

MEMBRANE



FOULING

Monitoring and Prevention
of Reverse Osmosis
Membrane Fouling
and Scaling

X Lewabrane®

LANXESS
Energizing Chemistry

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Notice: Please note that the information and recommendations provided in this technical brochure do not claim to be universally valid; in particular, they are not meant to substitute, amend or supplement the information and/or instructions provided by the OEM of the RO membrane system and/or the facility operator. In fact, LANXESS strongly recommends to obtain written confirmation from the OEM of the RO system and/or the facility operator before using the chemicals described in our technical brochure, installation of the RO elements and operation of the RO membrane system, and to verify the advice and information provided herein in each case as to its compatibility with the overall water treatment facility and RO membrane system.

1. Fouling and Scaling in RO Membrane Systems

1.1 Introduction

Pretreatment is one of the crucial steps for successful operation of an RO membrane system in a cost effective way. The performance and efficiency of an RO system depends directly on the quality of its feed water. The impurities in the RO feed water may decrease the membrane performance by causing fouling, scaling or membrane degradation. The upstream pretreatment must be designed to prevent and minimize these performance losses, and thereby increasing the overall system reliability to achieve the design permeate flow and salt rejection.

A proper pretreatment process can be designed only based on a complete and accurate analysis of the feed water. The pretreatment design will depend on the feed water source. For example, well water as RO feed water has a low fouling potential (low SDI), and typically a simple pretreatment is required. On the other hand, surface water has a high fouling potential (high SDI) and requires an extensive pretreatment. The pretreatment design should also take into account seasonal fluctuations in the water composition. Configuration of the pretreatment process should include coagulation, chlorination and dechlorination, antiscalant dosing or acidification for preventing scale formation.

Another technology increasingly employed in modern water treatment systems is the usage of membrane filtration, like MF/UF.

Types of Fouling Materials

The concept of “fouling” means that the performance of RO membrane declines not due to the change of membrane structure, but from the attached (settled or adsorbed) materials on the membrane surface. The most common types of fouling are listed in Tables 1.1 and 1.2, and the mechanism associated with the fouling phenomena is listed according to foulant type (Table 1.1), and effect on RO system performance is listed in Table 1.2.

As mentioned in Tables 1.1 and 1.2, different foulant types can affect the membrane system performance. The accumulation of fouling substances can block the membrane. They may act by membrane pore blocking, adsorption on the membrane surface, and blocking of the flow in the element. Most probable location of fouling is usually in the lead element at first stage.

Materials	Examples	Fouling Mechanism
Insoluble Solids	Clay, Silt, Particles	Settling, accumulation
Metal Oxide Fouling	Fe, Mn, Cu, Ni, Zn	Settling, accumulation
Microbiological Fouling	Bacteria, Slime, Algae	Settling, growth, accumulation
Soluble Organic Fouling	Humic acid, Fulvic acid	Adsorption (hydrophobic interaction)
Insoluble Organic Fouling	Oil, n-Hexane extractive	Adsorption (hydrophobic interaction)
Cationic Charged Materials	Coagulant, Detergent, Biocides	Adsorption (electrostatic interaction)

Table 1.1: Fouling types and mechanism

Foulant Materials	Examples	Effect on RO system performance		
		Pressure Drop	Product Flow Rate	Rejection
Insoluble Solids	Clay, Silt, Particles	↑	↓	↘
Metal Oxide Fouling	Fe, Mn, Cu, Ni, Zn	↑	↓	↘
Microbiological Fouling	Bacteria, Slime, Algae	↑	↓	↘
Soluble Organic Fouling	Humic acid, Fulvic acid	↑	↓	↘
Insoluble Organic Fouling	Oil, n-Hexane extractive	→	↓	→
Cationic Charged Materials	Coagulant, Detergent, Biocides	→	↓	→

Table 1.2: Operating conditions and effect on RO system performance

↑	increase
↓	decrease
→	constant
↘	slightly decrease
↕	strongly

Usually fouling phenomena are divided into four groups. These groups are:

- Particle fouling
- Fouling by organic compounds
- Fouling by inorganic compounds, often called scaling
- Biofouling

1.2 Methods to monitor particle and organic fouling

1.2.1 Silt Density Index

Silt Density Index (SDI) is a test which is the most commonly used test method to

measure the fouling potential of particle and colloidal materials in the RO process. The test is defined in ASTM Standard D4189, the American Standard for Testing Material.

