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Arabic gum as a novel pore-forming and hydrophilic agent in polysulfone membranes

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ABSTRACT

In this study, novel polysulfone (PS) membranes blended with Arabic Gum (AG) as pore forming agent were prepared via phase inversion technique. The performances of the newly synthesized PS/AG membranes cast at different AG contents (0.1–3.0 wt%) in dope solutions were examined for their surface morphology, cross-section, surface charge density, hydrophilicity, and mechanical strength using scanning electron microscopy (SEM), zeta potential, contact angle measurements and tensile testing, respectively. The antifouling properties of PS/AG membranes were evaluated during filtration of bovine serum albumin (BSA) solutions while the antibacterial tests were assessed using *Escherichia coli* bacteria. The addition of AG to the casting solutions displayed a remarkable enhancement on PS membrane hydrophilicity, surface charge, flux, rejection and antibacterial properties. The prepared PS membranes cast with 3 wt% AG possessed high oil rejection and BSA flux recovery of about 98% and 80% respectively. In addition, the mechanical properties of the cast membrane increased by 52% compared to the pristine PS membrane. Overall, this study shows that, AG is promising additives that can be used for fabrication of ultrafiltration membranes with improved performance for water treatment applications.

1. Introduction

Polysulfone (PS) as thermoplastic polymeric material is widely used for fabrication of a microfiltration or ultrafiltration membranes as well as support material in nanofiltration and reverse osmosis (RO) membranes [1,2]. Polysulfone (PS) membrane displayed excellent chemical resistance over a wide range of pH and high thermal stability [1,3]. Nevertheless, PS membranes are quite hydrophobic which makes them prone to fouling. Membrane fouling is a major problem in environmental membrane separations because it leads to higher operating pressures, more frequent chemical cleaning, shortened membrane life, reduced flux and lower product water quality [4,5].

It has been reported that membranes with hydrophilic surfaces are less susceptible to fouling with organic substances and microorganisms due to the drop in the interaction between the foulant and the membrane surface [6–8]. According to many researchers, the pore structure and the hydrophilicity of the PS membranes could be adjusted by incorporating some additives in the casting solutions. So far many additives have been used such as polyvinylpyrrolidone (PVP) [9–11], polyethylene glycol (PEG) [11–14], and lithium chloride (LiCl) [15].

PVP is the most frequently used additive during casting of PS membranes using phase inversion technique due to its high solubility in water and good miscibility with PS [9,16,17]. It has been reported that PVP induces thermodynamic instability and promotes instantaneous demixing in the dope solutions [9,16]. As a result, membranes with larger pore size and higher flux are formed [18,19].

Recently, polymeric additives with an amphiphilic nature have received much attention due to their unique behavior during membrane formation. Amphiphilic additives tend to segregate the membrane-water interface because of the presence of hydrophilic segments, whereas the hydrophobic parts of macromolecules firmly anchored in the polymer matrix [20,21]. Copolymers of poly(ethylene oxide) and poly (propylene oxide) (Pluronic copolymers) have been shown to possess both the pore-forming and surface-modifying properties during PES membrane fabrication [22]. Susanto and Ulbricht [23] compared the effect of three different macromolecular additives PVP, PEG and Pluronic on the membrane structure and their stability in the polymer membrane matrix of the PES membrane. They found that addition of Pluronic as a modifier agent results in the best membrane performance and stability.

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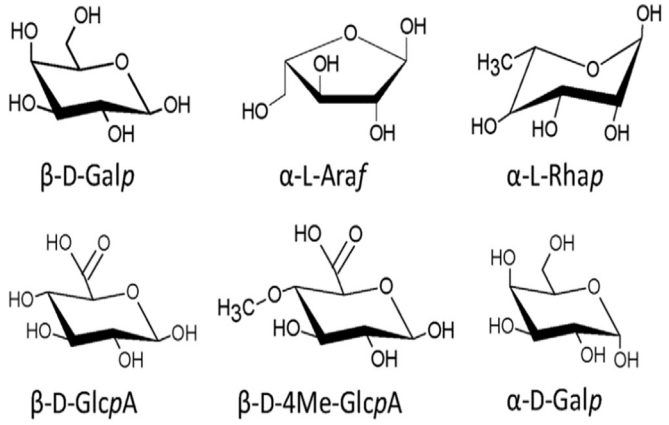

Fig. 1. The main mono-saccharides present in AG [28].

Recently Arabic Gum (AG) received the attention of many researchers due to amphiphilic properties that make it a promising additive for many applications. Historically, AG was used by Egyptians as an adhesive and ink stabilizer; today, AG is widely used in food (edible emulsifier), lithography, pharmaceutics and cosmetics [24]. AG is a natural gum which is made from the dried gummy exudation which can be extracted from some species of acacia trees [25]. AG is highly water-soluble and is widely used as an emulsifying and stabilizing agent in the food industry and as a binder in paints and pyrotechnic compositions [24]. Chemically, AG is a mixture of calcium, magnesium, sodium and potassium salts of Arabic acid in addition to high molecular weight polysaccharides which are made up of the six carbohydrate moieties galactose (Gal), arabinopyranose (Ara), rhamnose (Rha), glucuronic acid (Glca) and 4-methyl glucuronic acid (4Me-GlcA) [26,27].

