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Exergy and thermal assessment of a Novel system utilizing flat plate collector with the application of nanofluid in porous media at a constant magnetic field

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A B S T R A C T

A Novel system is introduced which utilizes Fe_3O_4/Water nanofluid in porous media at a constant magnetic field in a Flat Plate Collector (FPC) absorber tubes. The Fe_3O_4/Water nanofluid was used in 1% and 2% weight concentration flowing inside porous media with 0.8 porosity at constant magnetic fields of 200 and 400 G. The Novel system is studied by exergy and thermal analysis means and is compared to a Rival system which is a regular FPC that uses water as working fluid and porous foam inside its tubes. A new evaluation approach has been adopted which assesses the thermal effectiveness, exergy, and energy efficiencies in a variety of working conditions. Furthermore, a novel parameter, which is regarded as Feasibility Indicator Parameter (FIP), is introduced which represents the performance of the solar collector. The results reveal that the Novel system average Nusselt number is 1.36 times the average Nusselt number of the Rival system. Moreover, the overall heat loss coefficient is reduced to 3.149 W/m^{2}K in comparison to 3.4 W/m^{2}K in the Rival FPC. Additionally, the thermal efficiency of the Novel system has been demonstrated to rise to 83.97% compared with 83.63% efficiency in the Rival system. The absorbed heat flux, feasibility factor or Performance Evaluation Criterion (PEC), and the heat transfer coefficient enhancement of the Novel system are 1.015, 1.32, and 1.52 concerning the Rival system, respectively. Furthermore, the novel assessing parameter, FIP value is higher than unity for the Novel system with 200 G constant magnetic field and 1% and 2% wt nanoparticle. However, the required pumping power in the Novel system increases considerably. Hence, the relative exergy efficiency of the Novel system to the Rival system is below the value one. Although the Rival FPC system has a higher exergy efficiency than the Novel system, however, the Novel system provides better thermal performance and higher PEC and FIP than the Rival system. Thus, it can be used wherever the availability of space and higher thermal efficiency are crucial.

1. Introduction

Energy is an invaluable strategic asset and has a profound impact on the national treasury. Furthermore, it worth to mention that humankind exhausts over 90,000 billion liters of oil per year [1]. If one country could save its expenditure on fossil fuels by replacing them with renewable energy sources (RES), the addition of this secured income can have an enormous impact on that country's economic and environmental safety. One of the available options is the replacement of fossil fuels with RES. One of the most readily available and stable RES is the solar energy. An hour of the sunlight energy which reaches the earth exceeds the energy consumed by all of the humanity in a year [2]. Therefore, one must find more efficient and novel ways to harness such an immense power while keeping its cost as low as possible. So, it is a rational decision to study FPC refinement techniques because it is the cheapest harness equipment among the solar collectors.

One of the suggested methods which can be employed to enhance FPC overall effectiveness is the utilization of nanofluids because they have higher conductivity values than non-metallic liquids. He et al. [3] have done an experimental assessment on Cu/Water nanofluid as working fluid in FPC and concluded that it could enhance collector efficiency, highest outlet temperature and maximum heat gain by 23.83%, 12.24% and 24.52% respectively. Moghadam et al. [4] have reported that CuO/Water nanofluid with a volume fraction of 0.4% and a mass flow rate of 1 kg/min, enhances the efficiency of the collector by about 21.8%. For any specific working fluid, an optimum mass flux exists, which maximizes the collector efficiency. Sint et al. [5] have studied CuO/Water nanofluid application in FPC and reported 5% enhancement in efficiency at an optimum particle concentration of 2% (vol.), with 25 nm particle size. Gupta et al. [6] have experimentally

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Nomenclature

A	surface area (m^2)
B	magnetic field (G)
CC	change of variable to make Eq. (1) shorter which is defined in Eq. (3)
c_p	specific heat (j/kg K)
D	diameter (m)
ee	change of variable to make Eq. (1) shorter which is defined in Eq. (4)
Ex	exergy (W)
Ex_d	exergy destruction (W)
Ex_{sink}	sink exergy (W)
Ex_{source}	source exergy (W)
f	Darcy–Weisbach coefficient
ff	change of variable to make Eq. (1) shorter which is defined in Eq. (2)
F	fin efficiency
F'	collector efficiency
F''	collector flow factor
F_R	collector heat removal factor
FIP	feasibility indicator parameter
h	convective heat transfer coefficient (W/m^2 K)
h_{wind}	Wind heat transfer coefficient (W/m^2 K)
hh	enthalpy (J/kg)
I	current (ampere)
II_c	incident radiation flux (W/m^2)
k	thermal conductivity (W/m K)
k_{insol}	insolation thermal conductivity (W/m K)
K_B	Boltzmann constant
L_{insol}	insolation thickness (m)
$\dot{m}$	fluid mass flow rate (kg/s)
Mn	the dimensionless magnetic number
N	number of covering glasses in FPC
Nu	Nusselt number
Pr	Prandtl number
ΔP	pressure drop (Pa)
q'_u	useful Heat transfer per unit length (J/m)
$\dot{Q}$	heat transfer rate (W)
Re	reynolds number
s	specific entropy (J/kg K)
$\dot{S}_{gen}$	entropy generation rate (W/kg K)
T	temperature (K)
T_b	bonding temperature (K)
T_{am}	ambient temperature
$T_{p,m}$	absorbing plate mean temperature
T_{sun}	sun temperature (K)
U_b	heat transfer loss coefficient from below FPC (W/m^2 K)
U_{loss}	overall heat transfer loss coefficient (W/m^2 K)
U_t	heat transfer loss coefficient for the top side of FPC (W/m^2 K)
V	voltage (V)
W	pump consumption energy (W)
wt	nanoparticle weight percentage in nanofluid (%)
WW	absorber plate width (m)

