Chapter 4 : Results and Discussions

4.1 Separation of Nickel (II) Sulfate

4.1.1 $NiSO_4$: Trans-membrane Pressure Drop and Permeate Flow Rate

The experiments were planned considering the typical concentration of Ni and Cr in wastewater from electroplating industries. Available information on the concentration of heavy metals in electroplating wastewater in the Klang Valley, Malaysia shows Ni and Cr contents in the range of 10 to 50 mg/L. In the present work, three different concentrations namely 10 mg/L, 30 mg/L and 50 mg/L were used to study the permeate flow rate as against the trans-membrane pressure drop in a pilot plant. The objective of this work is to study the economic viability of using membrane filter to recover heavy metals in concentrated form and water which is suitable for using in the process. All the experimental data reported here are based on the minimum and the maximum delivery rate of the feed pump in the membrane filtration system (Model B-14A-PT from Applied Membranes Inc.).

The characteristic curves for trans-membrane pressure drop vs. permeate flow rate for 3 different concentrations of Ni namely, 10 mg/L, 30 mg/L and 50 mg/L have been shown in Figures 4.1.1 (a), (b) and (c) respectively. The curves show a general trend in increasing permeate flow rate with increasing trans-membrane pressure drop. For the range of concentrations in the present study, it was observed that there was very little change in permeate flow rate with increasing trans-membrane pressure drop. This is perhaps due to the fact that at such low concentrations of Ni, concentration polarization does not play a significant role. For example, when the Ni concentration is 10 mg/L [Figure 4.1.1 (a)], the maximum trans-membrane pressure drop was observed as 482.0 kPa for the permeate flow rate of 7.57 x 10^{-5} m^3/s and the minimum trans-membrane pressure drop was 96.0 kPa for the permeate flow rate of 4.42 x 10^{-5} m^3/s. The increase in trans-membrane pressure drop against the permeate flow rate increases rather steadily up to a permeate flow rate of 7.57 x 10^{-5} m^3/s beyond which the curve assumes a steady value for the range of parameters in this experiment. This might be due to the high flux characteristic of membrane which results in rapid convection of retained solutes to the membrane surface leading to well known phenomenon of concentration polarization (Porter, 1972).

For higher Ni concentrations, e.g. 30 mg/L and 50 mg/L the characteristic curves for the trans-membrane pressure drop vs. permeate flow rate do not change significantly as shown in Figure 4.1.1 (b) and (c). For both the cases the rise in trans-membrane pressure drop was slow for permeate flow rates in the range of 5.05 x 10^{-5} m^3/s to 6.94 x 10^{-5} m^3/s. For Ni concentrations of 10 and 50 mg/L, the trans-membrane pressure drop attains a value close to 500.0 kPa at permeate flow rates 7.57 x 10^{-5} m^3/s or higher. However, for Ni concentration of 30 mg/L the trans-membrane pressure drop attains a value of 600 kPa at the same permeate flow rate of 7.57 x 10^{-5} m^3/s or higher. These values of trans-membrane pressure drop and permeate flow rate indicate the range of parameters such as trans-membrane pressure drop and permeate flow rate to be employed to decide upon the appropriate operating condition. A flow rate of 8.0 x 10^{-5} m^3/s is the maximum allowable flow rate for the equipment. In this experiment, the limiting permeate was 9.0 x 10^{-5} m^3/s beyond which cavitation and vibrations occured in the booster pump.

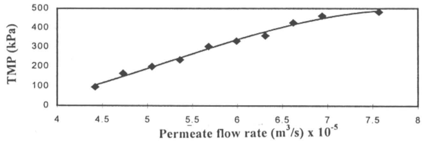


Figure 4.1.1 (a)

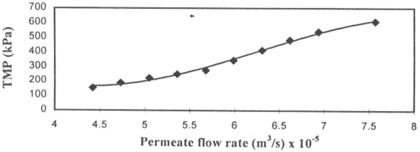


Figure 4.1.1 (b)

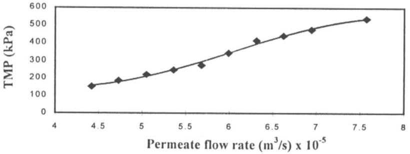


Figure 4.1.1 (c)

Figure 4.1.1 : Relationship between trans-membrane pressure drop (TMP) and permeate flow rate for $NiSO_4$

4.1.2 $NiSO_4$: Trans-membrane Pressure Drop and Ni in Permeate

As the trans-membrane pressure drop increases, the concentration of Ni in the permeate decreases. This behaviour is expected as for a given pore size distribution, a higher trans-membrane pressure drop would cause a relatively high permeation of water molecules than Ni salts. Experiments with feed concentrations of 10 mg/L and 30 mg/L exhibit the characteristic of curves which can be divided into three parts. For a Ni concentration of 10 mg/L as shown in Figure 4.1.2 (a), the minimum amount of Ni in permeate was 0.049 mg/L at a trans-membrane pressure drop of 482.0 kPa. When the trans-membrane pressure drop decreased, the concentration of Ni increased slowly until 330.0 kPa. In the range of 330.0 kPa to 120.0 kPa, the concentration of Ni increased rapidly and tended to a maximum level of 0.686 mg/L at 96.0 kPa. The same trend was observed for a feed concentration of 30 mg/L as shown in Figure 4.1.2 (b).

