THE EFFECT OF COATING CONDITION AND AQUEOUS PHASE COMPOSITION ON THE PERFORMANCE OF THIN FILM COMPOSITE REVERSE OSMOSIS FLAT SHEET MEMBRANES

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ABSTRACT

Thin film composite (TFC) layers are formed using interfacial polymerization reaction between an aqueous phase and organic phase on membrane supports. In the preparation of thin film composite membrane, there are many interfacial reaction factors that influence the membrane performance, amongst them are dipping time, curing temperature and composition of aqueous phase. Thus in this project these factors were studied in two stages. In the preliminary stage, the effect of dipping time and curing temperature on the performance of TFC membrane were evaluated using two different kinds of polymer membrane supports, cellulose acetate and polysulfone. Initial results revealed that dipping time does not affect the performance of TFC membranes especially rejection rate but curing temperature have significant influence. Curing temperature ranging from 40°C to 100°C was used during the interfacial reaction process. Cellulose acetate TFC membranes cured at 60°C exhibited highest rejection rate of 76% whilst polysulfone TFC membranes cured at 80°C showed not only highest rejection rate of 80% but also excellent flux rates. Since polysulfone TFC membranes showed superior performance compared to cellulose acetate, it is chosen for the second stage of the experiment. In this stage, a systematic experimental design based on the response surface methodology was used to identify the significant interfacial reaction factors which influence the membrane performance. The factors considered were the composition of aqueous phase that includes the ratio of *m*-phenyldiamine to hydroquinone as monomer, percent of tetrabutylammonium bromide as a catalyst and percent of sodium hydroxide as an acid acceptor. Rejection and flux rates were the response variables investigated. The experimental results indicate that the proposed mathematical model suggested could adequately describe the performance indicators within the limits of the factors that are being investigated.

ABSTRAK

Membran komposit filem nipis dihasilkan melalui tindak balas pempolimeran antara muka di antara fasa akuas dengan fasa organik di atas permukaan membran penyokong. Dalam penyediaan membran komposit filem nipis, terdapat beberapa faktor yang mempengaruhi antaranya masa pencelupan dalam fasa akuas dan suhu rawatan. Oleh itu melalui penyelidikan ini, kesan faktor-faktor tersebut dikaji melalui dua peringkat. Melalui peringkat pertama, kesan masa pencelupan dalam fasa akuas dan suhu rawatan diuji di atas dua jenis membran penyokong iaitu polisulfona dan selulosa asetat. Keputusan awal menunjukkan masa pencelupan dalam fasa akuas tidak mempengaruhi pekali penyingkiran secara siknifikan tetapi mempengaruhi kadar fluks. Suhu rawatan didapati mempengaruhi prestasi membran pada keseluruhannya Suhu rawatan di antara 40°C hingga 100°C diaplikasikan dalam penyediaan membran komposit filem nipis. Pekali penyingkiran untuk membran komposit selulosa asetat pada suhu 60°C menunjukkan keputusan tertinggi iaitu 76% manakala membran komposit polisulfona pada suhu rawatan 80°C bukan sahaja mencapai pekali penyingkiran yang lebih baik iaitu 80% malahan menunjukkan kadar fluks yang tinggi. Memandangkan prestasi keseluruhan membran polisulfona didapati lebih baik, lalu ia diaplikasikan pada peringkat seterusnya. Pada peringkat kedua, rekabentuk eksperimen dipilih berdasarkan kaedah tindak balas permukaan bagi mengenalpasti faktor dalam tindak balas antara muka yang sangat mempengaruhi prestasi membran. Faktor yang dipilih ialah nisbah *m*-phenildiamina terhadap hidrokuinon sebagai monomer, peratus tetrabutilammonium bromida sebagai katalis dan peratus natrium hidroksida sebagai asid penerima. Pekali penyingkiran dan kadar fluks dipilih sebagai reaksi variasi. Keputusan eksperimen menunjukkan model matematik yang dicadangkan cukup untuk menjadi penunjuk prestasi daripada keseluruhan faktor yang dikaji.

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LIST OF SYMBOLS

A	-	Pure water permeability constant (g-mol/cm^{2}sPa)
c_{Bm}	-	Concentration of water in membrane (mol/m^3)
c_1, c_2, c_3		Molar density of feed solution, concentrated boundary solution and product solution respectively (g-mol/m^3)
D_{BM}	-	Diffusion coefficient of water in the membrane (m^2/s)
$\frac{D_{AM}}{K\delta}$	-	Solute transport parameter (m/s)
FR		Flux rate (m^3/m^{2}day)
f'		True value of solute separation by membrane pore
G	-	Gas constant (8.314J/mol K)
J_v	-	Water flux (mol/m^{2}s)
J_A	-	Solute flux (mol/m^{2}s)
J_B	-	Solvent water flux (mol/m^{2}s)
k	-	Mass transfer coefficient on the high pressure side of membrane (m/s)
ℓ_p	-	Hydrodynamic permeability coefficient (m/skPa)
M_W	-	Molecular weight of water (kg/kmol)
P	-	Pressure (Pa)
P_A	-	Reflection coefficient solute (m^2/s)
P_B	-	Reflection coefficient water (m^2/skPa)
PWP	-	Pure water permeability through effective area of membrane surface (m^3/m^{2}day)
R	-	Fraction of solute separation (%)
S	-	Effective membrane area (cm^2)

T	-	Absolute temperature (Kelvin)
v_B	-	Molar volume of water (m^3/mol)
X_{A1}, X_{A2}, X_{A3}		Mole fraction of feed solution, concentrated boundary solution and product solution respectively (g-mol/cm^3)
ΔP	-	Pressure different across membrane (Pa)
Δx	-	Membrane thickness (m)
$\Delta \pi$	-	Osmotic pressure different across the membrane (Pa)

Greek letters

σ	-	Reflection coefficient
ω	-	Solute permeability coefficient (kmol/m^2skPa)
π	-	Osmotic pressure of solution (Pa)
$b(\rho)$	-	Dimensionless friction function
ϕ		Potential in the interfacial force field
$\phi(\rho)$	-	Dimensionless potential function
β_2	-	Dimensionless operating pressure
$\alpha(\rho)$	-	Dimensionless solution velocity profile in the pore
β_1	-	Dimensionless solution viscosity

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CHAPTER 1

INTRODUCTION

1.1 Overview

Membrane technology is still evolving and finding more and more applications in a broad range of fields and the development of membranes will strongly influence separation process in the future. Rapid growth in membrane technology development is primarily based on consciousness on the potential of this technology. The technology contributes to the solution of some of the most crucial problem nowadays. It has been widely used in many applications like industrial wastewater treatment, desalination of sea and brackish water and liquid food treatment.

In membrane separations, each membrane has the ability to transport one component more readily than the other because of differences in physical and chemical properties between the membrane and the permeating components. Furthermore, some components can freely permeate through the membrane, while others will be retained. The stream containing the components that permeate through the membrane is called permeate and the stream containing the retained components is called retentate. The transport of permeate across the membrane is achieved by the application of either mechanical, chemical, electrical or thermal works (Scott, 1998).

