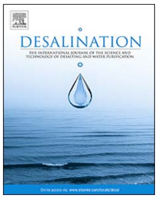
Desalination 424 (2017) 10–16

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal



Engineering advance

Sustainable RO desalination – Energy demand and environmental impact

Hilla Shemer, Raphael Semiat*

Rabin Desalination Laboratory, Wolfson Faculty of Chemical Engineering, Technion-Israel Institute of Technology, Haifa 32000, Israel

ARTICLE INFO

Keywords:
Reverse osmosis
Brine discharge, energy consumption, cost
Marine environment
Ecosystem

ABSTRACT

The expedient solution to water scarcity worldwide is desalinization. Nevertheless, common misconceptions of high cost, energy intensiveness and negative ecological footprint hinder global implementation. The objective of this paper is to refute some unsubstantiated claims regarding the energy demand and environmental impacts of reverse osmosis desalination. Energy consumption of RO desalination constitutes only a small fraction of a national cumulative energy demand. Meanwhile significant cost reductions of desalinated water are not expected in the near future. To date, worldwide chemical and biological monitoring programs show that brine discharge from desalination plants have localized minimal impacts on the marine environment. Properly sited, designed and operated RO desalination plants contribute to reduced energy demand and environmental footprint.

1. Introduction

Water is the cheapest natural resource on earth yet, its price varies significantly worldwide.

Table 1 summarizes the Rickards Real Cost Water Index™. This index is calculated using an algorithm that can be expressed in the following simplified form: (energy costs + operating expenses + capital expense + interest expense) / volume of water supplied [1]. In some places in the world tap water is free of charge due to historical reasons, religious believes or just because it is of abundance. On the other hand, the cost of 1.5 L bottled drinking water is very high, ranging from 0.3 to 3.3 US$ [2]. The costs of agricultural water (i.e., irrigation water) vary substantially with geographic location, water sources, and institutional arrangements.

Water scarcity is among the main problems encountered by many societies. Two thirds of the world's population currently live in areas that experience water scarcity for at least one month a year. About 500 million people live in areas where water consumption exceeds the locally renewable water resources by a factor of two. Water shortage results from climate changes (causing spatial and temporal variations of water cycle dynamics), accelerated urbanization, increase in population and life quality, and increased demand by industry and energy production [4]. Additionally, water conflicts occurred throughout history and are still occurring now days.

Water quality worldwide deteriorate due to discharge of untreated domestic and industrial wastewater, agricultural runoff and release of greenhouse gases, by polluting surface and ground water with nutrients, pesticides, synthetic organics, NO_x and SO_2 as well dissolution of naturally occurring environmental pollutants. The need to maintain clean water resources to supply all essentials is crucial. In order to do so new modern high quality water supply, which are able to accommodate the growing demand, should be prioritized. Industrially made water consume energy, require special equipment, financial expenses and trained worker. It is important on one hand, to find the best low cost and sustained solutions and on the other hand, to educate and regulate saving, smart use and minimize pollution.

Water may be generated from non-conventional resources including: (i) recovery of urban wastewater for irrigation or industry use, (ii) indirect potable reuse i.e., treated effluent is discharged into groundwater or surface water, after treatment it is supplied as drinking water; (iii) desalination techniques at which water is extracted from seawater (SW) or brackish water.

Desalination techniques consist of membrane separation processes such as reverse osmosis (RO) and electrodialysis (ED) or thermal processes such as multi stage flash (MSF) and multi-effect distillation (MED). At present, RO and MSF are the prevailing techniques for sea and brackish water desalination, as shown in.

Fig. 1 [5]. Cost breakdown for a typical seawater RO desalination plants, including capital expenses (CAPEX) and operational and maintenance (O & M) costs, can be found in Cohen et al., 2017 [6]. Overall, the cost vary depending on plant location, plant size, feed water quality, and local electrical energy cost [6].

Public awareness as well as the scientific community raise concerns over the potential adverse effects of desalination. The objective of this

---

* Corresponding author.
E-mail address: cesemiat@technion.ac.il (R. Semiat).

http://dx.doi.org/10.1016/j.desal.2017.09.021
Received 10 August 2017; Received in revised form 19 September 2017; Accepted 19 September 2017
0011-9164/

Table 1
Global water cost indices [3].

Location	Water cost index (US$)
Global	1.39
London	2.16
Manila, Philippines	0.35
Sao Paulo	1.10
Singapore	1.66
Uganda	1.49

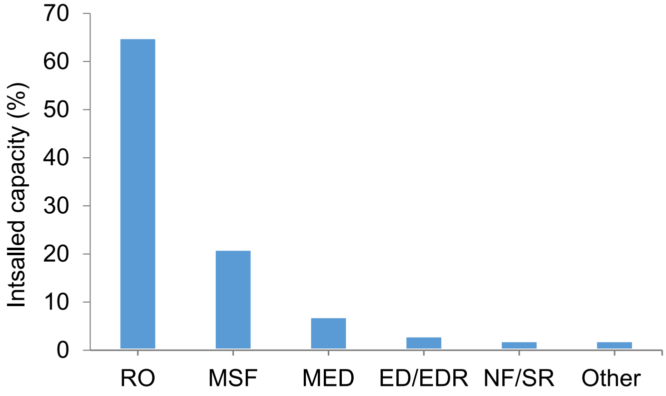


Fig. 1. Total worldwide installed capacity (85.6 Mm^3/d) by feed water type [5].

paper is to present misconceptions about the energy demand and environmental impacts of reverse osmosis desalination.

