Effect of Polyvinyl Pyrolidone on Morphology and Performance of Cellulose Acetate Based Dialysis Membrane

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Abstract—**Polyvinyl pyrolidone (PVP) was added as filler in cellulose acetate (CA) to produce mixed matrix membrane (MMM) for hemodialysis operation. Phase separation induced by diffusion (DIPS) was used for fabrication of mixed matrix CA/PVP flat sheet membranes. The effect of adding PVP was investigated on the morphology and permeation efficiencies of CA membranes. The surface arrangement of polymer and additives in pure and blended membrane was studied by FTIR, contact angle and SEM. Results revealed homogenous and significant mixing of PVP content into pure CA matrix. Performance efficiency of blended membranes was investigated by means of pure water flux (PWF), urea clearance and % rejection of bovine serum albumin (BSA). The observable decrease of contact angle from 83° to 69° in CA/PVP MMM membranes of varying composition effectively revealed enhancement in hydrophilicity of MMM membrane surface. For protein rejection, all CA/PVP membranes rejected>90% of BSA relative to 25% for pure CA membrane. Furthermore, urea clearance behavior for CA/PVP membranes was 62.4% in comparison to 52% for pure CA membrane. The incorporation PVP i.e 1% by weight (Mpvp1) significantly improved the hydrophilicity, PWF, BSA rejection and urea clearance percentages of modified CA membrane for dialysis application.**

Keywords-cellulose acetate; dialysis; membrane; poly vinyl pyrolidone

I. INTRODUCTION

Kidney problems either acute or chronic are one the major mortality causes. Diseases related to kidneys have increased tremendously, main reasons being diabetes and hypertension which are common nowadays [1-4]. The increase in the amount of uremic toxics beyond the normal range within blood, effect adversely and is called uremic syndrome. To prolong life, kidney patients undergo dialysis which is an expensive procedure and costs more than 1 billion US$ annually [5]. Hemodialysis is an important medical procedure for patients suffering from renal ailments. This process includes purification of blood from patient's body using hemodialysis equipment (artificial kidney) to remove uremic wastes and returning the filtered blood back to person's body [6]. The important part of hemodialysis apparatus is a membrane, which

function is to separate toxic wastes produced as a result of metabolic activities and excess water from the patient through transport via diffusive and convective phenomena. During the process, essential protein loss is controlled or prevented via pore size exclusion of the membrane [7]. Keeping importance of hemodialysis in view, progress is made in research field of high-performance membrane which will lead to enhance quality of treatment and increase patient's life.

Different polymers used for dialysis membrane preparation other than cellulose-based materials include polysulfone (PS), polyacrilonitrile (PAN), polymethyl methacrylate (PMMA), polyamide (PA), and polyvinylalcohol (PVA) [8–12]. Many additives have been used to enhance dialysis performance of prepared membranes. Among them are polyethylene glycol (PEG), monosodium glutamate, polyethylene imine (PEI) etc. In the present study, CA was chosen as a basic polymer for the fabrication of flat sheet dialysis membranes. Phase inversion technique is commonly used for the preparation of asymmetric flat sheet membranes. Casting solutions were made from CA in acetic acid as solvent and pure water as non-solvent agent. Choice of cellulose was made on the bases of its easy availability and low cost. The only drawback for CA is its non-biocompatibility. In order to overcome this problem, a biocompatible additive with good hydrophilicity was added to CA so that the synthesized membranes can have enhanced dialysis efficiency. PVP is hydrophilic additive which enhances the hydrophilic behavior of CA membranes. It is a water-soluble polymer which increases the porosity of membranes [13], and has good blood compatibility [14]. Keeping that in mind, the casting solution was later modified using polyvinyl pyrolidone (PVP) in various weight percentages.

Surface morphology, functional group identification, pure water flux, bovine serum albumin rejection percentage and urea clearance values of CA/PVP were inspected and were compared with pure CA flat sheet membranes. The purpose of this research was to synthesize a new kind of CA/PVP membranes with high BSA rejection and better urea clearance for dialysis application.

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II. MATERIALS AND METHODS

A. Materials

Asymmetric polymeric membranes were synthesized for dialysis application. CA polymer with average mol. wt of 30,000 Daltons having 39.8% degree of acetylation, 99.7% pure acetic acid, 98% pure urea with mol. wt 60.06, Bovine serum with mol. wt of 66,000 Dalton and PEG with mol.wt 10,000 and 35,000 were obtained from Sigma Aldrich. PVP with average mol. wt. 30,000 was purchased from Fluka.