Starting from a concentration of 0.595 mg/L at a trans-membrane pressure drop of 152.0 kPa, the concentration of Ni in permeate decreased slowly with increasing trans-membrane pressure drop. In the range of 248.0 kPa to 345.0 kPa, the concentration of Ni in the permeate decreased rapidly from 0.475 mg/L to 0.148 mg/L . Further rise in trans-membrane pressure drop reduced Ni concentration and a minimum amount of 0.024 mg/L was obtained at a trans-membrane pressure drop of 606.0 kPa.

Figure 4.1.2 (c) shows an exponential curve for a feed concentration of 50 mg/L. A maximum concentration of 0.605 mg/L Ni was observed at the trans-membrane pressure drop of 152.0 kPa and the concentration decreased exponentially with increasing trans-membrane pressure drop. A minimum Ni concentration of 0.077 mg/L in permeate was obtained at a trans-membrane pressure drop of 538.0 kPa.

Similar observations were made by Paul (1972), Matsuura *et.al* (1981) and Mukherjee *et. al* (1996). In all these cases the solute in permeate decreased as the trans-membrane pressure drop was reduced. This phenomenon can be explained by the fact that both the solute and solvent molecules compete with each other to pass through the pores. Ni ions in the solution being larger in radii than water molecules, have a reduced chance to pass through a pore. When the trans-membrane pressure drop increases, the flow of water (solvent) increases as compared to that of Ni. Moreover, the smaller pores which contribute little to water permeation at low trans-membrane pressure drops also transmit significant amounts of water.

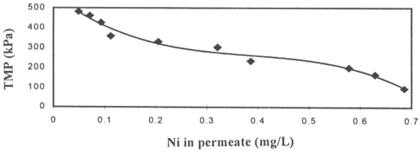


Figure 4.1.2 (a)

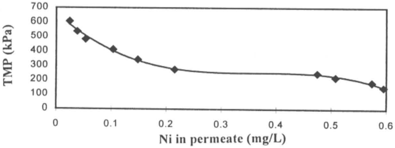


Figure 4.1.2 (b)

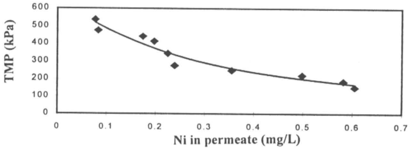


Figure 4.1.2 (c)

Figure 4.1.2 : Relationship between trans-membrane pressure drop (TMP) and Ni permeate for $NiSO_4$

4. 1. 3 $NiSO_4$: Transmembrane Pressure Drop and Ni in Concentrate

The effect of trans-membrane pressure drop on Ni in concentrate for feed concentrations of 10 mg/L , 30 mg/L and 50 mg/L are shown in Figures 4.1.3 (a), (b) and (c) respectively. For a Ni concentration of 10 mg/L in the feed , a minimum concentration of 11.519 mg/L of Ni in concentrate was observed at a transmembrane pressure drop of 96.0 kPa. The higher transmembrane pressure drop increased the amount of Ni in the concentrate and a rapid increase in Ni was observed until the trans-membrane pressure drop reached 428.0 kPa. Beyond this, the increment of Ni concentration slowed down as shown in Figure 4.1.3 (a). A maximum amount of 13.109 mg/L of Ni in concentrate was obtained at a trans-membrane pressure drop of 482.0 kPa.

Similar observations were made for feed concentrations of 30 mg/L and 50 mg/L of Ni. However, the initial and latter sections of the curve have a low gradient indicating a slow rise in Ni with respect to transmembrane pressure drop. In Figure 4.1.3 (b), for the feed concentration of 30 mg/L , the increment of Ni in concentrate started from minimum 33.575 mg/L at transmembrane pressure drop of 152.0 kPa and slowly increased until the transmembrane pressure drop reached 248.0 kPa. After this, the Ni concentration increased rapidly to 37.316

mg/L at a transmembrane pressure drop of 538.0 kPa. A maximum of 38.319 mg/L of Ni was obtained at a transmembrane pressure drop of 606.0 kPa.

For the feed concentration of 50 mg/L , Ni in concentrate starts with 57.123 mg/L at trans-membrane pressure drop of 152.0 kPa. The concentration increased rapidly with increasing transmembrane pressure drop until it reached a value of 476.0 kPa where the increment slowed down and a maximum concentration of 64.465 mg/L of Ni was obtained at 538.0 kPa.

