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Sericin Recovery from Silk Cocoon Degumming Wastewater by a Membrane Process

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ABSTRACT

Flat sheet asymmetric polymeric membranes were prepared from a homogeneous solution of polysulfone (PSF) in N-methylpyrrolidone by the phase inversion process with various concentrations and molecular weights of polydioxolane (PDXL) ($\overline{M}_n$ = 10,000 Da and 200,000 Da) and polyethylene glycol (PEG) ($\overline{M}_n$ = 300, 2000, 4600 and 10,000 Da) as the polymeric additives. The surface morphology of the prepared membranes was investigated. The performance of the prepared membranes was tested by their use in the recovery of sericin from silk cocoon degumming wastewater. The effects of polymeric additives and transmembrane pressures (200, 300 and 400 kPa) were studied in terms of the permeate flux (PF), protein retention and molecular weight cut-off (MWCO) of sericin retention. Results showed that the PF and MWCO of the permeate increased but protein retention decreased with increasing concentration, molecular weight of both polymeric additives and transmembrane pressure. Hence, it clearly revealed that the morphological parameters and flux performance of the membranes have a significant inter-relationship with the concentration, molecular weight of both polymeric additives and transmembrane pressure.

Key words: polysulfone membrane, phase inversion method, cocoon degumming wastewater, surface morphology, flux performance

INTRODUCTION

Thailand is well known for the traditional production of silk, which has been carried on for generations, making Thai silk a prestigious symbol of the country internationally. Silk is a natural protein fiber produced from silkworm (*Bombyx mori*) cocoons. It consists of 70-80% of a two-bundled fibrous protein called fibroin and 20–30% of an amorphous matrix of a water-soluble globular protein called sericin which functions as a gum to bond the two fibroin filaments together. In the silk production industry, sericin must be removed and discarded as waste from the cocoon cooking and silk degumming processes. During the last decade, sericin has emerged as a valuable commercial resource in many industries, such as those making cosmetics and pharmaceuticals, and food, as well as in the production of many functional biomaterials (Voegeli *et al.*, 1993; Kato *et al.*, 1998; Zhaorigetu *et al.*, 2001). Moreover, sericin has also been found to be useful as a degradable biomaterial, a biomedical material and for use as polymers for forming articles and functional membranes (Zhang, 2002; Altman, 2003). Hence, recovery of sericin not only can reduce the

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environmental impact but also can generate revenue as a natural value-added material in silk production.