Reverse osmosis is a well-developed industrial membrane separation processes. This process is well established and the market is served by a number of experienced companies. The separation process for reverse osmosis (RO) is not restricted to aqueous based solution, but it can essentially separate all solute species both inorganic and organic from solution. It involved the application of mechanical pressure without using any other energy like heat. Thus, RO is energy-saving separation process and indirectly reduce the cost of operation. The use of RO encompasses a variety of industries especially in the desalination to produce potable water.

Desalination of sea or brackish water entails forcing salt solution through a permselective membrane at pressure, which is sufficiently high to overcome the osmotic forces and tends to drive water in the opposite direction. These membranes must allow water to permeate at high rate but must reject permeation of the salt molecules to a high degree.

A breakthrough of RO membranes to industrial applications begun in 1960 with the invention of the first integrally skinned asymmetric cellulose acetate hyperfiltration membrane by Loeb and Sourirajan (Kesting, 1985). This membrane consist of a very dense top layer or skin with thickness of 0.1 to 0.5μm supported by a porous sub layer with a thickness of about 50 to 150μm. These membranes combine the high selectivity of a dense membrane with the high permeation of a very thin membrane.

In 1970's, the first commercial composite reverse osmosis (RO) membrane was developed. The membrane consists of a very thin dense top layer, which is supported by a porous sub layer of a different material, which is quite different from the asymmetric cellulose acetate membrane where it is developed with two layers of the same material. The advantage of the so-called thin film composite (TFC) membrane is that each layer can be optimized independently to obtain optimal membrane performance with respect to selectivity, permeation rate and chemical and thermal stability.

1.2 Background of the Problem

Thin film composite (TFC) membrane was developed by a combination of two or sometimes three layers that were made of totally different material, structure and function. A thin dense active layer consists of a very thin film supported by microporous support reinforced onto polyester fabric. In laboratory studies, the microporous layer need not actually be directly coated onto a fabric base, as it is proved to be difficult and inconvenient when done by hand (Peterson, 1993). Rather the microporous film can be casted on a glass plate because the fabric base is responsible for the formation of membrane defects as well as additional membrane pores (Berg and Smolders, 1990).

Microporous layer are commonly synthesized using phase inversion to develop an asymmetric membrane. It comprises almost the entire thickness and provides the required mechanical strength. Polysulfone are commonly used as membrane polymer because of their high performance, tough and has high temperature and chlorine resistant characteristic. Polysulfone is a hydrophobic polymer thus hydrophilic polymer such as polyvinylpyrrolidone and n-2-methylpyrrolidone are added as solvents.

Several techniques can be used to apply an ultrathin active layer upon a support like dip coating, spray coating, spin coating, interfacial polymerization, plasma polymerization and grafting, but the interfacial polymerization concept has been predominated as the optimal system (Peterson, 1993). Thin film composite structure membranes fabricated via interfacial polymerization meet this demand. The two phases that are involved in interfacial polymerization process includes aqueous phase and organic phase to form the active layer having semi permeability. The material as well as polymer molecular structure of the polymer in both of the two phases influenced the permeation properties of membrane performance (Arthur, 1989).

The successful interfacially membrane formed by Cadotte at Northstar Research in 1978 consists of a combination of aromatic amines with *aromatic* acyl chloride (Peterson, 1993). Best result was obtained by the reaction of *m*-phenylenediamine as aqueous phase and trimesoyl chloride as organic phase. The TFC polyamide membrane that is composed of a fully aromatic network structure was dominated as an outstanding recipe to produce good rejection rate and at the same time acceptable water permeability.

Polyamides have excellent intrinsic separation characteristics for reverse osmosis, however their chlorine tolerance is relatively low (Kawaguchi and Tamura, 1984; Tran *et al.*, 1989). Chlorine was widely added to water as a disinfectant and bactericide. A membrane is considered chlorine resistant, when it can withstand exposure for several years in a biocidal concentration of 1mg/l chlorine (Rajinder, 1994). Many attempts have been made to improve the chlorine resistant of composite membrane by changing molecular structure of the monomers used for the polymerization.

Blais (1977) has reported the correlation between chemical structure and membrane performance of polyamides. Few studies have been done to investigate the correlation between chemical structure of polyamides and their oxidation resistance (Kawaguchi and Tamura, 1984). Glater *et al.* (1983) have recently reported the sensitivity of polyamide to halogen disinfections by monitoring the decay of the membrane performance. A more extensive study of model-compound chlorine sensitivity was reported by Lowell *et al*. (Glater *et al.*, 1994). He found that ester linkages were generally chlorine resistant, in agreement with Jayarani and Kulkarni (2000) when they developed composite membrane with the incorporation of hydroquinone as an ester linkage. The membrane named as composite polyesteramides showed higher chlorine tolerance compared to commercial composite polyamide. Thus, based on these references, this study is aimed to develop TFC polyesteramide membrane by interfacial polymerization of aromatic amines in the presence of aromatic diol as ester linkages with *aromatic* acyl chloride on a microporous support.

Available TFC reverse osmosis membranes in the market, are highly effective in their intended application for desalination and industrial process water due to continuing searching for new and improved polymers for RO membrane materials (Jian and Ming, 1987; Ibbora *et al.*, 1996). To date, most of the research done was to improve thin film composite membrane performance by changing the structure of membrane monomer or the coating conditions. A few researchers studied the effect of polyamide molecular structure on the performance of reverse osmosis membrane (Cadotte, 1981; Hirose *et al.,* 1997). Roh *et al.* (2002) observed the influence of rupture strength of thin film structure, whilst Arthur (1989) investigated the structure and properties relationship of the thin film composite membrane.

The relationship between separation properties and coating condition is of particular importance for the development of new TFC membrane (Kim *et al.*, 2000; Rao *et al.*, 2003). The exact coating condition is important for attaining the desired stability of thin film composite membranes. This stability is important to give high water permeability and rejection rate. Thus, the major emphasis now seem to be focused on optimizing the membrane coating conditions and also to study how these conditions effect the structural changes on membrane formation of TFC membrane so as to enhance separation properties.

Most of the research work done previously had studied the performance of TFC membrane using polysulfone as a porous support. Literature search seem to suggest that there has been no study using cellulose acetate as a porous support for the TFC membranes. Thus, this study investigates the possibility of using cellulose acetate as a porous support and compares its performance with polysulfone microporous support membrane. Cellulose acetate was preferably used as a microporous support because of its low cost and low tolerant to chlorine reaction. In cellulose acetate, spaces in water swollen polymer matrix were the primary provider of continuous flow channel that contribute to the separation of salt and small organic molecules (Khulbe *et al*., 2002).

The growth of the interfacially polymerized film was influence by aqueous phase composition (Bartels and Kreuz, 1987; Bartels, 1989). Until now, not much has been said regarding the effect of the composition of aqueous phase such as the effect of the catalyst and acid acceptor on the performance of membrane. The catalyst is one of the factors affecting the reverse osmosis performance of the membrane (Wang, 1988a). The highest permeation rate was obtained in the presence of catalyst in the membrane recipe.

