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DESIGN, OPERATION AND MAINTENANCE OF IDEAL RO PLANTS

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Abstract

Purification of water and wastewater with reverse osmosis (RO) membrane, though simple in concept, is very much a process with complicated chemistries requiring validated design and trained operations team. The challenge for designing and operating RO membrane plants to run continuously, with membrane service lives of greater than 12 years forces one to examine the adequacy and integration of functions needed in the realms of process chemistry, plant equipment and people that operate and maintain the RO plants.

Our daily focus on solving major problems of existing RO plants, and closing the gap between these plants and those that run continuously without unscheduled stoppages for more than 12 years motivated this analysis of functions that relate to plant performances. We list the major functions in the process, equipment and people domains. Missing functions often can be correlated with poor plant performances. Since end-users have the economic burden of providing for these functions, their awareness of the relationship between the functions and outcomes in plant operation is very important. For the end-user's staff, contractors, suppliers and consultants, considerations and optimization of their functional effectiveness brings great value to their services. By pointing to the needed changes and missing functional components, we are very optimistic that through collaborations, our technical community can come together to promote a best practice for the much desired goal of seeing RO used as continuous processes without fouling, and at maximum recovery of precious water.

***Keywords**: Reverse osmosis, continuous process, membranes, service life, plant functions, performance.*

Introduction

The world is increasingly dependent on the use of reverse osmosis (RO) membrane plants for the purification of water and wastewaters (Pankratz and Strickland, 2007; Wangnick 2004; AWWA 2004). The performance of existing RO plants range from continuous operation with no need for stoppage for cleaning to daily cleanings. An international survey of 62 large plants indicated that more than 90% performed chemical cleanings with the median chemical cleaning frequency given as about twice a year (Burbano et al 2007). Among our clients, membrane service life varies from greater than 12 years to less than one year. Costly membrane replacements after 2 to 5 years of service are common. Since membrane purified water is critical to the overall continuous production of final products such as power, municipal drinking water and industrial products, unscheduled stoppages for cleaning or membrane replacements are extremely costly if not unacceptable.

Our daily focus on solving major problems of existing RO plants, and closing the gap between these plants and those that run continuously without unscheduled stoppages for more than 12 years motivated this analysis of functions that relate to plant performances. We list the major functions in the process, equipment and people domains. Missing functions often can be correlated with poor plant performances. Since end-users have the economic burden of providing for these functions, their awareness of the relationship between the functions and outcomes in plant operation is very important. For the end-user's staff, contractors, suppliers and consultants, considerations and optimization of their functional effectiveness brings great value to their services.

Functions necessary in the design and operation of RO plant

On the surface, production of pure water with RO seems to be a simple process, field data showing a wide range of plant performances indicate that it is not. Due to uncontrollable variations in quality of the incoming raw water, system upsets, and the sensitivity of the membrane to fouling, especially when high recoveries are needed, RO systems need to be carefully designed and operated using a full complement of functions. We shall point to the more obvious ones. Probably due to affordability, needed functions may have been missed. For problem plants, and those desiring improvements, a review of the functional weaknesses would be useful.

Figure 1: 3 Ps of water processing plant with RO

- Process chemistry
- Process Equipment
- Process Procedures/People

The acronym 3Ps in Figure 1, points to the three domains of functions that need to be integrated in design and operation. For each of the domains, we will list the main functions below in random order, and provide some comments based on our field experiences.

Process Chemistry

1. Water analysis: Concentrations in mg/liter of following cations: Ca, Mg, Ba, Sr, iron, manganese, aluminum, and following anions: bicarbonate, carbonate, sulfate,

fluoride, phosphate, along with pH, Total Dissolved Solids, turbidity, Silt Density Index, and reactive and total silica , are needed to project scaling potential in RO system, and antiscalant requirements. Although fouling by coagulation of organic and inorganic colloidal particles (1 to 100 nanometers in size) in RO feed-water is a major cause of fouling today, limitation of methodology to quantitate, speciate, and predict their fouling potentials makes control at the level of water analysis not useful today (Ning, 2005).

2. Percent recovery possible: Due to the rejection of nearly all dissolved and suspended impurities in water, the higher the % recovery of the permeate, the higher the scaling and colloidal fouling potential of the concentrate. Based on the water analysis, experiences with various sources of raw water and pretreatment steps adopted, an antiscalant and a dosage is recommended by a chemical supplier for trial and qualification. Antifoulant and dosages are chosen and tested empirically when needed.

