Incorporation of Kappa-Carrageenan as Additive in Improving Characteristics of Nanohybrid Polysulfone/Silver-Graphene Oxide Membranes

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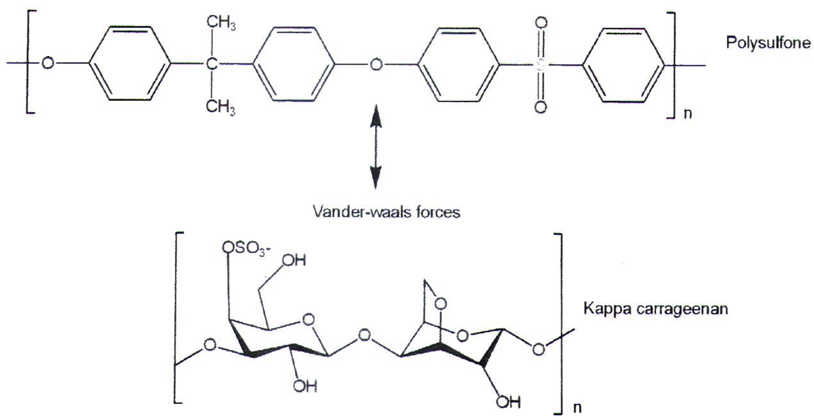
ABSTRACT
Mechanical strength and adaptability are both hallmarks of polymeric polysulfone (PSf) membranes. However, the hydrophobicity nature of PSf is the main reason to enhance water permeability and removal capabilities of membranes. Therefore, the characteristics of PSf membranes can be improved by the addition of kappa-carrageenan (ƙ-car), a highly hydrophilic biopolymer. In this study, the incorporation of ƙ-car, a biopolymer composed of anionic polysaccharides that were isolated from specific ocean red-algal species, was investigated. The quantities of ƙ-car ranged from 0.1 to 1.0 wt.% in a composite material including silver graphene oxide (Ag-GO) and PSf. A polymer solution consists of PSf/ ƙ-car /Ag-GO was prepared by dissolving with hydrocarbon solvent, N-methyl 2-pyrrolidone (NMP). The technique of phase inversion was employed in the membrane fabrication process. Membranes were investigated by evaluating their casting viscosity, contact angle, porosity, functional groups, and surface morphologies. The viscosity of the casting solution exhibits an upward trend as the concentration of ƙ-car increases. The observed contact angles for 0.25 wt.% ƙ-car supports the evidence related to the hydrophilic surface characteristic. Results showed that the highest porosity at 78.15% was achieved by the membrane fabricated with the addition of 0.25 wt.% ƙ-car. The incorporation of ƙ-car as a pore-forming agent in the PSf membrane has demonstrated a notable influence on both of its hydrophilicity and morphological properties.

Keywords: *kappa-carrageenan; polysulfone; silver-graphene oxide; biopolymer; hydrophilicity*

effect of kappa-carrageenan on the structure and the hydrophilicity of the nanohybrid membranes is the primary objective of this study. This research helps expand nanohybrid membrane technology by focusing on these factors, which can improve performance across a wide range of uses, such as energy generation and water purification. This research may pave the way for more efficient and environmentally friendly processes by informing the design and development of future nanohybrid membrane systems.

Figure 1: Composition of Polysulfone and Kappa carrageenan.



2.0 Materials and methods

2.1 Materials and Chemicals

The polysulfone (PSf) pellets and kappa carrageenan (ƙ-car) powder were acquired from Sigma (Darmstadt, Germany Silver oxide of graphene, or Ag-GO, was created at the Membrane Research Laboratory at Universiti Kebangsaan Malaysia. The N-Methyl-2-pyrrolidone (NMP) was obtained from R&M Chemicals, a Malaysian business with headquarters in Kuala Lumpur.

2.2 Membrane Fabrication

The PSf/ ƙ-car /Ag-GO membranes were fabricated with the help of the phase inversion technique. PSf was used as the polymer and NMP was used as the solvent to make the casting solution. The goal of using ƙ-car, a hydrophilic modifier/additive, was to increase the membrane's flow rate. According to Table 1, various concentrations of ƙ-car were included into membranes K1, K2, K3, K4, and K5; specifically, these concentrations ranged from 0.1% to 1.0%. The pure PSf (K0) membrane has been used as a reference sample in this study.

Table 1:Composition of hybrid PSf/ƙ-car/Ag-GO membranes.

Membrane	PSf (wt.%)	ƙ-car /Ag-GO (wt.%)	NMP solvent (wt.%)
K0	20.00	0.00	80
K1	19.90	0.10	80
K2	19.75	0.25	80
K3	19.50	0.50	80
K4	19.25	0.75	80
K5	19.00	1.00	80

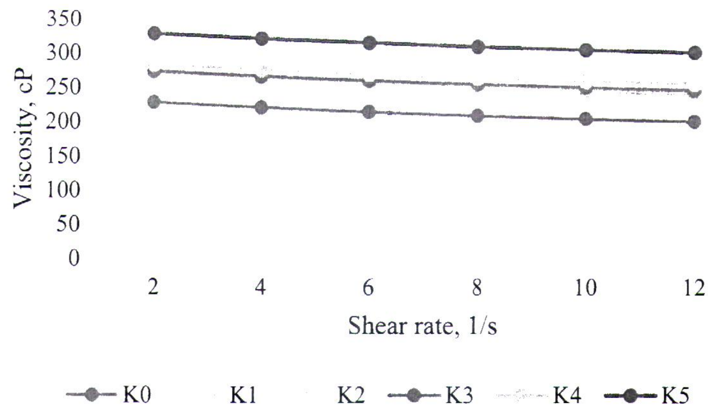


Figure 2: Viscosity of prepared membranes.

