Effects of Natural Organic Matter and Ionic Species on Membrane Surface Charge

YONGKI SHIM, HONG-JOO LEE, SANGYOUN LEE, SEUNG-HYEON MOON, AND JAEWEON CHO*
Department of Environmental Science and Engineering, Kwangju Institute of Science and Technology (K-JIST), Oryong-dong, Buk-gu, Gwangju 500-712, Korea

The surface charges of clean and natural organic matter (NOM)-adsorbed membrane surfaces of two different types of membranes (a UF and a NF membrane composed of the same material but having different pore sizes) were investigated. Concentrated NOM and its fractionated constituents were used as adsorbate and interacting macromolecules near the membrane surface. The ζ potential and the acidity of membranes were measured using electrophoresis and potentiometric titration methods, respectively, from the perspective of charge characterization, along with demonstration of ionic strength effects. The membrane surface was also characterized with attenuated total reflectance Fourier transform infrared spectra to determine intrinsic functional groups and those changes before and after NOM adsorption. As a comparative study for the electrokinetic property of membrane, the ζ potentials for both examined polymeric membranes were determined by the electrophoresis and the streaming potential measurement methods as functions of ionic strength and the pH of measuring solution. Selectivity tests were performed to decide the relative importance of charge valence of cation in terms of the surface charge of membrane. It was demonstrated that divalent cations (Ca\(^{2+}\), Mg\(^{2+}\)) increase ζ potentials relatively compared to monovalent cations (Na\(^{+}\), K\(^{+}\)) because divalent cations have a greater potential in approaching membrane surfaces (i.e., inside the Stern layer). Thus, divalent cations can provide a greater double layer compaction and, when near the shear plane (available for both the ζ potential measurement methods), exist to a lesser extent than monovalent cations.

Introduction

Recently, nanofiltration (NF) and ultrafiltration (UF) membranes have been used as an alternative method for removing natural organic matter (NOM) from water (1, 2). However, the effective application of membrane processes requires the control of membrane fouling by naturally occurring organic substances. It is recognized that membrane fouling is affected by physical and chemical properties such as surface roughness of the membrane and charge properties of foulants and the membrane. Colloidal fouling (especially the initial colloid-deposition rate) of NF and reverse osmosis membranes was significantly influenced by the membranes surface morphology such as surface roughness (3, 4). It is also known that fouling during pressure-driven membrane processes is affected by the surface charge properties of both foulants (both NOM and colloids) and the membrane surface. Thus, the determination of charge properties of a membrane is crucial to mechanistic research conducted to reduce membrane fouling. In this work, the surface morphology of the membrane was not considered because charge characterization was performed only in terms of mobility of a monitoring standard particle, which is assumed to be not adsorbed onto the membrane surface. These charge properties can be represented by the ζ potential (5–7), which is defined as the electrical potential value at the slipping plane (or slip layer) between the Stern layer and the diffuse layer. This, in turn, depends on the solution pH, the electrolyte solution concentration, and the polymeric physicochemical properties of the membrane’s surface. The dependence of the ζ potential on the electrolyte concentration is due to complexation (at the inner- or outersphere layers) and the adsorption of ions on the surface (8).

The objectives of this study were (i) to develop ways of characterizing membranes and NOM in terms of charge properties, (ii) to investigate electrostatic interactions between the membrane surface and NOM using electrophoretic mobility and the streaming potential measurement methods, and (iii) to determine the relative selectivities of various cations with respect to the charged membrane surface by measuring the ζ potential of the membrane surface.

Methods and Materials

Characterization of Polymeric Membranes. Two commercial polymeric membranes with polyamide thin-film composite (TFC), a UF (GM) and an NF (ESNA) membrane, were selected for the study. The ESNA and GM membranes consist of polyamide but have a different polymer-linking structure and different functionalities, which a manufacturer specific (see Figure 2). Table 1 lists the properties of these two membranes.

Spectra, used to identify functional groups of both polymeric membranes, were obtained with an attenuated total reflectance Fourier transform infrared (ATR-FTIR) spectrophotometer (PerkinElmer IR2000 series) and a ZnSe crystal at an incident angle of 45°. Spectral scanning range was between 500 and 2000 cm\(^{-1}\) at a resolution of ±2 cm\(^{-1}\). Prior to FTIR measurements, membrane samples were completely dried in a desiccator for more than 3 days. Potentiometric titration with a microtitrator (702SM, Metrohm, Switzerland) was performed to measure the membrane surface charge in terms of acidity (mequiv/g of dried membrane) with N\(_2\) gas purging to prevent carbonate effects. Carboxylic acidity and phenolic acidity were calculated using the amount of consumed NaOH over a pH range of 3–8 and 8–12, respectively. Ionic strength effects on the acidity of the membrane surface were demonstrated by the addition of NaCl.

