IMPROVEMENT OF THERMAL PERFORMANCE OF THE SOLAR AIR HEATERS BY USING V- CORRUGATED ABSORBER PLATE AND PCM FOR HYBRID DESALINATION APPLICATIONS

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ABSTRACT

The thermal performance of v-corrugated plate solar air heater implementing with PCM as latent heat storage material was investigated experimentally. The v-corrugated plate solar air heater using paraffin wax its melting temperature 54 ^{o}C as PCM was manufactured and tested under Standard weather circumstances of Tanta town (30^{o} 43$^{/}$ N, 31^{o}E), Egypt. The parameters affecting the thermal performance of the v-corrugated plate solar air heater were presented with and without PCM. These parameters include solar radiation, the temperature difference of air through the heater, convective heat transfer coefficient between the absorber plat and the flowing air, instantaneous thermal efficiency, daily average efficiency and the PCM freezing time.

Also, the thermal performance parameters were studied when the mass flow rates were 0.062, 0.028 and 0.009 kg/s. The effect of changing the thickness of PCM blow the absorber plate was also studied. It is found that when using the PCM, the outlet temperature of the v-corrugated plate solar air heater is higher than ambient temperature by 1.5 – 7 ºC for 3.5 hr, 2- 10.5 ºC for 5 hr and 3-13 ºC for 8 hr after sunset when the mass flow rates are 0.062, 0.028 and 0.009 kg/s, respectively.

It is also concluded that the daily efficiency for the v-corrugated plate with using PCM are 62, 52 and 27 % compared with 50, 43.2 and 22.2 % for the same heater without using PCM when the mass flow rates are 0.062, 0.028 and 0.009 kg/s, respectively.

Keywords: Solar air heater; energy storage; v-corrugated; PCM and Desalination

1 INTRODUCTION

Recently, the use of renewable energy finds a lot of interest due to the adverse environmental effects produced by the conventional energy sources, reducing the global energy demand from fossil fuel energy sources [1]. The development of solar energy heating systems such as the supply of hot air using solar air heaters corresponds to a major problem during periods in which a private non-existent radiation after sunset [2]. The solar thermal energy storage has become a very active role in overcoming the diffused and periodic nature of the solar energy [3].

Latent heat storage (LHS) using phase change materials (PCM) is an effective tool to enhance the thermal performance of solar heating systems. These materials have the ability to store the excess of thermal energy throughout the day during its melting and restore it after sunset during its discharging under constant melting temperature and large storage density [4].

Many efforts had been carried out to improve the thermal performance of solar air heaters without using thermal heat storage material by increasing the heat transfer area, besides improving the turbulence in the air duct with introducing fins [5,6] or corrugated surfaces with different designs [7-9]. Karim and Hawlader [10] investigated flat plate, finned and v-corrugated air heaters experimentally and theoretically. They indicated that the v-corrugated collector is 10 –15 and 5–11%

more efficient, compared to flat and finned plate collectors, respectively when $\dot{m}$=0.04 kg/s. El-Sebaii et al. investigated double pass v-corrugated [11] and finned plate [12] solar heater experimentally and theoretically under forced convection mode, and compared their performances with the double pass flat heater. They found that the v-corrugated plate is 9.3 – 11% and 11-14 % more efficient than the finned and flat solar air collectors, respectively, when $\dot{m}$= 0.02 kg/s.

