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Performance of ceramic ultrafiltration membranes and fouling behavior of a dye-polysaccharide binary system

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ABSTRACT

Ultrafiltration membrane processes have become an established technology in the treatment and reuse of secondary effluents. Nevertheless, membrane fouling arises as a major obstacle in the efficient operation of these systems. In the current study, the performance of tubular ultrafiltration ceramic membranes was evaluated according to the roles exerted by membrane pore size, transmembrane pressure and feed concentration on a binary foulant system simulating textile wastewater. For that purpose, carboxymethyl cellulose sodium salt (CMC) and an azo dye were used as colloidal and organic foulants, respectively. Results showed that a larger pore size enabled more solutes to get adsorbed into the pores, producing a sharp permeate flux decline attributed to the rapid pore blockage. Besides, an increase in CMC concentration enhanced severe fouling in the case of the tighter membrane. Concerning separation efficiency, organic matter was almost completely removed with removal efficiency above 98.5%. Regarding the dye, 93% of rejection was achieved. Comparable removal efficiencies were attributed to the dynamic membrane formed by the cake layer, which governed process performance in terms of rejection and selectivity. As a result, none of the evaluated parameters showed significant influence on separation efficiency, supporting the significant role of cake layer on filtration process.

1. Introduction

Through the last decade, ultrafiltration (UF) has become an established technology in drinking and wastewater treatment. At the same time, an increasing water demand combined with the lack of natural water resources have made possible the extensive use of that technology for the treatment and reuse of brackish water and secondary effluents from wastewater plants (Kim et al., 2009; Tian et al., 2013). In particular, one of the applications where UF, together with other membrane technologies, is being developed as a promising separation tool involves textile effluents treatment. Textile wastewaters have complex characteristics due to their high dye content, great quantity of salts, organic matter and other auxiliaries coming from the different textile processes. Furthermore, they exhibit high pH and temperatures (Vergili et al., 2012).

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The numerous advantages of UF and membrane processes over conventional separation processes, such as product quality, high efficiency, ease to operate and small footprint, have favored an increasing use. Moreover, decrease in fabrication costs, continuous research and development of new membrane materials only further contributed to this expansion (Muthukumaran et al., 2011; Resosudarmo et al., 2013; Tian et al., 2013; Zhu et al., 2012). Nevertheless, a critical issue arising as a major obstacle in the wider expansion of membrane technologies application in general, and UF in particular, is membrane fouling (Tian et al., 2013). Fouling results in decreasing membrane performance, increasing cleaning chemicals and energy consumption. As a result, both maintenance and operation costs are ultimately increased (Kim et al., 2009; Muthukumaran et al., 2011). Theoretically, fouling of ultrafiltration membranes may be classified into three main categories according to the fouling mechanism, where cake layer formation, pore blockage and foulants adsorption into the membrane pores causing pore constriction, may occur (Abrahamse et al., 2008; Qu et al., 2012).

In practice, feed streams to the membrane separation processes contain a combination of foulants rather than one particular foulant, therefore making difficult the identification of a specific fouling mechanism and the subsequent justification of the observed fouling behavior. As a result, the observed behavior of multifoulant systems may strongly differ from the individual fouling behavior (Arkhangelsky et al., 2012; Kim et al., 2009; Wang and Tang, 2011). It is well recognized that interactions between foulant species, together with membrane–foulant interactions, significantly affect membrane performance. In that way, although the specific interactions between the membrane surface and foulants may control the filtration process during the first stages of the separation process, the interactions between foulants may also play a major role (Jermann et al., 2007).

According to this, significant efforts are invested in studies related to fouling prevention and minimization, leading to a better understanding of the fouling phenomenon and ultimately overcome this problem. From those studies, operating conditions, membrane material and properties as well as feed water characteristics are identified as the main responsible for the process performance.

Regarding membrane material, ceramic membrane processes are an emerging technology for water treatment as an alternative to polymeric membrane processes. However, as stated by Lee et al. (2013) there is almost no information on its performance and fouling mechanisms. In this recent study, they evaluated the fouling characteristics of ceramic and polymeric membranes using polyethylene glycol, real and synthetic river water solutions. They found that ceramic membranes had less irreversible fouling than polymeric membranes. This was due to weaker interaction of the foulant with ceramic membranes than with polymeric ones, presumably due to the more hydrophilic nature of the ceramic material. Other authors have evaluated the behavior of polymeric and ceramic membranes in order to compare their filtration performance, concluding that ceramic membranes have several advantages over polymeric ones. For instance, Hofs et al. (2011) compared the permeability and fouling of four ceramic membranes and two polymeric membranes treating surface water. They found that TiO_2 and SiC membranes had a low TMP increase due to low reversible and irreversible fouling, compared to the Al_2O_3, ZrO_2 and polymeric membranes. Besides, removal of organic matter was higher for the ceramic membranes than for the polymeric ones. Lee and Cho (2004) compared ceramic and polymeric membranes for natural organic matter removal. They stated that ceramic membranes were more effective to remove disinfection by-products precursors and exhibited higher permeability than the equivalent polymeric membranes. Majewska-Nowak (2010) shown that after the initial drop in volume flux, membrane permeability remained almost constant during the long term ultrafiltration experiments treating solutions with only dye particles. Such membrane behavior can be an indication of the superiority of ceramic over polymeric membranes. Lee and Kim (2014) stated that with ceramic membranes more effective physical and chemical cleaning efficiency was achieved than with polymeric ones by 70 and 25%, respectively.

Furthermore, unlike polymeric membranes, ceramic ones have extremely high chemical and physical stability (allowing much more aggressive cleaning procedures without risk of damaging membrane integrity), outstanding separation characteristics and higher lifespan (Majewska-Nowak, 2010). Although some polymeric membranes have been used to successfully treat acids, bases and solvents, their long-term resistance has often been proved inadequate for industrial applications. Similarly, although new polymeric materials have been developed in order to increase the polymeric membranes resistance, they have not yet been widely proven. In that way, and taking into account the particular characteristics of the textile wastewaters (characterized by high temperatures and pH), ceramic membranes are a suitable and interesting alternative for the treatment of this kind of effluents.

Concerning membrane fouling, the interfacial characteristics of both foulants and membranes have been highlighted as one of the key responsible factors (Chon et al., 2012; Muthukumaran et al., 2011; Qu et al., 2012). These interfacial characteristics are primarily related to foulant type, molecular size, morphology, surface charge, concentration and hydrophobicity among others. Therefore, they can be determined by the chemical composition, properties and structure of both foulants and membranes (Arkhangelsky et al., 2012; Qu et al., 2012; Zhu et al., 2012; Zularisam et al., 2011).

In that way, membrane fouling may be caused by dissolved organic or inorganic components, colloidal matter, soluble microbial products, bacteria or suspended solids, which are considered as the main foulants in water treatment (Subhi et al., 2012; Zahrim et al., 2011). In particular, organic fouling is a significant problem in the case of treated textile wastewater, where either surfactants, dyes, sizing agents and effluent organic matter (EfOM) are principal constituents of the wastewaters, becoming common foulants and causing process deterioration (Işik, 2004; Srisukphun et al., 2009). From the different processes performed in a textile mill, desizing contributes significantly to the total organic load of the textile effluents while on the other hand, effluents coming from the dye processes result also extremely problematic mainly because of the residual azo dyes (Işik, 2004; Shaw et al., 2002).