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Review and performance evaluation of roughened solar air heaters

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ABSTRACT

Solar air heater is an eco-friendly, economical and simple device which is used to harness solar energy for space heating, process heating and agricultural applications. The thermal performance of solar air heater can be improved by the application of artificial roughness on the underside of absorber surface. The heat transfer and friction characteristics of artificially roughened solar air heaters with different roughness geometries have been reviewed in this article. The article presents the authoritative account of the current progress on topic, discusses the previous developments, and throws light on the future directions. An attempt has been made to compare the performance of solar air heater having different types of roughness geometries based on correlations proposed in the literature. Thermo-hydraulic performance parameter (η), thermal efficiency (η_{th}), thermal efficiency improvement factor (TEIF), effective efficiency (η_{eff}), and exergetic efficiency (η_{ex}) are evaluated to gauge the performance of different roughness geometries.

1. Introduction

Energy in various forms has played an increasingly important role in worldwide economic progress and industrialization. Solar energy is considered a vital energy source to meet the increased energy demand for sustainable development and to control the global climate change. The freely available solar radiation is infinite, non-polluting resource of solar energy. The easiest way to bestow solar energy is to convert it into thermal energy by using solar air heaters. Among different types of solar thermal systems, solar air heaters are widely used systems due to lower cost and simplicity in design. Direct as well as diffused solar radiations are absorbed at the absorber plate and transferred to the air that flows through the passage underneath the absorbing surface. The thermal efficiency of solar air heaters is depending on the useful heat gain by the collector fluid. As the value of heat transfer coefficient for air is low which reduces the heat transfer rate and thus increases the heat loss to the surroundings. It is believed that the formation of laminar viscous sub-layer over the heated surface offers thermal resistance to heat transfer. The methodology of any passive technique of heat transfer enhancement is directed towards creating disturbance in the flow by using irregular surfaces. A popular passive technique of heat transfer enhancement is the application of artificial roughness on the underside of absorber plate in the form of ribs, grooves, dimples, winglets, baffles, twisted tapes, mesh wires, etc. The primary objective of using artificial roughness is to enhance the convective heat transfer rate at the cost of minimum power consumption. It has been shown that the application of artificial roughness and baffles on the absorber plate of solar air heater brings out enhancement in the heat transfer rate by creating additional turbulence near the heated wall. However, since the roughness elements act as turbulence promoters, their presence would incur additional friction losses that lead to a greater pumping power consumption. In order to mitigate the friction losses, the turbulence affected zone should be in close proximity of the heated surface, i.e., within the laminar sub-layer region.

The present study aims to provide up-to-date information on the artificially roughened solar air heaters that will be a boon for many upcoming researches. Moreover, this work encompasses the detailed review of notable roughness geometries used in solar air heaters with their underlying mechanisms of heat transfer fluid flow. The performance of distinguished roughness geometries are also evaluated on the basis of different performance parameters proposed in the literature. On the basis of detailed discussion on varied aspects of roughness patterns used to date, a new roughness geometry is proposed to be investigated in the near future.

2. Historical background of artificially roughened solar air heater

Solar collector is a simple, compact, and cost effective system to utilize the solar energy for heating applications by converting solar