This is a filtration test using a 0.45 µm pore size membrane filter in a dead end mode. A feed pressure is maintained constant at 2.07 bar (30 psi) for the total duration of the test. It is recommended to connect the SDI test equipment as closely as possible to the influent of the RO membrane. Three steps are basically required for this measurement. First feed water is forced through the membrane according to the conditions mentioned above and the time (t_i) to collect 500 ml of permeate is recorded. Then, filtration is continued for 15 min (T).

After this period of filtration, the time (t_f) to collect 500 ml of permeate is measured again. The period of 15 minutes is the standard duration between the two measurements; however the test can also be run at 5 and 10 minute intervals. Using the three measured values (i.e. t_i , t_f and T), the SDI can be calculated according to the following equation:

$$SDI = \left(1 - t_i/t_f\right) \times \left(\frac{100}{T}\right) \quad (1.1)$$

In which:

T , total elapsed time (usually 15 min)

t_i , initial time required to collect 500 ml of sample

t_f , time required to collect 500 ml of sample after testing time, T

The SDI test is used to predict the aggressiveness of the feed water, and to properly design a system to prevent the particulate fouling on the membrane surface. The lower the SDI, the lower is the potential for fouling of membrane with suspended solids, or particles. The target SDI value is usually lower than 5, however, a value of less than 3 is usually required to minimize the fouling potential to an acceptable limit. This SDI test is also named Kolloid-Index (KI) or Fouling-Index (FI).

1.2.2 Turbidity

Turbidity is measured by the extent to which intensity of light passing through water sample is reduced by suspended materials. Turbidity results from suspended solid and colloids, such as clay, silt, finely divided organic or inorganic matter, plankton and other microscopic organisms. The turbidity of a water is based upon a comparison of the amount of light passing through a given water sample with that amount of light passing through a standard sample. The measurement is performed using a turbidity-meter, or nephelometer, and the result is usually given in nephelometric turbidity unit (NTU). Turbidity is often used for online control of particle

filtration processes. It is often recommended that the NTU value of feed water to the RO system should be less than 0.5 NTU.

1.3 Prevention of fouling by particles and organics

1.3.1 Pretreatment by MF or UF membranes

Microfiltration (MF) and ultrafiltration (UF) are increasingly used for RO system pretreatment. These membranes can remove microbes, algae and suspended materials, and in case of ultrafiltration, also dissolved organic compounds depending on their molecular weight and the pore size of the UF membrane. The implementation of a correctly designed and operated MF or UF pretreatment system can provide an SDI value lower than 3, which offers good fouling prevention of RO membrane. Many fouling compounds are also retained by MF or UF membranes, and the foulant is often easier to clean on the UF membrane surface by backwashing. However, it is important to note that UF or MF membranes do not remove dissolved ions and smaller organics, and under this condition, bacteria can thrive after membrane pretreatment filtration. The designer must understand the limitations of the pretreatment by MF and UF use.

1.3.2 Cartridge Microfiltration

Cartridge filters are often used to protect the high pressure pump and the membrane surface from particles. Cartridge filters are usually installed at the end of the pretreatment system. A pore size of 5 μ m is recommended for the cartridge filter, however, when there is a risk of fouling with colloidal silica or metal silica, a pore size down to 1-3 μ m is recommended.

The replacement of cartridges is managed by monitoring of the pressure drop through the filter. Nevertheless, it is typical to replace the cartridge filters every 3 months. If the substitution occurs more frequently, this is an

indication that there may be problems in the pretreatment equipment. It is important to remember that newly installed cartridges should be rinsed to prevent chemical fouling of the RO membranes with materials eluted from the cartridge filter.

1.3.3 Prevention of Alumina Fouling

In case of pretreatment systems using inorganic salt coagulant, the dosing rate should be accurately controlled because of the potential for membrane fouling with iron and alum hydroxide which can precipitate at increased concentration. The risk of fouling is higher for alum. Under poor pH control condition, overfeeding of alum can result in precipitation of aluminum hydroxide which will foul RO membranes. If alum is present in feed water, pH of feed water should be adjusted to the range to keep aluminum in solution (it is noted that alum solubility is the lowest at pH 6.5).

The second risk linked to the use of alum as coagulant is its reaction with silica. Even at a low concentration of aluminium and silica, the reaction can proceed, and results in aluminium silicate fouling of the membrane. Because of the high potential for fouling of alum, its use is not recommended, and an iron coagulant is often preferred as a coagulant.