3.2 Hydrophilicity

The hydrophilicity of a membrane was influenced by its surface wettability. More hydrophilic membranes are visible at lower angles of water contact with the surface. The most effective technique to improve polymer membranes that are less hydrophilic is by addition of nanoparticles or biopolymers to them. For instance, the work reported by Yadav and co-researchers [35] discovered that the membrane (UA-60) can be enhanced by adding graphene oxide in the preparation of membranes. In a study conducted by Suhalim et al. [36] also showed that addition of Ag-GO to PSf polymeric membranes has boosted their hydrophilicity. According to Lakshmi et al. [19] related on biopolymers, the addition of 2% Ulvan (green carrageenan) has caused PSf membranes become more hydrophilic. Figure 3 shows that adding ƙ-car concentration to K1 and K3 membrane enhanced the contact angle of composite membranes to 61.14° and 59.09°, respectively. However, the contact angle remains constant at 60.04° and 59.22° for membranes K4 and K5 respectively. It was found that adding ƙ-car to K2 membrane maximizes surface hydrophilicity with contact angle of 46.53 ° and improves hydrophilicity of PSf polymer membranes most effectively.

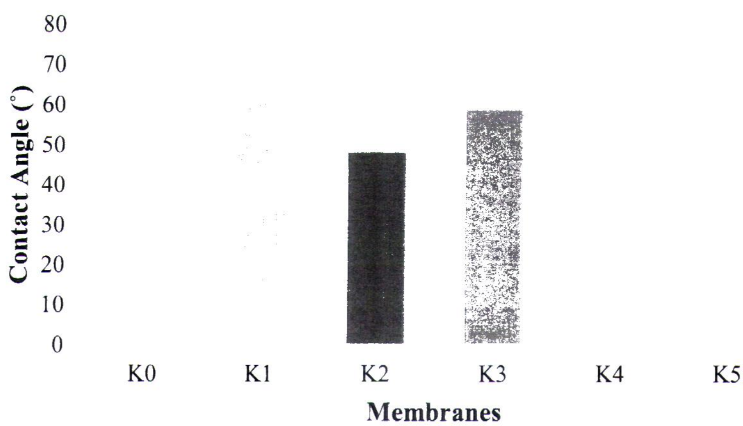


Figure 3: Contact angle of prepared membranes.

Table 2: Assignment of FTIR spectra K1, K2, K3, K4 and K5.

No. assignment	FTIR Frequency(cm^{-1})				
	K1	K2	K3	K4	K5
O-H stretching bonds	3363.62	3379.31	3368.87	3368.81	3366.97

3.4 Porosity

Table 3 presents results of observations made of membrane structure elements that significantly affect the water flux, such as porosity. According to the findings of this study, adding ƙ-car to the PSf matrix has a positive impact on how the PSf membrane grows, leading to the formation of more porous structure. The porosity of the synthetic polymer membranes varied from 69.10% to 78.15%. In comparison to K0 membrane, the porosity of K2 membrane that consists of 0.25 wt% of ƙ-car was raised by 78.15%. However, adding the ƙ -car content in K3 membranes resulted in a 74.61% decrease in the porosity value. It was found that when more ƙ -car was added to the K4 and K5 membranes, respectively, the porosity percent values remained unchanged at 74.71% and 74.67%. This is confirmed by the fact that K2 membranes had the lowest contact angle result, which indicated an increase in the hydrophilicity of the membranes. Additionally, the addition of ƙ-car has resulted that polymer membrane surfaces become more porous, which permits more water molecules to enter the matrix [41].

Table 3: Porosity of the prepared membranes.

Membranes	Porosity %
K0	69.10
K1	73.21
K2	78.15
K3	74.61
K4	74.71
K5	74.67

3.5 Effect of ƙ-car concentration on mechanical properties of PSf membranes

Figure 6 displayed the tensile strength test of the manufactured membranes, revealed significant mechanical strength improvement. The incorporation of ƙ-car into membranes resulted in an enhancement of their mechanical strength. However, a decrease in tensile deformation as the concentration of ƙ-car increased is presented in the graph. The observed outcome can be attributed to the fact that the K5 membrane exhibited a significantly higher concentration of ƙ-car, rendering it more prone to brittleness compared to the K1 membrane. This study is reminiscent of previous research that investigates the water solubility of ƙ-car in order to enhance its mechanical properties, it is necessary to combine it with cellulose nanocrystals [41], as well as sorbitol and glycerin [42].

though the K2 membrane does not has a same mechanical strength as the K1 membrane, it still fits into the category for being remarkable membranes that improves their qualities. The impact of incorporating ƙ-car into the PSf matrix on the fluidity of the casting solution is clearly observed in the obtained data. This alteration in viscosity subsequently influences both the structure and morphology of the resulting PSf/ƙ-car/Ag-GO hybrid membranes during the phase-inversion phase. The findings of this study indicate that the utilization of ƙ-car has significant potential in the development of PSf hybrid membranes with enhanced structural features. It is also important to investigate the possibility of using modified membranes for the removal of ionic solutes and dyes. Additionally, testing should be done to prove that the silver nanoparticles used to decorate graphene oxide composites contain outstanding antibacterial property (oligodynamic effect) against a wide range of bacterial strains. In conclusion, optimization of ƙ-car content improves PSf membrane lifespan in water treatment plants and drinking water industries.

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