Pretreatment Water Application: RO & NF Elements

Often times, feed water to reverse osmosis and nanofiltration systems have substantially more particulate matter, organic substances and other solids which may not be compatible with RO and NF membrane processes. Proper pretreatment plays a critical role in the performance, life expectancy and the overall operating costs of these systems.

This bulletin outlines how to determine when pretreatment is necessary, the objectives and role of pretreatment in the system as well as pretreatment options. For questions or additional information, please contact MANN+HUMMEL Water & Fluid Solutions Technical Service.

INTRODUCTION

Depending on the source, feed water may contain various concentrations of suspended solids and dissolved matter (refer to **Feed Water Parameters – Assessing RO & NF Feed Water Quality** (TSG-C-010)). Suspended solids may consist of inorganic particles, colloids and biological debris such as microorganisms and algae whereas dissolved matter may consist of highly soluble salts, such as chlorides, and sparingly soluble salts, such as carbonates, sulfates and silica. Suspended particles may settle on the membrane surface and block feed channels, which is referred to as membrane fouling and may result in an increased pressure drop across the system. Sparingly soluble salts may precipitate from the concentrate stream, create scale on the membrane surface and result in lower water permeability through the membranes. The primary objectives of pretreatment include allowing the membrane system to run more efficiently and lowering operating costs. This is achieved by improving the quality of the feed water, optimizing permeate flow and recovery, and preventing fouling, scaling and premature membrane failure and frequent cleaning requirements.

The type of pretreatment largely depends on the feed water source (i.e., well water, surface water or municipal water), the feed water composition and the application. For example, well water is a consistent feed source with low fouling potential and typically requires a very simple pretreatment scheme compared to surface water or industrial and municipal wastewaters. This is because surface waters are variable feed water sources that are easily affected by seasonal factors. Surface waters typically have a high fouling potential, requiring a more elaborate pretreatment regimen than well waters. Industrial and municipal wastewaters, on the other hand, have a wide variety of organic and inorganic constituents and require an entirely different pretreatment scheme. Lastly, the application often determines the type or extent of pretreatment required. For example, an industrial wastewater application may require a different pretreatment than that of a pharmaceutical, high-purity application due to the unique product water requirements. Once the feed water source and application have been determined, it is critical to design the proper pretreatment for the RO/NF system.

FOULING

Fouling is primarily caused by the combination of a biologically active feed water and improper pretreatment. It occurs when contaminants accumulate on the membrane surface, effectively plugging the membrane. Fouling typically occurs at the front end of a system and may result in an increased pressure drop across the system, lower permeate flow, and/or increased salt passage (refer to **Troubleshooting – Low Permeability** (TSG-T-004)). This typically translates to higher operating costs and may eventually lead to a system cleaning or element replacement. Having proper pretreatment in place reduces the fouling potential of the raw feed water.

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Fouling can be caused by the following:

1. Particulate or colloidal matter (dirt, silt, clay, etc.)
2. Organics (humic/fulvic acids, etc.)
3. Microorganisms (bacteria, etc.). Bacteria is one of the most common foulants because many membranes cannot tolerate the necessary disinfectants (i.e. chlorine) used to eliminate it. Microorganisms are therefore often able to thrive and multiply on the membrane surface, producing biofilms and resulting in heavy fouling.
4. Filter media upstream of the membranes.

SCALING

Scaling may occur if the concentration of certain dissolved (inorganic) compounds are concentrated beyond their solubility limits and precipitate on the membrane surface as scale. As a rule of thumb, as the recovery of the plant is increased, so is the risk of scaling. For example, if an RO plant is operated at 50% recovery, the concentration in the concentrate stream will be almost double the concentration in the feed stream.

In a brackish water RO/NF system, the most common sparingly soluble salts encountered include $CaSO_4$, $CaCO_3$ and silica. Other salts that may create a potential scaling problem include CaF_2, $BaSO_4$, $SrSO_4$ and $Ca_3(PO_4)_2$.

Scaling often times results in a higher pressure drop across the system, higher salt passage, low permeate flow and lower permeate water quality.

CHEMICAL ATTACK

Thin-film composite membranes are not tolerant to chlorine. Oxidizers such as free chlorine or bromine may catalyze the reaction between oxidizing agents and the membrane surface. Continuous exposure to oxidizers may eventually damage the membrane causing the membrane to be susceptible to a higher permeate flow and higher salt passage. This is why it is highly recommended to prevent chlorine from entering a thin-film composite membrane system. Granular Activated Carbon or sodium bisulfite may be used to remove residual chlorine prior to the RO or NF system. If a disinfection is necessary to sanitize a thin film composite system, please refer to MANN+HUMMEL Water & Fluid Solutions' **Membrane Disinfection Guide – Hydrogen Peroxide/Peracetic Acid Mixtures** (TSG-C-006).

MECHANICAL DEMAND

It is highly recommended to assess a system's plumbing and controls. If "hard starts" occur, mechanical damage known as water hammer may occur to the membranes. Likewise, if there is too much backpressure on the system, mechanical damage to the membranes may also occur. These potential issues may be addressed by using variable frequency drive motors to start high pressure pumps and by installing check valve(s) and/or pressure relief valves to prevent excessive back pressure on the unit that can cause permanent membrane damage.

PRETREATMENT SOLUTIONS

Below are some pretreatment solutions for RO and NF systems that may help minimize fouling, scaling and chemical attack.

Acid Addition

Most natural surface and ground waters contain high levels of $CaCO_3$. The solubility of $CaCo_3$ depends on pH as shown in the following equation:

$$Ca^{2+} + HCO_3^- \leftrightarrow H^+ + CaCO_3$$

By adding H^+ ions using acid (food-grade acid is typically recommended), the equilibrium can be shifted to the left in order to keep calcium carbonate dissolved. Sulfuric acid is typically easier to handle and is more readily available than hydrochloric acid, however, this means additional sulfate is added to the feed stream which may potentially cause sulfate scaling.

