INTERNATIONAL

Making an Ideal Process for Pure Water by Reverse Osmosis

By Robert Y. Ning, Ph.D.

Summary: *To treat brackish water of varying qualities, reverse osmosis (RO) systems are used in all sizes, ranging from plants with thousands of membrane elements to portable skids with perhaps three elements. Whatever the size of the system, however, great value is often associated with reliable and predictable production of pure water. Due to source water variability and RO system tendencies toward fouling, it's important to look at these not as machines but—along with other treatment equipment and chemicals—as a total water quality improvement process for production of vital water, be that for potable or other uses. Like all chemical processes, stability, dependability and ruggedness toward source water quality upsets require understanding of critical variables, validated process designs, documented operation and control.*

The high value placed on the process for treating water by RO offers equipment manufacturers, chemical suppliers and other related service providers great opportunities to fill a growing market need. We call attention to the need for collaborations to implement the concepts and principles of dependability and ruggedness in manufacturing processes pioneered by pharmaceuticals, chemical and electronic industries as embodied in the so called "Good Manufacturing Practices" of ISO9000 standards and food and drug regulations around the world.

When one is asked to define the ultimate method of purifying large volumes of water, the following definition would most likely be agreed upon by water treatment professionals today. The ideal is an RO system using: 1) minimal equipment, 2) minimal energy, 3) minimal amounts of chemicals, 4) no pretreatment units except for filtrations with 5-to-10 micron (µm) cartridges, 5) continuous operation with minimal stoppage for maintenance, 6) membranes lasting for more than 12 years, and 7) dependable pro-

cess for purifying all type of waters—lakes, rivers, wells, waste ponds and the sea.

In the 30-to-40 year history of large-scale application of RO technology, all these criteria have been met except one—the last one. The challenge remains for the development of an RO process rugged enough to operate reliably with challenging and varying feed water quality as operational constraints. In this context, rugged doesn't necessarily mean dragging it through the outback—although that may indeed be possible. Rather, ruggedness here is being defined as being able to handle varying water qualities within equal performance parameters.

Whether rich or poor, the world is experiencing a crisis of rapidly declining availability of quality water for human consumption. Rising regulatory requirements and public expectations for water quality needed for human and industrial use add to the crisis. In all this, the availability of a technology like RO has provided much hope and is increasingly used. Among competitive alternative desalination technologies[1] by RO, distillation, ion exchange and electrodialysis, RO commands the brackish water market when the total dissolved solids (TDS) in feed water is above 700 milligrams per liter (mg/L). Between 150 mg/L

Top photo: Taking data at a pilot unit at an Irvine, Calif., well which is high in silica.
Middle photo: With Dr. C.C. Chang (left) of Industrial Technology Research Institute and Dave Lee (right) of Crossbond Corp., at a Taiwan dye factory.
Bottom photo: A symposium on RO at Industrial Technology Research Institute in Hsing Tsu, Taiwan.

and 700 mg/L feed composition, RO competes with electrodialysis. Below 150 mg/L, ion exchange tends to be the dominant technology. In seawater application as single-purpose plants, RO has a clear economic advantage, demonstrated in international tenders or contracts, over all distillation processes in capital and operating costs. In dual-purpose plants for power and water, the world has tended to use thermal treatment to obtain drinking water. Keep in mind, the choice of technology isn't only a function of feed water quality, but the treated—product or permeate—water quality desired as well.

Brackish Water—A World View

There's a rising tide of interest in reliable processes for the purification of water by reverse osmosis (RO) around the world. In the desert areas of the Middle East, North Africa and Persian Gulf states, the efficiencies of RO processes for drinking water directly impact survival of almost entire populations of people.

In Bahrain, for example, fleets of water trucks fill up at RO plant stations to supply drinking and irrigation needs for civilians as well as naval ships that may weigh anchor there. Fouling potentials of high salinity well waters and colloidal sulfur and organic matter in oil-bearing aquifers need to be addressed and so can be controlled.

In India, sheer population density and resulting hygiene challenges demand a reliable supply of pure water. In the relatively wet Chennai (Madras) area of the southeastern coast for example, all industrial needs for water supplies have to come from processing sewage water purchased from municipal authorities! Many RO installations are experiencing severe fouling problems. Progress is being made in solving process problems, though very much handicapped by limited financial resources.

All over China, the new wave of industrialization and power stations are drawing on high turbidity river and pond waters to feed boilers for multi-family residential complexes and manufacturing processes. This makes reliability in RO processes used for these purposes very important.

In highly populated volcanic regions around the Pacific Ocean like the Philippines and Mexico, well waters with very high silica content provide many challenges.

In all industrialized nations, the reduction of volumes of wastewaters with RO pose great challenges due to the complexity and variability of feed waters. But with population and development issues continuing to grow, such challenges must be overcome.

Given a high utilization rate, RO plants—large and small—seek support of specialists to solve operational problems or to outsource the operation entirely under increasingly popular build-own-operate programs by experienced second parties, which are known as water-by-the-gallon contracts. Also becoming popular is the plan of large user organizations to have RO systems designed-built-owned-operated-transferred by other parties. In this manner, risk for the user of owning a problematic RO system is minimized and the burden of imperfection in processes, if discovered, is shared.

