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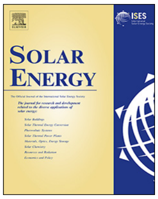

Daily, monthly and yearly performance of a linear Fresnel reflector

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ABSTRACT

The main objective of this study is to investigate the daily performance of a linear Fresnel reflector in energetic and exergetic terms. The collector is designed and examined in SolidWorks Flow Simulation in order to obtain the optical and thermal efficiency curves. These data are inserted in a developed numerical dynamic model for the prediction of the daily performance of the solar collector which is coupled to a storage tank. The collector has total aperture 27 m^2, concentration ratio 20.46 and the storage tank volume is 3 m^3. The system is investigated for twelve typical days, one for each month, and its yearly performance is determined by taking into consideration only the sunny days of every month. According to the final results, the mean yearly incident angle modifier is found to be 37% while the maximum yearly exergy efficiency is 8.0% when the system starts with 450 K inlet temperature at the morning. For this case, the mean yearly thermal efficiency is found to be 18.5% and also June is the month with the highest thermal and exergy outputs. Furthermore, it is important to state that the mean daily incident angle modifier is found to be the 81% of the maximum daily incident angle modifier for all the months.

1. Introduction

Solar energy exploitation is an important weapon for facing the modern environmental problems as the global warming and the high CO_2 emissions (Tiwari and Tiwari, 2017; Abbas and Martínez-Val, 2017; Pavlovic et al., 2017a). Concentrating solar collectors consist promising technologies for clean thermal energy production at various temperature levels, usually up to 500 °C (Desai and Bandyopadhyay, 2015; Hack et al., 2017; Pavlovic et al., 2018). The most usual concentrating technologies are parabolic trough collectors, linear Fresnel reflectors, solar dishes and solar towers (Mills, 2004; Qiu et al., 2016).

Linear Fresnel reflector (LFR) is a linear non-imaging concentrating collector which presents many similarities with the parabolic trough collector (PTC). The main difference is that the LFR have discrete mirrors close to the ground while the PTC has a continuous reflector which is moved far from the ground (Zhu et al., 2014; Morin et al., 2015). The use of discrete mirror strips leads to reduced wind loads and to a relatively simple construction. Thus, LFRs are generally low-cost technologies which can reach up to high concentration ratios without great mechanical problems (for instance huge movable reflector) (Montes et al., 2017, 2016).

The receiver of the LFR is non-movable and it is located some meters above the ground (about 3–5 m usually). In many cases, there is a secondary reflector in order to increase the amount of the solar irradiation that reaches on the absorber. The absorber is usually tubular (evacuated or not), but there are also other designs with flat absorbers. The secondary reflector is usually trapezoidal or it has a parabolic shape. The primary reflectors are either flat or curved, something that is depended on the selected technology. The curved mirrors can increase the optical efficiency but they are more sophisticated than the flat mirrors.

LFR presents lower optical performance compared to the PTC because of the differences in the design. The spaces between the primary reflectors, the shape of the primary reflectors, the shading effects and the need of a secondary reflector are the main reasons for the lower optical efficiency of the LFR (Nixon et al., 2013). However, the lower cost of LFR is able to overcome the lower optical efficiency and consequently the lower thermal efficiency. In the literature, there are a plethora of studies which investigates the thermal and optical efficiency of LFRs. Various designs with different advantages and disadvantages have been investigated experimentally and numerically. Moreover, many researchers have been worked on the optimization of LFR and on the detailed optical analysis.