The membrane process is a technique that permits concentration and separation without the use of heat and today has emerged as one of the fastest growing processes in the recovery of valuable materials from industrial wastewater. The phase inversion process is the most widely used process for preparing asymmetric polymeric membranes, in which solvent in the casting solution film is exchanged with the non-solvent in the precipitation bath forming a dense top-layer and porous sub-layer. These membranes are used in various applications because the dense top-layer plays the role of a selective barrier film for the solute while the porous sub-layer that includes macrovoids and micropores offers excellent mechanical strength to the membrane (Mulder, 1996; Kim *et al.*, 2005). Thus, structures and properties of membranes prepared by the phase inversion process depend upon the materials selected, such as the polymers, solvent, non-solvent and additives. Polysulfone (PSF) is a commonly used material for the fabrication of membranes. It is suitable for many applications because of its high thermal resistance, high chemical inertness, excellent mechanical strength and hydrolytic and biological stabilities (Harris *et al.*, 1988). A number of studies on the role of additives in the membrane structure and its properties have been reported in the literature (Han, 1999; Lee *et al.*, 2002). Polyethylene glycol (PEG) is miscible with the casting polysulfone solution and with the water used as the non-solvent and consequently the effect of a PEG additive on the formation of polysulfone membranes has been studied with regard to its thermodynamic stability and the precipitation kinetic rate of the polymer casting solution (Kim and Lee, 1998; Kim *et al.*, 2005; Zheng *et al.*, 2006a, b; Chakrabarty *et al.*, 2008a-c). It has been reported that the thickness of the top-layer and the finger-like macrovoid structure of the sub-layer of asymmetric membranes are relative to the solubility as well as relative diffusivity of the additives (Chakrabarty *et al.*, 2008c). The results showed that both the concentration and molecular weight of PEG play a significant role in the morphological as well as the flux properties of the membranes prepared. By increasing the concentration and molecular weight of PEG, the viscosity of the casting solution increases. Consequently, the increase in viscosity of the casting solution can hinder the diffusion exchange rate of the solvent and non-solvent in the sub-layer, which slows down the precipitation rate of the sub-layer. Therefore, the macrovoids in the sub-layer seem to be suppressed with the addition of high molecular weight PEG (Chakrabarty *et al.*, 2008c). In general, the top-layer becomes thicker as more additive is added but when the same amount of additive is used, the top-layer becomes thicker if a higher molecular weight of additives is added (Jung *et al.*, 2004). Because of low diffusivity of high molecular weight additives due to the higher viscosity relative to the solvent, polymer molecules take more time to come to the top surface giving the polymer molecules enough time to agglomerate and rearrange and thus a comparatively denser and thicker top-layer is formed. It is well known that asymmetric membrane formation not only depends on the kinetic parameters but also on the thermodynamic parameters (Boom *et al.*, 1992; Mulder, 1996; Han and Nam, 2002; Jung *et al.*, 2004). Because the solubility of PEG in water is inversely proportional to the molecular weight, the casting solution becomes thermodynamically less stable with increasing molecular weight of the PEG additive. It has been generally accepted as a common rule that a thermodynamically less-stable membrane-forming system can enhance the precipitation rate and produce a more porous membrane structure (Kim and Lee, 1998). Thus, addition of the high molecular weight PEG increases the pore size of the top surface and the porosity of the top-layer in the membranes. The PEG solubility pattern can be altered by including a hydrophobic comonomer in the polymer backbone. Polydioxolane (PDXL) is a perfect alternate copolymer of polyethylene oxide and polymethylene oxide. The solubility of PDXL is much more limited than that of PEG due to the extra methylene group. At room temperature, PDXL is generally considered insoluble in water, while an aqueous PEG solution is transparent. The solubility of PDXL increases upon heating to destroy the polymer aggregations until it reaches its lower critical solubility temperature (LCST) or cloud point. Phase separation of PDXL and PEG occurs at 70°C (LCST = 70°C) and 100°C (LCST = 100°C), respectively, in pure aqueous solutions (Benkhira *et al.*, 1992).

The total annual worldwide cocoon production has been reported as about one million metric tons, corresponding to around 125,000 metric tons of raw silk (Baker, 2004). This equates to 400,000 metric tons of dry cocoon and 50,000 metric tons of sericin mainly from the degumming process which are discarded as waste each year (Zhang, 2002). At present, most of the sericin has been recovered extensively from the silk degumming process (Wu *et al.*, 2007; Vaithanomsat and Kitpreechavanich, 2008), while little attention has been directed toward the recovery of sericin from the dry cocoon waste although it accounts for a lot more of the sericin (Capar *et al.*, 2008). This paper reports on the effect of two additives, PEG and PDXL, on the morphology of PSF membranes and their performance with regard to sericin recovery from silk cocoon degumming wastewater. Production of silk in Thailand is approximately 1,500 metric tons per year (Baker, 2004), which means that at least 300 metric tons of sericin is discarded. Therefore, the development of suitable membranes for the recovery of sericin from the silk production industry would definitely provide significant benefits for Thailand.

MATERIALS AND METHODS

Silk cocoon degumming wastewater

Bombyx mori silk cocoons were obtained from the Faculty of Biochemistry, Kasetsart University, Thailand. The silkworms were carefully separated and the cocoons were cut into small pieces. About 25 g of cut silk cocoon and 2 g of bromelain were mixed with 1 l of distilled water and were boiled at 55°C for 1 h in a controlled temperature water bath. The silk cocoon degumming wastewater obtained was centrifuged at 10,733 × g for 5 min using a Hermle Z323 Labortechnik (Germany) centrifuge to settle the suspended solids.

Polysulfone (PSF, $\overline{M}_n$ = 22,000 Da from Aldrich, USA) and N-methylpyrrolidone (NMP, 99.5% purity, from Aldrich, USA) were used without further purification. Polydioxolane (PDXL, $\overline{M}_n$ = 10,000 and 200,000 Da from Nippon Shokubai, Japan) and polyethylene glycol (PEG, $\overline{M}_n$ = 300, 2000, 4600 and 10,000 Da from Aldrich, USA) were used as the non-solvent pore-forming additives in the casting solution. Deionized water purified with the Millipore system (Millipore, France) was used as the main non-solvent in the coagulation bath.

