Desalination 423 (2017) 141–148

Contents lists available at ScienceDirect

Desalination

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

Seawater desalination using inclined stepped solar still with copper trays in a wet tropical climate

Mohammed Shadi S. Abujazar[a], S. Fatihah[b,*], A.E. Kabeel[c]

[a] Department of Civil and Structural Engineering, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[b] Research Centre for Sustainable Technology (CESPRO), Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[c] Mechanical Power Engineering Department, Faculty of Engineering, Tanta University, Tanta, Egypt

ARTICLE INFO

Keywords:
Desalination
Solar still
Inclined stepped solar still
Climatic parameters
Design parameters
Operation parameters
Efficiency
Still productivity
Seawater

ABSTRACT

In this study, a copper inclined stepped solar still was designed and fabricated to study the seawater desalination productivity of copper inclined stepped solar stills. The experimental setup mainly consists of two parts: a seawater settling and feeding tank and an inclined stepped solar still. The inclined stepped solar still with internal dimensions of L 1.8 m, W 1.2 m, and H 0.20 m consisted of 28 trays, and the tray dimensions are 0.6 m in height and 1.2 m in length. Its performance was tested in Bangi City - Malaysia, under Malaysian environmental conditions in the period from September 2016 to December 2016. The inclined stepped solar still was sealed to reduce vapour leakage to the environment. The experiment studies the effect of different environmental parameters (solar intensity, ambient temperature, wind velocity, humidity and cloud coverage) and operational parameters on the system productivity (water production and glass out, inner, vapour, water and tray "basin" temperature). The result shows that the productivity of the solar still was highly affected by environmental parameters. For example, the increase in solar radiation and ambient temperature increases the still temperature, and the difference between the cover inner and outer temperatures enhances the condensing process and water productivity. However, the decrease in humidity increases the productivity, the wind velocity significantly reduces the $(T_i - T_o)$ difference temperature, which adversely affects the productivity of the system, and the cloud coverage affects the solar radiation intensity. The productivity was 4383 mL/m^{2}d; the best hourly efficiency was approximately 58% at 17:00, which can be explained by the highest solar radiation and ambient temperature with respect to time lag for the system.

1. Introduction

Water and energy are two of the most important necessities to stay alive. The available fresh water on earth is limited, and the demand is increasing daily. The depletion of drinking water sources on the surface and groundwater is increasingly the result of an increase in the number of people worldwide, agricultural intensification, and industrial development [1]. Water is essential for the survival for all living species. Water covers approximately three-quarters of our planet [2], and potable water plays a main role in the development of nations and countries [3]. Water covers approximately 70% of land surface, but more than 90% of that water is salt water and is not suitable for drinking [4]. Less than 0.5% of the total fresh water supply resources on Earth comes from rivers and groundwater and is being depleted [5], whereas approximately 97% of the earth's water is ocean water, and 2% is stored as ice in the polar regions [6]. Seawater is an alternative to compensate for the supply shortage of raw water to drink. Solar device application is a green technology process that uses the natural energy of sunlight to produce clean water through a water distillation process. This technology directly converts solar energy into heat, which separates the water that evaporates from various impurities.

Water is available in various quantities in nature, but there is a shortage of fresh water in some areas of many countries worldwide [7]. The increase in regional freshwater shortage makes the practice of seawater desalination rapidly increase. Nearly 50% of the world's population lives within 100 km of an ocean, and seawater represents an alternative water resource [8]. However, two million people die per year because of water scarcity and shortage [9]. It is estimated that more than one billion people lack access to fresh water supplies. The required fresh water demand to satisfy human needs is 1000 m^3 per capita per year. It is projected that by 2050, approximately 1.7 billion people in 39 countries will fall below this level [10]. There is no single solution that satisfies the water demand in a given country because of numerous water problems [9].

* Corresponding author.
E-mail address: fati@ukm.edu.my (S. Fatihah).

http://dx.doi.org/10.1016/j.desal.2017.09.020
Received 6 March 2017; Received in revised form 30 July 2017; Accepted 19 September 2017

Nomenclature

T_a	ambient temperature, °C
T_o	outer temperature of the glass, °C
T_i	inner temperature of the glass, °C
T_v	vapour temperature, °C
T_w	water temperature, °C
T_t	tray temperature, °C
SR	solar radiation, w/m^2
η_h	hourly efficiency of solar still, %
m_{ew}	water production, mL/m^{2}h
L	latent heat, kJ/kg-K
I	solar radiation intensity, w/m^2
A	area, m^2

In addition to these water crises, a dramatic increase in resource and energy consumption, particularly since the Industrial Revolution, is another problem. The increase in fresh-water consumption, primarily because of modern lifestyles and population growth, has led to increases in energy consumption, which inevitably results in environmental pollution and fuel shortage issues [11]. The enormous population and energy consumption are the main reasons for these critical issues such as the environmental pollution [12]. Fossil fuel resources are fixed resources, i.e., they decline with time because of the rapid growth of technology development. In addition, they are a main reason for global warming.

