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# Surrogating membrane resistance variables for assessing reverse osmosis fouling during wastewater upgrading for unrestricted use

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ABSTRACT

Reverse Osmosis (RO) is one of the most efficient methods for salt removal from seawater, saline water and from wastewater. However, efficient application of RO for such purposes is still hindered by several operational drawbacks, the main one being membrane fouling. Herein, field experiments were conducted on a commercial scale membrane system treating domestic wastewater for agriculture irrigation. It was conducted for developing and verifying of a simple and practical tool for evaluating RO membrane fouling. The membrane system consisted of an UltraFiltration (UF) stage and a complementary RO one. The UF component is applied for the removal of the organic matter and pathogenic bacteria while the RO is used for the dissolved solids removal from the wastewater, bringing the water to drinking quality. In our field experiments the membrane system capacity was around 125 $m^3$/day and it was run smoothly for a continuous period of four years, providing unrestricted quality effluent that was used for irrigation of a series of seasonal commercial field crops.

Following analysis of both field and theoretical data, it was found that back flushing with clean water without adding extra chemicals can be applied in order to minimize fouling of the RO component. Back flushing has two major benefits: saving expenses for the chemicals utilization and improved environmental control.



## 1. Introduction

### 1.1. Wastewater reuse

Water scarcity along with the continuous decrease in water quality is one of the major threats on human survival in arid and semi-arid regions around the world, including most of the Mediterranean Basin, Africa, North-Western America (California) and others [1,2]. The rising demand for drinking water, together with growing environmental awareness has led to intensive efforts in the field of treatment and reuse of wastewater. During the last two decades, the reuse of treated domestic wastewater for agricultural irrigation has become widespread, especially in arid and semiarid regions [3–6]. Treated wastewater is now used for irrigation of field crops, vegetables, and orchard plantations as well as pasture irrigation throughout South and Latin America, the Mediterranean region. It is practiced in Northern Africa, Southern Europe, Western Asia, the Arabian Peninsula, South Asia, United States of America (USA) and the Mediterranean Region [7]. Extended recycling is experienced in developed regions suffering from water scarcity, such as the Middle East, Australia and parts of the USA [6]. Wastewater reuse is expanding in Europe which has been subjected to a growing stress on conventional water sources over the last two decades. Wastewater reuse is spreading out both in terms of quantity and quality, leading to a wider acceptance of water reuse practices [8].

One of most problematic issues associated with wastewater reuse, primarily for irrigation, is the water salinity [9–11]. For example, an individual fouling mechanism was investigated with

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polymeric RO membrane, commonly used for final purification of secondary-treated olive mill wastewater [11]. A non-uniform cake was built-up, on the fouled membrane, principally formed by the organic matter and residual iron colloids. A decline in flux of about 39.0% of the initial flux drop was observed and attributed to concentration-polarization reaction on the boundary region of the membrane.

Increased salinity of wastewater from house-holds and local small industrial plants, combined with the water evaporation from open-surface reservoirs used during the process of wastewater treatment, lead to a high salt concentration in the final effluent [12]. Field studies were conducted for two consecutive growing seasons under arid conditions at a southwest region of Cairo, Egypt [13], in very saline soils (Electrical Conductivity of the soil was 12.6 dS/m, which relatively high), using different mulches. Improved yields of around 15% as compared to the conventional treatments were obtained. When saline effluent is utilized for agriculture irrigation without any special treatment means it leads to an increase in soil salinity and adverse effects on the soil. . When soil salinity increases to critical levels, crop yields might be adversely affected [14]. The issue of soil salinity is particularly prominent in arid and semi-arid areas.

Reverse Osmosis (RO) nanotechnology is becoming one of the most efficient methods for salt removal from seawater, saline water, wastewater and energy generation [15–20]. A reverse osmosis membrane stage is frequently applied after the UltraFiltration (UF) stage which is mainly used for removal of the organic matter and pathogenic bacteria contained in the influent [4]. Membrane nanotechnology such as RO is commonly used in chemical and biomedical industries, for food and high quality waters (mainly for drinking) production [19,20].

### 1.2. Membrane fouling

Membrane fouling, which arises from specific interactions between the membrane material and foulants contained in wastewater. It is one of the major challenge and barrier of RO processes expansion [21–25]. Commonly, it is a result of organic matter content in the influent, although it can be detected in sea water as well [15,22,26]. Fouling can even be found in Forward Osmosis (FO). There is s strong trend to conduct FO experiments such as by [18,27–29] aiming also at energy saving. These experiments were conducted in view to explicitly correlate the increment of substrate membrane surface hydrophilicity in order to improve fouling resistance and reversibility the membrane. A decline in flux was observed. Forward Osmosis experiments in commercial cellulose triacetate and newly developed polyamide thin film composite membranes that treated high salinity and low salinity activated sludge. A steady state was reached within around 100 days however, with a declining flux [27].