B. Membrane Synthesis

Several casting solutions of CA/PVP/Acetic acid blend were prepared having constant CA weight % of 18.5. Table I shows the compositions of casting solutions prepared during this work. The casting solutions were agitated constantly to confirm complete mixing of added ingredients including polymer, solvent and additive. When the casting solution showed complete dissolution of polymer and PVP, it was degassed for 2 hours using ultrasonic bath to remove trapped air bubbles. Complete mixing of components is indicated by formation of clear solution. To slow down the aging process the casting solutions were kept in dark after degassing. The casting solution was poured on a glass plate and was spread with a doctor blade having wet membrane thickness of 200μm. The glass plate was instantly submerged in distilled water trough where phase separation took place [15]. During phase separation, exchange on solvent (acetic acid) and non-solvent (water) occurred. The prepared flat sheet membrane was then shifted to another trough containing fresh water and was washed to get rid of any excess solvent if present. Washing was carried out for 3-4 times. Finally, the casted membrane was kept in distilled water for 24 hours before final testing.

TABLE I.   COMPOSITION OF MEMBRANES

Membrane	CA wt. %	PVP wt. %	Acetic acid wt. %
Mpvp0	18.5	-	80.5
Mpvp1	18.5	1.00	81.5
Mpvp3	18.5	3.00	78.5
Mpvp5	18.5	5.00	76.5
Mpvp7	18.5	7.00	74.5

It was observed that when we increased the PVP concentration beyond 5% the membranes formed were having visible pores and the casting was not possible as it was for the rest of the membranes. The visible physical difference in membranes with concentration less than 5% and beyond 5% is shown in Figure 1.

III. MEMBRANE TESTING (WET)

A. Pure Water Flux

Dead end filtration setup was used to calculate pure water permeation flux (PWP) for dialysis membrane. The filtration cell was having 250ml capacity for feed solution and an active area of 12.57cm^2. Permeation experiments were operated under 2.0–3.0bar pressure. All experiments were carried out at ambient temperature at 25±0.5°C as shown in Figure 2. The fabricated membrane was positioned in test cell and was tested for water flux. Experiments were repeated several times to avoid data ambiguity. The PWP flux was measured using (1):

$$\text{Flux}(J) = Q/\Delta t \times A \qquad (1)$$

In (1), *J* represents the permeation flux (Lm-2h-1) for pure water, *Q* is the volume of permeated solution, *A* shows the active area of membrane and *Δt* is the permeation time (h) [16]. A similar method was used to analyze molecular weight cutoff for the fabricated membranes. Solutions of BSA (average mol wt 66000) and PEG with different molecular weights (PEG 10,000 and PEG 35,000) were used. All solutions were made having concentration of 1g/L. The concentrations of PEG and BSA solutions were found using Dragondorff reagent [17, 18] by UV-spectrophotometer.
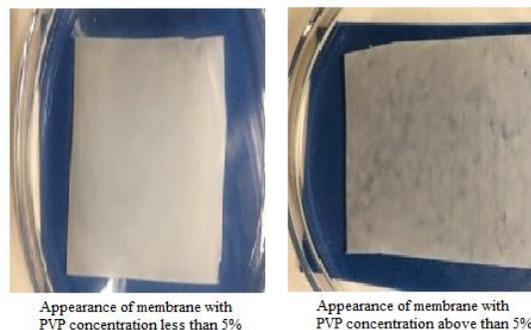

Fig. 1.   Difference in apearance of membranes.

B. Hydrophilicity Measurement

Contact angle and water uptake values were used to measure the CA/PVP membrane hydrophilicity. Sessile drop method was used to measure contact angle at a Tantec contact angle meter [19, 20]. Single drop of deionized water was released on a dried membrane flat surface using a micro-syringe. The tests were made under saturated water vapor atmosphere and the contact angle was measured after 10s. Minimum 8 contact angle readings were made to get an average value and all readings were taken at room temperature. To calculate water uptake/absorption, the membrane sample (2cm×2cm) was cut and desiccated in an oven at 60°C for 12h prior to testing. The dried piece was weighed (M_{dry}). The pre-weighed membrane sample was then waterlogged at room temperature for the next 24h. The waterlogged membrane was taken out and dapped with tissue paper to remove water. The membrane piece was weighed again (M_{wet}). All measurements were made at 25±0.5°C. The water uptake was determined using (2) where M_{wet} and M_{dry} represent the wet and dry membrane weights:

$$\text{Water take up} = \frac{M_{wet} - M_{dry}}{M_{dry}} \times 100 \qquad (2)$$

