Solar Energy 162 (2018) 278–288

Contents lists available at ScienceDirect

Solar Energy

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

Experimental analysis and numerical modeling of solar air heater with helical flow path

Ali Heydari[a,*], Mehdrad Mesgarpour[b]

[a] Energy and Sustainable Development Research Center, Semnan Branch, Islamic Azad University, Semnan, Iran
[b] Department of Mechanical Engineering, Semnan Branch, Islamic Azad University, Semnan, Iran

A R T I C L E I N F O

Keywords:
Helical path
Solar air heater
Experimental analysis
Numerical modeling

A B S T R A C T

In the present research, effect of helical channeling on the performance of a solar heater is investigated both experimentally and numerically. The innovation of this research is designing a triangular cross-section channel, in such a way to establish a helical air flow through the air heater, in which the flow exchanges heat with the bottom and the top of the absorber plate. Once finished with measuring various thermal parameters of the system experimentally at two different flowrates, overall heat transfer coefficient and thermal efficiency of the system are calculated. It is followed by numerical modeling of the flow inside the air heater which has 3% maximum error compared to experimental data. The results indicate that, the average thermal efficiency of a double pass solar air heater with helical channeling is estimated 14.7% higher than simple duct and 8.6% higher than double pass-finned solar air heaters with the same mass flow rate. For the mass flow rate of 0.026 kg/s the day average of overall heat transfer coefficient and thermal efficiency of the system are obtained 65.14 W/m^2 K and 55.4% respectively. Numerical aspect shows that Vortexes are formed at turning points inside the air heater, increasing heat exchange and pressure drop locally. Furthermore, as far as the application of the air heater in dryers is concerned, one can use nitrogen rather than air to maintain quality of the product while achieving the same heat exchange performance.

1. Introduction

One of the most applications of solar energy is to produce warm air for domestic and industrial uses. In industrial applications, this warm air can be used for preheating furnaces or evaporating in dryers. On the other hand, in construction industry, it can be adopted to provide a portion of heating requirements of interior spaces. On this basis, during the recent years, an extensive deal of research has been done on solar heaters. In these pieces of research, performance of various types of solar heaters has been investigated, ending up with remarkable advances in this scope.

Among other research works performed in this regard, one can refer to the work by Forson et al. (2003). In this research, two air heaters are considered and compared, namely a single-chamber one and a dual-chamber one. Of the concluded findings, one can refer to the effect of the number of collectors, mass flowrate, and relative humidity on thermal performance of the air heaters. Saini and Verma (2008) investigated a solar air heater equipped with artificial roughness in the form of arced parallel wires. They considered the effect of various parameters such as roughness height and arc angle on Nusselt number and friction coefficient at various Reynolds number in the range 2000–17,000. Accordingly, maximum increase in Nusselt number (by 3.8 folds) was obtained as a relative roughness height of 0.0422 and arc angle of 0.33. Nevertheless, the corresponding increase in the friction coefficient was only 1.75-fold. Aharwal et al. (2009) investigated heat transfer and friction properties of a solar air heater equipped with transverse and isolated ribs. Accordingly, maximum increase in heat transfer occurred in the relative position of 0.25, relative width of 1.0, relative roughness angle of 8.0 at an angle of attack of 60° and relative roughness height of 0.037. Furthermore, maximum friction coefficient was achieved for crossing discrete ribs with a relative roughness slope of 8.0.

Kumar et al. (2009) experimentally studied heat transfer and friction properties of a solar air heater equipped with isolated W-shaped roughness on wide wall of a solar air heater at an aspect ratio of 1:8. The parameters considered by them included Reynolds number, relative roughness height, and angle of attack. Maximum increase in Nusselt number and friction angle were 2.16 and 2.75 times, respectively, as large as that for smooth channel with an angle of attack of 60°.

Lanjewar et al. (2010) investigated heat transfer characteristics

* Corresponding author at: P.O.B: 35141-179, Semnan, Iran.
E-mail address: a.heydari@semnaniau.ac.ir (A. Heydari).

https://doi.org/10.1016/j.solener.2018.01.030
Received 5 November 2017; Received in revised form 7 January 2018; Accepted 10 January 2018

Nomenclature

A	surface (m^2)
a	accuracy of instrument
C_p	specific heat coefficient (kJ/kg K)
h	heat transfer coefficient (W/m^2 K)
H	fluid enthalpy
I	sun radiation (W)
K	conduction coefficient (W/m K)
Q	heat transfer rate (W)
P	pressure (Pa)
P_{fan}	fan power (W)
$\dot{m}$	mass flow rate (kg/s)
T	temperature (°C)
U	uncertainty
V	velocity vector (m/s)

Greek

η_{Th}	thermal efficiency
ρ	density (kg/m^3)
μ	viscosity (Pa·s)

