Egypt. J. Chem. **Vol. 65,** No. SI:13B pp. 735 - 744 (2022)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

The Effect of Microwave Irradiation on Morphological and Mechanical Characteristics of Nano Silica Loaded PVDF Hollow Fiber Membranes

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Abstract

This paper presents a comparative assessment of the effect of microwave (MW) on nano silica loaded Polyvinylidene fluoride (PVDF) hollow fibre membranes (HFMs). Tetraethyl orthosilicate (TEOS) was introduced into the dope and nano silica was introduced during interfacial polymerisation to prepare thin film nanocomposite (TFN) HFMs. Also, exposure to MW irradiation at 55°C for 10 minutes in salt solution has been undertaken. Characterisation using scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), atomic force microscopy (AFM), contact angle (CA), porosity and mechanical properties have been undertaken. Results showed unchanged morphological features after MW exposure. Surface roughness manifested moderate increase upon TEOS or nano silica loading from 37.5 nm to 73.1 nm, where such changes were partially rectified after MW exposure. Effect on mechanical properties showed changes in tensile strength between 1.85 to 2.36 MPa, changes in modulus between 50.5 to 97.2 MPa and changes in elongation at break between 38% to 55.6%. Increased hydrophilicity was observed due to nano silica loading and MW exposure, where CA reached a minimum of 33.6 for nano silica thin film PVDF HFM after MW exposure. Finally, porosity investigations manifested moderate changes of mean pore diameter with minor changes in membrane total porosity. In general, obtained results permit precise control of membrane characteristics by smart combination of nano silica loading and MW exposure, allowing improvement extent of membrane properties and performance for versatile applications.

Keywords: Hollow fibre membranes; mixed matrix membrane; silica nanoparticles; thin-film nanocomposite; Microwave-post-treatment

1. Introduction

Membrane technology is one of the emerging technologies where its importance stems from its applicability in various fields, ranging from water desalination, water treatment, food, energy, biotechnology to environmental and medical applications [1–5]. Hollow fibre membranes (HFMs) have many advantages over other configurations as they have a high packing density as well as the option to work inside-out or outside-in configurations, consequently offering more operation alternatives in different fields[6, 7].

Nanotechnology has critically influenced academic dialogue on membranes characteristics enhancement and manipulation as the properties of nanoparticles (NPs) differ completely from their parent ones[8–10]. There are two main methods to modify membranes with nanoparticles. First, blending the nanoparticles in the membrane during dope preparation to produce a nanocomposite membrane[11, 12], and, second incorporating the nanoparticles on the membrane surface through interfacial polymerization to produce a thin-film nano composite membrane[13–16].

Polyvinylidene fluoride (PVDF) has appealed to researchers in the membranes field owing to its favourable unique properties, such as good mechanical strength, chemically inert, has high thermal stability as well as its easy usage in porous membranes fabrication[4, 6, 17–19]. However, PVDF main drawback is its hydrophobicity and susceptibility to fouling.

Different inorganic materials are used in PVDF membrane modification, including ZnO[20], Al_2O_3 [21, 22], CuO [23, 24], silica and silica/GO [25, 26], TiO_2 [27], Fe_3O_4[28]. Silica is extensively studied due to its known

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Receive Date: 18 June 2022, Revise Date: 14 July 2022, Accept Date: 19 July 2022

