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Hourly yield prediction of a double-slope solar still hybrid with rubber scrapers in low-latitude areas based on the particle swarm optimization technique

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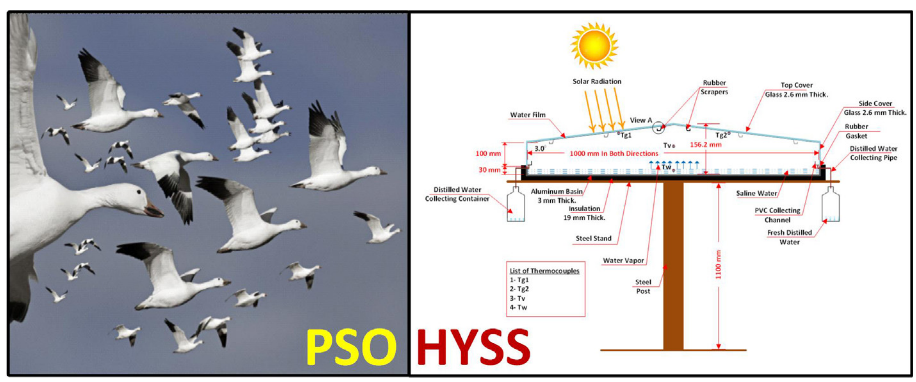
HIGHLIGHTS

- A modified model to predict the yield of solar still is developed by PSO technique.
- Particle swarm optimization (PSO) is used first time in still prediction model.
- This model considers the water falls from the cover with a small slope.
- The measurement of yield using the rubber scrapers is performed accurately.
- The model is validated with the experimental data and compared with other models.

GRAPHICAL ABSTRACT



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ABSTRACT

Several studies have attempted to improve the productivity of solar stills and build expressive models for yield prediction. However, most of these models do not consider the amount of condensed water that falls from the condensing cover towards the solar still basin, especially in the case of small-slope covers. This oversight can significantly affect the accuracy of these models. In this study, we developed a fairly simple method to estimate the amount of distilled water produced every hour from the double-slope solar still hybrid with rubber scrapers (DSSSHS) in low-latitude areas. The proposed model is based on the determination of the best values for the unknown constant (C) and the exponent (n) for the Nusselt number expression used to formulate the equation for the estimation of the hourly yield of a solar still (HYSS). This was achieved by solving an optimization problem using the particle swarm optimization (PSO) algorithm in which the optimal yields were determined by estimating the optimal values of the unknown C and n parameters. This technique, which is used for the first time in this study to build a yield prediction model, avoided the conventional trial-and-error approach to calculating unknown coefficients in a proposed model. Furthermore, the use of rubber scrapers to collect the condensed water that accumulates on the inner surfaces of the condensing cover enhanced the accuracy of the measurement of solar still experimental yields, which consequently improved the accuracy of the model. The proposed model was validated against the experimental data collected in this study. The results showed that the built model was able to accurately estimate the HYSS values.

