

Membrane fouling remediation in ultrafiltration of latex contaminated water and wastewater

Amira Abdelrasoul*, Huu Doan and Ali Lohi

Department of Chemical Engineering, Ryerson University, M5B 2K3, Toronto, Ontario, Canada.

*Corresponding author's e-mail: amira.abdelrasoul@ryerson.ca

Abstract

The goal of the present study was to remediate membrane fouling of latex effluent by altering the membrane surface charge or the ionic strength of simulated latex effluent either through the pH change or using anionic surfactants. Hydrophilic Polysulfone and Ultrafilic flat membranes, with MWCO of 60,000 and 100,000, respectively, as well as hydrophobic Polyvinylidene Difluoride membrane with MWCO of 100,000, were used under a constant flow rate and cross-flow mode in ultrafiltration of latex solution. The effect of Linear Alkyl Benzene Sulfonate (LAS) on the ionic strength of the latex solution and the zeta potential of latex particles at different LAS concentrations was investigated. LAS was also used, at different concentrations and various treatment times in order to improve the antifouling properties of membrane surface. The results obtained indicate that increasing the ionic strength of latex effluent was achieved by increasing its pH from 7 to 12, resulted in an increase of the zeta potential negativity of the latex particles from -26.61 to -42.66 mV, while LAS had an opposite effect even at high concentration and for long treatment times. The optimum enhancement of membrane surface hydrophilicity occurred in the LAS treatment at a concentration of 1×10^{-4} g/L. However, the optimum treatment time was different for each membrane. Increasing the ionic strength of latex effluent or enhancing the membrane surface hydrophilicity caused a significant increase in the cumulative permeate flux, a substantial decrease in the total mass of fouling, and a noticeable decrease in the specific power consumption.

Keywords: Fouling, hydrophilicity, latex, remediation, wastewater.

Introduction

The manufacturing of paint products, reactor cleaning, and mixing basins generate a large quantity of wastewater. Paint effluents typically have high levels of biological oxygen demand (i.e., BOD of greater than 580 mg/L), chemical oxygen demand (COD, greater than 5500 mg/L), and high levels of suspended solids and turbidity (Deyet *al.*, 2004). As a consequence, the wastewater needs to be treated before it is discharged. The low-pressure membrane applications considered the most effective and sustainable methods of addressing environmental problems in treating water and wastewater in order to meet or exceed stringent standards. Nevertheless, membrane fouling is one of the primary operational concerns that is currently hindering a more widespread application of ultrafiltration with a variety of contaminants. Examining the source and mechanisms of foulant attachment to the membrane's surface is critical when it comes to the research of membrane fouling and its potential practical implementation. There exist two major forces contributing to foulant attachment, specifically: the dispersion interaction force and the polar interaction force (Israelachvili, 1992). The Derjaguin, Landau, Verwey and Overbeek

(DLVO) theory quantified the particle–surface interactions in aqueous environments by balancing the Van der Waals attraction force and electrostatic double layer forces between particles and the membrane’s surface. These interactions elucidate the possible advantages of hydrophilizing the membrane’s surface as an effective fouling remediation technique (Abdelrasoulet *al.*, in press^b). In order to increase the antifouling properties of the hydrophobic membranes several methods have been implemented (Sui *et al.*, 2012; Zuo and Wan, 2013; Nikkolaet *al.*, 2014). Moreover, the ionic strength of the feed solution was found to significantly affect the fouling potential (Faibishet *al.*, 1998; Jones and O’Melia, 2000; Singh and Song, 2005; Mika *et al.*, 2006, Abdelrasoul *et al.*, 2014).

Nevertheless, the experimental observations are not sufficient for a thorough understanding of the fouling potential of latex particles at different solution ionic strength values. The relationship between the solution ionic strength and the particle-to-particle and particle-to-membrane attachment is critical for the elucidation of the underlying factors affecting membrane fouling. In the previously conducted study a mathematical model was developed using a homogeneous membrane with a uniform pore size for the ultrafiltration of latex paint solution with a wide range of particle size distribution (Abdelrasoul *et al.*, 2013a). This model accounts for the existing chemical attachments in the membrane fouling, and incorporates the coupled effects of the chemical and physical parameters in membrane fouling, allowing for a comprehensive understanding of the fouling phenomenon and its potential functions. The mathematical model is capable of accurately predicting the increase in the transmembrane pressure and the mass of the fouling retained by the membrane. As was demonstrated in our recent studies (Abdelrasoul *et al.*, 2013b, 2014, in press^b), the fouling attachments are dependent on the properties of foulants and membranes, operating conditions, and solution chemistry. In addition, a mathematical model that could be applied to heterogeneous membranes with non-uniform pore size was also developed (Abdelrasoul *et al.*, in press^a). Therefore, the aim of the present study is to remediate membrane fouling of latex effluent by altering the membrane surface charge or the ionic strength of the simulated latex effluent either by a pH change or using anionic surfactants. The influence of the ionic strength, via varying of the solution pH or adding anionic surfactant, on the fouling attachments, the total mass of fouling, cumulative permeate volume per unit area, and the specific power consumption are investigated. The impact of membrane surface treatment on improving the anti-fouling properties of the membrane, membrane fouling remediation, and decreasing the specific power consumption will be discussed.

