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Treatment of ion-exchange resins regeneration wastewater using reverse osmosis method for reuse

Karim Ghasemipanah

Research Institute of Petroleum Industry, Environment & Biotechnology Research Division, Water and Wastewater Treatment and Reuse Group, Tehran, Iran
Tel. +98 21 48255184; Fax: +98 21 44739736; email: ghasemipanahk@ripi.ir

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ABSTRACT

This study was designed to use reverse osmosis (RO) process for the treatment of high TDS regeneration wastewater of ion-exchange plant to reuse the treated wastewater. At present, the wastewater is discharged to evaporation lagoons without any treatment. Although numerous researches have been carried out on using membrane processes for industrial wastewater treatment, there has been no performed study on using reverse osmosis for the treatment of wastewater from ion-exchange resins regeneration process. The study was conducted in a pilot plant, including a FILMTEC membrane, with 4 inch diameter and 40 inch length to evaluate treatment of the wastewater. The obtained optimum conditions for the treatment of the wastewater in pilot plant were 15 bar pressure, 43 l/min influent wastewater flow rate which resulted in 3.9 l/min permeate flow rate, 99.4% salt rejection, 31.6 l/m^2 h flux and 9.1% recovery ratio for one element. To estimate recovery ratio for full scale wastewater treatment plant, the concentration factor (CF) was obtained in batch mode. This was done by directing the permeate stream into a second container while the concentrate stream was being returned to the feed tank of pilot plant. Both the permeate flow rate and permeate quality were monitored during the test. The test was stopped when the permeate flow rate reached up to 3 l/min which is minimum acceptable permeate flow rate for one element. Other factors such as chloride, sodium, Sodium Absorption Ratio (SAR) and pH of permeate were obtained at desirable CF to evaluate reuse of treated wastewater. Results showed with a value of 2.2 CF, permeate or treated wastewater can be used for agricultural irrigation.

Keywords: Ion exchange; Regeneration; Wastewater; Reverse osmosis; Reuse; Irrigation purposes

1. Introduction

Worldwide water shortage forces different parts of societies, especially the industries to consider various methods for recycling and reuse of wastewaters. Common methods used for disposal of resins regeneration wastewater (RRW) in the world consist of discharge to brackish or saline receiving waters, deep-well injection, and in case of small facilities, discharge to wastewater collection systems [1]. In some areas, land application has been used for some

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low-concentration brine solutions and controlled thermal evaporation may be the only option available in many areas [2]. Usually, final disposal of brine from ion-exchange regeneration process is used by evaporation lagoons, but in some cases, following decades of usage, the groundwater was found to be contaminated with salts [3]. In another study, production of some chemicals from salt concentrates was investigated; the process involved a series of chemical reactions to convert the NaCl to Na_2CO_3, $NaHCO_3$, and NH_4Cl [4]. Also, extraction of salts by solar evaporation is widely practiced in arid climates for the recovery of calcium, magnesium, barium, and strontium salts [5]. Furthermore, treatment of the regeneration of cation exchanger effluents by the membrane distillation (MD) process has been investigated. In the MD process; the two solutions at different temperatures are separated by a microporous hydrophobic membrane. During this process, the membrane pores are filled by the vapor phase, and therefore, the water vapor is only transferred across the membrane [6]. Membranes have been assigned a key role in water reclamation schemes that are aimed at higher water quality reuse application, including aquifers recharge, indirect potable reuse and industrial process water [7]. In addition, the potential of industrial wastewater reuse in a thermal power station was investigated. A significant amount of water was pumped from plant to the sewage plant and irrigation. Much of this wastewater could be treated by filtration, including RO, and recirculated in the plant as process water. The salty filtration and ion-exchange backwash here are two sources of discharge from the sewage treatment plant that can be potentially recycled into the plant [8]. In another research, power plant station faced with environmental and water shortage problems which have been solved by installing a reverse osmosis plant to treat mine water and spent cooling water [9]. Despite numerous researches on using membrane processes for industrial wastewater treatment, it seems that no study or research on using reverse osmosis for the treatment of wastewater form ion-exchange regeneration process was conducted. So, considering the similarities between RRW and brackish water or saline water, it has been hypothesized that reverse osmosis has the ability to remove dissolved solids from this kind of wastewater. So, treatability tests are necessary to confirm the hypothesis. These tests can be performed on a pilot plant. Thus, it is needed to provide a pilot plant with the facilities of indicating and controlling pressure, temperature and flow rate to evaluate and investigate the wastewater treatability. In this kind of pilot plant, spiral wound RO membrane is usually used.

In this research, firstly, the source and the characteristics of this kind of wastewater are introduced; secondly, recent disposing ways of RRW will be explained; and finally, the use of RO process for treatment and reuse of this wastewater for agricultural irrigation is proposed.

2. Materials and methods

Resins regeneration wastewater investigated in this study was from an ion-exchange plant of a petrochemical complex in south of Iran. The wastewater is currently discharged to evaporation lagoons without any treatment.