2. Energy consumption

2.1. Minimum work or heat energy demand

The absolute minimum energy necessary for removal of cubic meter of fresh water from very large quantity of seawater at 20 °C, as calculated based on the second law of thermodynamics, is 0.79 kWh/m^3 regardless of the separation technique used. For most brackish water, the minimum energy requirement is much less. For a process of 50% recovery ratio, at an initial 3.5% NaCl solution, the minimum energy increase to about 1.1 kWh/m^3 [7].

Evaluation of separation processes such as desalination, based on the second law of thermodynamics, is called exergy analysis. It provides an assessment of the maximum work that can be extracted from a certain system relative to the surrounding environment i.e., it identify sources of the inefficiency. Therefore, it may be used to improve/optimize the process [8]. The simplest desalination technique of a single-stage evaporator requires approximately 650 kWh of thermal heat per one cubic meter of seawater, depending slightly on the evaporation temperature [9]. Additional energy is needed to condense the vapor by pumping cooling water. Modern evaporation techniques require much less energy, not much higher than RO, as discussed in details previously [9].

2.2. Energy consumption of RO desalination

Common energy consumption of SWRO desalination plant is of the order of 3.5 kWh/m^3 [10,11]. The range of energy demand for the RO process itself, depending on the feed water salinity, the recovery ratio, the efficiency of the pumps and the efficiency of the energy recovery system, range between 1.7 and 2.5 kWh/m^3. Additional costs such as pumping, pre-treatment, brine discharge, and electric power used within the plant total to 0.3–1.5 kWh/m^3. Therefore, the overall energy consumption is 2.0–4.0 kWh/m^3. Smaller installations, remote locations, inexperience in design and/or operation may increase the energy consumption in the range of 3–7 kWh/m^3 [12].

There are several approaches aimed to reduce the energy consumption of RO processes. These include: (i) improvements of membrane technology by developing highly permeable membranes and/or low fouling composites and by increasing the lifespan of the membrane [13–16]. (ii) Energy recovery devices (reducing the total power consumed by high pressure pumps) [17,18]. (iii) Efficient high pressure pumps (to reduce electrical power consumption) [19–21]. (iv) Optimization of the RO process (operating conditions and configuration) [13]. (v) Intermediate chemical de-mineralization to obtain higher water recovery (brackish and wastewater) [22], and (vi) use of renewable energy resources. With regard to the latter, coupling renewable energy sources (solar, wind, waves and geothermal) and desalination processes is a mean to reduce the carbon footprint of the water production process. Combining renewable technologies with desalination processes face technical challenges such as energy storage and availability of low-cost renewable energy sources. Additionally, desalination process requires a constant energy supply. Therefore, most often the produced renewable power is added to the electricity grid to overcome the intermittence of the renewable energy and to allow straitening the electricity daily sine wave consumption. Otherwise, the cost of the water produced will be much higher. More information may be found in [9,23,24]. It should be realized, that none of the above approaches could lead to energy savings of 50–80%, as claimed by forward osmosis and humidification-dehumidification experts.

As example for an energy-efficient large-scale SWRO desalination plant is Tuaspring plant, Singapore. It is equipped with a self-sufficient on-site power plant, which enable significant capital and operating cost advantages by only using one intake and one outfall and associated pumps for both plants. An open seawater intake, with two separate inlet channels, is used to pump the feed water from the straits of Johor. The feed seawater salinity range between 28.5 and 32.0 g/L [25]. The lower than average salinity feed water are firstly used as cooling water in power plant. As a result, the temperature of the water, which is then fed directly into the desalination plant, rises resulting in less energy consumption by the RO pumps [26]. The intake is located about 50 m from the plant and the brine discharge about 150 m downstream as shown in Fig. 2. This configuration also contributes to the lower than average pumping energy. All of the above bring this plant to energy consumption of below 2 kWh/m^3.

To get prospective, today, ~2000 kW/year is needed to desalinate seawater to supply water for one household. This is less than that used by a household's refrigerator [27]. Pumping a cubic meter of fresh water for > 200 km requires more energy than desalinating the same amount of seawater.

2.3. RO as part of the national energy consumption-Israel as a case study

The main issue that should be considered is the existent of water need and the national energy consumption. In Israel, for example, the water scarcity was solved by construction of five SWRO desalination plants with total production capacity of 600 Mm^3/year, accounting for about 80% of domestic water consumption and approximately 40% of the total water consumption. Multiplying this number by the typical energy consumption of SWRO desalination (3.5 kWh/m^3) and divide it by the cumulative national energy consumption, it can be seen that the energy used for desalination is < 1.3% of the Israeli national energy consumption.

In fact, in Israel, about 60% of the desalinated water is produced during the night (off-peak time) using electricity that would been otherwise wasted. Prior to the desalination era, about 3% of the cumulative national energy consumption was used to pump water from the north to the south of Israel. Hence, it can be concluded the long distance transportation of water is more energy intensive than desalination. Taking in account all points raised above, the national energy consumption is in fact slightly negative in similar cases and add no