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Experimental study of tray materials in a thermal desalination tower with controlled heat source

Maria Eugênia Vieira da Silva [a], Klemens Schwarzer [b], Francisco Nascelio Pinheiro [a], Paulo Alexandre Costa Rocha [a,*], Carla Freitas de Andrade [c]

[a] Solar Energy and Natural Gas Laboratory, Campus of Pici, Bl. 718, 60455-760 Fortaleza, CE, Brazil
[b] Ingenieurbüro für Energie- und Umwelttechnik, Tuchbleiche 12, D-52428 Jülich, Barmen, Germany
[c] Fluid Mechanics and Aerodynamics Laboratory, Campus of Pici, Bl. 715, 60455-760 Fortaleza, CE, Brazil

HIGHLIGHTS

- A one-stage desalination system was built to study different tray materials.
- Five trays made of aluminum and stainless steel AISI 304 were tested.
- The aluminum tray yielded the highest production per energy input.
- The apparatus was adequate to study the performance of a desalination tower tray.

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ABSTRACT

Solar thermal desalination systems can operate with a variety of heat sources, and one of them is solar radiation. In solar heated systems, due to the variation in the daily radiation values, the study of the thermal variables and parameters is complicated. In this work, a new one-stage desalination system with controlled heat source was constructed to study its performance as a function of different tray materials. The system consisted of a storage tank with an electrical resistance immersed in brackish water as the heat source, and a one-stage desalination unit with a replaceable metallic tray. Five trays made of aluminum and stainless steel AISI 304 (polished, chrome-plated, and non-polished) were tested. The results show the overall heat transfer coefficient for each tray in the heating phases (sensible heating and steady state operation) and in the cooling phase, when the electrical resistance is turned off. The aluminum tray yielded the highest production per energy input (0.406 mL/kJ). Measurements of the electrical conductivity were used to indicate the produced water quality. The apparatus developed was adequate to experimentally study the performance of a thermal desalination tower tray.

1. Introduction

The shortage of drinkable water in many areas of the World is an old problem. Many regions have a limited supply of conventional energy, although some have a great potential in solar energy. In many coastal areas and arid zones worldwide, drinking water supply is an increasing problem. Overpopulation, growing tourism, industrialization and the use of chemical products in agriculture constantly degrade the quality of drinking water. Many arid areas have only limited underground water resources and, as a result of extensive pumping, the water quality has deteriorated and become brackish.

The UNESCO projection of worldwide water supply in 2025 presents average values of the water supply for each country as a whole, but it does not show the local needs of each region. It can be observed that most countries in Africa, Middle East, and some parts of Asia will suffer from water shortage [10].

Regardless of the need for a more sustainable supply of drinking water, in many regions it has to be produced from brackish or salt water sources. Various large scale desalination techniques have been developed and used. Due to high investment costs, lack of infrastructure, and operation costs, the use of these large scale plants has not been made possible in many coastal regions, such as in the Mediterranean countries, nor in developing countries, where there is a demand for a lower-price, low maintenance, environmentally friendly, and decentralized small-scale desalination systems.

Thermal desalination is a process that utilizes heat as the energy source for separation of the water molecule from the salt/brackish mixture. In the thermal desalination system with heat recovery, brackish water is heated in a tank to enhance the evaporation process, which

* Corresponding author.
E-mail address: paulo.rocha@ufc.br (P.A.C. Rocha).

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Nomenclature

A	horizontal surface area of storage tank, [m^2]
A_p	internal surface area of the storage tank in contact with the insulation, [m^2]
c_p	specific heat, [kJ/kg·°C]
$\dot{E}$	energy rate, [W]
f	frequency, [Hz]
$\dot{Q}$	heat transfer rate, [W]
h	heat transfer coefficient, [W/m^2 K]
h_{fg}	latent heat of vaporization, [J/kg]
i	instantaneous electric current, [A]
I	maximum electric current (or current range), [A]
I_f	mean quadratic current (or effective value), [A]
K_1	overall heat transfer coefficient, [W/m^2 K]
K_2	conduction heat loss coefficient to the environment, [W/m^2 K]
$\dot{m}$	mass transfer rate, [g/s]
m	water mass, [g]
p	instantaneous power, [W]
$P_{méd}$	average power, [W]
t	time, [s]
T_1	temperature, [°C]
v	instantaneous electric potential difference, [V]
V	maximum electric potential difference, [V]
V_f	mean quadratic potential difference or effective potential difference value, [V]
w	angular frequency, [rad/s]

