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A review of thermohydraulic performance of artificially roughened solar air heaters

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ABSTRACT

Solar air heaters form the major component of solar energy utilization system which absorbs the incoming solar radiation, converting it into thermal energy at the absorbing surface, and transferring the energy to a fluid flowing through the collector. The efficiency of flat plate solar air heater has been found to be low because of low convective heat transfer coefficient between absorber plate and the flowing air which increases the absorber plate temperature, leading to higher heat losses to the environment resulting in low thermal efficiency of such collectors. Artificial roughness in the form of repeated ribs is the most effective and economic way of improving the thermal performance of solar air heater. This paper presents an extensive review on the research carried out on artificial roughened solar air heater ducts. The objective of this paper is to review various studies, carried out on thermal as well as hydraulic performance of artificial roughened solar air heater ducts. The review presented in this paper will be useful for the researchers working in this area.

Contents

1. Introduction

Energy is a basic ingredient needed to sustain life and development. Energy is needed in various forms to fulfil our day to day requirements. Energy consumption rates of the people are directly

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Nomenclature

A_p	Area of heated plate, m^2
C_p	Specific heat of fluid at constant pressure, J/(kg K)
G	Mass velocity of fluid through the collector, kg/(m^2 s)
G_d	Gap or discrete distance, m
G_p	Gap or discrete position, m
G_r	Grashof number
G_P/Lv	Relative discrete or gap position
D	Hydraulic diameter of duct, m
e	Rib height, m
e/D	Relative roughness height
f_s	Friction factor of smooth duct
f	Friction factor of roughened duct
F'	Plate efficiency number
F_o	Heat removal factor
g	Gap or discrete width, m
g/e	Relative gap or discrete width
H	Depth of duct, m
h	Convective heat transfer coefficient, W/(m^2 K)
I	Solar intensity, W/m^2
k	Thermal conductivity of air, W/(m K)
L	Length of test section, m
L_v	Length of single v-rib, m
m	Mass flow rate, kg/s
Nu	Nusselt number of roughened duct
Nu_s	Nusselt number of smooth duct
P	Pitch of the rib, m
P/e	Relative roughness pitch
Pr	Prandtl number
Q_u	Useful heat gain rate, W
Re	Reynolds number
Ra	Rayleigh number
T_f	Average temperature of air, K
T_s	Temperature of the sun, K
T_i	Initial temperature of air, K
T_o	Final temperature of air, K
T_p	Average plate temperature, K
Ub	Bottom loss coefficient, W/(m^2 K)
Ue	Edge loss coefficient, W/(m^2 K)
U_L	Overall heat loss coefficient, W/(m^2 K)
Ut	Top loss coefficient, W/(m^2 K)
V	Velocity of air, m/s
W	Width of duct, m
w	Width of V-rib, m
W/w	Roughness width ratio
ΔT	Temperature difference
$\Delta T/I$	Performance parameter, K m^2/W

Greek letter symbols

α	Angle of attack, degrees
β'	Collector tilt angle, degrees
η	Thermo-hydraulic performance parameter
ρ	Density of air, kg/m^3
ρ_m	Density of manometric fluid, kg/m^3
μ	Dynamic viscosity of air, N s/m^2
$\tau\alpha$	Absorbance–transmittance product
η_{th}	Thermal efficiency
η_{eff}	Effective efficiency

related to the prosperity or the standard of living. Two types of energy resources are available: conventional and non-conventional [1,2]. Conventional energy resources such as fossil fuels (coal, crude oil and natural gas) are limited in amount. Total energy in recoverable conventional energy resources is estimated to be around 30–35 Q ($1Q = 10^{18}$ kJ) while the global energy consumption rate is roughly 0.4–0.5 Q/yr. Hence conventional energy resources are roughly estimated to last for 75–85 years. This awareness of the limited nature of conventional energy resources gave rise to the search of alternate energy resources. Non-conventional or alternate energy resources can be divided into two groups, namely, renewable and non-renewable resources. Renewable resources are those which have a short period of renewal (upto a few years) such as solar energy, wind energy, biomass energy, hydroenergy, ocean and tidal energy. Solar energy is the most promising of all these alternatives [3,4]. Solar energy has the greatest potential among all the sources of renewable energy and even a small amount of this renewable source of energy is sufficient to meet the total energy demand of the world. If we can use 5% of this energy, it will be 50 times what the world will require. Solar energy is readily available, well distributed and inexhaustible for all practical purposes, and has no polluting effects upon the environment when converted and utilized. Solar air heaters, because of their inherent simplicity are cheap and most widely used collector devices. Solar air heaters are being used for many applications for low and moderate temperatures. Some of these are space heating, crop drying, drying of concrete and solar dryer [1,2,5,6,7].

The use of artificial roughness on the underside of the heated plate can substantially enhance the thermal performance of the solar air heater due to increase in convective heat transfer coefficient from the plate to air. Surface roughness is one of the first techniques to be considered as a means of augmenting forced convection heat transfer. In order to attain higher convective heat transfer coefficient it is desirable that the flow at the heat transfer surface should be turbulent. However, the turbulence created in the core can increase the fan power exorbitantly. It is therefore, desirable that the turbulence must be created only very close to the heat transfer surface, i.e. in the laminar sub-layer only, where the heat exchange takes place. However, as pointed out above, it is necessary that while creating turbulence to break the laminar sub-layer, the core flow should not be disturbed so as to avoid excessive losses. This can be achieved by using artificial roughness with roughness height being such that it does not project into the core but is of the height that just project out of laminar sublayer. Numbers of experimental investigations involving roughness elements of different shapes, sizes and orientations with respect to flow direction have been carried out in order to obtain an optimum arrangement of roughness geometry. Hans et al., [8] carried out a review of roughness geometry in solar air heater ducts. They discussed different roughness geometries used in solar air heater ducts and explained the concept of artificial roughness, effects of various roughness parameters on the flow pattern and also briefly discussed and reviewed the roughness geometries used in solar air heater ducts. The objective of this paper is to review various studies, in which different artificial roughness elements are used to enhance the heat transfer rate with little penalty of increase in friction losses and also discuss the thermo-hydraulic (thermal as well as hydraulic) performance of artificial roughened solar air heater ducts.