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Full-scale Application of an Integrated UF/RO System for Treatment and Reuse of Electroplating Wastewater

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ABSTRACT
The purification of wastewaters containing heavy metals is one of the main ecological problems in the electroplating industry. This study describes a full-scale integrated ultrafiltration (UF)/reverse osmosis (RO) system for treatment and reuse of the electroplating wastewater in China. The quartz sand and granular activated carbon filtration were employed for the UF pretreatment. The UF and RO membranes used were poly (vinylidene difluoride) hollow fiber and polyamide composite membranes. The product capacity of the system was 1,200 m^3/d. The product water was used as tap water substitute for in-process rinsing water at the factory. The results showed that the chemical oxygen demand (COD) and conductivity after the treatment decreased from 90±10 mg/L and 5000±500 μs/cm in the feed to values below 8 mg/L and 70μs/cm, respectively. The rejection of COD and salts reached to 93.0±1.8% and 98.9±0.2%, respectively. The suspended solids (SS) had been fully eliminated. An economics evaluation shows that the annual reductions of sewage discharge and expenses were approximately 219,000 m^3 and ¥500,000 after two years of running, respectively. Overall, the full-scale UF/RO treatment plant provides a visible and feasible solution to the electroplating wastewater.

Keywords: Ultrafiltration (UF); reverse osmosis (RO); electroplating wastewater; heavy metals; water reuse

1. INTRODUCTION

An amount of heavy metal-containing toxic wastewater is generated from the electroplating plants. It is harmful to ocean life, live stock, and human beings. The treatment of wastewater containing heavy metals has received considerable attention as a result of the increasingly stringent environmental legislation. Consequently, different treatment techniques such as chemical precipitation (Peng and Tian, 2010), coagulation– flocculation (Li et al., 2003), flotation (Ying and Fang, 2006), adsorption (Dong et al., 2010), ion exchange (Panayotova et al., 2007), and membrane filtration (Wang et al., 2007) have been employed to treat the wastewater. Although chemical precipitation and coagulation–flocculation have been widely used to treat electroplating wastewater, there are still some disadvantages such as excessive chemicals consumption, sludge production, and impossibility of directly reusing heavy metals etc.

The membrane separation technology has many advantages, for example, low energy requirements, small volume of retentate that needs to be handled, and selective removal of pollutants with complexing agents by membrane surface modification, etc.. Therefore the combined ultrafiltration (UF) and reverse

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osmosis (RO) membrane processes have been increasingly used in the treatment of wastewater containing heavy metals due to the high efficiency and convenient operation (Qin et al. 2004; Jasmine and Francesco, 2004).

The aim of the present study is to present a full-scale integrated UF/ RO system with the product capacity of 1,200 m^3/d for treatment and reuse of the electroplating wastewater in Wuxi, China. The quartz sand and granular activated carbon (GAC) filtration were employed for the UF pretreatment. The product water was used as tap water substitute for in-process rinsing water at the factory. The water quality and the stability of the system were investigated.

2. MATERIALS AND METHODS

2.1 Description of the overall full-scale integrated UF/RO process

The schematic of the electroplating wastewater treatment process was shown in Figure 1. The pretreatment part constituted with quartz sand filter and granular activated carbon (GAC) filter. A full-scale UF/RO system (Figure 2a) with a maximum capacity of 1,200 m^3/d was installed in the city of Wuxi (China). The pretreatment aims to remove silica colloids, adsorbed organic compounds and particulate matter of iron. After the pretreatment, the chemical oxygen demand (COD) and suspended solids (SS) decreased from 90±10 mg/L and 25±5 mg/L to 45±5 mg/L and 7±2 mg/L, respectively. The process conditions and a periodic backwashing operation were automatically controlled by PLC (Programmable Logic Controller). In order to prevent filter material excess adsorption and the formation of agglomeration, the backwashing and air scour were employed every 24 hr of operation. The filtrate water was pumped to UF installation (Figure 2b) where smaller suspended solids and microorganisms were removed.