1.3.4 Avoidance of Chemical Fouling

The surface of RO membranes is negatively charged, and as a consequence, positively charged materials are often adsorbed on the surface. The adsorption of cationic organic materials (coagulant, detergent, biocide, etc.) on the surface results in a hydrophobic surface. As a result, the flow rate of the RO membrane elements may greatly decrease. The adsorption of insoluble organics (oil, n-Hexane extractive, etc.) may also cause a great decrease of the RO membrane element flow rate. It is strongly recommended that the RO system and pretreatment designer carefully consider how

to minimize the intrusion of chemical foulants to the RO system.

1.4 Prevention of Biofouling

The prevention of biofouling is an extremely important consideration in RO membrane system design. This is because microbial attachment on the membrane surface leads to the formation of a biofilm, which consist of microbial cells embedded in an extracellular polymeric substances matrix produced by the microbes. Biofouling (biofilms) lead to RO system performance decline usually from a decrease in product flow rate, decrease of salt rejection and/or increase in the pressure drop.

1.4.1 Difference between microorganisms and non-living particles

Biofouling is a dynamic process of microbial colonization and growth, which results in the formation of microbial biofilm from the secretion of extra cellular polymers. The biofilm is composed of living organisms such as algae, bacteria, and microbes plus non-living compounds (which are produced by micro-organisms). The extra cellular polymers form a protection gel layer of biopolymer surrounding the micro-organisms. Once started, the biofilm formation is difficult to suspend as it protected against biocide effects (because of diffusion limitations).

1.4.2 Influence of oxidation chemicals to biological fouling

The chemical oxidizers, which can be used to control biological fouling, act as disinfectant agents killing bacteria and micro-organisms. Chemical oxidizers, including ozone, chlorine and peroxide, are used in RO pretreatment to prevent membrane biofouling. Any oxidant, present in the feed water, should be reduced completely prior to entry to the membranes. Otherwise irreversible membrane damages can occur.

1.4.3 Assessment of the biological fouling potential

Microbial fouling of RO membranes could be a significant operational problem. The potential for biological fouling of membrane needs to be considered and several test methods are available to assist with this evaluation.

- Assimilable organic carbon (AOC)
- Culture method
- Total bacteria count (TBC)
- Biofilm formation rate (BFR)

For biofouling assessment, it is recommended that several sampling points be considered as sample test locations:

- The water source (i.e. well, surface, etc)
- The exit of the pretreatment system (or the closest entrance point to the RO system)
- Concentrate
- Permeate

1.4.4 Chlorination and De-chlorination

Chlorine is commonly used to kill microbes in pretreatment prior to RO membrane systems. It has a high oxidation reduction potential, and it is available in different forms (e.g. gas, sodium hypochlorite, chloramines, etc). However, while chlorine is efficient to kill micro-organisms, it can also cause irreversible damage to PA type RO membranes. Therefore, if chlorine is used for pretreatment, the RO membrane feed water must be de-chlorinated upstream of the RO membrane. De-chlorination can be performed using activated carbon filter or sodium bisulphite addition. Sodium bisulphite addition is the most commonly used technique.

1.4.5 RO membrane (Polyamide) durability to chlorine

RO membranes have a very limited resistance to oxidation, and therefore, a limited resistance to chlorine. The RO

membrane can however bear occasional and minor contact to chlorine without severe damage. The degradation of RO membrane on exposure to oxidants is due to the loss of polymer cross-linking (which are cut by oxidation). The degradation is more rapid at low pH and can be catalysed by the presence of transition and heavy metals (e.g. iron). The polyamide separating membrane is sensitive to free chlorine, and consequently, the degradation process takes place immediately upon exposure, and lasts as long as the membrane is exposed to chlorine. Moreover, the degradation might last even if chlorine is removed from the RO feed water. Significant membrane damage and reduction in rejection can happen after exposure to chlorine.

1.4.6 The Measurement of Oxidation Reduction Potential (ORP)

Oxidation/reduction potential (ORP) measures the tendency of a chemical species to acquire electrons, and thereby, undergo reduction. Each species has its own ORP value (in voltage) and the more positive the potential, the greater is the tendency to be reduced, and consequently, the capacity to oxidize other compounds. Table 1.3 shows the oxidation/reduction potential for various compounds.

