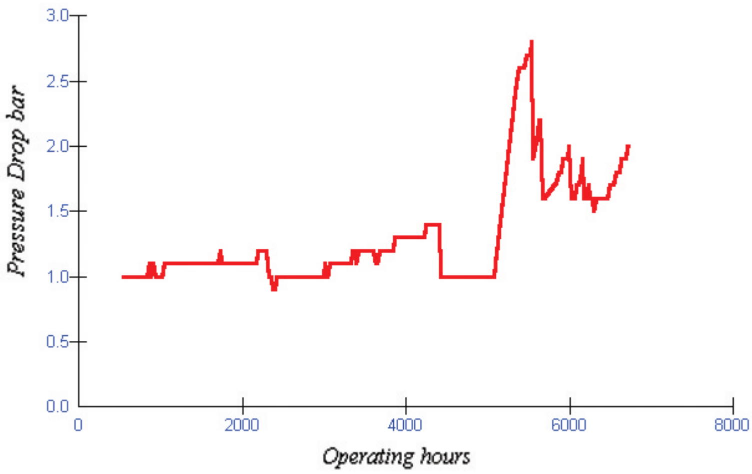

Fig. 5. Trans-membrane pressure drop history — seawater RO plant.

effect of more frequent cleanings, as governed by set limits in the membrane pressure drops, is clearly exhibited in this graph (i.e., peaks and valleys). A major worsening trend in both graphs started to occur at about 5,600 h, indicating a significant increase in the severity of the fouling situation.

Fig. 6 shows the normalized flux decline performance history of the same train at this plant (analyzed by both the ASTM and the Silent Alarm™ methods). The graph clearly shows a wide split between the ASTM and Silent Alarm™ curves, indicating a significant fouling situation is already in progress almost from start-up! Again, had the Silent Alarm™ technology been employed at the plant as an early-warning monitoring tool, it would have discovered the fouling development very early on (i.e., long before the ASTM normalized trending or even membrane pressure drop monitoring), and significant losses in plant performance and availability, at a high operating cost, would have been averted. The Silent Alarm™ FM averaged 12.6% during the first 5,800 h of operation, as shown by the Silent Alarmä program (Fig. 7).

Following a two-week trouble-shooting and testing effort at the plant site, organic fouling was

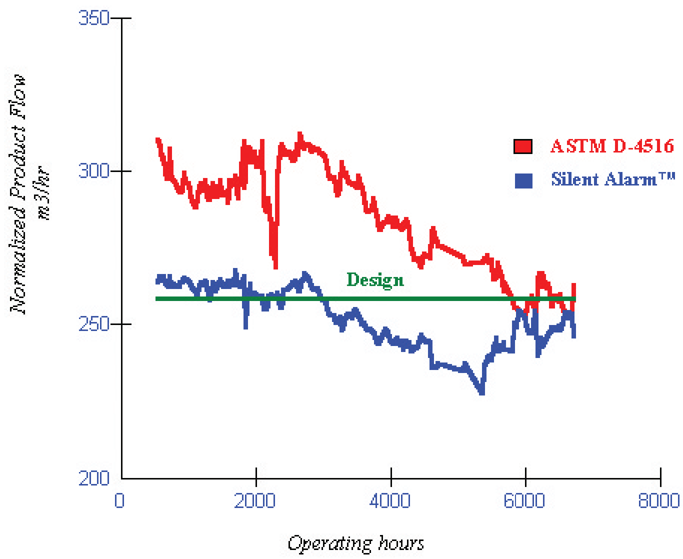

Fig. 6. ASTM and Silent Alarm™ normalized flux decline histories — seawater RO plant.