The operating team at a privately owned RO plant that supplies water trucks in Manama, Bahrain.

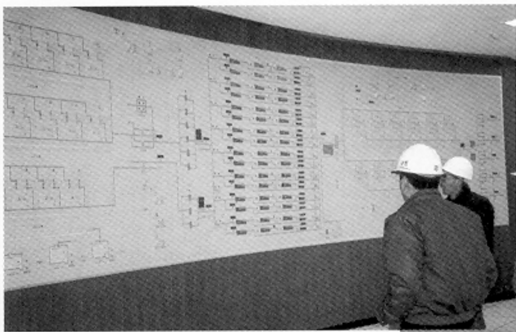
Problems with RO systems most frequently arise from inadequate consideration of the process chemistry.[2] Resolution of such problems by adjustment of pretreatment chemicals confirms importance of chemistry in process design considerations. Membranes are very sensitive to fouling. Due to the large volume of feed water containing potential foulants that pass through an RO system, even if a tiny fraction of the foulant mass is retained, the effect on membrane performance can be severe. In this brief article, we point out that RO process chemistry has progressed a long way toward ruggedness, as previously defined. A simple overview of the chemical challenge we are faced with[2,3] gives the reader appropriate warning for the need to pay attention to process chemistry, as well as confidence that greater reliability is attained with each problem solved.[4,5]

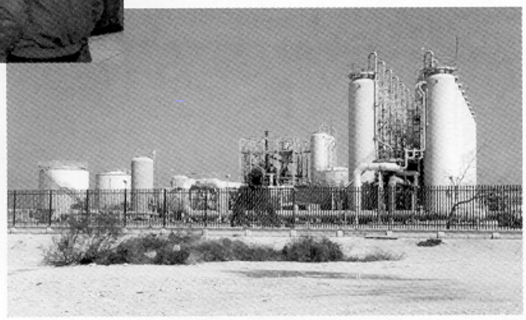
System performance is typically monitored through three parameters: normalized flow (NF) of permeate accounting for temperature and pres-

Project engineers at a new RO plant construction site for GMF Power Plant in Chennai (Madras), India.

sure differences between readings, differential pressure (DP) between entry point of feed water and exit point of concentrate, and feed water salt passage (SP) into product water. Thin layers of foulant on the membrane surface can cause a noticeable drop in NF. When the mass of foulant is large enough to plug the concentrate flow channels, an increase in DP is seen. Fouling can lead to some increase in SP by an effect termed concentration polarization. Increases in SP result from higher salt concentration in the foulant layer on the membrane surface compared to the flowing brine stream such that, at the same percent of salt passed, the actual amount of salt passed is higher. Large increases of more than 10-to-20 percent in SP are indicative of membrane damage—either chemical or mechanical. It's important that for each RO system, the trend of changes in these three parameters be charted. When instability occurs, adequate cleaning is conducted, while the cause of fouling is investigated and pretreatment chemistry adjusted to attain optimal stability. Without such continuous attention and efforts, even initially stable systems would decline and fail prematurely. Since product water quality is important, separate from system performance, critical permeate quality parameters such as conductivity can also be charted.

There are three main mechanisms by which fouling occurs: scaling, coagulation of colloidal particles and biofouling.[2] RO systems feed waters typically are concentrated by a factor of 2-to-10 (50-to-90 percent recovery)





Top photo: Control room during startup of RO plant at Hanbo Steel Mills, Seoul, Korea.
Right photo: The antiscalant dosage is being optimized at this 12 MGD Ras Abu Jajur RO plant in Bahrain.

during the production of permeate. As water is the best solvent on Earth, large bodies of water in nature such as oceans, lakes and rivers are saturated soups of dissolved and suspended matter equilibrated over a long time. When the TDS and other concentrations suddenly increase in an RO system, crystallization or coagulation occurs, resulting in scales or amorphous, soft (often slimy or sticky) foulants. This latter type of foulant describes the physical appearance of bio-foulants as well. Biofouling, however, needs to be differentiated from coagulation of colloidal particles in the important aspect that this is a foulant that can exponentially multiply by itself once anchored on the inside surfaces of membrane elements. Under ideal conditions, bacteria can undergo cell division about every 20 minutes.[6] This means that one cell has the potential of becoming 2^{24} (17 million) cells at the end of an 8-hour shift!

Conclusion

Minimal application of chemicals to the RO feed water by continuous injection has been shown to control all three types of mechanisms of fouling. Fouling problems when meticulously addressed, usually are resolved by the right choice of chemicals and modification of the process conditions. By continuous monitoring and optimization, ruggedness and dependability of the process increases. Due to complexity of the chemistry involved in the fractionation of water by RO membranes, the RO system should be viewed as a process and treated under good manufacturing practice (GMP) principles of documented validation of process design, operation and control. With this level of attention, dependability can be assured and purification of water by RO can be made to be an ideal process. ❑

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