



LG Water Solutions



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Nano:H₂O™

Technical Applications Bulletin

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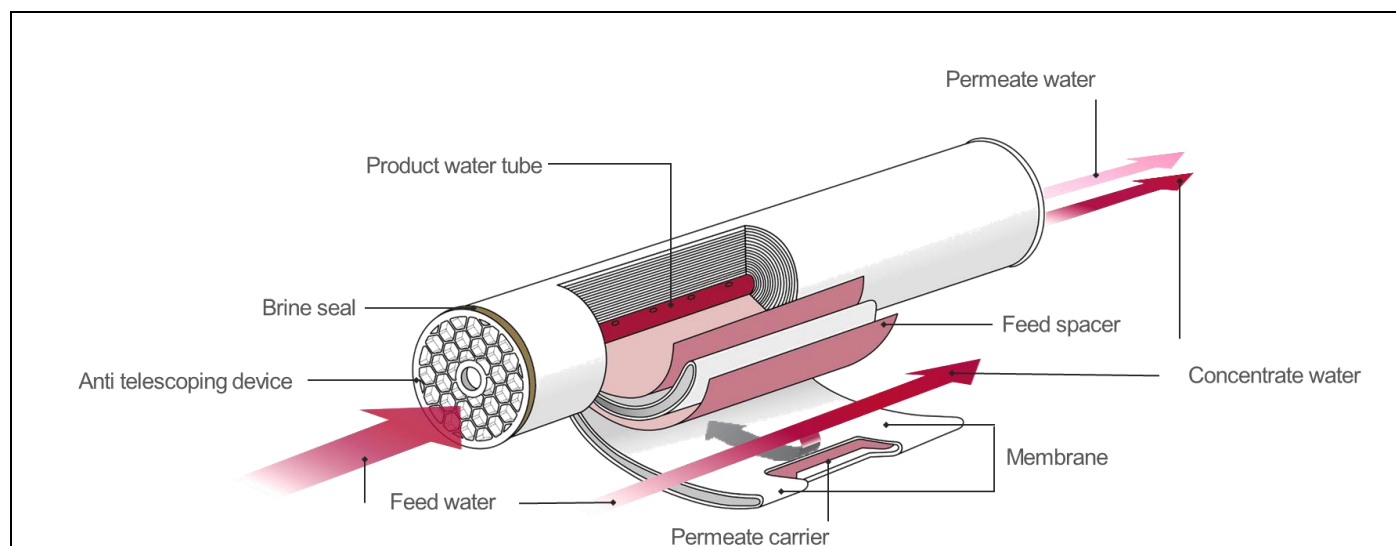
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Effect of Feed Spacer Thickness on Reverse Osmosis (RO) Membrane Performance

In a reverse osmosis (RO) process, pressure is applied to the saline side of a semi-permeable membrane to produce low salinity water. Upon application of the feed pressure, water molecules pass through the membrane while most of the dissolved solids remain on the saline side. The saline water then travels through a channel created by a feed spacer sandwiched between two flat sheet membranes (“membrane leaves”).

The primary function of the **feed spacer** is to separate the two leaves so the feed can freely flow between the membrane leaves while creating turbulence flow to minimize concentration polarization on the membrane surface. The low salinity water produced is called “permeate” and travels through the permeate channels filled with permeate carrier toward the central product water tube.

Figure 101.1 The above image depicts the construction of a typical spiral wound



Membrane elements are available with feed spacers in different thickness. 26- or 28-mil were standard spacer thickness adopted by many manufacturers in the earlier generation of membrane elements. With advancements in RO membrane manufacturing technology, it is now possible to accommodate thicker 34-mil RO feed spacer while still maintaining standard 400 square feet of active membrane area in an 8-inch diameter and 40-foot length membrane configuration.

