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Highly permeable asymmetric alumina hollow fibers for treating wastewater contaminated with Congo red dye

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Introduction

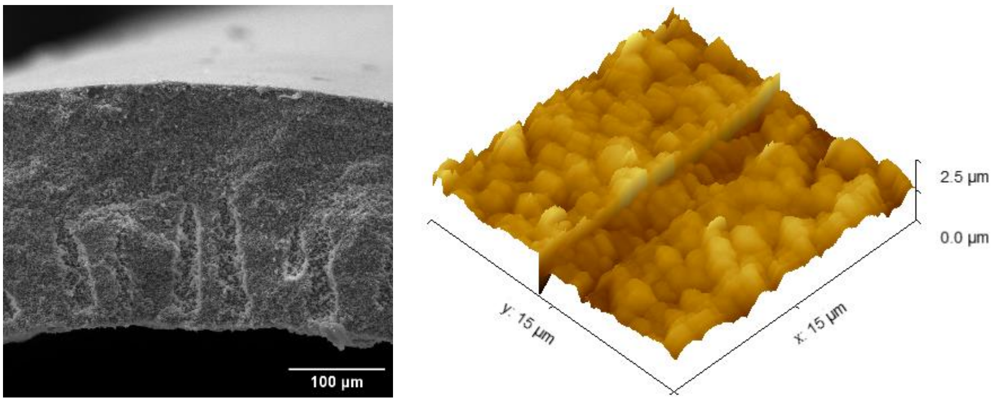
Synthetic dyes are extensively employed in various industrial sectors. However, the improper disposal of these substances leads to human health risks. Membrane separation processes are currently investigated for wastewater treatments [1], but the trade-off between membrane selectivity and permeance should be still considered. Ceramic membranes present the advantages of high mechanical strength and chemical resistance. Membranes with hollow fiber geometry are preferable due to the high packing density. Here, we investigated the application of asymmetric alumina hollow fiber membranes for the retention of Congo red dye from aqueous solutions.

Material and methods

Asymmetric alumina hollow fibers were produced according to the phase inversion process followed by a single sintering step [2]. Morphological analyses of the alumina hollow fibers were conducted using atomic force microscopy (AFM, Shimatzu SPM 9600) and scanning electron microscopy (SEM, Tescan, VEGA3 model). For the filtration experiments, a single hollow fiber with a filtration area of 4.28×10^{-4} m^2 was assembled in a permeation module that was connected to a filtration system (Convergence Inspector Minos module). After membrane compaction, the membrane hydraulic permeance was measured in the pressure range of 0.1 to 0.7 bar. Then, an aqueous Congo red dye (Neon Comercial, Brazil) solution at a concentration of 100 ppm was filtered through the membrane at 0.3 bar of transmembrane pressure. The filtrations were carried at dead-end mode and room temperature (approximately 25°C). The permeate flow was measured according to the filtration time. The concentration of the Congo red dye molecules in feed and permeate streams was measured using UV-VIS spectrophotometry (PerkinElmer, PDA UV/VIS Lambda 265) at a wavelength of 496 cm^{-1}. Congo red dye solutions before and after membrane filtration were also characterized according to the L*a*b* color space (Konica Minolta, CM-5 Spectrophotometer).

