Energy and Buildings 155 (2017) 296–307

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Replication Studies

Numerical investigation of rectangular fin geometry effect on solar chimney

Seyedeh Sahar Hosseini, Abas Ramiar*, Ali Akbar Ranjbar

Faculty of Mechanical Engineering, Babol Nooshiravani University Technology, Iran

ARTICLE INFO

Article history:
Received 10 April 2017
Received in revised form 2 August 2017
Accepted 8 September 2017
Available online 9 September 2017

Keywords:
Solar chimney
Rectangular fins
Solar radiation
Discontinuous fins

ABSTRACT

In this paper, the performance of solar chimney as a natural convection solar air heater with longitudinal rectangular fins is numerically investigated. Heat transfer and turbulent flow in a three-dimensional domain are investigated under steady state condition and the finite volume method is used to discretize the equations. Numerical results are verified by comparing with existing experimental results in the literature and a good agreement is achieved. Effects of rectangular fins on air temperature and mass flow are discussed and the results are compared with that of a flat absorber. Furthermore, ambient temperature, solar radiation intensity and geometry parameters of the channel and rectangular fins such as depth of the channel, depth, and width of fins are checked. By analyzing the results, appropriate channel dimensions are suggested to yield better performance in the solar chimney. Finally, discontinuous fins in the solar chimney with different interruption gaps are examined. Utilizing discontinuous fins with appropriate interruption gaps may enhance the performance of solar chimney in comparison with continuous fins.

1. Introduction

Due to the infinite source of solar energy and the lack of fossil energy, the solar energy has been increasingly considered in recent decades. The solar air heater is the simplest method to convert solar energy to thermal energy [1]. Space heating and cooling, drying of agricultural and industrial products, and air conditioning are some applications of solar air heaters [2]. The solar air heaters are simple, cheap, and clean. However, because of poor air thermo-physical properties, solar air heaters have a small thermal efficiency [3]. So their thermal efficiency should be improved with different ways such as phase change material, porous media, tabulators and longitudinal fins. Solar chimneys and trombe walls are kinds of solar air heaters which are being used for building's natural ventilation. There are limited works in the literature about the numerical and experimental study of natural convection solar air heaters.

Gao et al. [4] numerically investigated natural convection in solar air heater with the sine-wave absorber. Their results represented that the highest heat transfer coefficient happens in the inclination angle of about 60°. Mathur et al. [5] conducted an experimental investigation to study mass flow rate in different inclination angles, air gaps, and inlet heights for natural ventilation. It has been observed that the maximum mass flow rate was reached in the angle of about 45°. They showed that increasing the air gap and inlet height results in enhancing the mass flow rate. Harris and Helwig [6] numerically studied the effect of some parameters such as inclination angle, doubling the glass and utilizing a low-emissivity coating on the solar chimney. Optimum angles were obtained about 67.5° which shows 11% increase in mass flow rate in comparison to the vertical angle. Double glazing and low-emissivity coating improved the performance of solar chimney.

Hatami and Bahadornejad [7] experimentally investigated different cases of solar air heaters. Air could flow between the absorber plate and glass cover or between two glass plates or in the enclosed space. A New correlation for Nusselt number was suggested in their paper. It has been concluded that the efficiency of solar air heater with double-glass is better than that of a single-glass heater. Bassiouny and korah [8] studied numerically and analytically the effect of inclination angle and solar radiation intensity on flow pattern and air ventilation. The optimum angle has been achieved between 45° and 70° for the latitude of 28.4°. Their result denoted that the air temperature and mass flow rate grow as solar radiation intensity increases. parameters such as solar radiation intensity, ambient temperature, channel length, air gap, and inclination angle were also extensively studied in the literature [9–14].

Effect of longitudinal fins on performance of solar air heaters with natural convection is rarely studied, some of which are

* Corresponding author at: Faculty of Mechanical Engineering, Babol Noshirvani University of Technology, P.O. Box 484, Babol, Iran.
E-mail address: aramiar@nit.ac.ir (A. Ramiar).

https://doi.org/10.1016/j.enbuild.2017.09.017
0378-7788/

Nomenclature

A	Depth ratio
A_{ab}	Absorber surface area (m^2)
A_g	Glass surface area (m^2)
B	Width ratio
Cp	Specific heat capacity (J/Kg K)
D_{ch}	Depth of channel (m)
g	Gravitational acceleration (m/s^2)
I	Monthly average of solar radiation (W/m^2)
k	Turbulent kinetic energy (m^2/s^2), thermal conductivity (w/m.K)
L	Length of chimney (m)
$\dot{m}$	Mass flow rate (Kg/s)
P	Local fluid pressure (Pa)
P_∞	Ambient of pressure (Pa)
Pr	Prandtl number
Ra	Rayleigh number
T	Local fluid temperature (K)
T_a	Ambient temperature (K)
T_s	Sky temperature (K)
T_{out}	Outlet temperature (K)
T_{int}	Inlet temperature (K)
u	Average of velocity in x direction
v	Average of velocity in y direction
w	Average of velocity in z direction
w_{ch}	Width of channel between fins(m)
w_{fin}	Width of fins (m)
x, y, z	Cartesian coordinate (m)

