Advanced SWRO

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Controlling membrane fouling and thus energy consumption

Efficient use of energy plays a major role in determining the production costs of an industrial process. In a seawater reverse osmosis (SWRO) plant, 50% of the energy is consumed by high-pressure pumps; more is consumed where the plant is operated without energy-recovery units. One of the main challenges in SWRO plant operation is membrane fouling and its impact on energy consumption.

Membrane fouling is an inherent natural phenomenon of the membrane separation process. As the membrane becomes fouled over time, the specific energy consumption of an SWRO plant increases and the product quality decreases. The advanced operation of an SWRO process provides a platform to monitor membrane fouling and energy-efficient operation. The advanced operation of an SWRO plant requires excellent automation, which includes:

- Use of variable frequency drives (VFDs) for high-pressure pumps to control fluctuations in product water flow and product concentration due to fluctuations in the feed concentration, temperature and membrane fouling;
- Advanced process control and continuous monitoring of membrane performance during operation in order to prevent major membrane damage; and
- Optimization of SWRO plant operating conditions considering the dynamic nature of membrane fouling.

Meeting Potable Water Needs

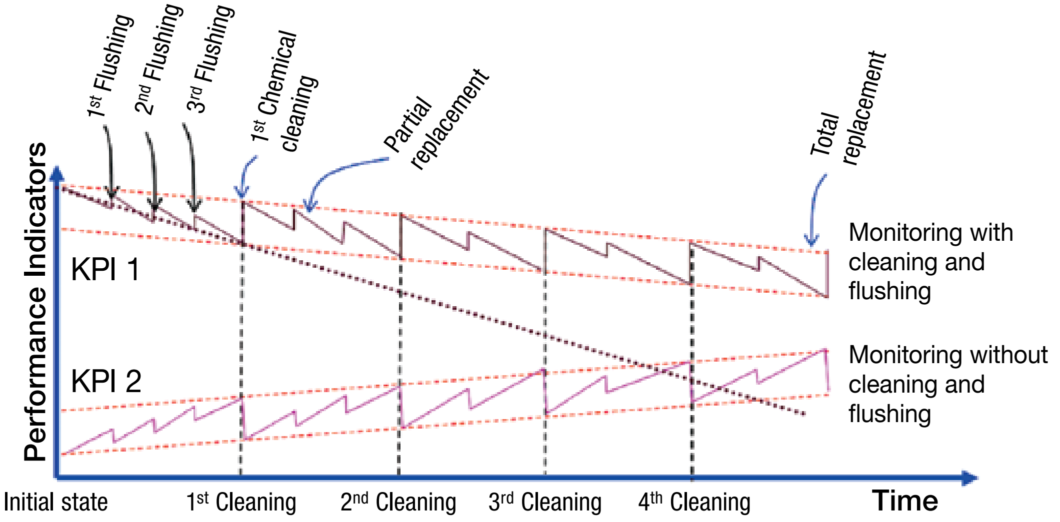
Potable water scarcity and conservation are becoming major issues this decade. Surface water and groundwater are the main potable water resources available. With the passage of time, surface water sources are becoming polluted by human activities, requiring extensive treatment to be used as potable water. In addition, groundwater levels are declining rapidly due to the imbalance between the rates of consumption and harvesting.

In the current scenario, available surface water and groundwater are not sufficient to supply the demand for potable water. As a result, desalination of seawater has become prominent as a way to support growing demand over the last two decades.

There are several conventional processes available to desalinate seawater. RO is emerging as one of the best options due to its low capital cost and energy requirements compared to other techniques, such as multi-stage flash. These benefits are achieved by the innovative development of stable and low-pressure RO membranes, modules, equipment, energy-recovery systems and pretreatment processes to remove scale-inducing material from seawater.

Although technology has not yet reached maturity to its thermodynamic limit, several opportunities to reduce the

Figure 1. Performance Parameters Reflecting Dynamic Nature of Fouling



production cost further exist. It is well known that water recovery rate is the process parameter that has the largest effect on the investment and operating cost. Here a different aspect of advanced SWRO plant operation is presented.

SWRO Control Strategy

In the SWRO process, high pressure is applied at the feed side of the membrane to overcome the osmotic pressure of solute and to transport the solvent from feed side to permeate side. Solute accumulates near the membrane surface, and its concentration increases gradually over time, adversely affecting the membrane performance. This phenomenon is called concentration polarization.

