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# Investigation of exergy and yield of a passive solar water desalination system with a parabolic concentrator incorporated with latent heat storage medium

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ABSTRACT

In the present study, two solar stills were assembled and experienced to evaluate the yield and energy performance of an improved passive solar desalination system compared to a conventional one. The improved still is incorporated with a latent heat thermal energy storage medium and a parabolic solar concentrator. A parabolic solar concentrator was added to concentrate and increase the amount of solar irradiance absorbed by the still basin. Paraffin wax was applied as phase change material (PCM) in the solar still bottom plate. In the current study also, the effect of impure water profundity inside the still on still's accumulated yield have been assessed. The following study involved a mathematical analysis for calculation of the exergetic proficiency as an efficient tool for the optimization, and yield evaluation of any energy systems and solar stills as well. Experimental research conducted in steady days of summer and winter at six different values of impure water profundity inside the solar still basin. The salinity of the impure water tested was about 3000–5000 ppm, while the salinity for the resulted drinkable water was about 550–500 ppm. The performed outcomes revealed that during summer, exergetic efficiency is higher than its qualified value in winter with approximately (10–15%) for the same water profundity. Results also disclosed that, the exergetic efficiency is higher when the water profundity in the basin is lower with approximately (6–9%). The experimental findings reveals that, the solar still with PCM and parabolic concentrator is higher in the daily freshwater yield in summer with an amount of (55–65%) and in winter with an amount of (35–45%) compared to the usual solar based still. The current work performed during January 2016 as a winter season, and July 2016 as a summer season from 8:00 am to 6:00 pm under the climate conditions of Tanta city-Egypt.

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## 1. Introduction

The must of pure water is a global critical subject for human needs in the upcoming age on earth. Even though, almost 75% of the earth covered by water. Unfortunaltley, only 1% of existing earth's water can be regarded as suitable for both essential human and industrial needes as well [1]. The valuable solution to overcome that issue is the water purifcation technique from the current non drinkable water supplies like saline water, dissipated water, industrial and other utilized sources. Nowadays, a range of techniques applied to purify the non-drinkable water. The applied effective positions for water purification generally can be classified into: (1) single phase water treatment, and (2) multi phase water treatment operations. Consequently, single phase treatment includes (Overturn Osmosis filtration (RO), Electro Dialysis membrane filtration (ED), Membrane filtration). Simultaneously, multi phase operations includes (Multiple effect desalination, Multiple Flash distillation, Vapor-compression purifIcation, Hybrid Humidification - dehumidification treatment, and the method of Solar still) [2,3].

Solar stills considered as a helpful and vital non drinkable water purification technique concerning the other systems. Basically, solar still is a mechanism which converts the impure water into pure water by use of the solar energy [4,5]. For solar stills, impure water placed in a collecting space then it is being evaporated by natural sun shine through clean plastic or glass cover [6,7]. On the other hand, proficiency of solar still as a water purification tool is comparatively small. Thus, for solar still evaporation as well as condensation process happens in the same enclosed gap with the resulted clean water resulted. Moreover, one of the majority drawbacks of solar still s is its little rate of clean water profitability compared to other purification techniques [8,9]. Consequently, diverse researches extensively studied and improved the yield of the solar

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**Nomenclature**

| | |
|---|---|
| PCM | Phase Change Material |
| RO | Reverse Osmosis filtration |
| ED | Electro Dialysis membrane |
| PLC | Programmable Logic Controller |
| $\eta_{EX}$ | exergetic proficiency (%) |
| L | latent heat of vaporization (J/kg) |
| $T_a$ | the ambient temperature (°C) |
| $T_w$ | the water temperature (°C) |
| $\dot{m}_{hw}$ | hourly produced water from the sun based still (kg/h) |
| $A_s$ | the effective area of basin in sun based still ($m^2$) |
| $I(t)_s$ | the amount of incident solar irradiance on the sun based still inclined glass ($W/m^2$) |
| $T_S$ | the sun temperature (6000 K) |

still by implementing various modifications [8,10]. Since, Solar still production rate concerned by various parameters such as: brackish or saline water profundity, adhesion or cohesive rate close to prevent the water vapor outflow, the slant of solar still condensation cover, mode of thermal insulation, and main design and material of the still itself [9,11]. The performance of a solar still at different water profundity has been extensively studied by a various number of research [12–14]. Experimental findings revealed that, for usual solar still system the clean water profitability decreases when increasing the water profundity inside the still basin [15,16].