Thickness of the feed spacer has several impacts on RO membrane performance. It has been found that when the feed flow rate is kept constant, linear liquid velocity becomes a function of the spacer thickness and a higher fluid velocity is achieved for thinner (e.g., 26- or 28-mil) spacer geometry. This thinner spacer geometry produces a higher initial pressure drop while the thicker feed spacer (e.g., 34-mil) has a lower initial feed pressure drop. More importantly, the pressure drop increase due to biofilm formation was found less in the thicker spacer compared to the thinner spacer. As a result, energy can be saved by using the 34-mil feed spacer. For poor water quality with higher biofouling potential, the membrane element with the 34-mil feed spacer will not experience biofouling channel plugging as rapidly, and therefore can be more easily cleaned.

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Surface Characteristics of LG Chem's NanoH₂O™ RO Membranes

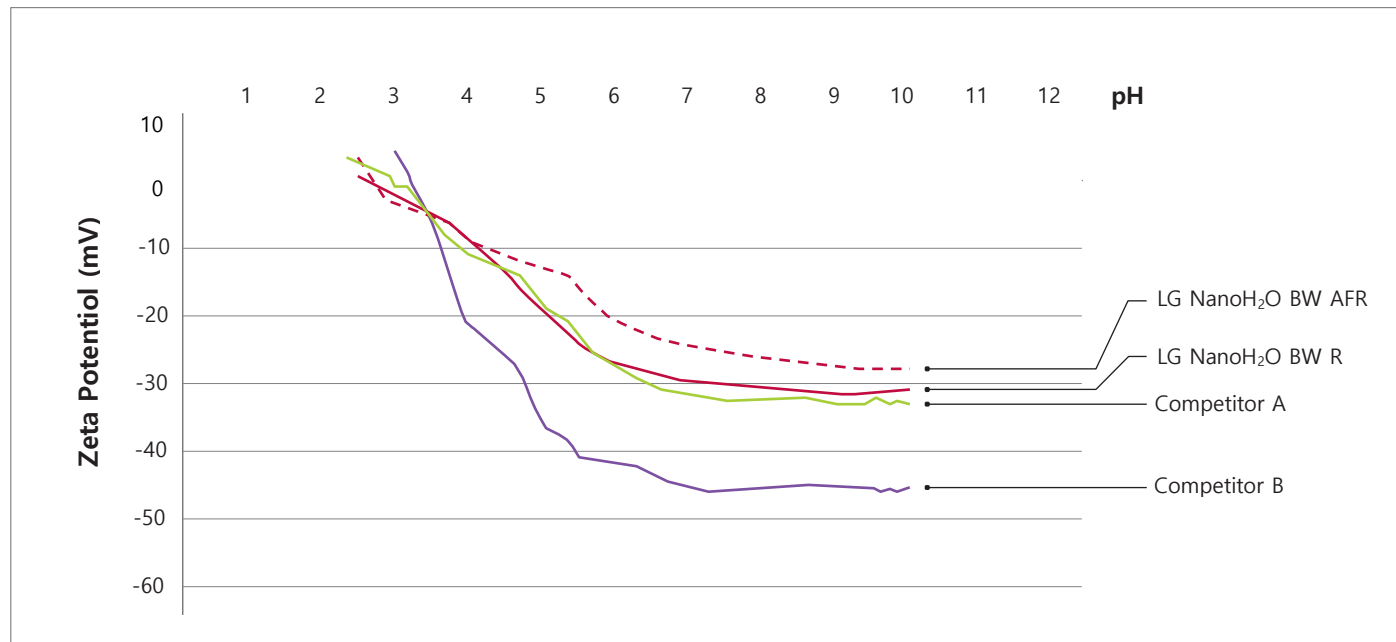
Membrane surface roughness and zeta potential are measured to analyze the surface characteristics of LG Chem's NanoH₂O membranes. It is understood that membrane surface roughness is correlated with colloidal fouling of RO membranes. Colloidal particles can plug the valleys of the relatively open and rough membrane surface, effectively increasing the resistance to water transport. In essence, lower surface roughness can contribute to reduced colloidal fouling potential. Surface roughness is represented by the root mean square (RMS) roughness. The roughness of LG Chem's NanoH₂O RO membranes is shown in Table 102.1 below.

