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The influence of aggregation of latex particles on membrane fouling attachments & ultrafiltration performance in ultrafiltration of latex contaminated water and wastewater

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ABSTRACT

The goal of the present study was to investigate the influence of latex particle aggregation on membrane fouling attachments and the ultrafiltration performance of simulated latex effluent using Cetyltrimethyl Ammonium Bromide (CTAB) as a cationic surfactant. Hydrophilic polysulfone and ultrafilic flat heterogeneous membranes, with molecular weight cut off (MWCO) of 60,000 and 100,000, respectively, as well as hydrophobic polyvinylidene difluoride with MWCO of 100,000, were used under a constant flow rate and cross-flow mode in ultrafiltration of latex solution. In addition, a polycarbonate flat membrane with uniform pore size of 0.05 μm was likewise used during the experiment. The effects of CTAB on the latex particle size distribution were investigated at various concentrations, different treatment times, and diverse agitation duration times. The effects of CTAB on the zeta potential of membrane surfaces and latex particles were also investigated. The data obtained indicate that the particle size distribution of treated latex effluent experienced significant shifts in the peaks toward a larger size range caused by the aggregation of particles. As a result, the mass of fouling contributing to pore blocking and the irreversible fouling were noticeably reduced. The optimum results occurred in the instance when CTAB was added at the critical micelle concentration of 0.36 g/L, for the duration of 10 min and with minimal agitation. Notably, a higher stirring rate had an overall negative effect on the membrane fouling minimization.

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Introduction

The process of treating simulated latex effluents prior to being discharged is essential due to its high levels of biological oxygen demand and chemical oxygen demand, and excessive levels of suspended solids and turbidity (Dey et al., 2004). The low-pressure membrane applications are considered to be the most sustainable and effective methods of dealing with diverse environmental problems, especially those related to water and wastewater treatments intended to produce water

that meet or exceed stringent industry standards. However, membrane fouling is one of the main operational concerns currently hindering a more diversified application of ultrafiltration with various contaminants. As a consequence, examining the sources and mechanisms of foulant attachment to the membrane's surface is a critical part of membrane fouling research and can further broaden their applications in the near future. The key forces contributing to attachment are dispersion interaction force and polar interactions force (Israelachvili, 1992). Foulants stay together on membrane surfaces primarily

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due to the presence of physiochemical interactions, such as, the dispersion interaction between aqueous entities. This dispersion interaction is caused by the Van der Waals attraction force between molecules in the solution and is counter-balanced by the electrostatic repulsion between particles and the membrane's surface due to the presence of surface charges. The Derjaguin, Landau, Verwey, and Overbeek (DLVO) theory (Gregory, 2005; Israelachvili, 1992) quantified the particle–surface interactions in aqueous environments by balancing out the Van der Waals attraction force and Electrostatic Double Layer (EDL) forces between particles and the membrane's surface. These interactions highlight the potential advantages of manipulating the membrane and latex particle surface charges (Abdelrasoul et al., 2014a, 2014b; Jones and O'Melia, 2000; Mika et al., 2006; Nikkola et al., 2014; Singh and Song, 2005; Sui et al., 2012; Zuo and Wan, 2013). Van der Waals interaction forces depend on the size of the interacting particles, the separation distance between particles and surface, and Hamaker constant of the interacting media (Rahimpour et al., 2007). In addition, the magnitude of the electrical double layer repulsion between similarly charged surfaces depends on the size of interacting particles, distance of separation, and surface charge of particles and surfaces (Kim et al., 2008). Further details about the effect of particle size on the interaction forces are presented in the Appendix A.