Attachment mathematical model

The details regarding the development of the model for homogeneous and heterogeneous membranes as well as the model’s equations are discussed elsewhere (Abdelrasoul *et al.*, 2013a, in press^a). As outlined in the earlier studies (Abdelrasoul *et al.*, 2013a), the model equations were solved for the depositional attachment (α_{pm}) and the coagulation attachment (α_{pp}), using the experimentally measured values of the mass of fouling contributing to cake formation and the mass of fouling contributing to pore blocking. The specific power consumption calculations for the filtration process were discussed in details in the recent publication (Abdelrasoulet *al.*, 2014).

Materials and Methods

Details of experimental set up, particulars of the procedure, membrane filtration unit, and latex paint used can be found in Section 3.1 of the previous study (Abdelrasoulet *al.*, 2013a). The description of the procedure used to measure the total mass of fouling (m_t), the mass of particles contributing to pore blocking (m_p), and the mass of particles contributing to cake layer (m_c) was likewise reported in the same publication. In the present study, Polysulfone membrane with MWCO of 60,000 and with the chemical structure of $[\text{OC}_6\text{H}_4\text{OC}_6\text{H}_4\text{SO}_2\text{C}_6\text{H}_4]_n$ (GE Water & Process Technologies), Ultrafilic membrane with MWCO of 100,000 and with the chemical structure of $(\text{C}_3\text{H}_3\text{N})_n$ (GE Water & Process Technologies), and PolyvinylideneDifluoride (PVDF) membrane with MWCO of 100,000 and with the chemical structure of $(\text{C}_2\text{H}_2\text{F}_2)_n$ (Koch Membrane Systems) were the flat membranes used. The zeta potentials of the untreated membranes used in the present study were -42.40 mV, -41.50 mV, and -2.50 mV for Polysulfone, Ultrafilic, and PVDF, respectively. In the current study, the solution temperature was maintained constant at room temperature (22-24 °C). In order to analyze the influences of the surface charge and/or the anionic strength as the main process parameters, the ultrafiltration time for each experiment was kept constant (25 minutes). In the case of membrane surface charge treatments featuring a pH change all the procedures have been recorded in details in Section 4.1 of our recent study (Abdelrasoulet *al.*, in press^b). Alternatively, in the case of membrane surface charge treatments using anionic surfactant, the flat membranes were immersed in Linear Alkyl Benzene Sulfonate (LAS) with the chemical structure of $[(\text{CH}_3)_2(\text{CH}_2)_9\text{CHC}_6\text{H}_4\text{-SO}_3\text{Na}]$ at different concentrations and various treatment times. The critical micelle concentration (CMC) of LAS was 0.1 g/L. LAS was also added at different concentrations to the simulated latex effluent in order to investigate its effect on the ionic strength of the latex solution and the zeta potential of latex particles. Moreover, the latex solution pH was adjusted with the aids of a pH transmitter (Mettlertoledo pH Transmitters 2100e, Mettler Toledo, Germany, <0.02 pH) using 0.1 N H_2SO_4 and 0.1 N NaOH. The detailed description of the analytical methods was illustrated in Section 4.2 of the recent publication (Abdelrasoul *et al.*, in press^b).

Results and Discussion

Simulated latex effluent treatment by pH change

The simulated latex effluent with a solid concentration of 1.30 kg/m^3 has a pH of 7. The zeta potential of latex particles at pH 7 is approximately -26.61 mV. As the pH increased from 7 to 11 the zeta potential negativity had increased significantly from -26.61 to -40.00 mV, as shown in Figure 1. The adsorption of OH^- group on the particle surface at higher pH values in turn caused the negative charge on the latex particle surfaces to increase until it achieved -42.66 mV at pH of 12. Furthermore, the solution conductivity increased from 0.094 to 20.4 mS/cm when the solution pH was increased from 7 to 11. Notably, the ionic strength is directly proportional to the solution conductivity. On the other hand, decreasing pH from 7 to 3 using sulfuric acid resulted in a substantial decrease in the zeta potential value from -26.61 to -11.20 mV. In addition, the zeta potential of each membrane surface was investigated at each pH value so as to simulate the effects of pH of the latex solution through the ultrafiltration process. As the pH of the simulated latex effluent was increased from 3 to 11, the zeta potential of PVDF, Ultrafilic, and Polysulfone membrane surfaces became increasingly negative: from -2.01 to -32.62 mV, -18.99 to -43.00 mV, and -5.67 to -41.98 mV, respectively, as shown in Figure 1. This indicates

