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Preparation of Ultrafiltration Ceramic Membrane Using Silica Nanopowder

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ABSTRACT

In this work, silica nanopowder was used as starting material for the preparation of an ultrafiltration (UF) membrane. The choice of these materials was based on their favorable physical properties, high thermal and chemical stability. Additionally, the silica membrane was prepared on a multilayers ceramic support (macro-porous support and interlayers) using a slip casting method from the silica powder suspension. After that, this membrane was dried at room temperature and then it was sintered at 450 °C. The resulting silica membrane showed good structural properties, with a thickness of $\approx 15 \mu\text{m}$ and an average pore size (APS) of about 30 nm. Furthermore, the membrane was tested for various applications, revealing a water permeability value of approximately 450 l/(h.m².bar), a high dextran retention rate (75%) and effective removal of heavy metals (approximately 92%). Finally, we can conclude that those significant properties enable the use of this membrane for water treatment and in the field of ultrafiltration.

Keywords: ceramic membranes, microfiltration, silica, permeability.

1 Introduction

Ceramic membranes have been prepared from several materials, such as alumina, zirconia and silica. Because of its separation efficiency, silica membranes have a great importance in many industrial applications [1, 2]. The preparation of macroporous ceramic membranes from natural silica powder is usually possible with no major difficulties. In contrast, the preparation of mesoporous membranes from this natural material is very difficult due to the large particle size [2, 3]. For this reason, many papers have been published on the use of novel methods for the preparation of mesoporous membranes from silica nanopowder [3, 4], where the structural membrane properties can be controlled according to the powder characteristics [4]. This study aimed to prepare and characterize mesoporous membranes with favorable properties and enhanced separation efficiency, using silica nanopowder. The membranes were utilized for both ultrafiltration and the removal of heavy metals.

2 Experimental

A silica membrane was prepared on a multilayer ceramic membrane support, consisting of a macroporous tubular base and two intermediate layers. The macroporous support was fabricated using natural kaolin (TEX) and calcium carbonates (CC). Initially, the first intermediate layer, made from natural kaolin (TEX), was applied to the macroporous support [5]. Subsequently, the resulting membrane served as a support for the second intermediate layer which was prepared from natural kaolin (DD2). Silica powder served as the starting material to prepare the silica top layer. The silica suspension solution was prepared by mixing 3 wt.% of silica powder with 70 wt.% of distilled water, followed by the addition of 27 wt.% of hydroxyethyl cellulose. Both membranes (DD2 and silica) were prepared using the slip casting method, similar to the TEX membrane [5]. The tubular multilayer support was then evacuated, and the silica membrane underwent a 24-hour drying process at room temperature. Subsequently, the membrane was sintered at 450 °C for 1 hour, with a heating rate of approximately 1 °C/min. For tangential filtration testing, dextran



rejection and heavy metals removal using the silica membrane, a home-made laboratory plant was employed. The tests were conducted at room temperature, and the working pressure was regulated using an air gas source. Permeability tests were carried out using distilled water.

3 Results and Discussion

The SEM micrograph structure of the silica membrane shows a good adhesion between the silica top layer and the interlayer support in the cross-section. It can be observed that the membrane has a uniformly thin thickness of approximately 15 μm (Figure 1A). Additionally, these images reveal a homogeneous surface without any defects or microcracks (Figure 1B). Furthermore, it is noted that the membrane exhibits a narrow, uniform pore size distribution ranging from 10 to 75 nm, with an average pore size (APS) of 30 nm. These results suggest that the membrane is suitable for use in the ultrafiltration (UF) range (Figure 1C).

The variation of water flows through the membrane given as a function of time and of a mean applied pressure was measured (Figure 1D). The results indicate that the water flows increased with the increasing of the applied pressure and a stable flux was obtained after few minutes, when the average water permeability is about 300 $\text{l/h.m}^2\text{.bar}$. This relatively low permeability value may be attributed to the small pores of the membrane. In the rejection test, the dextran powder (molecular weight about 250,000 g/mol) was used to prepare of the dextran solution (1 g/l). The obtained results indicated that the dextran rejection rate from silica membrane is about 75%. To assess the efficiency of the silica membrane in removing heavy metals, a water sample was filtered. A higher removal rate was observed for all tested heavy metals, with 92% for Cd, 78% for Zn, 76% for Fe, and 75% for Pb.

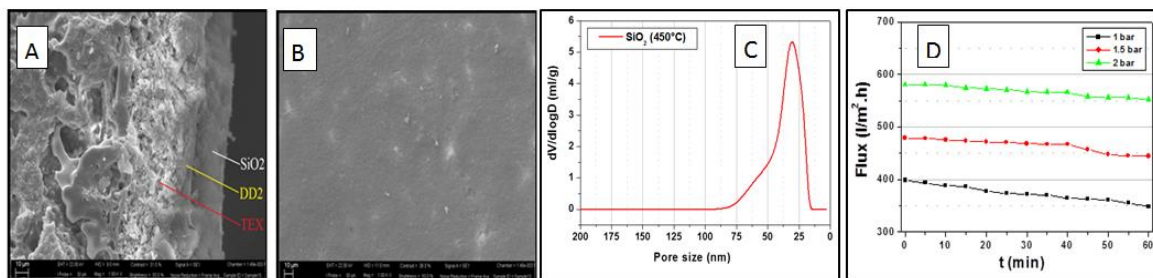


Figure 1: Some silica membrane characteristics sintered at 450°C for 1h, A: SEM micrographs of cross-section, B: surface, C: Pore size distribution, D: Water flux versus times at 3 working pressures.

4 Conclusion

The ultrafiltration silica membrane was prepared from silica nanopowder; this membrane was deposited on a ceramic tubular multilayer support. The prepared membrane has an APS value of around 30 nm and an average permeability for distilled water of approximately 300 $\text{l/h.m}^2\text{.bar}$. Furthermore, this membrane exhibits a higher ability for dextran rejection and heavy metal removal. In conclusion, we can assert that this silica membrane can be used in the field of ultrafiltration and for industrial applications, particularly in the elimination of toxic metals from water.

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