Reverse Osmosis Data Collection and Normalization

The purpose of Reverse Osmosis (RO) data collection ana analysis is to understand true RO membrane conditions and help troubleshoot any potential problems before they become serious. Normalizing data factors with external elements that affect membrane performace enables apples-to-apples comparisons when reviewing performance data. Normalized RO performance data is compared to an established baseline, such as when the membranes were new, replaced, or cleaned.

The following raw data is collected to determine RO membrane health:

1. Feed Temp (F^0)
2. Permeate Flow (GPM)
3. Concentrate Flow (GPM)
4. Feed Pressure (PSI)
5. Permeate Pressure (PSI)
6. Feed Conductivity
7. Permeate Conductivity

All these operating conditions directly affect the quality and amount of permeate water the RO membranes can produce. However, since these operating conditions are constantly changing, it is impossible to compare the observed performance of certain parameters at one point and compare them to another point under different operating conditions. Changing factors, such as temperature, feed water quality, permeate flow, and system recovers all affect membrane performance.

Normalizing RO data allows the user to compare RO membrane performance to a set standard which does not depend on changing operating conditions. Normalized data will measure the direct condition of the RO membrane and show the true RO membrane performance and health.

Data that is not normalized can be misleading, since so many variables can cause changes that may appear to be problems when, in fact, they are not. Feed water temperature is the most noticeable condition affecting RO system performance. The general rule of thumb is to estimate a 1.5% permeate flow change per degree Fahrenheit (F^0) change.

For example, if an RO produced 50 GPM of permeate when the feed water was 60 F^0 and then the feed water temperature dropped 5 F^0, then the RO would produce approximately 46 GPM. The 4 GPM decrease in product is perfectly normal with the temperature drop.

Data Interpretation

An RO operator is ultimately concerned about two outcomes: the quality and quantity of water being produced. As mentioned above, these two factors can be influenced by a number of variables such as feed water pressure, system recovery, and changes in feed water quality, to name a few.

There are three calculated values which help give a better picture of true membrane performance and help accurately troubleshoot potential RO system problems involving the quantity and quality of water produced by the RO system. By collecting operating data, normalizing the data, and then trending the normalized data over time, and comparing the values to the baseline (calculated from the start-up values when the RO membranes were new or after they have been cleaned or replaced) enables proactive action to address any problems before irreversible damage to the RO membranes occurs.

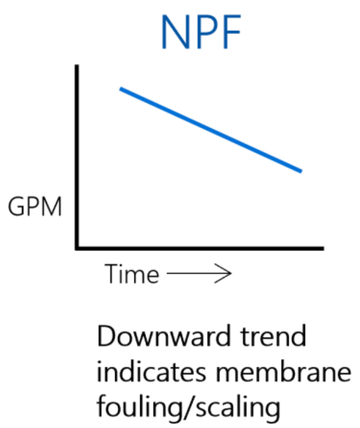
The three calculated values used to monitor and trend are:

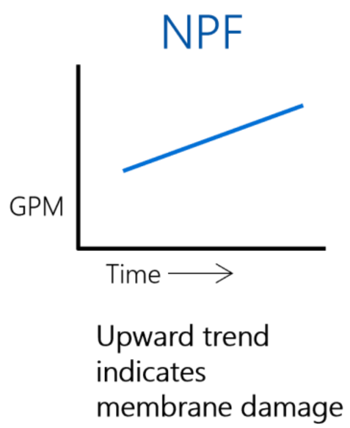
- Normalized Permeate Flow (NPF)
- Normalized Salt Rejection (NSR)
- Normalized Pressure Differential (NPD)

Normalized Permeate Flow (NPF)

NPF measures the amount of permeate water the RO is producing. If the NPF drops 10% to 15% below the baseline value (the NPF reading at start up with new membranes or when membranes were replaced or cleaned) then this indicates RO membrane fouling or scaling and the RO membranes should be cleaned.

If the NPF increases, then this implies there is damage to the RO membrane. The damage can be caused by chemical attack (from an oxidizer like chlorine) on the membrane or a mechanical issue (like an O-ring failure).





See Fig 1 to learn how NPF is calculated.

Normalized Salt Rejection (NSR)

NSR indicates how well the RO membrane is rejecting salts (contaminants) and so affects permeate water quality. If the NSR decreases, then the volume of salts going through the RO membrane increases creating lower quality permeate. An NSR decrease can indicate RO membrane fouling, scaling, or degradation.

A well performing RO membrane should be providing 97% to 99% rejection. A membrane is considered "bad" when the RO rejection drops to 90% or less. A normal RO operation span features a steady NSR decline during continuous use.

RO membranes usually last several years before they require replacement and a steady decline in NSR is a normal sign of an aging membrane. A proper RO membrane cleaning regiment can help improve the NSR.

NSR can be helpful for identifying biofouling issues. When biofouling is a concern, often the NSR will increase and the NPF will decrease. This is because the biofoulant will actually seal small imperfections in the RO membrane thereby increasing the rejection of salts.

