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Original Article

Application and Optimization in Chromium-Contaminated Wastewater Treatment of the Reverse Osmosis Technology

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Abstract

Background: Chromium (Cr) is the most important element used to plate other metals and electroplating factories are still considered to be the most important industries which pollute the environment to this metal. This paper describes a study conducted to determine the efficiency of reverse-osmosis (RO) as a membrane technique for removal of Cr from wastewater samples synthetically prepared to be similar to electroplating effluents.
Methods: The RO unit used in this study was a spiral wound module of 2521 TE made by a Korean CSM company. Synthetic wastewater samples containing Cr ions at various concentrations of 1 to 20 mg/L were prepared and subjected to treatment by RO, and quantitative analysis had been accomplished by a colorimetric method. Evaluation of optimized conditions of treatment had also been carried out by determining the effects of changing operating pressure, temperature and pH_S of samples.
Results: Optimum conditions of Cr-treatment by RO in 10 g/L initial Cr concentration were determined to be in the pH range of 6 to 7 and in temperature of about 25ºC at an applied pressure of 200 psi.
Conclusion: Considering the efficiency of Cr removal which was as high as 99% at the optimized conditions it could be concluded that RO membrane process may be selected and developed as an effective alternative for treatment of metal-contaminated effluents of electroplating and similar industries.

Keywords: *Reverse Osmosis (RO), Chromium, Electroplating- industry, Wastewater treatment*

Introduction

Chromium (Cr) is the first element in Group 6 B of the periodic table and belongs to the transition metals. It occurs in nature as the 21st abundant element and it has two valences of +3 and +6 (1). Cr in its +6 valence form is very toxic and is considered as an undoubtful carcinogen. It is introduced to our environment through wastes discharged from many industries as well as from its natural sources namely many minerals and ores such as the ore chromite. Conversion of Cr^{+3} to Cr^{+6} is happened when manganese and/or organic compounds are present in soil (2, 3). Cr found in valence 3 is an essential element for metabolism of lipids and glucose and it helps to keep human from diabetes mellitus and arthrosclerosis (3, 4). Cr^{+3} compounds do not have much use in industries, but chromates which are compounds of Cr^{+6} are used extensively in dying and the tanning of leather. Besides, Cr^{+6} compounds are widely used to plate materials that have lees resistance to corrosion (5). The toxic nature of Cr^{+6} is well known and described in published studies. Since Cr is the most important element used to plate other metals, electroplating industries are still considered to be the most leading sources of pollution of the environment to this metal (6, 7).
RO has been widely applied to separate or concentrate aqueous solutions containing organics or salts (8). It involves separating water from a solution of dissolved solids by forcing water through a semi permeable membrane. As pressure is applied, larger molecules such as metal ions are retained by the membrane. The purified

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stream is called permeate and the concentrated stream is called concentrate (9). Membranes are usually assembled in modules, each of which compacts a membrane of large surface area within a cylindrical shell of small volume. The type of commercially available module is the spiral-wound and the membrane materials which are in common use are aromatic polyamide and cellulose acetate (8, 9).

The objective of this research was to determine the efficiency of RO as a membrane technique for removal of Cr from electroplating effluents. Moreover, examination of optimum conditions of Cr treatment by using RO process had been carried out.

Materials and Methods

This research was a pilot plant experimental study and the essential components of the pilot used included a cartridge filter, a pressure pump and the RO membrane modules (Fig. 1).The RO unit used was a spiral wound module of 2521 TE made by a Korean CSM company.

At the first phase of this study, the mean concentration of Cr was inspected in the effluents discharged from electroplating industries and it was found that this figure was about 10 g/L, thus this concentration had been chosen as the initial amount for treatment in our RO system. For starting the work distilled water had been passed from the RO pilot to determine the initial flux in various pressures of 100, 120, 150, 170 and 200 psi at an ambient temperature of 25 ºC. Then, the RO system was operated to determine the optimized applying pressure. At last, the optimum amounts of temperature, pH and Cr concentration had been investigated at the optimum pressure.

