

Reducing RO Operating Costs with Automated Monitoring Technology

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Summary: Reverse osmosis is in wide use for sea water desalination. Operating these systems, however, can be expensive due to the amount of time required for proper monitoring. The use of modern, automated monitoring hardware can greatly reduce the cost of system operation by lowering these man power requirements.

INTRODUCTION

Reverse osmosis (RO) has gained wide acceptance in a number of applications for water treatment, particularly desalination. Unfortunately, operation and maintenance of these systems continues to be a challenge for many RO owners. Proper monitoring of an RO unit requires that a large number of primary parameters be recorded, and further processed, to arrive at an indication of RO performance. Furthermore, the quality of RO feed water must be closely monitored to insure that constituents in the feed water do not adversely affect the RO membrane.

Conventional RO monitoring involves manual data logging and further calculation to produce a set of normalized operating data. In some cases, data normalization may be accomplished by entering raw data into some type of computer spreadsheet or other normalization program. It is only with this normalized data that RO performance can be evaluated. Additional monitoring tasks involve silt density index (SDI) measurement and routine calibration of instrumentation. Conventional RO monitoring is expensive from a standpoint of manpower. However, failure to monitor the RO system properly may be even more expensive from a standpoint of membrane failure, excessive maintenance cost, or substandard product quality.

For the last five years, RODI Systems has worked on the development of automatic RO monitoring technology to monitor RO performance as well as SDI and other feed water characteristics. This technology is designed to reduce the cost of conventional RO monitoring while, at the same time, provide dependable and continuous monitoring capabilities. This paper examines the economic advantages of using automated RO monitoring technology.

A REVIEW OF RO MONITORING

INTRODUCTION. In concept, reverse osmosis (RO) is a simple process. Water is forced through a membrane under pressure. The membrane rejects both dissolved and suspended solids thus producing a very pure permeate.

The process may be described as filtration on a molecular or ionic level. Unlike most filtration processes, however, RO is not simple to monitor.

There are two aspects of RO monitoring. First is monitoring the performance of the RO unit itself. This involves observing a number of diverse parameters such as pressure, flow, temperature, and conductivity. The second aspect of RO monitoring is that of observing the quality of the feed water going to the RO unit. Monitoring parameters such as silt density index (SDI), pH, ORP, and temperature can help to avoid membrane damage before it has a chance to occur.

MONITORING RO PERFORMANCE. In order to determine whether an RO unit is operating properly, a number of parameters must be recorded. Table 1 lists the parameters that should be monitored and recorded during RO operation.

TABLE 1 - Raw Data Collected During RO Operation

Feed Pressure
Interstage Pressure
Reject Pressure
Permeate Pressure
Permeate Flow
Reject Flow
Feed Flow
Feed Temperature
Feed Conductivity
Permeate Conductivity

After recording the raw data listed in Table 1, yet another set of calculated values must be prepared using the raw data collected from the RO. It is only from these calculated values that a determination can be made regarding the performance of the RO unit. These calculated values are listed in Table 2.

The following sections show how each of these parameters are calculated and used to monitor RO performance.

TABLE 2 - Parameters Calculated from Raw Data

First Stage Pressure Differential
Second Stage Pressure Differential
Percent Recovery
Permeate Concentration
Feed Concentration
Reject Concentration
Salt Rejection
Normalized Permeate Flow

Differential Pressures. As the feed water passes through the pressure vessels of an RO unit, it encounters resistance due to the feed spacers in the membrane elements. Therefore, even new elements present some resistance to flow as the water passes through the system. As the membrane elements experience use, foulants will build up on the surface of the membrane and in the feed spacer material itself. As these foulants accumulate, the resistance to flow of the feed water increases. This resistance to flow may be measured as a differential pressure across the vessel.

Differential pressures are calculated using Eq. (1).

$$DP = P_f - P_r \quad (1)$$

Where:

- DP = Differential Pressure
- P_f = Feed Pressure (Vessel Inlet)
- P_r = Reject Pressure (Vessel Outlet)

Recovery. Recovery refers to the amount of permeate being produced by the RO relative to the amount of feed water. It is calculated with Eq. (2).

$$\%R = (F_p / F_f) \times 100\% \quad (2)$$

Where:

- %R = Percent Recovery
- F_p = Permeate Flow
- F_f = Feed Flow

Concentration. Conductivity is a physical characteristic of a given water. It is the ability of the water to conduct an electric current. Concentration is a chemical characteristic of a given water referring to the amount of solids chemically dissolved in the water.