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Nomenclature

A	surface area of the water (m^2)
C	unknown constant for Nusselt number expression (dimensionless)
C_v	specific heat of humid air (J/kg °C)
c_1; c_2	cognitive and social acceleration parameters, respectively; "acceleration coefficients"
d	characteristic length of solar still (m)
D	number of dimension problems
g	gravitational acceleration (9.807 m/s^2)
$gbest$	global best position of all particles
G_r	Grashof number (dimensionless)
$h_{c,w\text{-}g}$	convective heat transfer coefficient from water to glass cover (W/m^2 °C)
$h_{c,w\text{-}gD}$	convective heat transfer coefficient from water to glass cover for Dunkle's model (W/m^2 °C))
$h_{e,w\text{-}g}$	evaporative heat transfer coefficient from water to glass cover (W/m^2 °C))
$h_{e,w\text{-}gD}$	evaporative heat transfer coefficient from water to glass cover for Dunkle's model (W/m^2 °C))
K	thermal conductivity of humid air (W/m K)
k; k'	gradient for the regression line between the actual data and the predicted data (dimensionless)
L_v	latent heat of vapourization (J/kg)
$M_{Al\text{-}Sulttani,\ et\ al.}$	hourly predicted yield for Al-Sulttani et al. model (L/m^2 h)
M_{pre}	hourly predicted yield (kg)
M_{Dunkle}	hourly predicted yield for Dunkle's model (kg)
M_{PSO}	hourly predicted yield for PSO-HYSS model (L/m^2 h).
mp	performance index (dimensionless)
n	exponent for Nusselt number expression (dimensionless)
N	number of particles in swarm
np	performance index (dimensionless)
NS	number of data samples
Nu	Nusselt number (dimensionless)
$pbest$	best position for each particle
P_g	saturation vapour pressure of water at cover temperature (N/m^2)
Pr	Prandtl number (dimensionless)
P_w	saturation vapour pressure of water at water temperature (N/m^2)
$Q_{c,w\text{-}g}$	convective heat transfer from water to glass cover (W)
$q_{c,w\text{-}g}$	convective heat transfer rate from water to glass cover (W/m^2)
$q_{e,w\text{-}g}$	evaporative heat transfer rate from water to glass cover (W/m^2)
$Rand(\cdot)_1$; $Rand(\cdot)_2$	random variables uniformly distributed within range (0,1)
R_m	external predictability evaluation index (dimensionless)
Ro^2	squared correlation coefficient (through the origin) between predicted and experimental values (dimensionless)
Ro'^2	squared correlation coefficient (through the origin) between experimental and predicted values (dimensionless)
T	maximum number of iterations
t	number of iterations (generations)
t_{int}	time interval (s)
T_g	mean glass covers temperature (°C), (*average of* T_{g1} *and* T_{g2})
T_{g1}, T_{g2}	glass covers temperatures (°C)
T_v	vapour temperature (°C)
T_w	water temperature (°C)
V_i	velocity of the particles
w	inertia weight factor used to balance the global exploration and local exploitation
X_i	position of the particles
x^L	lower bound of the NS design variables
x^U	upper bound of the NS design variables
y	actual value
y_{av}	average actual value
y'	predicted value
y'_{av}	average predicted value

Greek symbols

β	volumetric thermal expansion coefficient (K^{-1})
ΔT	temperature difference between water and inner side of glass cover (°C)
μ	dynamic viscosity of vapour (N s/m^2)
ρv	mass density of vapour (kg/m^3)
$_{total}$	total accuracy
$_{sensor}$	sensor accuracy
$_{instrument}$	measuring instrument accuracy

Subscripts

g	glass
v	vapour
w	water

1. Introduction

Finding ways to improve the efficiency of water purification technology is a major challenge in the 21st century [1]. Humans need potable water to survive. Three-quarters of the earth's surface is covered with water, but only approximately 0.014% of this water is potable. Moreover, 97.5% of the global water supply is composed of seawater, which needs to be distilled and purified for human use [2]. Fresh natural water is scarce in several countries. With an increase in the population, standard of living, and industrial and agricultural activities comes a high demand for fresh water [3]. Hence, developing cheap, safe, sustainable, and eco-friendly techniques for producing potable water from seawater is essential. An important technique currently being used to produce fresh water for human consumption is solar distillation [2]. It involves the distillation of salty or brackish waters using solar energy. This process is eco-friendly and only makes use of sustainable energy [4].

Several studies have used a wide range of diverse experimental models to increase the productivity of solar stills by utilizing water and air flow [5] or by designing parabolic concentrator tubular solar stills [6], arrayed tubular solar stills [7], multistage active solar stills with different numbers of solar collectors [8], a solar collector with a water sprinkling system and a thermoelectric cooling device [9], tubular and triangular stills [10–12], using internal and external reflectors [13], and developing an alternative low-cost technique [14]. Experiments have also been conducted to attempt to improve the productivity of solar stills by using nanomaterials [15]. Moreover, previous studies have investigated the parameters that affect the productivity of solar stills [16,17]. Earlier studies have also explored numerical and theoretical designs to find a way to improve productivity and estimate the heat transfer