that the hydrophilicity of the membrane surface was enhanced as the pH value of the latex solution increased from 7 to 11 from -2.5 to -32.62 mV, and from -41.5 to -43.00 mV, for PVDF and Ultrafilic membrane, respectively. On the other hand, increasing the pH value from 7 to 11 resulted in an insignificant change in the surface charge of the Polysulfone membrane from -42.40 to -41.98 mV. This may be attributed to the fact that 25 minutes of the ultrafiltration process were not sufficient enough to change the zeta potential of Polysulfone membrane, of the unique chemical structure with the sulfone group, especially if compared to the two hour treatment of the surface soaked in alkaline as a membrane surface treatment.

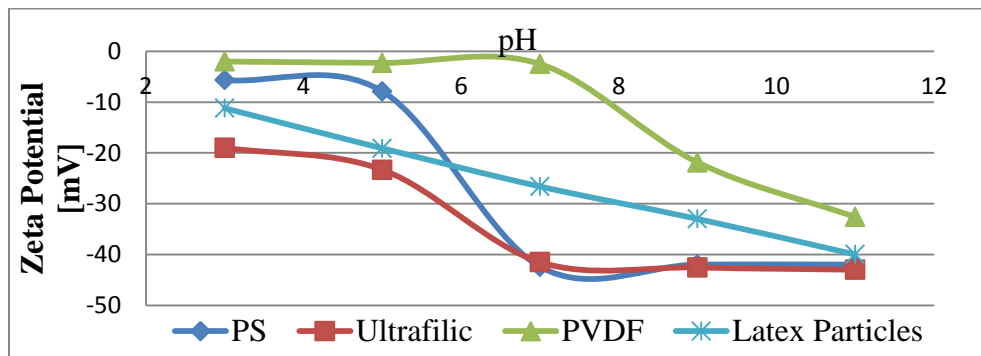


Figure 1. Effect of pH change of latex effluent on the zeta potential of latex particles and the membrane surface through the ultrafiltration process.

The results obtained indicated that the most significant influence of increasing the pH of simulated latex effluent through the ultrafiltration process occurred with the use of hydrophobic PVDF membrane. At the feed flow rate of 4 LPM, feed concentration of 0.78 kg/m^3 , and transmembrane pressure of 15 psi, using a PVDF membrane and increasing the pH value from 7 to 11 resulted in an increase in the zeta potential negativity from -2.5 mV to -32.62 mV. As a consequence, the repulsion force between the latex particles and the membrane surface would increase, causing the depositional attachment to decrease from 0.97 to 0.21. Hence, the total mass of fouling significantly decreased from 0.0125 to 0.0088 kg/m^2 and the specific power consumption experienced a substantial decrease from 15.4 to 1.83 kW.h/m^3 while the permeate flux noticeably increased from 0.01 to $0.07 \text{ m}^3/\text{m}^2$.

Simulated latex effluent treatment using anionic surfactant

As the anionic surfactant concentration increased from 0.0001 to 0.1 g/L , the ionic strength of the latex solution increased, and the solution conductivity increased from 0.0944 to 6.5210 mS/cm . However, the zeta potential negativity decreased from -26.61 to -4.86 mV , as shown in Table 1. This can be attributed to the electrostatic repulsions between the highly charged latex surface and the anionic head groups. As a sequence, the anionic surfactant stayed in the latex solution, which resulted in the low electrical stability of colloids, and a significant decrease in the potential difference between the dispersion solution and the stationary layer of fluid attached to the dispersed latex particles. Consequently, the zeta potential negativity of the latex particles was reduced. Furthermore, Table 1 illustrates the effects of LAS additions to the latex solution on the zeta potential of the membrane surface through the ultrafiltration process. The LAS concentration of 0.0001 g/L was an optimum concentration for the enhancement of hydrophobic

PVDF surface charge, while it had an insignificant effect on Ultrafilic membrane. However, the addition of LAS had an opposite effect on the Polysulfone membrane. This may attributed to the unique chemical structure of the Polysulfone membrane with the sulfone group. As a consequence, the repulsion between the functional group of anionic surfactant and the functional group of Polysulfone explain the unchanged hydrophilicity of the membrane surface after treatment with LAS. This result also indicated that increasing the LAS concentration of more than 0.0001 g/L resulted in a decreased zeta potential negativity of PVDF and Ultrafilic membrane surface, as presented in Table 1. It should be mentioned that the micellar ultrafiltration at the CMC of LAS of 0.1 g/L had the worst results for the zeta potential of latex particles and membrane surfaces. The reason for this behavior stems from the fact that when the micelles were formed they reduce the interfacial tension between a latex solution and the membrane surface or the latex particle surface. Moreover, the electrostatic repulsions between the highly charged membrane surfaces or the latex particles and the micelles increased. Hence, a substantial decrease in the potential difference between the dispersion solution and the surfaces can occur. Moreover, LAS at the concentration of 1×10^{-4} g/L in the discharged wastewater was found to be safe for marine and freshwater environments, because it is biodegradable (Morrow, 1993).

Table 1. Zeta potential of latex particles and latex solution conductivity at different LAS concentrations, and the zeta potential of membrane surfaces after the ultrafiltration process (After 15 minutes of LAS addition).

LAS Concentration [g/L]	Zeta Potential of Latex Particles [mV]	Latex Solution Conductivity [mS/cm]	Zeta Potential of membrane surface after ultrafiltration process [mV]		
			PS	Ultrafilic	PVDF
0	-26.61	0.0944	-42.40	-41.50	-2.50
0.0001	-24.05	0.3601	-25.22	-41.97	-28.66
0.001	-16.30	1.1020	-18.43	-27.51	-17.18
0.01	-10.02	2.4030	-8.09	-18.77	-11.67
0.1	-4.86	6.5210	0.96	3.58	-0.26

Furthermore, the effect of LAS at various time treatments was investigated at a concentration of 0.0001 g/L and the CMC concentration. At a zero concentration of LAS, the zeta potential of latex particles and the conductivity of simulated latex effluent are -26.61 mV and 0.0944 mS/cm, respectively. As presented in Table 2, after the simultaneous addition of LAS, the zeta potential of latex particles was dropped to -0.94 and -2.13 mV, at the concentration of 0.0001 g/L and 0.1 g/L, respectively. Due to the simultaneous increase of anionic heads in the latex solutions, there was a significant change in charge of the dispersion medium with respect to the dispersed particle, which in turn resulted in a significant decrease in the potential difference between the dispersion solution and the dispersed latex particles. Consequently, the zeta potential negativity was significantly decreased. The latex solution ionic strength increased through the addition of the anionic surfactant due to the presence of the negative charge hydrophilic head of the anionic surfactant. Hence, the latex solution conductivity was increased to 0.3070 and 6.4411 mS/cm, as LAS was simultaneously added at the concentration of 0.0001 and 0.1 g/L, respectively. The zeta potential measurements of latex particles indicated that the treatment time was ineffective, as presented in Table 2. Furthermore, the zeta potential of latex particles had very low negative values at the CMC of LAS, as depicted in Table 2. Due to the negative influence of micelles formation on the reduction of zeta potential negativity as previously discussed. Moreover, the treatment time had an insignificant effect on the solution ionic strength at both concentrations.

Table 2. Zeta potential of latex particles and latex solution conductivity at various time treatments at LAS concentration of 0.0001 g/L and 0.1 g/L.

Time [min]	LAS Concentration 0.0001 g/L		LAS Concentration 0.1 g/L (CMC)	
	Zeta Potential of Latex Particles [mV]	Latex Solution Conductivity [mS/cm]	Zeta Potential of Latex Particles [mV]	Latex Solution Conductivity [mS/cm]
0	-0.94	0.3070	-2.13	6.4411
15	-24.05	0.3601	-4.86	6.5210
30	-22.30	0.3870	-1.84	6.5401
60	-19.20	0.3870	-1.58	5.9806
90	-19.76	0.3865	-1.64	6.0110

The influence of adding LAS at a concentration of 0.0001 g/L to the latex solution 15 minutes before the ultrafiltration process using hydrophilic membranes was investigated. At the feed flow rate of 4 LPM, feed concentration of 1.30 kg/m³, and transmembrane pressure of 25 psi, the total mass of fouling substantially increased from 0.0135 kg/m² to 0.0931 kg/m², while the cumulative filtration volume significantly decreased from 0.115 to 0.078 m³/m² using Polyulfone membrane. Due to the decrease of the zeta potential negativity of latex particles and the membrane surface which resulted in an increase in the attraction force between the foulants and the membrane surface. At same operating conditions, Ultrafilic membrane showed insignificant changes in mass of fouling and cumulative permeate volume, from 0.025 to 0.0261 kg/m² and from 0.123 to 0.119 m³/m² respectively. This may be attributed to the slight enhancement of Ultrafilic surface hydrophilicity which balanced out the slight decrease in the zeta potential negativity of latex particles. Consequently, the results indicate that the LAS addition can be considered to be an ineffective pre-treatment for limiting the fouling propensity of the latex solution when using hydrophilic membranes.

