HYDRANAUTICS
High Performance Membrane Products
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What Is Membrane Performance Normalization?

The majority of Reverse Osmosis (RO) systems normally will operate under fairly steady conditions over long periods of time if operating parameters remain constant. Fouling does not occur, and membrane damage is avoided. Unfortunately, operating parameters (e.g. temperature, feed TDS, permeate flow, recovery) do change, and fouling of the membrane and element feed path can occur. Normalization is a technique that allows the user to compare operation at a specific set of conditions to a reference set of conditions. This allows the user to determine whether changes in flow or rejection are caused by fouling, dmamge to the membrane, or are just due to different operating conditions.

Hydranautics offers a Windows based normalization program: RODATA. This program can be downloaded from the "Designing" page.

Normalization Equations

Normalized Flow

Net Driving Pressure (NDP) and temperature influence the permeability of the membrane to water. NDP is a function of the applied pressure, pressure drop, osmotic pressure, and permeate pressure of the system. As NDP increases, the membrane will produce more water. Likewise, as temperature increases, the membrane becomes more permeable, and flow increases. A Temperature Correction Factor (TCF) correlates change in flow to change in temperature. By multiplying the given flow by ratios of initial and specified values of both the NDP and Temperature Correction Factor (TCF), the normalized flow is found.

Equation 1 gives the formula for general normalized flow.

$$Q_N = Q_t \times (NDP_r/NDP_t) \times (TCF_r/TCF_t) \qquad (1)$$

Where:

Q_N = Normalized flow rate (vol/t) at time t
Q_t = Actual flow rate (vol/t) at time t
NDP_r = Net Driving Pressure at reference point (units of pressure)
NDP_t = Net Driving Pressure at time t (units of pressure)
TCF_r = TCF for temperature at referenced conditions (no units)
TCF_t = TCF for temperature at time t (no units)

Equation 2 gives the formula for Net Driving Pressure. All units are pressure units such as psi, kPa, bar.

$$NDP = P_f - \tfrac{1}{2}\Delta P_{fb} - P_{osm} - P_p \qquad (2)$$

Where:

P_f = Feed Pressure
ΔP_{fb} = Pressure drop between the feed and brine streams
P_{osm} = Osmotic pressure
P_p = Permeate pressure

Osmotic pressure is further expanded in equation 3.

$$P_{osm} = CF_{lm} * C_f * 11/1000 * K_{p\text{-}cond} \qquad (3)$$

Where:

CF_{lm} = Log mean concentration factor. (no units)
C_f = Feed conductivity (µS-cm)
$K_{p\text{-}cond}$ = conversion factor, conductivity to pressure. This constant is a function of the TDS of the sample.

The log mean concentration factor can be further expanded as shown in Equation 4.

$$CF_{lm} = \ln [1/(1-R)] / R \qquad (4)$$

Where R is recovery, expressed as a decimal.

$$R = Q_p/Q_f \text{, Permeate Flow divided by Feed Flow.} \qquad (5)$$

Finally, the Temperature Correction Factor is given by equation 6.

$$TCF = \exp \{ K * [1/(273 °K + t) - 1/298 °K] \} \quad (6)$$

Where t is degrees Celsius, and K = 2700 °K for composite membrane.

Normalized Salt Passage

The salt passage of a system can be normalized by the following equation:

$$\%SP_n = (EPF_a/EPF_n) * (STCF_n/STCF_a) * \% SP_a \quad (7)$$

Where:

$\%SP_n$ = Percent Salt Passage normalized to standard conditions
$\%SP_a$ = Percent Salt Passage at actual conditions
EPF_n = Element Permeate Flow rate at standard conditions
EPF_a = Element Permeate Flow rate at actual conditions
$STCF_n$ = Salt Transport Temperature Correction Factor at standard conditions
$STCF_a$ = Salt Transport Temperature Correction Factor at actual conditions

Actual Salt Passage is given by equation (8):

$$\%SP_a = C_p/C_{fb} \quad (8)$$

Where

C_p = Permeate concentration, ppm
C_{fb} = Feed-Brine concentration, ppm,
which equals the feed concentration, in ppm, multiplied by the log mean average of the recovery, (equation 4)
= $C_f * CF_{lm}$

Element permeate flow at standard conditions is unique to the element, and is provided by the manufacturer. Element permeate flow at actual conditions is dependent on the system.