The effect of transmembrane pressure drop on Ni in concentrate also indicates the influence of concentration polarization which causes the accumulation of Ni ions at the membrane surface. This accumulation increases with the increasing transmembrane pressure drop. These ions carry identical charge and exert a repulsive force among them. This results in reduction in the transmission of Ni through the membrane.

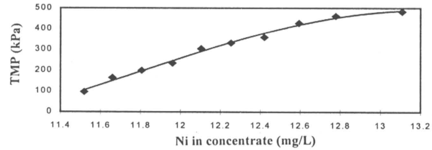


Figure 4.1.3 (a)

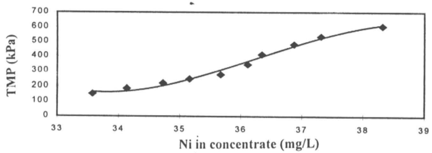


Figure 4.1.3 (b)

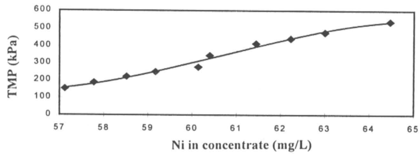


Figure 4.1.3 (c)

Figure 4.1.3 : Relationship between trans-membrane pressure drop (TMP) and Ni in concentrate for $NiSO_4$

4.1.4 $NiSO_4$: Flow Rate and Ni Concentration in Permeate

The increase in permeate flow rate showed reduction in Ni content in the permeate for all the three feed concentrations. Figure 4.1.4 (a) shows the relationship between permeate flow rate and transmembrane pressure drop for the feed concentration of 10 mg/L. A maximum concentration of 0.686 mg/L of Ni was obtained at the permeate flow rate of 4.42 x 10^{-5} m^3/s. The concentration of Ni decreased slowly with increasing permeate flow rate until a value of 5.05 x 10^{-5} m^3/s was reached. A rapid reduction in Ni concentration was observed until the permeate flow rate reached 6.31 x 10^{-5} m^3/s. A further rise in permeate flow rate to 7.57 x 10^{-5} m^3/s resulted in a Ni concentration of 0.049 mg/L. A similar result was obtained for a feed concentration of 30 mg/L as shown in Figure 4.1.4 (b). In this case the maximum concentration of Ni was 0.595 mg / L at a flow rate of 4.42 x 10^{-5} m^3/s. The concentration of Ni decreased slowly to 0.475 mg/L at a permeate flow rate of 5.36 x 10^{-5} m^3/s and beyond this flow rate, a rapid reduction in Ni concentration was observed which fell to 0.215 mg/L at a flow rate of 5.68 x 10^{-5} m^3/s. The Ni concentration in permeate reduced slowly and a minimum value of 0.024 mg/L was observed at 7.57 x 10^{-5} m^3/s. A feed concentration of 50 mg/L also gives an inverse relationship between the permeate flow rate and Ni in the permeate as shown in Figure 4.1.4 (c). Maximum amount of Ni in permeate was 0.608 mg/L at a flow rate of 4.42 x10^{-5}

m^3/s and dropped to a minimum level of 0.077 mg/L at a permeate flow rate of 7.57×10^{-5} m^3/s.

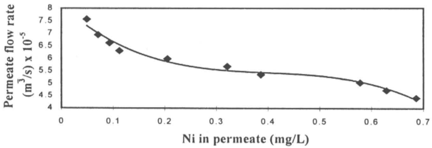


Figure 4.1.4 (a)

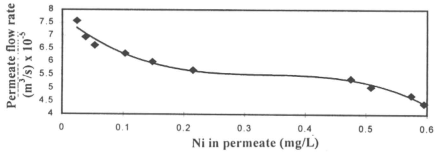


Figure 4.1.4 (b)

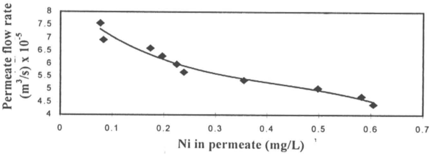


Figure 4.1.4 (c)

Figure 4.1.4: Relationship between flow rate and Ni in permeate for $NiSO_4$

4.2 Separation of Nickel (II) Chloride

4.2.1 $NiCl_2$: Trans-membrane Pressure Drop and Permeate Flow Rate

The experiments on nickel (II) chloride separation were carried out under the same conditions as for nickel (II) sulfate. The aim of the initial study was to establish the relationship between trans-membrane pressure drop and the permeate flow rate for different feed concentrations. The feed concentrations were maintained at 10 mg/L , 30 m/L and 50 mg/L . For a feed concentration of 10 m/L , a linear relationship was obtained as shown in Figure 4.2.1(a). The rise in trans-membrane pressure drop was proportional to the corresponding permeate flow rate. Starting with a permeate flow rate of 4.42 x 10^{-5} m^3/s and a transmembrane pressure drop of 193.000 kPa, a gradual increment was observed until a flow rate of 7.57 x 10^{-5} m^3/s and corresponding trans-membrane pressure drop of 661.700 kPa.