Membrane preparation

Flat sheet PSF membranes were prepared using the phase inversion method by dissolving 12 wt% of polymer (PSF) in 83 wt% or 86 wt% of NMP at room temperature (≈ 25°C) and about 72% relative humidity. Each preparation was then mixed with 2 wt% or 5 wt% of PDXL or PEG, separately. The PSF solution was stirred on a magnetic stirrer for about 24 h at room temperature. After the solution (consisting of polymer, solvent and additive) became homogeneous, it was kept undisturbed at room temperature for 24 h. Subsequently, the solution was spread uniformly on a glass plate (0.10m × 0.10m) with the help of a glass rod to maintain the sheet thickness at approximately 0.26 mm at room temperature. The resulting film was then immersed in a coagulation bath containing deionized water at room temperature for the PEG additive and at 60°C for the PDXL additive. The prepared membrane sheets were washed under running deionized water to remove any excess amount of additives and then kept overnight in a deionized water bath. Finally, the sheets were cut into circular disks with a diameter of 0.09 m to be placed inside the membrane cell for filtration experiments. The cross-sectional morphologies of the prepared membranes before and after filtration were characterized by scanning electron microscopy (SEM) (1455VP, Electron Microscopy Ltd, Cambridge, England) and Infinite Focus Microscopy (IFM) (Hi-Tech Instruments Sdn. Bhd., Alicona, Australia), respectively.

Membrane test cell

The batch performance of the prepared membranes was studied with a RO/UF flat sheet stainless steel membrane test cell having a maximum volume of 380 ml (Nitto Denko Corporation). A flat, circular, sheet membrane with a diameter of 0.09 m and an effective area of 0.0064 m^2 was placed over a base support inside the cell and the permeating solution was collected from the bottom of the cell. The transmembrane pressure applied was controlled using a nitrogen cylinder.

Permeate flux (PF)

The performance of the prepared membranes was evaluated by recovering sericin from silk cocoon degumming wastewater in terms of their permeability as a permeate flux when allowing silk cocoon degumming wastewater feed to pass through the compact membrane. Permeate flux values at different transmembrane pressures (200, 300 and 400 kPa) were measured under steady state conditions using Equation 1:

$$J_w = Q/A\Delta T \qquad (1)$$

where J_w is permeate flux (l m^{-2} h^{-1}), Q is volume of permeated water (l), A is effective membrane area (m^2) and ΔT is sampling time (h).

Analytical methods

The protein concentrations in the silk cocoon degumming wastewater in the feed and in the permeate were determined spectrophotometrically using a UV–Vis spectrophotometer (Perkin–Elmer, USA) at a wavelength of 650 nm (Lowry *et al.*, 1951). The percentage of protein retention was calculated using Equation 2:

$$\textit{protein retention}\ (\%) = (C_f - C_p/C_f) \times 100 \qquad (2)$$

where C_f and C_p are protein concentration in the silk cocoon degumming wastewater feed and permeate in mg l^{-1}, respectively.

The molecular weight cut-off (MWCO) to determine the molecular weight of sericin protein was obtained using the the SDS-PAGE technique.

RESULTS AND DISCUSSION

Membrane morphology

The morphology of the polysulfone (PSF) membranes prepared with the phase inversion process was investigated by scanning electron microscopy (SEM) and their cross sectional SEM morphologies are shown in Figure 1. All the prepared PSF membranes showed asymmetric structures consisting of a dense top-layer and a porous PSF matrix sub-layer with finger-like cavities with enclosed macrovoids. It was the same as most of the PSF membranes formed when using NMP/water as the solvent/non-solvent pair due to the high mutual affinity of NMP in the PSF casting solution with water during the phase inversion (Reuvers *et al.*, 1987; Mulder, 1996; Kim *et al.*, 2005). Addition of PEG or PDXL into the casting solution clearly played a significant role in the morphology of the membranes prepared. During the phase inversion process, micropores are formed both on the sites where PEG or PDXL and NMP exist via the exchange of water inflow and where NMP, PEG or PDXL outflow (Kesting, 1985; Munari *et al.*, 1988). The morphologies of the PSF membrane prepared from different concentrations and molecular weights of the pore-forming PEG and PDXL additives indicated that the pore size and porosity of the top-layer in the prepared membranes increased as the concentration and molecular weight of PEG or PDXL increased. Because the miscibility of the casting solution (PSF/NMP/PEG or PSF/NMP/PDXL) with water is inversely proportional to the concentration and molecular weight of PEG and PDXL, the casting solution becomes less thermodynamically stable when it contains a greater concentration and higher molecular weight of PEG and PDXL. The thermodynamically less stable, membrane casting solution then enhances the precipitation rate (increases the ratio of water inflow to NMP, PEG or PDXL outflow) and more porous membranes are formed (Young and Chen, 1995; Kim and Lee, 1998; Zheng *et al.*, 2006a; Zheng *et al.*, 2006b). In addition, it was observed