So far, a few studies dealt with the effect of using PCM on the thermal performance of the solar air heater. The different designs and parameters affecting the solar air heaters performance with using PCMs as thermal energy storage material are tabulated in detailed reviews performed by Mohammed et al. [13], Tyagi et al. [14] and Farid et al. [15]. Sharma et al. [16] also investigated in their survey the specifications of different types of PCMs and its classifications. Enibe [17] performed solar air collector with built-in PCM suitable for drying medicinal plant. Mettawee and Assassa [18] experimentally investigated integrated solar air heater implementing paraffin wax as latent heat storage material. They found that the discharging time and convective heat transfer coefficient increase as the PCM layer thickness blow the absorber plate is increased. Fath [19] investigated solar air heater using a set of copper cylinders filled with storage material as an absorber using paraffin wax as a PCM. He found that the daily efficiency is 63.35% when air flow rate equals 0.02 kg/s, and the hot air outlet temperature (5 ^{0}C above ambient temperature) extended for about 4 h after sunset, compared with 38.7% and 1.5 h, respectively, for the conventional flat solar air heater. Shalaby and Bek [20] carried out experimentally the performance of solar dryer with and without using paraffin wax as PCM. They found that after using the PCM, the temperature of the drying air is higher than ambient temperature by 2.5-7.5 ºC after sunset for seven hours at least. In addition, the solar heater provides a drying air temperature, after 2:00 pm, 3.5 to 6.5ºC more than the second case when it was free of PCM. Alkilani et al. [21] designed indoor solar air collector integrated with PCM using paraffin was as PCM genitive 0.5% aluminum powder to improve the heat transfer. They concluded that the PCM freezing time inversely proportional to mass flow rate and reached longer time 8 h at 0.05 kg/s. So far, there is no trial to use v-corrugated surface as well as using the PCM to improve the thermal performance of solar air heater.

In this work, for the first time as the authors know, the v-corrugated plat solar air heater is tested with and without using the PCM (paraffin wax) at a wide range of mass flow rates (0.009 - 0.062 kg/s) compared with (0.02-0.05 kg/s) as reported in the literature [11, 12, 19 and 21]. The effect of changing the thickness of PCM blow the absorber plate is also studied. Comparisons between the factors influencing the thermal performance of the proposed solar air heater were investigated with and without using PCM including the temperature difference of air through the heater, the instantaneous thermal efficiency, the daily average efficiency, the convective heat transfer coefficient and the PCM freezing time. In addition, the effect of insulating the glass cover surface of the solar air heater during night hours on the solar air heater thermal performance is also investigated.

2 THERMAL PERFORMANCE PARAMETERS

In this section, the governing equations of the thermal performance parameters of the solar air heater are evaluated as blow.
The useful thermal heat energy of the air across the heater (Q_u) is given by;

$$Q_u = \dot{m}\, c_p\, \Delta T_a, \qquad (1)$$

Where $\dot{m}$ is the air mass flow rate through the heater (kg/s), C_p is the specific heat of the air (J/kg,^{o}C) and ΔT_a is the temperature difference of air across the heater (^{o}C).
The mass flow rate through the heater ($\dot{m}$) is given by;

$$\dot{m} = \rho_a\, A_c v_a \qquad (2)$$

Where ρ_a is the air density through the heater = 1.2 kg/m^3, A_c is the across section area of the heater exit pipe (m^2) and V_a is the measured air velocity at the heater exit pipe (m/s).

Also, Reynolds number of the flow (Re) is given by;

$$Re = \frac{\dot{m}}{\pi d \mu} \tag{3}$$

where d is the diameter of the heater exit pipe (m) and μ is the dynamic viscosity of the flowing air that calculated at the average air temperature through the heater (Pa.s).

The instantaneous thermal efficiency of the heater (η_{ins}) is given by [22];

$$\eta_{ins} = \frac{Q_u}{I\ A_p}, \tag{4}$$

where A_p is the heater projected area (m^2) and I is the solar radiation incident on the heater (W/m^2). The convective heat transfer coefficient between the air and the absorber plate is given by [23];

$$h = Q_u \Big/ A_p\left(T_{pm} - T_{am}\right), \tag{5}$$

where Q_u is the useful heat gain by the air (W), T_{pm} is the average value of absorber plate temperature (^oC) and T_{am} is the average air temperature in the heater (^oC).

The daily efficiency of the collector. (η_{da}) is defined as the accumulative heat gain by the air to the cumulative input solar heat that incident on the heater throughout the day which is given by [22];

