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Elaboration of Ceramic Membranes for the Removal of Chromium Heavy Metal from Aqueous Solutions

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ABSTRACT

The development of various industries has produced a substantial quantity of liquid waste. Wastewater often contains harmful heavy metals that are detrimental to humans, animals, environmental organisms, and plants. Therefore, waste processing is an urgent task to restrict or, at the very least, reduce its negative impact. Chromium is commonly used in metal part plating, cooling-water towers, corrosion protection, and as a scale inhibitor. This research aims to develop and characterize ceramic membranes for the treatment of wastewater containing chromium in its Cr(III) state. Abundant local raw clays allow for the production of low-cost ceramic membranes. In this study, membranes have been prepared using a casting technique with these local raw materials. Characterization of the prepared tubular membranes was performed using XRD, SEM, and a water permeability and filtration plant. The obtained retention rate is 82%. Such a high value demonstrates the effectiveness of these membranes in filtering Cr(III) ions..

Keywords: Clay, Membrane, Ultrafiltration, Pre-nanofiltration, Permeability, Zeta potential.

1 Introduction

Separation processes are extensively employed in the industry, especially when chemical conversions tend to be incomplete. Among various separation methods, membrane techniques stand out for their cost-effectiveness and high selectivity. The favorable chemical, mechanical, and thermal stability of ceramic membranes, in contrast to organic ones, adds to their appeal. These properties position ceramic membranes as compelling candidates for separation processes. Micro-Filtration (MF) and Ultra-Filtration (UF) are commonly utilized to eliminate particles, microorganisms, and colloidal materials from suspensions. Ceramic membranes typically exhibit an asymmetrical structure comprising a porous support and an active membrane layer. In this study, we developed a membrane using local clay deposited on ceramic supports, and a tubular form of an ultrafiltration or pre-nanofiltration process plant was tested. As an application of these membranes, the filtration of chromium (III) ions is elucidated, considering the significant importance of removing these ions from the environment and industrial wastewaters [1].

2 Experimental

To prepare the membrane supports, a plastic paste is formulated with a mixture of quartz sand (SiO_2) weighing 70g, Dolomite ($CaCO_3.MgCO_3$) weighing 30g, and other organic additives, including 3g of amijel derived from methylcellulose and 3g of methocel derived from starch. The tubular support was created using the extrusion technique. After drying at room temperature for 24 hours, the supports were sintered at 1350°C for 1 hour. Figure 1 displays the microstructure of the support.

The main components of the clay used to form the top layer of the membrane are silica (45.90%) and alumina (37.49%). The organic additive used was HEC (Hydroxyethyl cellulose). Four grams of clay were added to distilled water, and the resulting mixture was thoroughly stirred at room temperature. The second step involved adding 30% by weight of the HEC solution as a binder and plasticizer. The resulting solution was then poured into the tube for a specified time. The tube was subsequently emptied of the solution and dried for 24 hours at room temperature. The final step involves the heat treatment of the tubes in a furnace at specific times and temperatures. The membrane was sintered at 570°C for 1 hour. Characterizations of

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the prepared tubular membranes were conducted using XRD, MIP, SEM, and a water permeability plant. Successively diluted solutions were prepared from the compound (Cr_2Cl_6, $6H_2O$) and distilled water. Absorbance (%) was measured using a UV-visible spectrometer.

3 Results and Discussion

The measured permeability coefficient of the support is about 24760 $Lm^{-2}h^{-1}bar^{-1}$, as could be seen from Figure 2. This value reflects the goodness of the support for use in membrane applications. The mean pore radius of the membrane is about 10 nm, and the value of the permeability coefficient is 98 $Lm^{-2}h^{-1}bar^{-1}$, clearly indicating the possibility of using this membrane in microfiltration, ultrafiltration, and/or as pre-nanofiltration processes.
The results of chromium Cr(III) filtration obtained for different pressures show that retention gradually increases to a constant value. This value is on the order of 82%. Such a high value demonstrates the appropriate efficiency of these membranes in filtering Cr(III) ions.
To measure the Zeta potential, the same experimental plant used in filtration experiments was employed. However, a small change to the cell comprising the tubular membrane must be made to allow two platinum electrodes to be arranged. The Zeta potential could then be calculated by the slope of this curve, equal to -0.052 V. The surface charge density according to the Gouy-Chapman theory could be calculated as -6.67 x 10^{-2} C/m^2. The electrostatic interaction between the membrane surface charge and ions of the solute represents one of the mechanisms that could explain the rejection behaviour of ions by ceramic membranes. The difference in ion concentrations between the membrane and bulk solution engenders an electrical potential called the Donnan potential. This potential repels ions that have the same charge sign as the membrane from passing through it [2].

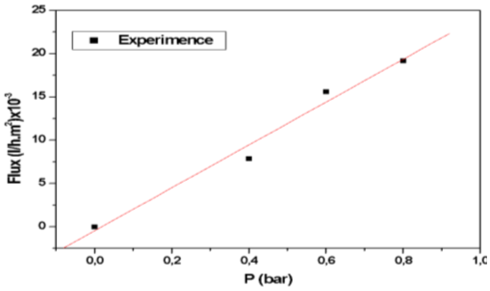

Figure 2: Variation of flux versus the pressure for the membrane support.

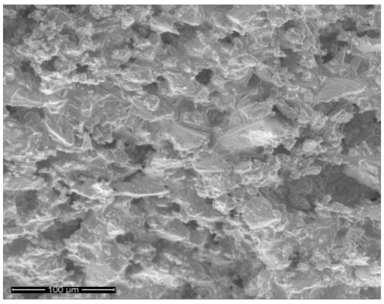

Figure 1: SEM micrograph of the membrane support sample sintered at 1350 °C for 1h.

4 Conclusions

In this work, we have developed a ceramic membrane using local clay as a low-cost raw material. The membrane was obtained through the slip casting process. We aimed to use this membrane to filter solutions containing trivalent chromium ions, which constitute waste in various industries, particularly the mechanical industry. The obtained results are very encouraging; with a high percentage of retention found experimentally (82%). Finally, we recommend using these membranes in water treatments to remove ionic species from pre-treated industrial wastewaters, offering the possibility of being incorporated as a co-process alongside other methods, such as nanofiltration.

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