Over time, the biofoulant layer ages and begins to die and chemicals such as CO2, methane, and/or organic acids begin to diffuse through the membrane affecting permeate water quality (less salt rejection resulting in a lower NSR).

See Fig 2 to learn how the NSR is calculated.

Normalized Pressure Differential (NPD)

The NPD tells us how clean the feed water spacer is on the membrane, These spacers are only around 30-thousandths of an inch thick and are extremely susceptible to plugging. As plugging occurs, the resistance to flow increases and pressure dop increases.

The NPD will begin to increase over time due to fouling and scaling. The RO membranes should be cleaned when the DPD increases by 15% to 25% above the baseline value. NPD and NPF should be monitored together to determine when the RO membranes should be cleaned. Often the NPF will decrease, and the NPD will remain unchanged. This is simply because the fouling/scaling issues have yet to plug the feed water spacers. In time, the NPD will increase in conjunction with the drop in NPF.

A decrease in NPD is usually due to faulty instrumentation or mistakes made during data collection.

If NPD can be measured for each stage of an RO, usually problems can be identified between fouling and scaling based on the location of the increased pressure drop. An increase in NPD in the front stage of an RO indicates fouling issue, and an NPD increase in the second stage indicates scaling.

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Figure 1 – Normalized Permeate Flow Calculation

$$\text{NPF} = \textit{Permeate Flow} \times \left(\frac{\textit{Baseline aNDP}}{\textit{aNDP}}\right) \times \left(\frac{\textit{Baseline TCF}}{\textit{TCF}}\right)$$

Where:

$$\text{Feed TDS} = \frac{\textit{Feed Conductivity}}{2}$$

$$\text{Concentrate Factor} = \frac{\textit{Permeate Flow} + \textit{Concentrate Flow}}{\textit{Concentrate Flow}}$$

$$\text{Concentrate TDS} = \textit{Feed TDS} \times \textit{Concentrate Factor}$$

aNDP (*Average Net Driving Pressure*)

$$= \left(\left(\frac{\textit{Feed Pressure} + \textit{Concentrate Pressure}}{2}\right) - \left(\frac{\textit{Feed TDS} + \textit{Concentrate TDS}}{200}\right)\right) - \text{Permeate Pressure}$$

$$\text{Feed Temp C} = \left(\frac{5}{9}\right) \times (\textit{Feed Temp} - 32)$$

$$\text{TCF } (\textit{Temperature Correction Factor}) = \textit{EXP}\left(2640 \times \left(\left(\frac{1}{298}\right) - \left(\frac{1}{273 + \textit{Feed Temp C}}\right)\right)\right)$$

TCF Explanation

Water temperature is one of the key factors in the performance of reverse osmosis membranes. Membrane manufacturers provide temperature correction factors for given operating temperatures, can vary by manufacturer, and can be calculated in different ways. The ASTM method, as shown above, with the Membrane Coefficient of 2640 is used for our purpose of finding RO variances. The Membrane Coefficient of 2640 is used because the majority of our membranes will conform to this number, and the effect of using a specific coefficient for each membrane on the calculations is negligible.

Figure 2 – Normalized Salt Rejection

NSR monitors the amount of salt that passes through the membrane.

$$NSR = 100 - \left(\left(\mathit{Salt\ Passage} \times \left(\frac{\mathit{Permeate\ Flow}}{\mathit{Baseline\ Permeate\ Flow}}\right) \times \mathit{TCF}\right) \times 100\right)$$

Where:

$$\text{Permeate TDS} = \mathit{Permeate\ Conductivity} \times 0.67$$

$$\text{Feed TDS} = \frac{\mathit{Feed\ Conductivity}}{2}$$

$$\text{Salt Rejection} = 1 - \left(\frac{\mathit{Permeate\ TDS}}{\mathit{Feed\ TDS}}\right)$$

$$\text{Salt Passage} = 1 - \mathit{Salt\ Rejection}$$

$$\text{Feed Temp C} = \left(\frac{5}{9}\right) \times (\mathit{Feed\ Temp} - 32)$$

$$\text{TCF } (\mathit{Temperature\ Correction\ Factor}) = EXP\left(2640 \times \left(\left(\frac{1}{298}\right) - \left(\frac{1}{273 + \mathit{Feed\ Temp\ C}}\right)\right)\right)$$

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Figure 3 – Normalized Pressure Differential

The Pressure Differential can help identify if the membrane is dirty. The normalized value (NPD) will account for changes in flow and temperature. An increase in the NPD is an early warning of scaling and/or fouling. To prevent complex problems, the membrane should be cleaned if the NPD is 15% or greater than the baseline.

$$\text{NPD} = \textit{Pressure Drop} \times \frac{\textit{Baseline Average Flow}}{\textit{Average Flow}}$$

Where:

$$\text{Pressure Drop} = \textit{Feed Pressure} - \textit{Concentrate Pressure}$$

$$\text{Average Flow} = \frac{\textit{Permeate Flow} + \textit{Concentrate Flow}}{2}$$