$$\eta_{da} = \frac{\sum Q_u}{\sum A_p I}. \tag{6}$$

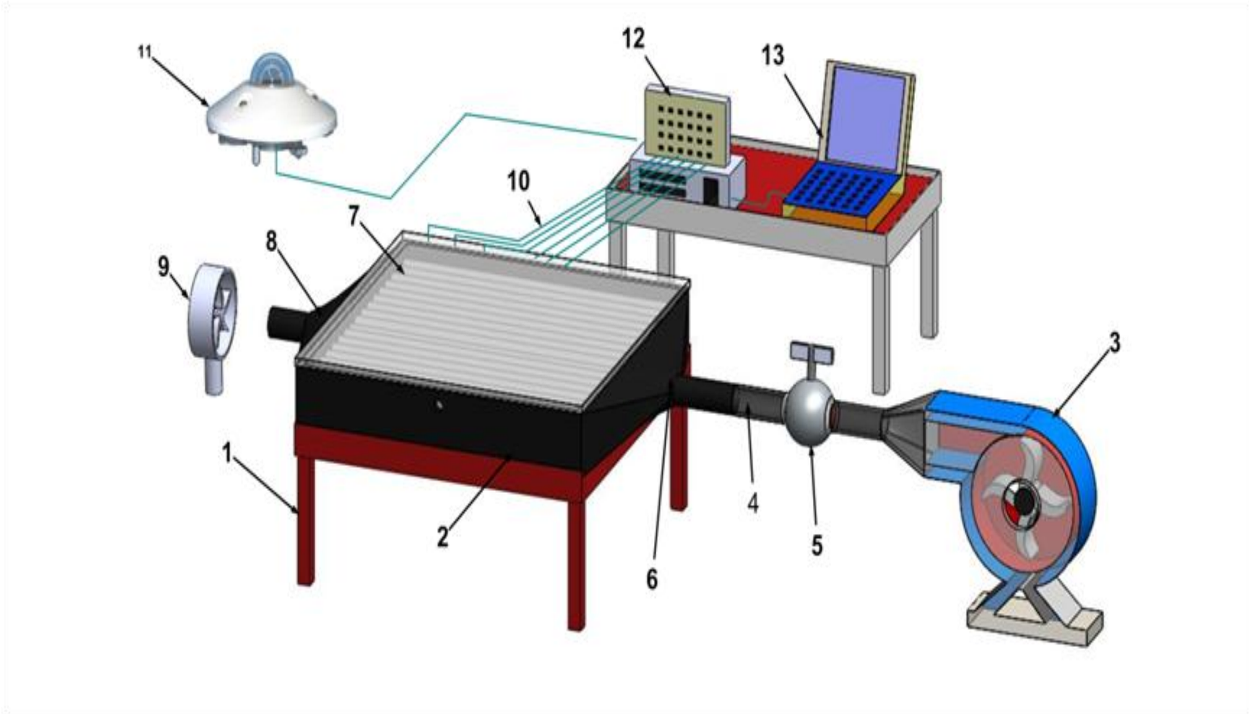
3 EXPERIMENTAL PROCEDURE

3.1. Experimental setup

The schematic diagram and photographic view of the experimental setup are shown in Fig. 1. (a) and (b). The experimental setup essentially consists of centrifugal blower, PVC connection pipe, solar air heater and PCM closed channel beneath the absorber surface of the heater.

The centrifugal blower was attached to air collector inlet with PVC connection pipe 10.5 cm inner diameter inserted with a gate valve used to control the air mass flow rate. The solar air heater was designed and fabricated using a local available material according to the guidelines of ASHRAE recommendations 93–77 [24]. It consists of a copper plate of 1 mm thickness was used as absorber plate which the projected area to solar radiation is 1x1 m^2 with total heat transfer area equals 1.8 m^2, the height of the v-groove is 2.15 cm and the v-corrugation angle is 60^o.The absorber v-corrugated surface was coated with mat black paint to increase the absorbed heat. A sheet of ordinary commercial glass (4 mm thickness) was used to cover the heater in order to minimize the top loss with an air gap 5 cm between the glass and the absorber plate.

The PCM closed channel was designed to be blow the absorber plate. It was fabricated from galvanized iron with 4 cm height and 1×1 m^2. Complete design of the air collector and the PCM closed channel are shown in Fig.2. The paraffin wax as PCM was used as energy storage material due to its high density storage, chemically stable, availability compared with other PCMs in Egypt and cheap price. The thermo- physical properties of the paraffin wax are given in Table 1.