3. Permeate quality: For each intended use of the RO permeate, there is a criterion of quality that has to be met through post treatment. For example, boiler water requires silica concentrations of <20 ppb. Post treatment may require a second pass RO followed by strong base ion-exchage.

4. Concentrate disposal: High requirements now exist for the issuance of discharge permits for RO concentrate. The cost and environmental impact of concentrate discharge is now stimulating development of processes for concentrate volume reduction and zero liquid discharge.

5. Pretreatment: For the RO, pretreatment is always needed, varying from simple guard cartridge filters to multi-unit operations such as clarifiers, multimedia filters, chlorination-dechlorination, acid or coagulant injections, carbon or manganese Greensand filters, membrane bioreactors and microfilters/ultrafilters. Where appropriate, low dosages of antiscalants and antifoulants can greatly simplify pretreatment (Ning, 2003). For example, the use of appropriate antiscalant can replace manganese greensand and iron oxidation and removal pretreatments.

6. Process design: Over-design can lead to as many RO operation problems as under-design. Many problems in existing RO plants are solved by simplification of pretreatment. Where necessary, contaminant reduction is best performed as a polishing step after RO. Activated carbon tower as pretreatment is a good example. Before the RO, carbon is susceptible to biofouling to such an extent that even with periodic steam sanitization, it sheds colloidal biomass and carbon fines which pass 1 micron cartridge filters, and foul RO membranes in ways that are difficult to clean. As post treatment if needed for removing trace organic contaminants, activated carbon is far less problematic.

7. Pilot plant: Piloting is necessary to validate a process design, to test the limits of critical operating parameters, and to test and document the nature of the limiting foulant(s). Cleaning studies on pilot scale will ensure that if fouling is encountered in the full scale plant, cleaning procedures are available to fully recover membrane performance from the foulants peculiar to that site.

8. Antiscalant/Antifoulant: Antiscalants vary greatly in their ability to control various inorganic scales and in their compatibility with contaminants in the feed-water. Antifoulants are designed to control colloidal foulants, preventing coagulation and deposition on membranes.

9. Validation: Validation is needed to document with data that each component of the design actually meets the design criteria, and the total system functions predictably within ranges of raw water quality.

10. Cleaning methods: If cleaning methods for a specific plant has not been developed during the pilot phase, fouled membranes best be removed from the system for off-line development of an effective cleaning method. Due to complexity for foulants deposited, and unpredictable responses to cleaners and procedures used, cleaning RO systems today is still very empirical and an art.

11. Process control: Due to the unpredictable nature of colloidal fouling, even for some deep-well brackish waters, and variability over time of raw water quality from all sources, turn-key automated plants are hard to build and seldom trouble-free. Human-assisted control with sufficient instrumentation to plot trend charts of normalized values of permeate flow, differential pressures and salt passage go a long way to ward off problems. Upsets from equipment failures, power outages, biofouling and operator errors can result in irreversible fouling. Careful monitoring by trend charting, and having support to respond to fouling events early is very important.

12. Troubleshooting: The object of troubleshooting is usually to recover membrane productivity and to reduce or avoid future fouling. The availability of the right chemicals and RO system expertise are keys to rapid problem resolution.

Process Equipment

The assemblage of membrane element with pressure vessels, pumps, instruments, pipes in recommended arrays using design software provided by membrane suppliers has become rather routine for system providers large and small. Based on purchasing patterns of users, price seems to be the main selection criterion rather than differentiations in equipment design and quality. Once purchased, users have to make the best of what they have.

In helping a variety of RO plants improve performances and solve operation problems, we will point to some aspects of process equipment that are most important for consideration.

1. Instrumentation: There needs to be a minimum set of instruments to record feed pressure, permeate pressure, concentrate pressure (separately for first and second stages preferred), feed temperature, permeate flow, concentrate flow, feed conductivity, and permeate conductivity. These measurements are needed to provide trend charts of normalized values of permeate flow, differential pressure, and salt passage, critical for careful monitoring of system performance (Troyer, 2006).

2. Clean-in-place system: To avoid irreversible deterioration of membrane, a CIP system is needed for rapid response to fouling if it does occur. A good rule of thumb is that cleaning with an effective procedure should be performed when normalized permeate flow drops, differential pressure or salt passage increase by 15%. The longer cleaning is postponed, the less effective cleaning would be due to channeling of recirculating cleaning solutions inside membrane elements during cleaning.

