Reuse of effluent discharged from tannery wastewater treatment plants by powdered activated carbon and ultrafiltration combined reverse osmosis system

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ABSTRACT

We evaluate the applicability of a reverse osmosis (RO) system that combines powdered activated carbon (PAC) and ultrafiltration (UF) to treat the effluent discharged from tannery wastewater treatment plants. Conventional treatment processes such as neutralization, clariflocculation, and biological processes are used to clean the effluent before feeding to the PAC and UF combined RO system. The efficiency of the combined system was evaluated using the chemical oxygen demand Mn (COD_{Mn}), color, pH, turbidity, total nitrogen, total phosphate, and conductivity. The PAC was effective in greatly reducing the COD_{Mn} and color. The turbidity and silt density index of the UF permeate satisfied the water quality indices required for the RO feed. The RO system was constantly maintained at approximately 75% RO recovery, and the RO permeate satisfied the water quality requirements for reusing the processed water. Therefore, the PAC-UF combined RO system can be used to process effluent discharged from tannery wastewater treatment plants for reuse.

Key words | combined, powdered activated carbon, reuse, reverse osmosis, tannery wastewater, ultrafiltration

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INTRODUCTION

Tanning is one of the oldest industries and requires huge amounts of water (approximately 15 to 20 m^3 per ton of hide processed) in several stages, generating enormous quantities of liquid effluents. Tannery wastewater typically contains high levels of salts, organic and inorganic matter, colored matter, dissolved and suspended solids, ammonia, organic nitrogen, and pollutants such as sulfides, chromium and other toxic metal salts (Aboulhassan *et al.* 2008). The characteristics of raw wastewater are listed in Table 1 (Fababuj-Roger *et al.* 2007). Tannery wastewater, which generates many complex and high effluent loads, is difficult to treat and requires extensive treatment prior to reuse. Conventional processes such as oxidation, chemical, and biological processes are used to treat the tannery wastewater (Durai & Rajasimman 2011).

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The final effluent discharged from tannery wastewater treatment plants cannot be reused because of its high load of organic matter, color, and high concentration of total dissolved solids (TDS).

To minimize pollution from tannery wastewater, several authors proposed the adoption of integrated clean technologies (Rao *et al.* 2003) and treatment of the waste streams, mainly by using membranes. This approach removes the pollutants and allows reuse of the processed water. Reverse osmosis (RO) membranes can solve the problem of TDS in the effluent and are necessary if reusing the effluent is the goal. Moreover, the high organic matter content in the effluent requires exhaustive pretreatment to minimize membrane fouling before RO (Phuntsho *et al.* 2011). The effectiveness of the powdered activated carbon (PAC) pretreatment and the consequent improvement of the membrane performance has been reported in studies concerned with membrane fouling in the PAC–ultrafiltration (UF) process used in

Table 1 | Characteristics of tannery wastewater

Parameter	Feed tannery wastewater
COD (mg/L)	5,000–5,500
BOD_5 (mg/L)	3,000–3,500
Suspended solids (mg/L)	2,500–3,000
Cr^{3+} (mg/L)	80–100
SO_4^{2-} (mg/L)	1,800–2,000
Cl^- (mg/L)	5,000–6,000
pH	8–9
Conductivity (μs/cm)	10–12

COD, chemical oxygen demand; BOD, biological oxygen demand.

water containing natural organic matter and (or) particles. Thus, further investigations into the effect of PAC and UF pretreatment on an RO system are needed (Gai & Kim 2008; Huang *et al.* 2009; Matsui *et al.* 2009).

The main objective of this study was to investigate the performance of PAC and UF pretreatment in an RO system, and to evaluate the subsequent reuse of the effluent discharged from tannery wastewater treatment plants.

METHODS

Commercial PAC was purchased from Shin Ki Chemical Ind. Co. Ltd and was used without further purification. The PAC was analyzed by the KSM 1802 method: it had a dry weight of 9.8 wt %, iodine number of 915 mg/g, methylene blue value of 175 mg/g, and pH of 7.7. A hollow fiber UF membrane made of polyacrylonitrile (Mann + Hummel Ltd, Germany) was used in the experiments. The outside-in UF membrane possesses a nominal cutoff of 100 kDa. The total active membrane area is 45 m^2. A spiral-wound polyamide RO membrane with effective membrane area of 7.6 m^2 was purchased from Toray Chemical Corporation (RE8040-FL).