As a result, the particle-to-particle and particle-to-membrane attachment becomes influential toward membrane fouling. In our previous research studies a mathematical model was developed to accurately predict the increase in transmembrane pressure and the mass of fouling retained by homogeneous and heterogeneous membrane in ultrafiltration of latex paint solution with a wide range of particle size distribution (Abdelrasoul et al., 2013a, 2014c). This model could accurately account for the chemical attachments in membrane fouling by incorporating the coupled effects of the chemical and physical parameters of membrane fouling, thus allowing for an in-depth understanding of the fouling phenomenon and its possible causes in a variety of settings (Abdelrasoul et al., 2013b, 2014a, 2014b). The model was developed based on the fouling potential of different size particles with diversified pore sizes membranes. The size of the latex particles and the membrane pores were regarded as the primary factors in determining the occurrence and the potential type of fouling (cake layer formation or pore blocking), as well as, the presence of adsorptive internal plugging. In literature, effects of cationic surfactants on the particle stability and the morphological characteristics of the aggregated particles were studied. It was determined that the cationic surfactants had a significant effect on the growth and aggregation of nanoparticles (Koopal et al., 1999; Mehta et al., 2009; Vyas et al., 2000). Nevertheless, none of these studies investigated the influence of the cationic surfactant addition on fouling phenomenon, and membrane performance in ultrafiltration of latex paint effluent, or the effect of aggregated particles on particles attachments. In this study, Cetyltrimethyl Ammonium Bromide (CTAB) was selected as a cationic surfactant for treating the simulated latex effluent. This attributed to the behavior of cationic surfactant molecules above the critical micelle concentration (CMC). Above CMC, it aggregates to form micelles since the formation of micelles is entropically favorable as compared to a system of un-associated surfactant molecules in solution. This cationic surfactant besides its surface activity

show antibacterial properties (Jha et al., 2014). In addition CTAB was selected as a cationic surfactant because it has a lower critical micellar concentration compared to Dodecyltrimethylammonium bromide (DTAB) and it's more economical to use.

Therefore, the purpose of the present study is to investigate the effects of CTAB, a cationic surfactant, as a feed pretreatment on the latex particle size distribution at different concentrations, various treatment times, and diverse agitation duration times. As a consequence, the effects of particle aggregation on fouling attachments, the total mass of fouling, and membrane performance will be investigated using homogeneous and heterogeneous membranes featuring uniform and non-uniform pore sizes, respectively. The effects of CTAB on the zeta potential of latex particles and membrane surfaces are also investigated in order to examine its effect on the deposition attachment. Finally, the combined effects of simulated latex effluent pretreatment using CTAB and treated membrane surface are further examined.

1. Materials and methods

The details regarding the model's development for homogeneous and heterogeneous membranes and the model's equations are discussed in our previous publications (Abdelrasoul et al., 2013a, 2014c). As showcased in previous studies (Abdelrasoul et al., 2013a, 2014c), 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 study reported on the specifics 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) (Abdelrasoul et al., 2014d). A schematic diagram of the experimental setup is shown in Fig. 1. A more detailed account of the experimental setup, the particulars of the procedure, the membrane filtration unit, and the characteristics of latex paint used can be found in the previous study (Abdelrasoul et al., 2013a). The specific power consumption calculations for the filtration process were also extensively discussed in the recent research publication (Abdelrasoul et al., 2014a).

In this study, hydrophilic polysulfone membranes with the chemical structure of $[\text{OC}_6\text{H}_4\text{OC}_6\text{H}_4\text{SO}_2\text{C}_6\text{H}_4]$ and molecular weight cut off (MWCO) of 60000 (GE Water & Process Technologies), and hydrophobic polyvinylidene difluoride (PVDF) membranes with MWCO of 100,000 (Koch Membrane Systems) were tested as heterogeneous membranes. The zeta potentials of the untreated membranes implemented in the present study were -42.40 and -2.50 mV, for polysulfone and PVDF membranes, respectively. The membrane surface charge was measured using the zeta potential analyzer (Zetasizer-Nano Series, Malvern Instruments Ltd., UK, ± 0.01 mV). During these experiments, a simulated latex effluent with a fixed pH of 7 was used for all of the experimental runs. The zeta potential of the latex particles at pH of 7 was approximately -26.61 mV.

As part of the current research study, the dodecylamine cationic surfactant was also tested. Dodecylamine has a melting point of $27\text{--}30^\circ\text{C}$ and thus cannot be used at room

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