If the solids dissolved in the water are ionic, concentration can be correlated to conductivity. This is due to the fact that the dissolved ions are the means by which the current

(electrons) flows through the water. Fortunately, in most naturally occurring waters, the vast majority of the dissolved solids are in the form of ions. On the downside, the exact correlation between conductivity and concentration depends upon the type of ions present.

For example, if the water contains monovalent ions such as sodium, chloride, hydronium, hydroxide, etc., the concentration (in mg/l) will be approximately one half of the conductivity (in micro Siemens). This relationship is often referred to as a conversion factor and is used as illustrated in Eq. (3).

$$\text{Concentration (in mg/l)} = \text{Conductivity (in uS)} \times \text{Conversion Factor} \quad (3)$$

The actual conversion factor is a function of the types of ions present. Since most waters contain a mixture of monovalent and multivalent ions, a common conversion factor is 0.67. Most conductivity meters which give results in mg/l (concentration) simply multiply the conductivity by this 0.67 conversion factor.

Salt Rejection. Salt rejection refers to the ability of the membrane to reject the dissolved solids (salts) in the feed water. There are a number of ways to calculate salt rejection. One of the most popular is the feed-reject average method. This is illustrated in Eq. (4).

$$\%SR = 100 - ((C_p / ((C_f + C_r) / 2)) \times 100\%) \quad (4)$$

Where:

- %SR = Percent Salt Rejection
- C_p = Concentration of Dissolved Solids in Permeate
- C_f = Concentration of Dissolved Solids in Feed Water
- C_r = Concentration of Dissolved Solids in Reject

Salt rejection is important since it has a direct impact on the quality of the water being produced by the RO unit. Even more important, a change in salt rejection may mean a change in membrane condition. It can indicate fouling, scaling, or chemical attack. It may also indicate a mechanical failure such as a leaking O-ring. Sudden changes in salt rejection are most often due to mechanical problems. Gradual changes are usually due to changes in membrane condition. For this reason, salt rejection must be monitored closely.

Normalized Permeate Flow. Actual permeate flow should not be used as an indicator of overall RO performance. Actual permeate flow from a given RO unit is a

function of three different variables. These are:

- Net Drive Pressure
- Water Temperature
- Membrane Condition

The last variable, membrane condition, is very important from a standpoint of RO performance. A change in membrane condition would indicate such things as fouling, scaling, and chemical attack.

If the first two variables were to stay constant, a decline in actual permeate flow would indicate a change in membrane condition. Unfortunately, this is seldom the case. Net drive pressure and temperature often change. When they do, a change in actual permeate flow may no longer mean a change in RO performance. Even worse, if the first two variables are changing, RO performance may also be changing (i.e., membrane fouling or damage may be occurring) although no change in actual permeate flow is seen.

Calculating normalized permeate flow involves a number of equations that take into consideration any changes occurring in the first two variables. If any changes in net drive pressure and water temperature are accounted for (by calculating normalized permeate flow) and a change in permeate flow is still observed, then this change must be due to the third variable (membrane condition). In other words, a change in membrane condition is taking place and something must be done about it (usually this means the membrane must be cleaned).

MONITORING RO FEED WATER. The previous section demonstrated the importance of monitoring the performance of the RO unit itself. Closely monitoring this performance is necessary to determine if fouling or chemical damage to the membrane is occurring. It is also necessary in order to determine if membrane cleaning has been effective.

In addition to monitoring the performance of the RO unit, it is also advisable to monitor the quality of the feed water going to the RO. By doing so, membrane damage may be avoided before it is detected as a change in RO performance. There are two aspects of monitoring feed water quality, observing the feed water chemistry (including temperature) and measuring feed water silt density index.

Feed Water Chemistry and Temperature. RO membranes can be sensitive to the chemical characteristics of the RO feed water. Thin film composite membranes are highly susceptible to damage from oxidizing compounds which may be present in the feed water. Therefore, the oxidation-reduction potential (ORP) of the feed water is often monitored continuously. Cellulose acetate mem-

branes degrade quickly at high or low pH ranges. A high pH in feed water going to either cellulose or thin film composite membranes could result in scaling. Excessively high feed water temperature may harm either type of membrane. For these reasons, ORP, pH, and temperature should be monitored continuously and the RO unit immediately shut down should excursions occur.

