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Exergoeconomic and enviroeconomic analyses of hybrid double slope solar still loaded with nanofluids

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ABSTRACT

In recent times, incorporation of nanotechnology in solar distillation systems for potable water production is a new approach harvesting solar thermal energy. In present manuscript, concentration of assisting nanoparticles and basin fluid (basefluid/nanofluid) mass have been optimized for hybrid solar still operating (a) without heat exchanger (system A), and (b) with helically coiled heat exchanger (system B). Corresponding to the optimized parameters, overall thermal energy, exergy, productivity (yield), and cost analysis of the proposed hybrid systems loaded with water based nanofluids have been carried out; and found to be significantly improved by incorporating copper oxide-water based nanofluid. Moreover, on the basis of overall thermal energy and exergy, the amount of carbon dioxide mitigated per annum is found to be 14.95 tones and 3.17 tones respectively for the hybrid system (A); whereas, it is found to be 24.61 tones and 2.36 tones respectively for the hybrid system (B) incorporating copper oxide-water based nanofluid. Annual performance of the proposed hybrid systems has been compared with the conventional solar still (system C).

1. Introduction

The solar photovoltaic (PV) technology is one of the most promising and fastest growing renewable energy technologies which will play a primary role in clean energy. Photovoltaic thermal systems or renewable energy (RE) systems on harvesting an ample source of (solar) energy are the viable option for various applications viz. solar water collector, solar air collector, space heating, greenhouse dryer, heat exchanger and building integrated photovoltaic thermal system, etc. Including clean food and air, potable water is a fundamental human need and it is essential to sustain life for all creatures on the Earth. Moreover, consumption of contaminated drinking water originates various diseases i.e. bacterial infections, viral infections, protozoal infections, etc. Worldwide, various nations are affected with water shortages. This problem basically originates due to change in climate conditions; rapid growth in population; floods, poor management of water resources and excess use of potable water. Therefore, the protection of safe drinking (potable) water requires proper “framework”; adequate, effective, and comprehensive policies for water distribution; and a system of independent surveillance.

Today, with advancement in science and technology, high and medium techniques have been developed to produce drinking water from the contaminated water. But, these techniques depend on the conventional source of energy i.e. electricity. Solar distillation is the simplest, cost-effect and environment friendly method for the production of potable water. Solar distillation systems or simply solar stills are categorized into passive and active solar stills [1]. There are some advantages of solar distillation over the other techniques i.e. no need of high tech exchange parts like batteries, filers, or membranes; purify highly saline water, feasible for local manufacturing, no conventional source of energy is required, and low initial investment.

The productivity of solar still mainly depends on the working temperature and internal heat transfer mechanism [2]. The heat transfer coefficients (HTCs) can be enhanced by improving the thermo-physical properties of water (basefluid).

In recent times, nanotechnology has been implemented in the solar stills in order to improve further their performance. Nanofluids are simply the suspension of 1–100 nm nanoparticles (NPs) in the basefluid (water, thermal oil, ethylene glycol, etc.). These are the embryonic fluids with ultrafast heat transfer capabilities due to their better thermo-physical and optical properties. These properties can be improved by tailoring the size and shape of the NPs in a particular basefluid.