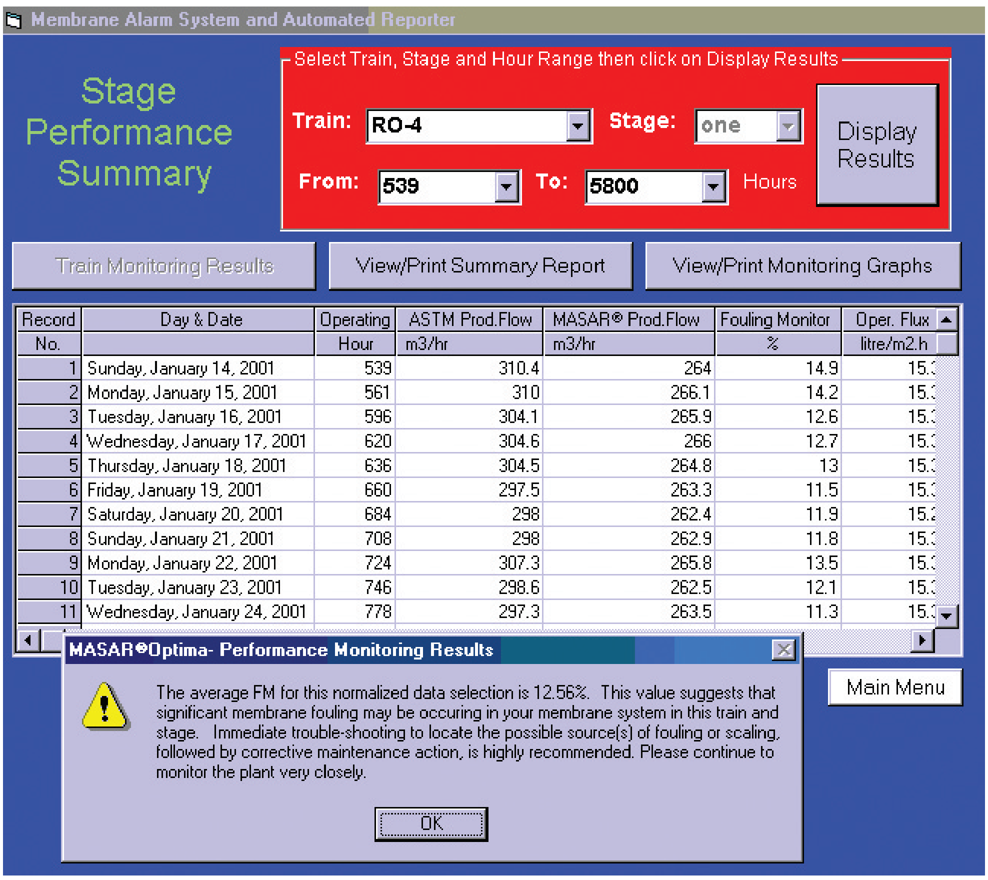

Fig. 7. Silent Alarm™ Fouling Monitor™ (FM) display screen — seawater RO plant.

subsequently identified at the plant, and corrective action was successfully implemented to stop its source.

Fig. 8 shows the FM immediate improvement after successfully resolving the fouling situation averaging 3.1% over nearly the last 1,000 h of operation (from 5,824 to 6,717 h of operation) since the fouling was corrected.

Based on the above case histories and many others from different membrane plants around the world, the Silent Alarm™ satisfies all of the listed requirements as an early-warning system for RO, NF, UF and MF membrane water purification and desalination plants.

5. Fouling Monitor™ practical guidelines

Based on 20 years of plant fouling and performance monitoring field experience and actual operational history data of tens of major membrane water desalination and purification plants around the world, both brackish and seawater, with hollow-fine fiber and spiral-wound membranes operated in any staging arrays and system design configuration, practical FM guidelines were developed (Table 1). Plants exhibiting FM values from 3 to 5% are considered well operated and maintained plants with little or no fouling. As soon as the system indicates an FM increase, within

Table 1
Silent Alarm™ Fouling Monitor™ (FM) guidelines

FM range, %	Fouling status	Recommended action
0–5	No significant fouling.	Good operation. Continue to monitor.
5–10	Low to moderate fouling may be starting to develop.	Monitor more closely. Consider trouble-shooting if trend rise continues.
10–20	Moderate to heavy fouling is in progress.	Start trouble-shooting immediately to identify and eliminate source of fouling.
Over 20	Heavy to irreversible fouling is occurring.	Significant membrane replacements required due to extensive loss of performance and possible physical damage.

