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Experimental Efficiency of Single Pass Solar Air Heater

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ABSTRACT

The solar heat collector with the impingement of jet lower plate (SAHJF) experimentally designed and operated with typical parameters obtained from theoretical analysis to contained the maximum efficiency of the performance of thermal transfer. Then it was developed by replacing the flat absorber by the corrugated absorber (SAHJC) to enhance the efficiency. The flow rate of mass was selected equal and more than the typical value and the intensities of the solar radiation were chosen equal and less than the typical value to investigate the effect of both on the thermal transfer efficiency for SAHJF and SAHJC. Since the system works with a short range of temperature, the temperatures recorded were sensitive and needed a large accuracy. Therefore, an analysis method was proposed and applied to the data to be sure that it reflects the variance of temperature with different operating parameters. The correlation of temperature difference between the outlet and the inlet air with different flow rate and different intensities of irradiation for SAHJF and SAHJC was presented and compared.

الكفاءة التجريبية لسخان الهواء الشمسي بمرورواحد

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الكلمات المفتاحية:
بلات مموج
الكفاءة
الاصطدام النفاث
درجة حرارة منفذ الخرج
وسخان الهواء بالطاقة الشمسية

الملخص

في الدراسة تم تصميم مجمّع الحرارة الشمسي مع اصطدام اللوح السفلي النفاث (SAHJF) بشكل تجريبي وتشغيله باستخدام معلمات نموذجية تم الحصول عليها من التحليل النظري لتحقيق أقصى قدر من الكفاءة لأداء النقل الحراري. ثم تم تطويره عن طريق استبدال الماص المسطح بالممتص المموج (SAHJC) لتحسين الكفاءة. تم اختيار معدل تدفق الكتلة متساويًا وأكثر من القيمة النموذجية وتم اختيار شدة الإشعاع الشمسي متساوية وأقل من القيمة النموذجية لاستكشاف تأثير كلاهما على كفاءة النقل الحراري لـ SAHJF وSAHJC. نظرًا لأن النظام يعمل مع نطاق قصير من درجات الحرارة، فإن درجات الحرارة المسجلة كانت حساسة وتحتاج إلى دقة كبيرة. لذلك، تم اقتراح طريقة تحليل وتطبيقها على البيانات للتأكد من أنها تعكس تباين درجة الحرارة مع معايير التشغيل المختلفة. تم تقديم ومقارنة العلاقة بين فرق درجة الحرارة بين المخرج والهواء الداخل مع معدل تدفق مختلف وشدة مختلفة من التشيع لكل من SAHJF و SAHJC.

Introduction

Solar energy is available freely, omnipresent and an indigenous source of energy provides a clean and pollution free atmosphere. The simplest and the most efficient way to utilize solar energy is to convert it into thermal energy for heating applications by using solar collectors which have been widely used in solar thermal systems for many commercial applications such as buildings, agricultural and industrial drying (Bansal 1999). The increase of equipment or appliances quality by providing high heat transfer performance is still a hot topic (Wazed et al. 2010; Gao et al. 2007). So, in any heat exchanger, a higher overall heat transfer coefficient is desirable. Flat plate solar air heaters are generally used for low and moderate temperature (Elbreki et al. 2016). However, the solar air heater has low efficiency due to low convective heat transfer coefficient in the smooth absorber surface (Prasad & Mullick 1983; C. 2013; Singh et al. 2012), air limitation to energy extraction (Chauhan & Thakur 2013) and flow rate limitations (Verma & Prasad 2000; Elbreki et al. 2016). Himation et al. (Hematian et al.

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2012) have experimentally observed the lower collector efficiency in forced convection than natural convection for a parallel plate solar air heater. But, heat loss is observed lower due to low temperature difference between outlet and inlet air. This makes it necessary to develop new techniques to enhance the heat and mass transfer. The roughened surface plate, the jet impingement lower plate, the double pass and the use of fin (Goldstein & Sparrow 1976) are the most important techniques that were proposed and individually applied to increase the thermal performance in solar air heat collector.

The double-pass technique in solar air heat collector provides substantial improvement in the performance of heat transfer because it prevents the heat transfer out to the ambient. Studding the influence of different parameters, such as mass flow rate, flow channel depth and collector length on this system and comparing it with single-pass was the target of many works theoretically (Yousef & Adam 2008) and analytically and experimentally (Ramani et al. 2010; Singh 2013). In many industrial applications, such as hospitals, where recirculation of air is not practical because of contamination (Wazed et al. 2010).