Compounds	Oxidation/reduction potential (voltage)
Hydroxyl	2,8
Ozone	2,1
Peroxide	1,8
Chlorine gas	1,4
Hypochlorite	0,9

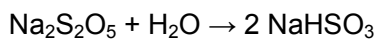
Table 1.3: Oxidation/reduction potential for various compounds

As can be seen, chlorine is not the most efficient disinfectant compared to ozone, hydroxyl or peroxide; however, chlorine is the most commonly used thanks to its ability to provide residual disinfection. Application of continuous chlorination of feed water is not

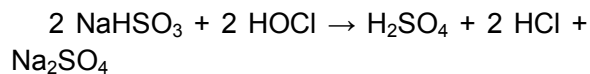
always recommended. Chlorination breaks dissolved organic matter into smaller fragments that could serve as food source for bacteria that survived chlorination-dechlorination treatment applied upstream of membrane units. Frequently, RO system that utilize continuous chlorination – dechlorination step experience severe biofouling downstream of dechlorination step.

1.4.7 Outline of SBS and shock treatment

Since the polyamide layer is very sensitive to oxidation, the residual chlorine should be removed from feed water prior to entering the membrane element by a de-chlorination step. This step is commonly performed using sodium bisulphite. In water solution, sodium metabisulphite becomes sodium bisulphite:



And, the sodium bisulphite reacts and reduces hypochlorous acid as follows:



The reaction shows that 1.34mg of sodium metabisulphite is required per mg of free chlorine which needs to be reduced. However, it is recommended to use 2mg of sodium metabisulphite per mg of free chlorine. The dosing is the last step before RO process, and the completion if the reduction reaction is monitored by an oxidation/reduction potentiometer to ensure that all free chlorine was removed from RO feed water.

Sodium bisulphite can also be used to control biological fouling. It is used as a shock treatment and can be applied directly to the membrane because it will lower the feed water pH. A solution with concentration in a range of 500 to 1000 ppm of sodium bisulphite is applied usually for a period of 30 minutes.

1.5 Scaling and Methods for prevention

Scaling by sparingly-soluble salts is an important concern in RO membrane system design. The mechanism of scale formation is as follows. Sparingly-soluble inorganic salts are rejected by RO membranes, and their concentration in the concentrate increase. When solubility of the salts exceeds saturation, these salts precipitate on the membrane surface. Scale formation cannot be tolerated because it may cause product flow decrease, pressure drop increase and solute rejection decrease (by damaging the PA separating layer). Thus, scaling has an adverse effect on production capacity, product quality and energy consumption. It is clearly essential to incorporate in the desalination process, scale control parameters that can be rationally designed, and are cost effective, and suitable to the feed water and pretreatment situation.

Scaling is a concentration phenomenon caused by high levels of calcium, silica, carbonate, sulfate, phosphate, and other ions. The most probable location of scale formation is at the end element at last stage of the RO system (where the concentration of salts rejected by the membrane is the highest). The types of scale and the common methods of scale prevention are shown in Table 1.4. Calcium salts (carbonate, phosphate, and fluoride), sulfates (calcium, barium, strontium) and silica could potentially form scale during the RO process.

Type of scale	Methods to prevent
Calcium carbonate	pH Adjustment (→ low), Antiscalant
Calcium phosphate	pH Adjustment (→ low), Antiscalant
Calcium fluoride	Antiscalant
Sulfates (Calcium, Strontium, Barium)	Antiscalant
Silica	pH Adjustment (→ high), Antiscalant

Table 1.4: Types of Scale and methods to prevent scale

In order to prevent scale formation, the designer may consider several strategies that could be implemented, such as acid addition, dosing of antiscalant (scale inhibitors) or softening and dealkalisation. In addition, pH and temperature influence the precipitation of scaling compounds. If necessary, the recovery rate can be adjusted to prevent the increase in the concentration beyond the saturation limit.