Concentration polarization is inversely proportional to the feed cross-flow velocity across the membrane module. As recovery of product or permeate water increases, the feed velocity across the membrane decreases, resulting in increased concentration polarization. The concentration polarization also depends on other variables, including feed concentration, feed pressure, pH and feed temperature. As a result, the plant production rate and product water quality will fluctuate due to seasonal changes in seawater conditions. To accommodate these variations, feed flow and pressure to the membrane have to be maintained to requirements.

For example, the typical variation of feedwater salinity and temperature is ±2,000 ppm and ±2˚C. When the effect of feedwater temperature and salinity on permeate total dissolved solids (TDS), permeate flow rate, net driving pressure (NDP) and recovery ratio is simulated for Fujairah SWRO plant, the product water flow and TDS increase with feed temperature. The NDP, which is directly proportional to the energy requirement, comes down. Product water TDS increases, and the quantity decreases for higher feed concentration. Seung J. K., et al. have proposed a control methodology for the feedwater temperature to meet desired product water (TDS 600 ppm) and not for constant product flow rate.

Thomas M., et al. studied minimizing RO energy consumption under variable conditions of operation. The results show that when the operational parameters of a plant vary, the key issue for minimizing SEC is to control the plant over the entire width of the operational range without creating throttling losses. This can be achieved only by using hydraulic equipment that allows for feed pressure adjustment at minimum energy dissipation and eliminates the need for throttling valves. Throttling or bleeding dissipates energy and increases specific energy consumption. This effect was proven to be the more significant with favorable mass transfer conditions. Systems using a VFD for control and a Pelton turbine for energy recovery proved to be superior.

Membrane Fouling Monitoring

The major issue in the operation of an RO plant is membrane fouling due to improper pretreatment and operation. This phenomenon decreases membrane performance in terms of product water quantity, quality and life of the module. As a result, an RO plant cannot be operated optimally. An advanced operational solution that monitors membrane fouling will help optimize plant operations.

The usual industrial practice is to clean the membranes at predetermined fixed intervals, or when pressure drops between the feedwater and brine reject exceed a threshold value. These practices are not ideal for scheduling membrane cleaning, as they are akin to rule-of-thumb methods.

Another way to monitor membrane system performance is through normalization of operating data. This method originally was developed by a membrane manufacturer based on in-house experiments, and it does not account for deviations from the design operating conditions practiced in real plants. Therefore, this method may not predict membrane performance accurately for a real plant.

ABB has developed a new solution for advanced operation of membrane processes (Optimax Membrane Performance), specifically for RO and nanofiltration, to overcome the aforementioned drawbacks. The solution consists of two modules: the first to cover the functional scope of membrane performance monitoring, and the second to cover membrane operation optimization.

The function of the performance monitoring module is to calculate the selected key performance indicators (KPIs) that reflect the dynamic nature of fouling, which provide proper monitoring of the membrane fouling condition. The calculation of KPIs is done using a first principle mathematical model. For the calculation, nominal process data such as feed temperature, feed pressure, differential pressure or reject flow rate is required. It does not require additional measurements, so the solution can be added to new or existing installations.

The calculation is done on a train-by-train basis, and the trains are described by models. In Figure 1, the two main KPIs show an adverse effect with occurring fouling: While one KPI increases (FP2), the other one decreases (FP1).

A combined analysis allows insight into to the actual condition. The calculation is done over time at regular time intervals. The associated mathematical model is tuned occassionally (e.g., when the membranes are chemically cleaned) in order to reflect the real plant behavior and characteristics. A prediction based on actual as well as historical data using the tuned model provides an estimated due date for taking chemical cleaning measures. Based on pre-configured limits, the status of the train is indicated using color coding (see Figure 2). The alarm limits can be defined flexibly.

The performance monitoring is applicable for different membrane elements, and it does not require additional sensors. It considers the hydrodynamics of membrane fouling at the membrane surface and addresses the complete membrane life cycle except for partial replacement. The performance monitoring function also allows an assessment of the quality of taken maintenance measures by comparing the condition before and after the maintenance measure using an analysis of the main two KPIs.

Optimization of SWRO Membrane Operations

The second module of Optimax Membrane Performance addresses the optimization of membrane operations in the SWRO process. It uses the results obtained from the performance monitoring solution as the basis. These optimal operation conditions are calculated considering the operational and physical constraints. Depending on whether VFDs are used to drive the pump motors, either feed pressure and feed flow (VFDs used) or feed pressure or feed flow (operation without VFDs) set points can be calculated.

Because fouling rate dynamics also depend on the operational set points, the optimal set points are calculated not only to increase productivity levels but also to minimize the fouling rate. The optimal conditions are calculated regularly, and the solution can be implemented for both open- and closed-loop operations.

