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Exergy analysis of a combined RO, NF, and EDR desalination plant

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Abstract

A brackish water desalination plant in California that incorporates RO, NF, and EDR units was analyzed thermodynamically using actual plant operation data. Exergy flow rates were evaluated throughout the plant, and the exergy flow diagrams were prepared. The rates of exergy destruction and their percentage are indicated on the diagram so that the locations of highest exergy destruction can easily be identified. The analysis shows that most exergy destruction occurs in the pump/motor and the separation units. The fraction of exergy destruction in the pump/motor units is 39.7% for the RO unit, 23.6% for the NF unit, and 54.1% for the EDR unit. Therefore, using high-efficiency pumps and motors equipped with VFD drives can reduce the cost of desalination significantly. The plant was determined to have a Second Law efficiency of 8.0% for the RO unit, 9.7% for the NF unit, and 6.3% for the EDR unit, which are very low. This indicates that there are major opportunities in the plant to improve thermodynamic performance by reducing exergy destruction and thus the amount of electrical energy supplied, making the operation of the plant more cost effective.

Keywords: Desalination; Reverse osmosis; Nanofiltration; Electrodialysis; Exergy analysis

1. Introduction

There is a growing need for potable water for domestic, industrial, and agricultural use, and desalination has long been a major source of additional potable water in many parts of the world, including the United States. A worldwide survey showed that in 1998 there were 12,451 desalting units (with capacity greater than 100 m^3/d) with a total capacity of 22.7 Mm^3/d (6.01 billion US gallons per day, GPD) installed or contracted [1]. This represents a 20% increase in capacity over a period of 4 years compared to

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5.0 billion GPD in 1994, and a 70% increase from the capacity in 1990. About 75% of all capacity is located in 10 countries. The seawater desalination plants constitute 58.5% of the total world desalination capacity. Most desalination plants are in the Middle East, with almost 50% of the world capacity. Saudi Arabia is the largest user of desalination with about 24% of total world capacity, and the US is the second largest user with about 16%. The major sources of saline water are brackish water, which is slightly salty ground water with total dissolved solids (TDS) of less than 1700 ppm, and seawater with an average salinity of 3.5% (or 35,000 ppm). The TDS of water intended for human consumption should be under 500 ppm.

The primary desalination methods used are multi-stage flash distillation (MSF), which constitutes 44% of installed world capacity, and reverse osmosis (RO), which constitutes 42%, which also includes nanofiltration (NF). Therefore, these two methods constitute about 86% of total world capacity. The remaining 14% is made up of electrodialysis (EDR) (6%), vapor compression (VC) (4%), and multiple-effect distillation (ME) (4%) [1].

Although these methods are well established, there is a need to push the state of the art forward, and to make the operation of these plants more efficient. A comparison of the idealized and actual desalination technologies showed that the actual energy cost of desalination is up to 20 times of the cost under ideal operation. This corresponds to a Second-Law efficiency as low as 5%, and points out that there are tremendous opportunities in both the MSF and RO plants for improvements. The first step in any improvement or enhancement project is diagnostics, and the most powerful diagnostics tool in thermodynamics is Second-Law analysis. Such an analysis helps to determine the sites of the highest entropy generation and thus exergy destruction, and to identify the components responsible for the greatest losses in the system.

The RO technique is gaining in popularity. The typical capital costs per m^3/d capacity are \$1100–1600 for MSF plants and \$700–1000 for RO plants. In Saudi Arabia, for example, the 5.43 Mm^3/d capacity of fresh water is produced by mostly MSF (64.2%) and RO (32.3%) plants [2].

2. Plant description

The data analyzed in this work were obtained from the Port Hueneme Water Agency, Brackish Water Research Demonstration Facility, located in Port Hueneme, California, with a fresh water production capacity of about 2250 gallons per minute (GPM). The plant operates a municipal drinking water treatment plant. The facility consists of separate side-by-side full-scale membrane plants of each major type: RO, NF, and electrodialysis reversal (EDR). The RO and NF plants use a semi-permeable membrane that allows water to pass but not salts. EDR uses an electric current to "withdraw" or "pull" dissolved ions from the water.

The flow diagrams of desalination plant for the three trains are shown in Figs. 1–3. General plant operation data are given in Table 1. Average monthly data for June 2000 for the RO, NF, and EDR units are given in Tables 2–4, respectively. Brackish water with a salinity of about 900 ppm (parts per million on mass basis or a mass fraction of 0.09% for salts) enters the plant at about 1 Soc and atmospheric pressure. Water is pumped by the main pump to 82 psig (667 kPa absolute), and is filtered and treated.

In the RO unit, a 100-hp booster pump raises raw water pressure to 132 psig (1011 kPa absolute) before it enters the first stage of the RO unit that consists of 14 pressure vessels with 84 layers of membranes. The concentrate from the first stage experiences a pressure drop of 30 psi and enters the second stage with seven pressure vessels and 42 layers of membranes at 102 psig