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Research Paper

Optimum number of internal fins in parabolic trough collectors

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HIGHLIGHTS

- This study studies the internally finned absorbers in parabolic trough collectors.
- The number and the location of the internal fins are investigated with details.
- The thermal efficiency enhancement and the pressure drop are evaluated.
- The use of three fins in the lower part of the absorber is the optimum design.
- Higher fin number leads to higher thermal efficiency and pressure drop.

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ABSTRACT

Parabolic trough collectors are among the most mature solar concentrating technologies which are applied in numerous applications. The enhancement of their performance is a crucial issue in order to be established as a feasible technology. The use of internal fins is one of the most interesting techniques for enhancing the heat transfer phenomena in the flow as well as for increasing the collector's performance. However, their utilization leads to higher pressure losses. The objective of this paper is to investigate the optimum number and location of the internal fins in the absorber of a parabolic trough collector. The examined fins have 10 mm length and 2 mm thickness, while their shape is rectangular. Various numbers of fins are investigated in various locations inside the absorber and in every case, the collector's performance is investigated by taking into account the increase of the Nusselt number and of the friction factor. According to the final results, the internal fins have to be placed in the lower part of the absorber where the higher amount of the solar heat flux is concentrated. A multi-objective procedure proved that the absorber with three fins in the lower part is the optimum case with 0.51% thermal efficiency enhancement.

1. Introduction

Solar energy utilization is one of the most promising renewable energy sources in order to face the existing environmental problems [1]. Parabolic trough collectors (PTCs) are among the most mature solar concentrating technologies and they can be used in many applications as industrial heat, electricity production and in chemical processes [2,3]. The increase in their performance is one of the most challenging issues in order to make them a feasible and vital technology [4,5].

Many techniques have been tested for enhancing their thermal efficiency, which are mainly focused on the increase of the heat transfer phenomena inside the flow. The use of nanofluids as working fluids is a recently examined technique which is under development [6,7]. The existing experimental results have not proved a significant increase in the thermal efficiency of the PTC and thus they have not been established yet [8]. On the other hand, the use of flow inserts or internal fins in the absorbers of PTCs is another reliable choice [9–12]. These techniques aim to increase the mixing of the flow and to create more turbulent conditions in the absorber. However, these techniques lead to high-pressure losses due to the existence of obstacles in the flow. Thus, the thermal enhancement has to be evaluated in every case with proper criteria. Moreover, it is important to state that the use of thermal enhancement techniques decreases the deformation problems in the absorber and in the glass cover, something very important for the lifetime of the PTCs [5].

The literature studies which examine inserts in the flow, usually examine metal foams [13], porous discs [14], twisted-tape inserts [9], wavy-tape inserts [14], helical coils [15] and perforated plate inserts [16]. On the other hand, the use of internally finned absorbers or absorbers with modified internal geometry is another great literature part. Huang et al. [17] examined internally dimpled absorbers and they

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Nomenclature

A_a	collector aperture, m^2
c_p	specific heat capacity under constant pressure, J/kg K
D	diameter, m
f	friction factor, –
F	focal distance, m
F_0	objective function, –
G_b	solar direct beam irradiation, W/m^2
h	heat transfer coefficient, W/m^2 K
h_{out}	convection coefficient between cover and ambient, W/m^2 K
L	tube length, m
m	mass flow rate, kg/s
N	number of fins, –
Nu	Nusselt number, –
PEC	performance evaluation criterion, –
Q	heat flux, W
T	temperature, K
T_{sky}	sky temperature, K
u	fluid velocity, m/s
V	volumetric flow rate, L/min
V_{wind}	ambient air velocity, m/s
W	width, m
W_p	pumping work, W

Greek symbols

β	peripheral absorber angle of the fins, °
ΔP	pressure drop, Pa
ε	emittance, –
η_{th}	thermal efficiency, –
ρ	density, kg/m^3
φ	peripheral absorber angle, °

Subscripts and superscripts

a	aperture
am	ambient
co	outer cover
fm	mean fluid
in	inlet
max	maximum
min	minimum
out	outlet
r	receiver
ri	inner receiver
s	solar
u	useful
0	reference/smooth case

Abbreviation

PTC	parabolic trough collector

found the performance evaluation criterion (PEC) to be close to 1.3. This criterion indicates the ratio of the heat transfer enhancement through the Nusselt number to the pressure drop increase through the friction factor. More details about this index are given in Section 2.2. Moreover, the same research team [18] proved that the optimum dimples have deeper depth and narrower pitch. Moreover, Bellos et al. [19] examined the use of an internally modified absorber with converging-diverging geometry and the found 4.25% mean thermal efficiency enhancement. Wang et al. [20,21] studied the use of corrugated absorber tube with asymmetric and symmetric outward convex. They found 27% lower thermal strain and PEC close to 1.5 with the asymmetric design [20], while with the symmetric design [21] they found 13.1% decrease in the thermal strain and 8.4% increase in the effective heat transfer coefficient.

The next part of the literature studies is focused on the use of internally finned absorbers. The use of pin fin arrays in the internal part of the absorber has initially introduced by Gong et al. [22]. These researchers found that this technique is able to enhance the Nusselt number close to 10%. Moreover, the use of longitudinal fins in the internal part of the absorber has been examined by Bellos et al. [23–26]. In Refs. [23,24], the authors examined the use of eight internal rectangular fins with different thickness and length of operation with Syltherm 800. They evaluated the PTC under various operating conditions with many criteria. Finally, the optimum fin was found to have 10 mm length and 2 mm thickness. Also, the same research team has performed studies for operation with gas working fluids [25,26] and again they have indicated that the optimum fin length is equal to 10 mm. The next literature studies are focused on the use of internal fins in the lower part of the absorber. The internally finned tubes with helical fins have been examined by Muñoz and Abánades [27]. These researchers found 2% thermal efficiency enhancement in the PTC and they indicated that this enhancement is able to increase the 0.5% of the total power production in a Power plant. Reddy and Satyanarayana [28] examined the use of porous trapezoidal and circular fins in the lower part of the tube. Finally, they found the trapezoidal fins with 4 mm thickness to be the most reliable solution. Cheng et al. [29] examined unilateral longitudinal vortex generators in the absorber's lower part and they found a high reduction of the thermal losses.

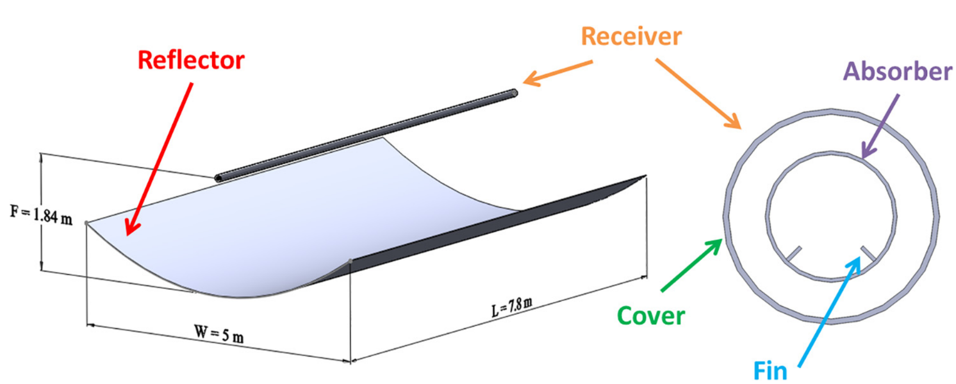

Fig. 1. The examined PTC and an example of internally finned absorber.

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