The Salt Transport Temperature Correction Factor is provided by the element manufacturer. If the factor is unavailable, substitute the TCF (equation 6).

Changes in Apparent Membrane Performance

Changes in operating parameters will have a normal effect on membrane performance. These influences can either result in an apparent reduction of permeate flow or quality. This section will enumerate those effects that normally affect membrane performance.

Loss of Flow:

The following changes in operating parameters will decrease the actual permeate flow of a system:

- A decrease in feed water temperature with no change in feed pump pressure.
- A decrease in RO feed pressure by throttling down the feed valve.
- An increase in permeate back pressure with no change in feed pump pressure.
- An increase in the feed TDS (or conductivity) since this increases the osmotic pressure that has to be overcome to permeate water through the membrane.
- An increase in the system recovery rate. This increases the average feed/concentrate TDS which then increases the osmotic pressure.
- Fouling of the membrane surface.
- Fouling of the feed spacer that results in an increase of feed-to-concentrate pressure drop (delta P) which starves the back-end of the system of net driving pressure (NDP) to produce permeate water.

Loss of Water Quality:

The following changes in operating parameters will result in actual lower quality permeate water, as indicated by an increase in permeate TDS as ppm or conductivity:

- An increase in feed water temperature with the system adjusted to maintain the same permeate flow (or flux).
- A decrease in the system permeate flow, which reduces the water flux, and results in less permeate water to dilute the amount of salts that have passed through the membrane.
- An increase in the feed TDS (or conductivity) since the RO will always reject a set percentage of the salts.

- An increase in the system recovery rate since this increases the average feed/concentrate TDS of the system.
- Fouling of the membrane surface.
- Damaged o-rings seals.
- Damage to the membrane surface (such as exposure to chlorine) which allows more salts to pass.

Use of the normalization program thus “factors out” the effects of changing feed pressure, concentration, and temperature. Factors related to fouling, degradation, or systemic factors (ie, blown o-rings) are thus more clearly discerned.

Normalized data that is graphed will show not only the instantaneous condition of the RO system at any given time, but also shows the detailed operating history. These graphs can be a useful tool for troubleshooting.

Normalization data

The normalized data graphs presented in the Hydranautics RODATA Normalization program are:

- **Normalized Salt Passage vs. Time**: This graph plots the normalized per cent salt passage of the system relative to the System Reference Data at start-up.

- **Normalized Permeate Flow vs Time**: This graph plots the normalized permeate flow in gpm or m^3/hr, relative to the System Reference Data at start-up.

- **Salt Transport Coefficient vs. Time**: This graph plots Salt Transport Coefficient (STC) for “membrane technophiles”. The importance of this number is that it measures the efficiency of the membrane in how fast it allows the passage of salts. The value is reported as m/sec (meters per second). This number allows the comparison of membranes from site to site, independent of what the on-site operating conditions are. This number will be affected by changes in the ionic makeup of the feed water. For example, an increase in divalent ions (like hardness or sulfate) will result in a lower Salt Transport Coefficient.

- **Water Transport Coefficient vs. Time**: This graph plots the Water Transport Coefficient (WTC) for "membrane technophiles". The importance of this number is that it measures the efficiency of the membrane in how fast it allows the passage of water. The value is reported as m/sec-kPa (meters per second per kilopascal. This number allows the comparison of membranes from site-to-site, independent of what the on-site operating conditions are.

- **Normalized Delta P vs. Time**: This graph plots the normalized feed-to-concentrate pressure drop in PSI or Bar relative to the System Reference Data at start-up. The normalized Delta P value reflects adjustments to pressure drop due to varying feed and concentrate flows.

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