The aqueous phase consists of alkaline amine solution, particularly when caustic is used as an acid acceptor. Acid acceptors are commonly added in aqueous phase as a neutralizer for hydrogen halide generated during the course of the reaction. A study of acid acceptor showed that base strength of the acid acceptor affected the degree of concurrent hydrolysis (Cadotte, 1979). A small amount of acid acceptor is enough in the preparation of TFC membrane.

Most of the previous research on membrane performance usually use one-factor-at-a-time experimental approach which can be time consuming and exorbitant in cost (Haaland, 1989). The conventional practice consisting in varying one variable at time does not allow evaluation of the combined effects of all the factors involved in the process and constitutes a time consuming methodology (Cochran and Cox, 1992). Recently, statistically approach was increasingly used for optimization steps in membrane process. Ismail and Lai (2004) developed the defect free asymmetric polysulfone membranes for gas separation using response surface methodology. Ani *et al.* (2002) has used the Taguchi method which is a statistical design to determine the significant factors affecting the spinning process and the optimal spinning parameter. Chau *et al.* (1995) had studied phase inversion factors influencing polysulfone ultrafiltration hollow fiber membranes fabrication in a systematic manner using the orthogonal array method, whilst Pesek and Koros (1994) studied the influence of four factors in production of gas membranes using the complete 2^k factorial methods.

Thus in this study an attempt is made to investigate the composition effect of the aqueous phase used on the interfacial polymerization of TFC reverse osmosis membrane performance using RSM. This research continues the quest for producing practical thin composite membrane with high rejection and flux rates. Emphasis is however placed towards studying the effect of the concentration of monomer, catalyst and acid acceptor in view of the fact that only a considerable amount of research had been done in this area. Using the RSM method, parameter interaction and optimum composition can also be determined. This work has demonstrated the use of a central composite design (CCD), which is the most popular class of RSM design. The rejection and flux rates were the response variables investigated.

Membrane morphology is very much related to the membrane performance. Recent advances in microscopy have led to attempts to correlate surface characteristics to the performance of membrane. Scanning electron microscopy (SEM) and atomic force microscopy (AFM) can provide direct characterization of membrane morphology with the aid of image analysis. The scanning electron microscopy (SEM) is a powerful tool to investigate the morphology of membranes. SEM not only views the cross-section of the membrane, but also shows the surface of the top layer and bottom layer of the membrane. Recently, atomic force microscopy (AFM) became popular and many AFM pictures of reverse osmosis membrane surface had been taken in attempts to relate morphology to membrane performance. Hirose *et al.* (1996) found a relationship between the flux of reverse osmosis membranes and their roughness parameters measured by AFM. According to their experiments, an increase in surface roughness resulted in a higher water permeation flux. This theory was confirmed by consequent research (Gao and Chen, 1998). Thus, in this study, an attempt is also made to correlate membrane morphology and membrane performance using SEM and AFM.

1.3 Objective of the Study

The objectives of the research are to investigate the effect of coating conditions such as dipping time and curing temperature on the TFC membranes performance using both cellulose acetate and polysulfone as the microporous support. The performances of these membranes were then compared. Consequently, the effect of aqueous phase composition such as monomer ratio, concentration of acid acceptor and catalyst is studied on using RSM central composite design (α=2) in order to identify the significant factors and to develop a mathematical model thus enabling the prediction of responses. Finally, the correlation of membrane morphology with fabrication conditions was studied to extend knowledge for producing high rejection and flux rate thin film composite membrane.

1.4 Scope of the Study

In order to obtain the objectives listed above, the scope of the study are identified as follows:

i. The active layer of TFC membranes is prepared using interfacial polymerization method, while the asymmetric microporous membranes were prepared using phase inversion methods. The microporous material comprises of two polymers, polysulfone or cellulose acetate. Various dipping and curing condition were used so as to determine their effects on the performance of TFC membranes.

ii. Membrane permeation study was evaluated in terms of rejection rate and flux rate. Transport properties were also determined using transport parameter equation by Kimura-Sourirajan analysis, while membrane morphology was characterized using scanning electron microscopy (SEM).

iii. Influencing factors such as ratio of monomer, percent of catalyst and percent of acid acceptor were studied using RSM, using the membrane with the favorable performance based on initial finding i) and ii). A total of 20 experiments were carried out and tested in a dead end permeation cell to obtain the flux and rejection rate, which are the response variables. This response variables obtained was evaluated and analyzed using response surface methodology so as to determine the significant factors. Based on the significant factors identified, the relationship of each factor with the response variable was determined so as to predict the mathematical model.

iv. Finally, atomic force microscopy was used to correlate the relationship between membrane structure and membrane performance.

1.5 Outline of the Thesis

The thesis is basically divided into five chapters. An overview, background of the problem, research objective and scope of this research are presented in Chapter 1. A comprehensive literature review had been carried out prior to any experimental work. Literature review was conducted in providing state of the art background to the research project and these were discussed in detail in Chapter 2. Chapter 3 provides preliminary studies for coating condition and comparison between cellulose acetate and polysulfone as porous support. In this chapter, membrane performance in term of rejection rate, flux rate, transport properties and membrane morphology was identified and discussed. Chapter 4 presents the application of response surface methodology in describing significant factor affecting TFC production, clarify the interaction between parameters and proposed mathematical models for predicting TFC membrane performance. The membrane morphology was also characterized. Finally, Chapter 5 discusses the overall objective of this research and concludes the outcome of research project. Some recommendation for future studies also discussed. The schematic diagram summarizing the overall methodology experimental is shown in Figure 1.1.

REFERENCES

Adinarayana, K. and Ellaiah, P. (2002). Response Surface Optimization of the critical Medium Components for the Production of Alkaline Protease by a New Isolated *Bacillus sp*. *Journal Pharm Pharmaceutical Science*. 5(3): 272-278.

Agresti, A. (2002). *Categorical Data Analysis*. 2th ed. New York: Wiley Interscience.

Ahmad, A. L. Ooi, B. S. and Choudhury, J. P. (2003). Preparation and Characterization of Co-Polyamide Thin Film Composite Membrane from Piperazine and 3,5-diaminobenzoic Acid. *Desalination*. 158: 101-108.

Akhnazarova, S. and Kafarov, V. (1982). *Experiment Optimization in Chemistry and Chemical Engineering*. Moscow: Mir Publications.

Allegrezza, L. E., Parekh, B. S., Parise, P. L., Swiniarski, E. J. and White, J. L. (1987). Chlorine Resistant Polysulfone Reverse Osmosis Module. *Desalination*. 64: 285-304.

Amago, T. (2002). Report Sizing Optimization using Response Surface Method in FOA. *R&D Review of Toyota CRDL*. 37(1).

