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Application and optimization in chromium-contaminated wastewater treatment of the reverse osmosis technology

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ABSTRACT

Background: Chromium (Cr) is essential element used to plate other metals. Electroplating industry's effluents are the most important sources of chromium pollution in the environment. This paper describes a study conducted to determine the efficiency of reverse-osmosis (RO) as a membrane filtration technique for removal of Cr from synthetic wastewater samples prepared 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 prepared and subjected to treatment by RO, and quantitative analysis 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 mg/L feed Cr concentration were determined to be in 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 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

1. 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 considered as an undoubtful carcinogen. It 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 chromate. 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 humans away from diabetes mellitus and arthrosclerosis [3, 4]. Cr^{+3} compounds do not have much use in

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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 least 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, the membrane retains larger molecules such as metal ions. The purified stream is called permeate and the concentrated stream is called concentrate [9]. Membranes 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 carried out.

2. Materials and methods

A pilot plant scale has been operated for this research. For starting, the distilled water is passed through the RO pilot to determine the permeate flux in various pressures of 100, 120, 150, 170, and 200 psi at an ambient temperature of 25ºC. Then, the RO system is operated to determine the optimized applying pressure. Finally, the optimum amounts of temperature, pH, and Cr concentration investigated at the optimum pressure the permeate flux was measured a cartridge filter, a pressure pump and the RO membrane modules (Fig. 1).

The efficiency of treatment by RO (Cr removal efficiency) is then determined by the following equation:

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

where
C_1 = feed Cr concentration
C_2 = Cr concentration after treatment

In each step, analyses of samples is carried out after measurement of flow and flux at the period of less than 1 hour (about 40 to 60 minutes). The measuring method of Cr^{6+} 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.

The effect of temperature on RO treatment had been accomplished in 15, 20, 25, 40 and 49 ºC, and the effect of feed Cr concentration had been examined at five concentration of 1, 5, 10, 15 and 20 mg/L. All these synthetic samples have been prepared in the laboratory by dissolving of certain amounts of pure salt of hexavalent chromium in distilled water.

Results and 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 are also investigated. Chromium wastes

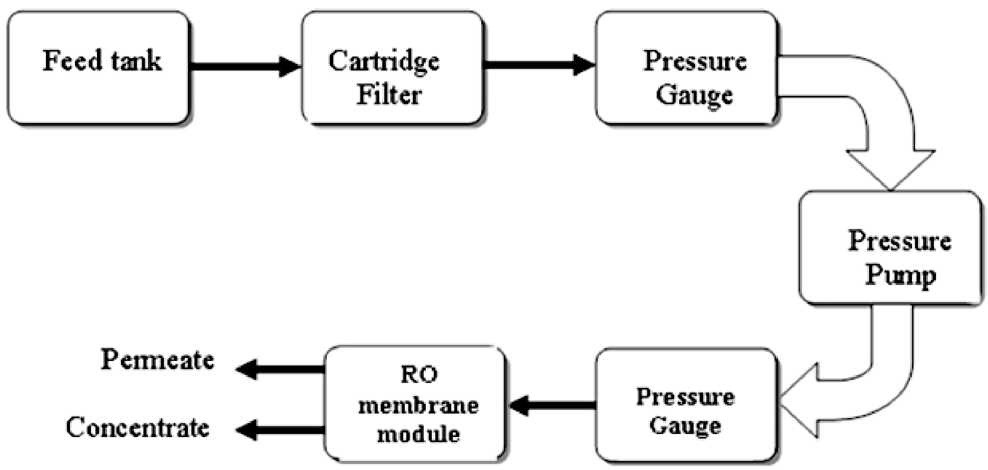

Fig. 1. RO pilot-plant system.

