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Influence of fin height on the performance of a glazed and bladed entrance single-pass solar air heater

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ABSTRACT

This paper communicates experimentally improving the performance of an entrance-modified single-pass Solar Air Heater (SAH) having nineteen longitudinal fins. The longitudinal fins were used to increase the heat transfer area and to distribute the air flow uniformly in the channel. Experiments were conducted at three various heights of fins (3, 5, and 8 cm) to investigate the effect of the height. To increase the heating area exposed to solar radiation, the entrance region was covered by a glass instead of steel cover. As well, guide blades were attached to the entrance for ensuring good air distribution over the surface of the absorber, and hence enhancing the performance. Experiments were conducted under four values of air flow rates ranged from 0.013 to 0.04 kg/s. Experimental results were compared with that obtained from a conventional SAH at the same operating conditions to evaluate the proposed SAH performance. The maximum daily efficiency of the ordinary finned SAH was 43.1% at 0.04 kg/s and 8 cm fins' height. Modifying the entrance region led to good enhancement in both output temperature and efficiency. For the modified finned SAH, the highest daily efficiency was 57% at 0.04 kg/s with fins' height of 8 cm. While for the conventional SAH, the highest daily efficiency was about 32%.

1. Introduction

SAH utilizes the solar energy for air heating to be used in many applications like drying applications, space heating and water desalination. The advantages which make the SAH used in such applications and more distinct from the liquid heaters are avoiding the freezing problems or stagnation, damage, environmental or health hazards risk from heat transfer medium and leaks (Kabeel et al., 2017a). The construction of the conventional SAH is a glazed air flow duct which is thermally insulated. A blower or fan is used to force air into the heater channel. The heating area consists of absorber which has heating capacity allows it to store the heat gained from the sun and heats the flowing air. Improvement of SAH performance has been concerned by many researchers either for single or double-pass types. It can be concluded that, to improve the performance of SAH, many methods may be used such as increasing the surface roughness, using storage materials, using selective coating and backing beds. Also, increasing the surface area using fins has a great effect on the SAH performance.

Creating a turbulent flow using artificial roughness has proved its ability to improve the thermo-hydraulic performance and hence enhancing the heat transfer process. Several geometries of artificial roughness have been studied. Different shapes of ribs are studied such as L-shape ribs (Gawande et al., 2016), V-ribs (Hans et al., 2010; Kumar and Kim, 2015), thin ribs at various orientations (Sharma and Kalamkar, 2017), equilatrial triangular ribs (Yadav and Bhagoria, 2014) and metal rib grits (Karmare and Tikekar, 2010, 2009). In addition, studies were done on different shapes of obstacles (Handoyo and Ichsani, 2016; Kulkarni et al., 2015), protrusions (Bhushan and Singh, 2011; Hans et al., 2010; Yadav and Kaushal, 2014) and arc-shaped wires (Pandey and Bajpai, 2016; Saini and Saini, 2008). Furthermore, artificial roughness can be added to the sides of SAH which give more enhancement according to Behura et al. (2016) and Prasad et al. (2014).

Using energy storage, absorbers coating and packed bed enhances the performance of energy systems in addition to its role in conservation the energy. Energy storage are commonly utilized in areas with variation in solar energy and areas having high temperature variation between day and night. The most common type of energy storage materials is phase change materials (PCMs) which have ensured an acceptable improvement in SAHs performance (Krishnananth and Kalidasa Murugavel, 2012; Alkilani et al., 2009). So, SAHs having PCMs are used in many applications like insulated green house (Kooli et al.,

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Nomenclature

A_h	heater surface area (m^2)
A_p	cross-sectional area of the air flow pipe (m^2)
C	total cost ($)
C_p	specific heat (J/kg K)
F	fixed cost ($)
FGBSAH	finned glazed-bladed solar air heater
I_R	solar radiation intensity (W/m^2)
$\dot{m}$	flow rate of air (kg/s)
PV	photovoltaic
Q_u	useful heat gained (W)
SAH	solar air heater
T_{in}	inlet air temperature (°C)
T_{out}	outlet air temperature (°C)
T_1, T_2, T_3	temperatures at various positions on the absorber (°C)
ΔT	temperature difference of air flow (°C)
ΔT_d	daily temperature difference of air flow (°C)
V	variable cost ($)
V_{air}	air velocity (m/s)
η	thermal efficiency
η_d	daily thermal efficiency
ρ	density of air (kg/m^3)

2015) and water desalination using humidification–dehumidification process (Summers et al., 2012). On the other hand, the absorptivity of the absorber plate can be increased using selective coating which increases its absorbing efficiency. Utilizing selective coating of nickel–tin (Ni–Sn) achieved the best performance (El-Sebaii and Al-Snani, 2010; Aboul-Enein et al., 2000). Furthermore, the storing ability can be increased using different beds on the absorber. Several types of beds have been studied such as porous beds which achieved enhancement in the thermal efficiency (η) of the double pass SAH by 20–25% and 30–35% higher than that of double pass SAH without porous material and single pass SAH (Ramani et al., 2010). Also, using a composite absorber of a non-porous corrugated iron sheet and a porous mesh of aluminum achieved a midday η of 61% according to the experimental and theoretical study of Dissa et al. (2016). In addition, using steel wire mesh as beds showed good enhancements in the SAHs performance (Chouksey and Sharma, 2016; Prasad et al., 2009). In addition, the metal corrugated packing SAH was ensured to be more appropriate for using in the cold regions rural buildings for its advantages of large heat transfer area, high heat transfer coefficient and good economic performance as studied by Zheng et al. (2017).