Indices

f	fluid
in	inlet
out	outlet
p	absorption plate
t	total

through a rectangular channel equipped with w-shaped ribs for both upstream-ward and downstream-ward flows. In this research, it was observed that, the w-shaped ribs exhibited better performance in downstream-ward flow, rather than the upstream-ward one. Saxena et al. (2015) investigated an active solar air heater in terms of thermal efficiency. In this research, two 300 W-halogen lamps were used to increase temperature inside the air heater and enhance the resultant thermal efficiency. Of the obtained results, one can refer to enhanced efficiencies by 18.04–20.78%, as compared to natural convection, and 52.21–80.05%, as compared to forced convection. Defining a mass flowrate in the range of 0.017 and 0.036 and considering glass color changes, Vaziri et al. (2015) investigated efficiency of air heater. According to the results of this research, maximum efficiency was obtained at a mass flowrate of 0.036 and with a black glass. Ho et al. (2015) experimentally studied and analyzed dual-shell air heater. In their research, efficiency of collectors was thoroughly examined and optimized. In the research reported by Singh and Dhiman (2016), the focus was on determining heat at different times. Temperatures were measured all along 9:00 a.m. to 6:00 p.m., and the research was performed on a stone bed solar air heater. In this research, it was proved that, the use of this type of air heater is highly appropriate due to its large heat storage. Temperature of the stone bed would directly affect the temperature of output fluid. El-Sebaii et al. (2011) theoretically and experimentally investigated thermal performance of double pass-finned plate solar air heater in Tanta. Their results indicated that the double pass v-corrugated plate solar air heater is 9.3–11.9% more efficient compared to the double pass-finned plate solar air heater. They also obtained the peak values of the thermohydraulic efficiencies for special mass flow rates.

Some mathematical modeling were performed to study thermal performance of different type of solar air heater. For example, Singh and Dhiman (2016) investigated the effect of fins and baffles in a recyclic-type double pass solar air heaters. It was indicated that the mass flow rate and the recycle ratio are the most significant factors which considerably increases the heaters efficiencies when the fluid velocity is increased. Abed et al. (2017) recently have investigated the performance of a hybrid (water and air heating) solar collector system in the presence of stable and less stable radiative regime. Their results indicate that the system has higher efficiency in clear sky and high flow rates. Arul Kumar et al. (2016) arranged an experimental setup to study the effect of fin absorber plate and latent heat storage material simultaneously in a forced convection solar air heater. In compared to a flat absorber plate their results conducted that the pin-fin absorber plate packed with paraffin wax has additional heat storage for the period of 3 h with 2–5 °C enhanced outlet air temperature and consequently 3–35% higher thermo-hydraulic efficiency with 2–15% higher exergy efficiency.

Of the other methods proposed to improve the system performance, one can refer to the use of porous media inside the absorber, which serves as an approach to improve efficiency of solar air heaters. This method was first proposed by Lansing et al. (1979). Indeed, the use of porous medium increases the area-to-volume ratio. According to presented reports, the use of a porous medium inside solar air heater enhances its performance (Bayrak et al. (2013)). Various porous media have been proposed and studied by different researchers, e.g. metal grids (Kareem et al., 2017; Togrul and Pehlivan, 2005; Sharma et al., 1991), hallow sphere (Swartman and Ogunlade, 1966), iron-made foil (Sharma et al., 1990), and crushed glass (Singh and Bansal, 1983). Thermal performance of solar absorber is enhanced by adopting the porous medium, even though this also results in some pressure drop, especially at high mass flowrates. In Ho et al. (2005), application of an absorber panel inside a two-way channel in a flat- panel solar air heater is proposed. This design improves thermal efficiency by increasing heat transfer coefficient. Recently, Devecioglu and Oruc (2017) have investigated experimentally thermal performance of a solar air heater with porous absorber plate and baffles to construct a helical path. They have claim that this scheme leads to more absorption of solar radiation and more distribution in thermal boundary layer. Their results show that the porous wire meshing results in a higher thermal efficiency of the air heater. Another way to enhance the heat transfer rate to flowing air in the duct of solar air heater and heat exchangers is employing various turbulators such as viz. ribs, baffles and delta winglets which are considered as effective techniques (Alam et al., 2014).

Most of the heat loss in flat-panel solar absorbers occurs via the upper coating, because the bottom and walls of the absorber are well insulated. As such, aiming at minimization of heat loss, the use of double glazed glasses has been proposed (San Martin and Fjeld, 1975). More recently, application of transparent insulating materials (TIM) rather than common glass covers has been proposed. Due to its low thermal conductivity, TIM tends to reduce the mentioned heat loss through the upper surface of the absorber (Stahl et al., 1984).

Considering the cited research works, it was found that, even though the investigation of geometry of air heater has been developed extensively, yet the considered geometry for air heater in the present research, which includes channels of triangular cross-section that guide the flow through a helical path, is novel and innovative. In the present work, we begin with experimentally investigating thermal performance of a solar air heater with helical flow path in two different days at two flowrates. Then, using Fluent 18.1 software, the problem was also numerically modeled to validate the obtained results and investigate the effect of more parameters.

2. Energy analysis of solar air heater

Writing energy balance equation as a function of input and output temperatures, one can obtain useful absorbed heat by the air heater as