The different designs of fins used in the solar air heater collector extensively gave the researchers much work to examine their efficiency. Normal fins was used by (Pottler et al. 1999) to increase the heat transfer area, and obstacles was fixed in the flow path of air flow inside the solar collector to increase turbulence (Abene et al. 2004; Gao et al. 2007). Singh 2006 analytically presented the heat transfer enhancement in a continuous longitudinal fins solar air heater for different pitches, and Kurtbas & Turgut 2006 studied solar air heater with free and fixed fins and obtained increased heat transfer coefficient and output air stream temperature. All these techniques have enhanced the thermal efficiency, but they causes pressure losses inside the collector (Belusko et al. 2006) and many studies have been carried out on this topic (Gao et al. 2007).

The use of the corrugated absorber in the design of the solar heat collector was one of the successful concepts that attacked engineers to increase the performance of heat transfer. CHOUDHURY & GARG 1991 presented a detailed theoretical parametric analysis on corrugated and flat plate solar air heaters of five different configurations and investigated the effects of the air flow velocities (or the air channel depths) on the air temperature increment, the system efficiency and the pressure drop experienced by the flowing air for different air channel lengths and different specific mass flow rates of air. More details of experiment and numerical studies on it were developed (Gao et al. 2000; Gao 1996). Comparisons between the flat plate and the corrugated absorber were adopted to investigate the performance of SAH in different configurations to present parametric study for future work (Lin et al. 2006; Gao et al. 2007). Recently, Andrassy 2012 has developed different numerical models in order to assess the influence of design and operating parameters such as bond conductance between absorber plate and tube, tube diameter, glass cover to absorber plate distance, optical properties of absorber and flow rate on thermal efficiency of collectors. It has recently been shown that the thermal transfer performance of these configurations significantly several times higher than the flat plate collector (Gao et al. 2007).

The adoption of the jet impingement concept was done in many researches and it is extensively used in the fields of space heating, drying of agriculture crops and supply of hot air in buildings due to its higher convective heat transfer coefficient and collector efficiency. The heat transfer characteristics for inline and staggered arrays of circular jets with cross flow spent air was studied by Metzger et al. 1979. For parallel air heater, KAYS & CRAWFORD 1980 developed the correlation of Nussle number for the case of turbulent flow between two plates with one side heated and another insulated. The heat transfer characteristics of impinging jets with cross–flow (Florschuetz et al. 1981) and the effects of various geometrical parameters such as the 'hole' or 'nozzle' diameter on the jet plate with a unique jet impingement were investigated to improve the efficiency of an air-based solar collector (Choudhury & Garg 1991). Gao et al. (Gao et al. 2005) investigated the efficiency of the solar collector with Two different arrays: one of uniform diameter holes placed in a stretched format and the second with increasing diameter holes. A theoretical and experimental investigation was presented by Belusko & Saman 2006 to identify the performance characteristics of jet impingement for the improvement of the thermal efficiency of a glazed collector. Yousef & Adam 2008 theoretically investigated the effect of mass flow rate, flow channel depth and collector length on the system thermal performance and pressure drop through the collector with and without porous medium. The correlation of Nussle number in terms of Reynolds number and in terms geometrical parameters such as the stream-wise and the span wise jet spacing and jet diameter and other operating parameters was investigated and used to experimentally include the friction factor (Chauhan & Thakur 2013) and theoretically optimised (Chauhan & Thakur 2014), or these parameters of the heater collector dimensions were investigated for better thermal performance (Nayak & Singh 2016; Kercher & Tabakoff 2016).

From all above, Since the problem of contamination with the use of the double-pass technique, the pressure losses accompanied to the use of fins, and the existence of theoretically typical parameters for the impingement jet plat with flat absorber to obtain the maximum efficiency in the SAH (Chauhan & Thakur 2014), and no recent work has adopted the jet plate impingement across the corrugated absorber as two concepts applied together yet, we have been motivated to combine these two concepts that could provide higher performance of heat transfer. So the present work is focused on investigating the typical parameters for the jet impingement plate with flat absorber and enhancing the efficiency of the thermal transfer performance of SAH with the jet plate and the corrugated absorber.