Greek symbols

α	Thermal diffusivity (m^2/s)
β	Coefficient of thermal expansion (1/K)
ε	Dissipation of kinetic energy (m^2/s^2)
μ	Dynamic viscosity (Kg/m s)
μ_t	Turbulent viscosity (Kg/m s)
υ	Kinetic viscosity (m^2/s)
υ_t	Eddy viscosity (m^2/s)
ρ	Density (Kg/m^3)
η	Thermal efficiency

described below. An experimental and numerical analysis was performed by Pakdaman et al. on natural convection solar air heater with longitudinal rectangular fins. They reported that increasing the area of heat transfer improves the efficiency of solar air heater. A 66% increase in heat transfer area caused the heat transfer to improve approximately 20%. Effects of solar radiation and ambient temperature on system performance were observed. A new correlation for the Nusselt number has been introduced which was in good agreement with other Nusselt numbers presented in previous studies [15]. Chabanne et al. [16] performed an experimental study to investigate the effect of the internal rectangular fin on solar air heater. They confirmed that fins improve the thermal performance of solar air heater. Bahremand and Ameri [17] mathematically checked geometry parameters in solar air heater with rectangular and triangular fins and single or double glass covers as well. Their results showed that the efficiency and air temperature in solar air heater with two glass covers and triangular fins are higher than the other solar air heaters. Aboghrara et al. [18] experimentally investigated efficiency and outlet temperature of a solar air heater with jet impingement on flat and wavy plate absorber and compared their efficiency. The investigation represented that the efficiency of solar air heaters with wavy plate was about 14% more than solar air heater with flat plate. Gilani et al. [19] studied solar

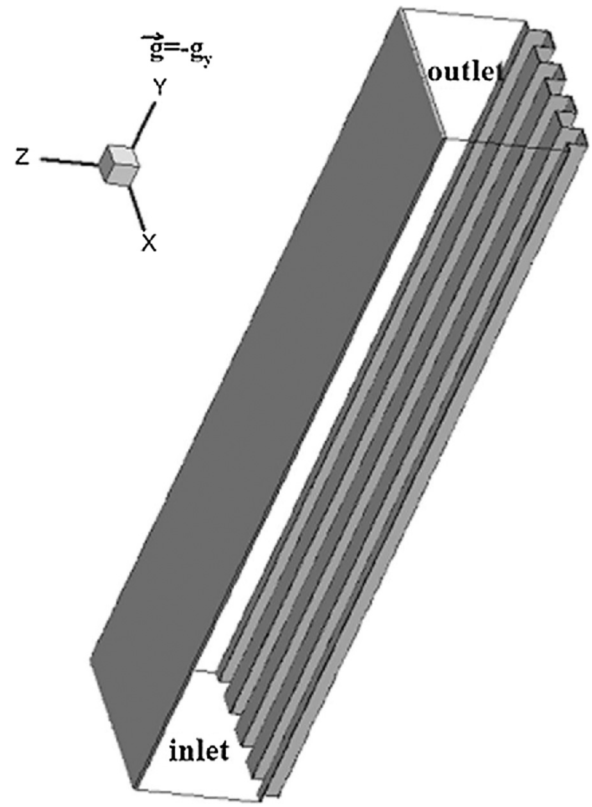

Fig. 1. Geometry of the studied problem (3D).

air heaters by conical pin protrusions on the absorber to enhance low performance of natural convective solar air heaters. They used small tabulators on absorber to break viscous layer of air. Pins with different pitches (16 mm, 32 mm and 48 mm) and different heights (2 mm, 3 mm and 4 mm) were tested. The results showed that pin with 16 mm pitch and 4 mm height was better than other sizes. The best inclination angle was about 45° in Malaysian region.

Fins increase heat transfer area and improve the thermal performance of solar air heaters. Effect of fins has rarely been investigated in solar air heaters with natural convection. Although some papers have studied the effect of fins on the performance of solar air heaters, the studies are limited to a fixed dimension of fins. Therefore, in this paper, the effect of solar radiation, ambient temperature, and geometry parameters of fins such as depth and width of fins are numerically checked.

2. Numerical model

Three-dimensional turbulence air flow in the middle section of solar chimney with longitudinal rectangular fins is simulated by CFD code.

Solar chimney with rectangular fins is shown in Fig. 1.

Important parameters of the fins and channel are defined as:

$$A = \frac{D_{ch}}{W_{ch}} \tag{1}$$

$$B = \frac{W_{fin}}{W_{ch}} \tag{2}$$

A and B are depth and width ratio respectively. W_{fin}, W_{ch} and D_{ch} are width of the fin and channel and depth of the fin respectively as shown in Fig. 2.

Dimensions of the geometry are summarized in Table 1.