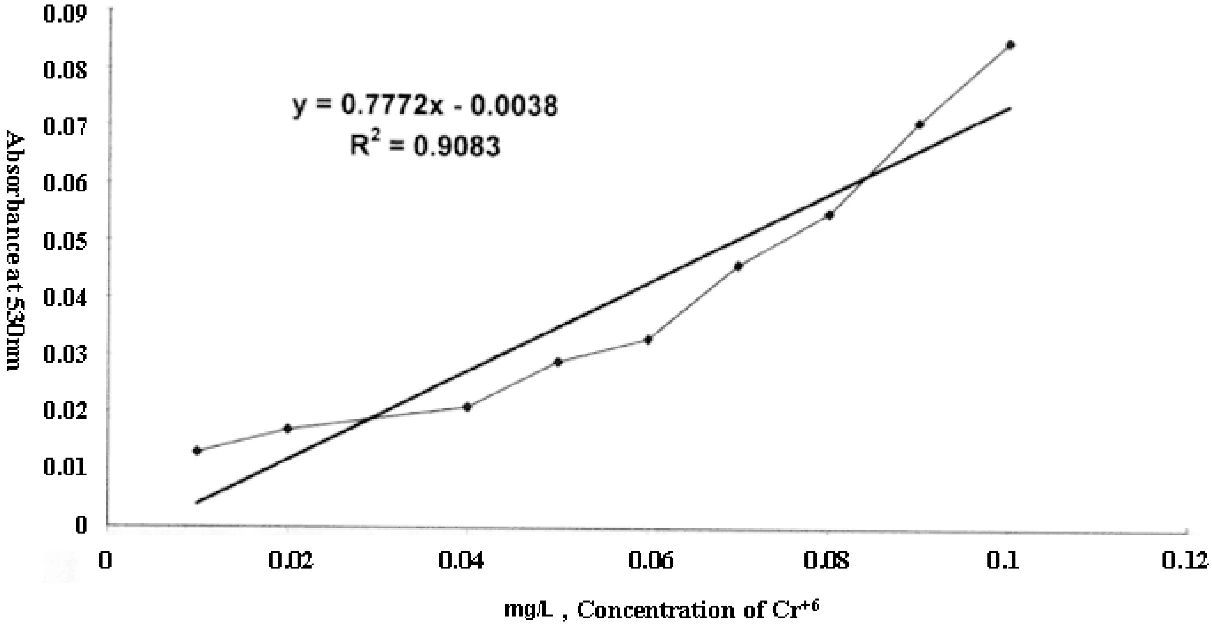

Fig. 2. Calibration curve for Cr^{+6}.

may be seen in several other industries but electroplaters discharge the most concentrated effluents. Moreover, they discharge large amounts of this toxic metal especially when Cr baths exchanged.

Figure 3 indicates that the rejection for Cr increased as the applied pressure and flux had increased. The best treatment efficiency obtained at 200 psi indicates that the permeate flux increases as the transmembrane pressure increases. Also, The chromium rejection increases with the increase of the transmembrane pressure; this may also be due to the decrease of pore size of the membrane surface due to chromium accumulation over time.

Figure 4 indicates the effect of Cr concentration on rejection percent. In the range of 10 to 20 g/L there was no considerable effect on the process of Cr rejection by the membrane, and in the other word, the efficiency of Cr treatment was not affected by feed Cr concentration.

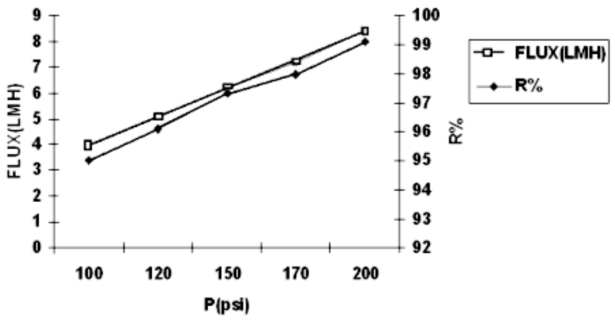

Fig. 3. Effect of operating pressure on flux and Cr removal efficiency (Cr conc.10g/L, T = 25ºC, pH = 7).

This result is similar to those reported by previous studies about removal of dye and other impurities from textile wastewater by nanofiltration [22, 23].

The optimum pH range for Cr treatment as shown in Fig. 5, was 6 to 7 because variation of pH had detrimental effects. It should be explained that the surface charge of a RO membrane is dependent on 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. 6 shows the effect of temperature on treatment efficiency. By increasing the temperature, 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 25ºC, thus this figure could be recommended as the optimum temperature. However, it should be noted that the optimum temperature was dependent on the type of the membrane used in the RO system.

In the last 20 years, 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, 11]. Other studies showed 74% to 99% Cr reduction in electroplating effluents by chemical coagulation sedimentation processes [12, 13], and about 54% removal by use of calcium alginate beads containing humic acids [14]. On the other hands, application of pinus sylvestris bark for Cr

