Operation Requirements for Membrane Processes: Differences Between Ultrafiltration and Reverse Osmosis/Nanofiltration

Ian C. Watson

The advancing popularity of membrane water treatment plants of all types, from ultrafiltration (UF) to seawater reverse osmosis (SWRO), has resulted in the presence of large numbers of UF plants in the surface water treatment market, and an increasing number of reverse osmosis (RO) and nanofiltration plants (NF) primarily treating groundwater. There are both similarities and differences in the operational requirements of each type. Optimum, cost-effective operation can only be achieved by understanding the differences between UF and RO/NF membrane plant requirements.

Plant Objectives

Perhaps the most important aspect of successful operation is to understand and correctly interpret the data that is available to the operator. However, to be able to interpret the data in the most effective way, the operational objectives for the plant must be well-stated and clear. In summary, these objectives are, or should be:

- Reliability: The public expects water to be available 24 hours a day when they turn on a faucet.
- Quality: The public expects that the water coming into the home or business is clean, healthful, and meets all of the requirements of the state and federal regulatory agencies.
- Cost: The public expects tap water to be inexpensive and that the provider will operate its facilities as cost efficiently as possible.

In setting these objectives, it is reasonable to suppose that both the provider and consumer have the same ones in mind. In general, this is the case. However, in order for providers to consistently meet their objectives, there are some additional considerations that should be pursued to restate their objectives:

- To run the system reliably, meeting all water quality goals at all times.
- To run the system efficiently, at the optimum design point, minimizing operational cost.
- To maintain the facilities in good working condition, minimizing repair and replacement costs.
- To maintain a stable, proactive well-trained staff that will look for ways to improve operation and lower costs.
- Make every attempt to avoid customer complaints.

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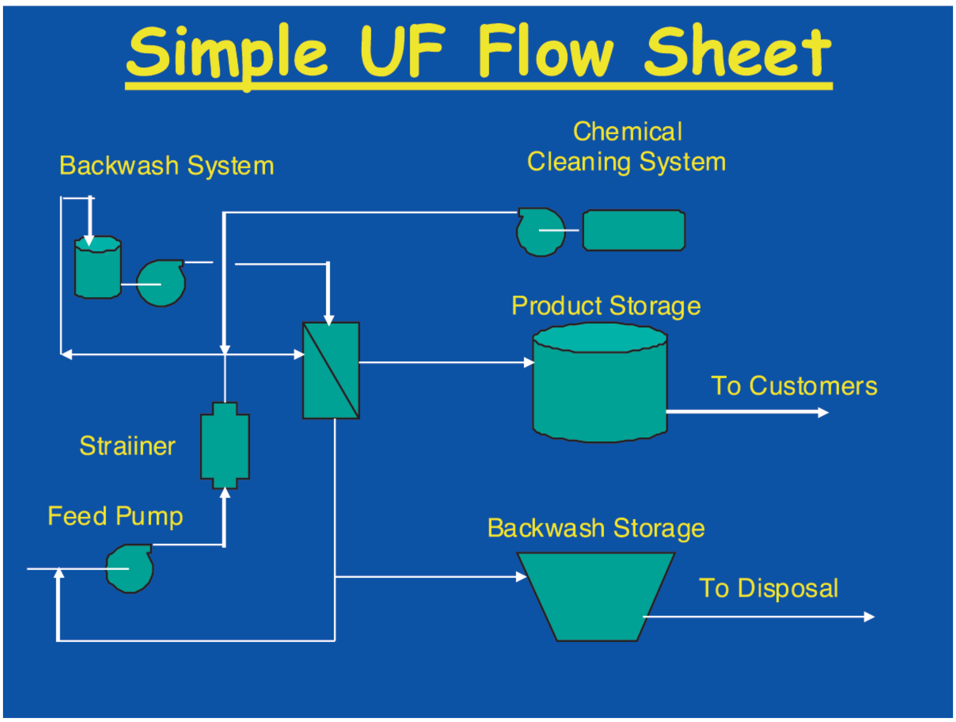
Because of the subtle differences between two types of membrane plants under consideration here, it is worthwhile to examine these differences and how they may impact operations decisions.



