

Study of the behaviour of a reverse osmosis membrane for wastewater reclamation — influence of wastewater concentration

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Received 20 December 2006; accepted 7 January 2007

Abstract

Water scarcity is becoming a serious problem in the Mediterranean countries. To minimize negative effects, wastewater reclamation can be one of the possible solutions. Reverse osmosis (RO) is the process that ensures the highest water quality. Thus, the required quality goal can be reached adjusting the wastewater portion to be treated and the portion directed to the blending tank. In this work, a study with a low-pressure RO pilot plant was conducted in the laboratory. A spiral wound composite polyamide membrane (*ESPA1-2540, Hydranautics*) with an active area of 2.59 m² was tested for increasing volume concentration factors (VFC). Thus, the membrane elements behaviour within a pressure vessel in a full-scale plant was simulated. The experiments were run three times to confirm statistically the results. These ones showed an almost constant permeate flux (17 L m⁻² h⁻¹) while keeping the transmembrane pressure constant at 6.8 bar with a VFC of 2.5. Concerning the salt retention, it was observed a slightly reduction on increasing the VFC. However, the permeate conductivity was lower than 80 μS/cm in all cases.

Keywords: Reclamation; Reverse osmosis; Wastewater

1. Introduction

Water scarcity is becoming a serious problem in the Mediterranean countries, especially in coastal zones and in the islands. As a consequence, the availability of freshwater for irrigation and other

non-potable uses has decreased and the interest in wastewater reclamation and reuse has increased considerably in Spain in the recent years.

Processes applied in wastewater reclamation can be divided into two groups: treatments that do not remove salts (they hardly affect the wastewater conductivity) and treatments that include salts removal, in which membranes have

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a key role. In this work, the application of the reverse osmosis (RO) in wastewater reclamation is studied.

RO has been studied by several authors [1–3], pointing out the quality of the final water and its use, including groundwater recharge. Chang et al. [4] compared the nanofiltration and the RO processes for reclaimed wastewater for irrigation use by means of studying the effects of these processes on the sodium adsorption ratio (SAR). Authors concluding that could increase the SAR in such a way that soils could be affected.

Wintgens et al. [5] presented an overview of the status of membrane processes in wastewater reclamation. Concerning the application of RO membranes, the authors stated the possible alternatives for RO pre-treatment and presented some case studies. However, recovery data of the plants were not collected.

Lew et al. [6] evaluated an integrated membrane process for water reclamation consisting in a membrane bioreactor and a final RO stage. The authors used a membrane element with a 10–15% of recovery, recirculating the reject stream in order to achieve a final recovery of 80%. No fouling problems were reported.

Xie et al. [7] evaluated the maximum recovery of a RO system treating a secondary effluent after microfiltration. The results indicated a maximum recovery of 90% (volume concentration factor, VCF of 10) and authors worked both with RO software and with a pilot plant. The main problems reported were related with scaling phenomena due to a high phosphate concentration.

Lee et al. [8] studied the fouling of the RO membrane using a model solution simulating the effluent organic matter (EFOM) of a biologically treated wastewater. Although authors work in a recirculation mode, concentration of the model solution components (alginic acid as a model hydrophilic organic matter, calcium, chloride, sodium and magnesium) was modified in order to study the effect of different concentrations on membrane performance. Severe fouling was

observed in the presence of calcium by complexation of alginate macromolecules.

In this paper a study of the behaviour of one RO membrane for wastewater reclamation has been conducted at different VCFs. In this way, it is studied the membrane element behaviour simulating any position inside a standard pressure vessel. The results will be useful to make an approach to the conversion in an industrial plant.

2. Material and methods

2.1. Samples characterization

The analyzed parameters were conductivity, pH, COD, turbidity and ions concentrations (chloride, bicarbonate, sulphate, nitrate, calcium, magnesium, sodium and potassium).

For the secondary effluent, SDI was also analyzed in order to check that its value was lower than that recommended by the membrane maker.

