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# Thermal performance and exergy analysis of solar stills – A review

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ABSTRACT

Over recent decades, the global demand for freshwater is increasing rapidly; however, the supply of freshwater is limited. Solar still (SS) is a valuable solar device that is used for converting the brackish and saline water into purified water. Several investigations depicted in literature have been performed, either experimentally or theoretically, on SS to assess its performance under different climatic and operational conditions. Apart from experimental studies, theoretical analysis is beneficial for evaluating the effectiveness of virtually designed SS. The theoretical analysis and simulation modeling of SSs can provide clear understanding on the mechanics, which may give directions on the design setup in experiments. In this review different theoretical approaches which have been used to assess the thermal performance of SS and exergy analysis of such devices are discussed. The reviewed studies indicate that the productivity of the SS depends on different external and internal operating parameters. In addition, the distillate quantity varies according to the design features and the related technical advancements of the SS. Our findings indicate that there are still few more parameters and design aspects to be considered while designing new SS. The objective of this paper is to highlight design methods so as to allow the researchers to optimize the SS for further development. Recommendations for further research have been also proposed.

## 1. Introduction

Freshwater water is one of the fundamental pillars for sustainable development economic and social progress as it is essential for drinking, industrial applications and agriculture. The global increase in potable water demand for both industrial and domestic purposes has led to a widening gap between potable water supply and consumption. Seawater desalination is considered as a promising tool to overcome such challenging issues. Over the last few years, there has been a growing interest in this field assessing and enhancing its technologies to reduce energy consumption, cost, and environmental impacts. For different kinds of technologies proposed such as solar chimneys [1], membrane processes [2,3], non-membrane processes [2,4], Hybrid PV/T [5], and humidification–dehumidification desalination technologies [6–11].

While water has a plentiful resources covering 75% of the earth surface, about 97.5% of this amount is saline and merely 2.5% of it is freshwater suitable for the needs of humans, animals and plants [12,13]. Therefore, the potable water scarcity is considered a massive humanitarian crisis that might outweigh the global oil crisis. In contrary to the constant amount of freshwater supply, potable water demand is expected to increases due to the predictable increase in world population reaching 9.1 billion in 2050 [14]. Therefore, there is an urgent need to develop low-cost energy efficient desalination systems.

Single-basin solar still (SS) is one of the simplest solar devices used to convert available wastewater or brackish into freshwater. This device can be easily fabricated using inexpensive readily obtainable materials. Moreover, its maintenance is inexpensive and simple requiring no proficient labor to implement. Single-basin SS can be an appropriate solution for potable water problem. Despite all these advantages, its use is limited due to low productivity. Several studies were devoted to