Furthermore, Fresh water yield from the solar still depending on the temperature diversity between the in base water and still glass [17]. Further analysis applied to investigate the effect of the basins number on the every day clean water yield [18]. Related studies revealed the effort rate of a single slant solar still amid summer as well as winter annual seasons [19]. Additionally, researches involve solar still conducted with double basin design [20,21], triple basin design [22], quadruple-basin stills assemblage [23], and solar still with thermoelectric schemes as well [24]. The findings consolidate that, the double-basin still offers superior clean water production rate. While, the triple- as well as quadruple-basin still keep producing sizeable amounts of pure water amid the night time, leading to elevated daily profitability. Results elucidates that, increasing the quantity of solar based basins more than three does not result in significant transform in the still's profitability [25].

The mainly drawback of a usual solar based still is that the total of resulted pure water per unit area is relatively low. The clarification intended to increase the performance of the usual solar still by modifying the usual solar still with a sun rays concentration mechanism to boost the solar still ability to collect more solar radiations particularly in the morning day time [26,27]. Mohamed and El-Minshawy [28] incorporated a parabolic figure solar collector with an outlet temperature less than 100 °C to make the resulted brackish water treatment system. Although, the parabolic shape collector thermal proficiency increased with higher solar radiation until it reached a peak then declined back. The profitability of the pure water treatment system improved when the daytime increasing till reached an optimal rate and then declined back again. The pure water production accomplishes rates of 42%, 37%, 33% and 29% through summer, spring, autumn and winter annual seasons respectively [29].

Numerous findings examined the impact of utilizing the latent heat storage in vicinity of water desalination system. Basically, phase change material (PCM) is a matter preserves and release quantities of energy when melting and solidify at any temperature. In other words, thermal energy is absorbed when the (PCM) alters from solid to liquid state of matter, then energy is released when the material goes from liquid to solid [5,8,14]. Saraswat et al. [30] experimentally and numerically examined impacts of the heat energy storing materials on treatment of impure water by a solar still carried out with a (PCM) in basin. The selection of the (PCM) matter type depends on the optimum temperature required by the impure water type [31,32]. The (PCM) present as a thermal energy source amid fewer sunshine day time, and even at night day time [33]. The solar still continues to add clean water even after sundown time. The yield of the collector coupled single slant solar still with and without (PCM) was increased by about (55–65%) compared with the conventional usual solar still [34,35].

Study of solar water purification systems along with the basic law of thermodynamics has attracted the concentration of various researchers extensively argued by a number of authors and evaluated by Deniz and Çınar [36] and Fitzsimons et al. [37]. Since thermodynamic investigation is a useful way to get accurate and precious information about energy competence and losses of irreversibility in water purification systems [38–40]. Exergetic proficiency analysis is an efficient tool for the optimization, and yield evaluation of any energy systems and solar stills as well [41–43]. Although the methods employing thermodynamics second law and the exergetic proficiency are well studied, to the best of knowledge for the authors of current research, there are no earlier distributed data of second law analysis in solar stills incorporated with (PCM) and solar concentrators as well.

The main plan of the present experimental effort is to evaluate the fresh water productivity as well as the exergetic proficiency of usual water desalination solar still with a parabola shaped solar accumulation. In addition, the study intends at prominence of thermal energy storage mechanism outcomes on purification of the impure water by a solar still with a parabola shaped concentrator, and (PCM) in the still sink. The findings of a parabola shaped concentrator on the yield of a solar still with (PCM) have been investigated in the present experimental effort.

The present research involves an evolution demonstration involving the adapted solar still with a usual one. The present study has been carried out at different in base water depth with and without (PCM) in the still's basin. As a novel study, the research involved a mathematical model and calculation for the exergetic proficiency as an efficient tool for the optimization, and yield evaluation for both usual and modified solar still. The solar still used in the present study is from the passive single slant solar still type. In this article, an analysis of the exergetic proficiency and its destruction for a passive solar still operating with and without (PCM) and is introduced. Current experimental work conducted amid January 2016 as a winter period, and July 2016 as a summer period from 8:00 am to 6:00 pm under climate of Tanta city –Egypt - with (Latitude 30.47°N and longitudinal 31°E).

## 2. Experimental setup

In the present Experimental study two single slants, single basin solar stills have been assembled and constructed to look at the impacts of various operating parameters under similar climate circumstances. Both solar stills were indistinguishable, from the passive type solar stills. One of solar stills is a conventional solar still with a single slant and a fixed glass inclination angle. While, the second solar still is an adapted one incorporated with major modifications like, a parabola shaped solar radiation concentrator and phase change material (PCM), paraffin wax, in the still's basin.

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