Feed Water Silt Density Index. The silt density index (SDI) test was developed in the 1970's as a method to monitor feed water quality in regard to the amount of suspended solids present in the feed water. The test, which has become an ASTM standard, involves passing feed water through a membrane filter with 0.45 micron pore size openings. By measuring the amount of time required for the filter to plug, a correlation can be made to the amount of suspended particulate in the feed water.

The SDI test has been adopted by most membrane manufacturers as the best means of predicting colloidal fouling tendency of a given feed water. Unfortunately, the manual test is time consuming and it is difficult to achieve reproducible results without careful attention to the technique used when conducting the test. Attempts to correlate other measuring methods, such as turbidity and particle counting, to SDI have met with limited success.

CONVENTIONAL RO MONITORING SYSTEMS. A conventional RO monitoring system consists of a group of individual instruments, gauges, and meters to display the primary parameters listed in Table 1. In addition to these instruments, the RO unit is usually equipped with a so called "wet panel". This is a separate panel holding pressure gauges and flow gauges (i.e., rotameters). Its name results from the fact that the indicators in the wet panel must be physically connected by piping to the water being treated by the RO unit.

In most cases, the instruments making up a conventional RO monitoring system only monitor one parameter. This means that a relatively large number of instruments are needed and that each instrument must be programmed and calibrated separately. This can lead to some confusion if a number of instruments from different manufacturers are being used on the same system. Operating and calibration methods vary from manufacturer to manufacturer. On some of the newer microprocessor based instruments the menu structure can be quite involved since only a few keys are available to perform a multitude of functions.

In most applications, data provided by a conventional monitoring system must be transcribed by hand from the display of the instrument to some type of log sheet. In rare occasions, analog outputs from the panel-mounted instruments may be routed to a data acquisition system or strip chart recorder. If the latter is used, data must still be

manually transcribed at some point. Real-time response to instrument output is commonly available in the form of relay outputs for various discrete alarm setpoints. The relay outputs are commonly used to illuminate indicator lights or signal a PLC of an alarm condition. Since only the primary (non-calculated) RO operating parameters are being monitored by the instruments, the alarms are based only on the condition of these primary parameters. Calculated parameters remain a mystery until the data is logged and proper calculations are performed.

PROBLEMS WITH CONVENTIONAL RO MONITORING. Monitoring RO performance is not difficult but it is time-consuming and tedious. A great number of RO failures can be attributed to poor monitoring. There are generally three reasons why an RO unit is not monitored properly.

Failure to Record Raw Data. This is probably the most common problem in RO monitoring, especially in the case of smaller RO systems. Manually recording raw data by writing it down on log sheets is a time-consuming process. Many small RO systems may only be manned a portion of the time thus allowing even less time for data recording. Many RO systems have inadequate or inoperable instrumentation. This may result in missing or inaccurate data points even when the data is recorded. Measuring SDI with the manual ASTM method is also very time-consuming. It is seldom performed on a regular and frequent basis. It is often not measured until RO performance begins to decline.

Failure to Analyze Data. Raw data does little good in determining the operating status of an RO unit without at least some data analysis. Unfortunately, data analysis is also a time-consuming process since calculations must be made. There are a number of computer programs which make it easier to examine and analyze RO data but in most cases the raw data still has to be manually entered into a computer. Many times the raw data does not get analyzed until membrane damage occurs. This will often identify the cause of the problem. However, had the data been analyzed in real time, it is likely that the problem could have been corrected before the damage occurred.

Failure to Respond After Data Analysis. This may be one of the most unforgivable sins in the world of RO operation. Failure to respond to the information provided by on-going data analysis can happen for a number of reasons. The person conducting the analysis may not be trained to identify the trends indicating a problem. It may also be a result of poor communication. This may be the case when data analysis is done in a central location and the results of the analysis have to be communicated back to field personnel.

In summary, the ability to monitor an RO unit is dependent upon the availability of raw operating data. If raw data is not recorded, it will not be normalized, trended, and used to monitor RO performance. Manual record keeping can be a time-consuming and tedious process, especially if multiple RO units are involved.