In ion-exchange plants deionized water is produced and ion-exchange resin saturation takes place after a few hours, depending on water quality, kind of resin, and conditions of the process. This saturated resin must be regenerated by acid or base, which results in production of large volume of industrial wastewater containing large amount of dissolved solids which, in turn, must be discharged. In brief, this plant consists of a mixed bed ion-exchange resin. To regenerate the mixed bed ion-exchange resin, sulfuric acid and sodium hydroxide solutions are utilized. Regeneration wastewater with 12,000 μs/cm electrical conductivity (EC), low turbidity (about 20–40 NTU), and pH of 8.5–9.5 is discharged to evaporation lagoons. Table 1 shows common characteristics of this wastewater.

In this research, a reverse osmosis pilot plant has been set up to treat and reuse the wastewater which is shown in Fig. 1. The pilot plant main parts were a wastewater tank with 250 liter volume, the low-pressure pump, cartridge filters, a high-pressure pump, a RO membrane, and devices for pressure and temperature control. The RO membrane divided influent wastewater to two different streams; permeate or treated and concentrated wastewater. Permeate was collected in a separate container for measuring volume and EC at specified time intervals. Permeate and concentrate streams were returned to the wastewater tank to fix the wastewater quality during the experiments. Meanwhile, pressure and temperature were controlled. For pressure control, a frequency inverter was used. Temperature was kept at 30˚C by a cooling system. A FILMTEC sea water membrane with 4 inch diameter and 40 inch length was used in the pilot plant to evaluate treatment and reuse of the wastewater. To start up the pilot plant, the wastewater tank was filled up with ion-exchange regeneration wastewater and the pumps were put into operation. Then, flow rate and pressure were adjusted according to predetermined figures by using bypass

Table 1
Common characteristics of ion-exchange resin regeneration wastewater

Parameters	Unit (mg/l)
Potassium	6.5
Calcium	150
Magnesium	20
Ammonium	3
Chloride	1,900
Strontium	0.2
Silica	1.5
Nitrate	33
Sulfate	2,600
Fe (total)	0.04
Zinc	0.17
Sodium	2,300

valve installed on bypass line and outlet valve installed on concentrate line. The process continues with fixed pressure and flow rate using the frequency inverter. In this study, temperature and EC parameters were kept at 30˚C and 12,000 μs/cm, respectively. To investigate the suitability of the wastewater for entering to membrane, Silt Density Index (SDI) tests [10] have been performed on the effluent after filtration by cartridge filters. SDI values were mostly below three. Moreover, the oxidation reduction potential (ORP) test has been performed to ensure the absence of oxidizing agents in the wastewater. The obtained ORP value was below 175 mV which is suitable for polymer membranes. During the experiments, pH of the RRW has been adjusted around seven by using sulfuric acid to inhibit carbonate calcium scaling. Pressures and feed flow rates were chosen according to Table 2.

To obtain recovery ratio for full-scale wastewater treatment plant, the concentration factor (CF) has been obtained in batch mode. This was performed by directing the permeate stream into a second container, and returning the concentrate stream to the feed tank of pilot plant as well. Both the permeate flow and permeate quality has been monitored during the experiments. The experiment was stopped when the permeate quantity reached to 3 l/min which is minimum acceptable permeate flow rate for one element. Other factors such as chloride, sodium, sodium absorption ratio (SAR) and pH of permeate at desirable CF have been obtained to evaluate reuse of treated wastewater.

3. Results and discussion

The pilot was equipped with the FILMTEC SW30-4040 element and the pressure was being kept at different influent pressures and wastewater flow rates according to Table 2. The results of pilot operation are listed in Table 2. According to this table and test No. 7, pilot studies confirmed that 15 bar pressure and 43 l/min RRW flow rate were the best operational conditions. At optimal conditions, 3.9 l/min permeate flow, 76 μS/cm permeate EC, 99.4% salt rejection, 31.6 l/m^2 h flux, and 9.1% recovery ratio per element