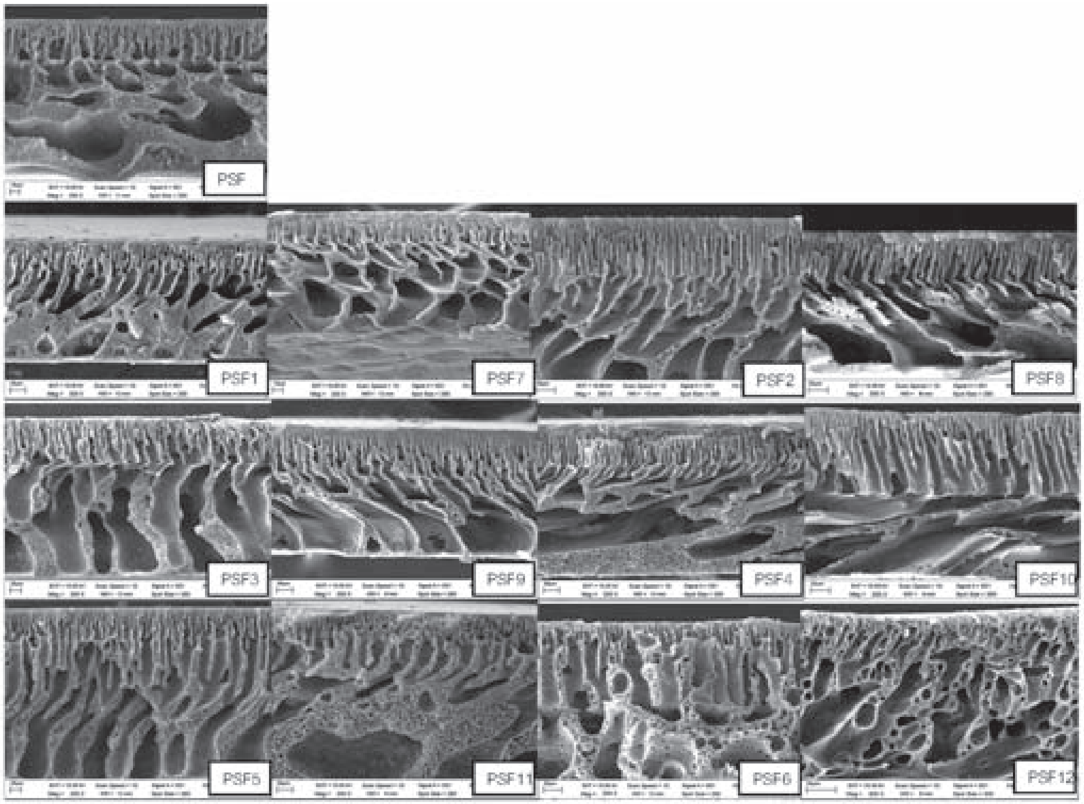


Figure 1 SEM cross-sectional morphologies of asymmetric membranes prepared (x200). (PSF) PSF/NMP = 12/88, (PSF1) PSF/NMP/PEG300 = 12/86/2, (PSF2) PSF/NMP/PEG2000 = 12/86/2, (PSF3) PSF/NMP/PEG4600 = 12/86/2, (PSF4) PSF/NMP/PEG10,000 =12/86/2, (PSF5) PSF/NMP/PDXL10,000 = 12/86/2, (PSF6) PSF/NMP/PDXL200,000 =12/86/2, (PSF7) PSF/NMP/PEG300 = 12/83/5 and (PSF8) PSF/NMP/PEG2000 =12/83/5 wt%, (PSF9) PSF/NMP/PEG4600 =12/83/5, (PSF10) PSF/NMP/PEG10,000 = 12/83/5, (PSF11) PSF/NMP/PDXL10,000 = 12/83/5 and (PSF12) PSF/NMP/PDXL200,000 = 12/83/5 wt%.

