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Effect of thermo-geometric parameters on entropy generation in absorber plate fin of a solar flat plate collector

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A B S T R A C T

The prime objective of the present numerical study is to obtain relatively more realistic values of performance parameters of a sheet and tube type solar flat plate collector of fixed collector area and number of tubes. Considering temperature dependent thermal conductivity and overall loss coefficient and assuming cubic temperature profile along the tube, pseudo-transient form of two-dimensional, nonlinear partial differential equation governing the steady state temperature distribution in the absorber plate fin is solved using Alternating Direction Implicit finite difference scheme. Numerical results are presented and discussed for wide range of values of aspect ratio of the absorber plate, overall loss parameter, and dimensionless fluid outlet temperature. On the basis of discussion of these results, it is concluded that assumption of constant thermal conductivity and overall loss coefficient results in overestimation of the total entropy generation rate with substantial error. It is also concluded that for any fixed set of values of dimensionless fluid outlet temperature and overall loss parameter, total entropy generation rate increases linearly with increase in aspect ratio of absorber plate. Further, it is found that total entropy generation rate increases with increase in overall loss parameter, the rate of increase being somewhat higher for lower values of overall loss parameter and a decrease in fluid outlet temperature results in an appreciable increase in total entropy generation rate.

1. Introduction

It is well known fact that the phenomenon of entropy generation occurs in various energy systems involving heat transfer such as solar flat plate collector wherein energy absorbed by the absorber plate is first conducted in the form of heat within the plate and finally dissipated to a fluid flowing through a certain number of tubes. Thus, entropy generation minimization in such systems will play a greater role in arriving at the optimal values of design parameters. During the past three decades, a number of studies on various thermal systems with the objective of minimization of entropy generation have been reported in the literature. A brief review of the literature which is relevant to the present study is presented below.

Garg et al. [1] theoretically studied the problem of optimization of fin and tube parameters of a flat plate collector and presented optimum collector configuration for six different geometries. Lund [2] carried out an analytical study on parallel flow flat plate solar collector and presented one universal design equation and a chart for determining collector efficiency factor. Ghamari and Worth [3] presented a simple method for determining the optimum spacing of tubes in a flat plate solar collector. Tiris et al. [4] analytically studied the effect of different fin designs on collector efficiency of a flat plate solar collector. Al-Nimr et al. [5] analytically obtained an expression for the optimum length of a flat-plate solar collector by assuming constant thermal properties. Shariah et al. [6] numerically investigated the effect of thermal conductivity of the absorber plate on the performance of a thermosiphon solar water heater. Torres-Reyes et al. [7] theoretically as well as experimentally obtained the optimal performance parameters of flat-plate solar collector for which entropy generation is a minimum. Saha and Mahanta [8] employed entropy generation minimization principle for obtaining theoretical models for isothermal and non-isothermal solar flat plate collectors. Mahanta and Saha [9] analytically as well as experimentally analyzed the problem of internal irreversibility in water heating solar flat plate collector. Yeh et al. [10] theoretically

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Nomenclature

a	constant in Eq. (3) (K^{-1})
a's	constants in Eqs. (6) and (13)
A_p	aspect ratio of absorber plate
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
N	dimensionless entropy generation rate
s	solar flux (W m^{-2})
$\dot{S}_{gen}$	entropy generation rate in the absorber plate (W K^{-1})
$\dot{S}'''_{gen}$	volumetric entropy generation rate in absorber plate (W m^{-3} K^{-1})
T	absorber plate 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)
θ	dimensionless temperature
θ_c	constant in Eq. (11)
ΔT_c	characteristic temperature difference

Subscripts

a	ambient
i	inlet
l	local
o	outlet
p	plate
t	total

studied the effect of aspect ratio on thermal efficiency of sheet and tube type solar collector. Kolenda et al. [11] employed the principle of minimum entropy generation for heat transfer through a plane wall and presented new forms of equations for steady state heat conduction. Kundu [12] analytically studied the thermal performance of an absorber plate fin by taking into account the dependence of thermal conductivity and overall loss coefficient on plate temperature and established the criterion for obtaining its optimum design. Aziz and Khan [13] analytically as well as numerically obtained minimum entropy generation temperature profiles for steady state heat conduction in a plane wall, a hollow cylinder and a hollow sphere. Considering both constant and variable thermal conductivity, these profiles were compared with classical results. Makhanlall et al. [14] numerically studied the problem of entropy generation due to convection and radiation heat transfer in the gas layer formed in the enclosure bounded by absorber plate and cover of a solar flat plate collector using FLUENT.

An up-to-date review of the pertinent literature presented above reveals that the theoretical and experimental studies of Torres-Reyes et al. [7], Saha and Mahanta [8], and Mahanta and Saha [9] are the only investigations reported in the literature which employ principle of minimum entropy generation for obtaining performance parameters of a solar flat plate collector. Nevertheless, these studies too are based on integral formulation and assumption of constant thermal conductivity and overall loss coefficient which are likely to produce erroneous results. Deriving motivation from some of these shortcomings of the previous studies, a serious attempt is made for determining somewhat more realistic values of performance parameters of a sheet and tube type solar flat plate collector for which entropy generation is a minimum. Accordingly, considering the effect of temperature dependent thermal conductivity and overall loss coefficient and assuming a cubic temperature profile along the tube, the steady, two-dimensional nonlinear partial differential equation governing the temperature distribution in the absorber plate is solved using second-order accurate Alternating Direction Implicit (ADI) finite difference scheme and Tri-diagonal Matrix Algorithm. Once the temperature field in the absorber plate fin is known, the values of local and total entropy generation rates are computed for wide range of values of involved performance parameters and a parametric study is performed.

2. Mathematical formulation

2.1. Physical model and assumptions

Fig. 1 depicts a schematic of a sheet and tube type solar flat plate collector having absorber plate of length L, width W, and thickness δ. The center-to-center distance between any two consecutive tubes is taken as $2w$ as indicated on the figure. Under steady state operation of the solar collector during certain period of the day, the solar energy absorbed by the absorber plate is first conducted within the plate resulting in entropy generation and finally dissipated to the fluid flowing through the tubes. As a result, the

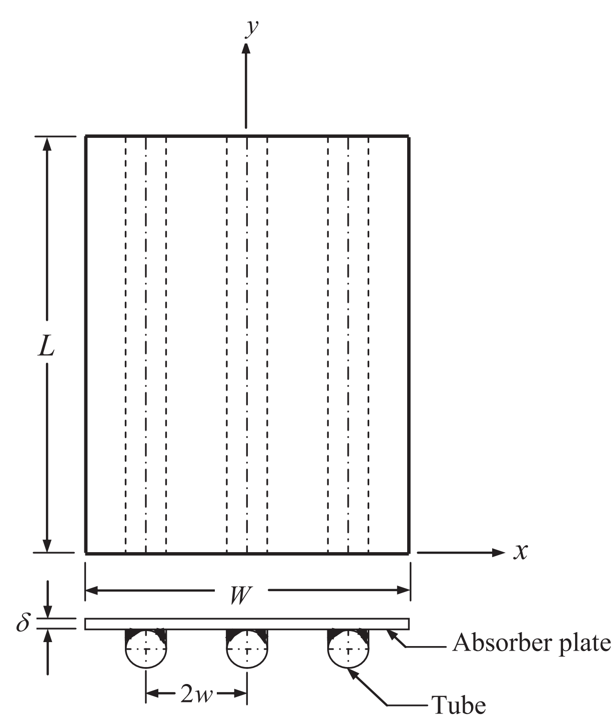

Fig. 1. Physical model.

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