Ani, I., Ismail, A. F., Iswandi, S. and Shilton, S. J. (2001). Effect of Methanol Concentration on the performance of Asymmetric Cellulose Acetate Reverse Osmosis Membrane using Dry/Wet Phase Inversion Technique. *Jurnal Teknologi* 34 (F): 39-50.

Ani, I., Ismail, A. F., Noordin, M. Y. and Shilton. S. J. (2002). Optimization of Cellulose Acetate Hollow Fiber Reverse Osmosis Membrane using Taguchi Method. *Journal of Membrane Science*. 205: 223-237.

Ani, I., Ismail, A. F., Norhayati , M. and Shilton S. J. (2003). Measurement of Rheologically Induced Molecular Orientation using Attenuated Total Reflection Infrared Dichroism in RO Hollow Fiber Cellulose Separation Performance. *Journal of Membrane Science*. 213: 45-54.

Applegate, L.E. and Antonson, C.R. (1972). In. Lonsdale, H. K. and Podall, H. K., eds. *Reverse Osmosis and Membrane Research*. New York: Plenum Press.

Arthur, S. D. (1989). Structure-Property Relationship in a Thin Film Composite Membrane. *Journal of Membrane Science.* 46: 243-260.

Baranowski, B. (1991). Non-equlibrium Thermodynamics as Applied to Membrane Trnasport. *Journal of Membrane Science*. 57: 119.

Bartels, C. R. (1989). Surface Science Investigation of Composite Membrane. *Journal of Membrane Science*. 45(3): 225.

Bartels, C. R. and Kreuz, K. L. (1987). Structure- Performance Relationships of Composite Membrane: Porous Support Densification. *Journal of Membrane Science*. 32: 291-312.

Belfer, S., Purinson, Y., Fainshtein, R., Radchenko, Y. and Kedem, O. (1998). Surface Modification of Commercial Composite Polyamide Reverse Osmosis Membranes. *Journal of Membrane Science.* 139: 175-181.

Belfort, G. and Altena, F. W. (1983). Toward an Inductive Understanding of Membrane Fouling. *Desalination*. 47: 105-127.

Berg, G. B. and Smolders, C. A. (1990). Flux Decline in Ultrafiltration Processes. *Desalination*. 77: 101-133.

Bessieres, A., Meireles, M., Coratger, R., Beauvillain, J. and Sanchez, V. (1996). Investigation of Surface Properties ofPolymeric Membranes by Near Field Microscopy. *Journal of Membrane Science*. 109: 271-284.

Bhattacharyya, D., and William, M. (1992). Theory- Revere Osmosis. In. Ho, W. and Sirkar, K. eds. *Membrane Handbook*. New York: Van Nostrand Reinhold. 269-280.

Bhattacharyya, D., Jevtitch, M., Schrodt., and Fairweather, G. (1986). Prediction of Membrane Separation Characteristics by Pore Distribution Measurements and Surface Force-Pore Flow Model. *Chemical Engineering Communications*. 42: 111-128.

Bhattacharyya, D., William, M. E., Ray, R. J. and Mc Cray. (1992). Reverse Osmosis: Design. In. Ho. W. and Sirkar, K. eds. *Membrane Handbook*. New York: Van Nostrand Reinhold.

Blais, P. (1977). Polyamide Membranes. In: Sourirajan, S. ed. *Reverse Osmosis and Synthetic Membranes*. Ottawa, Canada: National Research Council. 167-208.

Box, G. E. P. and Wilson, K. G. (1951). On the Experimental Attainment of Optimal Conditions. *Journal of Royal Statistical Society*. 1-45.

Box, G. E. P., Hunter, W. G. and Hunter, J. S. (1978). *Statistic for Experiments*. New York: John Wiley and Sons. 291-334.

Box, G. E. P. and Draper, N. R. (1987). *Empirical Model-building and Response Surface*. New York: John Wiley and Sons.

Bowen, W. R. (2002). The Use of Atomic Force Microscopy to Quantify Membrane Surface Electrical Properties. *Colloids and Surface A: Physichemical and Engineering Aspects.* 201: 73-83.

Bowen, W. R., Hilal, N., Lovitt R. W. and Wright, C. J. (1999a). Atomic Force Microscopy Studies of Membrane Surface Surfactant. *Surface Chemistry Electrichemistry Membrane*. 79: 1-37.

Bowen, W. R., Hilal, N., Lovitt R. W. and Wright, C. J. (1999b). Quantification of Membrane Properties using an Atomic Force Microscopy – Identifying the Perfect Membrane. Toronto: *Proc. ICOM'99*, 6: 12-18.

Brandt, D. C., Leitner, G. F. and Leitner, W. E. (1993). Reverse Osmosis Membranes State of The Art. In: Amjad, Z. ed. *Reverse osmosis: Membrane Technology, Water Chemistry and Industrial Application*. New York: Van Nostrand Reinhold. 1-32.

Budavari, S., O'Neil, M. J., Smith, A., Heckelman, P. E. and Kinneary, J. F. (1996). *The Merk Index*. 12th ed. New York: Merk and Co., Whitehouse Station. 1477-1478.

Cabasso, I., Klein, E. and Smith, J. K. (1977). Polysulfone Hollow Fiber. II. Morphology. *Journal Applied Polymer Science*. 21(1): 165-180.

Cadotte J. E. (1985a). Development of Composite Reverse Osmosis Membrane in Retrospect. *Membrane*. 10: 117-127.

Cadotte, J. E. (1985b). Evolution of Composite Reverse Osmosis Membrane. In: Lloyd, D.R. ed. *Materials Science of Synthetic Membranes*. Washington, D.C.: American Chemical Society. 273-294.

Cadotte, J. E., Peterson, R. J., Larson, R. E. and Erikson (1980). A New Thin Film Composite Seawater Reverse Osmosis Membrane. *Desalination*. 32: 25-31.

Cadotte, J. E. (1977). *Reverse Osmosis Membrane*. (U.S Patent 4, 039, 440).

Cadotte, J. E. (1981). *Reverse Osmosis Membrane*. (U.S. Patent 4, 259, 183).

Chadda, S. K., McCarry, B. E., Childs, R. V., Rogerson, C. V., Tse-Sheppy, I. O. and Dickson, J. M. (1987). Novel Thin Film Composite Membrane Containing Photoreactive Group Part I: Choosing the Photoreactive Group. *Journal of Applied Polymer Science*. 34(8): 2713-2732.

Chai, G.Y. and Krantz, W.B. (1994). Formation and Characterization of Polyamide Membrane Via Interfacial polymerization. *Journal of Membrane Science.* 93:175-192.

Chan, W. H., Lam-Leung, S. Y., Ng, C. F. and Wang, S. S. (1993). Synthesis, Characterization and Reverse Osmosis Performance of Poly(amide-sulfonamides). *Polymer.* 34: 4377-4381.

Chang, C. L. and Chang, M. S. (2004). Preparation of Multi-layer Silicone/ PVDF Composite Membranes for Pervaporation of Ethanol Aqueous Solution. *Journal of Membrane Science*. 228: 117-122.