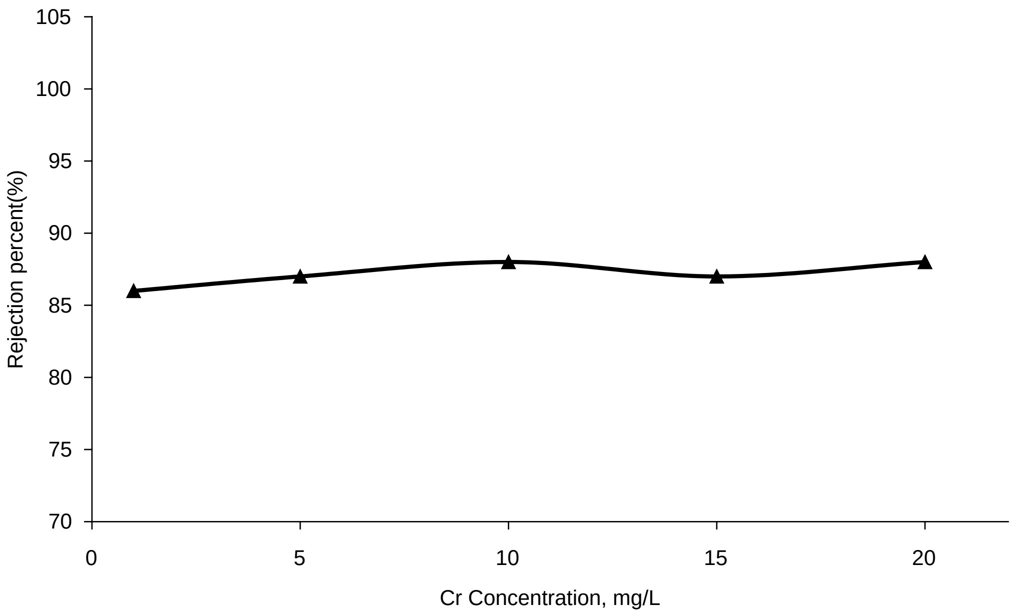

Fig. 4. Effect of Cr concentration on removal efficiency (P = 200 psi, T = 25°C, pH = 7).

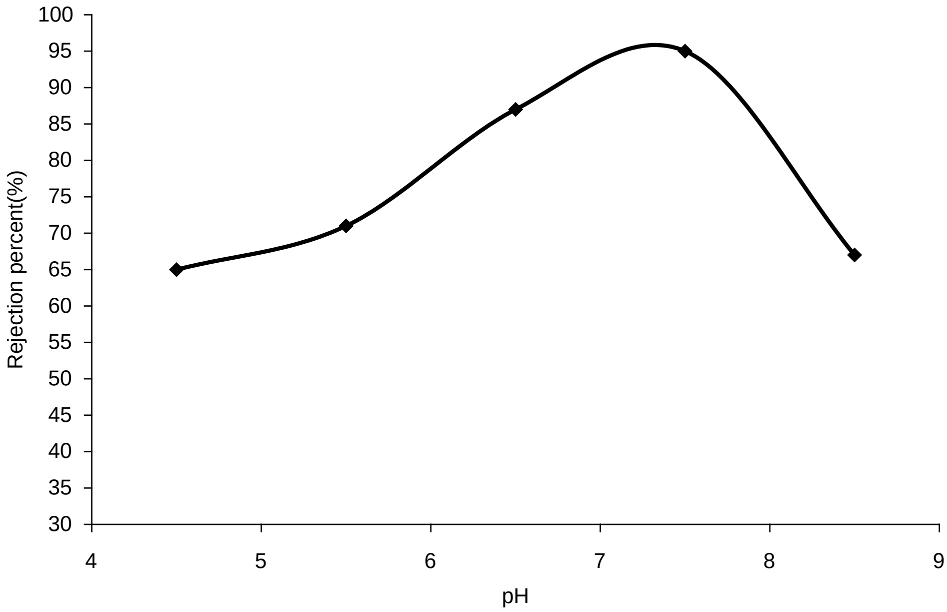

Fig. 5. Chromium removal efficiency versus pH (P = 200 psi, T = 25°C, C = 10g/L).

removal from tannery wastewater had shown more than 90% treatment efficiency [15] and about 99% removal by absorption of Cr onto bentonite clay [16]. 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. [17]. 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 [18,19]. Cr^{6+} removal has also investigated by use of three different kinds of activated carbon manufactured from the wastes of sugar industry and minimum 93% Cr removal reported for treating tannery wastewater by using these recovered samples of activated carbon [20]. Other low cost adsorbents had also used for Cr reduction but the efficiencies of treatment had not been so significant [21]. The pilot and full scale study that was carried out,

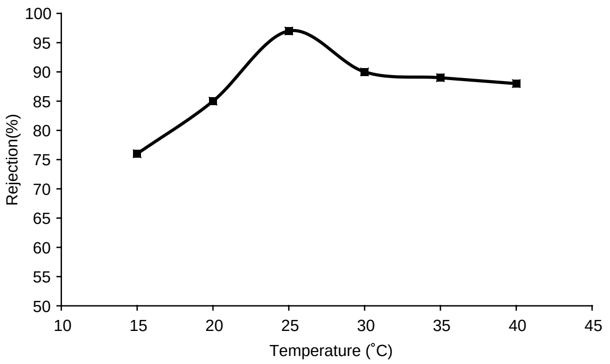

Fig. 6. Effect of temperature on treatment efficiency (P = 200 psi, pH = 7, C = 10 g/L).

showed that RO membrane technology can remove chromium within the limits of discharging into the public wastewater system [24, 25].

Conclusion

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) which had used for electroplating or other industrial effluents treatment.

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