In the next phase of the study, the amount of flux which could pass from the RO membrane had been measured with respect to the amount of the active surface of the membrane (the latter amount was obtained from the manufacturer). The efficiency of treatment by RO (Cr removal efficiency) was then determined by the following equation:

$$\text{Cr Removal Efficiency} = \frac{C_1 - C_2}{C_1} \times 100$$

Where

C_1= initial Cr concentration

C_2= Cr concentration after treatment

In each step of the experiments, analyses of samples had been done after measurement of flow and flux in a predetermined period of less than one hour (about 40 to 60 min). The method used for hexavalent Cr determination was the standard colorimetric method (10) and Fig. 2 shows the prepared calibration curve. Calibration standards had all been prepared at the time of analysis. Study the effect of temperature on RO treatment had been accomplished in 15, 20, 25, 40 and 49 degrees Centigrade adjusted by using heater with thermocouple and effect of initial Cr concentration had been examined by use of five solutions of Cr (1, 5, 10, 15 and 20 g/L). All these synthetic samples have been prepared in the laboratory by dissolving certain amounts of a pure salt of hexavalent chromium in distilled water.

Results

Fig. 3 shows the effect of changing applied pressure on flux of distilled water. Relationship between flux of water (as liter per square meter per hour) and RO pressure could be seen in Fig. 4. Fig. 5 is depicted for showing the effect of applied pressure on flux of Cr solutions and in Fig. 6, the effect of changing applied pressure on the efficiency of Cr rejection can be considered. Cr treatment by RO may also be affected by initial metal concentration and pH of solution and Fig. 7 and 8 demonstrate these effects. Finally, the effect of temperature on the process of Cr treatment by RO can be seen in Fig. 9.

