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Investigation of effect of the circular ring turbulators on heat transfer augmentation and fluid flow characteristic of solar air heater

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ABSTRACT

This study presented effects of the circular ring turbulators (CRTs) having different pitch ratio and hole number on heat transfer augmentation in a new type solar air heater (SAH). The experiments have been performed by varying the parameters, pitch ratio (*PR*), hole number (*N*) and Reynolds number (*Re*) in a range of between 3000 and 7500 under solar radiation heat flux (*I*). The results obtained using CRTs compared with conventional plain tube. The experimental results have shown a significant enhancement in heat transfer on SAHs with CTRs. According to the experimental results, the higher heat transfer augmentation with CRTs inserted inside the tube in SAHs have been obtained for $PR = 2$ and $N = 2$. The best experimental results were found with ~229% heat transfer enhancement, ~5.8 times friction factor compared to a conventional plain tube and the thermal performance factor (η) was computed as ~1.83. In addition, statistical correlations for *Nu*, *f* and η were developed. These correlation results illustrated a good agreement with experimental results with ±10% deviation.

1. Introduction

Solar air heaters (SAHs) are solar energy utilization systems. The SAHs absorb the solar radiations and convert it into thermal energy at the absorbing surface. This energy can transferred to a fluid flowing through the collector. SAHs use as heat exchanger and are cheap. SAHs performed for heating, timber seasoning and agriculture drying [1]. To augment and improve heat transfer, active and passive methods used in absorber surface in SAHs, heat exchangers and gas turbine blades. Active method needs the extra power sources as jet impingement, fluid vibration and injection. The other method is passive method that does not require extra power sources and forces [2]. Passive enhancing method includes extended surfaces, selective surfaces, swirl flow devices, rough surfaces, fins of the absorber surface, baffles to augment of the heat transfer. In SAHs, the heat transfer enhancement can provided with creating turbulence flow. In the literature with motivation from the augmentation of the heat transfer, the artificial roughness having form of repeated ribs used for the turbulence flow in SAHs. Literature investigations have carried out to the heat transfer enhancement of solar air heater with roughness elements on the surface. Karwa and Chitoshiya [3] performed the thermal hydraulic performance in SAHs to improve of heat transfer enhancement with 60 V-down discrete rib roughness's. Singh et al. [4], worked with varying parameters, relative roughness height (e/D), width (W/w), pitch (p/e) and arc angle (a) of Reynolds number (*Re*) in the range of 2200–22,000 to augmentation of heat transfer. Benli [5] conducted the heat transfer characteristics in the SAHs with use of corrugated trapeze, reverse corrugated, reverse trapeze, and a base flat-plate collector. Bopche [6] investigated effects of the form of specially prepared inverted U-shaped turbulators of the absorber surface for the heat transfer improvement. Promvonge and Eiamsa-ard [7] studied the thermal performance of a tube with combined conical-ring and twisted-tape insert and compared the experimental results. Obtained results showed that the conical-ring and twisted-tape insert provides better overall enhancement than the smooth tube. The improvement of heat transfer coefficient and friction factor with multiple V-rib roughness in solar air heater duct was performed for relative roughness height (e/D), pitch (P/e), width (W/w) and angle of attack (a) by Hans et al. [8]. The heat transfer characteristics in a SAHs channel fitted with combined wavy-rib and Skullonget et al. [9], investigated groove turbulators for different rib-pitch to channel-height ratios (*PR*) with a single rib-to-channel height ratio (BR). Acır and Ata [10] performed the heat transfer improvement and fluid characteristics with using CRTs having various angle ratios. The augmentation of heat transfer with use of artificial roughness in the

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Nomenclature

A_p absorber plate area of collector, m^2
c_p specific heat of air, J/kg °C
D diameter, mm
d_h hole diameter, mm
d_i inner diameter, mm
f friction factor
h heat transfer coefficient, W/m^2 °C
I solar radiation, W/m^2
k thermal conductivity, W/m^2 °C
L length, mm
$\dot{m}$ mass flow rate, kg/s
N hole number
Nu Nusselt number
P fluid pressure, Pa
Pr Prandtl number
PR pitch ratio
Re Reynolds number
Q_u useful heat gain, W
T temperature, °C
U air velocity, m/s
$\dot{V}$ volumetric flow rate, m^3/s