The relationship between the permeate flow rate and transmembrane pressure drop for a feed concentration of 30 mg/L is shown in Figure 4.2.1(b). A permeate flow rate of 4.42 x 10^{-5} m^3/s showed a transmembrane pressure drop of 213.700 kPa. The transmembrane pressure drop increased gradually to a value of 709.900 kPa corresponding to a permeate flow rate of 7.57 x 10^{-5} m^3/s. Figure 4.1.2(c) shows an increment from a flow rate of 4.42 x 10^{-5} m^3/s at a trans-membrane pressure drop of 248.100 kPa to the flow rate of 7.57 x 10^{-5} m^3/s at a trans-membrane pressure drop of 723.700 kPa for a feed concentration of 50 mg/L. In both the cases the transmembrane pressure drop increased linearly with the permeate flow rate. A further increase in the flow rate (> 7.5 x 10^{-5} m^3/s) caused cavitation in the pump and the unit became inoperable.

The observed transmembrane pressure drop vs. permeate flow rate characteristics for the three different feed concentrations have the similar linear pattern. This is expected as the permeate flow rate increases with the trans-membrane pressure drop. Owing to the limitation in the maximum allowable permeate flow rate of 7.5 x 10^{-5} m^3/s, the transmembrane pressure drop characteristics could not be observed at a higher permeate rate. According to the solution-diffusion models, the pressure differential induces a concentration gradient of liquid within the membrane, and transport proceeds by simple Fickean diffusion (Paul, 1972).

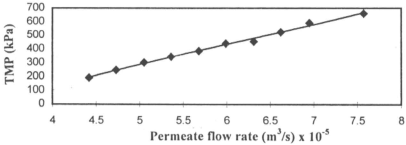


Figure 4.2.1 (a)

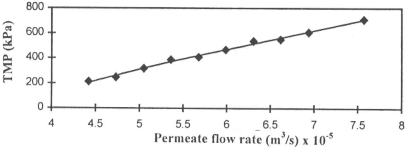


Figure 4.2.1 (b)

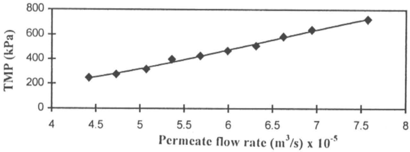


Figure 4.2.1 (c)

Figure 4.2.1: Relationship between trans-membrane pressure drop (TMP) and permeate flow rate for $NiCl_2$

4.2.2 $NiCl_2$: Trans-membrane Pressure Drop and Ni in Permeate

In general, Ni concentration in permeate declined with increasing transmembrane pressure drop. For a feed concentration of 10 mg/L [Figure 4.2.2(a)] ,a maximum amount 0.686 mg/L of Ni was obtained at the lowest trans-membrane pressure drop of 193.00 kPa. The concentration decreased slowly to 0.531 mg/L at 344.6 kPa and thereafter fell rapidly to 0.113 mg/L at 454.9 kPa. A minimum concentration of 0.018 mg/L was achieved at a trans-membrane pressure drop, 661.7 kPa.

In Figure 4.2.2(b), a similar curve for a feed concentration of 30 mg/L was obtained. At the trans-membrane pressure drop of 213.7 kPa, 0.695 mg/L of Ni was measured in the permeate. A further increase in trans-membrane pressure drop in the range of 386.0 kPa to 468.7 kPa, resulted in a drop in the Ni concentration from 0.480 mg/L to 0.140 mg/L . The lowest Ni concentration for this experiment was 0.015 mg/L at a trans-membrane pressure drop of 709.9 kPa.

Ni concentration vs. trans-membrane pressure drop characteristic for 50 mg/L nickel chloride is shown in Figure 4.2.2(c). The Ni concentration in the permeate is more uniform which starts from a concentration of 0.675 mg/L at 248.1 kPa. The Ni concentration was 0.021 mg/L at 723.7 kPa.