The UF membranes used were poly (vinylidene difluoride) hollow fiber with a nominal pore size of 0.1 μm. The UF permeate water was sent to the RO feed tank and then pumped to the RO installation (Figure 2c) for removing dissolved compounds such as salts and dissolved organic compounds. The RO permeate was sent to the product tank. The recovery of the full-scale UF/RO system was kept at 60%. The operation pressures of UF and RO were kept as 0.08-0.15MPa and 0.7-1.5 MPa, respectively. The backwash water and RO concentrate were sent to the wastewater treatment plant in the electroplate factory.

For the UF system, the on-line back-flushing lasting for 60 s was conducted every 30 min of operation. The off-line chemical cleaning process was conducted to remove organic contaminants using 1000ppm NaOH solution when the UF system has been operated for three months or the transmembrane pressure (TMP) exceeded 0.06 MPa. For the RO system, the off-line chemical cleaning process was conducted by using acid-base cleaning protocol when the RO system has been operated for three months or the operation pressure exceeded 1.5 MPa. The acid-washing and base-washing phases were conducted with 0.2% HCl solution and 0.1% NaOH solution, respectively.

2.2 Water quality analysis and reused water quality requirement

The main parameters of the electroplating wastewater qualities used in the full-scale plant were summarized in Table 1. The chemical oxygen demand (COD) and suspended substance (SS) were measured by the Chinese NEPA standard methods (NEPA 1997). The conductivity and pH were determined by the online conductivity meter

(GF+SIGNET-3-8850, USA) and the online pH meter (GF+SIGNET-3-8850, USA), respectively. According to the water quality requirement of electroplating rinsing water provided by the client, the reused water quality required was listed in Table 1.

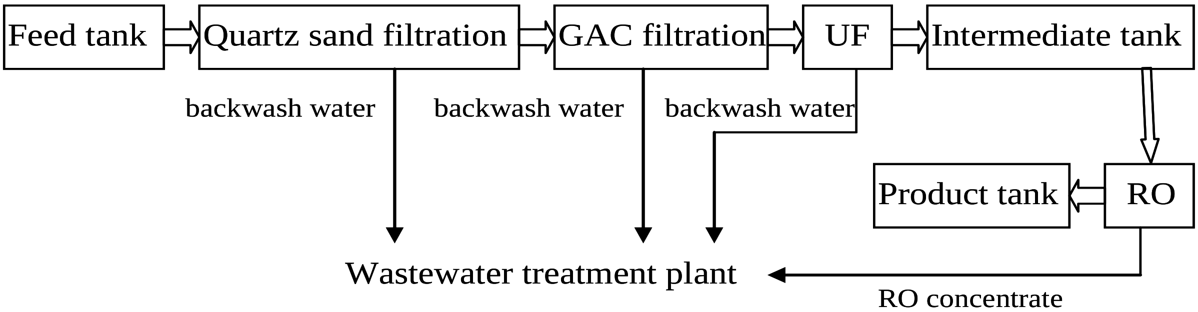

Figure 1 The schematic of electroplating wastewater treatment process

Figure 2 The photographs of the full-scale electroplating wastewater treatment plant: (a) a full view of the integrated UF/RO system (b) UF installation, (c) RO installation

Table 1 Feed water qualities and reused water quality requirement

Constituent	Feed water qualities	Reused water qualities
pH	6-9	6-9
COD (mg/L)	80-100	<20
SS (mg/L)	20-30	-
Conductivity (μs/cm)	4500-5500	<100
Copper (mg/L)	0.3	-
Nickel (mg/L)	0.1	-

3. RESULTS AND DISCUSSIONS

3.1 System performance of the full-scale plant

The quality of permeate water such as SS, COD and conductivity was monitored to study the stability of the integrated UF/RO system during the two years of running as shown in Figures 3-5, respectively.