Membrane surface treatment using anionic surfactant

As shown in Figure 2 (a), the LAS treatment had a noticeable effect on hydrophobic PVDF and hydrophilic Ultrafilic membranes at low concentration of 0.0001 g/L. Alternatively, LAS treatment was ineffective in the case of the Polysulfone membrane. Notably, the results suggested that LAS treatment was ineffective for Polysulfone membranes even in the instances where soaking was implemented for long periods of time. The original zeta potential value of each membrane is highlighted at Y-axis in Figure 2 (a). The optimum enhancement of membrane surface hydrophilicity occurred during the LAS treatments at a concentration of 0.0001 g/L. The optimum time for LAS treatment was 15 and 20 minutes, for Ultrafilic and PVDF membranes, respectively. At the CMC, LAS treatment had an opposite effect on the zeta potential of membrane surfaces due to the micelles formation, as shown in Figure 2 (b). Figure 3 (a), and Figure 3 (b), simulate the attraction between anionic surfactant hydrophilic head and hydrophilic surfaces, as well as, between anionic surfactant hydrophilic head and hydrophobic membrane surfaces. It should be mentioned that the LAS treatment for the membrane surface had a better effect than the addition of LAS to the latex solution as a feed pretreatment before the ultrafiltration process. This can be attributed to the fact that the soaking time for the membranes in LAS is more effective than the ultrafiltration process duration. In addition, the negative effects of LAS on the zeta potential of latex particles was avoided.

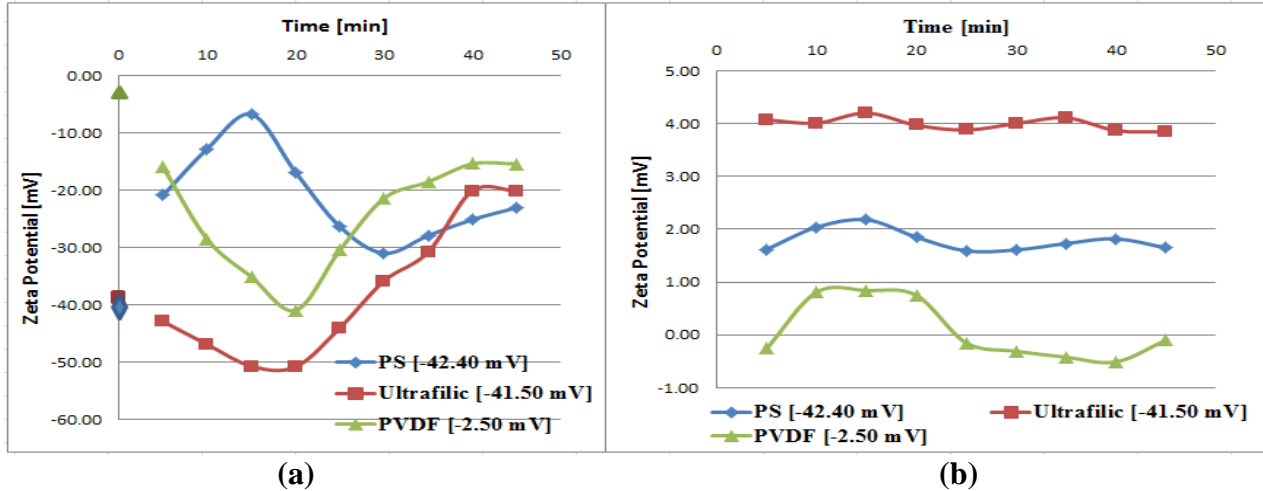


Figure 2. Zeta potential of membrane surfaces after LAS treatment at a concentration of (a) 1×10^{-4} g/L (b) 0.1 g/L.

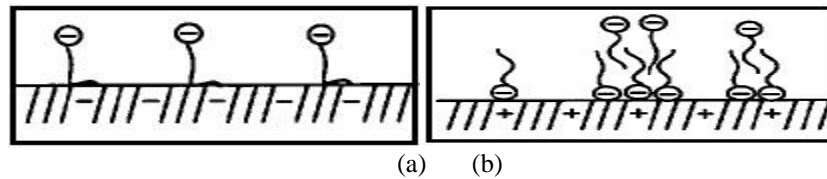


Figure 3. Schematic of adsorption of Linear Alkyl Benzene Sulfonate (LAS) into the membrane surface (a) hydrophilic membranes (b) hydrophobic membranes

As shown in Figure 2, the results obtained indicated that the most significant effect of LAS, at a low concentration of 1×10^{-4} g/L, was on the hydrophobic PVDF membrane by increasing the membrane surface charge from -2.5 mV to -40.9 mV after 20 minutes of membrane treatment. This increase was due to the high electrostatic attraction between the anionic heads of LAS and the PVDF membrane surface, as shown in Figure 3 (b). At the feed flow rate of 4 LPM, feed concentration of 0.78 kg/m^3 , and transmembrane pressure of 15 psi, the repulsion force between the latex particles and the membrane surface was increased. As a consequence, the depositional attachment (α_{pm}) decreased from 0.97 to 0.1. Hence, the total mass of fouling experienced a substantial decrease from 0.0125 kg/m^2 to 0.007 kg/m^2 , the specific power consumption significantly decreased from 15.4 kW.h/m^3 to 1.21 kW.h/m^3 , while the permeate flux noticeably increased from 0.01 to $0.124 \text{ m}^3/\text{m}^2$. Figure 4 presents the SEM images of PVDF membrane after ultrafiltration at the mentioned operating conditions at zeta potential of -2.5 mV and -40.9 mV.