that the thickness of the top-layer and the structure of sub-layer also depended on the solubility and diffusivity of the PEG and PDXL. The thickness of the top-layer is important in membrane filtration, because the permeate flux decreases as the thickness of the top-layer increases (Jung *et al*., 2004). The top-layer became thicker as the concentration and molecular weight of the added PEG was increased. Because of the lower diffusivity of the higher molecular weight PEG due to the higher viscosity relative to the NMP, PSF molecules took more time to come to the top surface, which gave the PSF molecules enough time to agglomerate and rearrange and thus form a comparatively denser and thicker top-layer (Kim and Lee, 1998; Jung *et al*., 2004; Chakrabarty *et al*., 2008c). However, the thickness of the top-layer did not depend on the concentration and molecular weight of PDXL. This may have been due to the relatively comparable high diffusivity of both PDXL10,000 and PDXL200,000. When keeping the temperature in the precipitation bath at 60°C, PDXL allowed much less time for PSF molecules to agglomerate on the top surface. Therefore, a thin top-layer was observed. Finally, both PEG and PDXL additives caused significant suppression of the sub-layer with finger-like cavities containing macrovoids, because the low molecular weight additives could be easily washed out quickly together with the NMP into the water precipitation bath during the formation of the membrane. In fact, the top-layer porosity was closely related to the macrovoid formation. When a more porous top-layer was obtained, as in the case of PSF/NMP/PDXL200,000, the macrovoid formation was largely suppressed. The more porous top-layer needed the larger distance from the top surface to the starting point of the macrovoids to limit the large non-solvent inflow to the sub-layer because a large non-solvent inflow induced the formation of many nuclei in the sub-layer and thus, prevented macrovoid formation. Therefore, a porous sponge-type membrane with no macrovoids was formed under the highly less stable system, because the top-layer of the membrane was too porous to form the resistance layer which could limit the formation of many nuclei in the sub-layer (Kim and Lee, 1998).

Permeate flux (PF)

The effect of permeates flux on compaction time for all the PSF membranes prepared is shown in Figure 2. It clearly shows that PF declined gradually due to compaction with time and after about 2 h of compaction, it had reached a steady-state value. This was due to the reduction in pore size on the membrane surface from the physical adsorption of the gummy sericin protein on the membrane surface causing the walls of the pores to become closer and denser (Mulder, 1996; Capar *et al*., 2008). Additional PEG and PDXL additives in the prepared membranes, PSF/NMP/PEG and PSF/NMP/PDXL, exhibited better PF than that prepared only from PSF/NMP. The PF for each membrane was found to increase with increasing concentration, molecular weight of both additives and transmembrane pressures (200, 300 and 400 kPa). The PF was higher using PDXL as the additive (PSF/NMP/PDXL10,000, 22.4 l/m^2h) compared with using PEG as the additive (PSF/NMP/PEG10,000, 19.5 l/m^2 h). These PF results agreed well with the enlargement of pore size and porosity of the top-layer in the PSF membranes prepared, as the concentration and molecular weight of PEG or PDXL increased from the SEM observations. It was also found that the top-layer was thicker as the concentration and molecular weight of the PEG added was increased. However, it has been widely accepted that the permeate flux decreases as the thickness of the top-layer increases (Jung *et al*., 2004). Therefore, it can be concluded that PF was dependent on the pore size and porosity rather than on the thickness of the top-layer for the PSF-prepared membrane. The cross-sectional morphology of membranes after filtration was characterized by infinite focus