The heat transfer to the air flow can be increased by increasing the area of absorber plate. The widest and popular technique of increasing the absorber area is attaching fins. Several studies were done on several shapes of fins. Priyam and Chand (2016) analyzed analytically the performance of a SAH having an absorber plate with attached two transversely positioned wavy fins. The bottom side is insulated while the upper one is subjected to uniform heat flux. The effects of mass flow rates and fin spacing on the performance were studied compared to flat plate SAH. The results showed that the predictions of that SAH performance be useful in designing such types of SAH. Wave-like absorber plate at different positions was analytically and experimentally studied by Gao et al. (2007). Aboghrara et al. (2017) studied the enhancement of heat transfer using jet impingement on corrugated absorber plate with increase in η by 14% more as compare to the smooth duct. Corrugated fins achieve good enhancement in the thermal efficiency (η) of the SAHs. Using v-corrugated collector (Karim and Hawlader, 2006) resulted in increasing η by 10–15 in single-pass SAHs and 5–11% in double-pass SAHs.

The present work focuses on using longitudinal fins which was studied by many researchers. Experimentally, Chabane et al. (2014) compared a finned single-pass SAH having five longitudinal fins placed inferior the absorber plate with another SAH without fins. This study indicated a preferable improvement on η for two values of mass flow rate ($\dot{m}$) of 0.012 and 0.016 kg/s compared to conventional SAH. Using longitudinal fins integrated with a mesh of steel wire was studied by Omojaro and Aldabbagh (2010) for both single and double-pass SAH for $\dot{m}$ ranged between 0.012 kg/s and 0.038 kg/s and using bed heights of 3 cm for the upper channel and 7 cm for the lower channel. The study showed that utilizing packing material and absorber plate in the shape of mesh made from steel wire showed a much more substantial enhancement in the SAH performance. The results of the comparison study of three different types of SAHs made by Alta et al. (2010) illustrated that the largest irreversibility occurs at the heater without fins and hence the efficiencies of the finned SAHs are higher than that without fins. Also, many of theoretical studies proved the enhancement resulted in using fins. Rai et al. (2017) studied analytically the effects of fins geometric and $\dot{m}$ on the thermal and thermohydraulic (effective) efficiencies. It found that, the maximum percentage enhancement in thermal and thermohydraulic efficiencies increases to 114.1 and 112.65% respectively with decrease in fin spacing and increase in fin height. The increase of thermohydraulic efficiency was limited at $\dot{m}$ of 0.028 kg/s but the increase of thermal efficiency had no limits. Also, Naphon (2005) presented the analytical model for the prediction of the characteristics of heat transfer, performance and entropy generation for double-pass SAH with longitudinal fins at various $\dot{m}$, fin height and fins number. The results showed that the maximum η was 62% when using 55 fins and fins height of 8 cm. Attaching baffles to the finned air solar heater improves the performance regarding the baffles in-between distance and the baffles height because of affecting the pressure drop and hence the consumed power (Mohammadi and Sabzpooshani, 2013). Also, recycling process with various reflux ratios was studied to obtain the ratio which achieves the best performance of SAHs (Ho et al., 2012, 2009; Yeh, 2012).

A lot of researches made in the field of SAHs did not concerned with the entrance region however its extreme importance. So, the current study investigates the effect of fins height in addition to modifications made at the entrance region on the performance of a SAH of single-pass type.

The entrance region of some researches was made in the of triangular, convergent or conical area. But these researchers fabricated the entrance region from steel or opaque materials (Bayrak et al., 2013; Bouadila et al., 2013; El-Sebaii et al., 2011; Kabeel et al., 2017b). Although there is a heat gain through the entrance region, it is not considered and used as a heat collecting area. So, the present study aims to first insulate the entrance region and replace the un-transparent material or steel used at entrance by glass cover to increase the heating area exposed to I_R. Also, replacing the steel cover with glass avoids the restriction of solar radiation occurred due to steel which decreases the absorber surface temperature and hence T_{out}.

In addition, the heating efficiency is influenced by the distribution of the air at as much as possible area. So, the air distribution has an effective role on improving the performance of SAHs. To overcome the problem of pressure-drop across the air distribution systems, simple fixed guide blades are used in the present study. The used guide blades are made of aluminum to have an additional role as fins at the entrance which enhances the heat transfer process at the entrance.

From the previous review, the effect of glazing the entrance region on the finned SAH is not recognized. In addition, the effect of attaching guide blades to the entrance region is not studied before. So, The current work studies experimentally the performance of finned glazed-bladed (FGBSAH). The following test cases are studied: