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Performance prediction of extended surface absorber solar air collector with twisted tape inserts

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ABSTRACT

The present work predicts the thermal and thermohydraulic performance of the extended surface absorber solar air heating collector equipped with twisted tape inserts of twist ratio $Y = 2$, 4, 6 and 8. A mathematical model has been formulated based on energy conservation equations of the various elements of the collector under consideration. The model is numerically solved using the MATLAB codes. Effects of mass flow rate, twist ratios and the solar intensity of the performance of the heater have been investigated. The results obtained are compared with the results of conventional and finned absorber solar air collector. Results conveyed that at mass flow rate of 0.025 kg/s, with increase in solar intensity from 500 W/m^2 to 1000 W/m^2, the thermal efficiency of the collector with twist ratio $Y = 2$ increases by 8.3%. Furthermore, integrating fins and twisted tape (FTTs) with the absorber plate, a maximum enhancement of 22.56% in the thermal efficiency has been achieved as compared to 11.49%, when only fins are attached. This maximum enhancement is observed with the tape with minimum twist ratio. Hence, the collector having absorber plate attached with fins and twisted tapes of twist ratio $Y = 2$ is the most efficient.

1. Introduction

Increased population, economic growth, industrialization and depletion of fossil-based energy sources have compelled the researchers to focus on unorthodox sources of energy. Among all the available choices, the solar energy is most important and promising source of energy because of its clean, free and abundant availability. Solar air collector is commonly used device to utilize the solar energy because of its simple design, low fabrication and operating cost. Solar air collector is a heat exchanger which collects the sun radiation and transfer heat to the air. The heated air is used in various applications like crop drying, timber seasoning, laundering and space heating etc. (Duffie and Beckman, 1980). However, it suffers from meager heat collection efficiency due to the poor heat transfer coefficient of air. Augmenting the heat transfer rate from the absorber surface to the air can improve the collector efficiency. This can be attained by improving the surface conductance (product of convective heat transfer coefficients and the heat transfer area). Various techniques have been invented for the heat transfer augmentation in engineering applications by inserting fins (Fudholi et al., 2013; Kabeel et al., 2016), fins with baffles (Ho et al., 2009; Yeh, 2012), wire coils (Chang et al., 2015; Garcia et al., 2007), twisted tape (Nanan et al., 2013) etc. in the passage of fluid flow. Bahrehmand et al. (2016) studied the single and double glass cover solar air collectors having fins with and without thin metal sheet. They concluded that for low Reynolds number, among the collectors without fins, the collector having a double glass cover and thin metal sheet is more efficient while for the higher Reynolds number the collector with single glass cover and thin metal sheet is more efficient. Also, the systems with fin and thin metal sheet are more efficient than other systems considered for all ranges of Reynolds number. Mohammadi and Sabzpooshani (2014) analyzed the performance of an upward type baffles solar air heater based on energy and exergy efficiency. Results showed that utilizing fins and baffles boosted the energy efficiency but hindered the effective efficiency at a high mass flow rate. They concluded that increasing the width of baffles and the decreasing distance between baffles in turbulent flow was not economically feasible. However, adding fins under external recycle at high flow rate is an effective option. Chabane et al. (2014) in their experiment on single pass solar air heater in the range of air flow rate of 0.012 kg/s and 0.016 kg/s found that integrating longitudinal fins to the absorber surface resulted in a substantial enhancement in the thermal efficiency. Naphon (2005) examined the thermal efficiency and the entropy generation rate of the double pass solar air heater with longitudinal fins. It was shown that the thermal efficiency and the entropy generation rate increased with the increase in air flow rate while the outlet air temperature decreased. Further, they mentioned that for a given air flow rate the thermal efficiency

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Nomenclature

A_c, , A_{ap}	area of collector and absorber plate respectively (m^2)
C	conversion factor
c_p	specific heat of air (J/kg K)
D_h	hydraulic diameter (m)
F_p	fin pitch (distance between two fins, m)
f	fanning friction factor
H	duct height (m)
H_f	fins height (m)
h_w	heat transfer coefficient due to wind flowing over the glass cover (W/m^2 K)
h_r	radiative heat transfer coefficient (W/m^2 K)
h_c	convective heat transfer coefficient
I	radiation intensity (W/m^2)
k	thermal conductivity (W/m K)
L	distance between glass cover and absorber plate (m)
L_1	length of the collector (m)
L_2	width of the collector (m)
$\dot{m}$	mass flow rate of air (kg/s)
N	number of fins
Nu	Nusselt number between absorber plate and glass cover.
p	pitch for 180° rotation of twisted tape (m)
Q_u	useful heat gain (W)
Re	Reynolds number
T	temperature (K)
t	thickness (m)
U_b	bottom heat loss coefficient (W/m^2 K)
V_w	wind velocity (m/s)
W	width of twisted tape
Y	twist ratio = p/w, dimensionless

