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Proceeding Paper

Integration of CO/PES Support Modules for Enhancement of Modified Chitosan-Filtration Membranes †

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Abstract

The impact of plain cotton (CO) and polyester (PES) fabric support modules on the filtration performance of chitosan/silver nanoparticles/graphene oxide (CS/AgNP/GO) was determined in this study. The experimental results revealed that both the CO and PES fabrics can successfully serve as support modules for CS/AgNP/GO composite membranes, increase water permeability, and effectively improve the filtration process. The effectiveness of the membrane separation process depends on molecular interaction between the composite structure and the support materials. Although both fabric- supported modules improved membrane wettability adequately, the CO is more hydrophilic than the PES of approximately the same thickness. This was attributed to higher wettability and capillary pore sizes within the molecular structure of the CO-supported membrane than the PES-supported modified CS composite over the same duration of time, confirming greater adhesive force with improved hydrophilicity. The improved chemical bonding between the CS composite and the support materials resulted in an increase in mechanical properties. The maximum tensile strength of 48.46 MPa was attained by the CO-supported composite, followed by the PES-supported modified CS filtration membrane (43.73 MPa), while the non-fabric-supported membrane exhibited the lowest tensile strength of 37.23 MPa with the highest elongation at break (64.2%).

Keywords: modified-chitosan (MCS); fabric support modules; filtration performance; mechanical properties

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1. Introduction

Waste reduction is paramount to ensuring environmental protection and sustainability. The reuse of fabric materials as support membrane modules to enhance water purification systems could be useful alternative approach to enhance membrane water purification process. Water is necessary for healthy ecosystems, the generation of energy and food, and sustainable development. However, increased water pollution and a decline in water quality, particularly in developing nations, have severe effects on population development, industrialization, and socioeconomic growth [1,2]. The lack of clean drinking water affects one-third of the world's population; if not controlled by 2030, this percentage is anticipated to reach two-thirds [3]. Approximately two million people each year die from waterborne illnesses spread by contaminated water sources or sewage because over a billion people lack access to safe drinking water and proper sanitation.

Therefore, it is urgently necessary to improve the performance of polymer membranes by using suitable accessible support materials. Chitosan (CS) is a biopolymer that is non-toxic, biodegradable, and natural, making it an eco-friendly alternative to synthetic materials. The principal use of CS in water treatment is to remove dispersed particles and turbidity as a coagulant/flocculant, as well as to function as an adsorbent for heavy metals, dyes, and organic contaminants [4,5]. Positively charged functional amide groups in CS allow for efficient binding to negatively charged contaminants. Furthermore, structural alterations, such as the production of nanocomposites, increase its adsorption capacity, selectivity, and overall efficacy in a wide range of activities, including membrane filtration and bioremediation. In order to increase the tensile strength of modified CS separation membranes under increasing stress, fabric materials may be used as support membrane modules. Fabric materials are abundantly available and constitute significant resource waste; the quantity of discarded fabric materials used in textiles is seen as a critical problem for waste management [6]. Fabric wastes do not easily degrade in the outdoor environment over a long period of time as they accumulate in garbage dump sites. The utilization of fabrics like polyester (PES) and cotton (CO) may be viable alternatives support materials to improve polymer membrane functionality. Therefore, this study investigated the effects of CO and PES support materials to enhance filtration performance of modified-chitosan (MCS) membranes.

2. Synthesis of MCS Composite

Silver nanoparticles/graphene oxide (AgNP-GO) nanocomposite was prepared by directly reducing silver nitrate ($AgNO_3$) with trisodium citrate in a solution of graphene oxide (GO) by adopting standard procedures. The CS/AgNP/GO (MCS) membrane composite was prepared by the phase inversion method, while PES and CO fabrics served as membrane supports. Briefly, a gram of CS was dissolved in a 1% acetic acid (HAc) aqueous solution at room temperature, and the mixture was vigorously stirred for 60 min. To neutralize the HAc, 0.5 mL of 2% (*w*/*v*) sodium hydroxide (NaOH) was added to the mixture. The reaction was continuously stirred and allowed to run for 24 h to ensure that air bubbles were completely expelled. 80 mL of CS solution were combined with 0.5 mL of a 10 wt% AgNP-GO aqueous solution after one hour of stirring.