Table 102.1 Summary of membrane RMS surface roughness obtained using AFM

Membrane Type	LG SW ES	LG SW R	LG SW SR	LG BW R	LG BW AF
Average RMS (nm)	112	105	107	94	94

The polyamide membrane typically carries a negative membrane surface charge. The interactions with charged foulants can be reduced by altering the membrane surface charge. Using neutral compound to cover the negative charges of the polyamide membrane surface can reduce the interactions between charged foulants and the membrane surface. LG Chem's NanoH₂O BWRO products show a surface charge closer to neutral between pH 6 to 10 due to the cross linking protective layer. In addition, this antifouling layer protects the membrane's surface to reduce damage to the polyamide membrane surface during CIP operation between pH 2 to 13.

Figure 102.1 LG Chem's NanoH₂O BWRO membranes zeta potential data compared to other commercially available membranes



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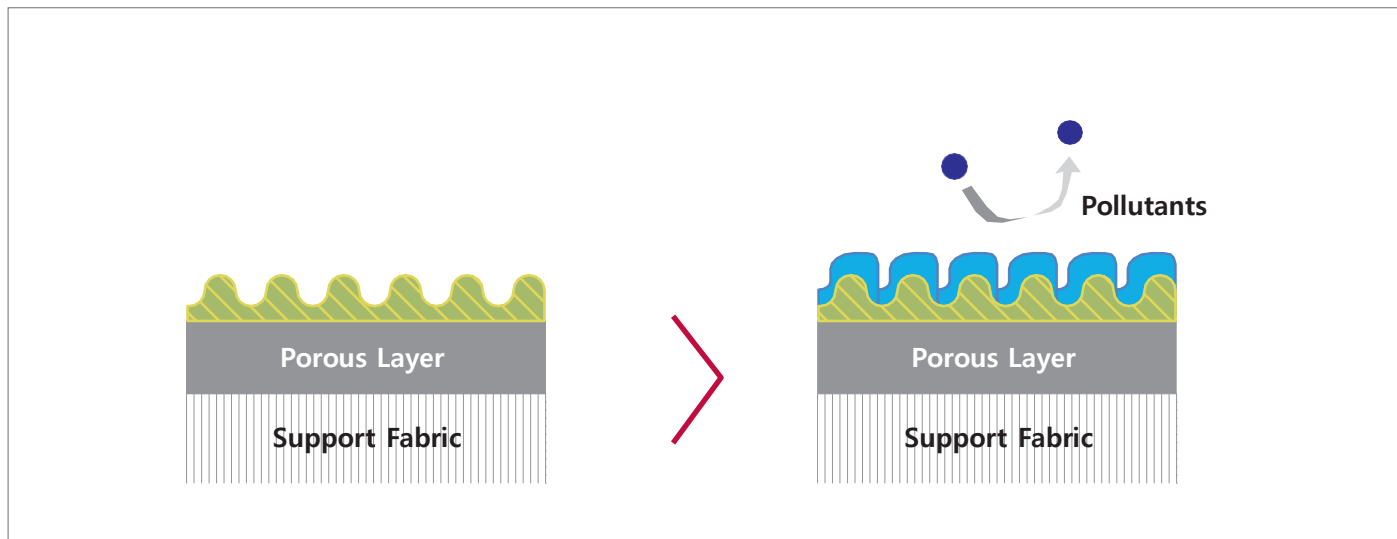
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Characteristics and Advantages of LG Chem's NanoH₂O™ Anti-Fouling RO Membranes

Biofouling has long been recognized as one of the most problematic types of fouling for polyamide reverse osmosis (RO) membranes. To avoid flux decline caused by biofouling, protective chemistry has been introduced to LG Chem's NanoH₂O Anti-Fouling membranes

Figure 103.1 The above image depicts the construction of a typical spiral wound element.



Protective material with cross-linking properties was added into the functional groups of the polyamide surface layer which then underwent a chemical reaction. The protective materials cross-link with themselves and with the reactive groups on the surface of the polyamide membrane. The protective layer is attached to and built up on the membrane's surface, thus making it part of the active layer.

Permanently bonded protective layer is resistant to chemical agents during the CIP process and it provides additional protection against particular matters such as colloidal foulants. Furthermore, this cross-linked protective layer can help alter the membrane's surface roughness to create a smoother membrane surface and reduce fouling potential by preventing foulant adsorption and attachment to the membrane's surface.