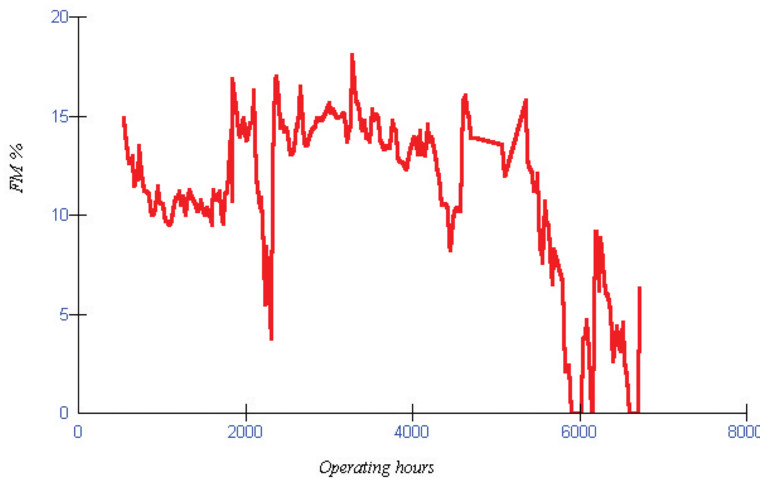

Fig. 8. Silent Alarm™ Fouling Monitor™ (FM) history — seawater RO plant.

just a few hours or days, the operator is soft-alarmed so that trouble-shooting can be quietly and immediately initiated and corrective action systematically implemented to identify and isolate the source of fouling or scaling while the plant is apparently still performing well and delivering the required capacity and quality, and no panic cleaning, which is often ineffective, is needed.

6. Silent Alarm™ technology applications

Table 2 lists design and operational data input requirements, the same as required by ASTM D-4516 method. Data can be entered manually by the operator, imported from the plant's Supervisory Control and Data Acquisition Systems (SCADA), or converted from existing data spreadsheets or from membrane manufacturers' normalization program data storage files.

Fig. 9 shows the Silent Alarm™'s software system menu and functionality flow chart in the design, operation and performance monitoring modes.

Table 2
Silent Alarm™ data input requirements

Required parameters	Optional parameters
1. Train or skid name	1. Feed turbidity (NTU)
2. Stage number	2. Feed SDI
3. Date data collected	3. Micron filter pressure drop
4. Operating hour	4. RO feed pH
5. Feed temperature	5. Redox potential (ORP)
6. Feed salinity or conductivity	6. Chlorine residual
7. Feed pressure	7. Others (customized)
8. Membrane pressure drop	
9. Permeate pressure	
10. Final reject flow	
11. Permeate flow	
12. Permeate salinity or conductivity	
13. No. of pressure vessels on-line	
14. No. of membrane cart. per p.v	
15. Membrane cartridge area	
16. O&M cost basis	
17. Actual O&M cost data	

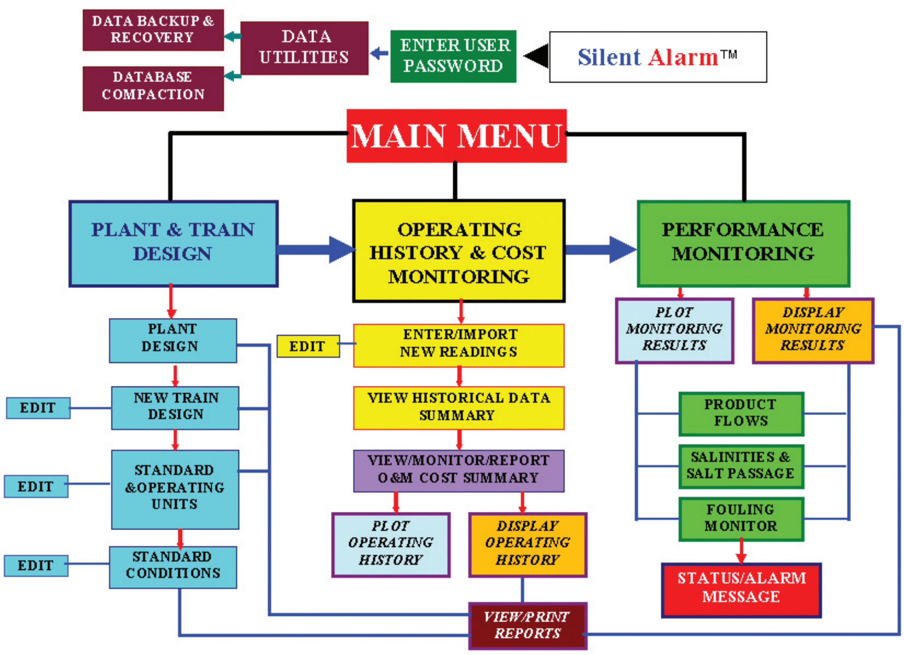

Fig. 9. Silent Alarm™ software system flow chart.