It can be seen from Figure 3 that the SS had been completely removed from the feed concentration of 24±5 mg/L. The COD and conductivity decreased from 90±10 mg/L (Figure 4) and 5000±500 µs/cm (Figure 5) in the feed to 8 mg/L and 70 µs/cm in the RO permeate, respectively. The rejection of COD and salts reached to 93.0±1.8% and 98.9±0.2%, respectively. The produced water of the integrated UF/RO system could fully meet the reused water quality requirement as shown in Table 2. These results indicate that the UF/RO process is a reliable and effective method for the treatment and reuse of electroplating wastewater. In order to further investigate the fouling behavior of the membranes, the following studies were to demonstrate the TMP of the UF system and the operating pressure of the RO system during the 720 days of operation.

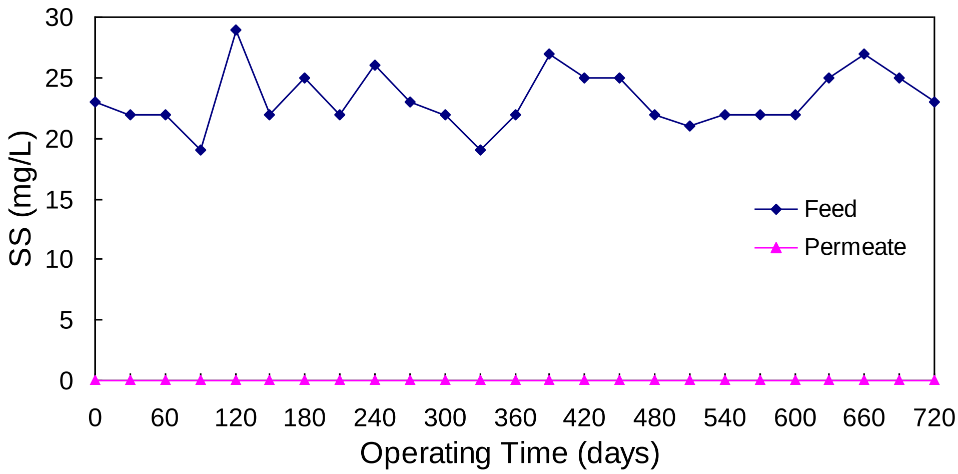

Figure 3 SS results for the feed and permeate of the UF/RO system during the 720 days of operation.

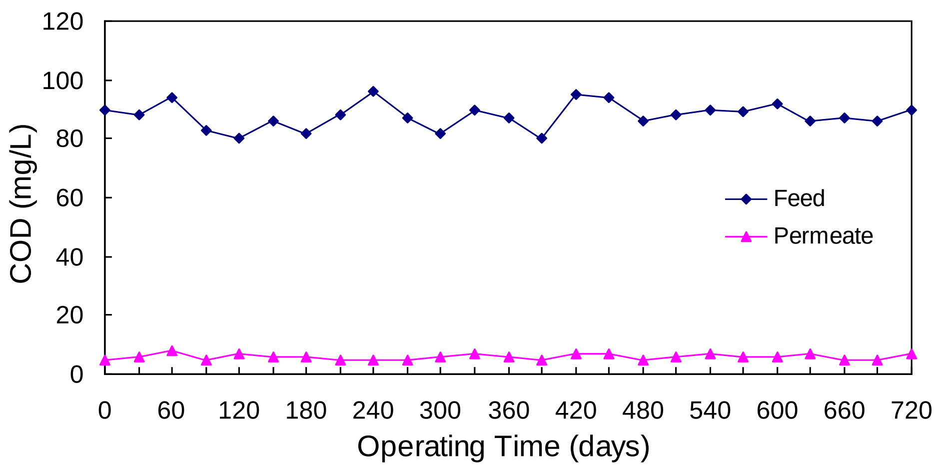

Figure 4 COD results for the feed and permeate of the UF/RO system during the 720 days of operation.

