CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Effect of Polymer Concentration

The best PVDF-UF membrane for proteins separation was produced at 17 wt% polymer concentration related to the good and fine membrane structure. Membrane with polymer concentration more than 17 wt% PVDF demonstrated poor performance compared to other membranes. Based on BSA and EA proteins separation performance study, the PVDF-UF membrane which contains 17 wt% polymers shows the best performance membrane due to its high water productivity (455.82 $Lm^{-2}h^{-1}$) and separation performance (BSA=84 % ; EA=73 %) as well as it has good membrane characteristics in terms of membrane morphological structures and pore properties. Moreover, the membrane structure of the prepared membranes showed almost similar finger-like structure and spongy-like layer in the middle of the membrane cross-structure.

5.1.2 Effect Addition of Different Polymeric Additives

The results revealed that PVP additive increased hydrophilicity properties of the PVDF/NMP/PVP membrane compared to PVDF/NMP membrane without PVP additive. The introduction of PVP additive enhanced the PWP (472.39 $Lm^{-2}h^{-1}$), permeate flux (BSA= 151.72 $Lm^{-2}h^{-1}$; EA =55.72 $Lm^{-2}h^{-1}$) and proteins rejection (BSA= 85%; EA=78%) due to the change in the structure properties of the skin-layer and sub-layer of the membranes. It is also revealed that the addition of PVP affected the molecular orientation of the membrane. On the other hand, the addition of PEG 200 and LiCl decreased the PWP, corresponding to the morphology change of the membranes.

SEM photographs proved that the enlargement of pore size in morphological membrane structure of PVDF/NMP/PVP membrane due to addition of PVP. The PVP acts as a pore former and a phase separation enhancer and formed porous membrane structures. Besides, the addition of PEG 200 and LiCl to the polymer casting solution decreased the finger-like length and width of the membrane. The big macrovoid size was formed by adding PEG 200 additive due to its strong interaction with polymer and NMP to delay the dope precipitation. By the end of the experiment, the addition of 3 wt% PVP and PEG 200 in to membrane casting solution as pore former and pore reducer additives, respectively produced membrane with favorable hydrophilicity and surface pore characteristics with a similar BSA protein rejection up to 85 %. Therefore, the PVP and PEG 200 additives were selected as the best high performance membranes.

5.1.3 Effect Addition of Different Surfactants towards PVP Additive

The UF PVDF-PVP membrane prepared with addition of different types surfactants (SDS, Triton X-100 and Tween 80) added to the polymer casting solution effectively improved the performance such PWP of the membranes throughout the study. Maximum PWP (811.92 $Lm^{-2}h^{-1}$) at pressure of 300 kPa was obtained by the PVDF/NMP/PVP membrane with 2 wt% Tween 80 surfactant content, giving BSA and EA proteins rejection of 85 % and 73 %, respectively. It was found out that addition of small amounts (2 wt%) of hydrophilic surfactants to the polymer casting solution increases formation of macrovoids and finger-like pores in the sub-layer of the membranes. Thus, this enhances the permeation flux and proteins rejection. When Triton X-100 was used as surfactant in the PVP-casting solution, the BSA protein rejection was higher (88 %) compare to other surfactants. However, the addition of surfactants showed almost similar result of BSA protein rejection which is more than 80 % meanwhile EA protein rejection within the range of 69-75 %.

5.1.4 Effect Addition of Different Surfactants towards PEG 200 Additive

The performance results indicate that the proteins permeated flux increases while the proteins rejection decreases for membranes prepared from dopes with surfactant content. Based on the morphology of the membranes, the addition of surfactants in the casting solution increases the formation of macrovoids and large finger-like pores in the sub-layer of the membranes. There were changes in the absorption intensity and the shift of IR spectra in the presence of the surfactants implying that polymer and surfactants were interacted. The most notable interaction was described in IR spectra in the presence of surfactant, was due to the difference in the stretching frequencies of the chemical groups.

5.1.5 Combination of Different Surfactants towards PVP and PEG 200 Additives

From this study, it can be said that all the membranes have asymmetric structure as observed from SEM images. It was found out that the combination of small amounts ionic surfactant (i.e SDS) and non-ionic surfactants (i.e Tween 80 and Triton X) to the casting solution increases formation of macrovoids and finger-like pores in the sub-layer of the membranes. With combination of anionic/non-ionic surfactants to the casting solutions, the thickness of the prepared membranes significantly increases and hence, probably enhanced the PWP and proteins rejection. As the combination of surfactants, interaction between hydrophobic chain and the non-polar sites of the membranes were observed which leading to hydrophilization of the membrane surface and pores. It can be conclude that the best performance of PVDF-UF membrane was developed from PVDF/NMP/PVP/SDS/TWEEN 80 casting solution which contained 3 wt% PVP and combination both of 1 wt% anionic (SDS) and non-ionic surfactants (Tween 80).

5.2 Recommendations

Few recommendations can be considered to improve the results of this study for future research:

i. Behavior of different types of polymers (PES, PSf, or PEI) under shear rate should be investigated. Thus, the separation performance results should be compared to the results of PVDF membranes.

ii. The study of properties of the different types additives and surfactants in the casting solutions are important in order to relate its properties with membrane performance and morphological structural analysis. Hence, the viscosity study of the additives is important to relate its rheological properties with the thermodynamics and kinetics mechanism during membrane fabrication process which in turn produced variation in membrane morphological structures.

iii. Different characterization techniques should be employed for further characterization of membranes such as Atomic Force Microscopy (AFM) and Nuclear Magnetic Resonance (NMR). AFM technique has demonstrated versatility in the characterization of surface morphology and interaction forces. It is a high resolution imaging technique by using a sharp probe as a stylus to feel the surface in three dimensions. It can also be used to probe the interaction forces between opposing surfaces, detecting both long range and adhesive interactions. It's wide range of application make it a versatile tool for the study and characterization of membrane surfaces, not just through production of high resolution imaging, but through the production of quantitative data such as surface roughness, surface pore size and pore size distribution and quantification of foulant–membrane interaction forces. Besides, NMR finding is a very effective method for determining pore size distributions of UF membranes with asymmetric pore structures.

iv. In terms of proteins separation performance, further research should be done by investigating the influence of operating parameters such as pH, concentrations of proteins. The study of surface charge (zeta potential) of the membranes is important to clarify the separation mechanism and transport studies at the membrane surface.

v. The study of flat-sheet membrane should be extended to hollow fiber membranes in continuous flow mode in order to achieve high performance membrane separation process to be used in a large-scale proteins separation process.