Greek letters
ν kinematic viscosity, m^2/s
ρ fluid density, kg/m^3
η thermal performance factor

Subscripts
a air
b bulk
e environment
in inlet
out outlet
p plain tube
s surface
t turbulator

form 60° inclined discrete rib for various parameters viz. relative roughness height (e/D), pitch (P/e) and gap position (d/W) was examined by Kumar et al. [11]. Kongkaitpaiboonet al. [12], performed the thermal performance of a tube with CRTs. It observed that the CRTs provide better overall enhancement than the smooth tube. Sethi et al. [13] investigated the enhancement of heat transfer with dimple shaped roughness and empirical equations for Nusselt number and friction factor derived and compared. Jaurker et al. [14], investigated the effect of relative roughness height 0.0181–0.0363; relative roughness pitch 4.5–10.0, and groove position to pitch ratio 0.3–0.7 to improve of heat transfer. Hobbi et al. [15], studied the thermal performance analysis of a flat-plate solar collector with use of the twisted strip, coil-spring wire and conical ridges. Bhagoriaet al. [16], performed the thermal performance

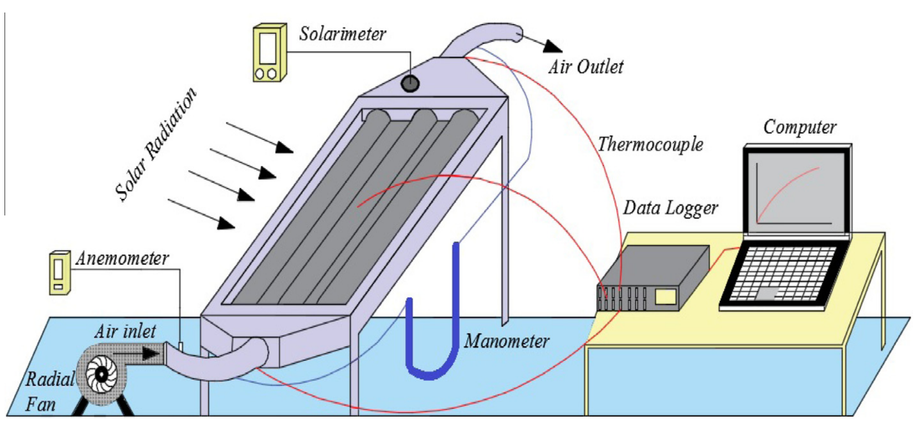

Fig. 1. Schematic view of experimental set-up.

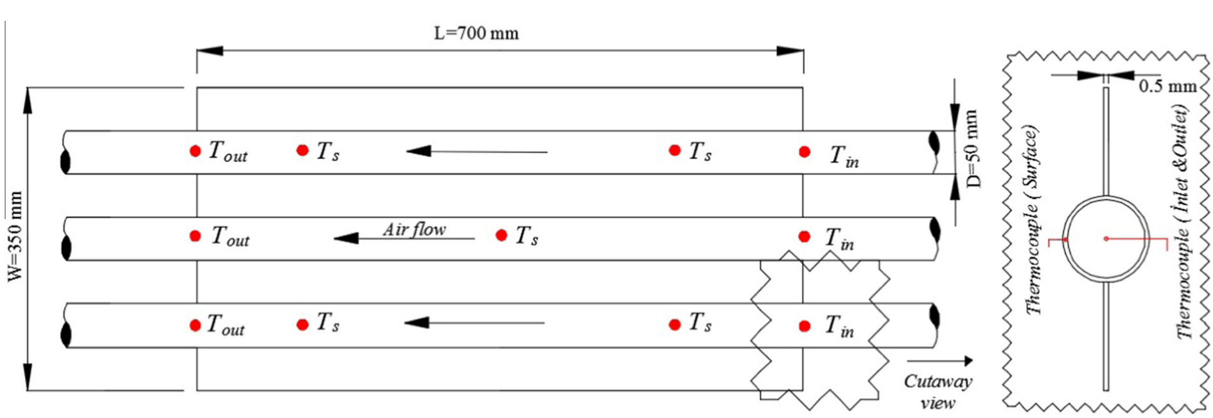

Fig. 2. Sectional view of absorber plate in experimental setup.