Journal of Membrane Science 368 (2011) 34–40

Contents lists available at ScienceDirect

Journal of Membrane Science

journal homepage: www.elsevier.com/locate/memsci

Internal and surface structure characterization of cellulose triacetate hollow-fiber dialysis membranes

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ARTICLE INFO

Article history:
Received 4 August 2010
Received in revised form 22 October 2010
Accepted 2 November 2010
Available online 9 November 2010

Keywords:
Cellulose triacetate
Hollow-fiber dialysis membrane
Structure characterization
AFM (atomic force microscopy)
Pore diffusion model

ABSTRACT

A cellulose triacetate (CTA) dialysis membrane is generally regarded as a homogeneous membrane. The objective of the present study was to characterize the internal structure of CTA dialysis membranes. We used FB-150E, FB-150F, and FB-150UH CTA hollow-fiber membrane dialyzers. The pore-size distribution and porosity of the CTA membrane surfaces were calculated from surface image data obtained by using atomic force microscopy (AFM). The internal porosity of the CTA membranes was measured by weight analysis. Further, the pore diameter of the CTA membranes was calculated from data on pure-water permeability and diffusive permeability using a pore diffusion model. The pore diameters on the inner surface of the CTA membranes were much greater than those on the outer surface. The surface porosity determined using AFM was much lesser than the internal porosity determined using weight analysis. The pore diameters on the inner and outer surfaces of the CTA membranes determined using AFM were much lesser than pore diameter calculated on the basis of the permeability data. We conclude that the CTA dialysis membrane, which is generally regarded as a homogeneous membrane, is actually a multilayer membrane. The CTA dialysis membrane has tight layers at the inner and outer surfaces, and has a loose layer inside the membrane.

1. Introduction

Patients with severe chronic renal failure (CRF) are unable to urinate, which leads to the accumulation of uremic toxins in the patients' bodies. Unless such patients are treated by blood purification, they die of uremia immediately [1]. Hemodialysis is a representative treatment of blood purification, in which uremic toxins are removed by indirect contact between the patients' blood and dialysis fluid via the dialysis membrane in a hemodialyzer [2]. The diffusive permeability of dialysis membranes depends on the membrane structure [3–7]. Various mathematical models have been proposed to elucidate the mechanism of diffusive permeability through dialysis membranes [8–11]. The tortuous capillary pore diffusion model is a representative mathematical model of hemodialysis membranes [3–5,12,13]. Clinically used dialysis membranes have pores of a variety of sizes, divergences, and dead ends [13]. Structure characterization of dialysis membranes is needed for the development of a novel solute permeation model that will be useful for manufacturing dialysis membranes with high diffusive permeability.

Dialysis membranes are made from various materials such as cellulose triacetate (CTA), polysulfone (PSf), and polyethersulfone (PES) [14–16]. CTA dialysis membranes have a homogeneous structure, whereas PSf and PES dialysis membranes have asymmetrical structures [16–18]. A homogeneous membrane has a thick separation layer, while an asymmetrical membrane is composed of a thin separation layer (a skin layer) and a supporting layer. In order to obtain higher diffusive permeability, a thinner separation layer is needed. The objective of the present study was to characterize the internal structure of CTA dialysis membranes by using atomic force microscopy (AFM) and transmission electron microscopy (TEM), and by performing membrane permeability measurements.

2. Materials and methods

2.1. Materials

We used FB-150E, FB-150F and FB-150UH (Nipro, Osaka) of CTA hollow-fiber membrane dialyzers. The technical data on these dialyzers are shown in Table 1. The dialyzers were washed by feeding reverse osmosis (RO) water (conductivity <2 μm/s) at 100 mL/min for 20 min.

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doi:10.1016/j.memsci.2010.11.008

Table 1
Technical data on CTA hollow-fiber membrane dialyzers.

Dialyzer	Manufacturer	Membrane area [m^2]	Inner diameter [μm]	Membrane thickness [μm]	Sterilization	Membrane condition	UFR [$mL\,h^{-1}\,mmHg^{-1}$][a]
FB-150E							20.5
FB-150F	Nipro	1.5	200	15	γ-ray	Dry	37.1
FB-150UH							50.1

[a] Ultrafiltration rate (UFR): Q_B = 200 mL/min, TMP = 100 mmHg.

