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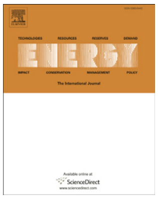

Exergetic performance evaluation of a single pass baffled solar air heater

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ABSTRACT

In this study, the exergetic performance of a baffled type solar air heater has been evaluated theoretically. A detailed parametric study was done to investigate the effect of variation of fin and baffle parameters, number of glass covers, bottom insulation thickness and inlet air temperature at different mass flow rates on the exergy efficiency. The results indicated that attaching fins and baffles at low mass flow rates can lead to noticeable enhancement of the exergy efficiency. The results revealed that the trend of variation of the energy and exergy efficiencies are not the same and the exergy efficiency is the chief criterion for performance evaluation. Increasing the baffles width, reducing the distance between baffles and increasing the number of fins are effective at low mass flow rates, but at high mass flow rates the inverse trend is observable, such that exergy efficiency reduces sharply. The results showed that exergy efficiency increases with increasing the solar radiation intensity. By adding the second glass cover the exergy efficiency enhances at low mass flow rates. Increasing the insulation thickness over an optimum value doesn't improve the exergy efficiency. Increasing the inlet air temperature increases the exergy efficiency especially at high mass flow rates.

1. Introduction

Solar thermal systems are used to utilize solar energy. Among different types, solar air heaters are widely employed due to simplicity in design, maintenance as well as low cost of materials required for construction. Nevertheless, in spite of these multiple benefits of solar air heaters, their fundamental deficiency is the low rate of heat transfer between absorber plate and flowing air due to unfavorable thermo-physical properties of air. Thus, scientists have focused their studies toward diverse performance improvement strategies. It has been shown that attaching fins and baffles on the absorber plate are an effective strategy used to enhance the heat transfer rate of solar air heater by extending the heat-transfer area and creating more turbulence [1–4]. In addition to using fins and baffles, many different studies have been done in terms of using absorber plate with several kinds of artificial roughness [5–9], using packed bed materials [10–13], utilizing corrugated surfaces such as V-corrugated and cross-corrugated surfaces [14–16] and external and internal recycling of the flowing air in different types [17–20]. Nonetheless, in contrast with desirable influence of all of these improvement strategies on the performance of solar air heaters which will eventually leads to higher efficiency, an adverse effect exist in which the higher pump work is required due to increased friction losses.

In order to balance the quality of energy gain and friction losses, the exergy analysis is more appropriate in comparison to the energy analysis [21,22]. This analysis can be considered as a fruitful manner to supplement, not to replace, the energy analysis [21]. Exergy (or availability) is the maximum work potential that can be obtained from a form of energy. Due to this fact that exergy analysis deals with irreversibility minimization or maximum exergy delivery, it usually provides more helpful results as well as more realistic sight of process. The exergy analysis has proved to be a powerful tool in the design, optimization, and performance evaluation of energy systems [23]. Hence, many attentions have been drawn by researchers to investigate the exergy based performance of solar air heaters.

Gupta and Kaushik [24] established the optimal performance parameters for the maximum exergy delivery in a flat-plate solar air heater. They investigated the effects of AR (aspect ratio), mass flow rate per unit area (G) and the channel depth (H) on the energy and exergy output rates of the solar air heater. They found that based on energy-based evaluation, the energy output rate increases