Conductivity and pH were determined by means of CRISON instruments. COD was determined with Spectroquant NOVA 60 from MERCK and turbidity with D-112 apparatus from DINKO. SDI measurements were performed according to the ASTM standard test method D 4187-82. Ions concentrations were measured with 790 Personal IC ionic chromatograph from METROHM.

2.2. Laboratory plant description

In Fig. 1 a scheme of the laboratory plant can be seen.

The feed tank included a stirrer to homogenize the feed solution and a level switch that enables continuous operation of the pilot plant. A 5-micron pre-filter was placed upstream in order to minimize the membrane fouling. Two manometers at each side of the membrane module were used to measure the transmembrane pressure. A flow meter was located in the reject stream to measure its volumetric flow rate. The valve located next to the flow meter was used to regulate the transmembrane pressure. The plant was equipped with

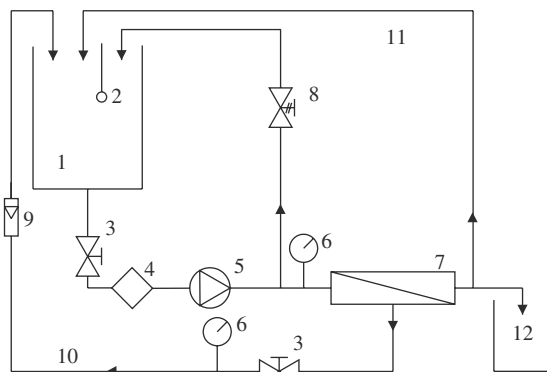


Fig. 1. Scheme of the laboratory plant. 1 feed tank; 2 temperature sensor; 3 regulation valve; 4 filter (5 μm); 5 pump; 6 manometer; 7 membrane module; 8 security valve; 9 flow meter; 10 reject stream; 11 permeate stream; 12 auxiliary tank.

a pressure vessel containing a 2.5" diameter spiral wound membrane.

2.3. Membrane

The membrane tested was ESPA1-2540 from Hydranautics. The total effective membrane area is 2.59 m². The main characteristics of this membrane are shown in Table 1.

Table 1
ESPA1-2540 characteristics (provided by Hydranautics)

Material	Composite polyamide
pH operating range	3–10
Maximum operation pressure, MPa	2.1
Maximum temperature, °C	45
Free chlorine tolerance, mg L ⁻¹	<0.1
Salt rejection (%) ^a	98
Maximum feed water SDI	5.0
Maximum feed water turbidity (NTU)	1.0

^aTest conditions: 1500 ppm NaCl solution, 1.05 MPa, 25°C.

2.4. Methodology

Experiments were carried out to study the transmembrane pressure to be applied at increasing VCF for constant membrane permeate flux (i.e. constant permeate flow rate). At the same time the influence of the VCF on the salts rejection is studied. For that, the operation mode was of total recirculation (permeate and reject streams recirculation to the feed tank) and after reaching the steady state a constant permeate volume was extracted from the system in order to modify the VCF. These experiments were repeated three times in order to confirm statistically the results.

Experiments were run at a constant permeate flow rate (corresponding with approximately 10% of conversion). In this way, transmembrane pressure was adjusted for each VCF. Temperature was maintained at 25°C.

3. Results

3.1. Secondary effluent characterization

Table 2 shows the average values of the parameters measured in the characterization of the WWTP secondary effluent after 40 μm filtration.

Table 2
Secondary effluent characterization

Parameter	Average value
pH	7.42
Conductivity ($\mu\text{S/cm}$)	1853
Turbidity (NTU)	1.88
SDI	5.5
COD (mg/L)	99
Cl ⁻ (mg/L)	250
HCO ₃ ⁻ (mg/L)	390
NO ₃ ⁻ (mg/L)	1.95
SO ₄ ²⁻ (mg/L)	312
Na ⁺ (mg/L)	182
K ⁺ (mg/L)	18
Ca ²⁺ (mg/L)	132
Mg ²⁺ (mg/L)	52

It can be observed that turbidity and SDI are slightly higher than those recommended by the membrane maker. As a consequence, a further filtration (5 μm) was performed to minimize the membrane fouling.