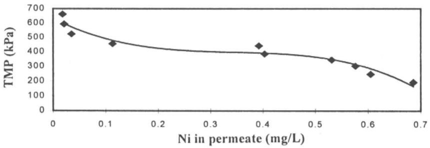
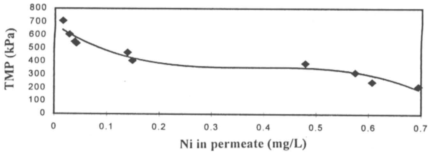


Figure 4.2.2 (a)



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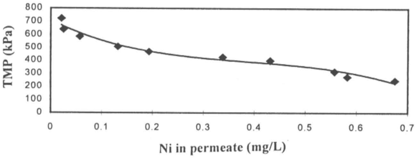

Figure 4.2.2 (c)

Figure 4.2.2 : Relationship between trans-membrane pressure drop (TMP) and Ni in permeate for $NiCl_2$

4.2.3 $NiCl_2$: Trans-membrane Pressure Drop and Ni in Concentrate

The Ni in concentrate increased with transmembrane pressure drop for three different feed concentrations. Figure 4.2.3 (a), (b) and (c) show the relationship between the trans-membrane pressure drop and Ni in concentrate for 10 mg/L , 30 mg/L and 50 mg/L respectively. A smooth curve for 10 mg/L Ni was obtained with a maximum amount of 12.819 mg/L Ni at a transmembrane pressure drop of 661.7 kPa.

For a feed concentration of 30 mg/L, a linear relationship was obtained for Ni in concentrate vs. the trans-membrane pressure drop. A maximum concentration of 38.115 mg/L Ni was obtained at a trans-membrane pressure drop of 709.9 kPa.

For a feed concentration of 50 mg/L, the concentration of Ni was the lowest at a transmembrane pressure drop of 248.1 kPa and gradually increased to 64.549 mg/L at 723.7 kPa.

The relationship which was observed above, is due to higher retention of solute at a higher trans-membrane pressure drop. A higher trans-membrane pressure drop enhances the flux rate as compared with the transmission of larger solute molecule.

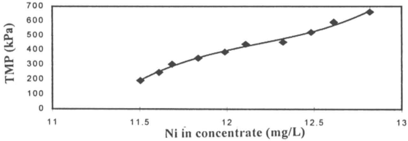

Figure 4.2.3 (a)

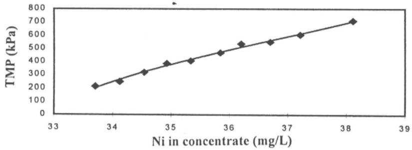

Figure 4.2.3 (b)

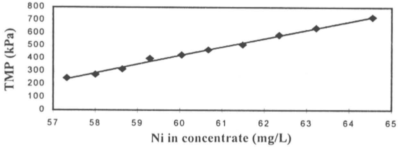

Figure 4.2.3 (c)

Figure 4.2.3 : Relationship between trans-membrane pressure drop and Ni in concentrate for $NiCl_2$

4.2.4 $NiCl_2$: Flow Rate and Ni Concentration in Permeate

The experimental data indicate that the concentration of Ni in the permeate increases as the trans-membrane pressure drop decreases. This was observed in all the three feed concentrations used in this experiment. As shown in Figure 4.2.4 (a), for a feed concentration of 10 mg/L, the maximum level of Ni in permeate is 0.686 mg/L at a permeate flow rate of 4.42 x 10^{-5} m^3/s. In the begining , the concentration of Ni fell slowly to a value of 0.392 mg/L and then, it dropped rapidly to 0.113 mg/L at a flow rate of 6.31 x 10^{-5} m^3/s. The amount of Ni continued to decline slowly until a minimum amount of 0.018 mg/L was obtained at permeate flow rate of 7.57 x 10^{-5} m^3/s.

For a feed concentration of 30 mg/L [Figure 4.2.4 (b)] , a maximum Ni concentration of 0.695 mg/L was observed at a flow rate of 4.42 x 10^{-5} m^3/s. The Ni concentration rapidly declined from 0.480 mg/L to 0.149 mg/L as the flow rate decreased from 5.36 x 10^{-5} to 5.68 x 10^{-5} m^3/s. A minimum concentration of, 0.015 mg/L of Ni was obtained at a permeate flow rate of 7.57 x 10^{-5} m^3/s.

At a feed concentration of 50 mg/L of Ni, the characteristic curve shows a gradual fall in Ni concentration with increasing permeate flow rate [Figure 4.2.4 (c)]. From a maximum concentration of 0.675 mg/L at 4.42 x 10^{-5} m^3/s, Ni concentration in permeate reduced to a minimum level of 0.021 mg/L at 7.57 x 10^{-5} m^3/s.