Concept of the Experimental design

The use of the jet impingement across the absorber is to increase the turbulent flow, which provides longer time for heat conduction between the absorber and the air. The idea of using corrugated absorber instead of the fins has two privileges. First is to increase the area of the absorber exposed to the solar radiation and to the air inside the collector, which increases the absorption of solar energy and the dominant conduction of heat to the air inside the collector. Secondly, the topography of the corrugated absorber creates turbulent flow of eddies with diameters closer to the diameter of the corrugation, which allows the air to be in contact with the absorber rather than to be away from the surface of the absorber. It is certain that the stream wise and the hole diameter of the jet plate and the distance between the two plate influence these eddies, but studding these factors is out of the scope of the present work. Considering such previous factors lowers the friction and makes the system works with more optimal state. This friction causes energy loss in the pumping system and this lost energy is supposed to be considered when the efficiency of the system is calculated.

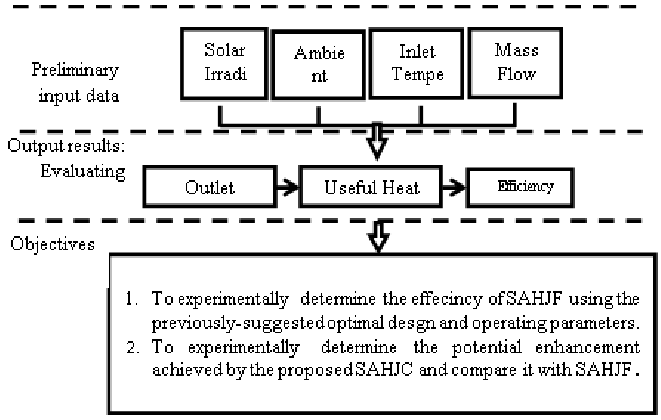

Fig. 1: Block diagram of the experimental design

Figure 1 illustrates the block diagram of the experimental design adopted in this study. The proposed design is compared with previous models of SAHJF to determine the potential enhancement that can be achieved regarding the temperature difference, the thermal energy transferred, and its efficiency. The schematic diagram of the SAH designs with, SAH design with jet impingement on flat absorber plate are shown in fig 2 (A), and the schematic diagram of the proposed SAH model with jet impingement on corrugated absorber plate is illustrated in figure 2(B). The collector includes a frame of rectangular cross-section having an inlet and outlet for passage of air, sheet of glass covers at the top of the frame, an absorber plate mounted in the frame below the cover. The absorber is a corrugated plate coated with black paint on both sides and a jet plate spaced a distance below the absorber plate. Therefore, the jets of air are directed through the holes of the jet plate and impinge on the lower surface of the corrugated absorber plate to produce efficient heat transfer, while channels facilitated the corrugated flow of the spent jets are to be discharged through the outlet

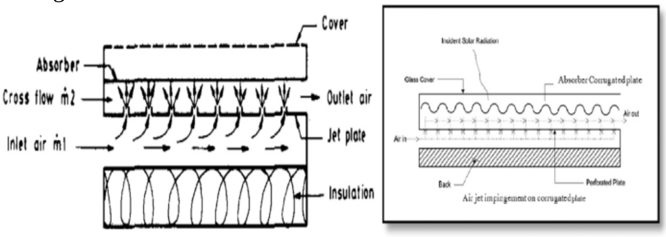

Fig. 2: Schematic diagram of SAH design with jet impingement (A) on flat absorber plate. (B) on a corrugated absorber plate

Experimental Set Up, Systems, and Design Parameters

The experimental setup was designed and fabricated to study the effect of adding corrugated absorber to the plate jet impingement in the solar heat collector Fig 3. It consists of a heat collector, a radiation simulator and an air flow systems and measuring devices. The solar simulator is fixed over the heat collector duct to provided uniform heat flux. the whole periphery of the rectangular duct was covered with 50 mm thickness wooden blocks from all its sides in order to prevent heat loss to surroundings.

Fig. 3: Photograph of the experimental setup

3.1 Heat collector

the collector, as shown in Figure 4 includes a frame of rectangular cross-section having an inlet and outlet for passage of air, sheet of glass covers at the top of the frame, an absorber plate mounted in the frame below the cover. The absorber was made from a plane plate, coated from both sides with black colour, and pressed by a mould to make it corrugated as shown in figure 5 Gao et al. 2007 reported that coating the absorber increases the efficiency by about 10%. The jet plate, made as shown in Figure 6 is spaced a 3-cm distance below the absorber plate. Moreover, the jets of air are directed through the holes of the jet plate and impinge on the lower surface of the corrugated absorber plate to produce efficient heat transfer, while the channels facilitated the corrugated flow of the spent jets to be discharged through the outlet.

