An Innovative Approach to Optimize Reverse Osmosis Membrane Performance

Lance R. Littrell and Glenn W. Dunkelberger

Reverse osmosis (RO) plants require precise data monitoring for proper operation and troubleshooting. A variance of 2 to 5 percent on one parameter can adversely affect the membrane and cost the utility significant amounts of down time and money.

Typically, membrane systems are monitored for the "Big Three" parameters: pressure, conductivity, and flow. With proper monitoring and analysis, these three parameters can indicate a system's successful operation or the beginning stages of a dramatic decline in performance.

A few other parameters are also helpful in successful monitoring and will be discussed briefly. For the purposes of this article, the RO plant and monitoring parameters will define a two-stage, brackish membrane system with permeate throttling and no energy recovery.

Pressure

Why is pressure important? Pressure is a key parameter for determining problems within the membrane system. It indicates problems with integral components such as pumps, valves and membranes.

A high feed pressure can indicate plugged membranes (membranes with the feed spacers partially or completely blocked by sand, silt or other debris), closed or partially closed valves, or a change in water quality that requires operator intervention. Low feed pressures can indicate a failing or worn pump, excessive pressure loss in pretreatment equipment, or valve related problems.

Interstage pressure devices assist in determining the membrane cleanliness of the first and second stage. The interstage pressure used in conjunction with the feed pressure determines the first-stage pressure differential (head loss through the first stage), which is critical to early detection of membrane plugging or fouling. Similarly, the interstage pressure used with the concentrate pressure identifies membrane scaling in the second-stage membranes.

The concentrate pressure can indicate a concentrate throttling valve malfunction and is also used for the differential pressure across the second-stage membranes. A permeate pressure monitoring device indicates various problems with post-treatment equipment, valves, and membrane backpressure devices.

All in all, the various pressure-sensing devices can indicate a variety of problems within any membrane system, many of which can be corrected without damaging membranes or other equipment if they are detected immediately.

Conductivity

What does conductivity tell us about membrane systems? Conductivity measurements and samples are important in determining changes within water quality prior to, during, or after membrane treatment.

Feed conductivity measurements indicate a changing water source, perhaps because of seasonal variations or surface water influences—both of which require operational interface to ensure proper operation of the membrane system. In a two-stage system, two of the three permeate conductivities are measured, with the third being calculated.

For simplicity, this section defines a system with monitoring devices for the second-stage permeate and the total permeate. The total permeate conductivity typically is measured because it is critical for product water quality reports. The second-stage permeate is measured, but the first-stage permeate is not.

The second-stage permeate conductivity determines the quality of the second-stage membranes and similarly for the total permeate conductivity sensor. The first-stage permeate conductivity can be determined using mass balance calculations in a spreadsheet or PLC. Either permeate conductivity sensor will determine pass-through or rejection problems for the respective membrane stage.

Both pass-through and deteriorating rejection can cause a membrane plant to fail regulatory compliance standards. They can also be the preliminary signals of membrane performance problems. Concentrate conductivity is not usually measured unless it is required for disposal monitoring purposes. Similar to pressure monitoring, conductivity monitoring is an early detection indicator of a failing system.

Flow

Without flow monitoring, how do we know what the system is doing? Flow monitoring is perhaps one of the most critical components of the Big Three. This process can indicate all the problematic situations described previously, as well as many other warning signs that can prevent significant damage to the membrane system.

Lance R. Littrell, P.E., is a project manager with the consulting engineering firm Reiss Environmental Inc. in Orlando. Glenn W. Dunkelberger, P.E., is a senior project manager with the firm. This article was presented as a technical paper at the 2007 Florida Water Resources Conference.

Typical flow monitoring points include feed, first- or second-stage permeate, total permeate, and concentrate. These are used to determine all aspects of membrane productivity, mechanical failures, and critical regulatory compliance.

Other Important Monitoring Parameters

Several monitoring and sensing devices outside the Big Three can be helpful for successful membrane operations. Some of these include pH, oxidant reducing potential (ORP), temperature, and feed turbidity. Necessity for each component and critical set points for each of these parameters are considered on a case-by-case basis and should be implemented accordingly.