3. Results and Discussion

3.1. Membrane Surface Molecular Interactions

MCS molecular interactions are vital towards understanding the mechanism of surface hydrophilicity of the membrane composite. The chemical structures are shown in Figure 1. The molecular surface structures of MCS and cellulose from cotton could influence their chemical interactions. Cellulose is a linear polymer composed of glucose units linked by beta-1,4-glycosidic bonds, constituting the primary chemical structure of cotton [7].

The presence of highly electronegative oxygen atoms in the composite film is the primary factor facilitating the formation of an additional carbonyl group (C–O) and driving the chemical interaction within the MCS structure [8]. The presence of highly electronegative oxygen atoms on the PES support layer may primarily govern the chemistry of the interaction between the modified CS membrane and the PES support. The presence of an oxide group between the CS interface and the support module may enhance the probability of forming a non-polar covalent bond (O–O) between CS and the polyester structure. The enhanced composite's N-acetyl group of chitosan may facilitate electrostatic attraction between the H-group of chitosan and the O-group of polyester, ensuring membrane integrity throughout the filtration process.

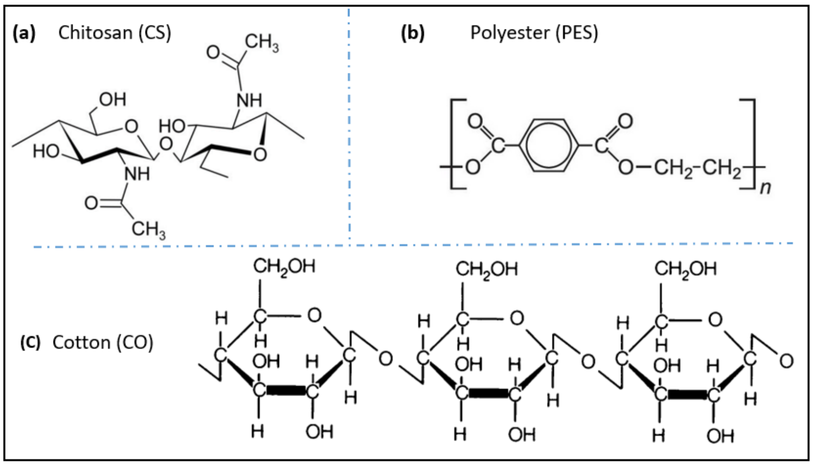

Figure 1. Chemical structures (**a**) CS; (**b**) PES; (**c**) Cotton.

3.2. Permeation Flux Analysis of MCS Composites

CS/AgNP/GO (MCS) composite permeation flux was assessed to evaluate membrane permeation characteristics and the influence of fabric supports on separation efficiency. The addition of CO and PES to MCS composite membranes enhanced water permeation flux. Table 1 illustrates that the permeate flux for all samples exhibited a gradual decline over a 3-h period at a pressure of 0.2 MPa.

Table 1. Permeation flux analysis.

Time (h)	MCS Flux (Lm^{-2} h^{-1})	MCS/CO Flux (Lm^{-2} h^{-1})	MCS/PES Flux (Lm^{-2} h^{-1})
0.5	45.2 ± 1	61.4 ± 1	52.1 ± 2
1.0	40.9 ± 3	54.7 ± 1	46.3 ± 1
1.5	37.4 ± 2	49.2 ± 3	41.6 ± 1
2.0	33.3 ± 1	45.8 ± 1	37.1 ± 3
2.5	29.5 ± 3	42.3 ± 4	34.7 ± 1
3.0	27.1 ± 1	40.5 ± 2	32.2 ± 2

The permeation flux performance indicates that the MCS/CO-supported membrane sample achieved the highest water flow rate, with a permeation flux of 61.4 ± 1 Lm^{-2} h^{-1}. This trend was followed by the MCS/PES at 52.1 ± 2 Lm^{-2} h^{-1}, while the MCS demonstrated the lowest flux performance at 45.2 ± 1 Lm^{-2} h^{-1} after 0.5 h. After 3 h of filtration, the general permeation flux decreased significantly across all samples. The flux for MCS/CO decreased to 40.5 ± 2 Lm^{-2} h^{-1}, while MCS/PES and MCS reduced to 32.2 ± 2 Lm^{-2} h^{-1} and 27.1 ± 1 Lm^{-2} h^{-1}, respectively. This decline can be attributed to variations in the physicochemical properties of the fabric materials.