DOI: 10.21608/EJCHEM.2022.145444.6338

chemical and physical properties including stability, high surface area, non-toxicity, and reactivity [5]. Liao et al. [29] studied the effect of incorporating Nano and mesoporous SiO_2 types inside the dope, on PVDF/SiO_2 membrane properties. Results demonstrated that mesoporous SiO_2 enhanced mechanical stability, hydrophilicity, and antifouling performance while surface roughness was decreased. Yu et al.[30] prepared PVDF/SiO_2 composite hollow fibre membranes using different loadings of TEOS (0-5 wt%) inside the dope. Mechanical and thermal properties were enhanced at low TEOS contents as well as hydrophilicity and permeability. At higher TEOS contents (>3 wt%) SiO_2 formed networks leading to deterioration of the tested properties. Qianqian Xu et al.[26] prepared PVDF/SiO_2 nanocomposite MF membranes through non-solvent induced phase separation. Results confirmed the ability of SiO_2 nanoparticles addition to enhance hydrophilicity, permeability, and rejection of oil droplets. Arahman et al.[19] modified PVDF membranes via incorporating phospholipid with SiO2 from bagasse. Results demonstrated that all modified membranes showed improved hydrophilicity, five times higher permeability as well as high humic acid rejections 75-90%. Sun et al. [31] synthesized PVA-SiO2 and used it to prepare PVDF UF nanocomposite membrane through phase inversion technique where the mean pore size and porosity improved while contact, angle decreased indicating more hydrophilic surface. Further, pure water flux increased from 60% to 96% and fouling ratio decreased. A thorough review on thin film composite and thin film nanocomposite HFMs using different polymers for several applications in water treatment, pervaporation, and gas/vapor separation has been published by Khulbe et al. [32]. Safarnia et. al.[33] prepared PVDF/polydopamine/silica thin film nanocomposite membranes where the results confirmed the formation of a negatively charged hydrophilic layer as well as diclofenac rejection increased. Abolfazli et al. [34] prepared PS/SiO_2 thin film nanocomposite HFMs where contact angle and surface roughness decreased with increasing SiO_2 content in the thin-film. Moreover, several endeavours have taken place to upgrade membranes properties via post-treatment procedures. Microwave (MW) irradiation technology is one of the attractive fields for membranes post-treatment as they offer a clean non-expensive source. Lee et al. [35], compared two different post-treatment techniques on PES HF membranes. Results confirmed the superiority of MW irradiation post-treatment to hypochlorite post-treatment in altering the HFMs morphological structure and performance regarding UF separation of PEG. Abed et al, [36–38] studied the effect of MW post-treatment on PES/PVP HFMs immersed in water and NaCl solution at different temperatures and time durations. Results confirmed MW irradiation is a powerful clean post-treatment technique capable of tailoring the membranes properties and characteristics according to the needed application. Fazullin et al. [39, 40] studied the effect of MW irradiation, at different time durations in air and ammonium vapor media, on nylon thin film coated membranes. Membrane weight and surface roughness decreased upon MW exposure, while hydrophilicity increased, and oil emulsion specific productivity increased.

Prior studies have thoroughly investigated nanocomposite membranes and thin film nano composite membranes. Thus, assessment of international endeavours on the subject revealed scarce data of the effect of MW exposure on nano silica loaded PVDF HFMs. This paper fills the gap by exploring the effect MW irradiation to PVDF HFMs modified with silica on their morphological and mechanical characteristics. Two different PVDF dopes with and without SiO_2 (TEOS) were prepared in addition to using SiO_2 nanoparticles to produce thin-film nanocomposite membranes. All produced HFMs were MW post-treated in saline solution and the results were thoroughly analysed.

2. Experimental Investigations

2.1 Materials

Polyvinylidene fluoride (PVDF), used as the base polymer, was purchased from Alfa Aeser, Germany. Dimethylacetamide (DMAc) used as the solvent was supplied from Carl-Roth. Polyvinyl pyrrolidone (PVP) of molecular weight (360 k) was acquired from Sigma-Aldrich and used as pore former. Tetraethyl orthosilicate (TEOS) purchased from Acros, Dimethyl formamide and HCl supplied from Carl-Roth were used to prepare TEOS solution. Distilled water (DW) was used as the bore fluid and in coagulation, washing baths and preservation. Isopropyl alcohol was purchased from TEDIA. Silicon (IV) oxide, nano powder (20 nm) purchased from Alfa Aesar used for thin film nanocomposite preparation. Polyamide active layer was prepared using m-phenylene diamine (MPD), Piperazine (PIP) and Trimesoyl chloride (TMC) purchased from Fine Chem Limited and Sigma-Aldrich. Triethylamine (TEA) and Adipoyl chloride were supplied from Fisher Chemicals and Acros, respectively. Cyclohexane used as the organic solvent was purchased from El Nasr Pharmaceutical Chemicals Co. Magnesium chloride ($MgCl_2$) and 0.1% formalin purchased from AL Naser Pharmaceutical chemicals were used to preserve as spun and coated PVDF fibres. Sodium chloride (NaCl) supplied from Chemika was used before MW post-treatment. Kerosene oil was supplied from Misr Petroleum Co. was used for membrane porosity measurements.

