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Thermal performance characteristics of an absorber plate fin having temperature dependent thermal conductivity and overall loss coefficient

G. Jilani [a,*], Ciby Thomas [b]

[a] Department of Mechanical Engineering, National Institute of Technology Calicut, Kerala 673 601, India
[b] Department of Mechanical Engineering, Rajiv Gandhi Institute of Technology, Kottayam, Kerala 686 501, India

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ABSTRACT

The prime objective of the present numerical study is to analyze the thermal performance characteristics of an absorber plate fin of a sheet and tube type solar flat plate collector of fixed collector area. Considering temperature dependent thermal conductivity and overall loss coefficient and assuming cubic temperature profile along the tube, pseudo-transient form of two-dimensional, highly nonlinear partial differential equation governing the steady state temperature distribution in the absorber plate fin is solved using Alternating Direction Implicit finite difference scheme. Keeping ambient temperature, fluid inlet temperature and number of tubes fixed, numerical results are presented and discussed for wide range of values of aspect ratio of the absorber plate, fluid outlet temperature, overall loss parameter and solar flux. Finally, it is found that there exists an upper limiting value of solar flux beyond which increase in heat transfer rate is insignificant. Further, it is concluded that fin efficiency remains independent of aspect ratio of absorber plate whereas it increases significantly with decrease in overall loss parameter and decreases slightly with increase in fluid outlet temperature.

1. Introduction

Depletion of conventional energy sources and ever-increasing demand of energy have lead to exploration of renewable energy sources. Solar energy is one of the most promising and inexhaustible sources of renewable energy, which is capable of meeting the world wide demand of energy on a continuing basis. Solar flat plate collector is one of the solar energy collecting devices, which is generally used for supplying low grade thermal energy at temperatures less than 90 °C [1]. It is a special kind of heat exchanger that transforms solar radiation energy into internal energy of a fluid flowing through certain number of tubes [2,3]. Some of the important applications of solar flat plate collector can be found in domestic water heating, space heating, air conditioning and industrial heating processes [4]. Due to these important applications, quite a good number of theoretical and experimental studies on thermal performance of solar flat plate collector have been reported in the literature until recent past. Ong [5] numerically as well as experimentally evaluated the performance of a solar water heater operating under thermosyphon flow conditions by predicting mean system temperature and water mass flow rate. Grossman et al. [6] analytically carried out a two-dimensional heat transfer analysis of a solar flat plate collector made of two parallel conducting walls forming a channel. Garg et al. [7] analytically studied the effect of various design parameters and flow conditions of solar flat plate collector on its efficiency. Chiou [8] numerically analyzed the effect of nonuniform fluid flow distribution on the thermal performance of solar collector. Lund [9] presented a general differential equation for the heat transfer in solar flat plate collector by introducing shape factor accounting for various flow duct designs. Ghamari and Worth [10] experimentally investigated the effect of tube spacing on the cost effectiveness of a solar flat plate collector. Tiris et al. [11] analytically studied the effect of different fin designs on collector efficiency of a solar flat plate collector. Al-Nimr et al. [12] analytically obtained an expression for the optimum length of a solar flat plate collector by assuming constant thermal properties. Shariah et al. [13] numerically investigated the effect of thermal conductivity of the absorber plate on the performance of a thermosyphon solar water heater. Gorla [14] carried out a numerical study to predict the thermal performance

* Corresponding author. Tel.: +91 8089387505; fax: +91 495 2287250.
E-mail address: jilani@nitc.ac.in (G. Jilani).

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Nomenclature

a	constant in Eq. (3) (K^{-1})
a's	constants in Eq. (1)
A_p	aspect ratio of the absorber plate
b's	constants in Eq. (7)
b, c	constants in Eq. (4) (K^{-1}, K^{-2})
k	thermal conductivity of absorber plate material (Wm^{-1} K^{-1})
L	length of absorber plate (m)
n	number of tubes
q	heat transfer rate (W)
Q	dimensionless heat transfer rate
s	solar flux (W m^{-2})
T	temperature (K)
U	overall loss parameter
U_L	overall loss coefficient (W m^{-2} K^{-1})
w	half of the center to center distance between two tubes (m)
W	width of the absorber plate (m)
x, y	dimensional cartesian co-ordinates (m)
X, Y	dimensionless cartesian co-ordinates

Greek symbols

δ	thickness of the absorber plate (m)
ΔT_c	characteristic temperature difference
η	fin efficiency
η_{en}	energy efficiency
θ	dimensionless temperature