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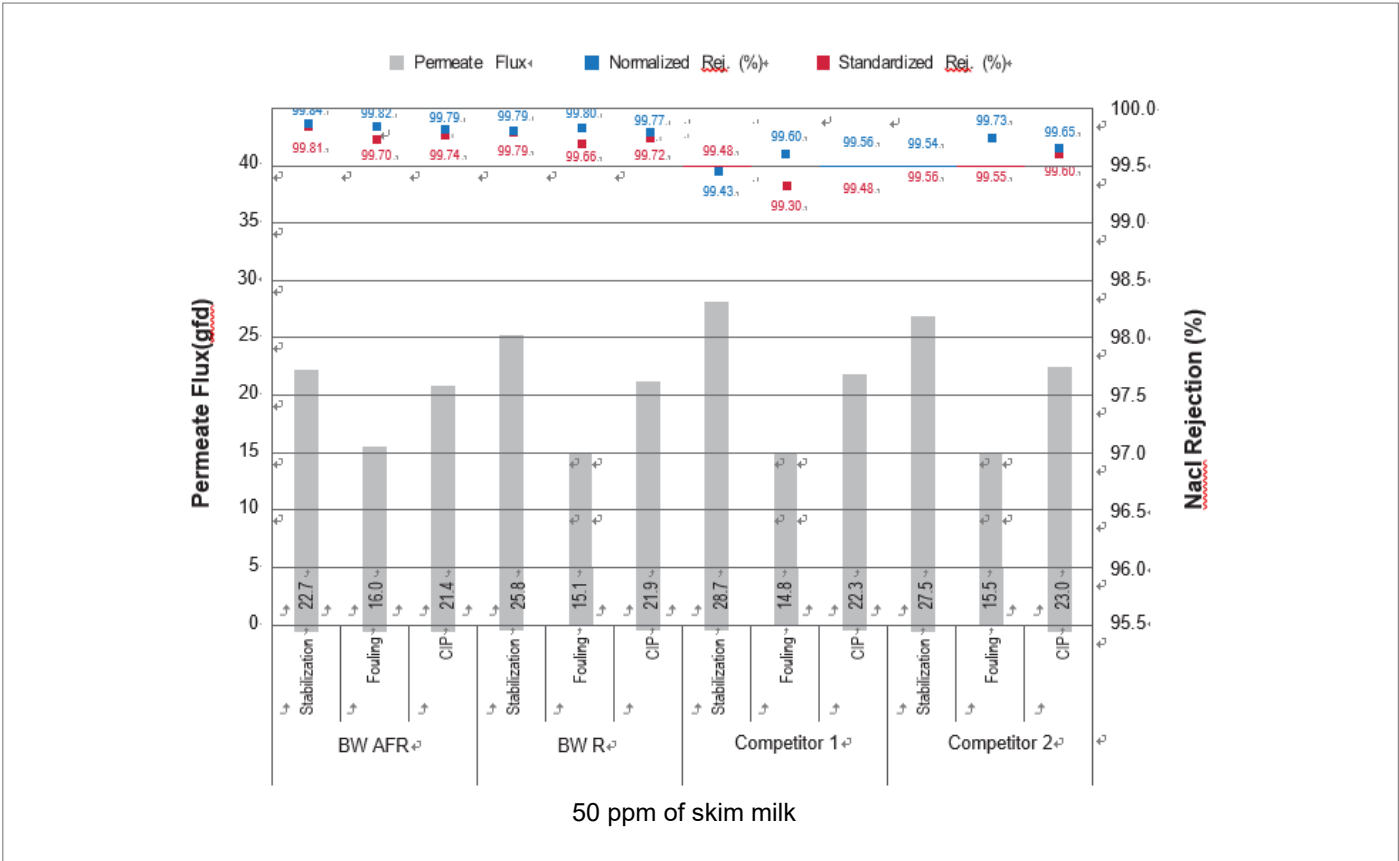
Fouling Studies on LG Chem's NanoH₂O™ RO Membranes

LG Chem has developed fouling-resistant membranes as part of its NanoH₂O™ line of brackish water RO (BWRO) membranes. A study was conducted to verify the anti-fouling properties of LG Chem's membranes against organic and inorganic foulants.

