Solar Energy 143 (2017) 142–161

Contents lists available at ScienceDirect

Solar Energy

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

Enhancement in energy metrics of double slope solar still by incorporating N identical PVT collectors

D.B. Singh [a,*], G.N. Tiwari [b]

[a] Centre for Energy Studies, Indian Institute of Technology Delhi, HausKhas, New Delhi 110016, India
[b] Bag Energy Research Society (BERS), SODHA BERS COMPLEX, Plot No. 51, Mahamana Nagar, Karaudi, Varanasi, UP 22 10 05, India

ARTICLE INFO

Article history:
Received 18 October 2016
Received in revised form 5 December 2016
Accepted 20 December 2016

Keywords:
Energy metrics
Cogeneration efficiency
N identical PVT collectors
Solar still

ABSTRACT

In this paper, double slope solar still has been analyzed by incorporating *N* identical partially covered photovoltaic thermal (PVT) collectors under optimized condition to assess the enhancement in energy metrics. Number of collectors, mass flow rate and water depth of N identical partially covered PVT flat plate collector (N-PVT-FPC-DS) have been optimized for climatic condition of New Delhi. Subsequently, annual distillate output, energy, exergy, energy metrics, cogeneration efficiency and cost of distillate output have been computed for the proposed N-PVT-FPC-DS at 0.14 m water depth. Results obtained have been compared with results reported by previous researchers and it has been concluded that the proposed N-PVT-FPC-DS performs better than double slope solar still incorporated with N identical PVT compound parabolic concentrator collectors (N-PVT-CPC-DS) and conventional double slope solar still (CDSSS) on the basis of energy metrics and cost of distillate output. The exergy based energy payback time is lower by 74.66% and 62.62%; energy production factor is higher by 43.30% and 38.14%; life cycle conversion efficiency is higher by 48.57% and 48.57% and cost of distillate output is lower by 35.37% and 4.88% for the proposed N-PVT-FPC-DS than N-PVT-CPC-DS and CDSSS respectively.

1. Introduction

Solar distillation is the process of getting potable water at the expense of solar energy with the help of device known as solar still. Solar still on proper incorporation with PVT collectors or similar other device is known as active solar distillation system. It can offer a promising option to assuage the contemporary problem of paucity of potable water and energy for far-flung areas as it is very simple in technology which can be maintained by a layman very easily, eco-friendly, more economical. Moreover, it is self sustainable and it can even deliver DC electric power to the society during sunshine hours if required. Solar distillation system is usually categorized as passive and active. The active solar distillation system can further be classified as nocturnal and high temperature distillation. In the case of high temperature active solar distillation system, additional heat can be made available to the basin of solar still through some external source either directly by incorporating flat plate collector (FPC)/Concentrator/evacuated tube collector (ETC) or indirectly by the use of heat exchangers to enhance the rate of vaporization of water with an aim to attain higher yield. A lot of researches by various researchers are available for active solar still.

The active solar still in forced mode was investigated theoretically for the first time by Rai and Tiwari (1983) and they reported that the daily yield was 24% higher than conventional solar still. At the same time, Zaki et al. (1983) studied the active solar still under natural circulation mode for the first time and reported a maximum enhancement in distillate output of 33% in comparison to conventional solar still. A number of series connected FPC can be coupled to the basin of solar distillation system in a closed loop either directly by discharging hot water to the basin or by providing heat exchanger in the basin. Yadav and Yadav (2004) studied the single slope solar still by incorporating inverted absorber asymmetric line-axis compound parabolic concentrating collector and concluded that the distillate output was increased in comparison to conventional solar still because solar still received solar energy both from top and bottom resulting in increased temperature difference between water surface and glass cover. Badran and Al-Tahaineh (2004) investigated solar still having mirrors at interior walls and coupled with FPC experimentally. They reported an increase in yield by 36% as compared to conventional solar still due to increased temperature difference between water surface and inner surface of glass cover. Abdel-Rehim and Lasheen (2007) investigated single slope solar still augmented with solar parabolic trough collector and heat gained by serpentine oil in collector was transferred to water in basin through heat exchanger

* Corresponding author.
E-mail address: dbsiit76@gmail.com (D.B. Singh).