Ultrafiltration

Ultrafiltration, generally described as a low-pressure membrane process, is used primarily for the filtration of fresh surface waters, replacing traditional clarification/filtration processes. As such, its primary function is the separation of suspended solids from the raw water, and in addition, because of the membrane pore size (<0.01 micron, 1 micron is 1 meter x 10^{-6}. 1 micron = 0.0004 inches), UF is capable of removing giardia and cryptosporidium oocysts, and bacteria. Because the process can remove bacteria, it is subject to biofouling during operation, in addition to the normal buildup of the cake layer formed during filtration. This is the one operational feature that UF shares with RO/NF, since UF does not reject salt, and RO/NF systems must have feedwater that contains no suspended solids.

Reverse Osmosis/Nanofiltration

Reverse Osmosis/Nanofiltration, because of the nature of the membrane is, like UF, subject to fouling, but because the membranes reject dissolved minerals, it's also subject to chemical scaling caused by the supersaturation of sparingly soluble salts, such as calcium sulphate. In a well-designed plant, the optimum recovery is selected based upon the water chemistry and the ability of feed water additives (called scale inhibitors to prevent the deposition of scale when a component(s) becomes supersaturated. In the early days of this technology, phosphates were used as scale inhibitors. These were not very effective, and the plants had to be designed to operate at a recovery that limited calcium sulphate concentration to a value less than 100 percent. Modern high-performance scale inhibitors allow plants to operate at much higher levels of supersaturation, as much as 250 to 300 percent for calcium sulphate, thus conserving the feed water resource and reducing energy requirements. However, the equipment used to deliver the scale inhibitor into the system must be highly reliable and well-maintained, and equipped with instrumentation that continuously informs the operator that the system is working correctly and that the scale inhibitor is in fact being introduced into the feed water.

Interpreting the Data

While there are many operational similarities between UF and RO/NF, and the operational data collected for both types is very similar, differences exist in interpretation of the meaning of the data. Operation of both types of membrane plants involves a complete understanding of how each type of plant is supposed to work in theory and in practice. To assist the operating staff, both types of plants are typically equipped with programmable logic controllers (PLCs), which interface with the source points of the process measurements and the control room. Operators can start and stop the membrane systems, and when necessary, can override the control sequences built into the control logic. Most of the time, however, once a membrane unit is started, it is self-monitoring and self-controlling.

The operating staff must monitor the plant operations and take action when the data shows the need. This means that the staff must be well-trained, not only in the theory of water treatment, including regulatory requirements, but also in the theory of membrane processes. Only with thorough and ongoing training can the staff meet the operational goals on a continuous basis. By keeping a finger on the pulse of the plant (reading, logging, and understanding the data; troubleshooting; and early problem identification), a well-trained staff can keep the membrane plant in peak condition.

The approach to training and operations varies from place to place, in many cases due to local practice and political reality. One of the truisms of life is that you get what you pay for, and this applies to the water industry. There is little doubt that an adequate pay scale, opportunities for advancement, and programs for personal development, are vitally important in recruiting and retaining a well-trained staff. The result: a well-maintained facility that operates reliably at, or better than, the design point, and at the least operating cost. This is what management, and more importantly the consumers, expect.

One of the most significant requirements of a UF membrane facility is that of membrane integrity testing. Most states have granted to low-pressure membrane technology a four-log removal credit for giardia and cryptosporidium. To maintain that credit, most states also require that at least a daily online integrity test be performed. This integrity test is based on a "pressure hold" concept, and readily identifies the presence of broken fibers in a membrane module. Once identified, the operations can isolate the broken fiber(s), block the fiber by pinning, and return the module to service.

The RO/NF membrane plants, on the other hand, consist almost entirely of spiral wound membrane modules, whose integrity cannot be tested using the pressure hold method. Plants of this type rely on changes in permeate conductivity to monitor the integrity of the system. In some instances, this can be problematic due to the differing sale rejection characteristics of RO/NF membranes. For example, a typical seawater RO plant may produce permeate that has a conductivity of 500-600 microsiemens, whereas the permeate from brackish water RO plant may be only 50-100 microsiemens. Conductivity meters in general have an accuracy of ±5 percent.

For the seawater case, an increase of 5 percent is much more significant, and could indicate a failing O-ring or even membrane damage. The operator can verify this by checking conductivity of each pressure vessel, and having isolated the vessel, can take further steps, including using a technique known as probing to further isolate the cause of the problem. However, starting from a much smaller base with the brackish water system, the elapsed time from when a potential leak or membrane damage occurs and the point at which the event can be identified, could be much longer. This use of a surrogate test, in lieu of a direct integrity log, explains why the maximum credit that can be expected for a RO/NF plant is two, although it is known that the membrane itself is capable of much higher separation.

