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Experimental Study of The Optimum Air Gap of a Rectangular Solar Air Heater

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Hussam S. Dheyab[1], Manar Salih Mahdi Al-Jethelah[1,*], Tadahmun Ahmed Yassen[1], Thamir Khalil Ibrahim[1]

[1] Mechanical Engineering Department, College of Engineering, Tikrit University, Tikrit, Iraq

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ABSTRACT

Many studies had investigated the optimum air gap of a solar air heater. Yet, no agreement has been indicated to find the optimum air gap height especially with different studied designs. In the present work, an experimental study was conducted to find an optimum air gap height for a rectangular solar air heater. To conduct the experiments, four solar air heaters with different air gap heights were designed and built. Each heater was 200 cm in length and 50 cm in width. The studied air gap heights were 3, 5, 7, and 9cm. The results showed that the highest air temperature difference was found for air gap height of 3 cm, i.e. 57.5 °C. An air gap of 3 cm resulted in highest air outlet temperature for all studied period. The highest mass flowrate, which consequently highest heat gain, was 9.0 g/s at 9cm and 13:00. The high mass flowrate resulted in high efficiency, i.e. 57.3% at 9 cm and 10:00. Both air mass flowrate and solar air heater efficiency showed insignificant increments as the air gap height exceeded 5cm.

1. Introduction

The global warming issue and the shortage in conventional energy resources have encouraged researchers to utilize the renewable energy resources to fulfill the growing demand for energy. The thermal solar energy is a crucial sector in renewable energy field. Numerous thermal solar energy applications have been studied and produced for heating, drying, power generation, and cooling [1–11]. Solar collectors are widely studied for heating purpose. One of the important design parameters of solar air heaters is the air gap height between the cover glazing and absorber plate. The importance of the air gap height comes from its impact on the amount of heat transfer from the absorber to the heated air. Keep in mind that the eventual goal of solar air heater is to produce hottest air with higher mass flowrate of the air flowing through the solar air heater. Many researchers based their solar air heater designs on a single air gap such as Singh *et al.,* [12] who used 10.2 cm and Pakdaman *et al.,* [13] who used 5.5 cm. Also, single air gap height was used in different solar dryers such as Lingayat

* *Corresponding author.*
E-mail address: m.aljethelah@tu.edu.iq (Manar Salih Mahdi Al-Jethelah)

et al., [14] who used 10 cm, and Zoukit *et al.,* [15] who used 5 cm. The discrepancy between different air gap heights has raised the need to optimize the height of the air gap in solar air heaters. Macedo and Altemani [16] optimized the air gap between the cover glazing and the absorber plate. The authors concluded that an air gap between 9 cm to 11 cm achieved better performance. Nahar and Garg [17] concluded that an air gap between 4 cm to 5 cm achieved minimum convection heat losses. Bassey *et al.,* [18] experimentally studied the effect of gap space on the performance of a solar dryer. Two gaps were studied by Bassey *et al.,* [18], i.e. 4 cm and 5 cm. With the 4-cm gap height, the performance of the dryer was improved. Subiantoro and Ooi [19] recommended a range of 1 and 1.1 cm of air gap height to gain better performance of a solar collector. To find the optimum air gap height for a solar water heater, Nahar and Gupta [20] experimentally studied three air gap heights, i.e. 2.5, 5, and 15 cm. The authors found that the 5-cm gap achieved the highest overall efficiency, i.e. 57.8%, compared to the other two studied gaps, 52.5% for 2.5 cm and 54.1% for 12.5 cm.

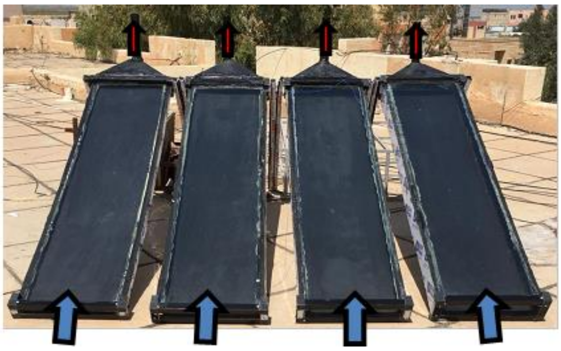
A review in published literature regarding the air gap height between the cover glazing and absorber flat plate of natural convection solar air heater reveals that no air gap height has been confirmed as an optimum air gap height. The air gap spacing is important design parameter to obtain highest exit air temperature and flowrate. The exit air temperature and flowrate are important parameters in the ventilation, drying, and up drafting solar chimney. Therefore, the present experimental study aims to find an optimum air gap height for a solar air heater.

2. Experimental Methodology

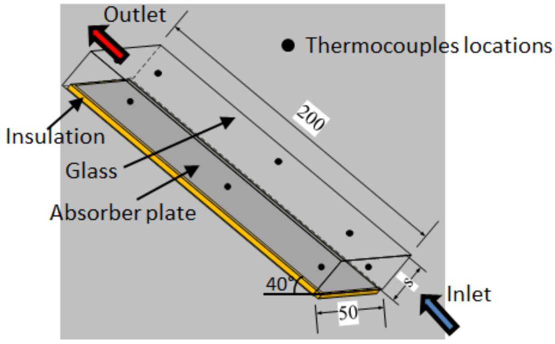
The experimental methodology in the present investigation includes the experimental apparatus and measurement equipment in addition to data analyzing and uncertainty.