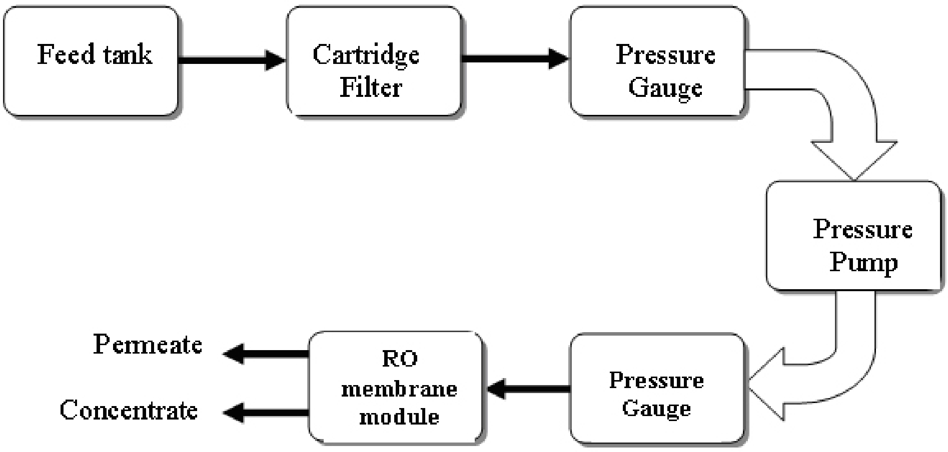

Fig. 1: Basic RO Unit

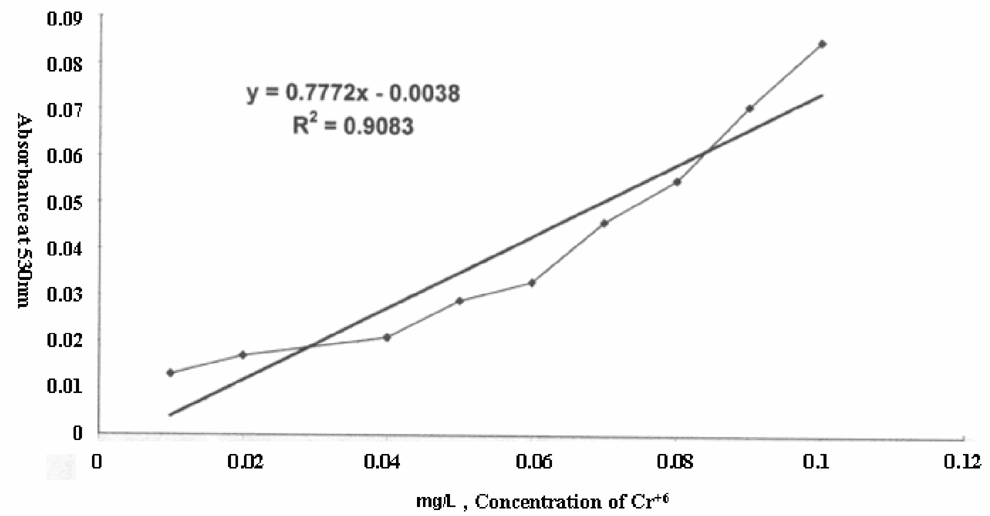

Fig.2: Calibration curve for hexavalent chromium

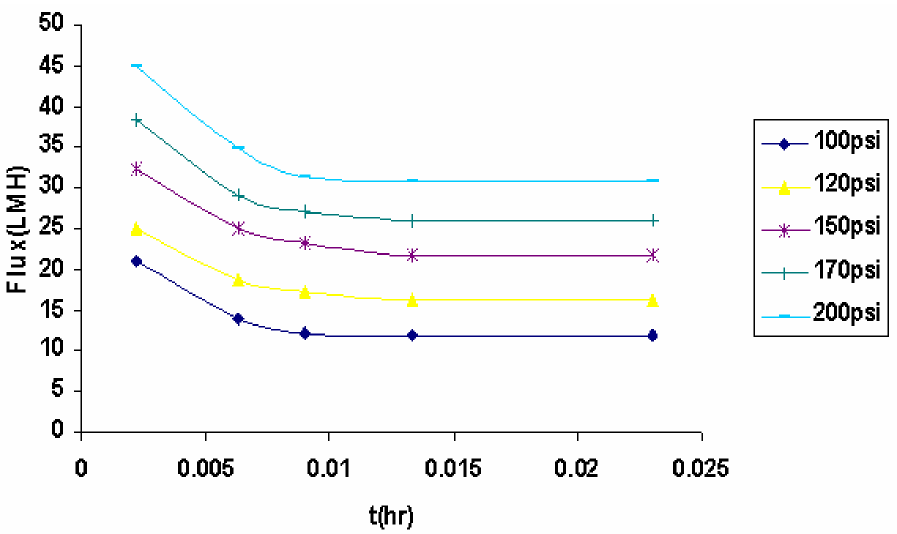

Fig. 3: Flux of drinking water versus time by applying different operating pressure of RO (T+25° C, Ph= 7)

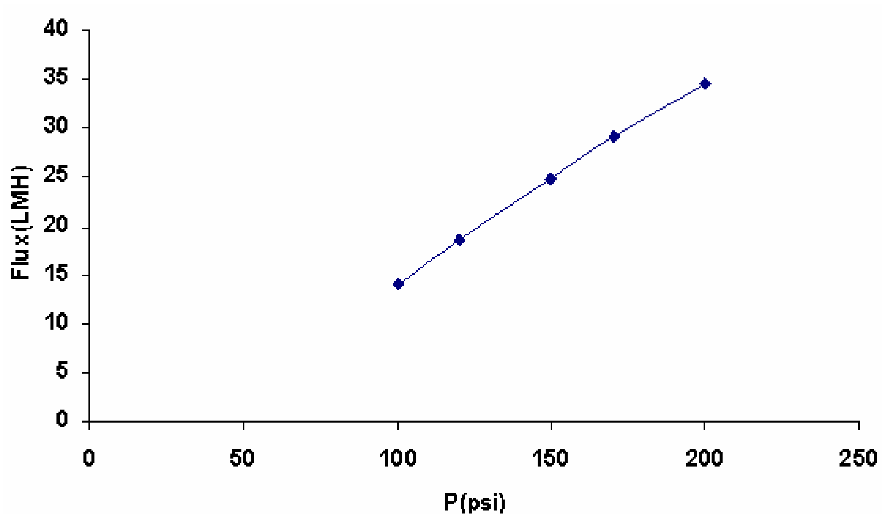

Fig. 4: Flux of drinking water versus operating pressure of RO (T+25° C, Ph= 7)