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Nomenclature

A_{baff}	total area of baffles (m^2)
A_{fin}	total area of fins (m^2)
$A_{\mathrm{fin,b}}$	base fins area (m^2)
A_{p}	area of air heater (m^2)
B	width of air heater (m)
C_{f}	conversion factor
C_{p}	specific heat (J/kg K)
D_{h}	equivalent diameter of channel (m)
Ex	exergy (W)
$\mathrm{Ex_s}$	exergy of solar radiation falling on glass cover (W)
$\mathrm{Ex_u}$	useful exergy gain ignoring pressure drop (W)
$\mathrm{Ex_{u,p}}$	useful exergy gain considering pressure drop (W)
f	coefficient of friction
h	enthalpy (J/kg)
h_{c}	convective heat transfer coefficient (W/m^2K)
h_{fin}	height of fins (m)
h_{r}	radiation heat transfer coefficient (W/m^2K)
h_{w}	wind heat transfer coefficient (W/m^2K)
H	height of channel (m)
I	solar radiation intensity (W/m^2)
IR	irreversibility (W)
k	thermal conductivity (W/m K)
L	length of air heater (m)
L_{baff}	distance between baffles (m)
$\dot{m}$	mass flow rate (kg/s)
n	number of fins
Nu	Nusselt number
Re	Reynolds number
S	entropy (J/K)
t_{fin}	thickness of fins (m)
T	temperature (K)
U_{b}	bottom heat loss coefficient
v	velocity of air through the channel (m/s)
V	wind speed (m/s)
W_{baff}	width of baffle (m)
W_{p}	pump work (W)

Greek symbols

α	absorptivity
δ	thickness (m)
ΔP	pressure drop (N/m^2)
ε	emissivity
η	energy efficiency
η_{baff}	baffle efficiency
η_{fin}	fin efficiency
η_{II}	exergy efficiency
μ	viscosity of air (Ns/m^2)
ρ	density of air (kg/m^3)
σ	Stefan–Boltzmann constant
τ	transmissivity
ϕ	dimensionless quantity defined by Eq. (4)
ψ	exergy efficiency of radiation

Subscript

a	ambient
f	fluid
g	glass cover
i	inlet
ins	insulation
m	mean value
o	outlet
p	absorber plate
pm	pump-motor
s	sun

with G and AR, and decreases with H and the inlet temperature of air. On the other hand, in terms of exergy-based evaluation criterion, they concluded that the energy output rate is not a monotonically increasing function of G and AR, and a decreasing function of H and inlet temperature of air. Singh et al. [25] analytically studied the exergetic performance of a solar air heater having discrete V-down rib roughness and compared the obtained results with a conventional flat-plate solar air heater. They investigated the effects of Reynolds number and rib–roughness parameters on exergetic efficiency. They stated that the exergy based criterion suggests use of the discrete V-down rib roughened solar air heater for the Reynolds numbers less than 18,000. Alta et al. [26] presented an experimental study based on energy and exergy analysis in order to determine the performance of three different types of flat-plate solar air heaters. Their results showed that the energy and exergy efficiencies of air heater with fins and double glass cover are higher. Esen [27] experimentally evaluated the energy and exergy efficiency of four types of flat-plate solar air heaters with and without obstacles on the absorber plate. He found that all of three solar air heaters with obstacle on the absorber plate show better performance in comparison with the one without obstacle. Moreover, his results indicated that the highest irreversibility happen for the solar air heater without obstacles, having the smallest value of efficiency. Öztürk and Demirel [28] carried out an experimental investigation on the performance of a solar air heater with packed bed material in its channel. They observed that the exergy efficiency varies from 0.01 to 2.16%, while the energy efficiency is in the range of 2.05–33.78%. In addition, the exergy and energy efficiencies of the packed-bed solar air heater enhances as the outlet air temperature increases.

So far, no efforts have been conducted in order to investigate the exergy based performance of a solar air heater with fins and baffles attached to the absorber plate. In this study, a theoretical model has been presented to evaluate the exergetic performance of an upward type single pass solar air heater with fins and baffles attached over absorber plate. The fins and baffles parameters, i.e. number of fins, width of baffles and distance between baffles as parametric variables as well as mass flow rate, solar radiation intensity have been varied to study their effect on the exergetic performance. For more complete analysis, the effect of number of glass covers, bottom insulation thickness and inlet air temperature have also been determined.

2. Theoretical analysis

The air heater considered consists of a flat glass cover and a flat absorber plate with fins and baffles attached. The schematic diagram of the air heater examined is shown in Fig. 1 and its top view is illustrated in Fig. 2. Combination of parallel flat absorber plate and glass cover makes a channel where the flowing air through the channel is heated by the absorbed solar radiation on the absorber plate. The bottom side of the absorber plate is well insulated.

2.1. Mathematical model

The one dimensional mathematical formulation in the flow direction in steady state condition has been considered. Also in writing