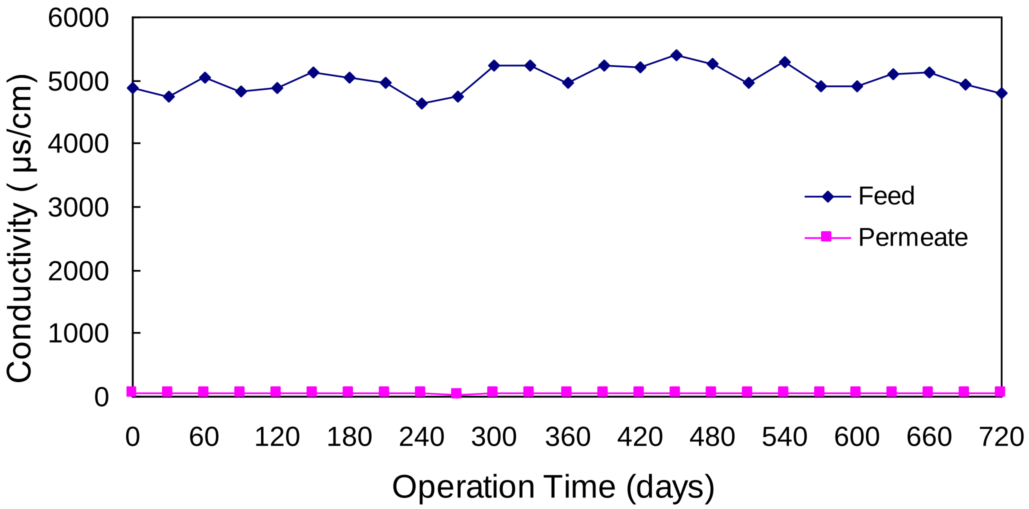

Figure 5 The conductivity in the feed and permeate of the UF/RO system during the 720 days of operation.

It can be seen in Figure 6 that the TMP increased sharply during the water treatment. It indicates that the whole UF system suffered from severe fouling after every two-three months of running. As discussed in section 2.1, the off-line chemical cleaning process was carried out once the UF system has been operated for three months or the TMP exceeded 0.06 MPa. It also can be seen in Figure 6 that the TMP decreased dramatically after the membrane cleaning. However, it could not fully restore the initial performance of the membrane. The restoring TMP gradually increased from 0.017 MPa to 0.027 MPa and the cleaning period decreased from 90 days to 60 days during the 720 days of operation. It suggests that the membranes could not be cleaned by the chemical cleaning completely. The adsorption of foulants within membrane pores may result in the irreversible membrane fouling (Qin et al., 2004).

It can also be found in Figure 7 that similar to the TMP of the UF system, the operating pressure of the RO system increased rapidly with the operation progressing. The restoring operating pressure after the chemical cleaning gradually increased from 0.7 MPa to 0.8 MPa and the cleaning period decreased from 90 days to 60 days during the 720 days of operation. The RO system still suffered from severe irreversible membrane fouling after two-three months of running, although the system performance was recovered obviously after the cleaning. In a word, it might be a good way to conduct a high frequency of cleaning to the UF/RO system to maintain the membrane performance over long-term operations.

3.2 Economic evaluation

On the basis of the performance results and the cost data, an economic evaluation of the UF/RO full-scale plant with a capacity of 1,200 m^3/d for treating the electroplating wastewater is summarized in Table 2. Approximately 219,000 m^3 of water could be reused every year as presented in Table 3. On the basis of the price for wastewater discharge (¥1.2/m^3), tap-water supply (¥4.05/m^3), the operating cost of the system (¥2.4/m^3) and system loss (¥0.57/m^3), ¥500,000/y could be saved after the installation of the integrated UF/RO system.