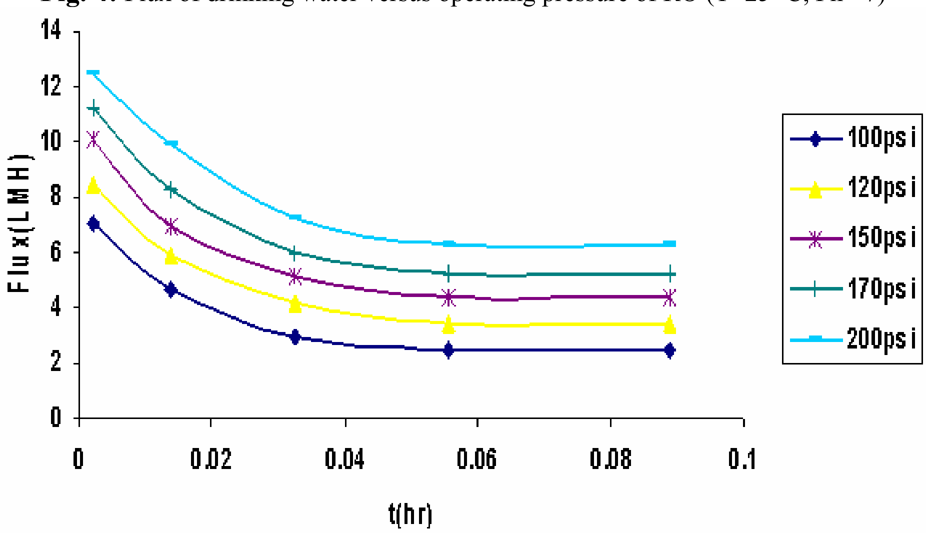

Fig. 5: Comparison of change in flux of the sample by applying different pressure versus time (Cr conc= 10g/L, T=25° C, pH=7)

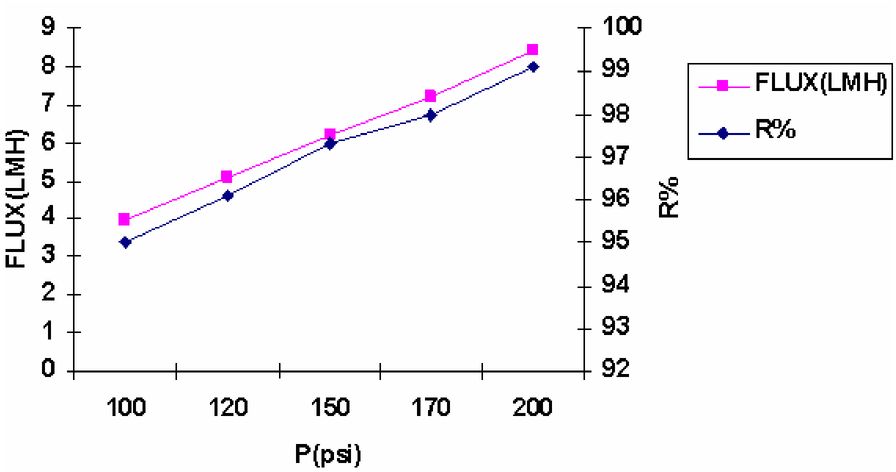

Fig. 6: Effect of changing operating pressure on flux and Cr removal efficiency (Cr conc.=10g/L, T=25° C, pH=7)