This work comprises three stages: (1) PAC adsorption, (2) pretreatment (UF system), and (3) the RO system. Figure 1 shows a schematic of the PAC and UF combined RO system. PAC adsorption tests were performed to characterize the adsorption of chemical oxygen demand Mn (COD_{Mn}) and color, using PAC in a 1 m^3 reaction tank at concentrations of 0.8, 0.9, 1.0, and 1.2 g/L. The tests were conducted at an agitation speed of 60 rpm and contact time of 30 min. The filtration conditions of the UF system were set to a feed pump frequency of 20 Hz, a filtration time of 5 min, a backwashing time of 30 s, and an air-scouring time of 30 s. The system efficiency was evaluated by observing the turbidity, silt density index (SDI), and the permeate flow rate.

The UF permeate was collected, stored in the 1 m^3 tank, and periodically fed using a high pressure pump to a pilot-scale RO system. The RO system operated in single-pass two-stage mode with a permeate flow rate of 12.3 L/min

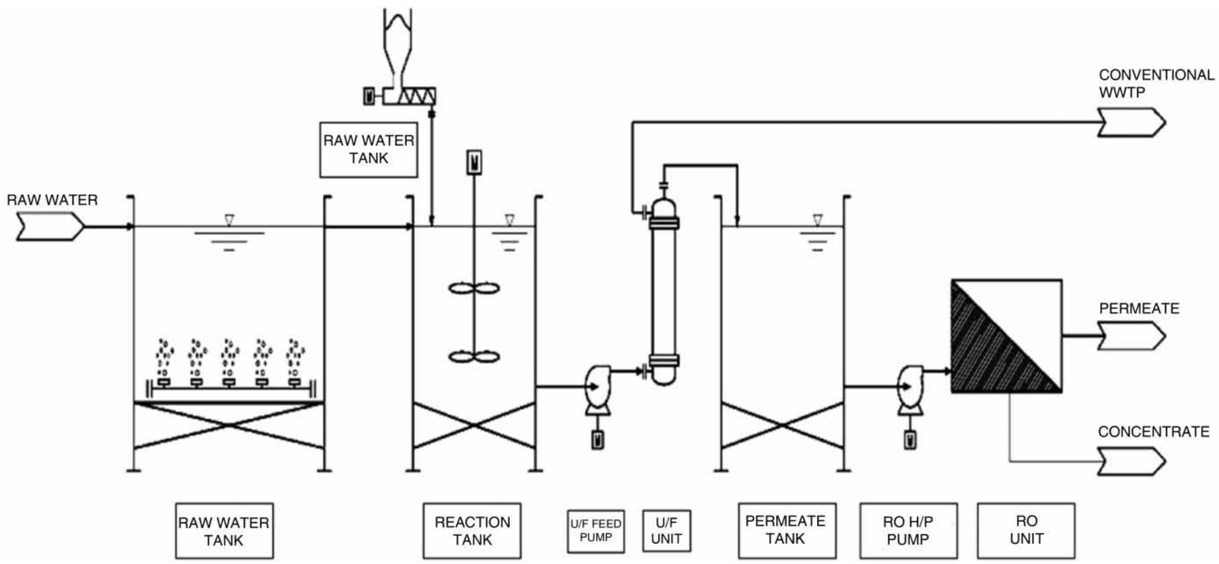

Figure 1 | A schematic illustration of the PAC and UF combined RO reuse system.

and feed flow rate of 16.5 L/min. A concentrate flow rate of 4.2 L/min was used in the transfer to the raw water tank, and the system recovery was about 75%.

RESULTS AND DISCUSSION

Figure 2 shows the physicochemical and biological characteristics of the treated wastewater effluent. The raw wastewater is mainly characterized by using the COD, color, total nitrogen (TN), total phosphorus (TP), pH, turbidity, and conductivity. The average values of COD, color, TN, turbidity, and conductivity are approximately 90.5 mg/L, 383.4 PtCo, 45.4 mg/L, 29.2 NTU, and 9255.2 μs/cm, respectively.