2.1 Experimental Apparatus and Measurement Equipment

An experimental study was performed to investigate the optimum air gap height of a solar air heater. The experimental investigation was performed in Tikrit-Iraq (34°40' N 43°39' E). For the sake of comparison, four identical inclined flat solar collectors were designed and built as shown in Figure 1. Each collector was 200 cm in length and 50 cm in width. However, the air gap height for each collector was 3, 5, 7, and 9 cm. The collector inclination angle was 40° [21,22] . The absorber was made of aluminium coated with matte black colour (ε = 0.97) [23]. The cover of the collector was a 4-mm thick transparent glass. At the top of the collector, a chimney made of black plastic was fixed. The chimney inner diameter was 5.3 cm, the outer diameter was 6.0 cm, and the height was 25 cm. Calibrated K-Type thermocouples, with diameter of 0.5 mm, were used to measure the temperature in eight different locations; at the entrance of the solar air heater, the absorber, the glass, and at the exit of the solar air heater. The temperature measurements were read using data logger type Applent AT4808 with accuracy of ±1.0 °C. The velocity of air leaving the collector was measured using BENETECH GM8 16C anemometer with accuracy of ±0.1 m/s. The solar radiation was measured using DAYSTAR DS-05 meter with accuracy of ±1.0 W/m^2. The uncertainties and relative errors of the experimental equipment are tubulated in Table 1.



(a)



(b)

Fig. 1. Experimental setup (a) a photo, (b) a schematic diagram (dimensions in cm)

2.2. Data Analyzing and Uncertainty

The collected measurements; i.e. inlet and outlet air temperature, the glass temperature, the absorber plate temperature, the air mass flowrate, and the solar intensity; were applied to calculate the thermal behaviour of the solar air heater. The thermal calculations included the mean heat transfer coefficient

$$\bar{h} = \frac{Q}{A_p\,(T_p - T_b)} \tag{1}$$

where Q is the useful heat gained by air, A_p is the absorber plate area, T_p is the absorber plate temperature, and T_b is the air bulk temperature which was calculated according to the method used in [24].

The useful heat gained by air flowing through the solar air heater could be calculated from

$$Q = \rho\, V\, A_c\, c_p (T_o - T_i) \tag{2}$$

where ρ is the air density, V is the air velocity, A_c is the cross-section area of the chimney, c_p is the air specific heat at constant pressure, T_o is the leaving air temperature, and T_i is the entering air temperature. The total heat losses Q_L from the solar air heater are sum of convection heat loss Q_C and radiation heat loss Q_R, which can be calculated from

$$Q_L = Q_C + Q_R = h\, A_s\,(T_p - T_{amb}) + \varepsilon\, \sigma\, A_s (T_p^4 - T_{amb}^4) \tag{3}$$

where h is the convection heat transfer coefficient, A_s is solar air heater surface area, T_{amb} is the ambient temperature, ε is the emissivity of the absorber plate, and σ is the Stefan–Boltzmann constant. The convection heat transfer coefficient was determined based on the following correlation [25].

$$h = \frac{k}{L_p}\,(0.664\, Re^{1/2}\, Pr^{1/3}) \tag{4}$$

where k is the air thermal conductivity, L_p is the solar air heater length, Re is the Reynolds number ($V_{amb}\, L_p / \upsilon$), and Pr is the Prandtl number (υ/α).

The thermal efficiency of the solar air heater can be defined as [26]

$$\eta = \frac{Q}{I\, A_p} \tag{5}$$

where I is the solar intensity.

From the calculated heat transfer coefficient in Eq. (1), the Nusselt number Nu is found from

$$Nu = \frac{\bar{h}}{k\, s} \tag{6}$$

where s is the air gap height.

The Rayleigh number Ra is determined from

$$Ra = \frac{g\, \beta (T_p - T_b)\, s^3}{\upsilon^2}\, Pr \tag{7}$$

where g is the gravity acceleration, β is the air coefficient of thermal expansion, and υ is the air kinematic viscosity.

To estimate the uncertainty of considered measured or calculated parameters besides the dimensionless numbers, Kline and McClintock method was used [27]. Based on this method, if a result R; which includes measured, calculated, and dimensionless parameters; is a function of n number of independent variables,

$$R = R(x_1, x_2, \ldots, x_n) \tag{8}$$

Then the uncertainty in the result R is W_R, and the uncertainties in the independent variables are $W_1, W_2, \ldots, and\ W_n$. The uncertainty in the result W_R could be calculated from

$$W_R = \left[\left(\frac{\partial R}{\partial x_1} W_1 \right)^2 + \left(\frac{\partial R}{\partial x_2} W_2 \right)^2 + \cdots + \left(\frac{\partial R}{\partial x_n} W_n \right)^2 \right]^{\frac{1}{2}} \tag{9}$$

The calculated uncertainties and relative errors of Eq. (1)-(7) are tabulated in Table 1.

Table 1
Uncertainty and relative errors analysis

Parameter	Uncertainty ±	Relative error%
Temperature (°C)	1.0	0.91
Air velocity (m/s)	0.1	6.45
Solar intensity (W/m^2)	1.0	0.100
Useful heat gained (W)	16.4	7.82
Mean convection heat transfer coefficient (W/m^2 K)	0.3	7.63
Reynolds number	11188.8	2.21
Convection heat transfer coefficient (W/m^2 K)	0.06	1.11
Total heat losses	7.94	0.66
thermal efficiency	0.016	0.03
Nusselt number	0.00057	0.01
Rayleigh number	61808.7	2.18

3. Results

The optimum height of an air gap in a rectangular solar heater was experimentally investigated in the present study. Four identical solar heaters were studied with different air gap heights for each heater. The studied air gap heights were 3, 5, 7, and 9 cm.

Figure 2 shows the average solar intensity and the ambient temperature through the tested period. The solar intensity increased as the sun moved toward its highest point in the sky. As the sun reaches its highest point, the solar intensity reaches its peak value. Then the solar intensity decreases as the sun moves away from its highest location in the sky. The strength of the solar intensity directly affects the thermal performance of the solar air heater. The ambient temperature increased during the tested period. The increase in the ambient temperature is beneficial to the thermal performance of solar air heater. With increasing the ambient temperature, the inlet air temperature increases, and the heat losses decrease from the solar air heater to its surrounding.

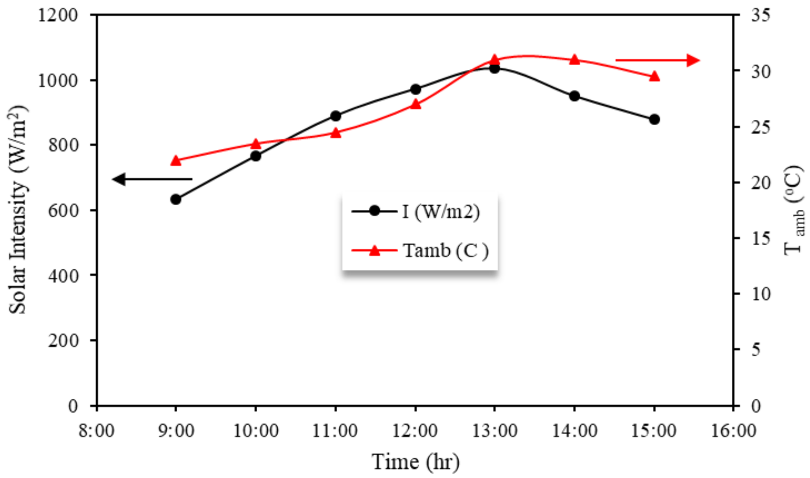


Fig. 2. Solar intensity and ambient temperature through the tested period

Figure 3 shows the total heat losses from the solar air collector through the tested period. The total heat losses were low at the beginning of the test when the solar intensity was low. Then the total heat losses increased as the solar intensity and the solar air heater temperature increased. After 13:00, the heat losses decreased due to the reduction in the solar intensity and the increase in the ambient air temperature [28]. The total heat losses had a direct impact on the temperature of different components of the solar air heater and its efficiency.

Before reporting the results and discussing them, it is worthy to point out that as the air gap height decreases, the volume of air inside the gap decreases. Also, all the solar air heaters were exposed to the same amount of solar intensity value. As a result, the solar air heater with the narrowest air gap would be heated up more than the ones with wider air gaps.

Figure 4 shows the temperature at the centre of the absorber plate through the tested period for the four studied air gap heights; i.e. s= 3, 5, 7, and 9 cm; and at 13:00 for all studied air gap heights. 13:00 was selected because it corresponded to the highest solar intensity. As can be seen in Figure 4(a), the highest temperature at the centre was noticed for the narrowest air gap, i.e. s= 3cm, which was 110 °C at 12:00. The high temperature of the absorber plate reveals that the flowing air above it was heated more compared to that in the other studied air gap heights. The impact of the air gap height on the temperature at the centre of the absorber plate at 13:00 is shown in Figure 4(b) for the four studied air gap heights. As the air gap height increased, the temperature of the centre of the absorber plate decreased. The reduction in the absorber temperature reduced the heating ability of the absorber plate. As a result, the temperature of the air leaving the solar air heater was less. The rate of decreasing the temperature at the centre of the absorber plate decreased as the air gap height reached 7cm.

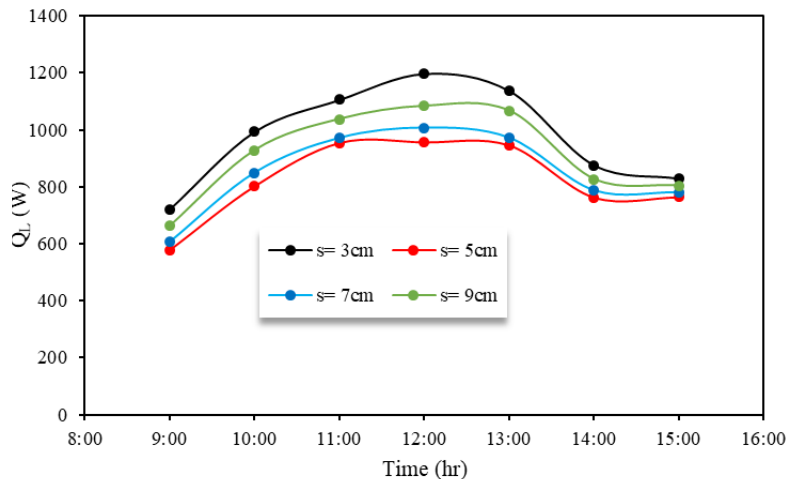
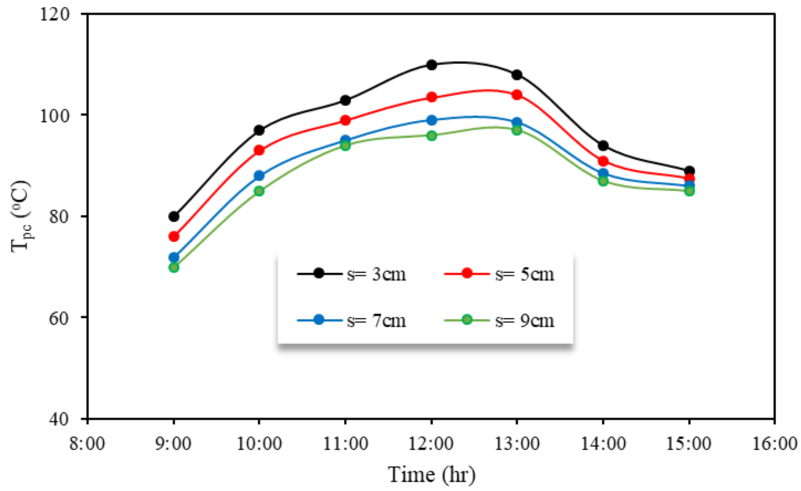
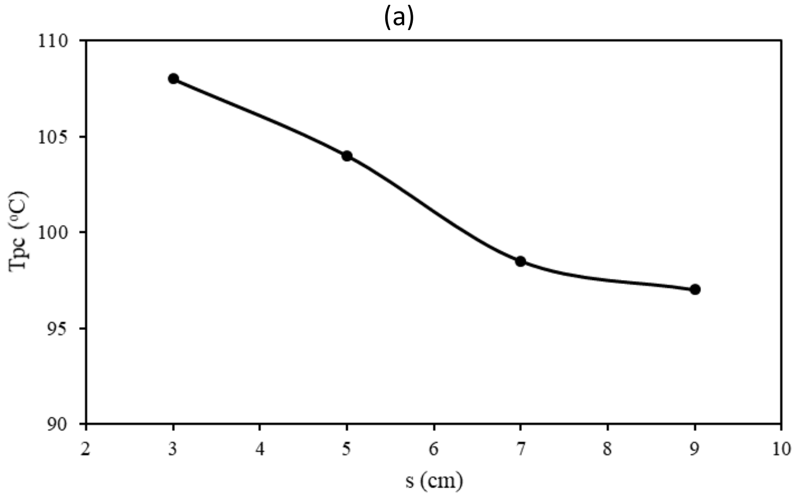


Fig. 3. Total heat losses from the solar air heater



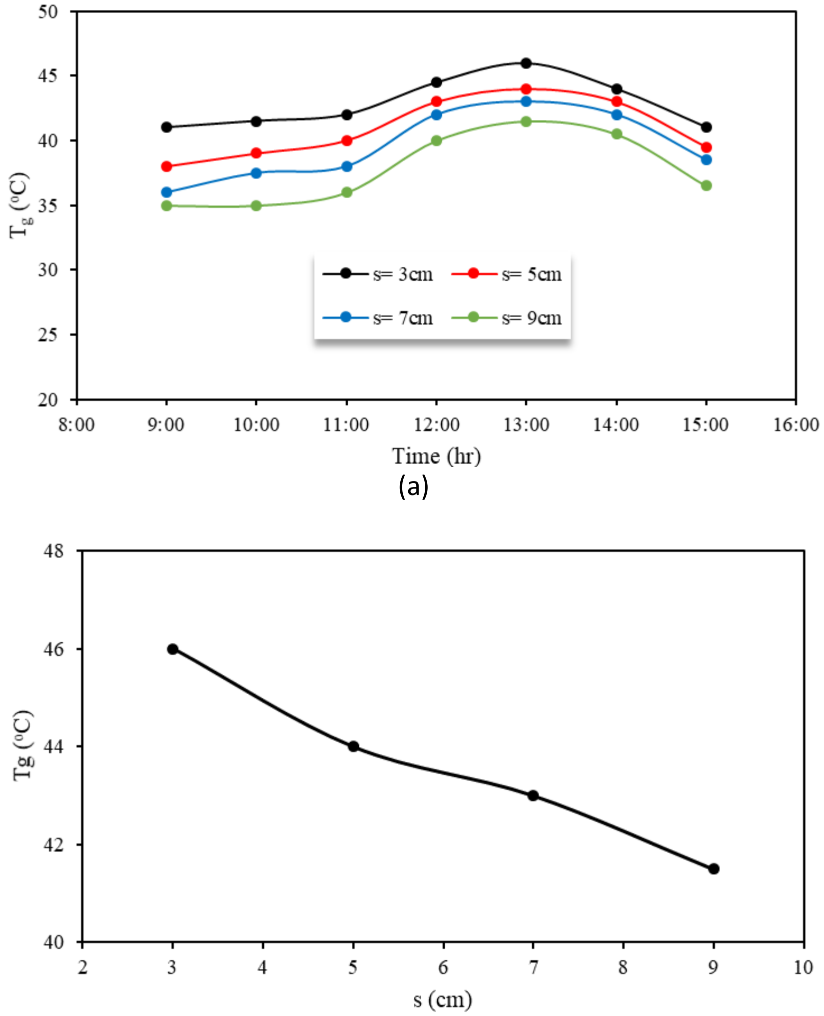
(a)



(b)

Fig. 4. The temperature at the centre of the absorber plate (a) through the tested period, (b) at 13:00

Figure 5 shows the glass cover temperature through the tested period for the four studied air gap heights; i.e. s= 3, 5, 7, and 9 cm; and at 13:00 for all studied air gap heights. The highest measured temperature of the glass was for the narrowest gap, i.e. s= 3cm, which was 46 °C at 13:00, Figure 5(a). As was aforementioned, the volume of the heated air inside the gap is lowest for the narrowest air gap. Therefore, the solar air heater components, i.e. absorber plate and glass, heated up more than the those for wider gaps. The advantage of the high temperature of the glass is to heat up the air flowing below it. As a result, the temperature of air leaving the solar air heater became higher. The impact of air gap height on the glass temperature is shown in Figure 5(b). The glass temperature decreased with increasing the air gap height. Although the reduction in the glass temperature reduced the heat loss from the solar air heater, the leaving air temperature was low.

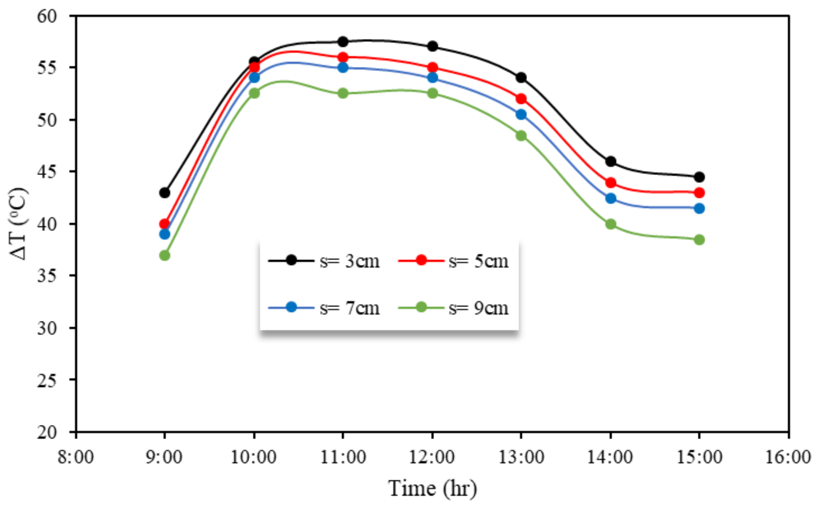


(b)

Fig. 5. Glass temperature (a) through the tested period, (b) at 13:00

Figure 6 shows the effect of the air gap height on the air temperature difference, i.e. $\Delta T= T_o-T_i$, through the tested period for the four studied air gap heights; i.e. s= 3, 5, 7, and 9 cm; and at 13:00 for all studied air gap heights. Similar trend of all profiles of the studied air gap heights was observed. The temperature difference increased with increasing the solar intensity. Then a plateau-behaviour of the air temperature difference from 10:00 to 13:00 was observed. The average temperature difference through this period was 56 °C. A thermal balance was reached at this point. When the sun moved away from its peak point, the temperature difference profile started to drop, first sharply then gradually, due to the reduction in solar intensity. As shown in Figure 4 and 5, the absorber plate and the glass temperatures for the narrowest gap were the highest in comparison with the other studied air gaps. The high temperatures of both the absorber plate and the glass temperatures; besides, the small air volume for the narrowest air gap, led to a higher temperature for the air leaving the solar air heater, Figure 6. In addition, in the narrow air gap, conduction heat transfer mode has an influence on the heat transfer from the absorber plate to the flowing air above it. Figure 6(b) shows that the highest air temperature difference at 13:00 was 54 °C. Then the air temperature difference linearly dropped. Figure 6(b) reveals that further increasing in air gap height decreases the temperature of the air leaving the solar air heater.

Figure 7 shows the air mass flowrate through the tested period for the four studied air gap heights; i.e. s= 3, 5, 7, and 9 cm; and at 13:00 for all studied air gap heights. From Figure 7(a), it can be noticed that the air mass flowrate increased with time until it reached its highest values at 13:00 with increasing the solar intensity, Figure 2. Then as the solar intensity decreased, the air mass flowrate decreased. The highest observed mass flowrate was 9.0 g/s at 13:00. The high mass flowrate assists to supply more hot air in shorter time. From Figure 7(a), it could be noticed that as the air gap height increased, the air mass flowrate increased. However, the rate of increasing in the mass flowrate decreased as the air gap height exceeded 5cm. Figure 7(b) confirms that the rate of increasing the mass flowrate decreased with increasing the air gap height.



(a)

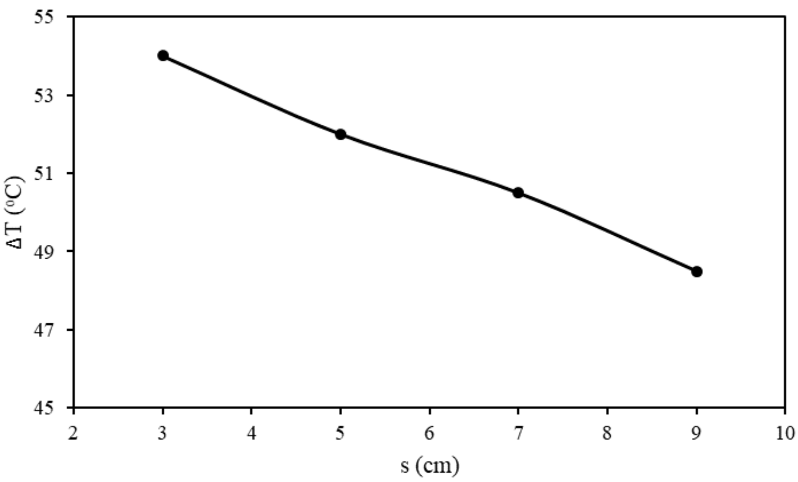


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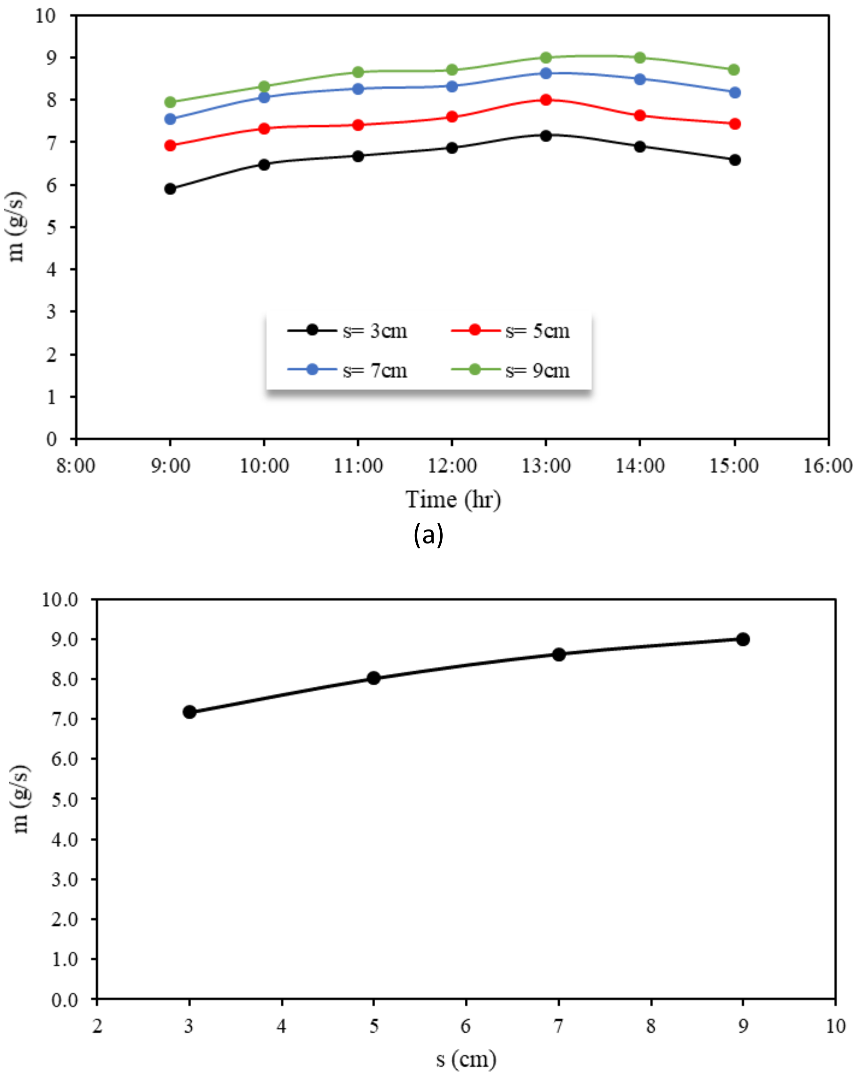
Fig. 6. Air temperature difference (a) through the tested period, (b) at 13:00



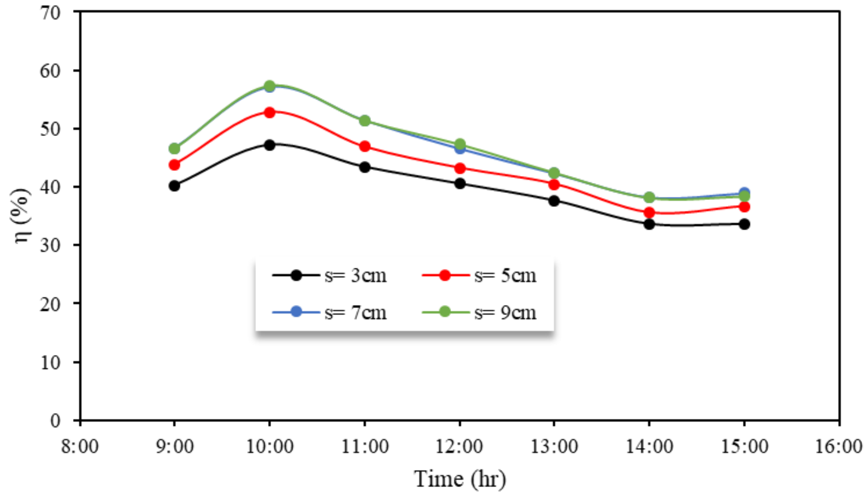
(b)

Fig. 7. Air mass flowrate and outlet velocity (a) through the tested period, (b) at 13:00

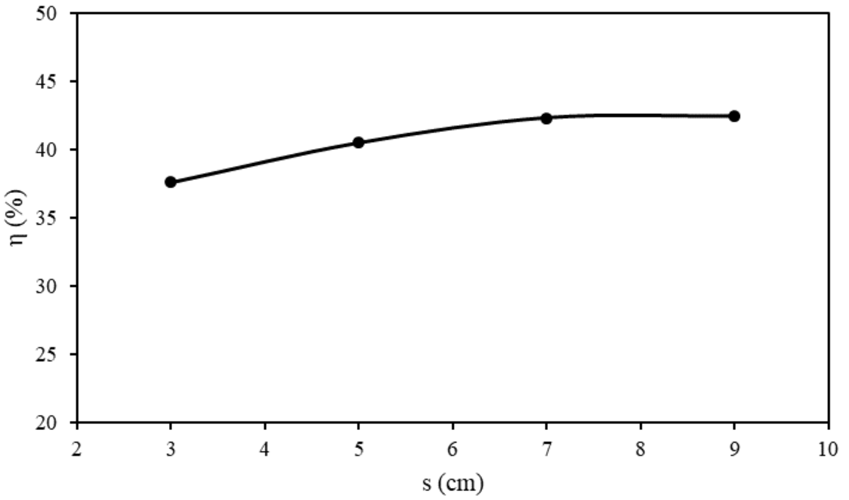
Figure 8 shows the effect of the air gap height on the solar air heater efficiency through the tested period for the four studied air gap heights; i.e. s= 3, 5, 7, and 9 cm; and at 13:00 for all studied air gap heights. The efficiency increased with time as the solar intensity increased. However, the efficiency decreased with decreasing the solar intensity and increasing the heat losses from the solar air heater. The highest efficiency was found for the solar air heater with air gap of 9cm, i.e. 57.3% at 10:00. Beyond 5cm, increasing the air gap height had insignificant impact on the solar air heater. Figure 8(b) shows the impact of air gap height on the solar air heater efficiency at 13:00. Again, the solar air heater with air gap height of 9cm had the highest efficiency compared to the other studied air gap heights, i.e. 42.4%. Figure 8(b) confirms that any increasing in the air gap height has insignificant impact on the solar air heater efficiency.

Figure 9 shows the overall average Nusselt number Nu versus Rayleigh number Ra for the four studied air gap heights, i.e. s= 3, 5, 7, and 9 cm. Nu increases with increasing Ra due to the increasing in buoyancy force [29]. It can be noticed from Figure 9 that the lowest Nu values were for the narrowest air gap, i.e. s= 3cm; while, the highest Nu values were for the widest air gap, i.e. s= 9cm. The narrow space, where the air moves through it, and the low Ra associated with it resulted in lower

Nu values. As the air gap height increased, the viscous force overcame the buoyancy force [28]. The low values of Nu reveal that conduction had an impact on the heat transferred to the air in the gap.



(a)



(b)

Fig. 8. Efficiency of the solar air heater (a) through the tested period, (b) at 13:00

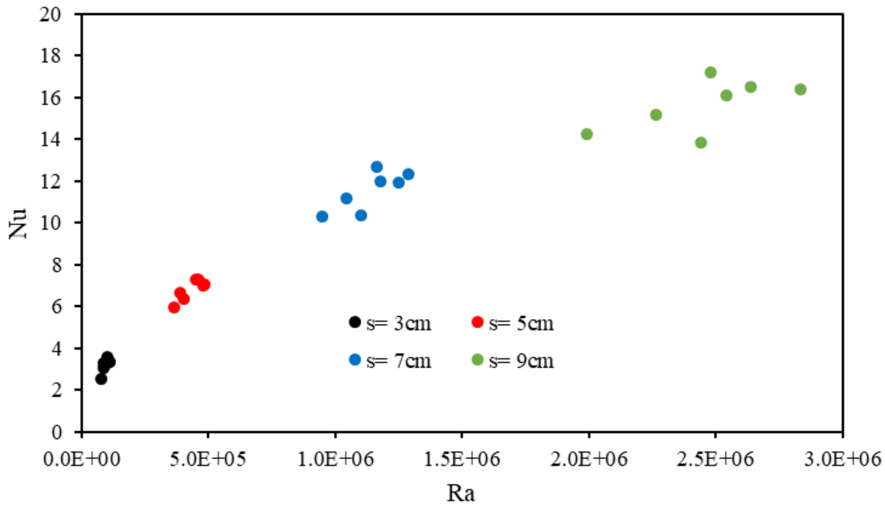


Fig. 9. The overall average Nusselt number Nu versus Rayleigh number Ra

From aforementioned results and discussion, it can be noticed that the small air gaps, i.e. less than 5cm, were associated with high air temperature difference. While, for air gap heights more than 5cm, the leaving air mass flowrate and efficiency were higher. However, beyond 5cm, both the air mass flowrate efficiencies increments were insignificant. A similar behaviour was noticed by Macedo and Altemani [16].

4. Conclusions

In the present study, an experimental investigation was conducted to find an optimum air gap height in solar air heater. To perform the experiments, four identical solar heaters were built. However, each heater had a different air gap height, i.e. s= 3, 5, 7, and 9cm. The temperatures of the inlet and outlet air, the absorber plate, the heater glass cover besides the solar intensity and the air velocity leaving the solar air heater were utilized to study the thermal performance of the investigated solar air heaters. Through the measured and calculated parameters, it was found that the air gap of 3cm-height had shown the highest air temperature difference compared to the other studied air gap heights. The average air temperature difference was 56 °C. In other words, the highest air temperature at the outlet was gained at the outlet of solar air heater of 3-cm gap height. The air gap of 9cm-height had shown the highest mass flowrate, i.e. 9.0 g/s at 13:00, which increased the heat gained by the flowing air through the solar air heater. The high heat gain resulted in high efficiency of the solar air heater at 9cm air gap height, i.e. 57.3% at 10:00, compared to other studied air gap heights. However, the air mass flowrate and efficiency increasing beyond 5cm was insignificant. The heat transfer through convection was higher for wider air gap heights.

References

[1] Al-Jethelah, Manar, Syeda Humaira Tasnim, Shohel Mahmud, and Animesh Dutta. "Nano-PCM filled energy storage system for solar-thermal applications." *Renewable energy* 126 (2018): 137-155.

[2] Al-Sammarraie, Ahmed Tawfeeq Ahmed, and Manar Salih Mahdi. "Theoretical study of heat transfer through a sun space filled with a porous medium." *Tikrit Journal of Engineering Sciences* 23, no. 2 (2016): 10-20.

[3] Hashim, Ghasaq Adheed, and NA Che Sidik. "Numerical study of harvesting solar energy from small-scale asphalt solar collector." *J. Adv. Res. Des* 2, no. 1 (2014): 10-19.

[4] Djedid Taloub, Abdelkarim Bouras, and Zied Driss. "Study of The Influence of External Parameters on Thermal Performance of a Solar Water Collector." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 53, no. 2 (2019): 213-222.

[5] Ghaderian, J., C. N. Azwadi, and H. Mohammed. "Modelling of energy and exergy analysis for a double-pass solar air heater system." *J. Adv. Res. Fluid Mech. Therm. Sci* 16, no. 1 (2015): 15-32.

[6] Mohd Syahmiyadiy Jamaluddin, Md Mizanur Rahman, Mohd Faizal Hasan, Aminuddin Saat, and Mazlan Abd Wahid. "Performance Evaluation of a Small-scale Solar Driven Refrigeration System." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 36, no. 1 (2017): 10-20.

[7] Awang, Norati Artini, Haslinda Mohamed Kamar, and Nazri Kamsah. "Energy Saving Potential of an Air-conditioner – Ice Thermal Storage (AC-ITS) system." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 31, no. 1 (2017): 1-10.

[8] Al-Sammarraie, Ahmed T., Manar Al-Jethelah, Mohammad Reza Salimpour, and Kambiz Vafai. "Nanofluids transport through a novel concave/convex convergent pipe." *Numerical Heat Transfer, Part A: Applications* 75, no. 2 (2019): 91-109.

[9] Ramli, Ahmad Syazwan, Firdaus Basrawi, Mohd Hazwan Bin Yusof, Ahmed Nurye Oumer, Nur Azfa Johari, Azira Muhamad, Mohd Razif Mamat, Khairul Habib, and Thamir Khalil Ibrahim. "Experimental analysis on a novel low-temperature vacuum drying with induced nucleation technique for dewatering stingless bees honey." *Drying Technology* 37, no. 2 (2019): 149-155.

[10] Zulkepli, Afzam, M. R. R. Chand, Thamir K. Ibrahim, Hamzah Sakidin, Firdaus Basrawi, and Mohd Hazwan Yusof. "Performance analysis of a Copper Indium Gallium Selenide (CIGS) based Photovoltaic Thermal (PV/T) water collector." In *MATEC Web of Conferences*, vol. 225, p. 04023. EDP Sciences, 2018.

[11] Basrawi, Firdaus, Thamir K. Ibrahim, Surendran S. Sathiyaseelan, and A. A. Razak. "Experimental Investigation on Performance of Solar-Powered Attic Ventilation." In *Sustainable Thermal Power Resources Through Future Engineering*, pp. 1-19. Springer, Singapore, 2019.
[12] Singh, Ajeet Pratap, and O. P. Singh. "Thermo-hydraulic performance enhancement of convex-concave natural convection solar air heaters." *Solar Energy* 183 (2019): 146-161.
[13] Pakdaman, M. Fakoor, A. Lashkari, H. Basirat Tabrizi, and R. Hosseini. "Performance evaluation of a natural-convection solar air-heater with a rectangular-finned absorber plate." *Energy conversion and management* 52, no. 2 (2011): 1215-1225.
[14] Lingayat, Abhay, V. P. Chandramohan, and V. R. K. Raju. "Design, development and performance of indirect type solar dryer for banana drying." *Energy Procedia* 109 (2017): 409-416.
[15] Zoukit, Ahmed, Hicham El Ferouali, Issam Salhi, Said Doubabi, and Naji Abdenouri. "Takagi Sugeno fuzzy modeling applied to an indirect solar dryer operated in both natural and forced convection." *Renewable energy* 133 (2019): 849-860.
[16] Macedo, I. C., and C. A. C. Altemani. "Experimental evaluation of natural convection solar air heaters." *Solar Energy* 20, no. 5 (1978): 367-369.
[17] Nahar, N. M., and H. P. Garg. "Free convection and shading due to gap spacing between an absorber plate and the cover glazing in solar energy flat-plate collectors." *Applied Energy* 7, no. 1-3 (1980): 129-145.
[18] Bassey, M. W., P. H. Oosthuizen, and J. Sarr. "Using heated chimneys and reduced collector air gap height to improve the performance of indirect passive solar dryers." *Renewable energy* 4, no. 2 (1994): 169-178.
[19] Subiantoro, Alison, and Kim Tiow Ooi. "Analytical models for the computation and optimization of single and double glazing flat plate solar collectors with normal and small air gap spacing." *Applied energy* 104 (2013): 392-399.
[20] Nahar, N. M., and Modish P. Gupta. "Studies on gap spacing between absorber and cover glazing in flat plate solar collectors." *International journal of energy research* 13, no. 6 (1989): 727-732.
[21] Mathur, Jyotirmay, and Sanjay Mathur. "Summer-performance of inclined roof solar chimney for natural ventilation." *Energy and Buildings* 38, no. 10 (2006): 1156-1163.
[22] Yassen, Tadahmun A., and Hussain H. Al-Kayiem. "Experimental investigation and evaluation of hybrid solar/thermal dryer combined with supplementary recovery dryer." *Solar Energy* 134 (2016): 284-293.
[23] Holman, Jack Philip. "Heat transfer, eighth SI metric edition." *Mc Gran–Hill Book Company* (2001).
[24] Khedari, Joseph, Patsada Yimsamerjit, and Jongjit Hirunlabh. "Experimental investigation of free convection in roof solar collector." *Building and Environment* 37, no. 5 (2002): 455-459.
[25] Cengel, Yunus. *Heat and mass transfer: fundamentals and applications*. McGraw-Hill Higher Education, 201q.
[26] Hamed, Mofreh, and A. W. Kandeal. "Influence of bladed and glazed entrance on the performance of solar air heater." *Scientia Iranica* 26, no. 3 (2019): 1388-1399.
[27] Holman, Jack Philip. *Experimental methods for engineers*. 2001.
[28] Al-Jethelah, Manar SM, Ahmed Al-Sammarraie, Syeda H. Tasnim, Shohel Mahmud, and Animesh Dutta. "Effect of convection heat transfer on thermal energy storage unit." *Open Physics* 16, no. 1 (2018): 861-867.
[29] M.S. Mahdi. "Natural Convection in a Vertical Rectangular Enclosure." Kirkuk Univ. J. Sci. Stud. 8 (2013) 1–16.