Chau, J. L., Wang, S. S. and Guo, C. L. (1995). Pilot Production of Polysulfone Hollow Fiber for Ultrafiltration Polyethersulfone Hollow Fiber Membranes. *Industrial Chemical Research*. 34: 803-919.

Cochran W. G. and Cox G. M. (1992). *Experimental designs*. 2th ed. New York: John Wiley and Sons.

Coker, S and Sehn, P. (2000). Four Years Field Experience with Fouling Resistant Reverse Osmosis Membrane. *Desalination* 132: 211-215.

Cornell, J. A. (1990). *How To Apply Response Surface Methodology.* 2th ed. United States of America: ASQC. 8.

Cuzin, D. and Judas, D. (1989). *Polyesteramides, Polyethesteramides and Process for Preparation Therof*. (U.S. Patent 4, 839, 441).

Dai, Y. Jian, X. G. Liu, X. M. and Guiver, M. D. (2001). Synthesis and Characterization of Sulfanoted Poly(phthalazinone Ether Sulfone Ketone) for Ultrafiltration and Nanofiltration Membranes. *Journal Applied Polymer Science*. 79: 1685-1692.

Dai, Y. Jian, X. Zhang, S. and Guiver, M. D. (2002). Thin Film Composite (TFC) Membranes with Improved thermal stability From Sulfanoted Poly(phthalazinone ethet sulfone ketone) SPPESK. *Journal of Membrane Science*. 207: 189-197.

Das, M. N. and Giri, N. G. (1986). Design and Analysis of Experiments. 2th ed. New York: Wiley Interscience.

Davies, O. L. (1967). *Design and Analysis of Industrial Experimenters*. New York: John Wiley and Sons.

Desai, N. V., Rangarajan, R., Rao, A. V., Garg, D. K., Ankleshwaria and Mehta, M. H. (1992). Preliminary Investigation of Thin Film Composite Reverse Osmosis Developed from SAN as Support Membranes. *Journal of Membrane Science*. 71: 201-210.

Dickson, J. (1988). Fundamental Aspects of Reverse Osmosis. In: Parekh, B. S. ed. *Reverse Osmosis Technology: Application For High-Purity-Water Production*. New York: Marcel Dekkar.

Eckelt, J., Loske, S., Goncalves, M. C. and Wolf, B. A. (2003). Formation of Micro and Nanospheric Particles (filter dust) During The Preparation of Cellulose Acetate Membrane. *Journal of Membrane Science*. 212: 69-74.

Elimelech, M., Zhu, X., Childress, A. E. and Hong, S. (1997). Role of the Membrane Surface Morphology in Colloidal Fouling of Cellulose Acetate and Composite Polyamide Reverse Osmosis Membrane. *Journal of Membrane Science.*127: 101-109.

Evers, R. C. and Ehlers, G. F. L. (1967). Preparation and Thermal Properties of some Piperazine Polysulfonamides. *Journal Polymer Science* Part A- 1(5): 1797

Flemming, H. C. (1993). Mechanistic Aspects of Reverse Osmosis Membranes Biofouling and Prevention. In: Amjad, Z. ed. *Reverse osmosis: Membrane Technology, Water Chemistry and Industrial Application*. New York: Van Nostrand Reinhold. 163-199.

Freger, V., Gilron, J. and Belfer, S. (2002). TFC Polyamide Membranes Modified by Grafting of Hydrophilic Polymers : on FT-IR/AFM/TEM Study. *Journal of Membrane Science.* 209: 283-292.

Gao, Y. X. and Chen, Y. H. (1998). The Latest Development in Japan for NF, Low Pressure RO and Their Application. *Membrane Science Technology*. 18(5): 11-18.

Gilron, J., Belfer. S., Vaisanen, P. and Nystrom, M. (2001). Effect of Surface Modification on Antifouling and Performance Properties of Reverse Osmosis Membranes. *Desalination*. 140: 167-179.

Glater, J., Zachariah, M. R., McCray, S. B. and McCutchen, J. W. (1983). Reverse Osmosis Membrane Sensitivity to Ozone and Halogen Disinfectant. *Desalination.* 48: 1-16.

Glater, J., Hong, S. K. and Elimelech, M. (1994). The Search for a Chlorine-Resistant Reverse Osmosis Membrane. *Desalination*. 95: 325-345.

Gooding, C. H. (1985). Apply The Membrane Advantage. *Chemtech*. 6: 348-354.

Gotor, A. G., Bachir, S. I. and Baez, O. P. (1999). Transport Characterization in Flat Reverse Osmosis Membranes: Utilization of Kimura-Sourirajan Analysis Method for The Determination of Mass Transfer Coefficient *K*, Transport Parameter *DAM/Kδ* and Permeability Constant *A*. *Desalination*. 126: 115-118.

Haaland, P. D. (1989). *Experimental Design in Biotechnology*. New York: Marcel Dekker Inc.

Hair, J. F., Anderson, R. E., Tatham, R. L. and Black, W. C. (1995). *Multivariate Data Analysis With Reading*. 4th ed. USA: Prentice-Hall.

Harris, F. L., Humphreys, G. B. and Spiegler, K. S. (1976). Reverse Osmosis (hyperfiltration) in Water Desalination. In: Meares, P. ed. *Membrane Separation Process*. New York: Elsevier.

Heijnen, M. L. (1998). Membrane which Comprises a Blend of a Polysulfone or a Polyethersulfone and Polyethylene Oxide/ Polypropylene Oxide Substituted Ethylene Diamine. (U.S. Patent. 6,495,043).

Hilal, N., Mohammmad, A. W., Atkin, B. and Darwish, N. W. (2003). Using Atomic Force Microscopy Towards Improvement in Nanofiltration Membrane Properties for Desalination Pre-Treatment: A Review. *Desalination*. 157: 137-144.

Hirose, M., Ito, H. and Kamiyama, Y. (1996). Effect of Skin Layer Surface Structures on the Flux Behavior of RO Membranes. *Journal of Membrane Science*. 121: 209-215.

Hirose, M., Minamizaki, Y. and Kamiyama, Y. (1997). The Relationship Between Polymer Molecular Structure of RO membrane Skin Layers and Their RO Performances. *Journal of Membrane Science*. 123: 151-156.

İbanoğlu, Ş. and Ainsworth, P. (2004). Application of Response Surface Methodology for Studying the Viscosity Changes During Canning of Tarhana, a Cereal-based Food. *Journal of Food Engineering*. 64: 273-275.

Iborra, M. I. (1996). Effect of Oxidation Agent on Reverse Osmosis Membrane Performance to Brackish Water Desalination. *Desalination*. 108: 83-89.

Ismail, A. F. and Lai, P. Y. (2004). Development of Defect Free Asymmetric Polysulfone Membranes for Gas Separation using Response Surface Methodology. *Separation and Purification Technology*. 40: 191-207.

Jain, S. and Gupta, S. K. (2004). Analysis of Modified Force Pore Flow Model with Concentration Polarization and Comparison with Spiegler-Kedem Model in Reverse Osmosis System. *Journal of Membrane Science*. 232: 45-61.