2.2 Dope Preparation

PVDF HFMs were prepared by dry-wet phase inversion method through a single orifice spinneret, according to the dope and operating conditions guided

by previous endeavours [41–43] with appropriate modification. PVDF powder was thoroughly dried at 70°C to ensure moisture removal before dope preparation. Two different dope compositions with and without TEOS were prepared to form dopes of about 17-20% PVDF dissolved in DMAc to which PVP was added as pore former. Table 1 presents sample codes. In PVDF-TEOS sample, 1% TEOS solution, prepared according to Lin-Yu et al. [30], was added to the dope mixture. HFMs were prepared from the dope solutions (PVDF/DMAc/PVP/TEOS composition proprietary) by the procedure adopted by Tewfik et al. [43] and presented in earlier work [44][45].This procedure is schematically presented in Figure 1.

The as-spun HFMs were soaked and rinsed thoroughly with DW, then PVDF and PVDF-TEOS samples were soaked in three consecutive isopropanol solutions of different concentrations (4%, 2% and 0.5%) for 20 minutes each, for surface activation.

Table 1: Sample codes of PVDF HFMs

Sample code	Membrane description
PVDF	PVDF/DMAc/PVP
PVDF-TEOS	PVDF/DMAc/PVP/TEOS
PVDF-TFN	PVDF/DMAc/PVP - SiO_2 TFN
PVDF/ MW	PVDF post-treated with MW
PVDF-TEOS/ MW	PVDF-TEOS post-treated with MW
PVDF-TFN/ MW	PVDF-TFN post-treated with MW

2.3 Thin Film Nanocomposite Preparation

PVDF sample was thin-film coated via horizontal dip-coating method. The fibres were thoroughly washed with DW before coating to ensure a clean activated surface ready for coating. The first coating solution, aqueous amine solution, was prepared through the dissolution of 2% MPD, in addition to PIP and TEA in distilled water. The solution was mechanically stirred for 2 hours at 25°C. 0.05% nano silica was added to the amine solution with sonication for 30 minutes at 25°C. The organic solution was prepared by dissolving 0.75% TMC in addition to Adipoyl chloride in Cyclohexane using mechanical stirring of for 1 hour at room temperature followed by 30 minutes sonication. Selected number of fibres of 30 cm length each were fixed onto a wooden frame separated from each other to ensure the formation of an intact coating layer. They were firstly dipped into the first coating of amine/nano silica for 3 minutes in a rectangular Pyrex pan on a shaker. Excess solution was drained from the fibres followed by air drying for 5-10 minutes. The fibres were then immersed in the second coating mixture, TMC organic solution, for 1 min. Fibres were again drained, air dried for 7 minutes followed by drying in an oven at 75 °C for 20 minutes then left to cool down gradually. Finally, the prepared thin film coated nano composite HFMs (PVDF-TFN sample) were stored in 1% $MgCl_2$ solution until further treatment.

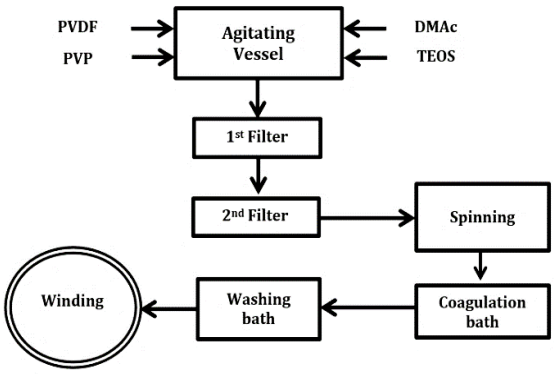

Figure 1: Block flow diagram of PVDF HFMs spinning process

2.4 Microwave Post-treatment

PVDF, PVDF-TEOS and PVDF-TFN samples were post-treated using microwave in a 900 Watts microwave oven (DAEWOO Electron KOR-1A 6A, Korea) equipped with a temperature on-off controller. The MW post-treatment conditions were adopted from Abed et al.[37] (2% NaCl solution at 55°C and 10 minutes). PVDF HFMs were washed thoroughly with DW and soaked in 2% NaCl solution before MW post-treatment in a stress-free orientation. Finally, they were subjected to microwave irradiation for 10 minutes at 55°C.