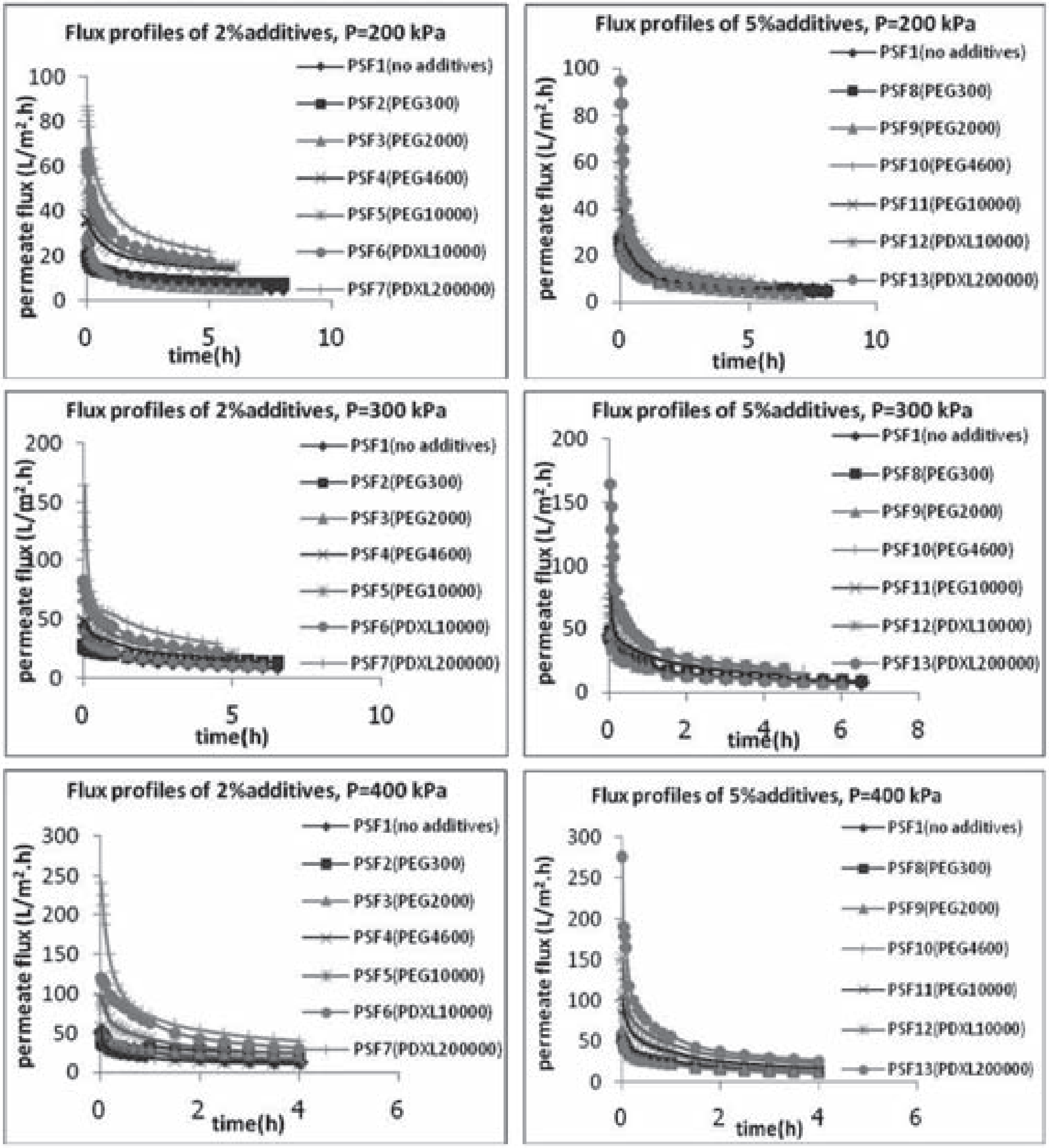


Figure 2 Flux profile during compaction of membranes prepared from 2 wt% and 5 wt% of PEG and PDXL at transmembrane pressure of 200, 300 and 400 kPa.

microscopy (IFM) as depicted in Figure 3. The IFM pictures were taken from PSF (PSF/NMP = 12/88 wt%) and PSF12 (PSF/NMP/PDXL200,000 = 12/83/5 wt%) and a layer of sericin protein was observed on the membrane surface.

Protein retention

Table 1 shows the concentration and percentage of protein retention obtained with silk cocoon degumming wastewater as feed. The effect of the concentration and molecular weight of the PEG and PDXL additives on protein retention at various transmembrane pressures is shown in Figure 4. The results show that with increasing transmembrane pressures from 200 kPa to 400 kPa, the concentration and percentage of protein