Jayarani, M. M. and Kulkarni, S. S. (2000). Thin Film Composite Poly(esteramide)-Based Membranes. *Desalination.* 130: 17-30.

Jayarani, M. M., Rajamohanan, R. R., Kulkarni, S. S. and Kharul, U. K. (2000). *Desalination*. 130: 1-16.

Jenkin, M. and Tanner, M. B. (1998). Operational Experience with A New Fouling Resistant Reverse Osmosis Membrane. *Desalination*. 19: 243-250.

Ji, J., Sun, M., Fei, M. and Chen, J. (1989). Study on The Interaction Between Membranes and Organic Solutes by HPLC Method. *Desalination*. 71: 107-126.

Jian, S. and Ming, S. K. (1987). Crosslinked PVA-PS Thin Film Composite Membrane for RO. *Desalination.* 62: 395-403.

John, R. and Jea, J. K. (2002). Mechanical Properties and Reverse Osmosis Performance of Interfacial Polymerized Polyamide Thin Films. *Journal of Membrane Science*. 197: 199-210.

Jonsson, G. (1980). Overview of Theories for Water transport in UF/RO Membranes *Desalination*. 35: 21-38.

Kawakami, H., Mikawa, M. and Nagaoka, S. (1996). Gas Transport Properties In Thermally Cured Aromatic Polyimide Membranes. *Journal of Membrane Science.* 118: 223-230

Kawaguchi, T. and Tamura, H. (1984). Chlorine Resistant Membrane for Reverse Osmosis, I. Correlation between Chemical Structures and Chlorine Resistance of Polyamides. *Journal of Applied Polymer Science.* 29: 3359-3367.

Kedem, O. and Katchalsky, A. (1958). Thermodynamics Analysis of Permeability of Biological Membranes to Non-electrolyte. *Biochem. Biophys. Acta*. 27. 229-246.

Kelkar, A. A., Kulkarni, S. M. and Chaudhari, R. V. (2002). *Process for the Preparation of Polyesteramides*. (U.S.Patent 6,410,681).

Kenneth, D., and Burris, F. O. (1992). *Drying Cellulose Acetate Reverse Osmosis Membrane*. San Diego, California: Gulf General Atomic Inc.

Kesting, R. E. (1985). *Synthetic Polymeric Membranes: A Structural Perspective*. 2th ed. Irvine, California: McGraw Hill. 1-17.

Khayet, M. and Mengual, J. I. (2004). Effect of Salt Type on Mass Transfer in Reverse Osmosis Thin Film Composite Membranes. *Desalination*. 168: 383-390.

Khedr, M. G. (2002). Development of Reverse Osmosis Desalination Membranes Composition and Configuration Future Prospects. *Desalination*. 153: 295-304.

Khulbe, K.C., Matsuura, T. and Feng, C.Y. (2002). Study on Cellulose Acetate Membranes for Reverse Osmosis and polyethersulfone Membarnes for Ultrafiltration by Electron Spin Resonance Technique. *Desalination*. 148: 329-332.

Khuri, A. I. And Cornell, J. A. (1996). *Response Surface: Design and Analysis*. New York : Marcel, Dekkar, ASQC Quality Press.

Kim, H. T., Park, J. K. and Lee, K. H. (1996). Preparation, Characterization and Performance of Poly(acrylamidocaproic acid) Partially Neutralized with Calcium for Use in Nanofiltration. *Journal of Applied Polymer Science.* 60: 1800-1819.

Kim, J. K, Chowdhury, G. and Matsuura, T. (2000). Low Pressure Reverse Osmosis Performance of Sulfonated Poly (2,6-dimethyl-1-4-phenylene oxide) Thin Film Composite Membranes: Effect of Coating Conditions and Molecular Weight of Polymer. *Journal of Membrane Science*. 170: 43-52.

Kim, S. H. (2003). Design of TiO_2 Nanoparticle Self-assembled Aromatic Polyamide Thin Film Composite (TFC) Membrane as an Approach to Solve Biofouling Problem. *Journal of Membrane Science*. 211: 157-165.

Koops, G. H., Nolten, J. A., Mulder, M. and Smolders, C.A. (1993). Poly(vinyl chlorides) Polyacrylonitrile Composite Membranes for the Dehydration of Acetic Acid. *Journal of Membrane Science*. 81: 57-70.

Košutiĉ, K. Kaštelan-Kunst, L. and Kunst, B. (2000). Porosity of Some Commercial Reverse Osmosis and Nanofiltration Polyamide Thin Film Composite Membranes. *Journal of Membrane Science*. 168: 101-108.

Kulkarni, A., Mukherji, D. and Gill, W. N. (1996). Flux Enhancement by Hydrophilization of Thin Film Composite Membrane Reverse Osmosis Membrane. *Journal of Membrane Science*. 114: 39-50.

Kwak, S. Y. and Ihm, D. W. (1999). Use of Atomic Force Microscopy and Solid-state NMR Spectroscopy to Characterize Structure-Property-Performance Correlation in High Flux Reverse Osmosis Membranes. *Journal of Membrane Science*. 158: 143-153.

Lee, D. J., Choi, Y. K., Lee, S. B., Ahn, K. H. and Min B. R. (1998). The Analysis of Electric Properties of Thin Film Composite Reverse Osmosis Membrane with Wet Impedance Method. *Journal of Membrane Science.*150: 9-21.

Lee, L.S. and Huang, H.Y. (2003). Liquid-liquid Equilibrium Behaviour of Tetrabutylammonium Bromide, Benzene and Water Mixture. *Fluid Phase Equilibria*. 205: 133-147.

Lim, C. K., Kim, J. H., Roh, I. J. and Kim, J. J. (2000). The Changes of Membrane Performance with Polyamide Molecular Structure in the Reverse Osmosis Process. *Journal of Membrane Science.* 165: 189-199.

Loeb, S. and Sourirajan, S. (1962). Sea Water Demineralization by Means of an Osmotic Membrane. *Advances in Chemistry Series*. 38: 117.

Lonsdale, H. K. (1982). The Growth of Membrane Technology. *Journal of Membrane Science.* 10: 81-181.

Lu, X., Bian, X. and Shi, L. (2002). Preparation and Characterization of NF Composite Membrane. *Journal of Membrane Science*. 5302: 1-9.

Mason, E. A. (1991). From Pig Bladders and Cracked Jars to Polysulfonated: A Historical Perspective on Membrane Transport. *Journal of Membrane Science*. 60: 125-145.

Matsuura, T. (1994). *Synthetic Membranes and Membrane Separation Process*. Boca Raton : CRC Press. 131-270.

Matsuura, T. (2001). Progress in Membrane Science and Technology for Seawater Desalination- A Review. *Desalination*. 134: 47-54.

Matsuura, T. and Sourirajan, S. (1981). Reverse Osmosis Transport Through Capillary Pores Under The Influence of Surface Forces. *Ind. Eng. Chem. Process Des. Dev.* 20: 273-282.