http://dx.doi.org/10.1016/j.solener.2016.12.039

Nomenclature

A_b area of basin (m^2)
A_c area of flat plate collector under glazing (m^2)
A_g area of glass cover (m^2)
A_m area of PVT (m^2)
a clear days (blue sky)
b hazy days (fully)
C_f/C_w specific heat capacity of water (J/kg-K)
CPC compound parabolic concentrator
CDSSS conventional double slope solar still
C_{wp} production cost of water (₹/kg)
C_e cost of electricity gain (₹/kW h)
C_{DSSS} cost of DSSS (₹)
$C_{PVT-FPC}$ cost of $PVT - FPC$
C_{fab} fabrication cost which includes the cost of piping and labor (₹)
c hazy and cloudy days (partially)
d cloudy days (fully)
DS double slope PVT-FPC active solar distillation system
$\dot{E}x$ hourly exergy (W)
E_{out} overall annual energy available from N-PVT-FPC-DS (kW h)
Ex daily exergy (kW h)
Exm monthly exergy (kW h)
E_{in} embodied energy (kW h)
EPF energy production factor (fraction)
EPBT energy payback time (yr)
E_e annual electricity gain (kW h)
FPC flat plate collector
F' collector efficiency factor
$F_{CR,i,n}$ capital recovery factor (fraction)
$F_{SR,i,n}$ sinking fund factor (fraction)
$G_{ex,annual}$ annual overall exergy gain (kW h)
h_i heat transfer coefficient for space between the glazing and absorption plate (W/m^2-K)
h'_i heat transfer coefficient from bottom of PVT to ambient (W/m^2-K)
h_o heat transfer coefficient from top of PVT to ambient (W/m^2-K)
h_{pf} heat transfer coefficient from blackened plate to fluid (W/m^2-K)
h_{bw} heat transfer coefficient from basin liner to water (W/m^2-K)
h_{ba} heat transfer coefficient from basin liner to ambient (W/m^2-K)
h_{rwgE} radiative heat transfer coefficient from water to inner surface of glass cover on east side (W/m^2-K)
h_{rwgW} radiative heat transfer coefficient from water to inner surface of glass cover on west side (W/m^2-K)
h_{cwgE} convective heat transfer coefficient from water to inner surface of glass cover on east side (W/m^2-K)
h_{cwgW} convective heat transfer coefficient from water to inner surface of glass cover on west side (W/m^2-K)
h_{ewgE} evaporative heat transfer coefficient from water to inner surface of glass cover on east side (W/m^2-K)
h_{ewgW} evaporative heat transfer coefficient from water to inner surface of glass cover on west side (W/m^2-K)
h_{1wE} total heat transfer coefficient between water surface and glass cover on east side
h_{1wW} total heat transfer coefficient between water surface and glass cover on west side
I(t) radiation falling on collector (W/m^2)
$I_{sE}(t)$ solar intensity falling on glass cover on east side (W/m^2)
$I_{sW}(t)$ solar intensity falling on glass cover on west side (W/m^2)
i rate of interest (%)
K_g thermal conductivity of glass (W/m-K)
K_i thermal conductivity of insulation (W/m-K)
K_p thermal conductivity of absorption plate (W/m-K)
L latent heat (J/kg)
L_c length of collector under glazing only (m)
L_i thickness of insulation (m)
L_g thickness of glass cover (m)
L_m length of PVT (m)
L_p thickness of absorption plate (m)
LCCE life cycle conversion efficiency
ln natural logarithm
M maintenance cost of PVT-FPC active solar distillation system
M_w mass of water in basin (kg)
M_{ew} annual yield from solar distillation system (kg)
$\dot{m}_f$ mass flow rate of water (kg/s)
N number of collectors
n life of N-PVT-FPC-DS (year)
n' number of days
PVT photovoltaic thermal
PF_1 penalty factor due to the glass covers of module
PF_2 penalty factor due to plate below the module
PF_3 penalty factor due to the absorption plate for the glazed portion
PF_c penalty factor due to the glass covers for the glazed portion
P_s net present cost (₹)
P_m annual power generated from photovoltaic module (kW h)
P_u annual power utilized by pump (kW h)
N-PVT-FPC-DS double slope photovoltaic thermal flat plate collectors active solar distillation system
N-PVT-CPC-DS double slope photovoltaic thermal compound parabolic concentrator collectors active solar distillation system
$\dot{Q}_{uN}$ the rate of useful heat from N identical partially (25%) covered PVT-FPC connected in series (kW h)
R reflectivity
r ratio of daily diffused to daily global irradiation
$(SP)_w$ selling price of water (₹)
$(SP)_e$ selling price of electricity (₹)
S_s salvage value (₹)
T_a ambient temperature (°C)
T_c solar cell temperature (°C)
T_p absorption plate temperature (°C)
T_{fi} fluid temperature at collector inlet (°C)
T_f temperature of fluid in collector (°C)
T_{foN} outlet water temperature at the end of Nth PVT–FPC (°C)
T_s temperature of sun, °C
T_w temperature of water in basin, °C
T_{wo} water temperature at t = 0, °C
$\overline{T}_{CN}$ average solar cell temperature
T_{giE} glass temperature at inner surface on east side, °C
T_{giW} glass temperature at inner surface on west side, °C
ΔT temperature difference between T_w and T_{giE}/T_{giW}
t time, h
UAC uniform end-of-year annual cost (₹)
U_{tca} overall heat transfer coefficient from cell to ambient (W/m^2-K)
U_{tpa} overall heat transfer coefficient from plate to ambient (W/m^2-K)
U_{Lm} overall heat transfer coefficient from module to ambient (W/m^2-K)