Study: Brackish RO Plant in Central Florida

The subject water treatment plant was built several years ago, and the membrane system was designed with two trains. Each train consisted of a three-stage membrane array.

Recently the plant was retrofitted to include a membrane change and further modifications, reducing the trains to two-stage membrane arrays. Also, the retrofit included a separate micron filter installed in parallel to the existing filters in an effort to reduce loading rates on the cartridges.

It is apparent that no additional instrumentation equipment has been installed since the plant was constructed. The system consists of a typical feed, interstage, and concentrate arrangement with one permeate collection header for all stages of vessels.

The three feed wells have deteriorated in quality over time to the point that one of the wells is not used for feeding the RO plant outside of an emergency condition. The current monitored parameters include pressure (feed, interstage, concentrate, and permeate); conductivity (total permeate); and flow (permeate and concentrate).

Problematic Issues

Problematic issues identified with the current water treatment plant include:

1. Deteriorated well quality
2. Accelerated replacement schedule for micron filters
3. High first-stage flux and low second-stage flux rates
4. Accelerated membrane scaling

First, we'll discuss the deteriorating wells and areas of concern. The current well quality has deteriorated in total dissolved solids (TDS), which can result from a number of influences upon the source water lens.

Increased salinity has been an effect of this well degradation, along with increased sand and silt discharge upon startup. SDI tests taken upon startup of the well system indicate that the well discharge is beyond the range suitable for membrane feed water for up to 25 minutes after startup. Remedies for deteriorated wells are widely discussed among the water industry and should be considered on a case-specific basis.

Micron filters are the first, last, and only line of defense for the membrane system in the subject application. Over the past two years, the micron cartridge life has dropped from three months to approximately two months with steady signs of decline. This situation is most assuredly caused by deteriorating water quality and specifically the sand and silt being pumped from the wells upon startup.

During the latest membrane retrofit, an additional cartridge housing was added in parallel to reduce loading rates for the individual cartridges. This addition has increased the cartridge life but has added an additional set of filters to replace. Essentially, the new micron housing has delayed the replacement time, yet hasn't changed the replacement cost.

Since the micron filters are a direct effect from the deteriorating well quality, the ultimate remedy for their problem lies within the well treatment. The wells may never improve with the specified treatments, so there is a need for an alternative solution.

One solution requires flushing to waste until the suspended solids levels drop into an acceptable range for membrane feed water. This poses additional discharge to perk ponds and would require a revision to the discharge permit, which we will consider not acceptable for this project. Additional equipment such as centrifugal separators are also not considered due to low project budget and little or no room for installation.

The remaining option requires sending all the startup solids to the micron filters with hopes that the filters will catch most of the solids prior to loading the membranes. To increase filtration of the solids, we will include an additional stage of cartridge filter housings in series to provide further protection for the membranes.

The design adds a one-micron stage of cartridge filters downstream of the original stage of five-micron cartridge filters and in theory will remove more suspended solids without reducing the replacement lifespan of the cartridge filters. Unfortunately, there is no specific solution in the operation and design of the micron filters that will permit longer periods between filter replacements.

High first-stage flux and low second-stage flux are directly related. The high flux in the first stage is problematic because it produces low flux rates in the second stage, promoting membrane scaling.

Let's examine a high-flux situation. More than the designed rate of water passes through the membrane. In this instance and over time, more water is passing through the membrane and less water is traveling across the membrane surface. This reduces cross flow (flow over the membrane surface) and the system's ability to keep dissolved solids in solution and moving past the membrane surface.

As indicated on all membrane manufacturers' recommendations, membranes require a minimum cross flow or concentrate

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stream to keep solids in solution. When solids precipitate out of solution, they attach to the membrane surface, limiting membrane surface area and effectively reducing the membrane's capacity.

A low-flux situation represents a flow through the membrane surface which is less than the manufacturer's required flow. Theoretically, in an extreme low-flux situation, osmosis can occur and the permeate water can be pulled back through the membrane to the concentrate side. In this low-flow case, the membranes will foul gradually and then foul at an exponential rate if the fouling issues are not corrected.

Before discussing solutions to the operational issues described previously, the product water configuration must be discussed. The subject membrane system was constructed with only one permeate header collecting flows from both the first and second stages. This configuration doesn't allow the operator to monitor any parameters for the individual stage performance.