IV. MEMBRANE PERFORMANCE

Membrane performance tests were based on the extent of removing uremic toxins and rejecting bovine serum albumin from feed solution. Urea clearance and BSA rejection was measured separately using dialysis setup and dead-end filtration method. For urea clearance, the experiments were performed in a dialyzer with one compartment (donor) containing 50ml feed solution and the other (receiver) filled with 2L distilled water as shown in Figure 2.
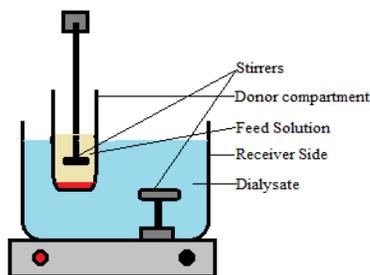
Fig. 2.   Schematic presentation of dialysis setup.

Two similar stirrers were fitted in the compartments. The membrane to be tested was clamped between the two chambers. The concentrations of urea and BSA were kept similar to their concentrations in human blood. For urea clearance, experiments were started by bringing the feed solution in contact with the testing membrane. The concentration gradients of solute (urea or BSA) in two sides of the dialysis membrane act as the driving forces for the transport of urea and BSA from the feed side to the distilled water side. The concentration of urea was measured every 30min from the start of the experiments and the experiment was performed continuously for 210min. Urea concentrations were tested using total organic carbon analyzer methods and UV-spectrophotometric method was applied for measuring BSA concentration. The membrane performance, i.e. urea clearance and BSA rejection was calculated from (3) where C_i and C_f represent initial and final concentrations respectively.

$$Urea\ clearance\ \% = \frac{c_i - c_f}{c_i} X\ 100 \qquad (3)$$

BSA rejection % was estimated using dead end filtration cell (Figure 3). A feed solution having concentration 1mg/ml BSA was prepared. The active membrane area was 12.57cm^2. The quantity of BSA in feed and permeate was measured by observing its absorbance with a spectrophotometer (Shidmazu UV mini 1240) operated at a wavelength of 278nm. The experiments were carried out at room temperature at 2-3bar pressure by employing (4) where C_p, C_r stand for permeate and retentate concentrations respectively [21].

$$Percent\ Rejection = \left(1 - \frac{c_p}{c_r}\right) \times 100 \qquad (4)$$
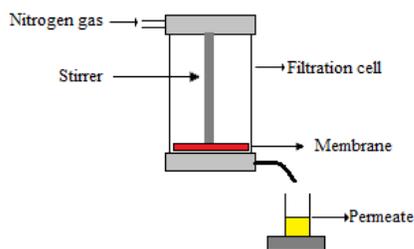

Fig. 3.   Dead end filtration setup.

V.   MEMBRANE CHARACTERIZATION

The cross-section and surface morphologies of casted membranes were analyzed using a JSM 6409A scanning electron microscope. The membranes were first frozen in liquid nitrogen and later were broken and spluttered with gold before undergoing SEM analysis. FTIR Spectrum 100 PerkinElmer, MID IR was used to carry out FTIR analysis of prepared membranes. The membrane pieces were cut and placed in a pallet holder one after the other. The holder was then fixed in an instrument. Wave numbers from 450 to 4000cm^{-1} were used to record the spectra in transmission mode. This procedure was repeated for every sample separately.