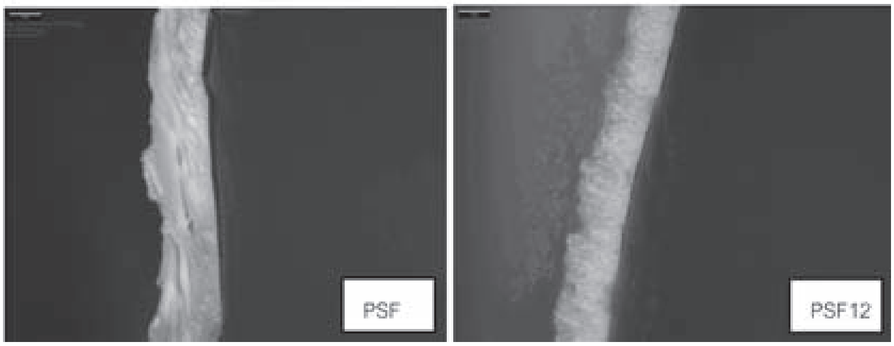
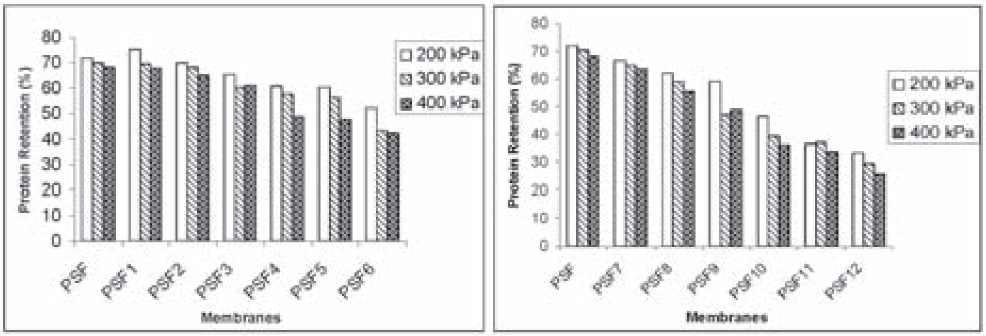


Figure 3 IFM cross sectional images of PSF (PSF/NMP =12/88 wt%) and PSF12 (PSF/NMP/PDXL200,000 = 12/83/5 wt%) membranes after filtration.

Table 1 Protein concentration and percentage of protein retention from prepared membranes.

Membrane	Concentration of protein (mg l^{-1}), Protein retention (%)		
	200 kPa	300 kPa	400 kPa
Feed	832000	832000	832000
PSF	598000, 71.9	608000, 73.1	566000, 68.2
PSF1	628000, 75.4	580000, 69.7	564000, 67.8
PSF2	582000, 70.0	568000, 68.3	540000, 64.9
PSF3	546000, 65.6	504000, 60.6	510000, 61.3
PSF4	506000, 60.8	482000, 57.9	406000, 48.8
PSF5	504000, 60.6	472000, 56.7	396000, 47.6
PSF6	436000, 52.4	360000, 43.3	352000, 42.3
PSF7	552000, 66.4	538000, 64.7	528000, 63.5
PSF8	516000, 62.0	492000, 59.1	462000, 55.5
PSF9	492000, 59.1	392000, 47.1	404000, 48.6
PSF10	386000, 46.4	326000, 39.2	300000, 36.1
PSF11	304000, 36.5	308000, 37.0	278000, 33.4
PSF12	276000, 33.2	244000, 29.3	212000, 25.5



(a) (b)

Figure 4 Effect of transmembrane pressure on protein retention for PSF membranes prepared with (a) 2 wt%; and (b) 5 wt% of PEG and PDXL as additives.

retention slightly decreased. For example, at a transmembrane pressure of 200 kPa with the same 2% concentration of PEG and PDXL, the percent protein retention was decreased from 75.4% of PSF1 to 60.8% of PSF4, and from 60.6% of PSF5 to 52.4% of PSF6, when the molecular weight was increased from 300 to 10,000 Da, and from 10,000 to 200,000 Da for PEG and PDXL, respectively. With the same molecular weight (300Da) of PEG used and a transmembrane pressure of 200 kPa, the percent protein retention also decreased from 75.4% of PSF1 to 66.4% of PSF7 when the concentration of PEG increased from 2% to 5%. This protein retention corresponded with the permeate flux and also agreed well with the enlargement of pore size and porosity of the top-layer in the PSF membranes prepared as the concentration and molecular weight of the PEG or PDXL additives increased, as seen from the SEM observations.

Molecular weight cut-off of sericin

The molecular weight cut-off (MWCO) in the silk cocoon degumming wastewater feed prior to membrane filtration and in the permeate were analyzed by sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) as shown in Table 2 and the profile of their molecular weight distribution is shown in Figure 5. The electrophoresis results indicated that the molecular weight distribution of sericin in the silk cocoon degumming wastewater feed obtained was 10 kDa to 250 kDa. The molecular weight of sericin commonly ranges from 10 kDa to over 300 kDa, thus sericin might be somewhat degraded by bromelain to a lower molecular weight during the preparation. The results showed that the molecular weight cut-off (MWCO) of the permeate increased according to the pore size in the top-layer of the prepared membrane. The bigger the pore size was, the higher the molecular weight that could permeate. Thus, the PSF-prepared membrane can be used for sericin recovery with different molecular weights range from silk cocoon degumming wastewater for suitable end use products. For example, PSF1 (PSF/NMP/PEG300 = 12/86/2 wt%) can only be used to concentrate silk cocoon degumming wastewater feed, while PSF6 can be used to separate sericin with a molecular weight greater than 50,000 Da at 200 kPa and PSF12 can be used to separate sericin with a molecular weight greater than 75,000 Da at 200 kPa.