Fouling results in an increase of membrane resistance which causes permeate flux decline and elevated demand for energy. It reduces the economic feasibility of membrane processes due to increased energy demand for filtration and the extra costs required for membrane cleaning [20,30,31]. One ways to decrease RO membrane fouling is to apply cleaning constituents such as antiscalants (e.g., Sodium hexametaphosphate) or to utilize pH regulators. Nevertheless, several.

studies have reported that the use of antiscalants was to some extent less effective [30–36]. Noteworthy is that these results were obtained and related to different operation conditions, mainly changing the values of Volume Concentration Factor (VCF) [34], which is the ratio of feed to retentate volumes. It was reported that antiscalants which were tested under different operation conditions, had mingled effects on membrane characteristics and influent quality García-Figueruelo et al. (2008) [12] reported that during laboratory scale experiments they conducted, up to VCF≅3 almost no fouling phenomena were observed. However, for VCF values larger than 3 “permeate flux dropped drastically”, according to salt precipitations [34]. Thus, the prediction and behavior of membrane fouling with time in the absence of antiscalants and pH regulators can be of great benefit [37–39].

### 1.3. Previous field results

Preliminary experiments with the RO field systems were conducted. The approximate influent inflow rate was between 3.0 $m^3/h$ and 5.0 $m^3/h$. Different series of experiments were conducted. The series refer to three brine flow rates, namely 0.5 $m^3/h$, 1.0 $m^3/h$ and 1.5 $m^3/h$. Each experiment lasted approximately two hours for the arbitrary series. The results for the brine disposal of 1.5 $m^3/h$ are given by Eq. (1):

$$SR = 6.0E{-}07 * \Delta R + 92.474 \qquad R^2 = 0.99 \tag{1}$$

where SR is the Salt Rejection (percent) and $\Delta R$ (bar*s/m) are the changes in membrane resistance due to fouling. Most other field results are given in Fig. 1. As can be observed the higher the disposal rate of the brine the better is the salt rejection (Fig. 1). For the lowest brine disposal the line even gets a negative sign. It is probably true due to a higher salt accumulation (increased resistance) under low brine disposal.

### 1.4. The purpose of the work

The main goal of this study was to develop and verify a simple and practical tool, which will include a limited number of

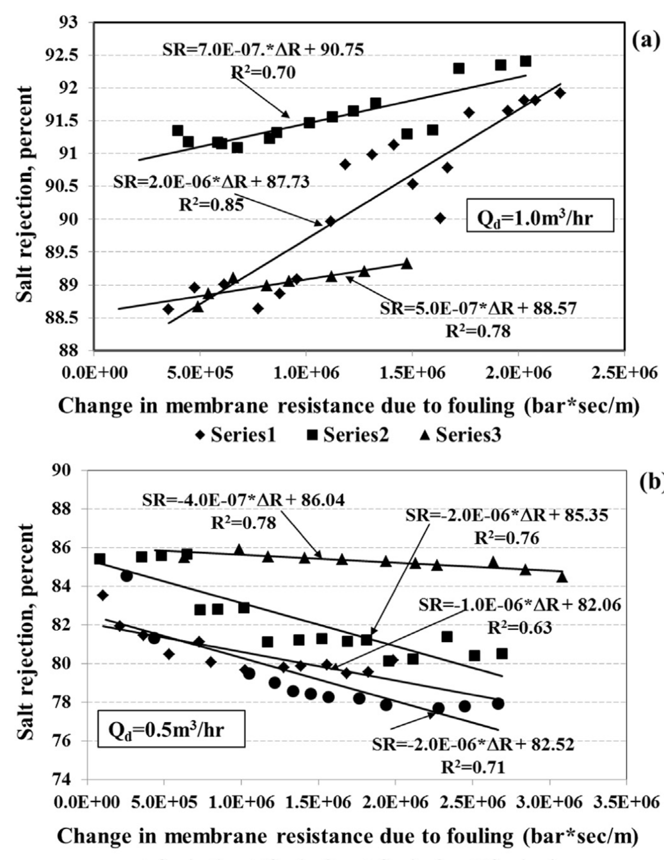


**Fig. 1.** Salt Rejection (SR) for the different experimental series conducted [(a): brine disposal – 1.0 $m^3/h$; (b): brine disposal – 0.5 $m^3/h$; Inflow into the membrane system between 3.0 $m^3/h$ and 5.0 $m^3/h$].