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Characterization of a macro porous polymer membrane at micron-scale by Confocal-Laser-Scanning Microscopy and 3D image analysis

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Abstract

Due to the structural complexity of phase inversion macroporous polymer membranes there is a general need for characterization methods on the pore size scale of such membranes. Structure characteristics like pore size distribution, porosity, pore size gradient and the specific surface area often have an impact on the requested performance of such membranes in their field of usage. Here, a commercially available, symmetric, phase inversion nitrocellulose membrane, typically applied in lateral flow immunoassays in the field of in-vitro diagnostics, is investigated. However, commonly used methods for the determination of these characteristics are either cumulative methods, not being able to resolve a 3D pore structure on a local level, or are limited in their ability to reproducibly quantify pore size characteristics. The proposed membrane characterization method uses confocal laser scanning microscopy (CLSM) images combined with computer based image analysis to derive a complete 3D representation of the membrane structure with sufficient resolution and a quantitative characterization thereof. In order to extract quantifiable structural information, the CLSM derived images are binarized using a suitable threshold to match experimental values for porosity. Afterwards a signed distance function is calculated in the 3D structure measuring the smallest distances between pore boundaries followed by a medial axis marking the center of the signed distance function. Structure characteristics like pore size distribution, porosity and specific surface area of the membrane can be determined on a local level. Furthermore, using Stokes equation, the permeability of the membrane is calculated to support the 3D representation obtained by CLSM and the structure characteristics determined by computer based image analysis. Pore size distribution and permeability derived by image analysis show very good agreement with experimental values for the membrane.

Keywords: CLSM, 3D image analysis, porous polymer membrane, diagnostic membrane, membrane characterization

1. Introduction

Commonly used methods for the pore structure characterization of macro porous membranes, like e.g. permeability, capillary flow porometry [1] [2] [3] [4], BET-analysis [5] or Bubble Point measurements [6] [7] produce integral structure parameters that do not give locally resolved information. Although this information is quite important as it often correlates with the performance of the membrane, local structure information, especially along the thickness of the membrane, can be very helpful for the full consideration of this performance. Scanning electron microscopy (SEM) and CLSM image analysis of differently prepared membrane samples have been used to generate locally resolved structural information [8] [9] [10], however, due to the 2D character of SEM imaging techniques and the reported 2D CLSM images, where only a single optical section was recorded, a quantitative evaluation of