The main mono-saccharides present in AG are: (1) neutral mono-saccharides (such as: Gal, Ara, and Rha) and (2) acidic monosaccharides (such as: GlcA and 4Me-GlcA) (Fig. 1) [28–31].

So far AG has not been used as an additive in PS membrane fabrication. In this study, AG as an additive is used for the first time in preparation of PS membranes. The aim of this work was to study the effect of using Arabic gum as an additive on the performance of polysulfone membranes by investigating some important properties related to membrane performance such as: water flux, pore size, porosity, surface charge, hydrophilicity, mechanical strength and bacterial properties.

2. Materials and methods

2.1. Materials

PS (molecular weight of 35,000), DMAc (purity ≥99%), AG with a molecular weight of approximately 250,000, PVP (molecular weight of 10,000) and bovine serum albumin (BSA) were purchased from Sigma-Aldrich. Millipore deionized water (DW) was used in the coagulation bath as non-solvent.

2.2. Preparation of the membrane

PS membranes incorporated with AG were cast via a phase inversion method using a flat sheet membrane casting system (Philos, South Korea). The membrane samples with different concentrations of AG namely: 0.1, 0.5, 1.0, 1.5, 2.0 and 3.0 wt% in the dope 16 wt% PS/DMAc solutions have been prepared (Table 1). In preparing the casting solutions, DMAc, PS and additive (AG or PVP) were sonicated using a probe ultra-sonicator (Cole Parmer, USA) and mixed using an IKA Ultra Turrax T25 digital mechanical stirrer (IKA, USA) for about 2 h at 60 °C to ensure the dissolving of PS and AG in the solvent. The resultant solution was then degassed for about 6 h and cast onto a clean glass plate using a casting knife with 200 mm gap height at a casting speed of 2.5 m/min at room temperature. The glass plate with the cast membrane film was immersed in DW and left till the membrane was detached from the glass plate. The membranes were thoroughly washed and kept in DW for 24 h at room temperature to remove traces of the solvent. For comparison, the membrane samples with PVP (5 wt% in the dope solution) were also cast under the same conditions.

Table 1
Composition of the dope polymer solution for preparation of PS membranes.

Membrane	Additive (wt%)		PS (wt%)	DMAc (wt%)
	AG	PVP		
M1	0	0	16	84
M2	0	5		
M3	0.1	0		
M4	0.5	0		
M5	1	0		
M6	1.5	0		
M7	2	0		
M8	3	0		

2.3. Membrane characterization and testing

2.3.1. Characterization of porous structure

Field emission scanning electron microscopy (FESEM) was used to examine the cross-sectional structures of the fabricated membranes using Gemini model SUPRA 55VP-ZEISS (Oberkochen, Germany). Liquid nitrogen was used to fracture the membranes and all the membranes were coated with platinum before scanning. In order to obtain the high quality membrane cross-sectional and surface images, vacuum condition at 3 kV was used in this study.

The membrane porosity was evaluated using the gravimetry method [32]. First, the membranes were dried for 24 h in an oven at 50 °C and weighed. Then the membranes were immersed in DW for 24 h at room temperature (25 °C). After removing the membranes from water, the water droplets on the membrane's surface were wiped off using filter paper before being weighed again. The average values of the wet and dry weights corresponding to each membrane were recorded and used to calculate the total membrane porosity (ε) using the following equation:

$$\varepsilon = \frac{\frac{(w_w - w_d)}{\rho_w}}{\frac{(w_w - w_d)}{\rho_w} - \frac{w_d}{\rho_m}} x\ 100\% \quad (1)$$

where w_w, w_d are the wet and dry weight of the membranes, respectively, ρ_m is the density of the polymer at 25 °C (1.24 g/ml) and ρ_w is the density of the distillated water which is around 0.998 g/ml [32]. Using the porosity data and Guerout–Elford–Ferry equation, the pore sizes of the fabricated membranes were calculated as follows [19]:

$$r_m = \sqrt{\frac{(2.9 - 1.75\varepsilon)8\eta l Q}{\varepsilon . A . \Delta P}} \quad (2)$$

where η is the water viscosity (8.9×10^{-4} Pa s), Q is the volume of pure water permeated through the membrane per unit time (m^3/s) and ΔP is the operating pressure (4 bar).

2.3.2. Membrane hydrophilicity and surface charge

The water contact angle measurements on the membrane surface were performed using a Ramé-hart Model 200 standard contact angle goniometer. Drop size was set at 2.0 μl. Each sample had droplets placed at 5 different points on the sample surface, with 5 measurements made on each droplet, to give a total of 25 measurements per