3.3. Morphological Analysis

Surface morphological analysis of PES and CO exhibit significant differences, as illustrated in Figure 2a,b. PES fabric reveals a smoother and more uniform surface structure compared to CO fabric, attributable to inherent differences in fiber composition and manufacturing processes. These variations may influence the quantity and surface characteristics of the MCS matrix on each support layer. The SEM images presented in Figure 2c–e demonstrate distinct structural arrangements of MCS on both support modules.

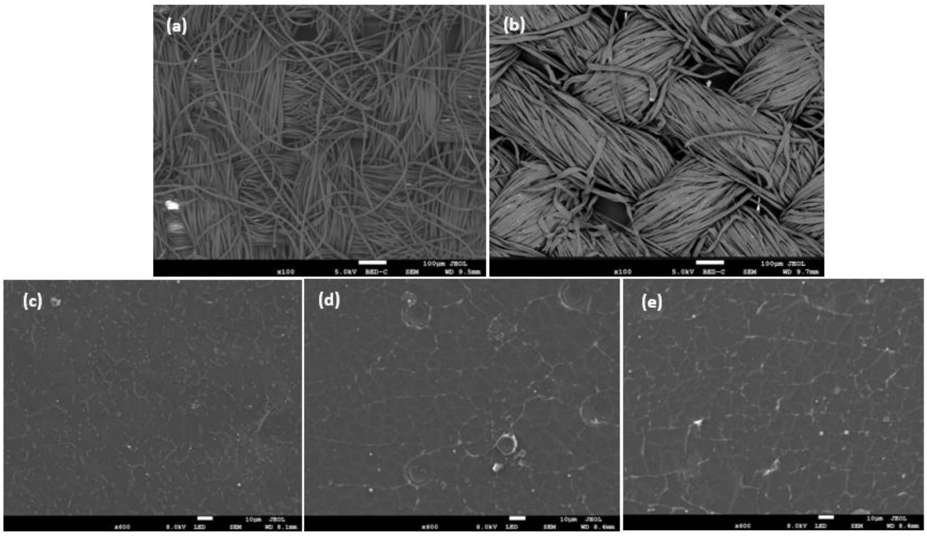

Figure 2. SEM images of (**a**) PES; (**b**) CO; (**c**) MCS; (**d**) MCS-PES; (**e**) MCS-CO.

Figure 2c illustrates the effective dispersion of MCS, with an absence of agglomeration on the membrane surface. Both PES- and CO-supported membranes exhibited wide range of surface pore densities that differed from those of unsupported MCS (Figure 2d,e). The MCS morphology of PES supported membrane (Figure 2d) demonstrated a significant reduction in uneven surfaces and a decrease in surface cracks when compared to the CO-supported MCS membrane sample (Figure 2e), likely due to the presence of expanded loose fibers in the fabric support material. The quantity of MSC on CO support displays a denser layer with increased surface cracks, which could be attributed to its elevated surface porosity and irregular twisted morphology. Also due to the presence of free hydroxyl groups on its surface, CO may engage in hydrogen bonding with the functional groups of modified chitosan. Such bonds may generate sufficient adhesive force through Van der Waals interactions, enhancing chemical bonding between the CS composite and CO support layer, thereby improving the water permeation flow rate.

3.4. Mechanical Properties of MCS Composites

The mechanical properties of different CS-based composite membrane samples are shown in Table 2 and Figure 3. MCS/CO composite membrane sample exhibited the greatest tensile strength at 48.46 ± 1 MPa and yield stress (35.5 ± 2 MPa), while the MCS/PES composite displayed better toughness (27.2 ± 2 kJ·m^{-2}) relative to the other samples.

Table 2. Mechanical properties of the modified chitosan composites.