LG Chem's models LG BW R and LG BW AFR were tested under normal/standard operating conditions alongside two competitor's membranes. The feed water consisted of 2,000 ppm of NaCl and 100 ppm of NaHCO₃, and the study was performed under 225 psi at a temperature of 25 °C.

After initial membrane performance was stabilized, 50 ppm of skim milk (representing organic foulants) and 100 ppm of colloidal silica (representing inorganic foulants) were added into the feed water. After running 24-30 hours with the aforementioned foulants, a clean-in-place (CIP) was performed with all membranes. After the CIP, the membranes were re-tested under standard operating conditions. The results from the study are shown below.

Figure 104.1 Permeate flux and NaCl rejection during organic fouling test using skim milk



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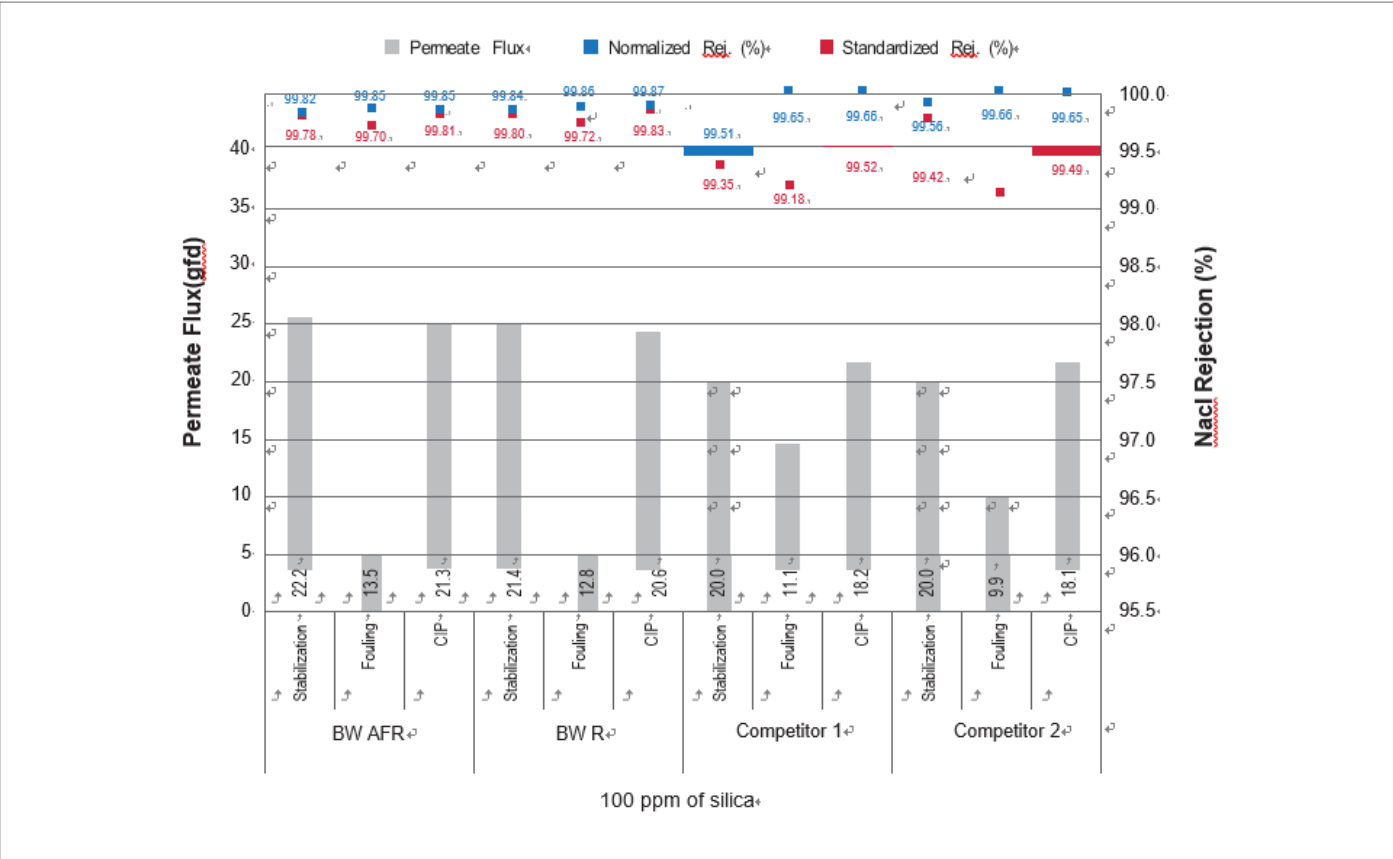
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Element Loading Guidelines