NOM. NOM solution from the Nakdong River was concentrated by a reverse osmosis apparatus (Saehan, Korea) with a molecular weight cutoff (MWCO) of less than 150 Da. The NOM concentrate was filtered using a 0.45 \(\mu\)m membrane filter of mixed cellulose ester to remove suspended particles. The initial concentration of the concentrated NOM solution was approximately 500 mg/L as dissolved organic carbon (DOC). Prefiltered NOM solution was processed through XAD-8 and then XAD-4 resin, and by using a 0.01 N NaOH solution, the hydrophobic (XAD-8 adsorbable), transphilic
TABLE 1. Properties of the Two Membranes

<table>
<thead>
<tr>
<th>membrane</th>
<th>manufacturer</th>
<th>materials</th>
<th>MWCO</th>
<th>contact angle*</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESNA</td>
<td>hydranautics</td>
<td>polyamide TFC</td>
<td>200</td>
<td>60</td>
</tr>
<tr>
<td>GM</td>
<td>desal osmonics</td>
<td>polyamide TFC</td>
<td>8000</td>
<td>55</td>
</tr>
</tbody>
</table>

* Reference 27.

TABLE 2. Characteristics of NOM

<table>
<thead>
<tr>
<th>property</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>dissolved organic carbon (DOC)</td>
<td>500 mg/L</td>
</tr>
<tr>
<td>average molecular mass</td>
<td>1570</td>
</tr>
<tr>
<td>acidity total</td>
<td>9.1 mequiv/g of C</td>
</tr>
<tr>
<td>carboxylic</td>
<td>7.4 mequiv/g of C</td>
</tr>
<tr>
<td>phenolic</td>
<td>1.7 mequiv/g of C</td>
</tr>
<tr>
<td>NOM fractions</td>
<td></td>
</tr>
<tr>
<td>hydrophilic</td>
<td>58%</td>
</tr>
<tr>
<td>transphilic</td>
<td>22%</td>
</tr>
<tr>
<td>hydrophilic</td>
<td>20%</td>
</tr>
</tbody>
</table>

(XAD-4 adsorbable), and hydrophilic (neither XAD-8 nor XAD-4 adsorbable) constituents were isolated (9). Characteristics of the isolated NOM constituents are summarized in Table 2. The properties of the NOM as functions of pH and ionic strength were determined by measuring the electrophoretic mobility (using a commercially available electrophoresis measurement unit (ELS-8000, Photal, Otsuka Electronics, Japan)) (10).

ζ Potential Measurements by Streaming Potential and Electrophoresis Methods. The streaming potential measurement method has been widely used to determine the ζ potential of polymeric membranes with a flat surface, because of its simplicity and reproducibility (11, 12). When an electrolyte flows tangentially across a flat membrane, in the streaming potential method, the measurable potential difference, \(E_s\), between the two ends of the system can give direct information on the electrostatic charge at the shear plane of the electrical double layer (5, 13–15). Using \(E_s\) and other parameters, the ζ potential, \(ζ_p\), can be calculated using the Helmholtz–Smoluchowski eq 1, which is applicable to an electrolyte with a relatively high ionic strength (5, 15)

\[
ζ_p = \frac{E_s}{\Delta P} \frac{\eta}{\epsilon_0} \frac{\epsilon_0}{\epsilon_0} \tag{1}
\]

where \(E_s\) is the streaming potential (mV), \(ΔP\) the hydrodynamic pressure difference (Pa), \(η\) the liquid viscosity (0.89 \times 10^{-3} Pa·s), \(\epsilon\) the liquid conductivity [mS/m], \(\eta\) the liquid permittivity (=78.38), and \(ε_0\) the permittivity of free space (8.854 \times 10^{-12} F/m). The streaming potentials for GM and ESNA were determined using a commercial streaming potential measurement cell (BI-EKA, Brookhaven Instruments Corp., Holtsville, NY), and the ζ potential values were estimated using the Helmholtz–Smoluchowski eq 1. Pressures were adjusted to be in the range 1.0–5.0 psig by controlling flow rates.