To solve this problem, various advanced technology desalination techniques using fossil fuel or electrical energy derived from fossil fuel are used worldwide, e.g., either the thermal process or the membrane process [13], which directly affect global warming and have high economic costs. Nevertheless, the huge shortage of fossil fuel resources, crude oil and energy resources is attributed to the increasing tendency of replacing expensive energies with renewable energies [14]. However, for remote areas that lack fresh water, the land is available at a low cost and is blessed with abundant solar radiation, so solar energy is preferred as an alternative energy source. Since desalination is an energy-consuming process, which increases the fossil fuel problem, solar distillation is more suitable and promising [15]. The use of solar stills can be an alternative cheap and simple method using sunshine to provide drinking water, and its environmentally safe outcome is the major attraction point to research interests.

The main obstacle when using solar-still desalination techniques is the low productivity rate in terms of three main parameters: environmental, design, and operation parameters. Solar stills have a lower permeate productivity than other desalination systems such as thermal and membrane processes. Although it is a suitable solution for the lack of fresh water supply, its low productivity impedes its application. Many studies have been performed [16] to improve the efficiency rate of solar still productivity (which is 2.5–5 l/m^{2}d) [17] with either experiments [18–21] or mathematical modelling [22–26].

Hence, the main scope of this study is to improve the productivity of stepped solar stills by improving the design, e.g., increasing the evaporation area, decreasing the foot print area and using copper trays in the wet season of Malaysia climate.

2. Experimental setup

In this study, a copper inclined stepped solar still was designed and fabricated to study the productivity of copper inclined stepped solar stills. The schematic diagram of the inclined stepped solar still is shown in Fig. 1. It can be seen the inclined stepped solar still was placed at an angel of 30° angel with the horizontal as shown in Fig. 2, to get an inclined shape as well as for smoothly condensing purposed. The experimental setup mainly consists of two parts: a seawater-settling tank and an inclined stepped solar still. An experimental setup is presented in Fig. 3, and Fig. 4 is a photograph of the inclined stepped solar still.

The inclined stepped solar still has internal dimensions of L 1.8 m, W 1.2 m, and H 0.20 m and consists of 28 trays; the tray dimensions are 0.6 m in height and 1.2 m in length. The trays were made from copper sheets. Fig. 5 shows a cross-sectional view of the copper trays in the system. In order to increase the thermal capacity of the system, as copper has high thermal capacity (k = 390 W/mK) compared to steel and aluminium (k = 48 W/mK, and k = 200 W/mK, respectively)

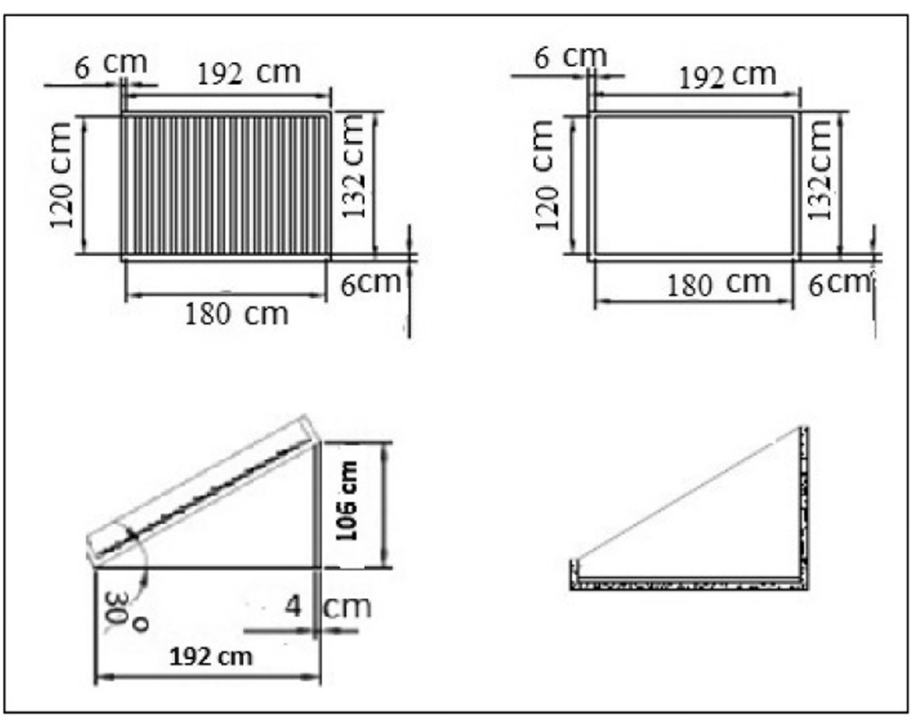

Fig. 1. Schematic diagram of the inclined stepped solar still.