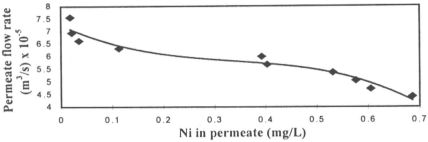

Figure 4.2.4 (a)

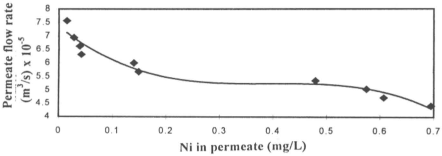

Figure 4.2.4 (b)

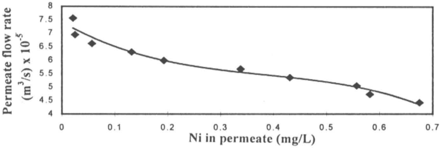

Figure 4.2.4 (c)

Figure 4.2.4 : Relationship between flow rate and Ni in permeate for $NiCl_2$

4.3 Separation of Chromium (III) Chloride

4.3.1 $CrCl_3$: Transmembrane Pressure Drop and Permeate Flow Rate

The effect of trans-membrane pressure drop on permeate flow rate shows the same trend as previous studies with nickel (II) sulfate and nickel (II) chloride. Figures 4.3.1 (a), (b) and (c) indicate the effect of transmembrane pressure drop on Cr concentration in the permeate obtained from this experiment. For a feed concentration of 10 mg/L, a smooth curve was obtained starting from a permeate flow rate of 4.42 x 10^{-5} m^3/s at 220.6 kPa. The permeate flow rate increased significantly with a trans-membrane pressure drop up to a flow rate of 7.57 x 10^{-5} m^3/s, corresponding to a trans-membrane pressure drop of 620.3 kPa.

The characteristic curve for feed concentrations of 30 mg/L and 50 mg/L showed a similar trend as shown in Figures 4.3.1(b) and 4.3.1(c) respectively. The permeate flow rate was 4.42 x 10^{-5} m^3/s for both concentrations at a trans-membrane pressure drop of 193.0 kPa. As the permeate flow rate increased slowly, a rapid increase in transmembrane pressure drop was observed for a feed concentration of 50 mg/L as compared to 30 mg/L. A transmembrane pressure drop of 606.6 kPa was observed at a permeate flow rate of 7.57 x 10^{-5} m^3/s for 30 mg/L of Ni in the feed, whereas 675.500 kPa was observed for 50 mg/L at the same permeate flow rate. The relationship is similar to the previous studies.

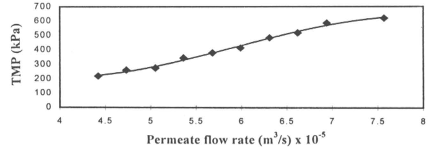

Figure 4.3.1 (a)

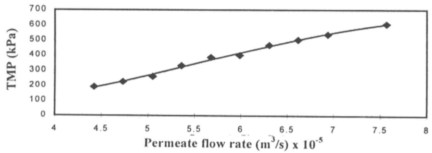

Figure 4.3.1 (b)

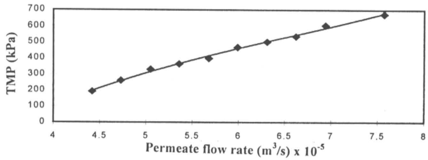

Figure 4.3.1 (c)

Figure 4.3.1 : Relationship between trans-membrane pressure drop and permeate flow rate for $CrCl_3$

4.3.2 $CrCl_3$: Trans-membrane Pressure Drop and Cr in Permeate

The effect of transmembrane pressure drop on the concentration of Cr in permeate was studied and it exhibited a similar behaviour as Ni salts. The concentration of Cr in permeate dropped as the transmembrane pressure drop increased. Figure 4.3.2(a) shows the declining concentration of Cr from a maximum concentration of 0.237 mg/L at 220.6 kPa for a feed concentration of 10 mg/L. The concentration reduced to a level of 0.008 mg/L at a trans-membrane pressure drop of 620.0 kPa.

For a feed concentration of 30 mg/L , a maximum concentration of 0.456 mg/L was obtained at a trans-membrane pressure drop of 193.0 kPa [Figure 4.3.2(b)]. The concentration reduced to a minimum level of 0.083 mg/L at a trans-membrane pressure drop of 606.6 kPa.

Figure 4.3.2(c) shows the characteristic curve for a feed concentration of 50 mg/L. The concentration decreased slowly from a maximum value of 0.641 mg/L at 193.0 kPa. The concentration of Cr dropped rapidly from 0.562 mg/L to 0.431 mg/L corresponding to the trans-membrane pressure drop of 330.8 kPa to 60.6 kPa respectively. A minimum concentration of 0.095 mg/L Cr was obtained for transmembrane pressure drop of 675.5 kPa.

The concentration of Cr in the permeate decreased as the transmembrane pressure drop increased . Ni salts demonstrated similar characteristics and this phenomenon has been already explained.