The results show more consistent salt rejection of LG Chem’s LG BW AFR and LG BW R membranes during membrane fouling and CIP tests when compared to the competitors. Additionally, when compared to the competitor’s membranes after the CIP, LG Chem’s NanoH2O membranes recovered closer to the initial flux before the fouling test.

In comparing Figure 1 versus 2, the results also show that organic fouling provides more adverse impact to the membrane’s performance compared to inorganic fouling. The CIP after organic fouling was not able to recover the membrane flux as well as the CIP after inorganic fouling.

Figure 104.2 Permeate flux and NaCl rejection during inorganic fouling test using silica



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Technical Highlights and Chemistry Evolution of LG Chem's NanoH₂O™ Membranes

The original introduction of NanoH₂O high flux nanocomposite membranes in the year 2011 led to higher membrane flux while maintaining industry-standard salt rejection. The nanostructured membrane features a high degree of surface area and surface roughness yielding very high flux and built-in resistance to some types of fouling. This formulation is still utilized in the energy-saving LG SW ES membrane line.

LG SW SR/GR/R G2 products were introduced as the second generation nanocomposite membrane line that boasted higher salt/ boron rejection and comparable flux when compared to competitors' products. The membrane's higher rejection allows it to be operated at lower pressures while still meeting water quality targets and reducing energy.

In late 2015, LG Chem introduced its brackish water RO nanocomposite membranes, the technology of which developed from the first generation NanoH₂O high flux membranes. LG Chem's BWRO membrane product yields extremely high membrane flux while rejecting salt under the spectrum of brackish water test conditions.

In addition to the energy savings and superior overall performance of LG Chem's NanoH₂O high flux and high rejection membranes, these membranes deliver stabilized performance more quickly and provide a more accurate active area relative to competition.

For more information on the full line of LG Chem's NanoH₂O RO membranes, please visit www.lgwatersolutions.com

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Feed Water Quality Guidelines

For successful operation of the membrane system, it is strongly recommended to operate the membrane system within the feed water quality limits per manufacturer's suggestion and to maintain membrane elements by good industry engineering practices. The table below summarizes some of the feed water quality parameters, along with comments and conditions. Additionally, critical parameters and their effects are described below the table.

Table of Feed Water Quality Guidelines

Parameter	Unit	Max. level	Comments & conditions
SDI		5	
Oil and Grease	mg/L	0	
TOC	mg/L	2	
Al	mg/L	0.05	
Mn	mg/L	0.05	Total form
Fe	mg/L	3	Ferrous iron (pH <6, oxygen <0.5ppm)
		0.05	Ferric iron
Free Chlorine	mg/L	0.1	Exposure to chlorine damages RO membranes and should be avoided. LG Chem recommends to continuously monitor the residual chlorine concentration and Oxidation Reduction Potential (ORP).
ORP	mV	250	
Turbidity	NTU	1	
H₂S	mg/L	0.1	If the system can be kept under anaerobic conditions, Sulfur precipitation may be avoided.
Ba	mg/L	0.002	if H ₂ SO ₄ is dosed
		0.005	in Brackish water w/o H ₂ SO ₄
		0.015	in Seawater
Sr	mg/L	0.05	
SiO₂	mg/L		Consult antiscalant manufacturer if projected concentrate SiO ₂ exceeds 140 mg/L
LSI		0	If LSI > 0, Customer must be consulting an antiscalant selection with chemical manufacturer. The antiscalant selected, must be compatible with RO membranes

1. Silt Density Index (SDI)

SDI is a parameter to predict the colloidal fouling potential of the feed water. SDI shall be measured per ASTM 4189 standard and for 15 minutes. In general, it is desirable to have feedwater SDI below 5.