2.5 Characterization

2.5.1 Membrane Morphology

Morphological structures, dimensions and elemental analysis were obtained using JOEL JCM-6000 Neoscope desktop apparatus at high vacuum of 15 kV. HFMs were cut using a sharp razor, then fixed on the sample holder using carbon tape then gold sputtered to increase the sample conductivity for better images. Also, elemental dispersion spectroscopy (EDS) measurements were carried out using the same device to identify elemental peaks in the sample surface. A minimum of 5 fibers were studied for each sample and their average values were calculated to ensure reproducibility of results.

2.5.2 Surface Roughness

Surface topography and roughness were studied using atomic force microscopy (AFM) model TT-AFM workshop of 1.5micron resolution, equipped with 400X zoom video optical microscope. Samples were fixed on a magnetic plate using a double face tape. Testing was done in the vibrating scan mode with a scan area of 5μm×5μm. "Gwidyyon" software was used to calculate roughness parameters. An average of five samples were tested.

2.5.3 Mechanical Properties

Mechanical properties of HFMs were tested using Tinius Olsen H5kS, a bench top tensile testing machine equipped with a 5N load cell. Testing was done at a gauge length of 100 mm and 50 mm/min jog

speed. Six fibres were tested for each sample and average values obtained.

2.5.4 *Contact Angle (CA)*

Hydrophobicity of the HFMs was tested through measuring their contact angles through manipulating of water drop shape on the samples using the OCA 15EC Contact angle model produced by the company of Data Physics Instrument GmbH. Five different positions were tested for each HFM condition, and their averages were calculated.

2.5.5 Mean Pore Size and Porosity Measurement

Mean pore size of the prepared PVDF HFMs were determined using a device BELSORP max made in Japan. Before measurement, the surface of the sample has been dried and activated at 60 degrees under vacuum (10^{-2} bar). After that, samples were measured under liquid nitrogen temperature as nitrogen gas passed and was adsorbed on the sample surface. The surface area is automatically measured via Brunauer-Emmett-Teller (BET) method.

Porosity of PVDF HFMs was measured using the gravimetric method [46]. HFMs were weighed after drying for 1 hour at 60°C in an oven, then weighed again after soaking in Kerosene oil for 24 hours. Fibers were wiped with filter paper before weighing the wet membrane to remove excess oil then porosity was calculated according to Equation (1):

$$\varepsilon = \frac{\frac{w2-w1}{\rho k}}{\frac{w2-w1}{\rho k}+\frac{w1}{\rho p}} \times 100 \qquad \text{Equation (1)}$$

Where:

w_1: weight of dry membrane (g)

w_2: weight of wet membrane (g)

ρ_k: density of Kersone (0.8 g/cm^3)

ρ_p: density of polymer (PVDF= 1.78 g/cm^3)

3. Results and Discussions

3.1. Membrane Morphology

SEM cross-sectional images are shown in Figure 2. Cross-sections of all PVDF HFMs manifest the successful formation of a characteristic double finger-like structure, confirming inner and outer phase inversion process, with a small dense inter-layer and an outer selective layer. PVDF-TEOS sample demonstrated an increased number and narrower finger-like structures when compared to PVDF sample, which could be attributed to TEOS addition promoting pore formation as well as accelerating the phase separation process. This finding were not in agreement with those of Yu et al. [30] where addition of TEOS (up to 4 wt%) suppressed the finger-like structure and increased the spongy interlayer. This difference could be due to different spinning conditions as well as higher TEOS loading in their work. MW post-treatment maintained the PVDF HFMs morphological structure intact without alteration, which confirms it as a clean non-destructive post-treatment technique which agrees with our previous findings, Abed et al [37], on Polyether sulfone HFMs. Also, thin-film coating of PVDF-TFN sample did not affect the characteristic structure for the as-spun fibres, only causing an acceptable dimensional change due to the thickness of the coating layer

Table 2 presents EDS values of all the prepared and post treated PVDF HFM samples. All EDS results exhibit clear elemental peaks of C, N, O and F, indicating the presence of PVDF, DMAc and PVP in the dope. Moreover, in PVDF-TEOS and PVDF-TFN samples, an evident Si peak supports the presence of SiO_2 in the produced fibres due to TEOS addition in the dope for PVDF-TEOS sample or nano silica in the coating layer for PVDF-TFN samples. It is worth mentioning that Si content in PVDF-TEOS and PVDF-TFN samples was comparable despite the initial loading due to probable leaching of TEOS from the porous as-spun membrane.