The specific conductivity in eq 1 includes the conductivity properties of both the bulk electrolyte solution and the surface layer near the membrane surface. The associate surface charge conductivity is impossible to be determined; thus, it was assumed that this specific conductivity could be replaced with a lumped constant that takes into account length, cross-sectional area, and the ohmic resistance of a measurement cell (15). This assumption concerning the use of such a lumped constant is valid only for ionic strengths higher than 10^{-3} M and very sensitive to the experimental set up. On the other hand, the electrophoresis method (also used in this article along with the streaming potential measurement method) does not rely on assumptions to determine the ζ potential of membranes.

For comparative study of electrokinetic properties, the electrophoresis method was also used for ζ potential measurement. In an electrophoresis cell consisting of membrane and quartz cells, asymmetric electroosmotic flow occurs due to the accumulation of ions on the membrane surface during the electrophoresis method (16–21). The electrophoretic flow of a standard particle then takes place due to the induced electroosmotic flow. The electrophoretic mobility of the particle can be measured, and exhibits a parabolic flow velocity profile, as shown by Figure 1. From determined electrophoretic mobility, the ζ potential can be calculated using the Smoluchowski eq 2 (18, 19, 22).

\[
ζ_p = 4πηU/ε_0\epsilon_0 \tag{2}
\]

where \(ζ_p\) is the ζ potential by electrophoresis (mV) and \(U\) the electrophoretic mobility of a particle (cm²/(V·s)).

The ζ potential values of the ESNA and GM membranes were determined from electrophoretic mobility measurements using a commercially available electrophoresis measurement apparatus (ELS-8000, Photal, Otsuka Electronics, Japan)) with a plate sample cell. Polystyrene latex particles (diameter 520 nm, Otsuka Electronics, Japan) coated with hydroxy propyl cellulose (HPC) and with a molecular weight of 300 000 (Scientific Polymer Products, Japan) were used as mobility-monitoring particles. These were dispersed in a 0.01 M KCl solution to prevent the interactions with, or adsorption on, the quartz cell surface during measurement (10).

The effect on ionic strength on the ζ potential was demonstrated using various KCl solutions with different concentrations, ranging from 0.0001 to 0.1 M of KCl. The dependence of the ζ potential on the pH of the solution was evaluated at 0.01 M KCl. The effects of NOM concentrations on ζ potential were investigated by varying NOM concentrations from 5 to 500 mg/L as DOC at a KCl concentration of 0.01 M. The electrophoretic mobilities of the NOM were measured at 100 mg/L as DOC to demonstrate the effects of ionic strength and pH on the electrokinetic property in 0.01 M KCl containing NOM. In addition, the ζ potentials (i.e., mobility) of the monitoring particle were estimated in various chloride electrolytes (NaCl, KCl, CaCl₂, MgCl₂), which included different mono- and divalent cations to investigate their effects on the membrane surface charge. Several different electrolyte solutions with the same concentration (0.01 M) were used as background for the mobility measurement of latex particle. It was hypothesized that they exhibit almost the same values due to high ionic strength condition. The ζ potentials of the membrane surface were then measured using the latex particle under the same electrolyte condition as previously described; a ζ potential for the membrane surface was obtained with a specific electrolyte and was normalized by a ζ potential for the membrane surface obtained from a 0.01 M NaCl solution. This normalized ratio is called the selectivity ratio and represents how the membrane surface charge is affected by electrolyte type (i.e., monovalent vs divalent cation).

Results and Discussion

ζ Potential As Determined by the Electrophoresis Method as a Function of pH. Both ESNA and GM membranes are comprised of polyamide, but they differ in terms of their polymer-linking structures and pore sizes, as shown in Table 1 and Figure 2. The results show that the GM membrane presents negatively higher ζ potential values than the ESNA membrane (see Figure 3). Two reasons can be put forward based upon the differences in the ionizable functionality and...
the effect of pore size. Even though the material of both membranes is nominally the same, the ESNA membrane appears to contain a lower density of ionizable groups. Another possible explanation for the higher negative \( \zeta \) potential values of the ESNA membrane may be related to pore size. Because of differences in pore size, ionizable functional groups both on the membrane surface and in the pore wall can influence the \( \zeta \) potential values. Above pH 6, \( \zeta \) potential values of both membranes became relatively stable, which is believed to be due to the deprotonation of membrane carboxylic groups. These results also imply that carboxylic functional groups are more than phenolic groups (ionizable at relatively higher pH range), which will be described in the section on functionality and ATR-FTIR spectrum analyses. In the case of a more negatively charged membrane, NOM, the precursor of disinfection byproducts (DBPs), and negatively charged colloids are expected to be removed more effectively than noncharged solutes.