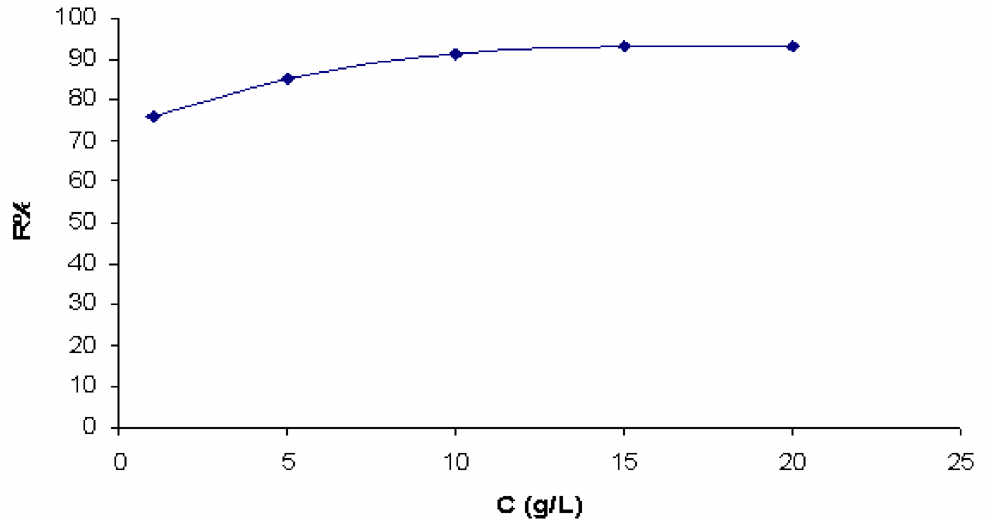

Fig.7: Effect of Cr concentration on removal efficiency (*P*=200psi, T=25º C, pH=7)

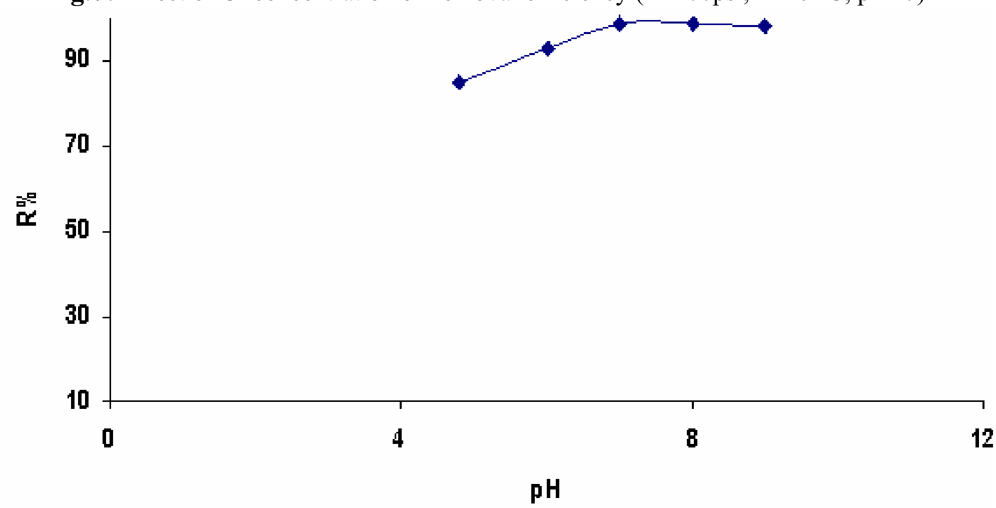

Fig.8: Chromium removal efficiency versus pH (*P*=200psi, T=25º C, C=10g/L)

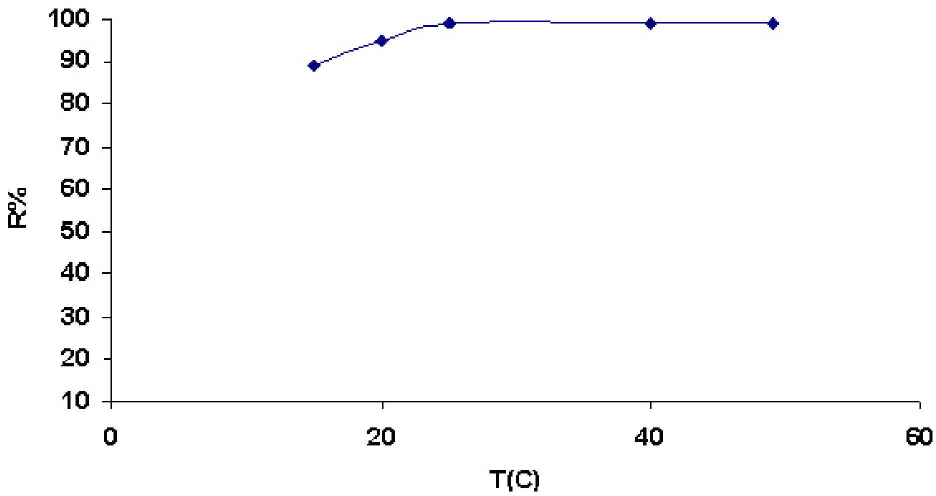

Fig.9: Effect of temperature on treatment efficiency (*P*= 200psi, pH= 7, C= 10g/L)