Results and discussion

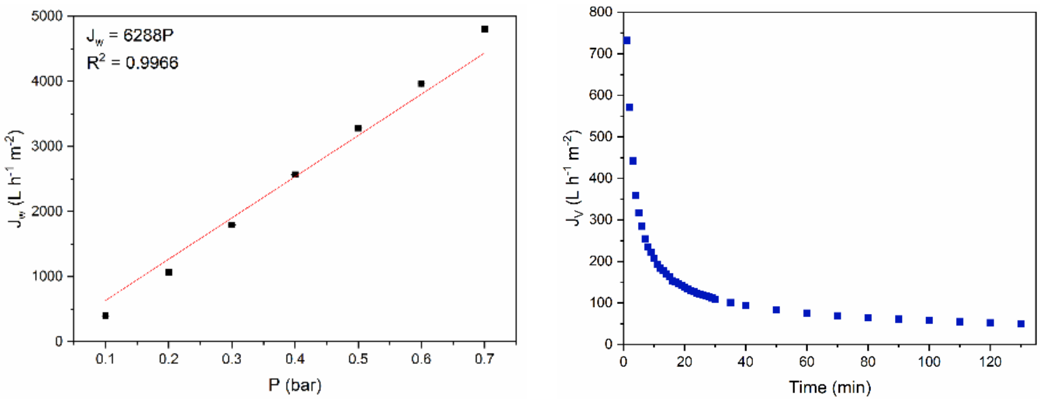
SEM and AFM images of the prepared alumina hollow fibers are presented in Fig. 1(a) and 1(b), respectively. As presented in Fig. 1(a), some microchannels were formed in the inner surface of the hollow fiber due to the contact of the ceramic suspension with the bore fluid (water) which caused the polymer phase inversion [2]. Also, a dense sponge-like layer was formed on the fiber outer surface due to the applied air gap between the extruder and the coagulation bath. The microvoids contribute to the increase in the permeate flux, while the sponge-like layer is responsible for the membrane mechanical strength. Using the AFM technique (Fig. 1(b)), the roughness of the alumina hollow fiber was determined to be 122.53 ± 5.07 nm, which follows the values reported in the literature for ceramic hollow fibers [2,3].



(a) (b)

Fig. 1. (a) SEM and (b) AFM images of the alumina hollow fiber.

According to the water flux (J_w) data presented in Fig. 2(a), as adjusted to the Dacy law, the hydraulic membrane permeance was 62.88 ± 4.03 L h^{-1} m^{-2} kPa^{-1}, in agreement with the results reported in the literature for ceramic membranes [2, 3]. Fig. 2(b) presents the flux (J_V) decay according to the filtration time for the treatment of the Congo red dye solution. A pronounced flux decay was observed in the first 60 min of filtration, followed by a flux stabilization at 54.02 ± 3.13 L h^{-1} m^{-2}. Sharma et al. [4] filtered a Congo red dye solution at an initial concentration of 25 pm through PVDF mixed matrix membranes and reported a steady state flux at approximately 20 L h^{-1} m^{-2}. Then, Sharma et al. [4] suggested the incorporation of zeolitic imidazolate frameworks to improve the permeate flux. Here, we highlight the application of asymmetric alumina hollow fibers to obtain high permeation fluxes.



(a) (b)

Fig. 2. Flux characteristics of the asymmetric alumina hollow fiber: (a) pure water flux (J_W) according to the transmembrane pressure; (b) flux decay of Congo red dye solution (J_V) according to the filtration time.

Table 1 presents the color parameters of feed, permeate, and concentrate samples. The membrane filtration was efficient to improve the luminosity (L*) of the dye solution and to reduce the coordinates related to red and yellow colors (a* and b*, respectively). Related to the Congo red dye concentration, the alumina hollow fiber showed a removal efficiency of 31.19 ± 1.16%. This result indicates that the proposed membrane can remove Congo red dye from aqueous solutions, making it a potentially viable option for pre-treatment of water for both domestic and industrial consumption. Sharma et al. [4] showed that a polymeric PVDF membrane was able to retain almost 90% of the Congo red dye solution, but the tradeoff between membrane permeance and selectivity should be considered.

Table 1. Color coordinates of Congo red dye solutions before and after filtration through the asymmetric alumina hollow fiber.

Sample	L*	a*	B*
Feed	80.46 ± 0.01	35.52 ± 0.02	22.99 ± 0.04
Permeate	84.65 ± 0.04	28.59 ± 0.08	16.04 ± 0.04
Concentrate	80.12 ± 0.03	36.10 ± 0.06	23.65 ± 0.01

Conclusion

The results obtained in this study demonstrated that alumina hollow fibers can retain Congo red dye from aqueous solutions. Therefore, this work represents a viable alternative for industrial effluent treatment and water purification for domestic consumption.

References

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