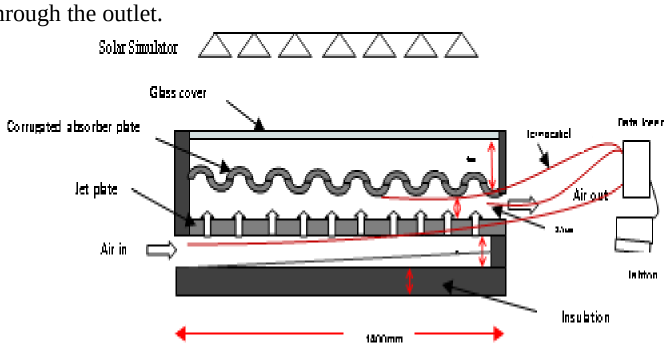

Fig. 4: Schematic diagram of proposed design of experimental.

Fig. 5: corrugated plate fabricated and coated

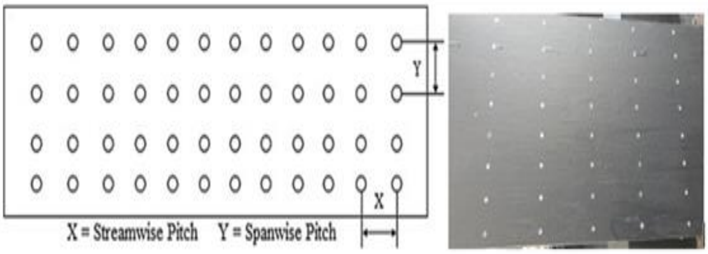

Fig 6 Impingement plate geometry: Location of (X) stream wise and (Y) span wise pitch.

The parametric design of all parts of the heat collector are shown in table (1). The dimensions of the duct (1400*300*140) mm, the entry and the exit sections (600, 400) mm were chosen as in Ref. (Chauhan & Thakur 2013) to guarantee the ASHRAE standards (ASHRAE 1977) for typical turbulent flow regime. The distance between the corrugated plate and the jet plate was 2.5 cm. The small gap between the two plate is to have slender configuration along the air flow direction, which increases the efficiency of the heat transfer (Lin et al. 2006). For mass flow rate (0.01-0.028 kg/s) conducted in the present work, the critical Reynolds numbers are ranged from 3,224 to 9,027, obtained from the velocity in the duct and the hydraulic diameter of the duct. Singh & Sidhu 2014 experimentally study the efficiency of the solar heat collector roughened transverse ribs and observed that the Reynolds numbers lie between 2564-6206l yield thermal efficiency lies between 36% to 61% that becomes more for larger Reynolds number. The diameter of the corrugated plate was chosen 1cm. Two studies used very small diameter (0.1-0.3 cm) (Andrassy 2012) and large (1.5cm) (Gao et al. 2007), and both obtain an enhancement of about 40% in thermal convection efficiency.

Table (1) Details for parts, size and type of SAH.

Parts	Size	Type of material
Solar air heater box	(1400*300*140) mm inside	Glass Wood, Coated with black paint
Entry section, and exit section	(600, 400) mm	(Aluminium)
Glass cover	(1400*300) mm Thickness (3) mm	Glass, Transitivity (0.9) , Emissivity (0.85)
Jet plate	(1400*290) mm, Thickness (1) mm Jet diameter (3) mm stream wise pitch X= 80 mm , and span wise pitch Y= 40 mm	Aluminium, Emissivity of 0.9 Absorptivity of 0.9 Coated with black paint
Corrugated absorber plate	(1400*300) mm, Thickness (1)mm Diameter cycle of corrugated (10) mm	(Aluminium) Emissivity of 0.9 Absorptivity of 0.9, Coated with black paint

3.2 Air Flow System

Because of the working fluid is air, the flow passage should be below the absorber plate to minimize the heat loss. However, the forced is used in this research to extract the heat from the absorber to the application in accordance with suitable air temperature needed. The inlet must be initially at a straight and stable condition, so that it can be used as a air flow straightened of 60 cm long jointed to the collector (see figure 6). The air speed was controlled by a controller linked with a blower of 99 W powers and the operating voltage of (230 - 240V) generated an air velocity range of (0-15 m/s).

