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Analytical approach for evaluation of thermo hydraulic performance of roughened solar air heater

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ABSTRACT

Mathematical modeling and simulations are seen as vital methodologies to predict the thermal performance optimization of thermal systems. Solar air heater roughened with 20° angled rib is simulated using an algorithm developed in MATLAB to predict the optimal set of design and operating parameters. Correlations developed using second order polynomial are used for simulations. In the entire range of flow rates, the thermal efficiency of the roughened solar air heater is higher as compared to smooth duct. In fixed value of solar insolation, thermal efficiency increases with the increase in mass flow rate while effective efficiency decreases. The effective efficiency of the system increases with an addition in the number of glass covers and width of the duct. Thermal and effective efficiency increases with the increase in solar insolation. An increase in velocity increases the convective heat transfer coefficient of air, which reduces the useful heat gain by increasing the top losses which in turn affects the increase in effective efficiency for the rise in velocity in the solar air heater. The effect of mass flow rate, the number of glass covers, heat flux, velocity and variation in width of duct on thermal and effective efficiencies of roughened solar air heater are presented in the form of plots in the present study.

1. Introduction

A solar air heater is a thermal system which is used to convert solar energy into thermal energy. A wider application of solar air heater involves drying of agricultural and marine products, space heating and heating of buildings to maintain comfort in the winter season. Solar fish dryers are very useful for small fisherman groups. It has been noted that the performance efficiency of solar air heater is very low because of low convective heat transfer coefficient between absorber plate and flowing working fluid (air). The presence of a laminar viscous sub layer is the possible cause for low convective heat transfer coefficient. The resistance to heat transfer arises due to this laminar viscous sub layer is eliminated by providing artificial roughness on the underside of the absorber plate. Many researchers investigated the effect of various roughness geometries on heat transfer and friction characteristics in the solar air heater. The researchers have also developed mathematical algorithms as an analytical tool to simulate solar thermal systems and to optimize the thermal performance of solar air heater. The optimization technique helps to predict an optimized set of designs and operating parameters. Ahmad et.al. [1] experimentally investigated the effect of system and operating parameters, viz. geometry of

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Nomenclature

D	Equivalent or hydraulic diameter of duct, mm.
A_p	Surface area of the absorber plate, m^{-2}.
C	Conversion factor.
e	Rib height, mm.
F_0	Heat removal factor.
F_p	Collector efficiency factor.
G	Mass velocity of air, $kg\ s^{-1}\ m^{-2}$.
h	Heat transfer coefficient, $W\ m^{-2}\ K^{-1}$.
h_w	Convective heat transfer coefficient of wind, $W\ m^{-2}\ K^{-1}$.
W	Height of the duct, mm.
I	Solar insolation, $W\ m^{-2}$.
K	Thermal conductivity of air, $W\ m^{-1}\ K^{-1}$.
K_i	Thermal conductivity of insulation, $W\ m^{-1}\ K^{-1}$.
m	Mass flow rate, $kg\ s^{-1}$.
A_0	Cross section area of orifice, m^2.
W	Width of the duct, mm.
ΔP_0	Pressure drop across orifice meter, $N\ m^{-2}$.
ΔP_d	Pressure drop across duct test section, $N\ m^{-2}$.
C_p	Specific Heat of air, $J\ kg^{-1}\ K^{-1}$.
L_1	Inlet length of duct, mm.
L_2	Test length of the duct, mm.
L_3	Outlet length of duct, mm.
P	Pitch, mm.
U	Mean airflow velocity in the duct, $m\ s^{-1}$.
C_d	Coefficient of discharge for orifice meter.
u	Air flow velocity in x direction, $m\ s^{-1}$.
υ	Air flow velocity in y direction, $m\ s^{-1}$.
T	Air temperature, K.
Δh_0	Difference in levels of U-tube manometer, m.
T_o	Outlet temperature of air, K.
T_i	Inlet temperature of air, K.
T_p	Mean temperature of absorber plate, K.
Q_u	Useful heat gain, W.
T_p	Average plate temperature, K.
T_f	Average air temperature, K.
N	Number of glass covers.
L	Length of the test section.
ΔT	Bulk mean temperature of flowing fluid, K.
ΔT/I	Temperature rise parameter, $m^2\ KW^{-1}$.
U_L	Overall heat loss coefficient, $W\ m^{-2}\ K^{-1}$.
U_t	Top loss coefficient, $W\ m^{-2}\ K^{-1}$.
U_b	Bottom loss coefficient, $W\ m^{-2}\ K^{-1}$.
U_e	Edge loss coefficient, $W\ m^{-2}\ K^{-1}$.

Dimensionless parameters

e/D	Relative roughness height.
f	Friction factor.
f_r	Friction factor for rough surface.
f_s	Friction factor for smooth surface.
Nu	Nusselt number.
Nu_r	Nusselt number of rough surfaces.
Nu_s	Nusselt number of smooth surfaces.
Pr	Prandtl number.
P/e	Relative roughness pitch.
Re	Reynolds number.
W/H	Duct aspect ratio.
I	Turbulence intensity,.

Greek symbols

μ	Dynamic viscosity, $N\ s\ m^{-2}$.
ρ	Density of air, $kg\ m^{-3}$.
ρ_m	Density of manometer fluid, $kg\ m^{-3}$.
k	Turbulent kinetic energy, $m^2\ s^{-2}$.
β	Ratio of orifice diameter to pipe diameter.
υ	Kinematic viscosity, $m^2\ s^{-1}$.
θ	Tilt angle of manometer, degree.
K	Thermal diffusivity, $m^2\ s^{-1}$.
α	Chamfer angle.
ε_p	Emittance of plate.
ε_g	Emittance of glass cover.
η_{th}	Thermal efficiency.
η_{eff}	Effective efficiency.
η_{Tr}	Transmission efficiency.
η_m	Motor efficiency.
η_f	Pump efficiency.
$\tau\alpha$	Transmittance absorbtance product of glass cover.

Subscripts

THPP	Thermo hydraulic performance parameter.
r	Roughened.
s	Smooth.
CFD	Computational Fluid Dynamics.

wire screen matrices, insolation, inlet temperatures and mass flow rates on thermohydraulic performance characteristics of packed bed solar air heaters. Their study reported that relatively higher enhancement in the thermohydraulic efficiency has been found corresponding to higher values of temperature rise parameter. They suggested that it would be advantageous to use packed bed solar air heater when higher grade energy is required even when the insolation is relatively low. The effect of roughness and operating parameters on the thermal as well as the hydraulic performance of roughened solar air heaters was discussed and the thermohydraulic performance of roughened solar air heaters was compared with that of conventional smooth solar air heaters by Gupta et. al. [2]. Their study found that the systems operating in a specified range of Reynolds number shows better thermohydraulic performance depending upon the insolation. Thermohydraulic investigations on a packed bed solar air heater having its duct packed with blackened wire screen matrices of different geometrical parameters (wire diameter and pitch) were carried out by Mittal et. al. [3]. The thermohydraulic performance of a solar air heater was evaluated using a mathematical model and they reported that packed bed solar air heater is thermohydraulically