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Optical and thermal analysis of a parabolic trough solar collector for production of thermal energy in different climates in Iran with comparison between the conventional nanofluids

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ABSTRACT

Optical and thermal analysis of the most well-known solar concentrator system; parabolic trough collector (PTC) are investigated and analyzed. To evaluate performance of the PTC, four cities of Iran with different weather conditions are chosen as case studies. Effective parameters such as concentration ratio, incident angle correction factor, collector mass flow rate are considered. The main objective of this work is evaluation of the solar energy potential using PTC in under consideration cities with different climates. Numerical modeling of the analysis is done using MATLAB software. Simulation results shows that Shiraz, with an average annual thermal efficiency of 13.91% and annual useful energy of 2213 kWh/m^2, is the best region to use solar concentrator systems. The impacts of other parameters such as fluid inlet temperature, input fluid flow rate and aperture area of the collector on the output of the system are also investigated. Finally, the effect of using nanofluids as heat transfer fluid on increasing the heat transfer is investigated.

1. Introduction

By decreasing the fossil fuel resources and increasing the cost of electricity in recent years, the use of renewable energy is an attractive solution to solve the current problems of energy (Bellos et al., 2016; Mehrpooya et al., 2016; Ahmadi and Mehrpooya, 2015). Fossil fuels releases large amounts of CO$_2$ into the atmosphere, but renewable energy, such as solar, wind, geothermal energy, fuel cell and etc. do not generate any emissions (Onder Kizilkan and Dincer, 2016; Mehrpooya and Sharifzadeh, 2017; Mohammadi and Mehrpooya, 2017; Ahmadi et al., 2016). Among those, solar energy has received considerable attention, because it is a clean and interminable energy source (Onder Kizilkan and Dincer, 2016). Utilization of solar energy has become considerable in many processes due to its advantages, such as: reduction of the greenhouse gas emissions and cost of the electricity, and prevention of the global warming through reduction of fossil fuels. Solar energy is able to produce thermal energy for house-heating and cooling, domestic hot water, industrial heat demand and electricity production in the solar power plants (Bellos et al., 2016). In addition, solar energy has great economic benefits by decreasing the consumption of fossil fuels and electricity (Onder Kizilkan and Dincer, 2016). Solar collectors can be used to produce thermal energy from solar energy.

Solar thermal collectors are used to increase fluid temperature in both industrial and residential applications, which depends on the configuration of use, heat transfer fluid, generally water or a mixture of water and glycol. There are several types of solar thermal collectors, which all of them have the common principle of capturing solar radiation, converting it to useful heat and transferring it to a working fluid (Kalogirou, 2004). Solar water heating (SWH) is the conversion of solar radiation into heat for water heating using a solar thermal collector. SWHs are widely used for residential and some industrial applications. Solar process heating systems are designed to provide large quantities of hot water or space heating for nonresidential buildings. One of the most important issues in solar energy is energy storage. On the

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Nomenclature

A	Area (m^2)
C	Concentration ratio (–)
C_p	Specific heat at constant pressure ($kJ\,kg^{-1}\,K^{-1}$)
D	Diameter (m)
f	Focal length (m)
F_R	Heat removal factor (–)
h	Heat transfer coefficient ($Wm^{-2}\,K$)
G_b	Beam radiation (Wm^{-2})
$K(\theta)$	Incident angle correction factor
k	Thermal conductivity (W/m K)
k_m	Thermal conductivity ($Wm^{-1}\,K^{-1}$)
L	Tube length (m)
m_a	Specific mass flow rate in tube ($kgs^{-1}\,m^2$)
m_c	Collector mass flow rate (kgs^{-1})
Nu	Nusselt number (–)
T	Temperature (°C)
Pr	Prandtl number (–)
Q_u	Useful energy, (Wh)
r_r	Mirror radius (m)
Re	Reynolds number (–)
U_L	Collector loss coefficient ($Wm^{-2}\,K^{-1}$)
V_{air}	Air velocity (ms^{-1})
W	Width (m)
W_a	Aperture of the parabola (m)
X_{end}	End loss
α_r	Receiver absorbance (–)
β	Constant factor(–)
μ	Dynamic viscosity (kg/m s)
γ	Intercept factor (–)
ε	Emittance (–)
η	PTC efficiency (–)
η_o	Optical efficiency (–)
θ	Solar incident angle (o)
θ_r	Rim angle (o)
ρ	Density (kg/m^3)
ρ_{CL}	Trough reflectance(–)
σ	Stefan-Boltzmann constant ($Wm^{-2}\,K^{-4}$)
τ_{env}	Cover transmittance (–)
ϕ	Particle volume fraction