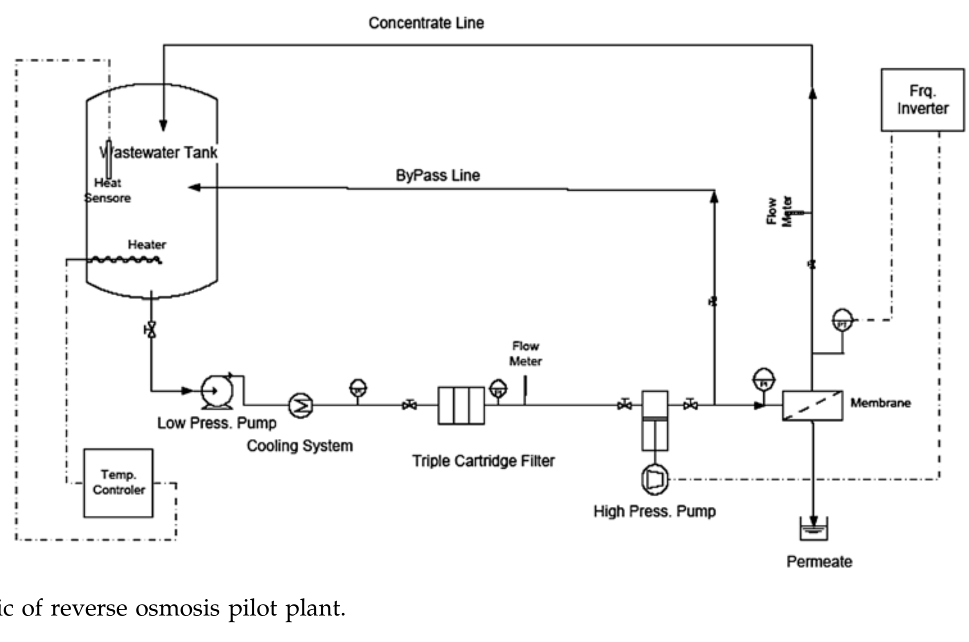

Fig. 1. Schematic of reverse osmosis pilot plant.

Table 2
Results of ion-exchange regeneration wastewater (EC 12,000 μs/cm) treatment with FILMTEC SW30-4040 membrane

Membrane and wastewater type	Test no.	Pressure (bar)	Feed Q (l/min)	Permeate Q (l/min)	Permeate EC (μS/cm)	Permeate flux (l/m^2 h)	Salt rejection (%)	Recovery (%)
FILMTEC SW30-4040	1	6	43	0.9	206	7.3	98.2	2.1
	2	8	43	1.5	129	12.2	98.9	3.5
	3	10	30	2	125	16.2	98.9	6.7
	4	10	43	2.1	91	17	99.2	4.9
	5	10	60	2.5	145	20.3	98.8	4.2
EC of wastewater (12,000 μS/cm)	6	12	50	2.7	125	21.9	98.9	5.4
	7	15	43	3.9	76	31.6	99.4	9.1
	8	18	50	4.9	50	39.7	99.6	9.8
	9	18	60	5	60	40.5	99.5	8.3
	10	20	43	5.4	43	43.8	99.6	12.6

Table 3
The comparison of treated wastewater 55% recovery with FAO standard

Parameters	Parameters for treated wastewater 55% recovery	FAO standard Slight to moderate degree of restriction on use
EC (μS/cm)	300	700–3,000
Chloride (meq/l)	1.6	<4
Sodium (meq/l)	1.7	<3
SAR	2.8	3
pH	6.7	6.5–8.5

were obtained. Obtained recovery value was less than maximum recovery per element (14%) according to FILMTEC manual [11]. Results of permeate flow rate and permeate flux confirm that the applied pressure and influent wastewater flow rate values were the optimal ones. FILMTEC manual indicates that maximum recommended element permeate flow rate for FILMTEC SW30-4040 is 3.9 l/min which is equal to permeate flow of test No. 7. To achieve recovery ratio for the full scale wastewater treatment plant, CF has been obtained from batch mode. At first, feed tank was filled up with 235 liter ion-exchange regeneration wastewater and test for CF determination was started; then experiment continued by directing the permeate stream into a second container, while the concentrate stream was being returned to the feed tank of pilot plant. Both the permeate flow and permeate quality were monitored during the test. The test was stopped when the permeate flow rate reached up to 3 l/min as minimum acceptable flow rate for one element and EC of permeate was 300 μS/cm with salt rejection of 97.5%. The total volume of permeate and concentrate in separate tanks were 130 and 105 liter, respectively. CF was calculated by dividing 235 over 105 which was equal to 2.2. The obtained recovery ratio was 55% or $[(235 - 105/235) \times 100]$. It means 55% of this wastewater is useable for reuse. The chemical and physical characteristics of the effluent are considered important when the treated wastewater is to be used as irrigation water. The suitability of water for irrigation is determined not only by the total amount of salt present but also by the kind of salt and plant type. Usually, parameters such as EC, chloride, SAR, and pH will consider for irrigation suitability. The SAR value is the ratio of sodium to calcium and magnesium ion concentration. Fifty-five percent of recovery-treated wastewater parameters are compared with FAO irrigation standards in Table 3 [12].

4. Conclusion

Based on the previous sections, the conclusions can be listed as follows:

- Ion-exchange resin regeneration wastewater is almost clear with high value of EC equals to 12,000 μS/cm.
- Industrial wastewater from ion-exchange regeneration unit can be treated satisfactorily by the method presented in this study. Pilot results confirmed that 15 bar pressure, 43 l/min influent flow rate were the best options at which 3.9 l/min permeate flow rate, 76 μS/cm EC of permeate, 99.4% salt rejection, 31.6 l/m^2 h flux, and 9.1% recovery ratio per element were obtained.

- The concentration factor (CF) obtained in batch mode was 2.2 at acceptable permeate quantity of 3 l/min which is minimum acceptable flow rate for one element.
- Considering the results at CF equal to 2.2 showed that the salt rejection was almost higher than 97%. It indicates that treated wastewater can be reused as desalinated water.
- Parameters such as chloride, sodium, sodium absorption ratio (SAR) and pH of permeate at desirable CF (2.2) were suitable for agricultural irrigation with slight to moderate restriction on use, according to FAO standards.

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