Discussion

In this research, a membrane system including RO had been evaluated for Cr removal from synthetic solutions whose Cr concentrations (1 to 20 g/L) were similar to those found in many effluents of Iranian electroplating industries. The RO effectiveness in treatment at various conditions was also investigated. Cr waste may be seen in several other industries but the most concentrated effluents are discharged by electroplaters. Moreover, they discharge large volumes of this toxic metal especially when Cr baths are exchanged.

As shown in Fig. 3 and 4, the permeated flux of water as liter per square meter had been increased per hour when the pressure applied was increased. This result was in consonance with previous studies showing the effect of pressure in the full extent of the membrane and yielding much more water at higher pressures. Fig. 5 and 6 also indicate that the rejection for Cr increased as the applied pressure and flux had been increased. The best treatment efficiency was obtained at 200 psi. It should be noted that at higher pressures the membrane resistance is also increased.

According to Fig. 5 and 7 the increase of flux versus time was not infinite. The reason should be attributed to polarization phenomenon as well as the consequent fouling of the membrane. Fig. 7 also indicates that increase of Cr conc. In the range of 10 to 20 g/L had no considerable effect on the process of Cr rejection by the membrane, and in other words the efficiency of Cr treatment was not affected by initial Cr concentrations. This result is similar to those reported by previous studies about removal of dye and other impurities from textile wastewater by nanofiltration (11, 12).

The optimum pH range for Cr treatment as shown in figure 8 was 6 to 7 because other pHs had detrimental effects. It should be explained that the surface charge of a RO membrane is dependent to the ionic strength of the surrounding solution and the best performance of a membrane is expected when its surface charge becomes similar to the electrical charges of the molecules in solution witch obviously may be happened only in a definite pH range.

Finally, Fig. 9 shows the effect of temperature raise on treatment efficiency. By increasing the temperature of solutions it would be possible to improve the treatment to some extent but it is restricted and in fact the permeated flux would increase up to 25º C, thus this figure could be recommended as the optimum temperature. However, it should be noted that the optimum temperature was not independent of the type of the membrane used in the RO system.

Comparison with other studies

In the last 20 yr, a large variety of chemical and biological methods for the removal of chromium from industrial effluents have been proposed and reported. In a survey conducted for Cr recovery from electroplating effluent it was denoted that 99.8% recovery by using ion exchange process was practicable (3,13). Other studies showed 74 to 99% Cr reduction in electroplating effluents by chemical coagulation- sedimentation processes (14,15), and about 54% removal by use of calcium alginate beads containing humic acids (16). On the other hands, application of pinus sylvestris bark for Cr removal from tannery wastewater had shown more than 90% treatment efficiency (17), and about 99% removal by absorption of Cr onto bentonite clay (18). Besides, physicochemical methods various biological processes have also been developed. Relatively efficient removal of Cr from tannery wastewater had been reported by use of three species of fungi which were as high as 94, 92 and 81% by use of *A. niger*, *A. aryzae* and *P. chrysosporium*, respectively (4), and a similar study conducted for electroplating effluent treatment had shown 70% Cr removal by *Asperigillus* sp. (19). Evaluation of other bioreactors in which bacteria and/or fungi had been used for Cr treatment has shown removal efficiencies of more than 90% and 60% by these organisms (20, 21). Cr removal has also been investi-

gated by use of three different kinds of activated carbon manufactured from the wastes of sugar industry and minimum 93% Cr removal has been reported for treating tannery wastewater by using these recovered samples of activated carbon (22). Other low cost adsorbants had also been used for Cr reduction but the efficiencies of treatment had not been so significant (23).
Findings of our research indicate that Cr removal can be much better accomplished by RO technology compared to many other processes (either chemical or biological) witch had been used for electroplating or other industrial effluents treatment. This superiority may also be expected for treatment by RO in removing similar toxic heavy metals which are often present in industrial effluents and are not efficiently removed by conventional treatment.

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The authors declare that they have no conflict of interests.

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