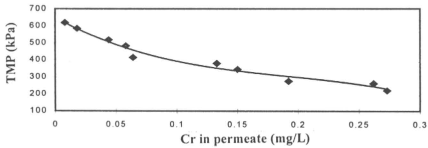

Figure 4.3.2 (a)

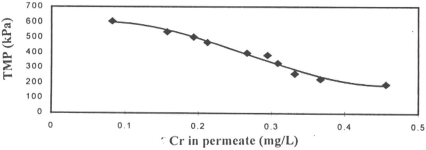

Figure 4.3.2 (b)

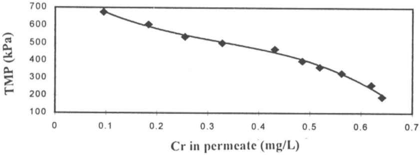

Figure 4.3.2 (c)

Figure 4.3.2 : Relationship between trans-membrane pressure drop and Cr in permeate for $CrCl_3$

4.3.3 $CrCl_3$: Trans-membrane Pressure Drop and Cr in Concentrate

In case of Cr, the increase in trans-membrane pressure drop caused a higher Cr retention in the concentrate. The same observation was made in the previous studies on nickel salts. Figure 4.3.3(a), shows a slow rise in concentration of Cr in the begining, starting from 11.352 mg/L at 220.6 kPa for feed a concentration of 10 mg/L . A rapid increase in Cr in concentrate from 11.705 mg/L to 12.435 mg/L was observed in the range of 275.7 kPa to 516.9 kPa. Further rise in transmembrane pressure drop led to a maximum concentration of 12.913 mg/L of Cr at a transmembrane pressure drop of 620.3 kPa.

For a feed concentration of 30 mg/L, the rise in transmembrane pressure drop resulted in an increase in Cr concentration [Figure 4.3.3 (b)]. A minimum amount of 34.291 mg/L Cr was observed at 193.0 kPa and increased with the rise in transmembrane pressure drop to a maximum level of 38.446 mg/L at 606.6 kPa.

A similar observation was made for a feed concentration of 50 mg/L as shown in Figure 4.3.3 (c). For a transmembrane pressure drop of 193.0 kPa, a minimum concentration of 57.341 mg/L Cr was observed . The amount of Cr increased to a maximum level of 64.466 mg/L at a trans-membrane pressure drop of 675.5 kPa.

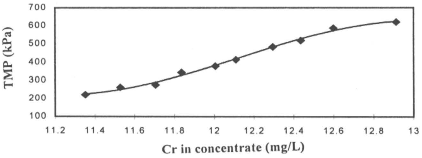

Figure 4.3.3 (a)

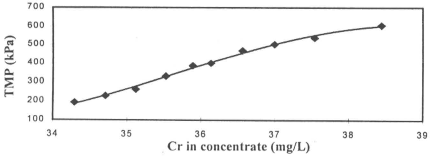

Figure 4.3.3 (b)

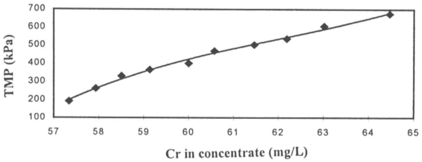

Figure 4.3.3 (c)

Figure 4.3.3 : Relationship between trans-membrane pressure drop and Cr in concentrate $CrCl_3$

4.3.4 $CrCl_3$: Flow Rate and Cr Concentration in Permeate

The relationship between permeate flow rate and Cr in permeate was studied in this experiment. All three feed concentrations showed a similar behaviour with regard to Cr concentration in the permeate with increase in permeate flow rate. For a feed concentration of 10 mg/L , the amount of Cr in permeate declined from a maximum level of 0.273 mg/L at 220.6 kPa to 0.008 mg/L at 620.3 kPa [Figure 4.3.4 (a)]. A rapid reduction was observed when the transmembrane pressure drop increased from 275.7 kPa to 413.6 kPa.

In Figure 4.3.4 (b), the characteristic curve for a feed concentration 30 mg/L is shown. The concentration of Cr was 0.456 mg/L at a permeate flow rate of 4.42 x 10^{-5} m^3/s and decreased gradually as the permeate flow rate increased. A minimum concentration of 0.083 mg/L was achieved at a flow rate of 7.57 x 10^{-5} m^3/s.

For a feed concentration of 50 mg/L , a similar reduction in permeate concentration was observed as the permeate flow rate increased. Starting from a maximum concentration of 0.641 mg/L Cr at 4.42 x 10^{-5} m^3/s, the concentration reduced to 0.095 mg/L at a permeate flow rate of 7.57 x 10^{-5} m^3/s as shown in Figure 4.3.4 (c).