The adsorption efficiencies of COD, color, and TN at PAC dosages of 0.8, 0.9, 1.0, and 1.2 g/L are shown in Figure 3. The PAC adsorption efficiency for COD and color are considerably higher than that for TN. In addition, the PAC adsorption efficiency for COD increased with increasing PAC dosage from 0.8 g/L to 1.2 g/L, at about 43.4 mg/L and 69.1 mg/L, respectively (approximately 1.6 times higher than for a PAC dosage of 0.8 g/L). The average COD adsorption capacity of different PAC dosages is about 55 mg COD/g PAC. For a PAC dosage of 1.2 g/L, the adsorption efficiencies for color and TN are about 95.1% and 35.8%, respectively.

Figures 4 and 5 show the performance and treatment efficiency of the UF system for PAC dosages of 0.8, 0.9, 1.0, and 1.2 g/L. As shown in Figure 4, increasing the PAC dosage decreases the permeate flow rate and backwashing flow rate, whereas the backwashing pressure increases because higher PAC dosages have higher osmotic pressures. Subsequently, increasing the PAC dosage decreases the permeate flux owing to the membrane fouling by PAC adsorption. Figure 5 shows the SDI and turbidity of the UF permeate. The turbidity and SDI of the UF permeate were always lower than 0.8 NTU and 2.6, irrespective of

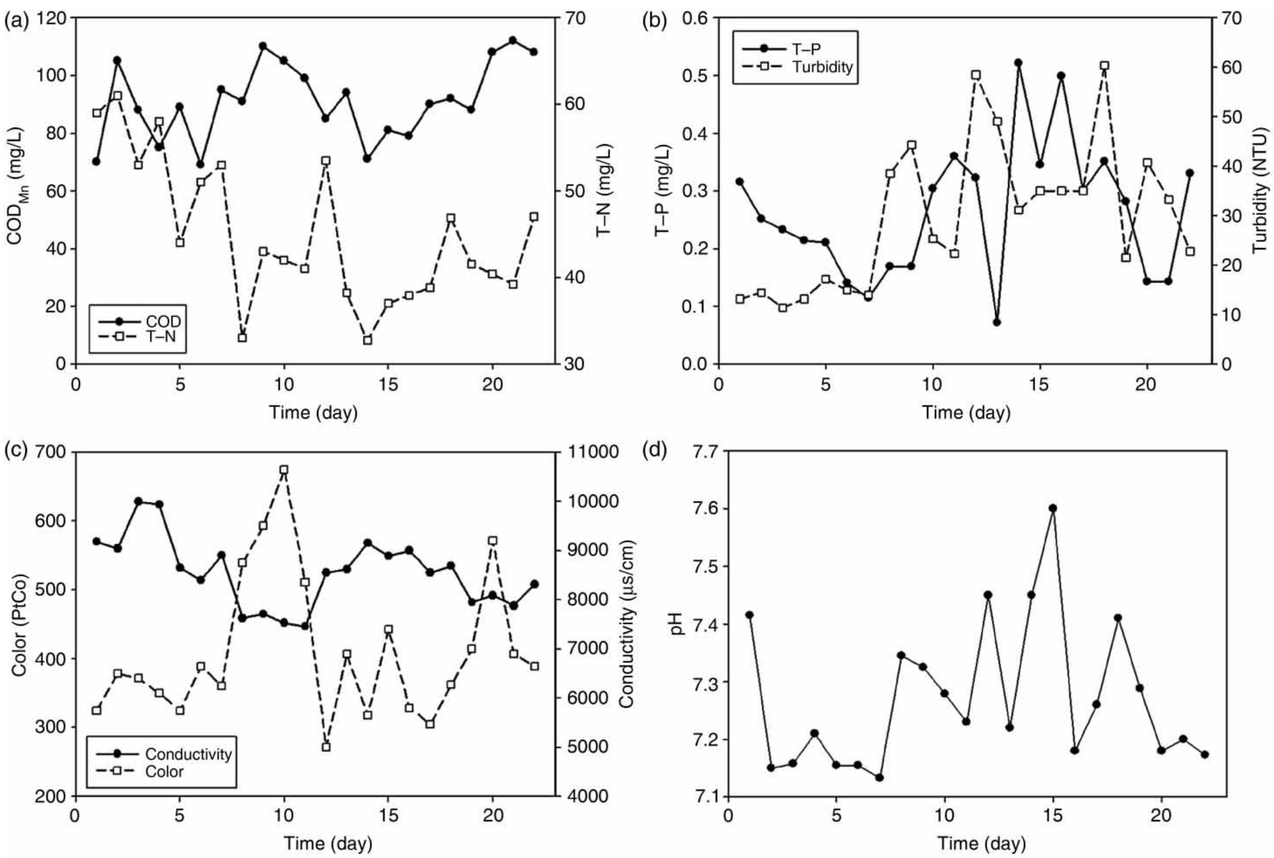

Figure 2 | Variation of treated tannery wastewater quality over time.