1.6 Methods to measure scaling potential

1.6.1 Langelier Saturation Index (LSI)

The Langelier Saturation Index (LSI) is an index which evaluates the calcium carbonate scaling and corrosion tendency of water. For RO membrane process, the LSI must be calculated for the concentrate flow where the calcium and bicarbonate ions have the highest concentration. This index is based on pH, calcium hardness, alkalinity, temperature and TDS concentration. The LSI is calculated using the following formula:

$$LSI = pH - pH_s \quad (1.2)$$

$$pH_s = pCa + pAlk + C \quad (1.3)$$

In which:

$pCa = 5 - \text{Log}_{10} [Ca^{2+}]$; $[Ca^{2+}]$ in mg/l as $CaCO_3$

$pAlk = 4 - \text{Log}_{10} \{[\text{alkalinity}]/5\}$; $[\text{alkalinity}]$ in mg/l as $CaCO_3$

$C = A + B$, a constant decided by TDS concentration and temperature

where A, TDS factor = $(\text{Log}_{10} [\text{TDS}] - 1)/10$; $[\text{TDS}]$ in mg/l

and B, temperature factor = $- 13.12 \times \text{Log}_{10} (^\circ\text{C} + 273) + 34.55$

If the value of LSI is higher than 0, scaling by calcium carbonate precipitation might occur. If the LSI is equal to 0, water is considered in chemical balance, and no scaling should happen. If the LSI is lower than 0, the water is corrosive. To prevent calcium carbonate scale, pH adjustment (to lower pH by adding an acid) is very effective. The Langelier Saturation Index is usable up to a concentration of 4,000 mg/l TDS. At higher concentration, for example, such as in seawater desalination, the Stiff and Davis Saturation Index (SDSI) is usually applied for determination of scaling potential.

1.6.2 Stiff and Davis Saturation Index (SDSI)

The Stiff and Davis Saturation Index is calculated in a manner similar to the Langelier Saturation Index (LSI) by using this formula:

$$SDSI = pH - pH_s \quad (1.4)$$

$$pH_s = pCa + pAlk + K \quad (1.5)$$

In which:

$pCa = 5 - \text{Log}_{10} [Ca^{2+}]$; $[Ca^{2+}]$ in mg/l as $CaCO_3$

$pAlk = 4 - \text{Log}_{10} \{[\text{alkalinity}]/5\}$; $[\text{alkalinity}]$ in mg/l as $CaCO_3$

K = a constant based on ionic strength and temperature

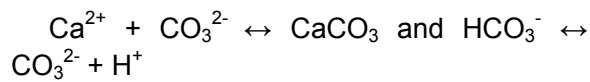
If the value of SDSI is higher than 0, calcium carbonate scale is considered a possibility.

1.7 Prevention of Scaling

1.7.1 Acid Dosing

Acid dosing can be used to control the scaling caused by calcium carbonate and

calcium phosphate. In the case of calcium carbonate, the formation is driven by the following equations:



The acid dosing shifts the equilibrium of the chemical reaction to the left (a decrease of carbonate ion), and therefore keeps calcium dissolved in solution. As mentioned above LSI and SDSI are used to determine the scaling potential of calcium carbonate, and the addition of acid decreases the pH which can be equal or lower than the pH of saturation. Therefore, dosing of acid will decrease the LSI or SDSI, and this reduces the risk of calcium carbonate scaling without removing calcium. Sulphuric acid is usually used to adjust the pH, however care must be given to minimize sulphate-based scales due to sulphuric acid dosing. In the case of adding an acid, the designer must consider what will happen to the permeate pH value, and design the post treatment processing accordingly.

1.7.2 Antiscalants

Antiscalants are used to minimize the potential for scale formation and work by the following mechanisms:

- Threshold inhibition – the ability to keep supersaturated salts in solution
- Crystal modification – the ability to change crystal shapes, resulting in soft, non-adherent scales
- Dispersion – the ability to impart a highly negative charge to precipitation crystals thereby keeping the crystals separated in solution, and preventing propagation

The components of the antiscalant are inorganic phosphate (ex. SHMP), organic phosphates, polycarboxylic acid and the mixtures of the components.

SHMP (sodium hexametaphosphate) is a traditional antiscalant, and its mechanism is to inhibit the growth of calcium carbonate and sulphate-based scales. SHMP is inexpensive,

but easy to hydrolyse which decreases its efficacy, and enhances the risk of calcium phosphate scaling. Instead of SHMP, the more common practice today is to apply organic phosphates which are more stable and more efficient than SHMP. Polyacrylates are used to prevent silica scaling owing to their good dispersion quality. It is important to note that antiscalants are completely rejected by RO membranes, and do not usually affect the membrane performance. In the case of adding antiscalant, it is recommended to confirm the performance characteristics of the antiscalant with the supplier, and follow their instructions (type, dosing rate etc.) for usage in your application.