VI.   RESULTS AND DISCUSSION

A. *Effect of PVP Addition on Morphology and Performance of CA Membranes*

SEM investigation was made to study the effects of adding PVP to CA matrix. Figure 4 shows the micrographic view of surface morphology and cross-sectional arrangements of polymer and additive in all prepared membranes. As revealed in the surface morphology, addition of PVP to CA matrix leads to the generation of asymmetric membranes with compact top layer and sub-layer with finger like porous structures all over. From these images, it is seen that keeping bath temperature constant at 25°C and rising PVP concentration from 0 to 3wt.% caused development of macro voids and porous structure with good water flux. However, further increment of PVP concentration beyond 4wt.% resulted in formation of large visible pores making membranes not functioning for filtration, purification and dialysis operations. It was observed that the existence of hydrophilic additive PVP resulted in immediate demixing in the coagulation bath and generates macro voids in membrane structure till the concentration was below 3wt.% [22, 23]. Whereas due to low affinity between PVP and CA polymer, large pores were formed when wt.% was increased beyond 4wt.% as shown in Figures 1 and 4. Conclusively, it is said that addition of a hydrophilic additive PVP, to the CA polymeric solution induces a dual effect on the membrane morphology. The membrane structure attained is subjected to the dominance of instantaneous or late demixing. These both phenomena are occurring because of the presence of the PVP casting matrix. Conferring to Figure 4, adding PVP from 0 to 3wt.% causes development of pores and voids in the membranes. However, increasing PVP concentration beyond 3% in CA matrix, results in formation of larger finger like projections and highly porous structures. Therefore, it is concluded that little addition of PVP, i.e up to 3 wt.%, promotes immediate demixing, whereas further increment of PVP, beyond 3 wt.%, results in formation of membranes with large and visible pores.

B. *FTIR Analysis of CA/PVP Blended Membranes*

Addition of PVP to CA matrix resulted in the broadening and shifting of bands and peaks in FTIR spectrum (Figure 5). FTIR spectrum of CA/PVP blended membranes presented prominent carbonyl group (−C=O) stretching vibration of at ~1734cm^{-1} and stretching vibration of −CH group at ~2960cm^{-1}, which are defining peaks of CA [24, 25]. Mpvp1, Mpvp2 and Mpvp3 also showed stretching vibration of (C=O-N) amide carbonyl group at ~1656cm^{-1}, bending vibration of −CH2− group at ~1498cm^{-1}. C−N group also exhibited stretching vibration of tertiary at ~1295cm^{-1} [26, 27].

It is visible from the spectrum that as wt. % concentration increases, the peaks are becoming sharper. Mpvp5 shows the same trend as Mpvp1 and Mpvp3 but the values were small so not as prominent as in the case of the other two membranes. So, the presence of PVP in CA matrix is confirmed by the bands and peaks shown by Mpvp1, Mpvp3 and Mpvp5.
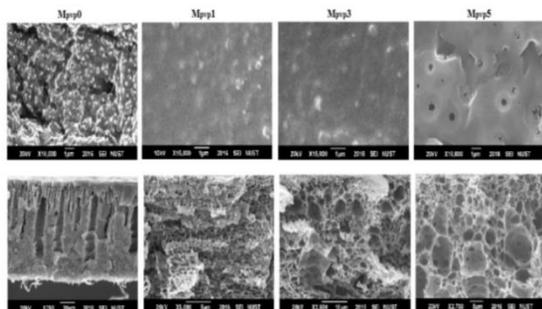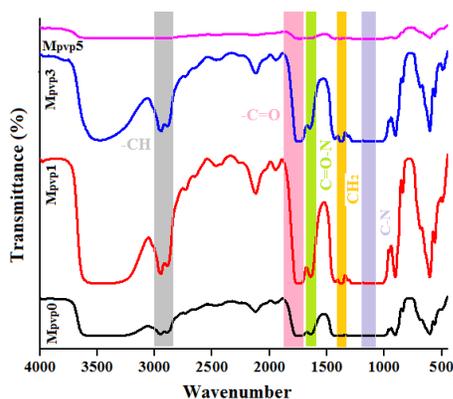

Fig. 4.   SEM images showing the surface.

Fig. 5.   FTIR spectrum of CA and CA/PVP blended membranes.

C. Effect of PVP Concentration on Hydrophilicity and Water Uptake

Water absorption or water uptake capacities and contact angle measurements are commonly used to estimate the extent of hydrophilic or hydrophobic nature of the membrane. If a membrane has low contact angle and possesses high-water absorption then it is high hydrophilic. Contact angle values and water absorption measurements for CA and modified CA membranes are shown in Figure 6. It is seen that water absorption of the PVP membrane increases and increasing PVP concentration up to 5% decreased the contact angle. These results indicated that the assimilation of PVP can increase the hydrophilicity for CA membrane obviously.