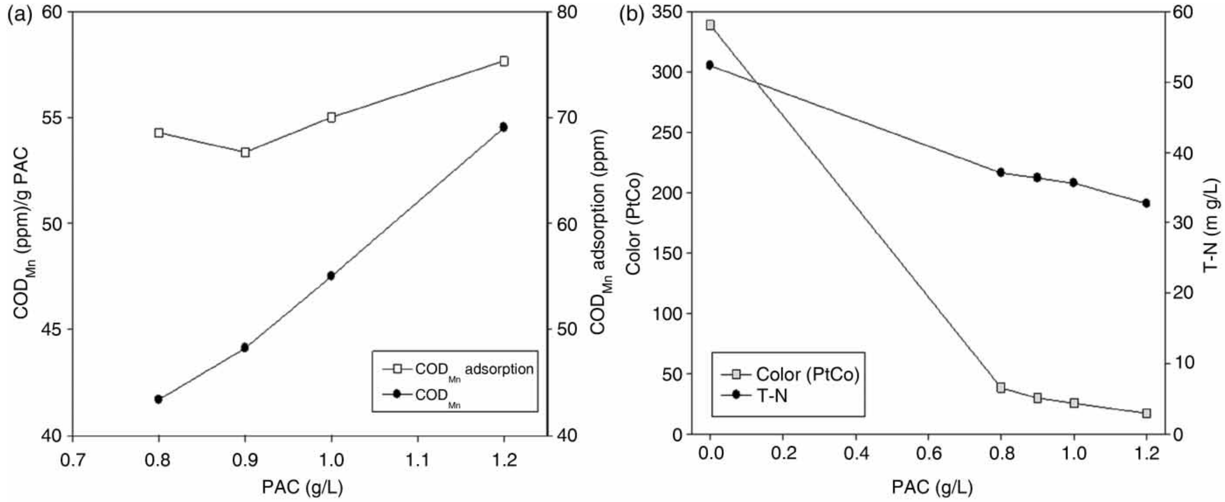

Figure 3 | Effect of PAC dosage on the removal of COD, color, and TN.