3.2. Surface Roughness

Surface 3D images and values, average (Ra) and root mean square (Rms) surface roughness, are shown in Figures 3 and 4, respectively. 3D topographical images show typical peaks and valleys of the surface where alterations were induced due to silica loading and MW exposure. It is worth mentioning that the surface roughness values (Ra) increased to 60.6 nm with 61% for PVDF-TEOS sample compared to PVDF sample (37.54 nm) which agrees with Huang et al. findings, where roughness increased from 15 nm to 66.2 nm [47]. Moreover, PVDF-TFN sample roughness Achieved highest value of 73.09 nm, with an increase of 94.5%, 20.6% as compared to PVDF, PVDF-TEOS samples, respectively. This is in accordance with Yang et al. findings, where the increased roughness from 8.64 nm to 43.1 nm, was attributed to the leaf like morphology formed on the membrane surface due to the polyamide thin-film coating layer as well as nano silica incorporation in PVDF flat sheet membrane [13]. Despite of the comparable silica loading rates of mixed matrix, yet Yang's work focused in 80 nm silica nanoparticles while our work focused on 20 nm nanoparticles.

A consistent decreasing trend in surface roughness was observed for all MW post-treated samples. Percentage decrease reached 60% and 54% for PVDF-TEOS and PVDF-TFN after MW post treatment, respectively. As expected from our previous endeavours, Abed et al. [37], MW decreased the surface roughness due to localized thermal heating effect which would further reduce possible membrane fouling. This explanation is supported by Fazullin et al. [39] associated the decrease of surface roughness upon MW irradiation of nylon thin film flat sheet membranes to the destruction of the defect regions on the membrane surface due to oxidation.

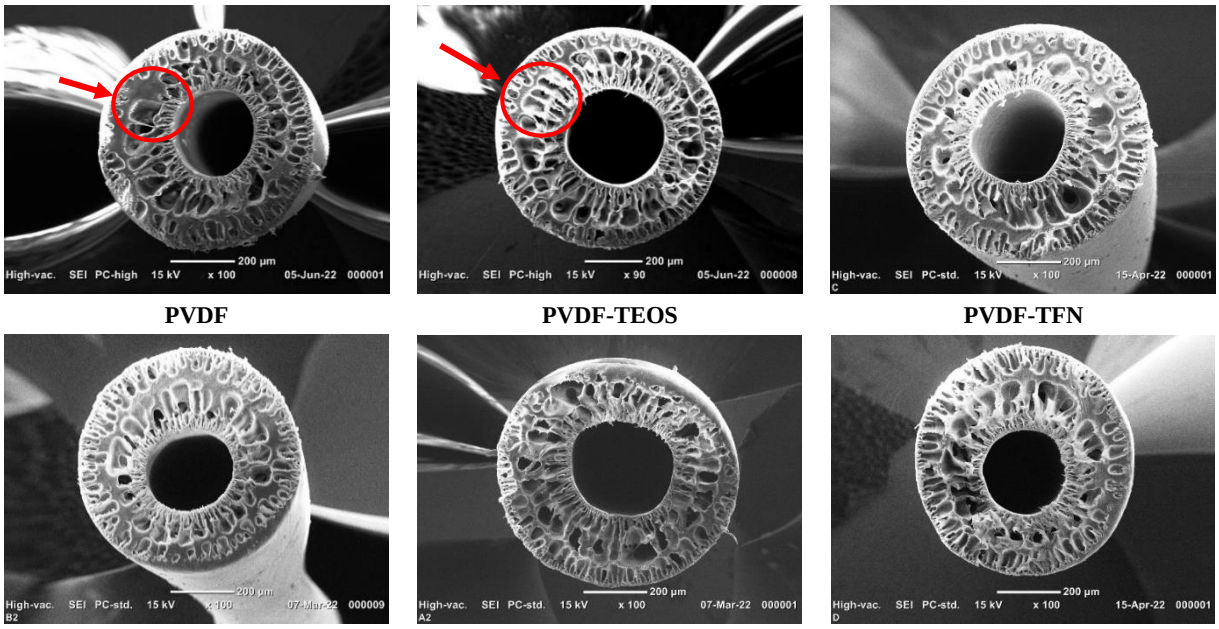

Figure 2: Cross-sectional images of control PVDF, PVDF-TEOS, PVDF-TFN and MW post-treated PVDF membranes

