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Exergy analysis of a seawater reverse osmosis plant

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Abstract

Exergy analysis is a powerful tool to determine how inefficiencies of the processes influence system performance. The exergy analysis of a seawater reverse osmosis desalination plant with 21,000 m^3/d of nominal capacity located in Tenerife (Canary Islands, Spain) was studied. Once defined, the flow chart of the process, the exergy rate and exergy cost of flows were determined as well as the exergy destruction rate in equipment. The main results indicate that 80% of the exergy destruction is placed on core processes (high pressure pumping and valve regulation, reverse osmosis separation and energy recovery), 29% extra exergy is necessary to obtain the unit of feed exergy from previous stages (seawater pumping and pretreatment) and extra exergy of 1.06 kJ is needed to generate 1 kJ of final product exergy (exergy performance about 50%). In addition, the moderate fluctuations of seawater environmental conditions in the Santa Cruz de Tenerife metropolitan area (and Canary Islands as a whole) establish that environmental parameters present a less important influence on exergy analysis.

Keywords: Exergy; Exergy analysis; Exergy destruction; Reverse osmosis; Plant performance

1. Introduction

This paper deals with the exergy analysis of the Santa Cruz de Tenerife desalination plant. This is a seawater reverse osmosis (RO) plant located at Santa Cruz de Tenerife, Tenerife, Canary Islands, Spain. Further details about the analysis performed can be found at Romero-Ternero [1]. Other exergy analyses of RO desalination are given in the literature [2–5]: Cerci [2,3] accomplished the analysis of a specific brackish water reverse osmosis (BWRO) desalination plant; Criscuoli and Drioli [4] made an exergy analysis of an integrated membrane desalination system for different nanofiltration, RO and membrane distillation (NF–RO–MD) configurations; and Splieger and El-Sayed [5] investigated lost

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work and economics of principal desalination processes.

The exergy analysis is based on thermodynamic potential exergy, which takes into account the energy as well as its potential use (quality). The exergy analysis provides a valuable piece of information about the influence of the efficiency of equipment on the efficiency of the global plant and the exergy cost of the product (exergy used to generate it). Therefore, this exergy analysis identifies where the major chances of improvement are in productive thermodynamic processes. In particular, Valero and Lozano's methodology [6] is considered for exergy analysis implementation.

2. Santa Cruz de Tenerife desalination plant

The Santa Cruz de Tenerife facilities were planned and designed by the Directorate General for Hydraulic Works and Water Quality of the Spanish Ministry of the Environment, and they were co-financed by the European FEDER funds. They were built by Cadagua-Pridesa, which nowadays performs the management and operation of the desalination plant. Later it will be transferred to EMMASA, the water supply municipal corporation. The main features of the plant are as follows [7,8]:

- The desalination plant has a nominal capacity of 20,700 m^3/d. A set of six SWC3 Hydranautics spiral-wound membranes is assembled into a permeator. There are 330 permeators distributed at three skids.
- The recovery of the process is 42%. A nominal permeate TDS concentration of 400 g/m^3 is obtained. Nevertheless, there is a second stage of low-pressure membranes which does not currently operate; this would permit an increase the quality of the product up to 200 g/m^3.
- Mechanical equipment for skids (there is an additional one for stand-in operation) consists of a high-pressure centrifugal pump, an engine and a Pelton turbine shaft coupled. High-pressure pumps, which increase seawater pressure from 245 kPa to 6865 kPa, are split case ones. The Pelton turbine yields energy recovery from high pressure blowdown.
- A regulation valve controls the seawater pressure as it enters the skid to maintain constant production.
- A valve at the product outlet ensures the required pressure of the product to enter the storage tank — 382 kPa. The storage capacity is 2000 m^3.
- The seawater intake consists of eight wells with electro-mechanical equipment. Seawater is pumped from a suction head of about 30 m.
- The physical pretreatment consists of eight sand filters, subsequently with four filters of sand/anthracite and finally four cartridge filters of 5 microns. The total pressure losses are normally in the range of 49–98 kPa, currently about 69 kPa.
- The chemical pretreatment is applied in two stages: in the first one, before the sand filters, coagulation–flocculation, pH regulation (acidification) and chlorination are performed on the seawater; in the second one, before the cartridge filters, antiscaling and dechlorination complete the pretreatment. Nevertheless, the quality of the seawater permits discontinuous chlorination and avoids the use of coagulant–flocculant and antiscalant. This partial pretreatment has a SDI in the range of 1.5–2.5, a reasonable limit for suitable protection of membrane lifetime.
- The post-treatment consists of pH adjustment and disinfection.
- The distribution of the product to the municipal storage tanks requires an increase of pressure of about 1372 kPa.

3. Exergy analysis

The data in the previous section will be completed with the main calculation assumptions