Without the individual stage parameter data and control measures, flux rates for both stages are allowed to vary uncontrollably. The current system configuration permits the operator to determine only the total system flux.

Rectifying the Process Issues

Deteriorated Well Quality

Remedying well disturbances or gradual degradation of water quality from a well is quite complicated and should be assessed by a hydrogeologist before corrective measures are implemented. For the subject case, a series of tactics will be implemented that are hopeful to reduce the high solids discharge upon startup.

The subject wells will undergo a series of periodic maintenance operations to help slow, stop, or even reverse deterioration. The wells will be flushed periodically at or above full capacity for an extended period of time to eliminate any solids buildup within them. Also, each well will undergo a periodic acid treatment consisting of a soaking period and a flushing period to eliminate as much iron buildup as possible. Further treatment will be diagnosed after the results of the flushing and acid treatments are reviewed.

Accelerated Replacement Schedule of Micron Filters

Continuous replacement of the micron filters is costly in both time and materials. Operators are burdened with growing preventative maintenance tasks and lists, not to mention daily monitoring assignments.

Cartridge filter replacements shouldn't be more frequent than every three months. Decreasing the loading rate per cartridge filter is a quick way to extend the life of a cartridge, but it doesn't solve the problem.

Because of budget, time, and regulatory restrictions, the design for the subject plant does not include remedying the wells prior to making further adjustments. Cleaning the well startup discharge of high suspended solids or diverting to waste will drastically improve the cartridge filter lifespan and also membrane cleanliness.

Since the implementation of the well improvements is uncertain, we have elected to add a second series of micron filters for the plant. The intent behind the design assumes that the five-micron cartridges will provide a barrier for all larger particles and the one-micron cartridges will provide an additional layer of protection before the feed water is subjected to the membranes. Without correcting the well quality issues, the only remedy for frequent micron filter replacements is to add more filters and reduce loading rates to the minimum design standards.

High First-Stage Flux & Low Second-Stage Flux Rates

Uncontrollable flux rates present big problems to an operator who is trying to monitor a membrane system correctly. As stated previously, high or low flux rates promote scaling in the later-staged membranes. This problem is remedied by separating the permeate headers and adding a few components of the Big Three monitoring devices.

With the latest retrofit, the installed permeate monitoring equipment includes total permeate flow and total permeate conductivity. The design improvements provide for the second-stage permeate to be collected through a separate header. The existing header will be used solely for the first-stage permeate collection, and the second header will be used solely for the second-stage permeate collection.

A flow control valve and pressure monitoring device were added to the first-stage permeate header to prevent excess production in the first-stage and reduce high flux problems. The valve is set to maintain a constant backpressure indicated by the new pressure monitoring device. The constant backpressure applied to the first-stage membranes controls and maintains the correct first-stage design flux.

The second-stage header is fitted with a conductivity sensor and new flow-monitoring sensor. The second-stage flow sensor data is subtracted from the total flow sensor data to determine the first-stage permeate flow. Similarly, the second-stage conductivity sensor data is used in conjunction with the existing total permeate conductivity sensor data to determine the first-stage permeate conductivity.

Effectively, the additional second-stage sensors and header modifications allow the necessary monitoring devices for accurate control of flux rates through both stages of membranes.

Accelerated Scaling of Membranes

Fortunately, the accelerated scaling of the membranes should be corrected with the modifications to the permeate headers discussed previously. Scaling occurs when the concentrate flow is of high constituent concentrations that precipitate out of solution and onto the membrane surface. The reduction of the first-stage flux and increased second-stage flux ultimately will result in a cohesive membrane system operating at optimum levels of performance.

Conclusions & Results

Membrane systems are controlled and monitored successfully using the Big Three monitoring parameters as a minimum amount of instrumentation. Problems arise when one or multiple parameters are not available for operator monitoring and warning detection.

Membrane systems that do not currently have the Big Three monitoring devices adequately placed are running the risk of membrane damage or excessive labor-intensive cleanings. The subject water treatment plant was rectified by simply adding a few of the Big Three monitoring devices and properly accessing early warning signals, ultimately yielding a protected, optimized reverse osmosis membrane treatment plant. ◊