3.3. Mechanical Properties

Table 2: EDS elemental mass % values of control PVDF, PVDF-TEOS, PVDF-TFN and MW post-treated PVDF membranes

Sample	C	N	O	F	Cl	Si
PVDF	35.84	17.51	5.47	41.18		
PVDF/ Mw	34	16	5	44.9	0.4	
PVDF-TEOS	34.4	16.05	6.67	41.55	0.08	0.34
PVDF-TEOS/ Mw	33.5	16.3	6.5	43.5	0.2	0.2
PVDF-TFN	33.85	20.79	18.38	25.98	0.66	0.35
PVDF-TFN/MW	33.73	16.85	8.63	40.65	0.05	0.09

Table 3. Minor changes in elongation at break have been observed due to 1 wt% TEOS incorporation, on the other hand, nano silica loading decreased the elongation at break values from 83.9% to 59% for PVDF-TFN sample. On the other hand, modulus, and tensile strength at break of PVDF-TEOS sample decreased. As for PVDF-TFN sample, modulus decreased from 53.3 MPa to 38 MPa as well as a slight decrease of tensile strength from 2.36 MPa to 2.06 MPa, which is attributed to rigidity of PA thin film

Results of mechanical properties assessment of prepared and post-treated PVDF HFMs are shown in Table 3

layer. A probable explanation is the incorporation of nano defects in the membrane structure due to TEOS or nano silica loading.

Inspections of MW effect on mechanical properties revealed minor to moderate alterations where elongation at break, tensile strength, and modulus decreased for PVDF/MW sample, while it enhanced all mechanical properties for PVDF-TEOS/MW sample which could be due to MW irradiation interaction with -OH groups formed due to silica incorporation, leading to a more relaxed fibre. As for PVDF-TFN/MW sample elongation at break and modulus increased which is related to the fine matrix of nano silica acting as underlying support of the polyamide layer, while elongation at break decreased upon MW exposure. Thus, this phenomena merits additional planned investigations with different loading ratios to come up with the governing mechanisms in future work

Table 2: EDS elemental mass % values of control PVDF, PVDF-TEOS, PVDF-TFN and MW post-treated PVDF membranes

Sample	C	N	O	F	Cl	Si
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PVDF/ Mw	34	16	5	44.9	0.4	
PVDF-TEOS	34.4	16.05	6.67	41.55	0.08	0.34
PVDF-TEOS/ Mw	33.5	16.3	6.5	43.5	0.2	0.2
PVDF-TFN	33.85	20.79	18.38	25.98	0.66	0.35
PVDF-TFN/MW	33.73	16.85	8.63	40.65	0.05	0.09

Table 3: Mechanical properties of control PVDF, PVDF-TEOS, PVDF-TFN and MW post-treated PVDF membranes

Sample	Tensile strength (MPa)	Elongation at break (%)	Modulus (MPa)
PVDF	2.36 ±0.0447	83.9 ±5.8	53.3 ±2.72
PVDF/ MW	2.13±0.05	78.7±12	50.5±7.18
PVDF-TEOS	1.85±0.058	84.5±9.56	38±1.93
PVDF-TEOS/ MW	2.36±0.046	97.2±4.67	40.8±8.73
PVDF-TFN	2.06±0.062	59±11.5	46.7±5.03

PVDF-TFN/ MW	2.12±0.06	50.5±10.5	55.6±5.79

74.4° to 87.8° and from 72.7° to 81.5°, respectively.