1- Collector frame 2- Collector box 3- Centrifugal blower 4- PVC connection pipe
5- Gate valve 6- Conical inlet section 7- Glass cover 8- Conical exit section
9- Anemometer 10- DS- digital temperature sensors 11- Pyranoameter
12- ARDUINO board 13- PC-lap

(b)

Figure 1. (a) a schematic diagram of the experimental setup, (b) a photograph for the v-corrugated plate solar air heater system.

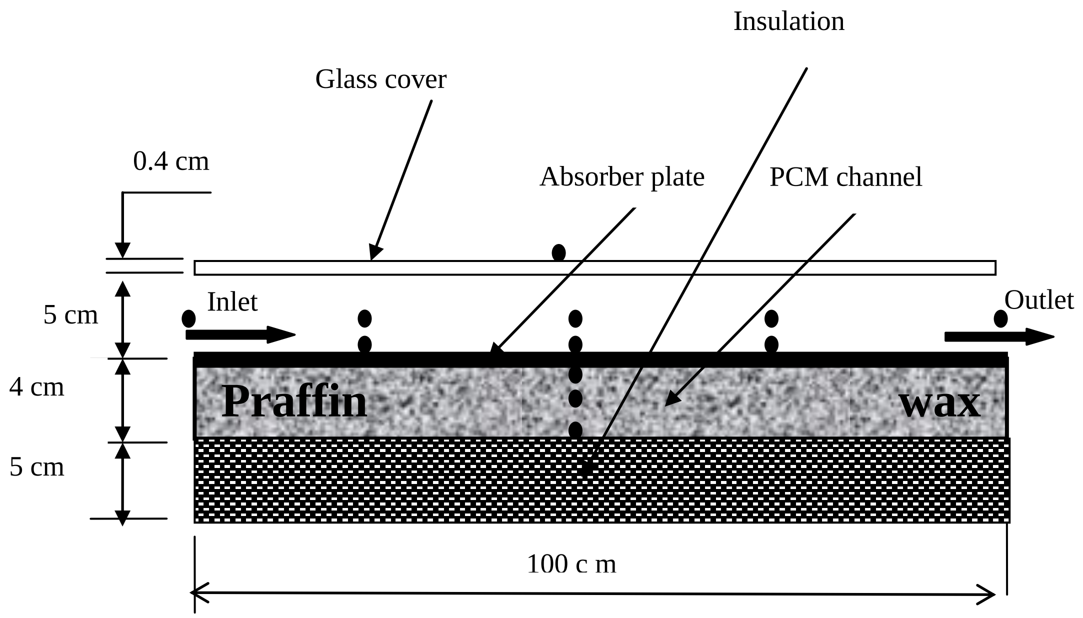


Figure 2. Section view of the solar air heater and the PCM channel.

The experiments were conducted when the thickness of PCM is 4 cm (the whole height of channel) and 2 cm. For 4 cm thickness of the PCM, the closed channel was completely filled with PCM where 38 kilograms of melting paraffin wax was poured from external channel located at the side of the heater to ensure that the surface of the paraffin is completely contiguous with the absorber surface. While, in the case of 2 cm thickness of the PCM, the total amount of paraffin wax was removed from the closed channel, after that, a layer of wood 2 cm thickness and 1×1 m^2 was inserted to the PCM channel. Then 19 kg of paraffin was poured in the same explained sequence to fill the channel with the prepared thickness. The PCM closed channel bottom and the sides of the heater were insulated using 5 cm foam layer. A conical exit section with exit pipe of 20 cm length and 10.5 cm diameter was installed to remove any downstream effect of air at the heater exit. The collector was used horizontally in order to avoid the leakage of the molten paraffin wax happens if the collector tilted by the site latitude angle 30^o.

Table 1 Thermo physical properties of paraffin wax as a PCM [25].