3.3 Radiation Intensity System

The Solar Simulator shown in Figure 7 consists of a solar simulator lamps arrangement. Solar simulator is an essential part for collector indoor testing. It was built in the Solar Simulator Laboratory and tested under the solar simulator which had 48 tungsten halogen lamps each having 500w and rated at 240V and 11A. A uniform heat flux is provided by solar simulator, to maintain uniform heat flux of (500-1000) W/m^2.

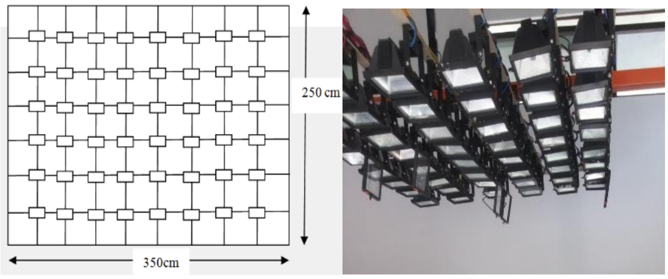

Fig 7 The solar simulator lamps arrangement

The halogen lamps were arranged in 8 lines where each line contained 6 lamps for uniform distribution of the irradiance with a distance of (50) cm from center to center between them, as shown in Figure 7. The dimensions of the simulator were 350x250 cm. The distance between the simulator and the collector surface was120 cm. The intensity of the radiation simulator was adjustable by 48 controllers.

To calibrate the irradiance on the collector surface, the collector surface was divided into squares of 7.5 cm dimensions same as the pyrometer base diameter. The total number of squares was (72) squares. The radiation was measured each square then represented by an excel surface to ensure the equalization distribution on the radiation on the collector surface, and to increase or decrease the radiation using the controllers. The calibration procedure was repeated for 500, 600,700,800,900, and 1000w/m2 radiation intensities.

4.Experimental procedure & Measuring

Fifteen thermocouples were adjusted on the absorber to monitor the air temperature. Each row consisted of 3 thermocouples adjusted carefully. Also this may make a difference in the air temperature distribution. Accordingly, these numbers of thermocouples were employed to monitor the actual and accurate air temperature. Figure 8 exhibits the distribution of thermocouples in the collector. The inlet air entered the air heater at temperatures of 30°C and 35°C.

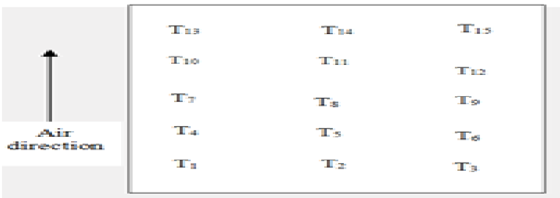

Fig 8 exhibits the distribution of thermocouples in the collector.

The thermocouple signal was based on the current generated when two different metals wire were jointed with each other in a loop to form two junctions, maintained at two different temperatures, an electrical current will be generated and flow through the loop. This voltage signal was very weak (millivolts) and could be affected across the long distance of the connector. Moreover, this voltage was supposed to be linear with the change in temperature. Therefore, two temperatures were sufficient to achieve the calibration of a thermocouple. The freezing and boiling temperatures of the water at the atmospheric pressure were known well and used easily for calibration in the Solar Simulator Laboratory.

The absorber plate heated by the fabricated solar simulator placed over the test section of the absorber to produce uniform heat flux of (500-1000) W/m2. Then, the blower was switched ON to let a predetermined rate of air inflow into the duct before changing the air flow rates for each experiment at uniform heat flux. The system allows attaining a steady state before the data record. The constant state assumes to be achieved when no considerable variations in temperatures between successive scans are observed for 10–12 min. The air leakage from the setup was checked before each experimental run.

Many tools have been used in this study to measure and control the air velocity. The main device used to measure the air velocity was an anemometer. The anemometer vane probe was linked to the data logger to record the data. It was actually used to monitor any variation and to ensure the stability in the flow rate during the experiment. The mass flow rate $\dot{m}$ can be calculated from the product of the density of the air, the cross section area of the air flow channel and the velocity of incoming air measured by the probe. Each value of the air velocity is corresponded to a certain magnitude of the mass flow rate and the consumption in the electrical power of the air pump depended upon the air velocity chosen to operate the system. The pumping power and the air velocity were directly proportional to each other.