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Nomenclature

A_p	Surface area of absorber plate/collector [m^2]
b	Effective width of roughness element [m]
C_p	Specific heat [J/kg-K]
D_h or D	Equivalent hydraulic diameter of duct [m]
e	Rib height [m]
e/D_h or e/D	Relative roughness height [dimensionless]
f	Friction factor [dimensionless]
f_r	Friction factor of roughened duct [dimensionless]
f_s	Friction factor of smooth duct [dimensionless]
G	Mass velocity of air [kg/s-m^2]
H	Collector depth [m]
h	Convective heat transfer coefficient [W/m^2-K]
h_w	Wind heat transfer coefficient [W/m^2-K]
I	Insolation [W/m^2]
N	Number of glass cover [dimensionless]
N_g	Number of gaps [dimensionless]
Nu	Nusselt number [dimensionless]
Nu_s	Nusselt number for smooth duct [dimensionless]
Nu_r	Nusselt number for roughened duct [dimensionless]
Nu_r/Nu_s	Nusselt number enhancement ratio [dimensionless]
p	Pitch of rib [m]
p/e	Relative roughness pitch [dimensionless]
p/P	Relative staggered pitch [dimensionless]
Q_u	Useful heat gain [W]
Re	Reynolds number [dimensionless]
W	Width of absorber plate [m]
W/w	Relative roughness width [dimensionless]
W/H	Duct aspect ratio [dimensionless]
d/x	relative gap distance [dimensionless]
k_a	Thermal conductivity of air [W/m-K]
k_i	Thermal conductivity of insulation [W/m-K]
L_{pg}	Air gap between absorber plate and glass cover [m]
$\dot{m}$	Mass flow rate of air [kg/s]
$(\Delta P)_d$	Pressure drop across duct [N/m^2]
P_m	Pumping power [W]
t_e	Thickness of collector edge [m]
T_a	Ambient temperature [K]
T_f	Mean bulk air temperature [K]
T_i	Inlet air temperature [K]
T_o	Outlet air temperature [K]
T_p	Mean plate temperature [K]
T_{sun}	Sun Temperature [K]
t_g	Thickness of glass cover [m]
t_p	Thickness of absorber plate [m]
ΔT	Temperature rise across duct [°C]
$\Delta T/I$	Temperature rise parameter [°C-m^2/W]
U_b	Bottom loss coefficient [W/m^2-K]
U_s, U_e	Side/Edge loss coefficient [W/m^2-K]
U_l	Overall heat loss coefficient [W/m^2-K]
V_w	Wind velocity [m/s]
TEIF	Thermal efficiency improvement factor [dimensionless]
d_d	Print diameter of dimpled obstacles [m]
e_d/d_d	Ratio of dimpled depth to print diameter [dimensionless]
P_d/e_d	Relative dimple pitch [dimensionless]
E_n	Net exergy flow [W]
E_s	Exergy inflow [W]
w/e	Staggered rib length to rib height ratio [dimensionless]
G	Gap width [m]
G/e	Relative gap width [dimensionless]
l/s	Relative length of grit [dimensionless]
C	Conversion efficiency [dimensionless]
F'	Collector efficiency factor [dimensionless]
F_R	Collector Heat removal factor [dimensionless]
C_p	Specific heat at constant pressure [J/kg-K]

Greek symbols

α	Flow angle of attack [Degree]
β	Collector tilt from horizontal [Degree]
μ	Dynamic viscosity of air [Ns/m^2]
ρ_a	Density of air at mean bulk temperature [kg/m^3]
η_{th}	Thermal efficiency of solar collector [dimensionless]
η_{eff}	Effective efficiency [dimensionless]
η_{ex}	Exergetic efficiency [dimensionless]
η_c	Carnot Efficiency [dimensionless]
η	Thermo-hydraulic performance parameter [dimensionless]
ϕ	Chamfer angle [Degree]
δ_i	Thickness of insulation [m]
σ	Stefan-Boltzmann constant [W/m^2K^4]
ε_g	Emissivity of glass [dimensionless]
ε_p	Emissivity of plate [dimensionless]
$(\tau\alpha)$	Transmittance-Absorptance product of glass cover [dimensionless]

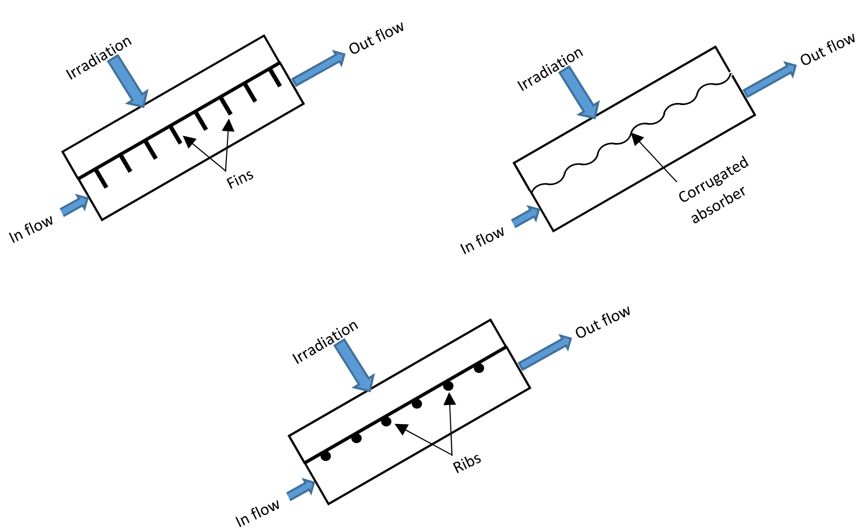

Fig. 1. Modified Solar air heaters.