1.7.3 Influence of Fe, Al (coagulant) on Antiscalants

When the concentration of suspended solids is high, a coagulation/flocculation step is often used in the pretreatment design to reduce their TSS concentration in the feedwater. Coagulants can be inorganic salts such as ferric or aluminium sulphate, or organic compounds such as polyacrylamide. Care should be taken to avoid overfeed of cationic coagulants when an antiscalant is dosed. The cationic coagulant (iron or alum) can complex with negatively-charged antiscalant rendering the antiscalant poisoned, and ineffective for scaling control. In addition, the precipitated antiscalant can serve as a food source to microorganisms, and enhance biofouling.

1.8 Membrane degradation by chemicals

Chemical membrane degradation usually means that chemical presented in the feed water reacted with polyamide membrane layer resulting in a loss of membrane integrity and decline in operating performance. This degradation can be the result of membrane oxidation, where oxidizing chemicals attack the membrane polymer, as described above. In this case, an increase in permeate flow and a decrease in product quality is usually

observed. Oxidizers such as free chlorine, ozone, peroxide, etc. can damage the membrane layer. Oxidation can be accelerated by the presence of transition or heavy metals (e.g. iron, copper, manganese, etc.) which catalyse the oxidation of RO membranes. And also the separating membrane can be damaged by strong acid or strong base resulting in hydrolysis of membrane polymer.

In addition to the chemical damage from oxidation, a physical degradation of an RO membrane can occur. Particles or scale crystals might abrade the membrane surface, and thus decrease the membrane performance (rejection). Those situations, where membrane integrity is lost, can usually be prevented by the careful design of an appropriate upstream pretreatment system.

1.9 Summary of pretreatment options

In consideration of fouling and scale formation, two types of mechanisms can be distinguished:

1. material which chemically damages the membrane
2. material which physically blocks the permeation or flow in the element.

The materials of the first category are considered to modify the chemical structure of the membrane by oxidation or hydrolysis and dissolution which can be made by some oxidizing agents (e.g. chlorine, free oxygen), strong acid or strong base and organic solvents.

The materials of the second category are fouling and scaling materials. The fouling can be due to bacteria, colloids and organic compounds including proteins, carbohydrates, hydrocarbons, natural organic matter (NOM) and cationic organic compounds. Membrane scaling results from the increase in concentration of salts beyond their solubility

limits and their precipitation onto the membrane surface. Inorganic foulants (scale) include calcium salts, sulfates, metal hydroxides, and silica.

In general, an improved pretreatment, or additional pretreatment should be considered if the below fouling and scaling are above the given target values.

Name (unit)	Desirable values
SDI (-)	< 3
Turbidity (NTU)	< 0.5
LSI (-)	≤ 0
SDSI (-)	≤ 0

Table 1.5: Fouling and scaling indices

Table 1.6 shows the common materials in RO membrane system feed water and their influence on RO membrane. The pretreatment options for fouling and scaling are shown in Table 1.7.

Category	Materials		Influence on RO Membrane	Pretreatment
	Type	Example		
Membrane Degradation	Oxidizing Agents	Chlorine, Ozone	Decomposition of separating membrane (oxidation)	○
	Acid and Base	HCl, NaOH	Decomposition of separating membrane (hydrolysis)	Δ
	Soluble Organic Compounds	Acetone, DMF	Dissolving polysulfone	Δ
Scale	Sparingly-soluble Inorganics	Calcium salts, Sulfates, Silica	Precipitation, accumulation and damage of active membrane layer	Δ
Fouling	Insoluble Solids Biological Debris	Clay, Silt, Particles, Bacteria, Slime	Settling and accumulation	Δ
Chemical Fouling (Adsorption)	Insoluble Organic Compounds	Oil, n-Hexane extractive	Adsorption and membrane surface hydrophobic	○
	Cationic Organic Compounds	Surfactants, Coagulants	Adsorption and membrane surface hydrophobic	○

○ : Pre-treatment must be done in spite of the concentration (Zero is desirable)

Δ : Pre-treatment should be done according to the concentration.

Table 1.6: Fouling and scaling indices

Pretreatment	Scaling	Biofouling	Organic Fouling	Particles Fouling
Media filtration		X		X
Microfiltration/Ultrafiltration		X		X
Cartridge filtration				X
Coagulation flocculation			X	X
Chlorination/Dechlorination		X		
Acid dosing	X			
Antiscalant dosing	X			
Softening	X			
Dealkalization	X			

Table 1.7: Pretreatment options for fouling and scaling

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