ECONOMICS OF RO MONITORING

It is imperative that an RO system be monitored properly. By not doing so, the RO owner risks early membrane replacement or excessive downtime for cleaning and maintenance. In this section, the costs of monitoring a system manually are compared to the costs of automatic monitoring.

ECONOMICS OF MANUAL MONITORING. Manually monitoring a conventional RO system is a labor-intensive task. For even the smallest systems, data should be recorded at least twice daily providing two data points per day for on-going trending of the RO performance. Manual monitoring involves transcribing data to some type of log sheet from the numerous gauges, meters, and instruments on the RO system. After transcribing the data, the operator must then either perform manual normalization calculations or enter the data into some type of normalization program or spreadsheet. It is important that normalization be performed on a daily basis as well. It is common for operators to wait several days or weeks before normalizing data. This lowers the amount of time spent on a daily basis. However, not having current normalized data prevents the operator from knowing the current, true performance characteristics of his system.

Table 3 lists the costs of manually monitoring a typical RO system. These costs are based on the following:

- Labor for monitoring includes manual recording three sets of data per day and data entry for normalization once per day.
- Labor for SDI includes three manual SDI tests per day.
- Labor rate is fully burdened with all benefits and overhead.
- Time for calibration involves removal of all sensors from piping, calibration, and reinstallation.

TABLE 3 - Manual RO Monitoring Costs

Cost Item	Basis	Cost for Three Years
Labor for Manually Logging Raw Data and Data Entry for Normalization	Three Man Hours per Day @ \$30.00 per Hour	\$32,850.00
Labor for Monthly Calibration of Monitoring Instrumentation	Four Man Hours per Month @ \$30.00 per Hour	\$ 4,320.00
Standard Solutions for Calibration	One Set of Solutions per Month @ \$ \$75.00 per Set	\$ 2,700.00
Labor for Manual SDI Tests	Three Man Hours per Day @ \$30.00 per Hour	\$32,850.00
Filter Media for SDI Tests	Sixty Filters per Month @ \$0.75 per Filter	\$ 1,620.00
	Total	\$74,340.00

ECONOMICS OF AUTOMATIC MONITORING.

Automatic RO monitoring equipment is designed to greatly reduce the amount of manpower required to properly monitor an RO system. Table 4 lists the costs of monitoring an RO system using automated equipment, including the cost of the equipment. These costs are based on the following:

- Labor for monitoring includes downloading of data once per week.
- Price for SDI media assumes two tests per day.
- Labor rate is fully burdened with all benefits and overhead.
- Time for calibration reflects the fact that individual sensors do not have to be removed from piping for calibration.

TABLE 4 - Automated RO Monitoring Costs

Cost Item	Basis	Cost for Three Years
Capital Cost for Automated Monitoring Equipment	Current List Price	\$14,700.00
Labor for Equipment Installation	Eight Man Hours @ \$50.00 per Hour	\$ 400.00
Labor for Weekly Download and Examination of Operating Data	One Man Hour per Week @ \$30.00 per Hour	\$ 4,680.00
Labor for Monthly Calibration of Monitoring Instrumentation	One Man Hour per Month @ \$30.00 per Hour	\$ 1,080.00
Standard Solutions for Calibration	One Set of Solutions Every Two Months @ \$ \$75.00 per Set	\$ 1,350.00
Labor for Replacement of SDI Filter Media	One Man Hour per Week @ \$30.00 per Hour	\$ 4,680.00
Filter Media for SDI Tests	Fifteen Filters per Month @ \$3.00 per Filter	\$ 1,620.00
	Total	\$28,510.00

CONCLUSIONS

Use of automated technology for monitoring the performance of RO systems and the quality of the water being fed to the RO offers a number of benefits to owners and operators of RO systems. These are listed in Table 5.

TABLE 5 - Conclusions

Feature	Manual Monitoring	Automatic Monitoring
Frequency of Data Monitoring	Generally One to Three Data Sets per Day	24 One Hour Averages of 3600 Scans per Hour
Frequency of Data Normalization	Generally Once per Day at the Most Frequent	24 One Hour Averages of 3600 Scans per Hour
System Control and Alarm Shut-down	Automatic Shutdown Only for Primary Parameters. Shutdown for High SDI Only by Operator Intervention	Automatic Shutdown for Normalized Data and SDI
Monitoring and Data Retrieval Remotely Via Modem	No	Yes
Cost Over Three Years	\$74,340	\$28,510

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