**Functionality and ATR-FTIR Spectrum Analyses.** The FTIR spectrum was obtained to determine qualitatively the types of functional groups on the membranes surface. As expected, the carboxylic acid functionality was identified at a wavenumber of around 1250 cm\(^{-1}\) for both membranes (see Figure 4) (2). However, no significant difference was observed between the absorbance intensities of the ESNA and GM membranes.

The acidity of ionizable functional groups of the membrane surface implies the amount of ionizable functional groups attached to the membrane surface in units of milliequivalents per unit membrane mass. Thus, higher acidity values indicate higher charge densities. Potentiometric titration results for both membranes estimated without the addition of any electrolytes, namely, deionized water or using another solution of higher ionic strength (i.e., after the addition of 10 mM NaCl), are shown in Figure 5. These results indicate that the GM membrane contains more ionizable functional groups than the ESNA membrane. When the ionic strength was adjusted, the acidities of the two membranes were reduced because ionizable functional groups on the membrane surface were complexed by the added cations probably at the outersphere plane (23).

**Effect of Ionic Strength and pH.** As mentioned previously, the GM membrane contains larger pores with a higher molecular weight cutoff and higher charge density (proved by acidic titration as shown in Figure 4). Thus, it can be anticipated that the GM membrane has a more negative \( \zeta \) potential than the ESNA membrane. Therefore, it is believed that the electrokinetic properties of the ESNA membrane mainly depend on the membrane surface charge, because it has less dense functional groups and small molecular weight cutoff (8).

The effects of electrolyte concentration (i.e., ionic strength effect) on the \( \zeta \) potential values determined by both
electrophoretic and the streaming potential methods are demonstrated in Figure 6. The $\zeta_{EP}$ of both membranes reduced, as the ionic strength increased, which is in good agreement with the electrical double layer compaction theory (1). As ionic strength increased, the $\zeta$ potential of the GM membrane exhibited more negative values than the ESNA membrane. It is believed that the decrease in the $\zeta_{EP}$ of the GM membrane is due to a decrease in the velocity of the monitoring particle near its surface because of the stronger interaction between the particle and the membrane's surface (24–27). Differently from the trends of $\zeta_{EP}$, $\zeta_{SP}$ values for both membranes increased negatively as ionic strengths increased. **FIGURE 2.** Polymeric structures of both membranes suggested by the corresponding manufacturers: (a) ESNA membrane and (b) GM membrane. **FIGURE 3.** $\zeta$ potential of ESNA and GM membranes determined by electrophoresis method. **FIGURE 4.** Functionality of two polymeric membranes: (a) estimated with pure water and (b) estimated with 10 mM NaCl. **FIGURE 5.** ATR-FTIR spectra of clean ESNA and GM membranes.
increased, which may be due to an accumulation of Cl\textsuperscript{-} near the membrane surface under conditions of high ionic strength (6). As discussed previously in the case of the streaming potential method, solution conductivity (particularly membrane conductivity) may influence the \(\zeta\) potential of the membrane surface to some extent, particularly when the measuring solution has relatively low ionic strength. It should be also noted that the \(\zeta\)SP trends show little difference between the ESNA and GM membranes. These results also imply that the streaming potential primarily represents the adsorption of anions near the membrane surface (i.e., the Stern plane) and is not affected significantly by pore charge properties (5, 11).

From the \(\zeta\) potential trends versus pH, shown in Figure 7, it was observed that the isoelectric point of the ESNA and GM membranes were 4.9 and 5.8, respectively, in terms of \(\zeta\)SP. The \(\zeta\) potential of both membranes at a high pH range exhibited more negative values due to the accumulation of anions near the membrane surface. At a lower pH range than the isoelectric point, the effects of cations and H\textsuperscript{+} on the charge properties of membrane increases near the Stern plane (or shear plane), yielding more positive \(\zeta\) potentials.