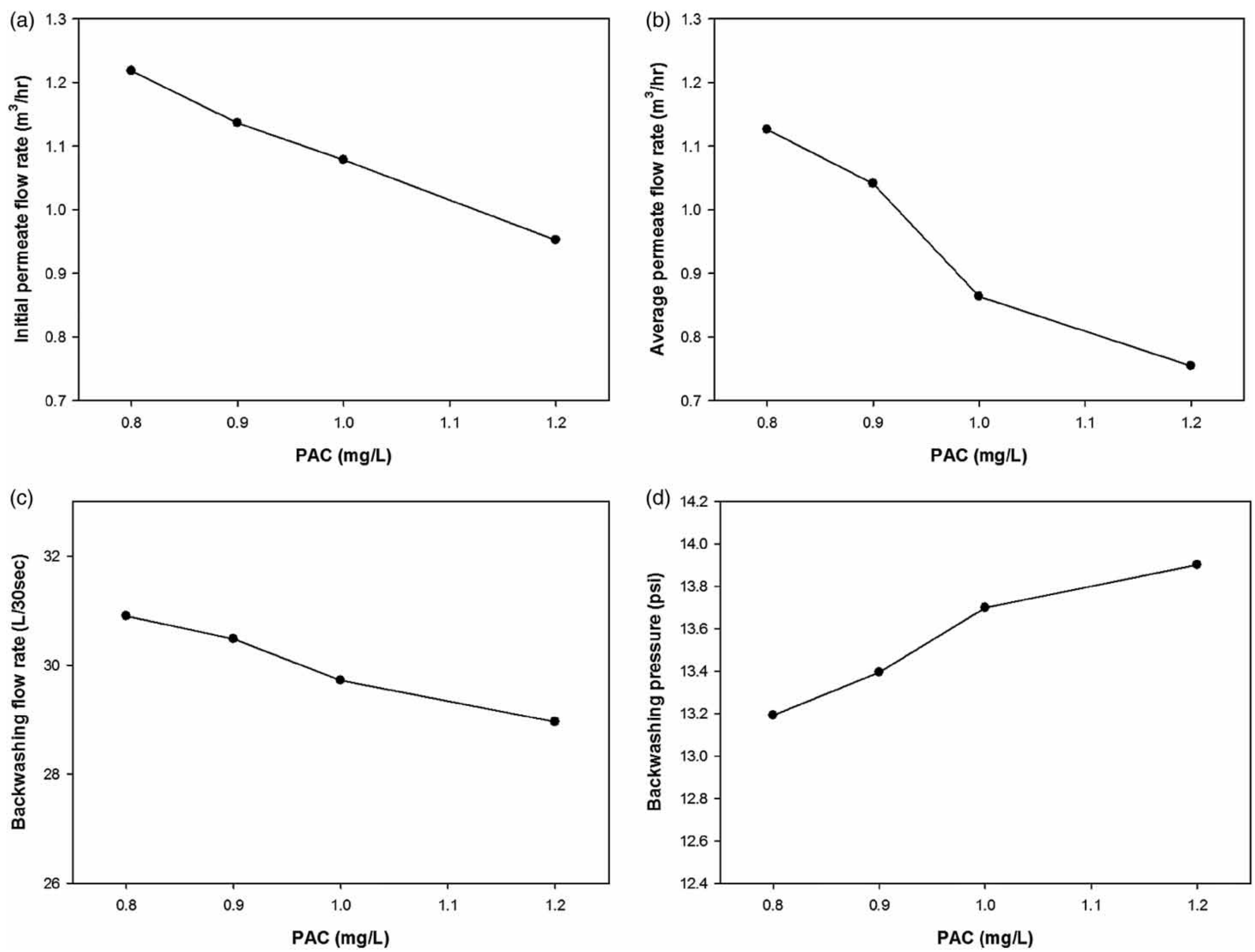

Figure 4 | Effect of PAC dosage on flow rate and pressure of the UF system.

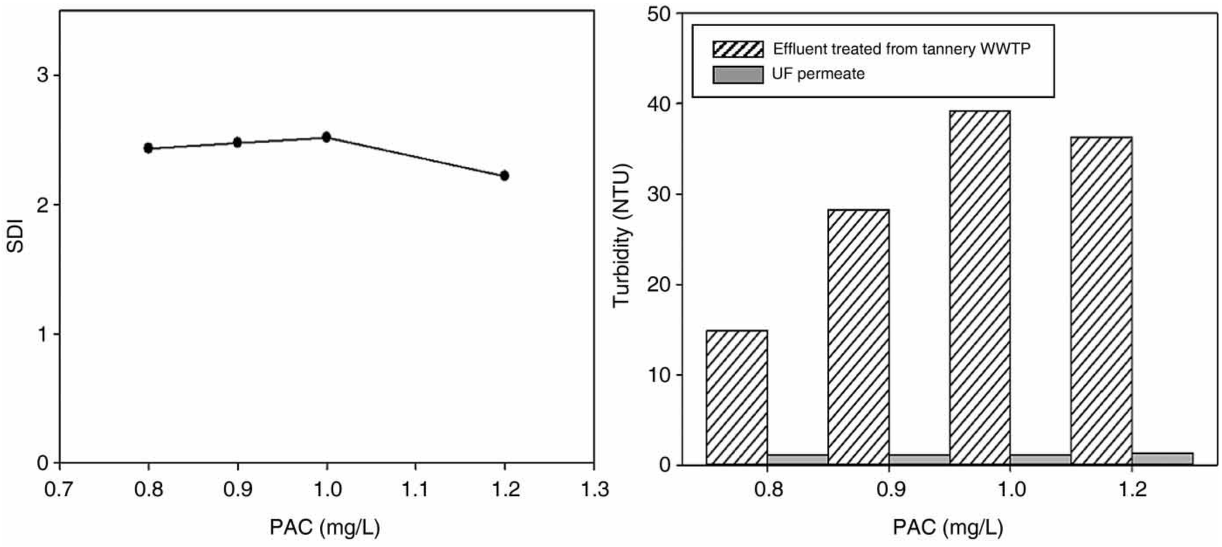

Figure 5 | Effect of PAC dosage on the SDI and turbidity of the UF system.