Table 2 Molecular weight cut-off (MWCO) of the permeate for PSF-prepared membranes.

Membrane	MWCO (Da) of the permeate		
	200 kPa	300 kPa	400 kPa
PSF	20,000	25,000	20,000
PSF1	10,000	17,000	15,000
PSF2	15,000	25,000	15,000
PSF3	20,000	25,000	20,000
PSF4	37,000	40,000	50,000
PSF5	40,000	40,000	45,000
PSF6	50,000	60,000	75,000
PSF7	20,000	27,000	25,000
PSF8	25,000	30,000	30,000
PSF9	35,000	37,000	40,000
PSF10	45,000	50,000	50,000
PSF11	50,000	75,000	80,000
PSF12	75,000	80,000	100,000

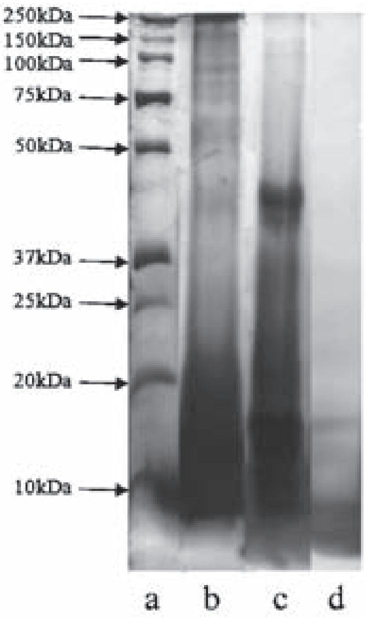


Figure 5 SDS–PAGE of sericin (a) markers consisted of synthesis protein from 10 kDa to 250 kDa; (b) silk cocoon degumming wastewater feed; (c) and (d) permeate sample from PSF12 and PSF1 at transmembrane pressure 200 kPa, respectively.

CONCLUSION

Flat sheet polysulfone (PSF) membranes were successfully prepared by the phase inversion process from a homogeneous casting solution having the solvent and additive concentration varying from 83 to 86 wt%, and 2 to 5 wt%, respectively, while the polymer concentration was held constant at 12 wt%. In the membrane preparation, concentrations of two different additives, PDXL and PEG, with various molecular weights ($\overline{M}_n$) of 300, 2,000, 4,600 and 10,000 Da for PEG and 10,000 and 200,000 Da for PDXL were used.

Cross-sectional SEM morphologies showed that all PSF membranes prepared with PEG or PDXL as additives had asymmetric structures consisting of a dense top-layer and a porous sub-layer with finger-like cavities. The pore size and porosity of the top-layer increased as the concentration and molecular weight of PEG or PDXL increased. The top-layer of the prepared membranes became thicker as higher concentrations and greater molecular weights of PEG were used, but it did not thicken when PDXL was used as the additive. Increasing the concentration and molecular weight of both additives caused significant suppression of the finger-like cavities in the sub-layer.

Addition of PEG and PDXL additives exhibited better permeate flux (PF) than with membrane prepared from only PSF/NMP. However, PF of all the PSF membrane prepared was dependent on the pore size and porosity rather than on the thickness of the top-layer for the PSF membrane. PF declined gradually due to compaction with time, while the steady-state value of PF for each membrane was found to increase with increasing concentration, molecular weight of both additives and transmembrane pressures (200, 300 and 400 kPa).

The percentage of protein retention decreased with increasing concentration, molecular weight of PEG and PDXL in the casting solution and transmembrane pressures. The molecular weight distribution of sericin in the silk cocoon degumming wastewater feed obtained was 10 kDa to 250 kDa. The SDS-PAGE results showed that the molecular weight cut-off (MWCO) of the permeate increased with an increase in the concentration and molecular weight of both the PEG and PDXL additives and with an increase in the transmembrane pressure.

The PSF-prepared membrane can be used for sericin recovery with different molecular weights range from silk cocoon degumming wastewater for suitable end use products.

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