The Optimax solution has high flexibility in terms of application, and it is developed based on an information management system used for data handling, storage and information management. The information management system is capable of consolidating data from various process control systems. In addition, the system provides for visualization of results.

The calculated results from the performance monitoring and optimization modules are stored in the information management system, and they can be transferred to the process control system using standard interfaces for visualization. Extensive reporting functions are available with the information management system. Reports can be created in Microsoft Office and deployed as .html files on the Web server of the information management system. These reports are accessible and viewable using thin client technology.

The performance monitoring and optimization solution has been implemented successfully using this architecture. With the pilot, it was possible to demonstrate that the solution is capable of capturing the dynamics of fouling in real time and to give insight into the membrane condition. By implementing the optimization module, it is possible to reduce the gap between actual and optimal set points by gradually applying optimal set points to increase productivity. By gradually implementing optimal set points, it was possible to achieve an approximately 2% productivity increase during the pilot and to optimize the fouling rate.

The solution is demonstrated with the pilot. The pilot plant does not have VFDs for high-pressure pumping, so the Optimax membrane performance tool is used to estimate the benefit of VFD.

The solution is energy efficient as well. It monitors membrane fouling and calculates the optimal operational conditions, maximizing the product flow rate and minimizing SEC.

The membrane monitoring solution also helps minimize membrane maintenance costs by reducing the amount of chemicals required for cleaning and the risk of membrane damage, as they are dependent on the condition of the membrane system. In addition, the plant availability is increased by lowering cleaning and replacement activities, thus reducing plant downtime. The solution is applicable to different membrane configurations and can be used with existing or new installations without requiring additional measurements.

With this new approach, the maintenance process for membrane systems can be changed from reactive and preventive to a predictive, condition-based way of operation. MT

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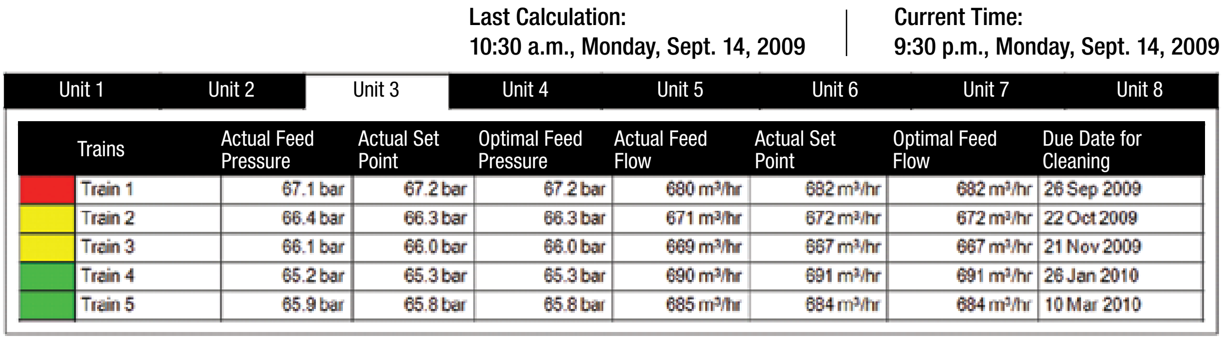
Figure 2. Results Visualization Giving Membrane Condition and Estimated Due Date per Train



Last Calculation:
10:30 a.m., Monday, Sept. 14, 2009

Current Time:
9:30 p.m., Monday, Sept. 14, 2009

	Trains	Actual Feed Pressure	Actual Set Point	Optimal Feed Pressure	Actual Feed Flow	Actual Set Point	Optimal Feed Flow	Due Date for Cleaning
🟥	Train 1	67.1 bar	67.2 bar	67.2 bar	680 m^3/hr	682 m^3/hr	682 m^3/hr	26 Sep 2009
🟨	Train 2	66.4 bar	66.3 bar	66.3 bar	671 m^3/hr	672 m^3/hr	672 m^3/hr	22 Oct 2009
🟨	Train 3	66.1 bar	66.0 bar	66.0 bar	669 m^3/hr	667 m^3/hr	667 m^3/hr	21 Nov 2009
🟩	Train 4	65.2 bar	65.3 bar	65.3 bar	690 m^3/hr	691 m^3/hr	691 m^3/hr	26 Jan 2010
🟩	Train 5	65.9 bar	65.8 bar	65.8 bar	685 m^3/hr	684 m^3/hr	684 m^3/hr	10 Mar 2010

Red - membrane requires cleaning <15 days

Green - membrane requires cleaning >60 days

Yellow - membrane requires cleaning <15 days; >60 days