Calibration is a test during which known values of input are applied to the measurement system and corresponding outlet readings are recorded under specific conditions. The values used in the calibration are typically known as the standard. In this study, the calibration of the solar simulator irradiation and the irradiation controllers were achieved through a previous research reported for, 500, 600,700, 800, 900, 1000 W/m2 [i]

During experimentation the following parameters were measured for each set of readings:

1. Average Temperature of the absorber plate at various locations (Tap).
2. Temperature of air at inlet (Ti).
3. Temperature of outlet. (To)
4. Mass flow rate. ($\dot{m}$)
5. Solar radiation. (I)

5.Results, Observations and discussion

The thermal transfer efficiency of solar air heaters was first investigated with flat absorber and the impingement of lower jet plate (SAHJF), then, the flat absorber was changed with the corrugated (SAHJC). For each setting, a set of measures was achieved for radiation 500-1000 W/m2 and mass flow rate 0.010-0.028 kg/s. For each value of radiation, the blower was adjusted to obtain the required value of the mass flow rate at steady state and the temperature reads were recorded. The design and the operating parameter of the present work for the jet plate with flat absorber were typically chosen as in Ref. (Chauhan & Thakur 2014) to obtain maximum efficiency (see table 1). The other parameters are Hydraulic diameter 4.615cm, the stream wise pitch ratio 1.733, the span wise pitch ratio 0.8666, the jet diameter ratio 0.065, mass flow rate 0.010-0.028 kg/s and the Reynolds numbers 3224 – 9027.

It is important to remember the solar heat collector works in a small range of temperature (303 K -312 K) within the operating parameters chosen in the present experiment. And, there were some factors in the experimental setting that let the measures of the inlet and outlet temperatures slightly variant in the heat collector due to the different ambient temperature (not due to the different design or operating parameters). This makes the system implicitly works in different values of temperature or different values of temperature ranges (not Δt) because the measures were taken in different days for each individual intensity of solar radiation. So, the room temperature was little different from day to another before the commence of the experiment of everyday. For instance, in the measures of temperature with the flat absorber, the lowest inlet temperature was 303.0 K in the first day with 500 W/m2 irradiance and the highest was 306.60 with 1000 W/m2 in the sixth day. The 3 degrees' difference could affect the accuracy of the data especially when the recorded data were sensitive due to the small difference between a read and another next, and it is desired to show comparison between these two records together in one graph. In addition, there were some sources of heat inside the room:

the simulator, the outlet hot air, the heat collector and the electric blower. These increased the room temperature in the same day of the experiment and caused clearly variant ranges of temperature especial when the simulator irradiance was high. This does not affect the intensity of the radiation of the absorber because the simulator was adjusted to obtain the specific values but it affected the temperature of inlet air. The outlet hot air was placed close to the door to let it mostly out of the room. The effect of room temperature increase should be considered and evaluated to ensure the accuracy of the efficiency obtained. It can assume that the implicit temperature increase is same for the inlet and outlet air. The average temperature of the air can be normalized to both the flow rate and the intensity of the radiation to show the increase of the implicit temperature that affects the dynamic viscosity and the Reynolds numbers. This normalized average temperature behavior is shown in Figure 8. As can be seen in this figure, the curvature of these graphs belongs to the nonlinearity between the temperature and the dynamic viscosity and their behaviors of all data are similar. The existence of clear gaps or the non-intersection or overlap among these graphs indicate that the reads are accurate enough to show a clear variant behavior. It is possible to normalize (flow rate * radiation) to the first day value to show a unit less factor of days' variance in data. And, the different values in each graph reflects the good variant among the data in one day. It is also possible to normalize the data of each day to the first read of the same day to obtain another unit less factor of one-day variance. These factors have not been shown here because the graphs obtained was clearly enough.

