Piezoelectric Nanofiber Membranes for Fouling Control in Membrane Separation Processes

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Abstract: Electrospinning was used to fabricate nanofiber membranes with piezoelectric potential as a novel fouling control approach for membrane-based water treatment processes. Electrospinning parameters were systematically varied to optimize the membrane's piezoelectric characteristics. In addition, several solvents were tested to elucidate differences in piezoelectric characteristics, morphology, and hydrophobicity induced by solvent properties. Preliminary filtration testing evaluated performance of the electrospun membranes compared to commercial membranes and the efficacy of piezoelectric fouling control during synthetic biofouling.

Membrane separation processes are an essential technology in advancing water reuse. However, membrane fouling and associated energy demands for fouling control remain a major barrier to full-scale implementation. In response to these concerns, novel membrane materials and/or fouling mitigation strategies need to be explored to improve the environmental and economic efficiency of water reuse. Piezoelectric polymers are one option that have been gaining interest as a membrane material due to their ability to convert electrical energy to mechanical energy as a vibrational response. Harnessing this material's unique property within membranes subjected to high fouling environments could significantly reduce energy demands for fouling control.

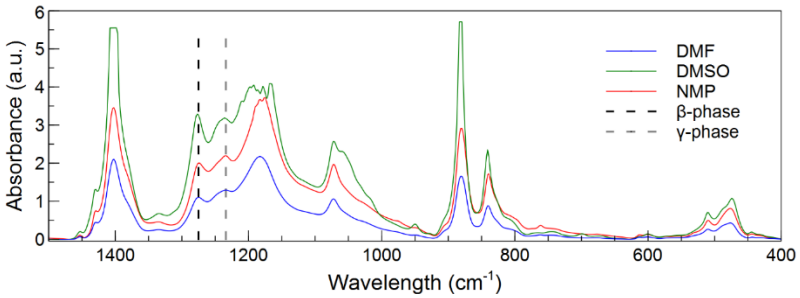


Figure 1. FTIR spectrum of membrane samples with three different formulations using DMF, DMSO, and NMP as solvents. The two dashed lines mark the wavelengths indicating the presence of β-phase and γ-phase, the electrically active crystalline phases of PVDF.

Polyvinylidene fluoride (PVDF) is a common polymer for conventional flat-sheet membranes that also has piezoelectric potential, particularly when electrospinning is used to generate nanofiber membranes. Three solvents, dimethylformamide (DMF), dimethylsulfoxide (DMSO), and NMP were tested to elucidate the solvent's effect on the electrospun membranes' properties and filtration performance. Acetone was used as a co-solvent to improve fiber formation and to further maximize piezoelectric properties. Piezoelectric properties in the fabricated membranes were confirmed using Fourier transform infrared spectroscopy (**Figure 1**). SEM imaging was used to characterize differences in membrane morphology and nanofiber structure between the different solvent mixtures (**Figure 2**).

Membrane performance was evaluated by continuously filtering a solution mimicking biofouling (2 g/L sodium alginate with 1 mM calcium addition for crosslinkage). Flux and transmembrane pressure (TMP) across the membrane were monitored throughout testing. A customized membrane housing with piezoelectric activation capabilities was used in a submerged configuration to test the electrospun PVDF nanofiber membranes and flat-sheet commercial PVDF microfiltration membranes (Synder Filtration, Vacaville, CA) under two different conditions:

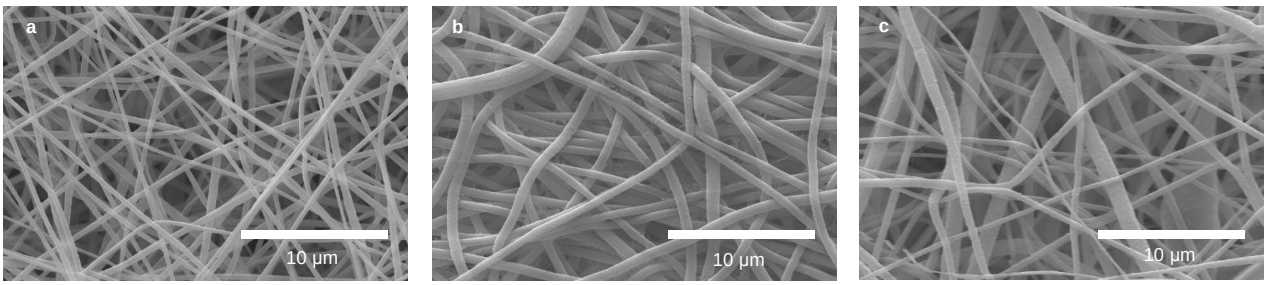


Figure 2. SEM images (4000x) of membranes fabricated using three different solvent. (a) DMF, (b) DMSO, and (c) NMP.

without electrical activation and with electrical activation. Additionally, the electrospun membranes fabricated with different solvents were tested, non-activated and piezoelectrically activated, in the same configuration to determine performance differences among nanofiber membranes with different properties. During the sodium alginate testing, piezoelectrically activated nanofiber membranes demonstrated excellent flux retention while maintaining low TMP compared to non-activated nanofiber membranes, which experienced drastic flux decline and a sharp rise in TMP (**Figure 3**). Both configurations for the electrospun membranes, with and without piezoelectric activation, demonstrated significant performance improvement over conventional flat-sheet membranes. Flux and TMP remained stable for the electrospun membranes up until about 5 hours, where the electrospun membrane without fouling control started to experience flux decline and a sharp rise in TMP. Both of the commercial membrane conditions had flux decrease significantly and TMP rise to 12 psi within the first hour. Performance of membranes fabricated with NMP and DMSO was evaluated under the same conditions as the previous filtration testing, with and without piezoelectric activation. The non-activated DMSO membrane had fouling occur earlier than for the non-activated DMF and NMP membranes. This was expected due to the major differences in membrane morphology observed in the SEM images; the denser fiber structure of the DMSO likely caused a faster fouling rate.

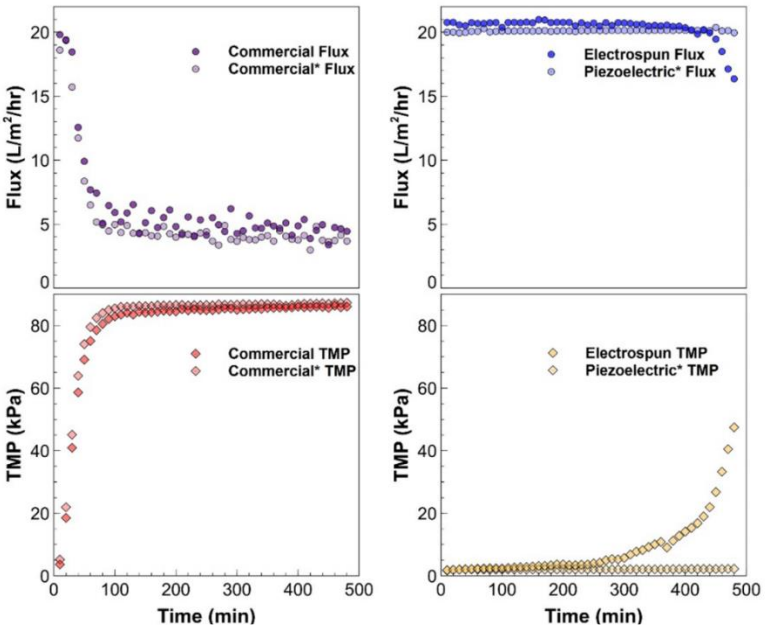


Figure 3. Flux and TMP for (a) commercial membranes and commercial with electric field* and (b) electrospun membranes and piezoelectrically activated electrospun membranes*.

Ongoing work is evaluating performance of the electrospun membranes in a bench-scale anaerobic membrane bioreactor system alongside commercial flat-sheet PVDF membranes treating synthetic domestic wastewater at ambient temperatures. Short- and long-term trials will test the performance of the nanofiber membranes with and without piezoelectric activation. The performance results will be used to determine the fouling mitigation effectiveness of the piezoelectric response under a more realistic biochemical environment prone to severe membrane fouling. Preliminary data from these ongoing experiments will be presented at the NAMS conference.