Subscripts

a	ambient
i	inlet
o	outlet
p	plate
t	total

of solar flat plate collector. Kazeminejad [15] numerically analyzed the temperature distribution in the absorber plate of a parallel flow solar flat plate collector. Eisenmann et al. [16] developed a correlation between collector efficiency factor and the material content of the absorber plate fin and tubes with the fin-and-tube geometry of a solar flat plate collector. Kundu [17] developed an analytical model for evaluating the thermal performance and optimum dimensions of an absorber plate fin having recto-trapezoidal profile. Alvarez et al. [18] experimentally as well as numerically analyzed the thermal performance of a solar flat plate collector of fin-and-tube type with a serpentine tube arrangement. Kundu [19] analytically as well as numerically studied the thermal performance of an absorber plate fin by considering the dependence of thermal conductivity and overall loss coefficient on temperature. Del Col et al. [20] experimentally as well as numerically studied the thermal performance of glazed solar flat plate collectors with a roll–bond absorber plate made of aluminium with different coatings. Ciby and Jilani [21] numerically studied the effect of temperature dependent thermal conductivity and overall loss coefficient on fin efficiency and total entropy generation rate in an absorber plate fin of a sheet and tube type solar collector. They concluded that the assumption of constant thermal conductivity and overall loss coefficient results in overestimation of fin efficiency which is found to be as high as 14.7%.

An up-to-date review of the relevant literatures presented above reveals that with exceptions of the studies of Chiou [8], Lund [9], Gorla [14], Kazeminejad [15], Alvarez et al. [18] and Del Col et al. [20], most of the studies are not essentially based on determination of two-dimensional temperature distribution in the absorber plate of the solar flat plate collector. While Chiou [8], Lund [9] and Gorla [14] assumed constant values of thermal conductivity and overall loss coefficient, the value of overall loss coefficient corresponding to absorber plate mean temperature was taken by Kazeminejad [15], Alvarez et al. [18] and Del Col et al. [20]. Although Kundu [19] assumed the dependence of thermal conductivity and overall loss coefficient on temperature, his study was essentially based on one-dimensional heat conduction in the absorber plate fin. Deriving motivation from some of these shortcomings of the previous investigations, the present study deals with thermal performance characteristics of a sheet and tube type solar flat plate collector of fixed collector area by employing two-dimensional differential formulation and by considering dependence of thermal conductivity and overall loss coefficient on temperature. Accordingly, assuming a cubic temperature profile along the tube, highly nonlinear, two-dimensional partial differential equation governing the steady state temperature distribution in the absorber plate fin is solved numerically using second-order accurate ADI (alternating direction implicit) finite difference scheme. Once the temperature field in the absorber plate fin is known, the values of heat transfer rate and fin efficiency are computed for wide range of values of involved thermo–geometric parameters and a parametric study is performed.

2. Mathematical formulation

Fig. 1 depicts the schematic of absorber plate-tube assembly of a sheet and tube type solar flat plate collector. The length, width, and

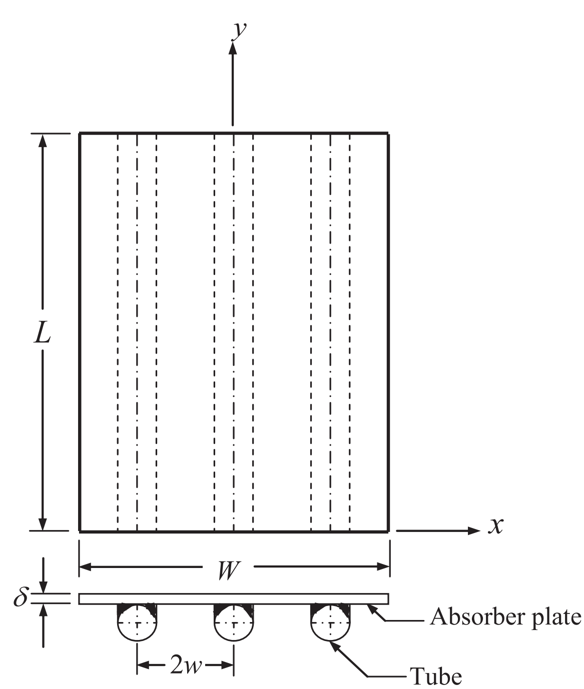

Fig. 1. Physical model.