For both types of membrane plants, the key operating data will include the following parameters:

- Temperature – impacts the water mass transfer coefficient, and in the case of RO/NF, the salt mass transfer coefficient
- Flow – feed and filtrate (permeate), also backwash flow for UF, and concentrate flow for RO/NF
- Pressure – feed, filtrate (permeate), and concentrate for RO/NF
- Turbidity – feed and filtrate for UF; feed only for RO/NF

In addition, several other parameters are often measured. For example, particle counters may be used for UF filtrate, in addition to turbidity. Because RO/NF membranes reject

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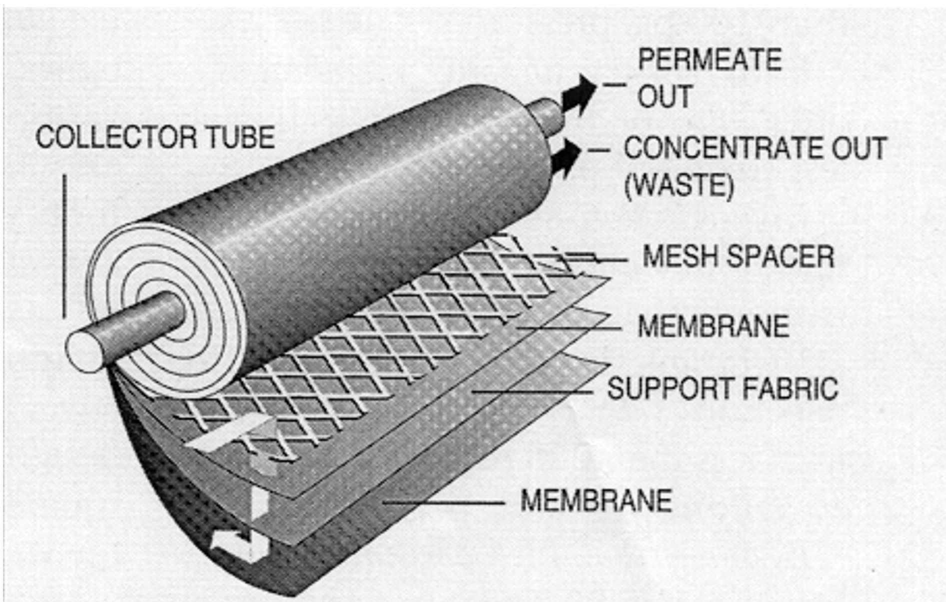

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salt, conductivity of all three process streams is measured. A helpful tool for operators is to use a conductivity balance as a crosscheck for RO/NF recovery. Recovery is generally established at or slightly below the limits of scaling, and typically is calculated from flow:

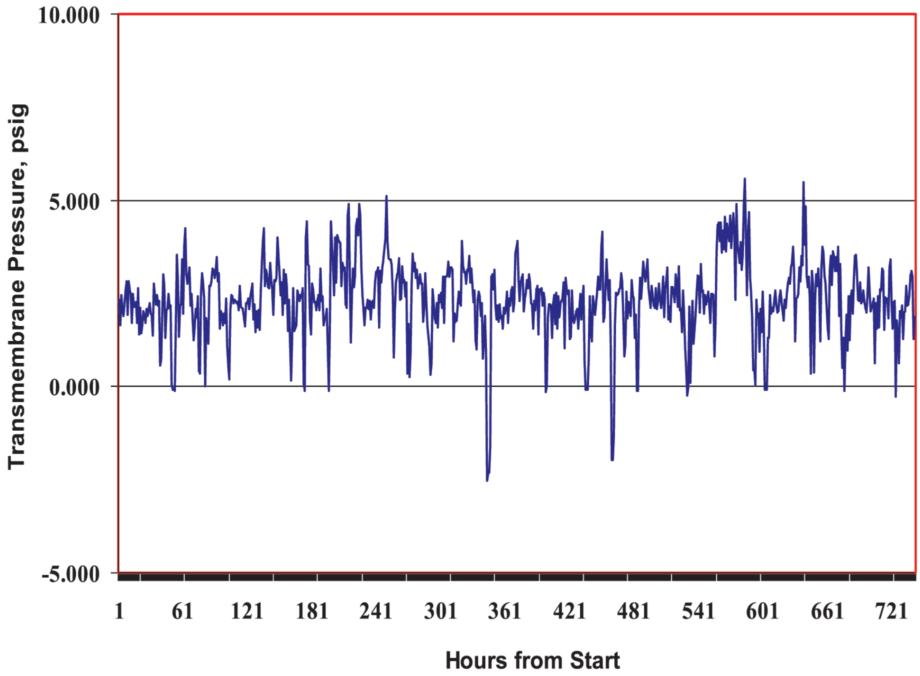
Recovery (Y) percent = (permeate flow / feed flow) x 100

and:

Concentration Factor (CF) = 100/(100-Y)

For example, at 75 percent recovery, the concentration factor is 4, assuming 100 percent salt rejection. Therefore, the concentrate conductivity should be four times the feed conductivity, as a rough check.

For UF, most systems operate in the "dead end" mode, where recovery is 100 percent during the filtration cycle, and the concentrate valve is closed. During backwash, the concentrate valve is open to permit the solids cake to be flushed from the system. The volume of water used for backwashing is deducted from the volume of filtrate produced and the recovery is calculated from these two volumes. It is evident that as the backwash frequency and duration increase, the net recovery of a UV system will go down. This leads to an important UF operational decision for systems where the raw water turbidity may rise and fall with storm events. Many plants are programmed to stop operating when incoming turbidity reaches a predetermined value, and to restart when the turbidity spike has passed.



The RO/NF plants on the other hand are not backwashed. Foulants are allowed to build up on the membrane to a certain point, and then the system is chemically cleaned. The cleaning solution normally consists of aqueous surfactants, with acids or alkalis, and is applied to the feed side of the membrane. The process of separation takes place, so cleaning chemicals do not appear in the permeate.

Cleaning is usually dictated by an increase in feed pressure, or an increase in differential pressure. The limiting difference is recommended by the membrane manufacturer, and is typically around 10 to 15 percent. Of course, continued operation when the differential is reached is possible, but the changes after this point can be asymptotic, and very frequently are not completely recoverable, resulting in increased energy usage to maintain the design output from the plant.

Record Keeping and Warranties

Perhaps the most critical aspect of membrane plant operation is record keeping. A unique aspect of membrane water treatment plants is the extended performance warranty that is provided to the user by the manufacturer. The typical warranty period is three to five years, but all membrane warranties are negotiable, and may extend 10, 12, or sometimes even 20 years.

Long-term warranties are basically insurance policies, where the owner is paying a premium for the manufacturer to review the operating data and to replace membrane modules as necessary to maintain the guaranteed plant performance. Such long-term agreements are unusual, and do not exist at all for RO/NF plants. The standard RO/NF warranty is similar to a car battery warranty, and is typically three years after the initial materials and workmanship warranty. Longer warranties can be negotiated, but the manufacture of RO and NF membranes is so much more sophisticated today that actual membrane material failures are almost unknown. Membrane life is easily five to seven years, and in some facilities, has exceeded 10 years.

The three charts shown consist of data from an RO plant that has experienced severe operating issues. These issues came about as a result of inexperienced designers, and poor contractor performance. The first chart shows a loss of rejection, or conversely, an increase in salt passage, over a relatively short period of time. This indicates damage to the rejection layer of the membranes. The other two charts show an increase in differential pressure in both stages of the plant, also over a short period of time. This is an indication of plugging rather than fouling. From these data, a well-trained operator can deduce that suspended solids of an abrasive nature are causing the problems and will lead to a check of the pretreatment system, a membrane autopsy (probably lead and tail end elements), and opening of vessels to inspect the front surface of the lead element for signs of suspended solids, all of which could prevent a small problem from becoming a large one.

For both types of membrane plants, complete and detailed documentation of operating life of the membranes is required for a membrane warranty claim to be upheld. In most cases, the operating SCADA system will archive the rejected data, but if not, the daily printouts must be retained. It is also essential that a detailed operations logbook be maintained and frequently reviewed by management, and anything that could possibly impact the life or performance of the membranes should be recorded in some detail.

Regulatory record keeping is also important, and must be maintained in compliance with state requirements. However, in terms of plant operations, optimization, and warranty claims, the operational logs require more detail and will be the only avenue to a successful warranty claim.

Conclusion

In summary, membrane plants are simple in concept and straightforward in operation. Each type requires its own approach, and has its own unique set of needs. The plant should be designed by knowledgeable engineers and the operators well-trained, with continuing education provided to keep up with changes in membrane technology.