Matsuyama, H., Bergmans, S., Batarseh, M. T. and Lloyd, D. R. (1998). Effect of Thermal History on Anistropic and Asymmetric membranes Formed by Thermally Induced Phase Separation. *Journal of Membrane Science.* 142: 27-42.

Mavrov, V. and Velikova, S. (1991). Transport Characteristics of the RO Thin Film Composite Membranes. *Desalination*. 83: 279-288.

Mazid, M. (1984). Mechanisms of Transport Through Reverse Osmosis Membrane. *Separation Science and Technology*. 19: 357-388.

Mehdizadeh, H. and Dickson, J. M. (1989). Theoritical Modification with Surface Force-Pore Flow Model for Reverse Osmosis Transport. *Journal of Membrane Science*. 42: 119-145.

Mohammad, A. W., Hilal, N. and Abu Seman, M. N. (2003). A Study on Producing Composite Nanofiltration Membrane with Optimized Properties. *Desalination.*. 158: 73-78

Mokhtar, A. (1994). *Analisis Regresi*. Kuala Lumpur: Dewan Bahasa dan Pustaka.

Mothgomery, D. C. (2001). *Design and Analysis of Experiments*. 5th ed. New York: John Wiley and Sons. 170-210.

Mukherjee, D. and Kulkarni, A., Gill, W. N. (1996). Chemical Treatment for Improved Performance of RO membranes. *Desalination*. 104: 239-249.

Mukherji, D., Kulkarni, A. and Gill, W. N. (1994). Flux Enhancement of Reverse Osmosis Membrane by Chemical Surface Modification. *Journal of Membrane Science*. 97: 231-249.

Mulder, M. (1996). *Basic Principles of Membrane Technology*. Dordrecht, Boston, London: Kluwer Academic.

Myers, R. H. and Montgomery, D. C. (2002) *Response Surface Methodology: Process and Product Optimization Using Designed Experiments*. 2th ed. New York: John Wiley and Sons.

Naaktgeboren, A. J., Snijders, G. J. and Gons, J. (1988). Characterization of New Reverse Osmosis Composite Membrane for Industrial Application. *Desalination*. 68: 223-2242.

Nakao, S. (1994). Determination of Pore Size and Pore Size Distribution: 3. Filtration Membrane. *Journal of Membrane Science*. 96: 131-165.

National Toxicology Program (NTP) (1989). *Toxicology and Carcinigenesis Studies of Hydroquinone* (CAS No. 123-31-9) in F344?N Rats and B6C3F, Mice (Gavage Studies). US. Bethesda. MD: Department of Health and Human Services, Public Health Service, National Institutes of Health. TR No. 366.

Neter, J., Kutner, M. H., Nachtsheim, C. J. and Wasserman, W. (1996). *Applied Linear Statistical Models*. 4th ed. Chicago: McGraw Hill.

Neplenbroek, A. M., Bargeman, D. and Smolders, C. A. (1992). Supported Liquid Membrane: Instability Effects. *Journal of Membrane Science*. 67: 121-132

Noble, R. D. and Stern, S. A. (1995). *Membrane Separation Technology: Principles and Application*. Amsterdam: Elsevier.

Pesek, S. C. and Koros, W. J. (1994). Aqueous Quenched Asymmetric Polysulfone Hollow Fiber Prepared by Dry/Wet Phase Separation. *Journal of Membrane Science*. 88: 1-19.

Peterson, R. J. (1993). Composite Reverse Osmosis and Nanofiltration Membranes. J*ournal of Membrane Science*. 83: 81-150.

Pinnau, I. and Koros, W. J. (1991). Structures and Gas Separation Properties of Asymmetric Polysulfone Membrane Made By Dry, Wet and Dry/Wet Phase Inversion. *Journal of Applied Polymer Science*. 43: 1491-1502.

Pinnau, I. and Peinemann, K. V. (1992). *Membrane Formation Workshop*. Kentucky: Lexington.

Porter, M. C. (1990). *Handbook of Industrial Membrane Technology*. New Jersey, USA: Noyes Publisher. 314-333.

Potts, D. E., Ahlert, R. C. and Wang, S. S. (1981). A Critical Review of Fouling of Reverse Osmosis Membanes. *Desalination*. 36: 235-264.

Push, W. (1986). Measurement Techniques of Transport Through Membrane *Desalination*. 59: 105-198.

Pusch, W. and Walch, A. (1986). Membrane Structure and its Correlation with Membrane Permeability. *Journal of Membrane Science.* 10: 325-360.

Rajinder, Singh. (1994). Characteristic of a Chlorine-resistant Reverse Osmosis Membrane. *Desalination*. 95: 27-37.

Rangarajan. R., Desai, N. V., Mody, D., Mohan and Rao, A. V. (1991). Development of Reinforced Polysulfone Membranes. *Desalination.* 85: 81-92.

Rao, A. P., Desai, N. N. and Rangarajan, R. (1997). Interfacially Synthesized Thin Film Composite RO Membranes for Seawater Desalination. *Journal of Membrane Science*. 124: 263-272.

Rao, A. P., Joshi, S. V., Trivedi, J. J., Devmurari, C. V and Shah, V. J. (2003). Structure-Performance Correlation of Polyamide Thin Film Composite Membranes: Effect of Coating Conditions on Film Formation. *Journal of Membrane Science.* 211: 13-24.

Razdan, U. and Kulkarni, S. S. (2004). Nanofiltration Thin Film Composite Polyesteramide Membranes based on Bulky Diols. *Desalination*. 16: 25-32.

Rautenbach, R. and Albrecht, R. (1989). *Membrane Process*. Chichester: John Wiley and Sons.

Rhim, J. W., Chowdary, G. and Matsuura, T. (2000). Development of Thin Film Composite Membranes for Carbon Dioxide and Methane Separation Using Sulfonated Poly (phenylene oxide). *Journal of Applied Polymer Science* 76: 735-742.

Riley R. L., Lonsdale H. K. and Lyons C. R. (1971). Composite Membranes for Seawater Desalination by Reverse Osmosis. *Journal of Applied Polymer Sceince.*15(5): 1267-

Riley, R. L., Lonsdale, H. K., Grang, L. D. and Lyons C. R. (1969). *Development of Ultrathin Membranes*. NTIS Report No.PB-207036.

Robinson, J. P., Tarleton, E. S. Millington, C. R. and Nijmeijer, A. (2004). Solvent Flux Through Dense Polymeric Nanofiltration Membranes. *Journal of Membrane Science*. 230: 29-37.

Roh, I. I. J., Kim, J. J. and Park, S. Y. (2002). Mechanical Properties and Reverse Osmosis Performance of Interfacially Polymerized Polyamide Thin Film. *Journal of Membrane Science*. 197: 199-210.

Roh, I. I. J. (2002). Influence of Rupture Strength of Interfacially Polymerized Thin Film Structure on the Performance of Polyamide Composite Membranes. *Journal of Membrane Science*. 198: 63-74.

