

Article

# Innovative Poly (Vinylidene Fluoride) (PVDF) Electrospun Nanofiber Membrane Preparation Using DMSO as a Low Toxicity Solvent

Francesca Russo <sup>1,2</sup>, Claudia Ursino <sup>1</sup>, Elisa Avruscio <sup>1</sup>, Giovanni Desiderio <sup>3</sup>, Andrea Perrone <sup>4</sup>, Sergio Santoro <sup>5</sup>, Francesco Galiano <sup>1</sup> and Alberto Figoli <sup>1,\*</sup>

<sup>1</sup> Institute on Membrane Technology (ITM-CNR), Via Pietro Bucci, Cubo 17/C, 87036 Rende (CS), Italy; f.russo@itm.cnr.it (F.S.); c.ursino@itm.cnr.it (C.U.); elisa.avruscio@gmail.com (E.A.); f.galiano@itm.cnr.it (F.G.)

<sup>2</sup> Laboratory of Industrial and Synthetic Organic Chemistry (LISOC), Department of Chemistry and Chemical Technology, University of Calabria, via P. Bucci 12/C, 87036 Rende (CS), Italy

<sup>3</sup> CNR/Nanotec c/o Dipartimento di Fisica, Università della Calabria 87036 Rende (CS), Italy; giovanni.desiderio@fis.unical.it

<sup>4</sup> DeltaE srl, C/o Università della Calabria, Via Pietro Bucci cubo 31D, Arcavacata di Rende, 87036 Rende (CS), Italy; info@deltaeonline.com

<sup>5</sup> Department of Environmental Engineering (DIAM), Università della Calabria, Via Pietro Bucci, Cubo 44/A, 87036 Rende (CS), Italy; sergio.santoro@unical.it

\* Correspondence: a.figoli@itm.cnr.it; Tel.: +39-0984-49-2027

Received: 20 January 2020; Accepted: 22 February 2020; Published: 26 February 2020

**Abstract:** Electrospinning is an emerging technique for the preparation of electrospun fiber membranes (ENMs), and a very promising one on the basis of the high-yield and the scalability of the process according to a process intensification strategy. Most of the research reported in the literature has been focused on the preparation of poly (vinylidene fluoride) (PVDF) ENMs by using N,N- dimethylformamide (DMF) as a solvent, which is considered a mutagenic and cancerogenic substance. Hence, the possibility of using alternative solvents represents an interesting approach to investigate. In this work, we explored the use of dimethyl sulfoxide (DMSO) as a low toxicity solvent in a mixture with acetone for the preparation of PVDF-ENMs. As a first step, a solubility study of the polymer, PVDF 6012 Solef®, in several DMSO/acetone mixtures was carried out, and then, different operating conditions (e.g., applied voltage and needle to collector plate distance) for the successful electrospinning of the ENMs were evaluated. The study provided evidence of the crucial role of solution conductivity in the electrospinning phase and the thermal post-treatment. The prepared ENMs were characterized by evaluating the morphology (by SEM), pore-size, porosity, surface properties, and performance in terms of water permeability. The obtained results showed the possibility of producing ENMs in a more sustainable way, with a pore size in the range of 0.2–0.8  $\mu\text{m}$ , high porosity (above 80%), and water flux in the range of 11.000–38.000 L/m<sup>2</sup>·h·bar.

**Keywords:** DMSO; low toxic solvent; electrospinning; electrospun fiber membranes (ENMs); water treatment; membrane preparation

## 1. Introduction

Membrane technology plays a key role in all those processes where water treatment is required, e.g., desalination and wastewater treatment. Membrane processes, in fact, include several separation techniques, such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), membrane distillation (MD), pervaporation (PV), etc. Membrane processes are widely recognized for their numerous advantages, including low energy consumption, relatively small