Sample	Tensile Strength (MPa)	Elongation at Break (%)	Yield Stress (MPa)	Toughness (kJ·m^{-2})
CS	19.14 ± 1	52.7 ± 1	18.2 ± 1	9.2 ± 2
CS/AgNP	23.21 ± 3	54.4 ± 2	22.6 ± 1	12.8 ± 1
CS/GO	28.35 ± 1	52.7 ± 1	24.1 ± 2	13.5 ± 2
MCS	37.23 ± 2	64.2 ± 2	29.3 ± 1	18.3 ± 1
MCS/CO	48.46 ± 1	42.5 ± 1	35.5 ± 2	24.1 ± 1
MCS/PES	43.73 ± 1	44.1 ± 1	32.2 ± 3	27.2 ± 2

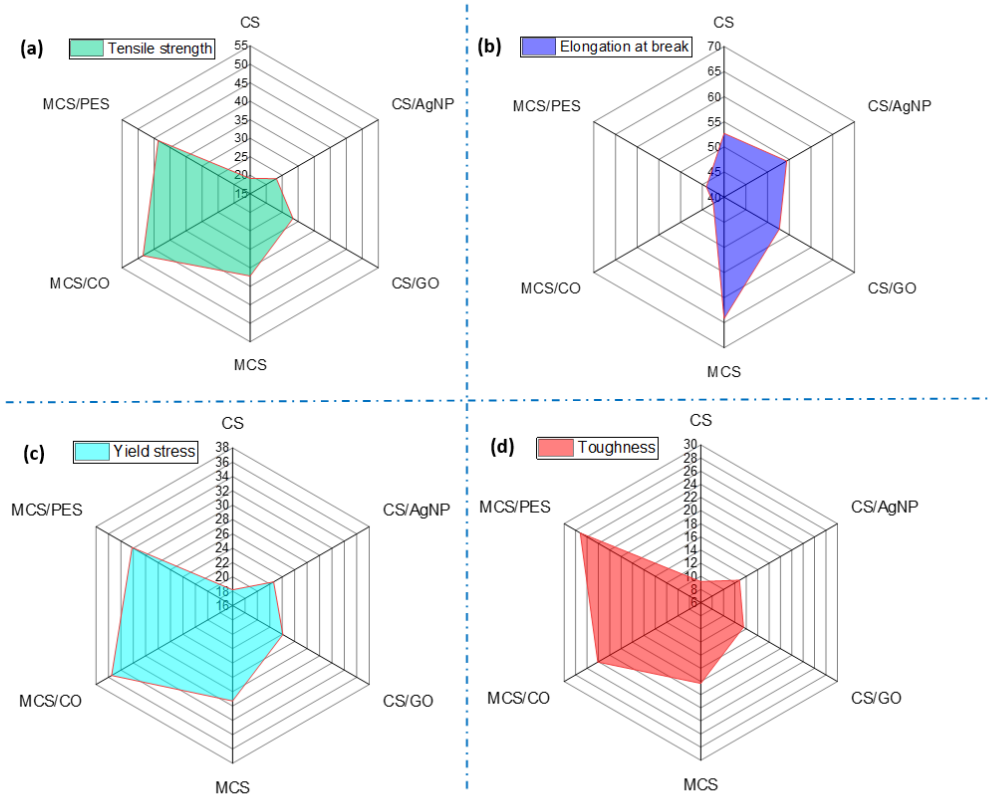

Figure 3. Mechanical characteristics of MCS components.

The compatibility of chitosan monomers with the fiber surface may explain the superior bonding between the MCS composite and the CO fabric support, resulting in increased mechanical characteristics. The CS/AgNP/GO (MCS) exhibited the greatest maximum elongation at break (64.2 ± 2%), due to improved mobility of polymer chains inside the matrix. Conversely, the MCS/CO bond had the minimal elongation upon break (42.5 ± 1%). The strong electrostatic interactions between the MCS composite and the CO fabric support could have resulted in a decrease in the elongation at break of the composite film. The heightened entanglement between the MCS membrane composite and the CO fiber tissues during membrane fabrication may explain the augmented material strength found in the CO-supported membrane sample.

4. Conclusions

The integration of CO and PES support modules enhanced the modified chitosan filtration membrane by significantly improving permeability and mechanical strength without compromising rejection rates. The molecular surface structures of the modified chitosan (MCS) composites and cellulose from CO influenced their chemical interactions, while the presence of an oxide group between the CS interface and PES enhanced the non-polar covalent bond (O–O) between them. Therefore, the utilization of both fabrics could be viable membrane support materials to improve CS polymer membrane functionality despite CO having greater permeability performance than PES.

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