Roh, I. I. J., Park, S. Y., Kim, J. J. and Kim, C. K. (1998). Effect of Polyamide Molecular Structure on The Performance of Reverse Osmosis Membrane. *Journal of Polymer Science*, *Part B: Polymer Physic*. 36: 1821-1830.

Scott, K. (1998). *Handbook of Industrial Membranes*. 2th ed. Oxford, UK: Elsevier Science Publishers.

She, J. and Shen, X. M. (1987). Crosslinked PVA-PS Thin Film Composite Membrane for Reverse Osmosis. *Desalination.* 62: 395-403.

Singh, S. Khulbe, K. C. Matsuura, T. and Ramamurthy, P. (1998). Membrane Characterization by Solute Transport and Atomic Force Microscopy, *Journal of Membrane Science*. 142: 111-127.

Soltanieh, M. and Gill, W. (1981). Review of Reverse Osmosis Membranes and Transport Model. *Chemical Engineering Communications*. 12: 230.

Song, Y., Sun, P., Laurence, L., Henry and Sun, B. (2005). Mechanisms of Structure and Performance Controlled Thin Film Composite Membrane Formation via Interfacial Polymerization Process. *Journal of Membrane Science*. unpublished.

Sourirajan, S. (1970). *Reverse Osmosis*. London: Logos Press Ltd.

Sourirajan, S. and Matsuura, T. (1985). *Reverse Osmosis / Ultrafiltration Process Principles*. Ottawa, Canada: National Research Council.

Spiegler, K. S. and Kedem, O. (1966). Thermodynamics of Hyperfiltration (RO): Criteria for Efficient Membranes. *Desalination*. 1: 311.

Srathmann, H. (1981). Membrane Separation Process (Review). *Journal of Membrane Science*. 9: 121-198.

Strano, M. S., Zydney, A. L., Barth, H., Wooler, G., Agarwal, H. and Foley, H. C. (2002). Ultrafiltration Membrane Synthesis by Nanoscale Templating of Porous Carbon. *Journal of Membrane Science*. 198: 173-186.

Sundet, S. A. Murphey, W. A. Speck, S. B. (1959). Interfacial Polycondensation: IX Polysulfonamides. *Journal Polymer Science*. 40: 389

Sung, C. S. P. (1981). A Modified Technique for Measurement of Orientation from Polymer Surfaces by Attentuated Total Reflection Infrared Dichroism. *Macromolecules*. 14: 291-594.

Suter, S. M. (1944). The Organic Chemistry of Sulfur. New York: John Wiley and Sons. 573

Tam, C. M., Matsuura, T., Tweddle, T. A. and Hazlett, J. D. (1993). Polysulfone Membrane. III. Performance Evaluation of Polyethersulfone-PVP Membranes. *Separation Science and Technology*. 28 (17&18): 2621-2633.

Tinghul, L., Chan, K., Matsuura, T. and Sourirajan, S. (1984). Determination of Interaction Forces and Average Pore Size and Pore Size Distribution and Their Effects on Fouling of Ultrafiltration Membranes. *Ind. Eng. Chem. Prod. Res. Dev*. 23: 116-124.

Tran, C. N., Chung, H. C. and Light, W. G. (1989). Chlorine-Resistant Semipermeable Membranes. (U.S. Patent 4,830,885).

Tran, C. N., Maldonado, A. C. and Somanathan, R. (1994). Method of Making Thin Film Composite Membrane. (U.S.Patent 5,358,745).

Trägårdh, G. (1989). Membrane Cleaning. *Desalination.* 71: 325-335.

Trushinski, B. J., Dickson J. M., Smyth, T., Childs, R. F. and McCarry, B. E. (1998). Polysulfonamide Thin Film Composite Reverse Osmosis Membranes. *Journal of Membrane Science.* 143: 181-188.

Trushinski, B. J., Dickson, J. M., Childs, R. F. and McCarry, B. E. (1993). Photochemically Modified Thin Film Composite Membrane. I. Acid and Ester Membranes. *Journal of Applied Polymer Science*. 48: 187-198.

Trushinski, B. J., Dickson, J. M., Childs, R. F. and McCarry, B. E. (1994) Photochemically Modified Thin Film Composite Membrane.II. Bromoethyl Ester, Dioxolan and Hydroxyethyl Ester Membranes. *Journal of Applied Polymer Science*. 54: 1233-1242.

Uemura, T., Himeshima, Y. and Kurihara, M. (1986). *Interfacially Synthesized Reverse Osmosis Membrane*. (U.S. Patent 4,761,234).

U.S. Environmental Protection Agency. (1987). *Health and Enviromental Effects Document for p-Hydroquinone*. ECNAO-CIN-G015. Enviromental Criteria and Assessment Office, Office of Health and Enviromental Assessment, Office of Research and Development, Cincinnati, OH.

Velikova, S., Dave, A. M., Mavrov, V. and Mehta, M. H. (1993). Comparative Evaluation of Industrial Membranes: Correlation Between Transport and Operationa Parameter. *Desalination*. 94: 1-10.

Voros, N. G., Maroulis, Z. B. and Marinous-Kouris, D. (1995). Salt and Water Permeability in RO Membranes. *Desalination*. 104: 141-154.

Vos, K. D. and Burris, Jr. F. O. (1969). Drying Cellulose Acetate Reverse Osmosis Membranes. *I & EC Product Research and Development*. 8 (1): 84-89.

Wang, W. (1988a). Composite Melamine-Formaldehyde-Fulfuralcohol Copolymerization Membrane for Reverse Osmosis. *Desalination*. 70: 137-142.

Wang, W. (1988b). Investigation of Performance of TMM-FA Composite for Reverse Osmosis. *Desalination*. 69: 235-239.

Wang, Y. W., Lau, W. L. and Sourirajan. S. (1994). Effects of Pretreatments on Morphology and Performance of CA (Formamide Type) Membranes. *Desalination*. 95: 155-169.

Wankat, P. C. (1990). *Rate- Controlled Separation*. New York: Elsevier. 631.

William, M. E. (2003). *A review of Reverse Osmosis Theory*. Williams Engineering Services Company, Inc.

Xu, T. J. and Ting, Y. P. (2004). Optimization on Bioleaching of Incinerator Fly Ash by *Aspergilus niger*- Use of Central Composite Design. *Enzyme and Microbial Technology*. 35: 444-454.

Yasuda, H. (1977). Composite Reverse Osmosis Membrane Prepared by Plasma Polymerization. In: Sourirajan. S. ed. *Reverse Osmosis and Synthetics Membranes*. Ottawa, Canada: National Research Council. 263-294

Zhang, S., Jian, X. and Dai, Y. (2005). Preparation of Sulfonated Poly(phthalazinine ether sulfone ketone) Composite Nanofiltration Membrane. *Journal of Membrane Science*. 246: 121-126.

Zhao, L., Zhu, L. and Lee, H. K. (2002). Analysis of Aromatic Amines in Water Samples by Liquid-liquid-liquid Microextraction With Hollow Fibers and High-performance Liquid Chromatography. *Journal of Chromatography A*. 963: 239-248.