Greek symbols

α	thermal diffusion
β	slope of FPC (degree)
ε_g	emittance of glass cover
ε_p	emittance of absorber plate
ρ	density (kg/m^3)
μ	dynamic viscosity (N s/m^2)
μ_0	permeability of vacuum ($4\pi \times 10^{-7}$ Tm/A)

Subscripts

col	collector
f	fluid
i	inlet or inside
m	mean
nf	nanofluid
O	outlet or outside
p	nanoparticle
0	dead state

studied Al_2O_3/Water nanofluid in FPC with a gross area of 1.4 m^2. Experiments have been performed testing diverse volume fractions of 20 nm Al_2O_3 nanoparticles with volume fractions of 0.05%, 0.01%, 0.005% and 0.001%, which showed efficiency improvements of 18.75%, 24.6%, 39.6% and 22.1% respectively. The experimental results also indicated that the collector efficiency reached an apex at a certain volume fraction, and decreased for higher and lower values of this distinct volume fraction. Jouybari et al. [7] have experimentally evaluated SiO_2/Water nanofluid application in a porous filled channels FPC. The results indicated an 8.1% improvement in thermal efficiency. Nasrin et al. [8] expressed that the Ag/water nanofluid has a higher heat transfer than Cu/Water, CuO/Water, and Al_2O_3/Water nanofluids. It is sufficient to say that more reviews on the nanofluid application in FPC can be found in the other references [9–11].

To justify nanofluids application in FPC; it is needed to evaluate exergy and energy efficiencies in addition to the heat transfer assessments. Alim et al. [12] have analyzed the heat transfer, and pressure drop variations of Al_2O_3, CuO, SiO_2, TiO_2 nanofluids in laminar flow. They have reported that CuO nanofluid would enhance the convective heat transfer coefficient by 22.15%. It would also decrease the generated entropy by 4.34% compared to water. However, it causes a small increase in the pumping power by 1.58%. Mahian et al. [13] have studied Al_2O_3/Water nanofluid in FPC. The contributory factors of tube roughness, nanoparticle size, different thermophysical models and volume concentrations on heat transfer and entropy generation behavior have been assessed. It is seen that the trend of changes in the outlet temperature is precisely opposite to the Nusselt number trend. The second law study have demonstrated that the entropy generation declines with increasing the nanofluid concentration. It has been observed that the tube roughness increased the generated entropy. Moreover, this effect has been intensified at higher mass flow rates. Shojaeizadeh and Veysi [14] optimized the exergy efficiency of Al_2O_3/Water nanofluid in an FPC. The outcome of this study illustrated that the optimum exergy efficiency and each of corresponding optimum parameters (mass flow rate of the fluid, nanoparticle volume concentration and collector inlet temperature) declined exponentially with ambient temperature to solar radiation ratio enhancements. Said et al. [15] analyzed entropy generation and heat transfer enhancement of single-wall carbon nanotubes (SWCNTs). They concluded that the generated entropy reduced by 4.34% and heat transfer coefficient enhanced by 15.33% compared to water as the absorbing fluid. Moreover, the power consumption of the pump increased by 1.2%. In another paper, Said et al. [16] also completed energy and exergy analyses of Al_2O_3/Water nanofluid for the size of (13 nm and 20 nm) nanoparticles with a volume fraction of 0.1% in an FPC. The results showed that 13 nm Al_2O_3 nanofluid had the highest energy efficiency of about 73.7% and second law efficiency of about 20.3%, compared to Al_2O_3/Water (20 nm) nanofluid, which had an energy efficiency of 70.7% and exergy efficiency of 15.8%. Edalatpour and Solano [17] numerically modeled Al_2O_3/Water nanofluid in a conjugated laminar mixed convection flow and concluded that using