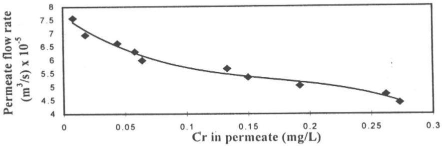

Figure 4.3.4 (a)

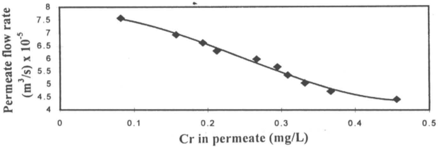

Figure 4.3.4 (b)

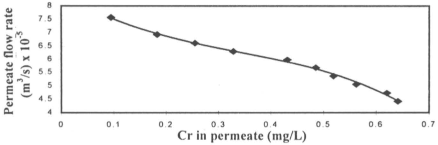

Figure 4.3.4 (c)

Figure 4.3.4 : Relationship between flow rate and Cr in permeate for $CrCl_3$

4.4 Conclusion

The present work was aimed at determining the effect of trans-membrane pressure drop on the permeate flux for three different salts, namely $NiSO_4$, $NiCl_2$ and $CrCl_3$. The concentration of the salts are chosen to resemble that in electroplating wastewater effluent in Klang Valley, Malaysia.

The performance of the system in relation to process water reclamation was dependent on the trans-membrane pressure drop. In this work, a spiral wound cellulose acetate membrane module was used (Model FT30, Filmtec Membranes) for concentrating the heavymetals and recovering the high purity process water. The delivery pressure of the pump was a limiting factor in controlling the trans-membrane pressure drop. Owing to this constraint the trans-membrane pressure drop was restricted in the range of 190.0 kPa to 750.0 kPa. At low trans-membrane pressure drop, the flow became too strong and the unit was operated on a bypass mode. This caused a vortex in the feed tank and resulted in some fluctuations.

For this equipment, the maximum attainable flow rate is 8.0×10^{-5} m^3/s. For $NiSO_4$, $NiCl_2$ and $CrCl_3$ the maximum flow rates were 7.57×10^{-5} m^3/s

corresponding to trans membrane pressure drop of 606.0 kPa, 723.7 kPa and 675.5 kPa respectively.

The various concentration of the salts, namely 10 mg/L, 30 mg/L and 50 mg/L did not have much bearing on the trans-membrane pressure drop vs. permeate flow rate characteristics. For example, corresponding to a permeate flow rate of 7.57×10^{-5} m^3/s, the trans-membrane pressure drops were 482 kPa, 606 kPa and 538 kPa for the $NiSO_4$ concentrations of 10 mg/L, 30 mg/L and 50 mg/L in the feed. The reason for such aberrations are not clear. It is possible that due to fluctuations in trans-membrane pressure drop at the highest admissible flow rate, the time averaged recording was not very accurate. On the other hand, for the lower end of the permeate flux which is 4.42×10^{-5} m^3/s, the trans-membrane pressure drops were 96 kPa, 152 kPa and 152 kPa respectively. The fluctuations were considerably high at this lower end of the permeate flow rate.

However, for $NiCl_2$, the trans-membrane pressure drop was close to 700 kPa for all the three salt concentrations corresponding to a permeate flow rate of 7.57×10^{-5} m^3/s.

For $CrCl_3$, the trans-membrane pressure drop was recorded as 620 kPa for a salt concentration of 10 mg/L and 606 kPa for 30 mg/L. Whereas for a 50 mg/L, the trans-membrane pressure drop was 675.0 kPa. It is concluded from the above results that irrespective of the concentration and the nature of the salt in this present work, the range of trans-membrane pressure drop was from 100 to 150 kPa for the permeate flow rate of 4.42 x 10^{-5} m^3/s. Whereas for a maximum admissible permeate flow rate of 7.57 x 10^{-5} m^3/s, the trans-membrane pressure drop varies from 500 kPa to 650 kPa.

The relationship between the concentration of heavy metal in permeate and trans-membrane pressure drop was also established in this study. The concentrations of Ni in permeate for $NiSO_4$ solution were decreased with increment of TMP. A minimum amount of Ni (i.e., 0.049 mg/L, 0.024 mg/L and 0.077 mg/L) was obtained for three different feed concentrations (i.e., 10 mg/L, 30 mg/L and 50 mg/L) at a maximum TMP of 482 kPa, 606 kPa and 538 kPa respectively.

The same pattern was observed for $NiCl_2$ solutions with low concentrations of Ni in permeate (i.e., 0.018 mg/L, 0.015 mg/L and 0.021 mg/L) for feed concentrations of 10 mg/L, 30 mg/L and 50 mg/L at TMPs of 661.7 kPa, 709.9 kPa and 723.7 kPa respectively.

The Cr concentration in permeate also decreased with increased in TMP. Cr concentration of 0.008mg/L, 0.083 mg/L and 0.009 mg/L were obtained for feed concentrations of 10 mg/L, 30 mg/L and 50 mg/L at maximum TMPs of 620 kPa, 606.6 kPa and 675.5 kPa respectively.

In general, the permeate purity improved with a higher TMP. This is due to the fact that at higher TMP, the transmission of water molecules increases and the water flux is high in relation to the heavy metal salts.