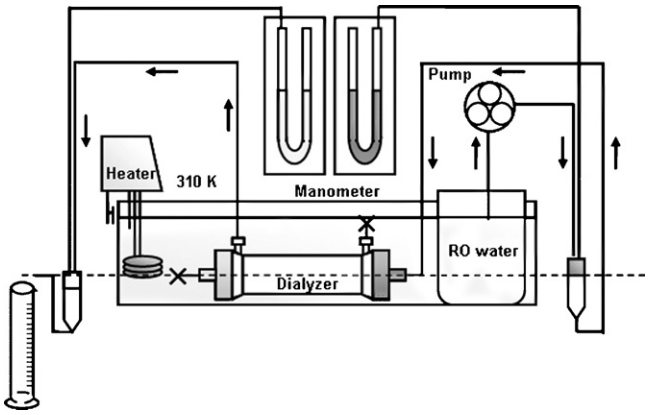

Fig. 1. Experimental apparatus for measurement of pure-water permeability.

2.2. Structure characterization of the wet dialysis membrane surface

Three-dimensional images of the inner and outer membrane surfaces were obtained using the SPM-9600 scanning probe microscope (Shimadzu, Kyoto). After washing with RO water, CTA membranes were taken out from the dialyzers and were stored in RO water prior to AFM observation. A 5-mm long CTA membrane was fixed to a micro Petri dish by using a double-faced tape, and was used as a sample for observing the outer surface. Then, the fixed hollow-fiber membrane was longitudinally cut open to expose its inner surface. The cut edge was pressed with tweezers in order to fix the opened sample onto the micro Petri dish. This piece was used as a sample for observing the inner surface. The micro Petri dish was then filled with RO water. These surfaces in RO water were observed using the AFM contact mode. The observation area of the inner surface was 2 μm × 2 μm, and that of the outer surface was 1 μm × 1 μm. We used a 100-μm tip of an OMCL-TR400PSA probe (Olympus, Tokyo) for AFM observations. Furthermore, the

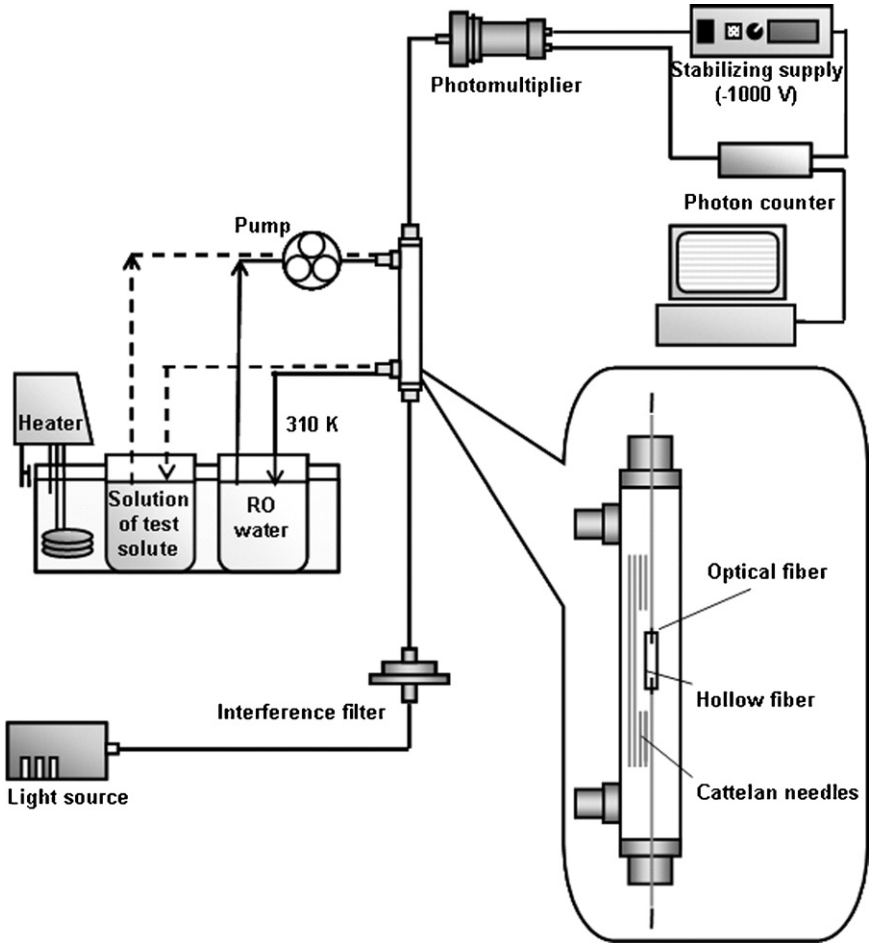

Fig. 2. Experimental apparatus for measurement of diffusive permeability.