In the hydraulic system, the amount of the heat transfer essentially depends on the temperature difference between the inlet and outlet air and the mass flow rate of the air when the incident solar intensity of radiation is constant. The efficiency of the system depends on the heat transferred and the heat absorbed. Therefore, it is important to present the change in the mechanism of the system with different operating parameters such as the mass flow rate of air and the intensity of the solar radiation. The difference in temperature versus the mass flow rate for the flat and the corrugated absorber is shown in Figure 10. As can be seen, it is decreasing with higher values of mass flow rate in each graph of constant intensity of radiation for the flat and corrugated absorber. The difference increase in the corrugated absorber is more than that of flat by about three degrees. In the corrugated absorber, the differences with all intensities of irradiation are close and overlapped. This will be shown and discussed more clearly in Figure 9. This decrease was also obtained in the analysis made by Choudhury & Garg 1991 (Choudhury & Garg 1991) for a single pass SAH. Lin et al. 2006 (Lin et al. 2006) theoretically analyzed the corrugated SAH and found that the temperature increment is nonlinearly decreasing with a constant flow rate of mass.

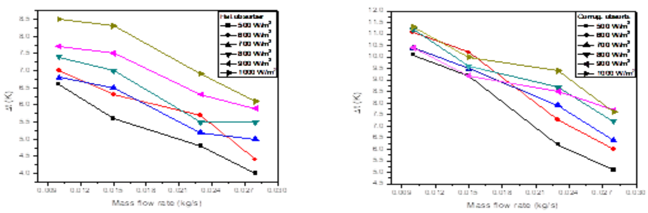

Fig 9 The temperature difference valus the mass flow rate for different intensities of solar radiation and for flat (on left) and corrugated (on right) absorber.

The effect of irradiation intensity on the temperature difference is depicted in Figure 10. As a general trend, the temperature difference rises with higher irradiation in all graphs. The heat collector with slow mass rate 0.010 kg/s is with highest temperature difference and with high irradiation the graphs are closer. This increasing behavior was also found by Choudhury & Garg 1991 (Choudhury & Garg 1991) but with linear relationship when they theoretically studied SAH with Corrugated absorber. From all graphs in both Figures 10 and 11, it can deduce that the hydraulic system shows well relationship between the temperature difference and both the mass flow rate and at intensity of irradiance. The general behavior of the temperature difference with the intensities and low flow rate of mass is generally constant or with small gradient, which could indicate that the system is subject to steady operating state.

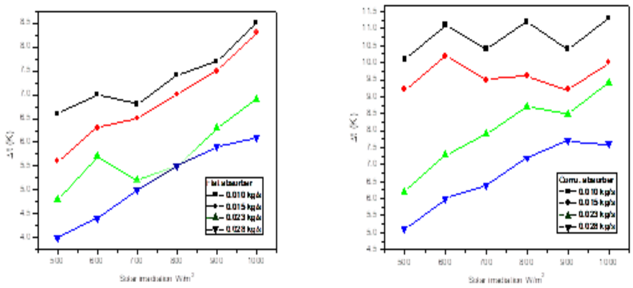

Fig10 The temperature difference verus the intensities of solar radiation for different mass flow rate and for flat (on left) and corrugated (on right) absorber.

The efficiency of heat transfer for the system of impingement with flat and corrugated absorber are shown in Figure 12. It can be seen, the efficiency is remarkably raising with higher flow rate of mass inside the heat collector and the highest efficiency obtained with low jet plate and the flat absorber is 0.54 and that with jet plate and corrugated absorber is 0.68. In the corrugated collector, it is noteworthy to observe the steady efficiency with high flow rate for the low intensities of irradiation. These steady state could be useful for designing the heat collector in the future, however the higher efficiency is still an important target. The efficiency obtained for the heat collector with the flat absorber is the best as that obtain in Ref. (Chauhan et al. 2016) in which the same experimentally optimized parameters were selected but with different Reynolds number. From the behavior of efficiency in SAHJF, it is clear to deduce that the efficiency could increase when higher flow rate of mass is carried out. Belusko & Saman 2006 experimentally used unglazed absorber and jet plate with only 500 W/m^2 low radiation for high 0.1 kg/s mass flow rate and obtained higher efficiency (0.53), and with 0.01kg/s and 0.028kg/s they obtained 0.25 and 0.41 respectively, whereas we obtained 0.34 and 0.55 efficiency respectively for the SAHJF and 0.46 and 0.68 respectively for SAHJC. The more enhancement in our results belongs to the adoption of the typical design parameters such as the stream wise and the jet hole diameter.