8. Conclusion

The membrane technology market around the globe is currently valued at over two billion US dollars a year with an annual growth rate of 10%. Water-scarce countries, as most countries in the Middle East and South Mediterranean region, will see a rise in the need for desalinated water capacity from 1.9 million m^3/y a year to 14.9 million m^3/y for the period from the year 2000 to 2025, an annual growth rate of 27%. This explosive growth in desalination, a great part of which will come from large-scale membrane plants, compels and mandates the need to address the critical problem of monitoring and evaluating membrane desalination plants performance, fouling development and operational cost-effectiveness. New mega-size sweater RO plants are already operating, coming on-line, or being designed or conceptualized for start-up in the new millennium, including new and refurbished plants of 50,000–130,000 m^3/d capacity in Bahrain (Ad-Dur), Kuwait (Sulaibiya), Saudi Arabia (Al-Jubail, Jeddah and Yanbu), the United Arab Emirates (Fujairah), Tunisia (Djerba, Gabes and Zarzis), Malta (Pembroke), Trinidad (Point Lisas), and in the United States, Florida (Tampa Bay), Texas (Corpus Christie), Arizona (Scottsdale), and Southern California (5 SWRO plants for San Diego County). Reliable performance and availability of these plants, for example, at minimum operating and maintenance costs are mandatory. The recent fouling and performance problems at the new 25 MGD Tampa Bay Seawater RO Plant in Florida exemplifies the need for reliable monitoring technology if this and future mega plants are to succeed. The new Silent Alarm™ technology can provide these plants and many others a unique tool to help them achieve these objectives on a daily basis. More important, this proven capability to monitor RO, nanofiltration and other membrane-based plant performance characteristics in real-time, and discovering, not trending, the actual development of any membrane fouling or scaling before too late has a direct and dramatic positive impact on optimizing the total cost of desalinated water.

Bibliography

Al-Mansour, A.-H., 30 desalination plants produce 3 Mm^3/day of drinking water. Arab Water World, 26(4) (2002) 42–43.

ASTM D 4516-00 method, Standard Practice for Standardizing Reverse Osmosis Performance Data, American Society of Testing Materials, 2000 (revision).

Brauns, E., Could fuzzy logic be the key to membrane fouling control. The International Desalination & Water Reuse Quarterly, 13(2) (2003) 18–24.

Bremere, I., M. Kennedy, A. Stikker and J. Schippers, Growth of 200% predicted for desalination in water-scarce countries by 2025. The International Desalination & Water Reuse Quarterly, 11(2) (2001) 7–12.

Henley, M., Desalination — demand for more fresh water drives desalination in many nations, UltraPure Water, April (2003) 14–18.

Metropolitan Water District Seeks Proposals on Desalting the Pacific Ocean, www.waterindustry.org, updated Dec 4, 2002.

Pursley, K., Software warns of early membrane fouling, Industrial Water World™, Automation, 3(1) (2002) 13.

Saad, M.A., Biofouling prevention in RO polymeric membrane systems. Desalination, 88 (1992) 85–105.

Saad, M.A., Optimize water cost by early prediction of membrane system fouling trends, Proc. 1999 IDA World Congress on Desalination and Water Re-use, San Diego, CA, USA, Aug. 29–Sept. 3, 1999.

Saad, M.A., Real-time membrane fouling monitoring — a case history, Proc. Water World™'s World Water Conference, Las Vegas, NV, USA, Dec. 10–13, 2001.

Saad, M.A., New, real-time monitoring technology for desalination plants. Arab Water World, 26(1) (2002) 6–7.

Saad, M.A., Manufacturer's case study: smart software optimizes membrane plants, International Desalination & Water Reuse Quarterly, 13(2) (2003) 45–49.

Texas Water Development Board, Demonstration seawater desalination project — Statement of Interest. Nov. 1, 2002.