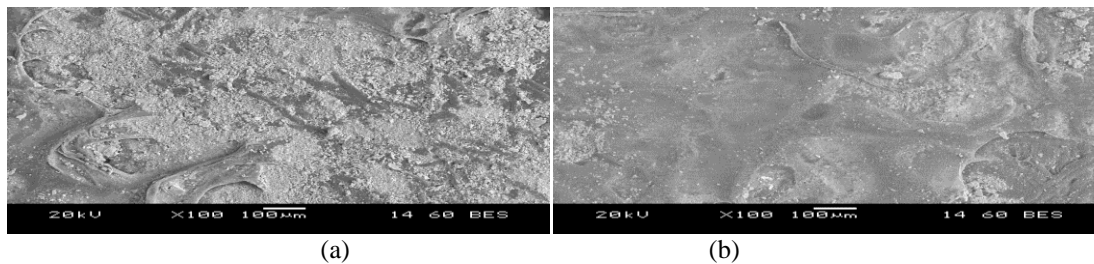


Figure 4. SEM images of PVDF membrane surfaces after ultrafiltration at [Q=4 LPM], [$C_f=0.78 \text{ kg/m}^3$], [15 psi]: (a) at original zeta potential of -2.50 mV (b) at zeta potential of -40.91 mV after 20 minutes treatment for the surface charge using LAS with concentration of 0.0001 g/L.

pH treatment for Membrane surface charge

This study investigated the effect of the surface hydrophilicity after the pH treatment of the membrane surface, on fouling attachments, the total mass of fouling, permeate flux, and specific power consumption. Changing the Polysulfone surface charge from -10 to -50 mV, were respectively obtained at pH treatments of 2.4 to 10.9 involving a 2 hour soaking. Under the operating conditions of 25 psi, 4.5 LPM, 1.30 kg/m³, increasing the zeta potential of the membrane surface from -10.00 to -50.00 mV, resulted in a substantial reduction of depositional attachment (α_{pm}) by 65%, from 0.99 to 0.35, as shown in Figure 5 (a). This could be attributed to the increased hydrophilicity of the membrane, which was created upon introducing more negative charges on the membrane surface. As a result, the electrostatic attraction force between the latex particles and the higher negatively charged membrane surface was significantly decreased. The particle-to-membrane attachment was thus notably reduced. On the other hand, increasing the zeta potential negativity of the membrane surface caused an insignificant decrease in the coagulation attachment (α_{pp}) by 5.3%, from 0.75 to 0.71, as shown in Figure 5 (a). The decrease in the depositional attachment resulted in a significant increase in the cumulative filtration volume per unit area (V_s) from 0.015 to 0.123 m³/m², an augmentation of about 10 folds, as shown in Figure 5 (a). This could be attributed to the significant reduction in the depositional attachment that resulted in a lower frequency of particle attached to the membrane pores, i.e. less pore blockage for the filtrate passage through the membrane. As a consequence, the total mass of fouling diminished by 61%, from 0.018 to 0.007 kg/m², as indicated in Figure 5 (b). Decreasing the total mass of fouling resulted in a lower rate of the transmembrane pressure increase during the filtration process. Accordingly, the specific power consumption was dramatically decreased by 92.5%, from 24.83 to 1.86 kW.h/m³, as presented in Figure 5 (b). From these observations a conclusion can be drawn that the depositional attachment is the predominant factor in membrane fouling. In addition, altering the particle-to-membrane attachment (α_{pm}) by manipulating the zeta potential of the membrane surface could be an essential process in fouling remediation. Figure 6 showcases the SEM images of Polysulfone membrane after ultrafiltration at the mentioned operating conditions, and surface charge.