The efficiency of thermal transfer behavior with different solar irradiance is shown in Figure 12. The efficiency of different flow rate for the flat and corrugated absorber is decreasing with the intensity of the solar irradiance. It is clear that the high efficiency in Figure 13 (left and right) is at low intensities of irradiance, which is more in SAHJC than in SAHJF. The little overlap in the flat and more in the corrugated positively indicates very good enhancement in the hydraulic system. This suggests that SAH with the corrugated well works with flow rate between 0.023-0.028 kg/s and 500-800 W/m^2.

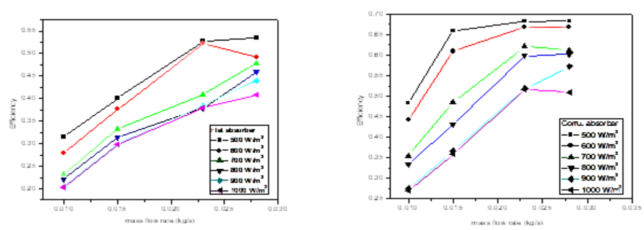

Fig 11 The thermal heat transfer efficiency verus the mass flow rate for different intensities of solar radiation and for flat (on left) and corrugated (on right) absorber.

The efficiency of thermal transfer behavior with different solar irradiance is shown in Figure 12. The efficiency of different flow rate for the flat and corrugated absorber is decreasing with the intensity of the solar irradiance. It is clear that the high efficiency in Figure 12 (left and right) is at low intensities of irradiance, which is more in SAHJC than in SAHJF. The little overlap in the flat and more in the corrugated positively indicates very good enhancement in the hydraulic system. This suggests that SAH with the corrugated well works with flow rate between 0.023-0.028 kg/s and 500-800 W/m^2.

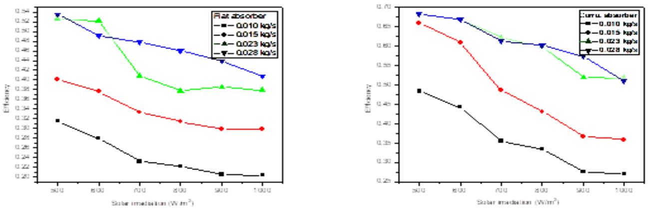

Fig 12 The effect of solar irradiation on the efficiency for flat absorber (on left) and corrugated absorber (on right).

1. Chauhan & Thakur 2014 theoretically optimized the parameters to obtain the maximum effective efficiency for the impingement jet plate with flat absorber. However, all parameters have been chosen same in the present work, the percentage efficiency experimentally obtained was 53% with more flow rate of mass but with the corrugated plate the efficiency enhanced to 68.3%. The maximum efficiency in flat plate SAH is with high flow rate of mass 0.028 kg/s and the lowest intensity of radiation 500 W/m^2 in the experiment.

Conclusion

Typically, parametric design and operating for SAHJF and SAHJC were carried out to investigate the efficiency of the performance of the thermal transfer. The influence of the flow rate of mass and the intensities of the solar irradiation on the efficiency were studied. Since the system worked with a short range of temperature, the recorded temperatures were evaluated to guarantee its accuracy. The correlation of temperature difference between the outlet and the inlet air with different flow rate and different intensities of irradiation for the to designs was presented and compared.

However, the theoretically typical parameters were carried out for the SAHJF, the maximum efficiency of about 53% was observed with the highest flow rate reaches 0.028 kg/s and lowest intensity of solar irradiation 500 W/m^2 applied in the present study. As an average, the comparison between the smooth and the corrugated surfaces of the absorber plate with different air flow rates and solar radiations revealed that the average thermal efficiency of the systems increases to about 14% with a 3K increment of temperature. When the extrapolation of the graphs is considered and in accordance with other previous studies that chose higher flow rate of mass, it can conclude that the efficiency could increase more when higher flow rate is adopted in the operation of the system. The developed system (SAHJC) enhanced the performance of heat gain to a maximum percentage value of 68.3% at also the highest flow rate and lowest intensity of solar irradiation applied in the present study.

The jet impingement on corrugated absorber plate is an effective technique to enhance the rate of heat transfer as compared to jet impingement on smooth solar air heaters. The study found that the thermal efficiency of the absorber plates increases with the increase in mass flow rates of air due to the breakage of laminar sub-layer that creates higher turbulence of air, which results in greater heat transfer. But the increase of the turbulent flow is always on the account of the energy loss by the pumping system due to the friction.

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