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Nomenclature

A_m	area of the PV module, (m^2)
A_c	area of the glazing, (m^2)
A_{gE}	surface area of condensing cover of east side of solar still, (m^2)
A_{gW}	surface area of condensing cover of west side of solar still, (m^2)
A_b	basin area of solar still, (m^2)
C_p	specific heat capacity of NP, (J/Kg-K)
C_{nf}	specific heat capacity of nanofluid, (J/Kg-K)
C_{bf}	specific heat capacity of basefluid, (J/Kg-K)
D_i	diameter of the FPC tube (mm)
d_p	diameter of nanoparticle (nm)
F'	collector efficiency factor
$h_{1g,E}$	total external heat transfer coefficient on east side, ($W/m^2\,°C$)
$h_{1g,W}$	total external heat transfer coefficient on west side, ($W/m^2\,°C$)
$h_{1f,E}$	total internal heat transfer coefficient on east side, ($W/m^2\,°C$)
$h_{1f,W}$	total internal heat transfer coefficient on west side, ($W/m^2\,°C$)
h_{EW}	internal radiative heat transfer coefficient between glass covers, ($W/m^2\,°C$)
$h_{ef,E}$	evaporative heat transfer coefficient on east side, ($W/m^2\,°C$)
$h_{ef,W}$	evaporative heat transfer coefficient on west side, ($W/m^2\,°C$)
h_{ba}	heat transfer coefficient between basin liner and ambient air, ($W/m^2\,°C$)
h_{FPC}	convective heat transfer in the flat plate collector, ($W/m^2\,°C$)
h_{HE}	convective heat transfer in the heat exchanger, ($W/m^2\,°C$)
$h_{b,f}$	heat transfer coefficient between basin liner and fluid, ($W/m^2\,°C$)
h_{pf}	heat transfer coefficient from blackened plate to ambient, ($W/m^2\,°C$)
h_i	heat transfer coefficient for space between absorption plate and glazing, ($W/m^2\,°C$)
h_o	heat transfer coefficient from top of PV water collector to ambient, ($W/m^2\,°C$)
I_{SE}	solar intensity on east side of the glass cover, (W/m^2)
I_{SW}	solar intensity on west side of the glass cover, (W/m^2)
I_{SW}	solar intensity on FPC, (W/m^2)
K_p	thermal conductivity of the absorption plate (W/m-K)
k_p	thermal conductivity of nanoparticle, (W/m-K)
k_{nf}	thermal conductivity of nanofluid, (W/m-K)
k_{bf}	thermal conductivity of basefluid, (W/m-K)
K_g	thermal conductivity of condensing cover, ($W/m^2\,°C$)
L	length of the helical heat exchanger (mm)
L_g	thickness of condensing cover, (m)
L_b	thickness of basin, (m)
L_p	thickness of the absorption plate (m)
M_f	mass of fluid in the basin of solar still (kg)
$\dot{m}_f$	mass flow rate of the fluid (kg/s)
$\dot{M}_{bf}$	yield obtained from the system (kg/h)
P_{gi}	partial saturated vapor pressure of the inner glass cover, (N/m^2)
P_f	partial saturated vapor pressure of the fluid, (N/m^2)
PF_1	penalty factor due to glass covers of the module
PF_2	penalty factor due to absorption plate below the module
PF_3	penalty factor due to absorption plate for the portion covered by the glazing
r_{11}	outer diameter of the heat exchanger tube (mm)
r_{22}	inner diameter of the heat exchanger tube (mm)
T_{goE}	outer condensing cover temperature of east side solar still, (°C)
T_{goW}	outer condensing cover temperature of west side solar still, (°C)
T_{bf}	basefluid temperature, (°C)
T_{nf}	nanofluid temperature, (°C)
T_{giE}	inner condensing cover temperature of east side of solar still, (°C)
T_{nf}	fluid temperature, (°C)
T_v	vapor temperature, (°C)
T_a	ambient temperature, (°C)
T_{giW}	inner condensing cover temperature of west side solar still, (°C)
ΔT_{DSSS}	temperature difference between NF and BF in DSSS, (°C)
ΔT_{FPC}	temperature difference between NF and BF at the outlet of PVT collectors, (°C)
ΔT_{HE}	temperature difference between NF and BF in heat exchanger, (°C)
Δt	time interval (s)
$U_{tp,a}$	overall heat transfer coefficient from absorption plate to ambient, ($W/m^2\,°C$)
$U_{L,m}$	overall heat transfer coefficient from module to ambient, ($W/m^2\,°C$)
$U_{L,c}$	overall heat transfer coefficient from glazing to ambient, ($W/m^2\,°C$)
$U_{tc,a}$	overall heat transfer coefficient from cell to ambient from the top surface, ($W/m^2\,°C$)
U_{ga}	overall heat transfer coefficient between condensing cover and ambient air, ($W/m^2\,°C$)
U_{ba}	overall heat transfer coefficient between basin liner and ambient air, ($W/m^2\,°C$)
U_{gaE}	overall heat transfer coefficient between outer condensing cover of east side and ambient air, ($W/m^2\,°C$)
U_{gaW}	overall heat transfer coefficient between outer condensing cover of west side and ambient air, ($W/m^2\,°C$)
$U_{tc,p}$	overall heat transfer coefficient from cell to the absorption plate, ($W/m^2\,°C$)
X	characteristic length of solar still, (m)

Greek letters

α_g	fraction of solar energy absorbed by condensing cover
α_b	fraction of solar energy absorbed by basin surface
α_f	fraction of solar energy absorbed by fluid
α_c	fraction of solar energy absorbed by solar cell
τ_g	fraction of solar energy transmitted by top glass cover of the PVT-FPC
φ_p	volume fraction of nanoparticles (%)
η_c	efficiency of the PVT- FPC collector (%)
β	packing factor
β_p	thermal expansion coefficient of nanoparticle, (K^{-1})
β_{nf}	thermal expansion coefficient of nanofluid, (K^{-1})
β_{bf}	thermal expansion coefficient of basefluid, (K^{-1})
μ_{bf}	dynamic viscosity of basefluid, (Ns/m^2)
μ_{nf}	dynamic viscosity of nanofluid, (Ns/m^2)
ρ_p	density of nanoparticle, (Kg/m^3)
ρ_{nf}	density of nanofluid, (Kg/m^3)
ρ_{bf}	density of basefluid, (Kg/m^3)

Subscripts

a	ambient
b	basin surface
v	vapor
gi	inner condensing cover
go	outer condensing cover