3. Cleaning pump: Cleaning pump should be sized to provide maximum cross-flow velocity across the face of the membrane and minimum or no permeation through the membrane in order to lift the foulant layer from membrane surface. High recirculation flow-rates for 8" elements is about 120 liters/minute, for 4" elements about 30 l/min and 2.5" elements about 15 l/min.

4. Membranes: The risk of colloidal fouling increases with higher water flux through the membranes. For desired productivity, sufficient membrane area should be provided. Conservative design calls for the following fluxes (in gallons per square foot per day- gfd unit) for the different qualities of feed-waters: RO permeate- 22 gfd; well water- 14 gfd; surface water- 10 gfd; tertiary wastewater- 7 gfd. Also, to minimize entrapment of coagulated particles in the concentrate flow channels, lower surface area membrane elements are preferred over high surface area elements which use thinner brine spacer screens to accommodate more membrane in the same internal volumes of the elements.

5. Supervisory control and data acquisition (SCADA) system: Large plants often have complicated SCADA system that do not easily inter-phase with monitoring programs on personal computers for calculating normalized values and plotting and reviewing of trend charts of normalized permeate flow, differential pressures and salt passage. Initial design of SCADA system with capability of easy downloading electronically of daily averages of the instrument data mentioned in (1) above to a personal computer software would greatly facilitate monitoring with trend charts of normalized operating data.

6. Chemical dosing systems: System is best designed for easy routine control by the operators for the preparation and dilution of antiscalants, observation and recording of

chemical uptake daily, recording and changing when needed of chemical dosages, and calibration periodically of actual injection rates.

7. Pretreatment unit operations: Due to frequent membrane fouling problems actually caused by inadequately maintained and controlled pretreatment equipment, each pretreatment step added to the process need to be justified with data and documentation that are then used in qualification and validation at startup, and as reference data for documented control of each step during operation.

8. Calibration of instruments: Reliable process control requires regular calibration of all instruments.

Process Procedure/People

In general, detailed procedure for the operation and maintenance of each unit of the process system is needed for qualification and validation during the startup. Following qualification and validation, detailed procedures are central to the transfer of a new plant to people who are qualified for the operation and maintenance of the plant and process. Training and qualification of operations and maintenance staff is essential. We point out below some additional people functions in the RO plant that are essential to success.

1. Monitoring procedures: Rigorous monitoring procedures using trend charts of normalized operating data are absolutely essential. Managers and operators need to be trained to understand and respond to changes observed in the performance of the system.

2. Ongoing training and discussions: Due to inevitable changes and events that occur in a membrane plant, regular meeting of the O&M staff with appropriate engineers and consultants is highly desirable if not necessary.

3. Cleaning method development: Since membrane fouling requires quick response in cleaning to fully recover membrane productivity, the trend charts of normalized performance data will indicate whether the cleaning procedure on hand is fully effective. Accumulation of residual foulant after repeated cleanings is a major cause of system failure and need for premature membrane replacement. Improved cleaners and procedures often need to be developed in a pilot skid at the plant site or have fouled membrane elements sent off site for studies by cleaning specialists. Keeping membranes in startup conditions is a responsibility of the O&M staff.

4. Control of fouling: When fouling occurs and cleanings become necessary, attempts should be made to identify the chemical composition of the foulants and ways of reducing or eliminating the observed fouling rate as seen in the trend charts. Experts can be contracted to provide diagnosis and solution. If modifications of existing pretreatment is needed and warranted, engineering staff and contractors would have to be involved.

5. Troubleshooting: O&M staff can be trained to perform troubleshooting function by correlating system performance changes to significant events that occurred in

the plant. Outside experts can be engaged when needed. The staff is then involved in solving the problem. These exercises are effective training opportunities. It is important to maintain a significant event log, especially of events of uncertain impacts.

6. Performance and cost improvements: Due to the intimate involvement of the O&M staff in the daily running of the plant, they are key to a program of continuous improvement in the performance of the process and lowering the cost of O&M.

Conclusions

In developing a best practice, we list the obvious functions that should be performed in the design and operation of an RO plant. We have listed these functions under the three headings of Process Chemistry, Process Equipment and Process Procedures/People. As a chemical and service provider to the plants, we have aimed to deliver maximum value by addressing all three areas of needed activities. As a single party to each complex project, our achievements have been very promising but unavoidably limited in many cases. By pointing to the needed changes and missing functional components, we are very optimistic that through collaborations, our technical community can come together to promote a best practice for the much desired goal of seeing RO used as continuous processes without fouling, and at maximum recovery of precious water.

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