Subscripts

a	Aperture
amb	Ambient
bf	Base fluid
c,c-am	convection between cover & ambient
c	Cover
eff	Effective
fi	Fluid inlet
in	Inlet
opt	Optical
out	Outlet
r	Receiver
r,c-am	Radiation between cover & ambient
ri	Receiver inner
ro	Receiver outer
r,r-c	Radiation between receiver & cover
s	Solid particle
sky	Sky conditions

Abbreviations

COP	Coefficient of performance
CSP	Concentrating solar power
DNI	Direct Normal Irradiance
DSG	Direct steam generation
FPC	Flat plate collector
HCE	Heat collection element
HTF	Heat transfer fluid
MWCNT	Multi walled carbon nanotube
PCM	Phase change material
PLC	Programmable logic controller
PTC	Parabolic trough collector
PTSC	Parabolic trough solar collector
PV/T	Photovoltaic thermal
SAHP	Solar-assisted heat pump
SWH	Solar water heating

other hand, one way of reducing the capital cost of the heat pump is to integrate it with a thermal energy storage system (Esen, 2000). Another way for heating/cooling applications is development of ground source heat pump systems (Esen et al., 2017). Meanwhile, a solar-assisted heat pump (SAHP) is a machine that represents the integration of a heat pump and thermal solar collectors in a single integrated system. The use of these systems is very economical and environmentally friendly (Esen et al., 2017).

Solar collectors are divided into two categories: stationary (or non-concentrating) collectors and concentrating collectors. Stationary collectors, such as flat-plate collectors, are not able to provide thermal energy for most industrial processes; because these processes require a temperature of about 100 °C–240 °C (Onder Kizilkan and Dincer, 2016). In order to solve this problem and achieve higher temperatures, solar concentrators such as PTC or dish can be used. A parabolic solar dish collector system used for supplying the required heat and power in a commercial tower is investigated (Moradi and Mehrpooya, 2017). PTCs operate at temperatures between 80 °C and 160 °C and are able to meet the requirements of domestic and industrial thermal processes (Ghodbane and Boumeddane, 2016). These concentrators can be applied in power plants for producing electricity, through production of superheated steam (Ghodbane and Boumeddane, 2016).

Review of thermal performance of PTC such as simulation and numerical methods and experimental set-ups is presented by Conrado et al. (Conrado et al., 2017). Potential of concentrating solar power (CSP) and thermal power plant of PTC in Algeria is reviewed by Boukelia and Mecibah (eddine Boukelia and Mecibah, 2013). One of the major applications of PTC technologies is water heating. Macedo et al (Macedo-Valencia et al., 2014) modeled this idea for laundries and nursery (soil sterilization). The result show that for a beam radiation of 783 W/m^2 at a flow rate of 0.2 L/min, the maximum outlet temperature is 47.3 °C. Binotti et al. (Binotti et al., 2013) developed a mathematical and analytical model to evaluate the optical performance of PTC. In this study 3-D optical performance is modeled by MATLAB and validated by the first OPTIC method. Oliveira Siqueira et al (de Oliveira Siqueira et al., 2014) use VB.NET programming for modelling the heat transfer of a PTC in Brazil for determined operating conditions and parasitic losses. Huang et al. (Huang et al., 2012) use numerical integration algorithm for analyzing the optical performance of PTC with vacuum tube receiver. In this two analytical methods is proposed for calculation of the optical efficiency of PTC with