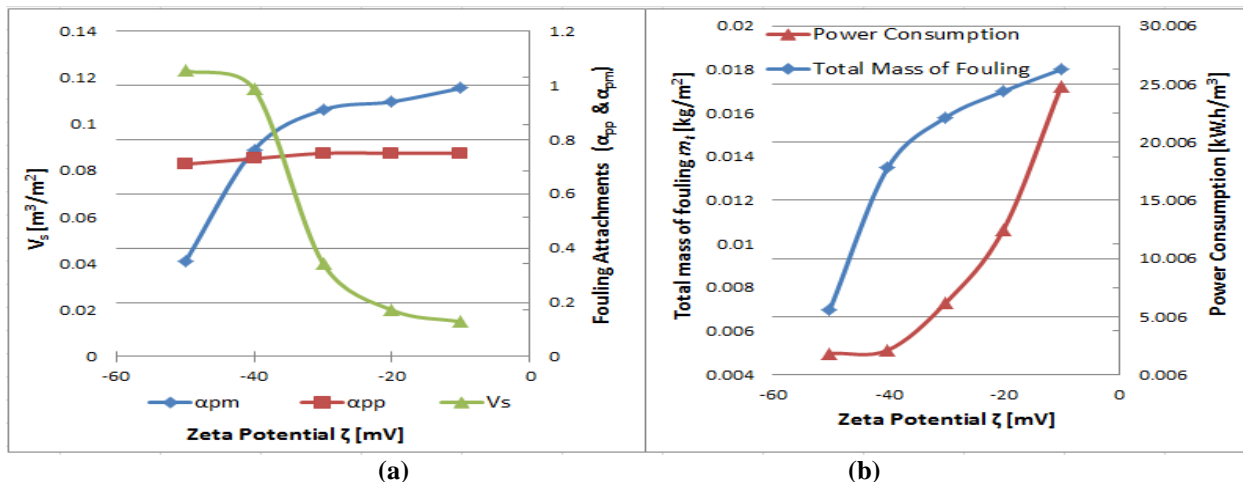


Figure 5. Effect of the zeta potential of Polysulfone membrane surface at [25 psi], [Q= 4.5 LPM], [$C_f=1.3 \text{ kg/m}^3$] on (a) Fouling attachment probabilities (α_{pp} , α_{pm}); and cumulative filtration volume per unit area (V_s) [m^3/m^2]; (b) Total mass of fouling (m_f) [kg/m^2]; and the specific power consumption [kW.h/m^3].

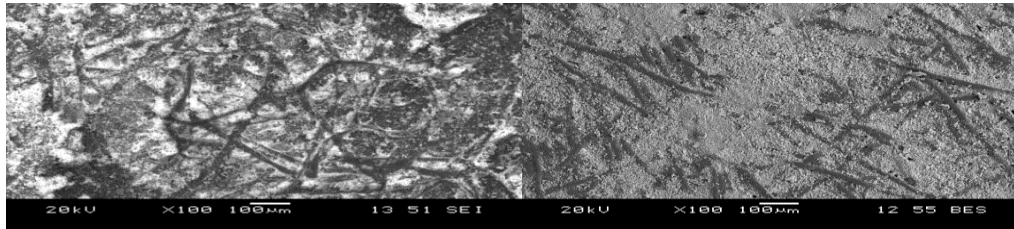


Figure 6. SEM images of Polysulfone membranes after ultrafiltration at [25 psi], [Q= 4.5 LPM], [$C_f=1.3 \text{ kg/m}^3$] (a) The zeta potential of Polysulfone membrane surface - 50.00 mV; (b) The zeta potential of Polysulfone membrane surface - 10.00 mV.

While operating in the same conditions, reducing the negativity of the Ultrafiltric membrane surface charge from the original zeta potential value of -41.50 mV to -15.00 mV resulted in a decreased repulsion force between the membrane surface and latex particles, which in turn caused the depositional attachment (α_{pm}) to increase from 0.70 to 0.96. Higher depositional attachment led to more particle attachments to the membrane surface, causing a higher pore blockage, a decrease in the cumulative filtration volume per unit area from 0.123 to 0.03 m^3/m^2 , an increase in the mass of fouling from 0.025 to 0.05 kg/m^2 , and the power consumption upsurge from 1.82 to 7.5 kW.h/m^3 . It should be noted that the coagulation attachment (α_{pp}) was 0.76 and 0.77 using Ultrafiltric membranes with the zeta potentials of -41.50 mV and -15.00 mV, respectively. Figure 7 (a) and Figure 7 (b) showcase the SEM images for Ultrafiltric membrane after ultrafiltration at a transmembrane pressure of 25 psi, a feed flow rate of 4 LPM, and a feed concentration of 1.3 kg/m^3 , at the zeta potentials of -41.50 mV and -15.00 mV, respectively.

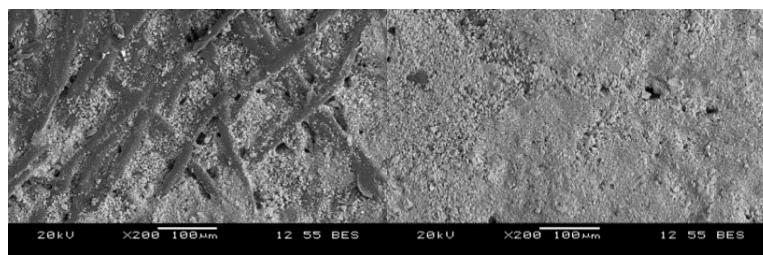


Figure 7. SEM images of Ultrafiltric membranes after ultrafiltration at [25 psi], [Q= 4LPM], [$C_f=1.3 \text{ kg/m}^3$] with Zeta potential of the Ultrafiltric membrane surface of (a)-41.50 mV; (b) -15.00 mV.