2. Oil and Grease

In principle, no oil and grease are allowed in the feed water. The detrimental effects of oil and grease on RO membranes are dependent on the nature of organics such as saturated, unsaturated, aromatic, or aliphatic and also largely dependent on the existence of functional groups. Hydrocarbons containing more than seven (7) carbons are known to have more adverse effects.

3. TOC, COD and BOD

High organics content in the feed water can increase bio- and organic fouling risks of RO membranes. Tolerable organics levels for RO membranes depends on the nature of the organics such as NOM/SOC, aromatic/aliphatic, charge, and molecular weight. General design guidelines on TOC, COD and BOD in the feed water are provided in LG Chem's projection software, QPlus.

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Feed Water Quality Guidelines

4. Aluminum, Manganese and Iron

Aluminum and manganese can cause severe membrane fouling and should be avoided. The maximum allowable concentration of aluminum and manganese in the feed water is 0.05 mg/L. Iron typically exists in ferrous form when pH is below 6 and dissolved oxygen is below 0.5 mg/L. Iron in ferrous form has a mild impact on the membrane and is allowed up to 3 mg/L. Iron in ferric form causes severe membrane fouling and should be avoided. The maximum allowable concentration of iron in a ferric form in the feed water is 0.05 mg/L.

5. Free Chlorine

Exposure to free chlorine damages RO membranes and should be avoided. LG Chem recommends to continuously monitor the residual chlorine concentration and Oxidation Reduction Potential (ORP).

6. Chloramine

Polyamide RO membranes have better tolerance to chloramine than free chlorine. In typical municipal wastewater reuse applications, 3-5 mg/L of chloramine is acceptable. However, it is difficult to specify the acceptable chloramine concentration, as chloramine may cause catalytic oxidation damaging the membrane under high temperature and low pH operation in presence of halogen ions (i.e. bromide, iodide) and transition metals in the feed water. Hence, detailed water analysis should precede before chloramine dosing is determined.

7. Chlorine Dioxide

Use of chlorine dioxide is not endorsed by LG Chem. Chlorine dioxide in the presence of transition metals or bromide may adversely affect the RO membrane performance. Effect of chlorine dioxide is not clearly understood yet and it is recommended, if used, that chlorine dioxide is fully removed from the feed water prior to reaching the RO membranes.

8. Sodium Bisulfite (SBS)

For dechlorination, as an industry practice, 3.0 mg of SBS is typically recommended to remove 1.0 mg of free chlorine. Caution should be exercised in order to not overdose SBS, since a high concentration of residual SBS from overdosing induces two major risks: membrane oxidation and biofouling. The excess amounts of SBS may lead to rapid membrane oxidation from catalytic reactions when the feed water contains transition metals (e.g. Co, Cu, Mn, etc.) and/or membranes are fouled with the transition metals. In addition, the excess amount of SBS may lead to biofouling from the growth of sulfate reducing bacteria, severely deteriorating the membrane performance. LG Chem recommends keeping the residual SBS in the feed water below 1 mg/L.

9. Oxidation Reduction Potential (ORP)

ORP is a parameter to measure the contents of oxidative chemicals, which can do potential harm to RO membranes.

To avoid anomalous membrane oxidation such as catalytic oxidation by SBS, LG Chem recommends monitoring ORP of the concentrate side as well as the feed side. It is desirable to monitor ORP while the system is in offline as well as in online. As a rule of thumb, it is recommended to set a high alarm to take immediate corrective action at 250 mV for the feed/concentrate side and set a high high alarm for emergency shutdown to protect RO membranes at 300 mV for the feed/concentrate side.

However, proper ORP value setting/adjustment should be determined by regularly measuring the residual chlorine and correlating that with ORP values.