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**Nomenclature**

*Symbols*

| | |
|---|---|
| $A$ | Area ($m^2$) |
| $B$ | Width of the SS (m) |
| $C$, $C_p$ | Specific heat capacity (J/kg K) |
| $d$ | Thermal diffusivity ($m^2$/s) |
| $G_s$ | Incident solar radiation |
| $h$ | Heat transfer coefficient (W/$m^2$ K) |
| $h_b$ | Heat transfer coefficient between basin liner and ambient (W/$m^2$ K) |
| $h_{fg}$ | Latent heat of vaporization (J/kg) |
| $h_{C,go-a}$ | Convective heat transfer coefficient from glass cover outer surface to ambient (W/$m^2$ K) |
| $h_{C,w-g}$ | Convective heat transfer coefficient from water to glass cover (W/$m^2$ K) |
| $h_{C,w-gi}$ | Convective heat transfer coefficient from water to glass inner surface (W/$m^2$ K) |
| $h_{C,w-gi}$ | Conductive heat transfer coefficient from glass inner surface to glass outer surface (W/$m^2$ K) |
| $h_{E,w-co}$ | Evaporative heat transfer coefficient from water to condenser (W/$m^{2/}$ K) |
| $h_{E,w-g}$ | Evaporative heat transfer coefficient from water to glass cover (W/$m^2$ K) |
| $h_{E,w-gi}$ | Evaporative heat transfer coefficient between water mass and inner surface of the glass cover (W/$m^2$ K) |
| $h_{R,b-a}$ | Radiative heat transfer coefficient from basin to ambient (W/$m^2$ K) |
| $h_{R,w-gi}$ | Evaporative heat transfer coefficient from water to glass cover inner surface (W/$m^2$ K) |
| $h_{R,go-a}$ | Radiative heat transfer coefficient from glass cover outer surface to ambient (W/$m^2$ K) |
| $h_{R,w-g}$ | Radiative heat transfer coefficient from water to glass cover (W/$m^2$ K) |
| $h_{R,w-gi}$ | Radiative heat transfer coefficient from water to glass cover inner surface (W/$m^2$ K) |
| $h_{T,b-a}$ | Total heat transfer coefficient between basin liner and atmosphere (W/$m^2$ K) |
| $h_{T,go-a}$ | Total top heat loss coefficient between glass cover outer surface and atmosphere (W/$m^2$ K) |
| $h_{T,w-g}$ | Total heat transfer coefficient from water to glass cover (W/$m^2$ K) |
| $h_{T,w-gi}$ | Total heat transfer coefficient from water to glass cover inner surface (W/$m^2$ K) |
| $h_w$ | Convective heat transfer coefficient between basin liner and water mass (W/$m^2$ K) |
| $F_R$ | Heat removal factor |
| $I(t)$ | Intensity of solar radiation (W/$m^2$) |
| $I(t)_s$ | Intensity of solar radiation on inclined glass cover surface of SS (W/$m^2$) |
| $I_{eff}$ | Effective solar radiation (W/$m^2$) |
| $K$ | Thermal conductivity (W/m K) |
| $l_b$ | Length of basin (m) |
| $L$ | Thickness (m) |
| $m$ | Mass per unit basin area (kg/$m^2$) |
| $m_{ew}$ | Hourly productivity from SS (kg/$m^2$ h) |
| $\dot{m}$ | Mass flow rate (kg/s) |
| $M$ | Mass (kg) |
| $M_{ew}$ | Daily yield from SS (kg/$m^2$ day) |
| $P$ | Saturated partial pressure (N/$m^2$) |
| $P_a$ | Atmospheric pressure (Pa) |
| $P_a$ | Partial pressure of vapor at dew point temperature (Pa) |
| $P_{go}$ | Saturated partial vapor pressure at glass temperature at t=0 (N/$m^2$) |
| $P_{gi}$ | Partial vapor pressure at glass inner surface temperature (N/$m^2$) |
| Pr | Prandtle number |
| $Q_b$ | Heat loss between basin and ambient (W/$m^2$) |
| $Q_{C,b-w}$ | Convective heat transfer rate with in SS from basin to water(W/m2) |
| $Q_{C,cf-a}$ | Convective heat transfer rate from cooling film to ambient (W/$m^2$) |
| $Q_{C,go-a}$ | Convective heat transfer rate from glass cover outer surface to ambient (W/$m^2$ K) |
| $Q_{C,w-g}$ | Convective heat transfer rate with in SS from water to glass cover (W/$m^2$) |
| $Q_{C,w-gi}$ | Convective heat transfer rate with in SS from water to glass cover inner surface (W/$m^2$) |
| $Q_{Cd,gi-go}$ | Conductive heat transfer rate through the glass cover thickness from its inner surface to its outer one |
| $Q_{E,w-g}$ | Evaporative heat transfer rate with in SS from water to glass cover (W/$m^2$) |
| $Q_{E,w-gi}$ | Evaporative heat transfer rate within SS from water to glass cover inner surface (W/$m^2$) |
| $Q_{mw}$ | Heat energy required to heat the makeup water to the basin temperature (W/$m^2$) |
| $Q_{R,go-a}$ | Radiative heat transfer rate from glass cover outer surface to ambient (W/$m^2$ K) |
| $Q_{R,w-g}$ | Radiative heat transfer rate within SS from water to glass (W/$m^2$) |
| $Q_{R,w-gi}$ | Radiative heat transfer rate within SS from water to glass cover inner surface (W/$m^2$) |
| $Q_{T,w-g}$ | Total heat transfer rate within SS from water to glass cover (W/$m^2$) |
| $Q_{T,w-gi}$ | Total heat transfer rate within SS from water to glass cover inner surface (W/$m^2$) |
| $Q_{T,go-a}$ | Total radiative and convective heat losses (W/$m^2$) |
| $Q_w$ | Heat transfer rate between basin liner and water mass (W/$m^2$) |
| $Q$ | Heat transfer rate (W) |
| $Q_{loss}$ | Losses heat flux (W/$m^2$) |
| $Q_{Cond}$ | Condensation heat flux (W/$m^2$) |
| $Q_{Evap}$ | Evaporation heat flux (W/$m^2$) |
| $Q_{Sun,b}$ | Solar absorption of basin (W) |
| $Q_{Sun,df}$ | Solar absorption of diffuse radiation (W) |
| $Q_{Sun,dr}$ | Solar absorption of direct radiation (W) |
| $Q_{Sun,ext}$ | Solar absorption of reflected radiation external reflectors (W) |
| $Q_{Sun,\ int}$ | Solar absorption of reflected radiation internal reflectors (W) |
| $Q_u$ | Rate of thermal feed from external devices to SS (W/$m^2$) |
| $r$ | Coefficient of correlation |
| $R$ | Reflectivity |
| $R_{wall}$ | Reflectivity of wall surface |
| Re | Reynold number |
| $s$ | Salinity (g/kg) |
| $t$ | Time (s) |
| $T$ | Temperature (°C) |
| $T_{go}$ | Initial temperature of glass cover (°C) |
| $T_i$ | Mean operating temperature(°C) |
| $T_t$ | Temperature at time t (°C) |
| $T_{wo}$ | Initial temperature of water (°C) |
| $U$ | Overall heat loss coefficient (W/$m^2$ K) |
| $U_b$ | Overall bottom heat loss coefficient between water mass and atmosphere (W/$m^2$ K) |
| $U_{bs}$ | Total bottom and side heat loss coefficient between water mass and ambient (W/$m^2$ K) |