Conclusions

The results obtained in this study indicate that an increase in the ionic strength of latex effluent was achieved by raising its pH from 7 to 12. This in turn resulted in an increase of the zeta potential negativity of the latex particles from -26.61 to -42.66 mV, while LAS was considered to be an ineffective pre-treatment for limiting the fouling propensity of latex solution using hydrophilic membranes even at high concentration values and long treatment times. The optimum enhancement of Ultrafiltric and PVDF membrane surface hydrophilicity occurred during the LAS treatment at a concentration of $1 \times 10^{-4} \text{ g/L}$. The optimal time for LAS treatment was 15

and 20 minutes for Ultrafilic and PVDF membranes, respectively. The improvement of Polysulfone membrane surface hydrophilicity was achieved at -50 mV with a pH treatment involving a 2 hour soaking in 0.1 N NaOH. Increasing the zeta potential negativity of latex particles or enhancing the membrane surface hydrophilicity caused a significant increase in the cumulative permeate flux, a substantial decrease in the total mass of fouling, and a noticeable decrease in the specific power consumption.

Acknowledgement

The authors are grateful for the financial support from the Natural Science and Engineering Research Council of Canada (NSERC). The assistance and facilities provided by the Department of Chemical Engineering, Ryerson University, have made this research possible and are also highly appreciated.

References

- Abdelrasoul A., Doan H., Lohi A. (2013)^a. A mechanistic model for ultrafiltration membrane fouling by latex. *Journal of Membrane Science*, 433, 88-99.
- Abdelrasoul A., Doan H., Lohi A. (2013)^b. Impact of operating conditions on fouling probability and cake height in ultrafiltration of latex solution. *Journal of Membrane and Separation Technology*, 2, 134-147.
- Abdelrasoul A., Doan H., Lohi A. (2014). Effect of pH on fouling attachments and power consumption in ultrafiltration of latex solution. *The Canadian Journal of Chemical Engineering*, 9999, 1-13.
- Abdelrasoul A., Doan H., Lohi A., and Cheng C.-H. Modeling development for ultrafiltration membrane fouling of heterogeneous membranes with non-uniform pore size. *The Canadian Journal of Chemical Engineering*, in press^a, CJCE -13-0744.
- Abdelrasoul A., Doan H., Lohi A., and Cheng C.-H. Modeling of fouling and fouling attachments as a function of the zeta potential of heterogeneous membranes surfaces in ultrafiltration of latex solution. *Industrial & Engineering Chemistry Research*, in press^b, ie-2014-01239h. (DOI:<http://dx.doi.org/10.1021/ie501239h>)
- Dey B.K., Hashim M.A., Hasan S., and Gupta B. S. (2004). Microfiltration of water-based paint effluents. *Advances in Environmental Research*, 8 (3-4), 455-466.
- Faibish R., Elimelech M., and Cohen Y. (1998). Effect of interparticle electrostatic double layer interactions on permeate flux decline in cross flow membrane filtration of colloidal suspension. *Journal of Colloid and Interface Science*, 204, 77-86.
- Israelachvili, J. (1992). *Intermolecular & Surface Forces* 2nd edn, Academic Press Inc., San Diego, CA, USA.
- Jones K. L., and O'Melia C.R. (2000). Protein and humic acid adsorption onto hydrophilic membrane surfaces: effects of pH and ionic strength. *Journal of Membrane Science*, 165, 31-46.
- Mika M., Arto P., and Marianne N. (2006). Effect of pH on hydrophilicity and charge and their effect on the filtration efficiency of NF membranes at different pH. *Journal of Membrane Science*, 280, 311-320.
- Morrow D., Piwoni M. (1993). LAS aquatic toxicity and biodegradation. *Waste Management and Research Centre Reports*, TN93-029.
- Nikkola J., Sievänen J., Raulio M., Wei J., Vuorinen J., and Tang, C. (2014). Surface modification of thin film composite polyamide membrane using atomic layer deposition method. *Journal of Membrane Science*, 450, 174-180.
- Singh, G., and Song, L. (2005). Quantifying the effect of ionic strength on colloidal fouling potential in membrane filtration. *Journal of Colloid and Interface Science*, 284, 630-638.
- Sui Y., Wang, Z., Gao, C., Wan, Q., and Zhu, L. (2012). An investigation on the antifouling ability of PVDF membranes by polyDOPA coating. *Desalination and Water Treatment*, 50, 22-33.
- Zuo G., and Wan R. (2013). Novel membrane surface modification to enhance anti-oil fouling property for membrane distillation application. *Journal of Membrane Science*, 447, 26-35.