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Workmanship and Materials Limited Warranty

LG Chem (hereinafter “Seller”) provides a limited warranty to the original Buyer on the workmanship and materials of its reverse osmosis membrane elements, (hereinafter “Product”), subject to the following terms and conditions:

1. Workmanship and Materials Limited Warranty

Seller warrants that its new Products are free from defects in workmanship and materials. Enforcement of this warranty is expressly conditioned on Buyer storing, installing, operating and maintaining Product in accordance with industry accepted good practices and Seller’s written instructions provided in the Seller’s Technical Manual, which may be reviewed and downloaded at www.lgwatersolutions.com/.

This warranty does not cover aesthetic attribute of Product and damage to Product caused by Buyer’s failure to comply with the accepted good practices and Seller’s written instructions.

2. Effective Date of Warranty

This limited warranty is effective for a period not exceeding twelve (12) months from the date of delivery to Buyer.

3. Limitation on Liability

Seller’s total liability shall not exceed the replacement value of Product and Product replaced due to faults in material and workmanship will be warranted as new Product.

Other than replacement of product, Seller shall not be liable for any consequential or indirect damages, including, but not limited to labor cost, operating cost, production loss, or lawsuits by third parties against Buyer.

This Warranty shall not be assigned or transferred by Buyer without the prior approval of Seller.

This Warranty shall be governed by and construed according to the laws Korea, without reference to its conflict of laws principles.

4. Remedies

Seller’s sole obligation under this warranty is limited to the repair or, at Seller’s sole option, the replacement of any Product or parts thereof which are returned freight prepaid to Seller and which, when examined by Seller are found to be defective under the terms of this limited warranty.

5. Disclaimer

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Estimated Rejection of Various Solutes (for reference only)

To aid customers in estimating the rejection performance of LG Chem Inc.'s TFN RO membranes, a table has been compiled featuring the rejection rates of various solute compounds. It is important to note that these rejection rates are provided for reference purposes only, as the actual system performance can differ due to factors like feed water concentration, ion composition, pH, temperature and system design condition. LG Chem Inc. strongly advises to conduct a pilot study to accurately determine the actual rejection rates in a specific system and application.

Table 108.1 Estimated Rejection of Various Solutes

Solute	Rejection (%)
1,2-Dichlorethane + Benzene	90
1,4-Dioxane	> 90
Acetaminophen	> 99
Acetone	66 ~ 67
Aluminum	83
Arsenic III	> 55
Arsenic V	> 99
Bromodichloromethane	45
Cadmium	> 90
Caffeine	> 99.9
Carbon disulfide	88
Chloroform	40
Chromate	> 80
Copper	> 96
Cyanide	86 ~ 92
DEET	99.7
Dibromochloromethane	70
Ethanol	50 ~ 65
Formaldehyde	66
Gemifibrozil	> 99
Iohexol	99.9
Iopromide	> 99
Iron	> 99
Isopropyl alcohol	80 ~ 98
Lead	> 95
Lithium	95

Solute	Rejection (%)
Manganese	> 95
Mercury	> 95
Methanol	10 ~ 15
Methylene chloride	50
NDMA	80
Nickel	> 95
Orthophosphate	> 99
Perfluoro-2-methoxyacetic acid	> 88
Perfluorobutanesulfonic acid	> 23
Perfluorobutanoic acid	> 71
Perfluoroheptanoic acid	> 77
Perfluorohexanesulfonic acid	> 35
Perfluorohexanoic acid	> 82
Perfluorooctanesulfonic acid	> 83
Perfluorooctanoic acid	> 74
Perfluoropentanoic acid	> 79
Phosphaste	95 ~ 98
Polyphosphate	96 ~ 98
Selenium	94 ~ 96
Silver	> 95
Sucralose	> 99
TCEP	> 99
Thiosulfate	97 ~ 98
Triclosan	> 99
Zinc	97 ~ 99

Notes:

1. The rejection rates in the table above are estimated values and for reference only.
2. LG Chem Inc. does not guarantee the performance of its membranes in terms of estimated rejection rates.
3. The Actual rejection rates must be verified by pilot study.

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