However, the pH dependence on \(\zeta_{\text{EP}}\) demonstrates the different behaviors of the ESNA and GM membranes. The \(\zeta_{\text{EP}}\) of ESNA has an isoelectric point at 3.5 and remains steady above pH 6 due to deprotonation of the carboxylic group on the ESNA membrane. The isoelectric point was not evident from the \(\zeta_{\text{EP}}\) of GM and had negative \(\zeta\) potential values over the whole pH range examined. In addition, the result implies that the \(\zeta_{\text{EP}}\) behaviors of the GM membrane may be related to its higher negative charge. Here, again, it is inferred from the different trends of \(\zeta\) potential obtained using the two different methods (i.e., the streaming potential and electrophoresis measurements methods) that the electrophoretic mobilities are affected by the charge properties of the membrane surface or the interior membrane pores, differently from the streaming potential.

**Effect of Different NOM Fractions and Concentrations on the \(\zeta\) Potential.** The three isolated fractions of NOM exhibited different characteristics in terms of molecular size, aromaticity, and charge density. The hydrophobic and transphilic NOM fractions contained primarily hydrophobic and hydrophilic acids, respectively (2). Meanwhile, the hydrophilic NOM was composed of mainly hydrophilic neutrals, such as polysaccharides that do not contain an ionizable functional group. To demonstrate the effect of NOM concentration on the \(\zeta\) potential of NOM, the electrophoretic mobilities of the isolated hydrophobic and transphilic NOM are depicted in terms of \(\zeta\) potential in Figure 8a. From these results, it is suggested that the NOM concentration be higher than approximately 5 mg/L as DOC in order for the electrophoretic mobility of NOM not to be influenced by instrumental precision in terms of detector. The pH effects on the \(\zeta\) potential were investigated using the electrophoresis measurement method for the hydrophobic NOM at 22 mg/L (as DOC) and the transphilic NOM at 18 mg/L (as DOC) (see Figure 8b). The \(\zeta\) potential of each NOM increased negatively with increasing pH, and the transphilic NOM exhibited a higher negative charge.

The electrophoretic mobilities of bulk NOM and isolated NOM acids were measured to demonstrate the effects of their different structural and chemical properties on the membrane surface charge (see Figure 9). The open circular
symbols in Figure 9 are \( \zeta \) potential values, as measured with the standard particle (i.e., latex) in 10 mM NaCl, and the other results obtained from measurements using NOM. The \( \zeta \) potentials of ESNA decreased negatively in the order of latex, bulk NOM, the transphilic NOM, and hydrophobic NOM. These results indicate that the hydrophobic and transphilic NOM (i.e., NOM acids) seem to influence the surface charge of the membrane, particularly in terms of \( \zeta \) potential caused by the ionizable functional groups present in the ESNA membrane. It can be envisioned that NOM acids approach and accumulate near the shear plane on the membrane surface and can even form complexes with the functional groups on the membrane, thus significantly influencing the surface charge (particularly the \( \zeta \) potential). The major difference between the hydrophobic and transphilic NOM are their molecular structures in terms of aromaticity. This difference results in a shift toward the higher negative \( \zeta \) potential range by the hydrophobic NOM than by the transphilic NOM, because of the hydrophobic interactions between the membrane surface (made of polyamide) and the hydrophobic NOM (based on aromaticity). In the case of the \( \zeta \) potential of nonisolated NOM, however, the amount of shifts were small as compared with the NOM acids, because it contains large amount of hydrophilic NOM with non-charged molecules.

Considering the \( \zeta \) potentials of both membranes determined using the monitoring particles in Figure 3, the GM membrane had a much higher negative \( \zeta \) potential than the ESNA membrane. The ESNA membrane showed different trends of \( \zeta \) potential, as compared with the GM membrane: latex particle solution < the bulk NOM < the transphilic NOM < the hydrophobic NOM (Figure 9a). The negatively increasing values of \( \zeta \) potential for the GM membrane was transphilic NOM, bulk NOM, hydrophobic NOM, and the latex particle (Figure 9b). Because the surface charge of the GM membrane is very highly negative originally, it was reduced by an adding solutes with lower charge densities. Interestingly, the \( \zeta \) potential trends of both membranes measured with hydrophobic NOM solution were similar, even though the \( \zeta \) potentials of the two membranes were different, as measured with the standard particles.

**Effects of NOM on the Membrane Surface Charge.** To investigate the variation of membrane \( \zeta \) potential from NOM adsorption, membrane adsorption tests were performed for 3 days using various NOM solutions containing different concentrations of bulk NOM (see Figure 10). Because the negative charge density of NOM (particularly from NOM acids) is believed to be much higher than that of the ESNA surface, the membrane adsorbed with NOM exhibits greater negative surface charge. These higher NOM concentration results in higher negative \( \zeta \) potentials. It was found that \( \zeta \) potential values became stable above pH 6 because almost all of the ionizable functional groups contributing to the membrane surface charge appeared to dissociate at below pH 6. NOM adsorption on the membrane surface was shown to be different for the ESNA and GM membranes. In the case of the ESNA membrane, as the NOM concentration (as DOC) increased, the \( \zeta \) potential of the membrane increased negatively; however, the opposite direction was shown by the GM membrane.