3.2. Membrane permeability

The distilled water membrane permeability previous to the experiments can be observed in Fig. 2.

It can be observed that the distilled water permeability was $4.3 \text{ L m}^{-2} \text{ h}^{-1} \text{ bar}^{-1}$. This value is important in order to evaluate the membrane fouling after its operation with the wastewater.

3.3. Experiments with secondary effluent

In Fig. 3, the influence of the operating transmembrane pressure on the VCF is illustrated. As commented in materials and methods section, experiments were carried out maintaining constant the permeate flow rate.

It can be seen that the similar operating transmembrane pressure were set for the different VCF, increasing slightly for $\text{VCF} = 2.5$. This VCF value corresponds with a conversion of 50% in a continuous process.

Concerning the membrane rejections, Fig. 4 shows how the salts retention, calculated as a function of the conductivity measurements, changed with the VCF.

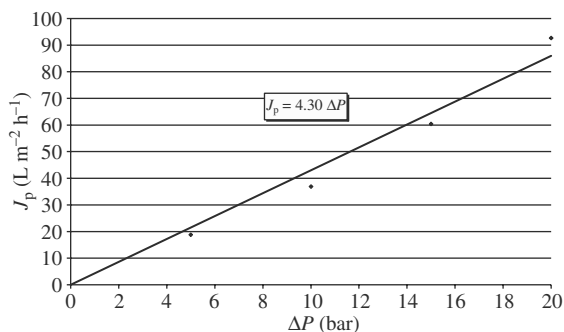


Fig. 2. Distilled water permeability.

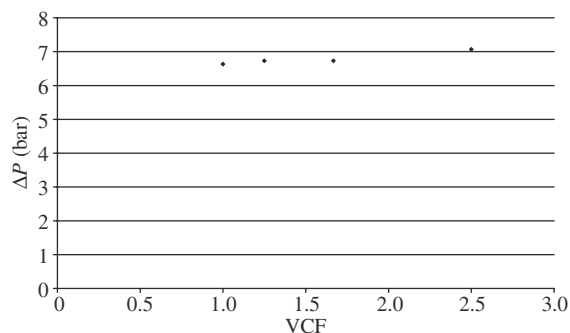


Fig. 3. Influence of the operating transmembrane pressure for constant permeate flow rate on the VCF.

As expected, salt retention decreased slightly with the VCF. This behaviour is due to the concentration polarization phenomenon on the membrane surface. It entails an increase in the salts concentration near the membrane surface. As a consequence, the apparent salts retention (considering the conductivity in the bulk solution) becomes lower. Anyway, the minimum calculated salts retention was higher than 98%.

Table 3 shows the permeate characterization for a sample corresponding with the experiment at $\text{VCF} = 2.5$ in the third series of the tests.

In order to evaluate the membrane performance at higher VCF values (higher global conversions) further experiments were conducted once checked that the operating transmembrane

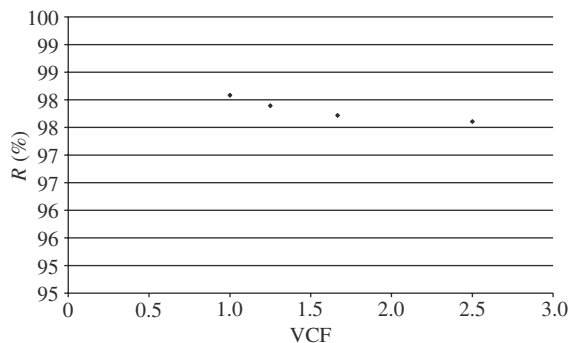


Fig. 4. Salts retention variation with VCF for constant permeate flow rate.