D. BSA Rejection % Study of CA/PVP Blended Membranes

Loss of albumin (≈67kDa) occurs while renal patient undergoes dialysis treatment. For good dialysis operation, albumin loss should be avoided during operation. Figure 7 signifies the % rejection of all pure CA and CA/PVP blend membranes. All membranes except pure CA have BSA rejection above 90% while membranes Mpvp1, Mpvp3 and Mpvp5 have rejection of 96.7%, 97.8% and 99.2% respectively which is relatively attractive for commercial dialysis

membranes to avoid albumin loss [28]. Membrane Mpvp1 with 96.7% rejection gives optimum properties for example urea clearance, contact angle, water uptake and water flux concerning dialysis.
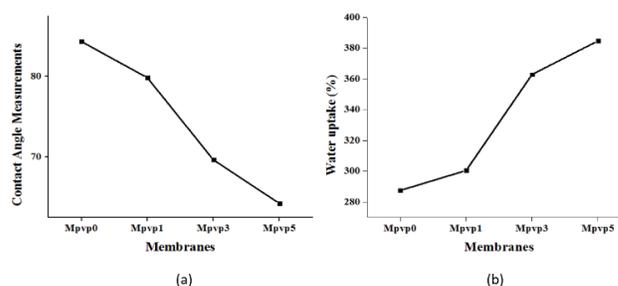

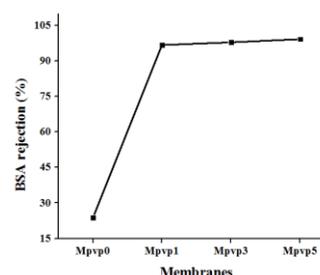Fig. 6.   (a) Contact angle and (b) water uptake of CA/PVP blended membranes.

Fig. 7.   BSA Rejection of CA/PVP blended membranes.

E. Effect of PVP Concentration and Evaporation Time on Pure Water Flux

The desired membranes were prepared with different evaporation times of 0, 10, 20 and 30sec. The prepared membranes were tested for pure water flux calculation using dead end filtration arrangement and it was found that evaporation time has a visible impact on CA/PVP blended membrane's performance. Increasing evaporation time affects inner structure and compaction of polymeric and additive particles within the membrane structure. The greater the evaporation time, the more suitable is the pore formation and uniform is the distribution of pores on membrane surface. From Figure 8, it is visible that the best membranes were casted when given 30s evaporation time to the casted membrane. These membranes gave optimum values of flux.

F. Urea Clearance Study of CA/PVP Blended Membranes

Urea clearance study is one of the major studies made to investigate the efficiency of hemodialysis membranes. Removal of waste including urea, excess water etc. is essential to maintain balance in patient's blood. For this purpose, prepared membranes were examined using the experimental arrangement shown in Figure 2. A fine dialysis membrane should have urea clearance value of at least 60%. Figure 9 demonstrates the % urea reduction of different CA/PVP blended membranes. Sample Mpvp1 exhibited urea reduction of 62% in comparison to pure CA membrane with 52.1%, which is better than considerations made for a good commercial dialysis membrane [29]. The percentage of urea clearance of Mpvp0, Mpvp3 and Mpvp5 is shown in Figure 9.
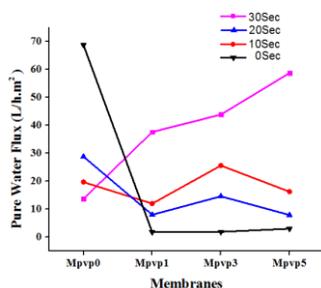
Fig. 8.   Graphical presentation of effect of evaporation time on pure water flux.
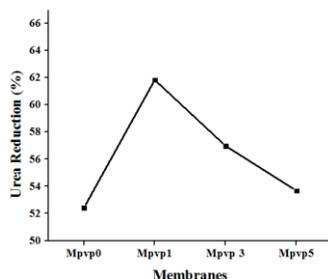

Fig. 9.   Urea clearance of CA/PVP blended membranes.

VII. CONCLUSION

During this research, PVP was used as additive for the manufacture of CA flat sheet membranes using phase inversion method. CA/PVP membranes showed compact structure with porous layer having macro voids when viewed in cross section. SEM and AFM characterization confirmed the uniform distribution of pores resulting in roughness at surface. FTIR studies revealed the effective bonding between PVP and CA. The hydrophilic nature was also studied by under taking contact angle and water uptake experiments. All these characterizations showed that hydrophilicity increased with addition of PVP to CA matrix. The performance testing showed that the efficiency of CA/PVP blended membranes was enhanced in terms of PWP flux, BSA rejection % and urea clearance values. This study revealed that PVP is an appropriate additive to enhance uremic waste clearance. Conclusively, the CA/PVP blended membranes can be used as a capable solution for hemodialysis treatment after some appropriate conditional changes.

ACKNOWLEDGMENT

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