Both of the two membranes exhibited very similar \( \zeta \) potential values after they had adsorbed NOM from a concentration of 500 mg/L as DOC. The results imply that adsorbed NOM influences the surface charge of the membrane. In other words, adsorbed NOM on the membrane surface predominantly influences the membrane surface charge but not intrinsic surface charge (i.e., as measured using the latex particles) when a high enough concentration is used for the NOM adsorption test.

**FIGURE 8.** \( \zeta \) potentials of hydrophobic and transphilic NOM constituents: (a) as a function of concentration (solution pH range of 5.8–6.0) and (b) as a function of pH.

**FIGURE 9.** \( \zeta \) potential of membranes measured with various NOM solutions of different constituents and concentrations: (a) ESNA membrane and (b) GM membrane.
Effect of pH on the Membrane Surface in the Presence of NOM. As shown previously, NOM accumulation on the membrane surface can alter the charge property of the membrane in terms of its \( \zeta \) potential. \( \zeta \) potential variation as a function of pH is shown in Figure 11 when NOM was used as a measuring solute at a concentration of 100 mg/L as DOC. The isoelectric points of the GM and ESNA membranes, as determined by the streaming potential method, did not change significantly, even though NOM accumulation on the membrane surface might have caused a somewhat different ion distribution. As shown previously, in the section on the effects of NOM on the membrane surface charge, the \( \zeta \) potential (in the case of the electrophoresis method) of the ESNA and GM membranes increased and decreased negatively, respectively, when measured with NOM, as opposed to latex. In the case of the streaming potential method, only the ESNA membrane was influenced by the presence of NOM; the \( \zeta \) potential increased dramatically. The GM membrane, however, provided similar \( \zeta \) potential values in both cases (i.e., with and without NOM).

Effects of Various Ions on the Membrane Surface Charge. From the results shown in Figure 12, the latex particles represented the highest negative \( \zeta \) potential, as expected based on the double layer theory (1, 5). Moreover, as the ionic strength increases, the \( \zeta \) potential decreases substantially because of double layer compaction. Irrespective of electrolyte types, the \( \zeta \) potential (or mobility) of the latex particles was virtually zero when the concentration of each electrolyte was 0.01 M. This virtually zero \( \zeta \) potential is also a fundamental condition of the electrophoresis method for the measurement of membrane \( \zeta \) potential, which can be determined by the mobility of latex particles.

To determine the relative selectivities of various ions with respect to the membrane surface, the \( \zeta \) potentials of both membranes were estimated with different electrolyte. The ratios of the \( \zeta \) potentials measured using various electrolytes to that measured with 10 mM NaCl are presented in Figure 13. The \( \zeta \) potentials of both the membranes were at a maximum when the \( \zeta \) potential was measured using latex particles in deionized water (i.e., at the lowest ionic strength), as expected from the double layer theory. An ionic strength adjustment with either 10 mM of NaCl or 10 mM of KCl did not reduce the membrane surface charge substantially because monovalent cations cannot enter the Stern layer to influence the electroosmosis of ions and subsequently induce latex mobility. Meanwhile, divalent cations could substantially influence the surface charge of the membranes probably by (inner- or outersphere) surface complexation with ionizable functional groups on the membrane’s surface (12).

Implications of Research on Membrane Filtration Applications. An electrophoretic method was mechanistically introduced to measure the \( \zeta \) potential of the membrane surface, as opposed to the streaming potential measurement.
method (containing the surface conductance assumption). With the methods developed in this work, optimum membranes (targeting maximum electrostatic exclusion and minimum organic fouling) are anticipated to be selected for an NOM solution (hydrophobic vs hydrophilic NOM; NOM with a higher vs a lower acidity) under different electrolyte conditions (mono- vs divalent cation). Moreover, suggested measurement procedures of the membrane surface charge can also be used to characterize membranes fouled with NOM (hydrophobic vs hydrophilic NOM; NOM with a higher vs a lower acidity), providing information on both foulants characteristics and cleaning strategies.

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Literature Cited