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Effect of wavelength and amplitude on the performance of wavy finned absorber solar air heater

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A B S T R A C T

A theoretical study for computing the effects of amplitude and wavelength of the wavy fin on the thermal performance of a single pass flat plate solar air heater is presented. A C^{++} program code with an iterative solution procedure has been developed to solve the governing energy equations and to evaluate the mean temperatures of the collector. The effect of mass flow rate, amplitude and wavelength variation of the wavy fin on the thermal and thermohydraulic performance of present solar air heater was investigated. For the entire range of mass flow and a constant value of amp = 0.75 cm, thermal and thermohydraulic efficiency decreases with increase in wavelength. Also, for constant value of wavelength = 7 cm, thermal efficiency increases with increase in amplitude whereas thermohydraulic efficiency increases up to the mass flow rate of 0.06 kg/s, beyond that thermohydraulic efficiency decreases. A comparison for the results of the present model is done with the plane solar air heater as well as the experimental results available in the literature. The results show a great enhancement in the thermal and thermohydraulic performance with the modified solar air heater.

1. Introduction

Flat plate collectors are very useful tool for requiring energy delivery at low to moderate temperature, i.e, up to about 100 °C above ambient temperature. They can be used for a lot of purposes including crop drying, food dehydration, space heating and thermal storage [24,25]. Flat plate collectors have simple characteristics, low initial cost, ease of fabrication and maintenance and not requiring continuous orientation.

A solar air heater is a device that transforms insolation into thermal energy of flowing air. Due to the lower thermophysical properties of air it leads to lower performance of air flat plate collectors. The performance can be enhanced by using packing of material, turbulence promoters, extended surfaces etc. without increasing size.

Several researchers have investigated the solar air heaters numerically and experimentally to enhance the performance. Thermal performances were obtained for double flow solar air heater with aluminium cans staggered as zig-zag, arranged and without cans on absorber plate and the highest efficiency was achieved at higher mass flow rate for the cans staggered as zig-zag on the absorber plate [1]. In a study, double glass cover with fins, single glass cover with fins and double glass cover solar air heaters were investigated for highest temperature rise [2]. Double pass solar air heaters using two, four and six transverse fins were investigated and the maximum efficiency was achieved with maximum number of fins (six) for same mass flow [3]. Analytical and experimental investigations on double pass finned plate solar air heater showed the significant performance enhancement in v-corrugated plate [4]. Five different surface shapes of solar collectors were analyzed to determine their performance [5]. Also, single pass air heater with fins and baffles attached over the absorber plate showed better thermal efficiency but the reduced effective efficiency [6]. In an another study, five configurations of solar air heaters were analysed to predict their performances [7]. Finned type of solar air heater holds a good agreement among experimental and theoretical analysis [8]. The collector efficiency of solar air heater with fins showed better efficiency when used double flow with fins rather than single flow at the same mass flow [9]. Rectangular fins mounted in staggered rows respectively under the