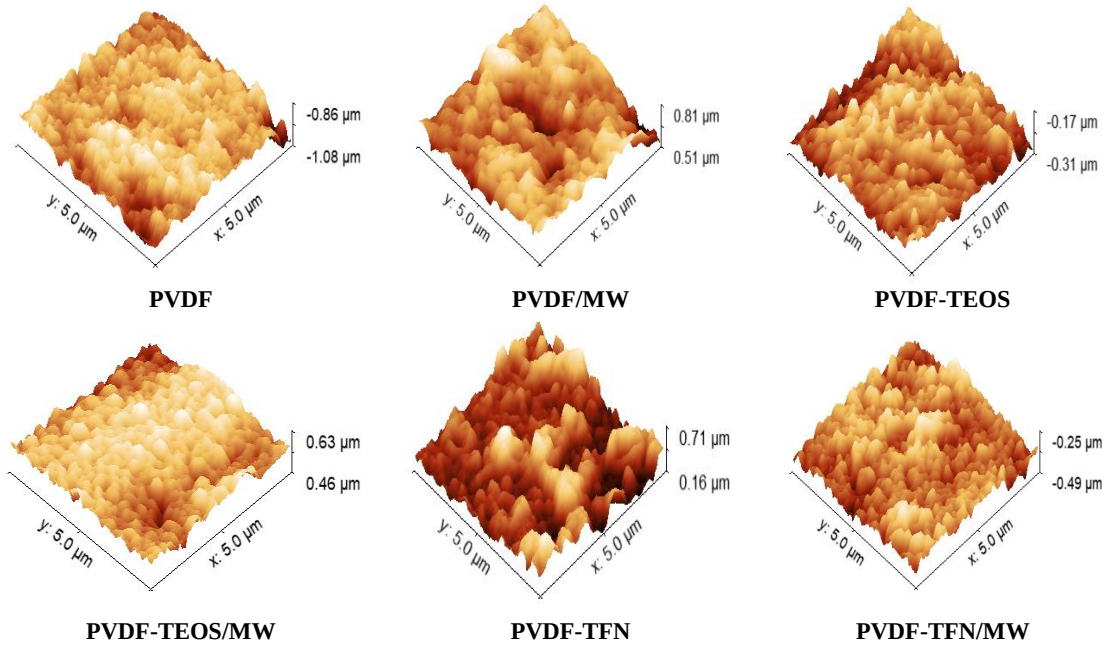

Figure 3: Surface roughness 3D images of control PVDF, PVDF-TEOS, PVDF-TFN and MW post-treated PVDF membranes

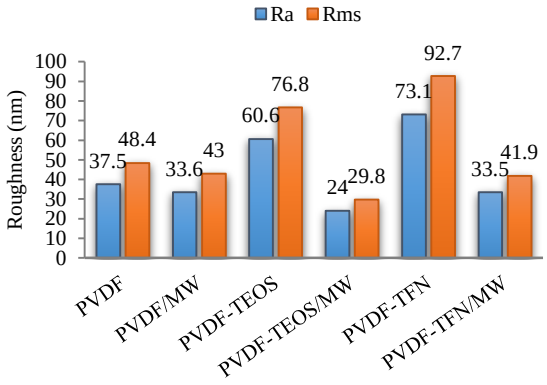

Figure 4: Surface roughness values, average (Ra) and root mean square (Rms), of control PVDF, PVDF-TEOS, PVDF-TFN and MW post-treated PVDF membranes

3.4. Contact Angle

A decreasing trend was observed for the contact angle (CA) for all samples as depicted in Table 4 where, PVDF>PVDF-TEOS>PVDF-TFN samples (74.4°>72.7°>58.7°), indicating higher hydrophilicity owing to the hydrophilic -OH groups introduced by silica incorporation in the dope or thin film improving the interaction between water and the membrane surface which was confirmed by several studies [33, 34, 48–50]. As for MW post-treatment, it is obvious that surface hydrophilicity decreased for PVDF/MW and PVDF-TEOS/MW samples by increasing CA from However, this trend was reversed for PVDF-TFN/MW sample, where CA decreased from 58.7° to 33.6° after MW post-treatment (42.8%) achieving the highest hydrophilic surface. Fazullin et al [39] depicted similar results of increased hydrophilicity by MW post-treatment of nylon thin film coated flat sheet membranes, by decreasing the CA from 130° to 99°.

3.5. Mean Pore Size and Porosity Measurement

Figure 5Table 4 depicts the mean pore size as well as the porosity of the prepared and post-treated PVDF HFMs. Mean pore diameter increased 14% for PVDF-TEOS sample from 10 nm to 11.39 nm. A similar increasing trend was observed by Huang et al. [47], where mean pore size of PVDF/TEOS flat sheet membrane increased from 50 nm to 150 nm. On the other hand, MW post-treatment for PVDF, PVDF-TEOS samples caused a decrease in mean pore diameter (7.12, 8.04 nm). Porosity of all fabricated and post-treated PVDF HFMs in this study was in the range of 86-88.9 %, as shown in Table 4, confirming MW irradiation is a strong post-treatment technique to alter HFMs properties.