Subscripts

1	first tray or first stage
∞	environment
a	accumulated, in the tank
c	conduction
cond	condensation
conv	convection
e	inlet
ele	electric resistance
evap	evaporation
g	generated
j	*j*th stage
rad	radiation
s	outlet

Greek

ε	emissivity, [non-dimensional]
σ	Stefan Boltzmann constant, [5.67 × 10^{-8} W/m^2 K^4]
ω	angular speed, [rad/s]

separates the H_2O from the brackish water. In the vapor state, the evaporated water comes in contact with the surface of the above stage, which is at a lower temperature, and transfers its condensation heat to this stage. The brackish water in this stage is then heated and the process is repeated in the next stages of the tower (Schwarzer et al. [16,17], da Silva et al. [18]).

The trays studied in the work are important parts of this decentralized desalination system with heat recovery. This system has a heat source and a desalination tower. It uses multiple condenser stages, vertically arranged. Each stage recovers the condensation heat from the vapor produced in the stage below. The condensate drains on the tilted condenser surface, moves through flow channels to be collected in a tank. Salt water in the lower stage (storage tank) is heated up to 95–100 °C. The flow of salt water is from the top to the bottom, in counter flow with the heat flux.

2. Literature review

Many articles have been published in the literature, describing the development of the thermal desalination technology. From the first articles [5] to the more recent ones [7,9,12,13], much information can be found about specific systems.

Delyannis [3] presented a historical review of the use of desalination systems using renewable energies. The article presented a detailed historic description, beginning with biblical passages and ending with the first books dealing with the subject.

Mezher et al. [11] evaluated the desalination technologies: Multi-Stage Flash (MSF) and Multiple Effect Distillation (MED), membranes for Reverse Osmosis (RO), and Hybrid (MSF/MED-RO). The assessment included energy requirements, cost of water production, technology trends, environmental impacts, and potential for technological improvements.

Adhikari et al. [1], Schwarzer et al. [16,17], Alves [2], and da Silva et al. [18] studied horizontal tray desalination towers with heat recovery mechanism. Because of the high water temperature reached in each stage, the system significantly reduced the water contamination by pathogenic microorganisms. These systems were designed for decentralized operation and to operate with different heat sources.

Hybrid systems were studied by Lopes [6], where solar energy might be associated with other renewable energy sources. Rodrigues [15] also presented a study using gas as the heat source in a desalination tower, which could also be solar heated.

Mathioulakis et al. [8] presented an article on desalination and alternative energies. They analyzed the process of solar thermal desalination, humidification and dehumidification, solar stills and membrane distillation. The authors concluded that, despite research investments, desalination plants with alternative energy sources represent a small number of installations worldwide. They highlighted the growing interest in the development of small-scale desalination plants for low-density populations (granges, farms, small islands), who live far from large urban centers, as a solution to the problem of lack of water and electricity in these communities.

3. Materials and methods

Fig. 1 shows the thermal desalination unit, which has two parts: a heat recovery desalination tower with metallic trays and polyurethane wall with lateral channels to allow the desalinated water to flow out of the tower; and a heating tank where brackish water is stored and heated. The tank is made of stainless steel and it is insulated with a 5 cm polyurethane sheet. An electrical resistance (max. 2000 W) was installed inside the tank to heat up the brackish water. A metallic tray was installed in the polyurethane wall of the first stage. Five trays made of aluminum and stainless steel AISI 304 (polished, chrome-plated, and non-polished) were tested.

The heating system consists of an electric resistance connected to a potential difference electrical device controller and a Volt-current

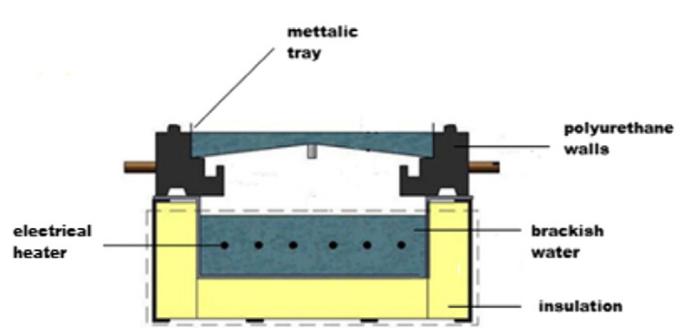

Fig. 1. Thermal desalination unit for testing of five different tray materials. Adapted from Rodrigues [15].