Table 2 | Feed, permeate and concentrate characteristics in RO experiments

Items	**COD (mg/L)**	**TN (mg/L)**	**TP (mg/L)**	**pH**	**Conductivity (μs/cm)**
Feed	15.9–25.1	30.1–42.6	0.06–0.5	7.4–7.6	8,360–9,812
Permeate	0.5–4	5–7.7	0.03–0.1	7.6–8	353–487
Concentrate	59.8–96.5	70.3–97	0.11–0.9	7.35–7.43	19,456–22,990
Reuse	<10	<10	<0.2	7–8	<500

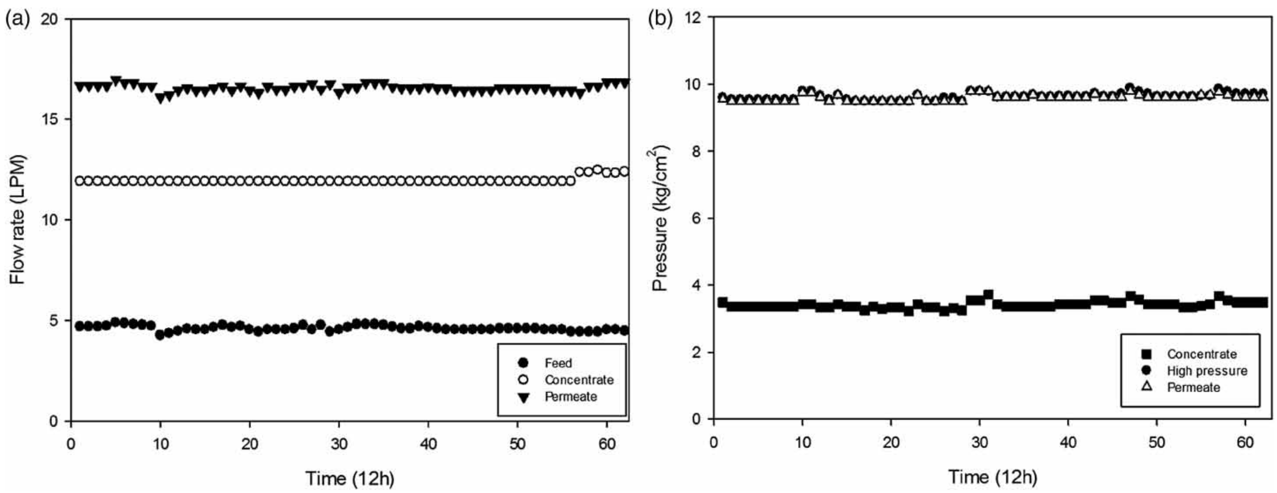

Figure 6 | Variation of flow rate and pressure in the RO system.

the PAC dosage, which satisfies the RO requirements of less than 1 NTU and 5, respectively.

The RO system was operated at a feed flow rate of 16.5 L/min and an operational pressure of 9.7 kg/cm^2. The performance of the RO system was evaluated in terms of the permeate pollutant concentrations and the membrane rejection in terms of conductivity. Figure 5 and Table 2 show data regarding the feed and the streams of permeate and concentrate in the RO experiments. Figure 6 shows the flow rate and pressure of the feed. The permeate and concentrate streams were constant over the 30-day test period, and a 75% membrane rejection was maintained. As expected, the conductivity rejection was higher than 95%, and COD, TN, and TP removal was higher than 80%. The RO permeate thus satisfies the water quality indices for reuse.

CONCLUSIONS

The high organic matter content, color, and salts in tannery wastewater require exhaustive pretreatment prior to using RO systems. The combination of a PAC and UF system greatly reduced the COD and color of tannery wastewater. In addition, the turbidity and SDI of the UF permeate satisfied the feed water requirement of the RO system. The RO system was constantly maintained at approximately 75% RO recovery, and the RO permeate satisfied the reused water level for processing. Therefore, a PAC and UF combined RO system can effectively process the effluent discharged from tannery wastewater treatment plants.

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