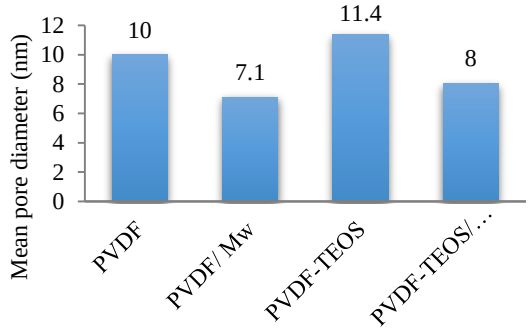

Figure 5: Mean pore diameter of control PVDF, PVDF-TEOS and MW post-treated PVDF membranes

Apparently, the effect of MW is restricted to the main surface while the total porosity was not sacrificed which permits control of membrane selectivity while maintaining the underlying membrane structure.

Table 4: Porosity and contact angle of control PVDF, PVDF-TEOS, PVDF-TFN and MW post-treated PVDF membranes

Sample code	Contact angle	Porosity (%)
PVDF	74.4	87.2
PVDF/ MW	87.8	87
PVDF-TEOS	72.7	88.9
PVDF-TEOS/ MW	81.5	88.8
PVDF-TFN	58.7	85.9
PVDF-TFN/ MW	33.66	86.2

3.6. Implications on membrane system design

Obtained results reveal numerous opportunities for extending applicability for membrane separation processes and improving efficiency of traditional separations. Effect of nano silica loading, and MW exposure provide larger window of opportunity for membrane design especially regarding surface roughness, contact angle, mechanical properties, and porosity characteristics.

4. Conclusions

This paper addresses smart manipulation of HFMs characteristics via combination of nano silica loading and specified MW exposure. Incorporation of 1 wt% TEOS and nano silica has been introduced to membrane dope and interfacial polymerization, respectively. Different measurements including SEM, EDS, AFM, mechanical properties, CA and porosity have been adopted to identify and monitor membrane characteristics. Results demonstrated a maintained morphological structure upon MW exposure and a slight increase in the finger-like structure upon TEOS incorporation. While surface roughness increased due to nano silica loading in the dope and in thin film nanocomposite membrane, reaching a maximum of 73.1 nm for PVDF-TFN sample. MW exposure decreased the surface roughness values due to its probable thermal effects on the surface, with a maximum roughness decreases of 60% for PVDF-TEOS/MW sample. It was confirmed that silica loading inside the dope and during interfacial polymerization increased the PVDF HFMs hydrophilicity with moderate alterations upon MW exposure, showing a minimum CA of 33.6° for PVDF-TFN/MW sample. Mechanical properties decreased slightly due to silica incorporation, while MW exposure imparted moderate alterations showing a maximum tensile strength and elongation at break of 2.36 MPa and 97.2%, respectively, for PVDF-TEOS/MW and maximum modulus of 55.6 MPa for PVDF-TFN/MW. As for porosity, MW exposure decreased mean pore diameter moderately to reach a minimum of 7.12 nm for PVDF/MW sample while not sacrificing membrane total porosity. Obtained results show the capacity of combined nano silica loading and MW exposure to precisely tweak PVDF membranes' characteristics towards achieving higher efficiency of membrane separation for different applications. It is worth mentioning that this paper explored three benefits of MW interventions for silica loaded PVDF HFMs summarized as follows; First, decreased roughness achieved via MW exposure makes the membrane less prone to fouling which makes it more suitable for medical applications. Second, decreased hydrophilicity achieved qualifies the membrane for membrane distillation applications. And finally, stability of porosity profile after MW irradiation enhances membranes for constant flux applications.

5. Acknowledgements

The authors would like to thank the Ministry of International Cooperation for securing funds to initiate and support the Hollow Fibre Membranes Program at the National Research Centre from the Islamic Development Bank and Kuwait fund for Arab Economic Development. This work is funded by Science and Technology Development Fund, STDF, Ministry of Scientific Research, Egypt; Project No. 30280 entitled “Development of a Solar Powered, Zero Liquid Discharge Integrated Desalination Membrane System to Address the Needs for Water of the Mediterranean Region,” within the scope of ERANETMED program ID 2-72-357.

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