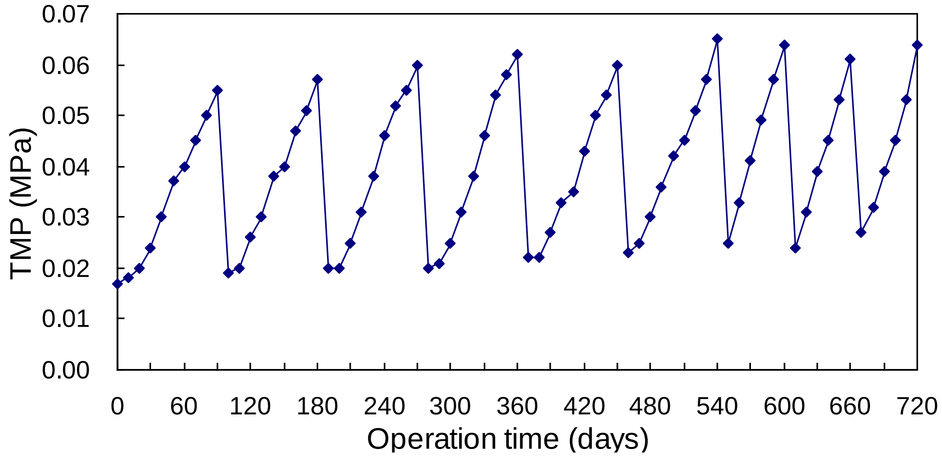

Figure 6 The TMP of the UF system during the 720 days of operation.

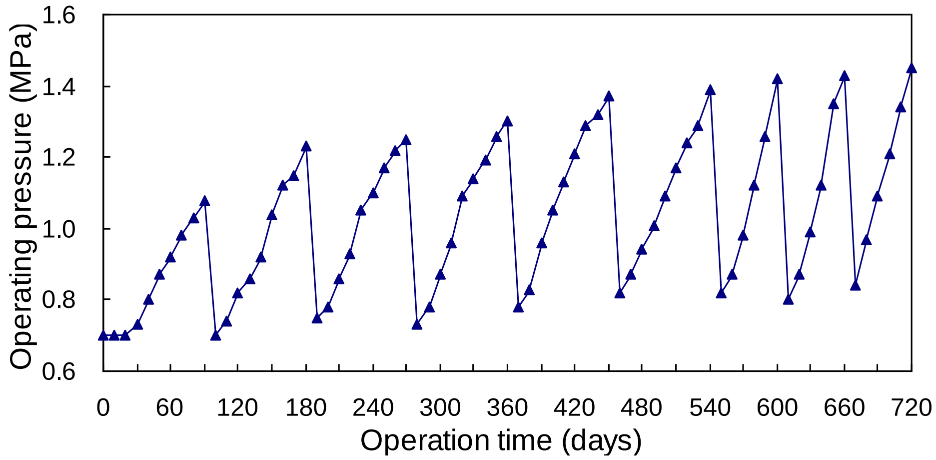

Figure 7 The operating pressure of the RO system during the 720 days of operation.

Table 2 Economic evaluation for treating the electroplating wastewater

Items	**Value**
Cost of tap water (¥/m^3)	4.05
Sewage discharge fee (¥/m^3)	1.2
Operating cost (¥/m^3)	2.4
System loss (¥/m^3)	0.57
Reduction of sewage discharge (m^3/y)	219,000
Saving tap water (¥/d)	2,430
Saving sewage discharge fee (¥/d)	720
Net return per day (¥)	1370
Net return per year (¥)	500,000

Note: ¥= Renminbi; 1 US dollar= 6.32 Renminbi

CONCLUSIONS

A full-scale plant consisting of pre-treatment, UF and RO membrane units and an auto-control system with a capacity of 1,200 m^3/h for treating the electroplating wastewater was successfully operated for 2 years in Wuxi, China. The overall recovery was over 60%. COD and conductivity of the product water obtained were below 8 mg/L and 70 μs/cm. The removal rate of COD and salts was 93.0±1.8 % and 98.9±0.2 %, respectively. The SS had been fully removed. Further, the product water had been recycled for use as a substitute for the electroplating rinsing water in the factory. The annual reductions of sewage discharge and savings were approximately 219,000 m^3 and ¥500,000, respectively. Overall, the integrated UF/RO process presents a very attractive technology for treating the electroplating wastewater.

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