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Nomenclature

A_c	Collector area (m^2)
A_{fr}	Minimum free flow area (m^2)
amp	Amplitude of wavy fin (cm)
A_p	Area of absorber plate (m^2)
A_r	Total heat transfer area (m^2)
C	Constant (defined by equation (19))
C_p	Specific heat at constant pressure (J/kgK)
D_h	Hydraulic diameter (m)
f'	Constant used to evaluate top loss coefficient
G	Mass velocity (kg/s/m^2)
h	Spacing between absorber plate and bottom plate (m)
h_e	Effective heat transfer coefficient (W/m^2K)
h_f	Height of fin (m)
h_{fb}	Convective heat transfer coefficient between air and bottom plate(W/m^2K)
h_{ff}	Convective heat transfer coefficient between air to air(W/m^2K)
h_{fp}	Convective heat transfer coefficient between air and absorber plate(W/m^2K)
h_r	Radiative heat transfer coefficient(W/m^2K)
H_w	Wind heat transfer coefficient (W/m^2K)
I	Intensity of Solar radiation (W/m^2)
k_a	Thermal conductivity of air (W/mK)
k_{GI}	Thermal conductivity of G.I sheet (W/mK)
k_{ins}	Thermal conductivity of insulating material (W/mK)
L	Length of the collector/Absorber plate (m)
L′	Actual length of wavy fin (m)
M	Quantity defined by equation (8)
n	Number of fins
N_{gc}	Number of glass covers
p	Porosity
P_m	Mechanical Power (W)
Q_u	Useful thermal energy gain (W/m^2)
S	Absorbed Solar Energy, $I(\tau\alpha)_e$ (W/m^2)
T_a	Ambient Temperature (°C)
T_{fi}	Inlet air temperature (°C)
T_{fo}	Outlet air temperature (°C)
T_{pcal}	Calculated Mean plate temperature (K)
T_{pm}	Mean plate temperature (K)
T_{sky}	Sky temperature (K)
U_b	Bottom loss coefficient (W/m^2K)
U_L	Total loss coefficient (W/m^2K)
U_t	Top loss coefficient (W/m^2K)
V	Average air velocity (m/s)
V_w	Wind velocity (m/s)
W	Wavy fin spacing (cm)
W	Width of the collector/Absorber plate (m)

Dimensionless numbers

Re	Reynolds number
Pr	Prandtl number
Nu	Nusselt number
j	Colburn j −factor
f	Friction factor
F′	Collector efficiency factor
F_R	Collector heat removal factor

Greek letters

$\dot{m}$	Mass flow rate (kg/hr)
ΔP	Pressure drop (N/m^2)
ρ	Density of air (kg/m^3)
θ	Collector tilt angle (°)
σ	Stefan-Boltzmann Constant ($5.67*10^{-8}$ W/$m^2K^{4)}$
ε_C	Emissivity of glass cover (0.88)
η_{eff}	Effective efficiency
η_f	Fan efficiency (0.65)
δ_{ins}	Thickness of insulation (m)
η_m	Motor efficiency (0.88)
ε_P	Absorber plate emissivity(0.95)
η_{Th}	Thermal efficiency of power plant (0.35)
η_{th}	Thermal efficiency of solar air heater
η_{tr}	Transmission efficiency (0.92)
β	Area enhancement factor
$(\tau\alpha)_e$	Effective transmittance absorptance product
Φ_f	Fin efficiency
λ	Wavelength of wavy fin (cm)
δ_f	Thickness of fin (m)

absorber plate or on the channel back have been tested [10]. Enhanced performance and entropy generation with the increase in height and number of fins have been predicted with the mathematical model of double pass solar air heater [11]. For the same mass flow rate, the highest efficiency has been found with double pass finned solar air heaters [12]. Investigation on single and double pass solar air heater with transverse fins and a packed wire mesh layer achieved highest efficiency with double pass [13]. In many studies wavy fins were tested in heat exchangers [14–18]. The available configurations of finned absorbers and their findings are listed in Table 1. These literatures revealed that solar air heater with various augmented surfaces have been developed to improve the performance of a solar air heater. Various fin geometries such as plain fins, wavy fins, perforated fins; louver fins etc., which besides increasing the surface area density also improve the convective heat transfer coefficients. Among these, wavy fins are extremely interesting for their simplicity of manufacture and prospective for enhanced thermohydraulic performances. Addition to this, the efficiency is affected by the distribution of air at as much as possible area. So, the wavy fin amplitude and the wavelength are the most important factor for air distribution that affects the overall performances. In the view of this, the present work has been chosen to study the impact of variation of wavelength and amplitude of wavy fin on the thermal and thermohydraulic performances of solar air heater.

Therefore, in this paper, theoretical studies of solar collectors are presented with different shapes of wavy fins, placed individually in the air channel duct. These fins are oriented along the flow of air and below the absorber plate. The different wavelength and amplitude of the wavy fin has been studied for the different mass flow rates. The significant impact of variation of wavelength and amplitude of wavy fin has been found on the performances of solar