Table 3
Permeate characterization (third series of tests, VCF = 2.5, $\Delta P = 7.1$ bar, $T = 25^\circ\text{C}$)

Parameter	Average value
Conductivity ($\mu\text{S}/\text{cm}$)	78.3
COD (mg/L)	7
Cl^- (mg/L)	20
HCO_3^- (mg/L)	37
NO_3^- (mg/L)	0.5
SO_4^{2-} (mg/L)	1.5
Na^+ (mg/L)	12.2
K^+ (mg/L)	$\cong 0$
Ca^{2+} (mg/L)	2.7
Mg^{2+} (mg/L)	0.6

pressure did not vary significantly with increasing VCF (up to 2.5) keeping approximately constant the conversion. In this way, Fig. 5 illustrates the results in terms of both operating transmembrane pressure and salt retention.

With VCF up to 1.5, the set transmembrane pressure was almost constant to obtain similar element conversions. However, for VCF higher than 1.5, it was necessary a significant transmembrane pressure increase to achieve it. In this way, transmembrane pressure had to be adjusted to 8 at a VCF of 6.

At this VCF value, it was observed significant flux decay. Hence, the transmembrane pressure was increased up to 3 bars in order to obtain the

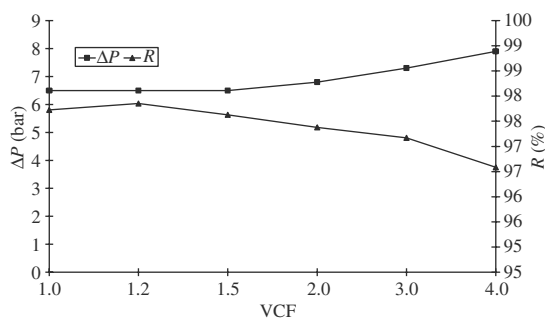


Fig. 5. Variation of the set transmembrane pressure and salts rejections in the experiment with higher wastewater concentration.

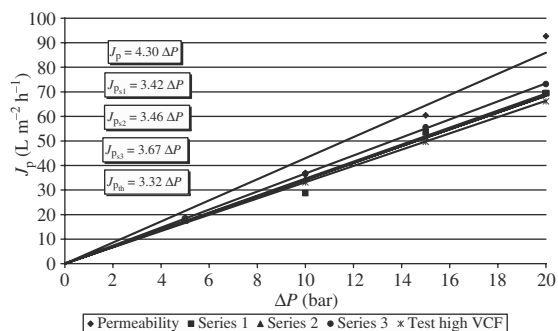


Fig. 6. Membrane water permeability after different experiments.

same flux. Salts retention was lower than those calculated for lower VCF values. This evolution has been explained above (comments on Fig. 4).

Water membrane permeability was measured after membrane rinse only with distilled water. Fig. 6 shows the distilled water membrane permeability after the three series of experiments at increasing VCF up to 2.5 and after the final experiment in which the VCF was increased up to 6.0.

It can be stated that only after the first experiment an irreversible fouling is detected. After the rest of the experiments distilled water permeability is recovered and thus the flux values measured for each transmembrane pressure were very similar.

4. Conclusions

In order to study the membrane elements behaviour in a pressure vessel of an industrial plant, experiments with only one element with increasing VCF can be performed in laboratory scale. This is possible if the element conversion is kept approximately constant.

Although ESPA1-2540 is not a low fouling membrane but a standard thin film composite membrane, no fouling problems were detected in the performed experiments for increasing VCF up to 3. Thus, the water membrane permeability

hardly decreased although no chemical cleaning was carried out.

Since there was no addition of antiscaling chemicals, higher VCF values (6.0) entailed a significant transmembrane pressure increase to keep the conversion and a salts retention reduction.

Acknowledgements

Authors thank the Spanish Ministry of Education and Science for the financial support (Project reference CTO2005-03398/PPQ). Authors also thank Depuración de Aguas del Mediterráneo for its technical support.

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