To control calcium carbonate scaling by acid addition alone, the Langelier Saturation Index (LSI) for brackish waters and the Stiff & Davis Stability Index (S&DSI) for seawaters in the concentrate stream must be negative. Acid addition is useful to control carbonate scale only.

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Antiscalants/Scale Inhibitors

Antiscalants and scale inhibitors are chemicals that can be dosed to the feed water prior to an RO or NF unit to help reduce scaling potential. Antiscalants and scale inhibitors increase the solubility limits of sparingly soluble salts, preventing those compounds from precipitating onto the membrane surface. By increasing the solubility limits, the salts can be concentrated further and therefore a higher recovery rate can be achieved and the system may run at a higher concentration factor. Antiscalants and scale inhibitors work by interfering with scale formation and crystal growth. The choice of antiscalant or scale inhibitor to use and the correct dosage depends on the feed water chemistry and system design.

The use of an antiscalant allows for the concentrate LSI of up to 2.5 (or 1.8 for more conservative design).

Granular Activated Carbon

Granular Activated Carbon (GAC) is used for both removing organic constituents and residual disinfectants (such as chlorine and chloramines) from the water. GAC media is derived of coal, nutshells or wood. Activated carbon removes residual chlorine and chloramines by a chemical reaction that involves a transfer of electrons from the surface of the GAC to the residual chlorine or chloramines. The chlorines or chloramines end up as chloride ions that are no longer oxidizers.

The disadvantage of using a GAC prior to the RO or NF unit is that the GAC will remove chlorine quickly at the very top of the GAC bed. This will leave the remainder of the GAC bed without any biocide to kill microorganisms. A GAC bed will absorb organics throughout the bed, which may become food for bacteria and create a breeding ground for bacteria growth which can easily pass through to the membranes. Likewise, a GAC bed may produce very small carbon fines that may have the potential to foul membranes. Because of its cost and disposal requirements, GAC is more commonly found in small systems.

Lime Softening

In most raw water sources, hardness is present as calcium and magnesium bicarbonate (sometimes referred to as carbonate hardness or temporary hardness). Lime softening can be used to remove carbonate hardness by adding hydrated lime, $Ca(OH)_2$:

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow 2\ CaCO_3^- + 2\ H_2O$$
$$Mg(HCO_3)_2 + 2\ Ca(OH)_2 \rightarrow Mg(OH)_2^- + 2\ CaCO_3^- + 2\ H_2O$$

Noncarbonate calcium hardness (hardness that is present as a sulfate or chloride salt, referred to as noncarbonated or permanent hardness), on the other hand, may be reduced by a combination of lime and sodium carbonate (soda ash), along with coagulant and flocculent chemicals to promote a precipitation reaction. The lime-soda ash process can also be used to reduce high silica concentrations. When sodium aluminate and ferric chloride are added, the precipitate includes calcium carbonate and a complex with silica acid, aluminum oxide and iron.

Lime softening may be performed at different temperature ranges to increase the solubilities of calcium, magnesium and silica. Cold lime softening is performed at ambient temperatures, warm lime softening is performed in the temperature range of 49 – 60°C (120 – 140°F) and hot process softening is performed at temperatures of 108 – 116°C (227 – 240°F).

Ultrafiltration & Microfiltration

Ultrafiltration (UF) and microfiltration (MF) are an effective way to remove suspended solids, colloidal particles and bacteria. UF and MF membranes are helpful in reducing fouling potential for a RO or NF system. Various ultrafiltration and microfiltration configurations are commercially available including hollow fiber, plate and frame as well as spiral- wound.

Multi-Media Filter

A multi-media filter (MMF) is often used to help prevent fouling of an RO or NF system. A MMF typically contains three layers of media including anthracite coal, sand and garnet, with a supporting layer of gravel at the bottom. These are the media of choice due to the differences in size and density. The larger (but lighter) anthracite coal is placed at the top and the heavier (but smaller) garnet will remain at the bottom of the filter. The filter media arrangement allows the largest dirt particles to be removed near the top of the media bed with the smaller dirt particles being retained deeper into the media. This allows the entire bed to act as a filter allowing for more efficient particulate removal.

A well-operated MMF can remove particulates as small as 15 – 20 microns in size. A MMF which uses a coagulant to bind tiny particles together to form particles large enough to be filtered, can remove particles as small as 5 – 10 microns.

Often times, it is recommended to install a MMF when the Silt Density Index (SDI) value of the feed water is greater than 3 or when the turbidity is greater than 0.2 NTU. These guidelines will help prevent premature fouling of the RO membranes.

It is important to have a 5 micron cartridge filter placed directly after the MMF unit in case the MMF fails. This will prevent the MMF media from damaging downstream pumps and from fouling the RO or NF system.

Sodium Bisulfite

Adding sodium bisulfite (SBS or SMBS) to the water stream before an RO or NF unit at the proper dose may remove residual chlorine and chloramines. In fact, sodium bisulfite is the most common means of removing chlorine. For more information on sodium bisulfite dosing as a pretreatment method, please refer to **Pretreatment – Dechlorination Using Sodium Metabisulfite** (TSG-C0012).

Water Softening

A water softener can be used to help prevent scaling in an RO or NF system by exchanging scale forming ions with non-scale forming ions. As with a MMF unit, it is important to have a 5 micron cartridge filter placed directly after the water softener in the event the softener fails. Due to its cost and disposal requirements, water softeners are more commonly found in small systems.

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