Abbas and Martínez-Val (2015) developed an analytical method for the optimization of LFR. The examined the curvature of the reflectors, as well as the width and the distance of the mirrors and they found enhancement margins in the collector performance. Moreover, Boito and Grena (2016) optimized an LFR using the reflector width, the focal

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Nomenclature

A	parameter of solar direct beam intensity, W/m^2
A_a	collector net area, m^2
A_T	tank outer surface, m^2
B	parameter of solar direct beam direction, –
C	concentration ratio, –
c_p	specific heat capacity under constant pressure, J/kg K
D	diameter, m
D_m	distance between reflectors, m
DR	daily range of ambient temperature, K
E	daily energy, kWh
Ex	exergy flow, W
F	focal length, m
f	friction factor, –
G_b	solar direct beam irradiation, W/m^2
h	heat transfer coefficient in the flow, W/m^2 K
h_{out}	convection coefficient between cover and ambient, W/m^2 K
K	total incident angle modifier, –
K_L	longitudinal incident angle modifier, –
K_{max}	daily maximum incident angle modifier, –
K_{mean}	daily mean incident angle modifier, –
K_T	transversal incident angle modifier, –
k	thermal conductivity, W/mK
L	tube length, m
m	mass flow rate, kg/s
N_D	day duration, h
N_{rf}	number of primary reflectors, –
Nu	Nusselt number, –
Pr	Prandtl number, –
Q	heat flux, W
Re	Reynolds number, –
T	temperature, K
T_{am}	ambient temperature, K
T_N	temperature at the end of the day, K
T_{st}	storage tank temperature during the day, K
T_{ref}	reference temperature, K
T_o	initial temperature at the morning, K
t	time, s
t_h	time, h
u	fluid velocity, m/s
U_T	thermal loss coefficient of the tank, W/m^2 K
V	volumetric flow rate, m^3/s
V_T	storage tank volume, m^3
V_{wind}	ambient air velocity, m/s
W	total width, m
W_0	mirror width, m
Z	daily exergy output, kWh

Greek symbols

α	absorber absorbance, –
γ	intercept factor, –
γ_s	solar azimuth angle, °
δ	solar declination angle, °
ΔP	pressure drop, kPa
ε	emittance, –
η_{ex}	exergy efficiency, –
η_{th}	thermal efficiency, –
θ	solar incident angle, °
θ_L	longitude solar incident angle, °
θ_T	transversal solar incident angle, °
θ_z	zenith angle, °
μ	dynamic viscosity, Pa s
ρ	density, kg/m^3
ρ_1	primary concentrator reflectance, –
ρ_2	Secondary concentrator reflectance, –
τ	cover transmittance, –
φ	local latitude, °
ω	solar time angle, °

Subscripts and superscripts

abs	absorbed
am	ambient
am,m	ambient mean
c	cover
ci	inner cover
co	outer cover
c,loss	collector thermal loss
day	day duration
fm	mean fluid
hmax	hour of maximum ambient temperature
in	inlet
loss	thermal loss of the tank
max	maximum
opt	optical
out	outlet
r	receiver
ref	reference conditions
ri	inner receiver
ro	outer receiver
s	solar
stored	stored in the tank
th	theoretical
u	useful

Abbreviations

CPC	compound parabolic concentrator
CFD	computational fluid dynamics
IAM	incident angle modifier
LFR	linear Fresnel reflector
ORC	Organic Rankine Cycle
PTC	parabolic trough collector
3D	three-dimensional depiction

distance and the reflectors distances as the optimization variables. Benyakhlef et al. (2016) stated that a small curvature of the primary reflectors (~2 mm) leads to enhanced optical performance. Sharma et al. (2015) found that the optical losses due to the blocking effects can lead up to 20%. Mathioulakis et al. (2018) examined the optical performance of an LFR with flat absorber using experimental results. They suggested an optical modeling which is able to predict the instantaneous optical performance of the collector with high accuracy. Hongn et al. (2015) developed a methodology for the yearly determination of the optical end losses in an LFR. Huang et al. (2014) examined the optical performance of an LFR with azimuth tracking and they found annual mean thermal performance equal to 61% when the collector operates at 400 °C. Hertel et al. (2016) found that the impact of the thermal losses is not high at the incident angle modifiers modeling.

The receiver design is the next discussed issue in LFRs. The first group of researchers investigated trapezoidal cavities with internal tubes. Singh et al. (2010) examined four LFRs with the trapezoidal