Greek letters

α_{ap}, α_{gc}	absorptivity of absorber plate and glass cover respectively
ε_{ap}, ε_{bo},ε_{gc}	emissivity of absorber plate, bottom plate and glass cover respectively
σ	Stefan–Boltzmann constant ($5.67 \times 10^{-8}\,W\,m^{-2}\,K^{-4}$)
Δp	pressure drop (N/m^2)
ρ	density of air (kg/m^3)
η_{th}, η_{eff}	thermal and effective (thermohydraulic) efficiency respectively

Sub-scribes

gc	glass cover
ap	absorber plate
am	ambient
bo	bottom plate
fn	fin
ins	insulation
i	inlet
o	outlet

increased with increase in the number of fins and fins height.

Twisted tape inserts are widely used passive elements to augment the rate of heat transfer in various heat transfer applications including heat exchangers, air conditioning, and refrigeration systems (Man et al., 2014). These twisted tape inserts produce swirl flow, offer effectively longer fluid flow with separation and blockage of flow cross section due to repeated changes in surface geometry. This results in an increased flow velocity and better fluid mixing. The net effect is the enhanced

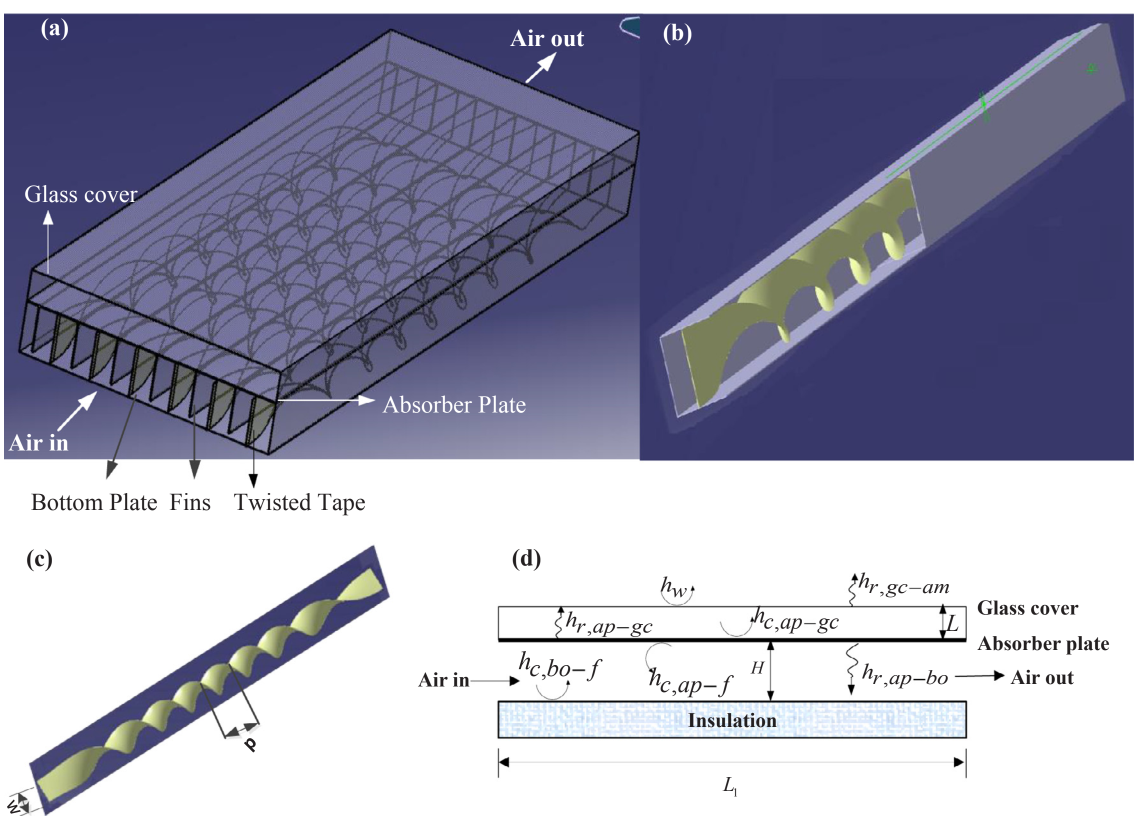

Fig. 1. Schematic diagram of (a) solar air heater with fins and twisted tape inserts, (b) twisted tape in the duct (c) geometry of twisted tape (d) various heat transfer coefficients linked with solar air heater.