S. No.	Property	value
1	Melting temperature	54 ^{o}C
2	Latent heat of fusion	190 kJ/kg.^{o}C
3	Thermal conductivity	0.21 W/m.^{o}C
4	Solid density	876 kg/m^3
5	Liquid density	795 kg/m^3
6	Specific heat	2.1 kJ/kg.^{o}C

3.2. Measurements and experimental procedure

The v-corrugated solar air collector was tested with and without using PCM. Firstly, before holding the experiments, it was ensured that there was no leakage at all links, joints, and fittings of the heater, the PCM closed channel and all instruments were working properly. Experiments were carried out in the clear sky days during August and September 2015 at the Faculty of Engineering, Tanta University, Tanta (30^o 43$'$ N, 31^{o}E), Egypt. The total solar intensity I was measured using a high precision Pyranometer model MS-802 (sensitivity of 7.03µvolts/W m^2). Calibrated DS-digital temperature sensors (-10 : 125 ^{o}C) were used in order to sense the temperatures of flowing air and the absorber plate at various locations in flow direction through the heater. Three DS-digital temperature sensor were installed inside the PCM channel at various heights to obtain the average temperature of PCM. The DS-digital temperature sensors positions are seen in Fig. 3. Also the atmospheric temperature was measured by thermometer.

The pyranometer and digital temperature sensors were connected with microcontroller (ARDUINO) board coupled to PC-Lap to observe and recorded the solar radiation and the different temperatures in the same time every five minutes automatically and accurately. After that the recorded values by ARDUINO board was imported to Excel sheet and saved for any predetermined data sampling rate. A three-phase induction motor (3 HP, 3.5 A, 390 V, 50 Hz, 2810 r/min) connected to fan (0.4 m diameter) was used to blow the air through the solar air heater. The air flow rate was measured by the mean of calibrated anemometer at the collector exit which measure the air exit velocity at ten positions from the whole exit pipe diameter then the average velocity was determined to get the mass flow rate by knowing the cross section exit area and air density.

3.3. The uncertainty in measurements

The uncertainties in the experimental results were affected by the errors in the primary measurements. Experimental error analysis was checked according to Holman [26]. Let the result R is a given function of the independent variables X1, X_2, X_3, X_n.

$R=R\ (X_1, X_2, X_3 \dots X_n)$

Let W_R be the uncertainty in the result and W_1, W_2, W_3,…………, W_n be the uncertainties in the independent variables X_1, X_2, X_3,……., X_n, respectively. W_R can be calculated from the following equation [26]:

$$W_R = [(W_1\, \partial R/\partial X_1)^2 + (W_2\, \partial R/\partial X_2)^2 + \cdots + (W_n\, \partial R/\partial X_n)^2]^{0.5} \quad (7)$$

The relative error can be calculated as follows.

$$E_R = W_R/R\ \% \quad (8)$$

The uncertainties and relative errors in measurements of solar radiation intensity, air temperature difference across the heater, mass flow rate, useful heat gain by air, convective heat transfer coefficient and the thermal efficiency of the solar air heater are summarized in Table 2.

Table 2The uncertainties and relative errors in measurements

S. No.	Parameter	Max. value	Uncertainty	Relative error (%)
1	Solar radiation (W/m^2)	970	± 6	0.63
2	Temperature difference across the heater (^{o}C)	11	± 0.1414	0.58
3	Mass flow rate (kg/s)	0.062	±1.039*10^{-3}	1.675
4	Useful heat gain by the air (W)	685.4	± 14.478	2.112
5	Convective heat transfer Coefficient (W/m^2.^{o}C)	29.8	± 0.6554	2.201
6	Thermal efficiency (%)	70.56	± 0.01554	0.022

4 RESULTS AND DISCUSSION

The thermal performance of the v-corrugated plate solar air heater is presented with and without using PCM on a wide range of mass flow rates (0.062, 0.028 and 0.009 kg/s). All experiments are conducted when the thickness of PCM beneath the absorber is 4 and 2 cm. Firstly, the v-corrugated solar air heater is tested without using PCM when the mass flow rates are 0.062, 0.028, 0.009 kg/s on consecutives clear sky days of August and September 2015.

Figure 3 shows the hourly variations of the measured temperatures of different elements of the v-corrugated plate solar air heater without using the PCM on 23th of August 2015 when $\dot{m}$= 0.028 kg/s. It clear that the temperatures of the various elements increase with time as the solar radiation increases to show their maximum values at 12:30 pm and starts to decrease after that. The maximum measured values of T_p, Ta_{out} and Ta_{avg} are found to be 77, 65 and 53.5 °C, respectively. It also found that the maximum measured solar intensity is 960 W/m^2 at 12:30 pm and the ambient temperature varies between 30 and 37°C as clearly seen in Fig.3.

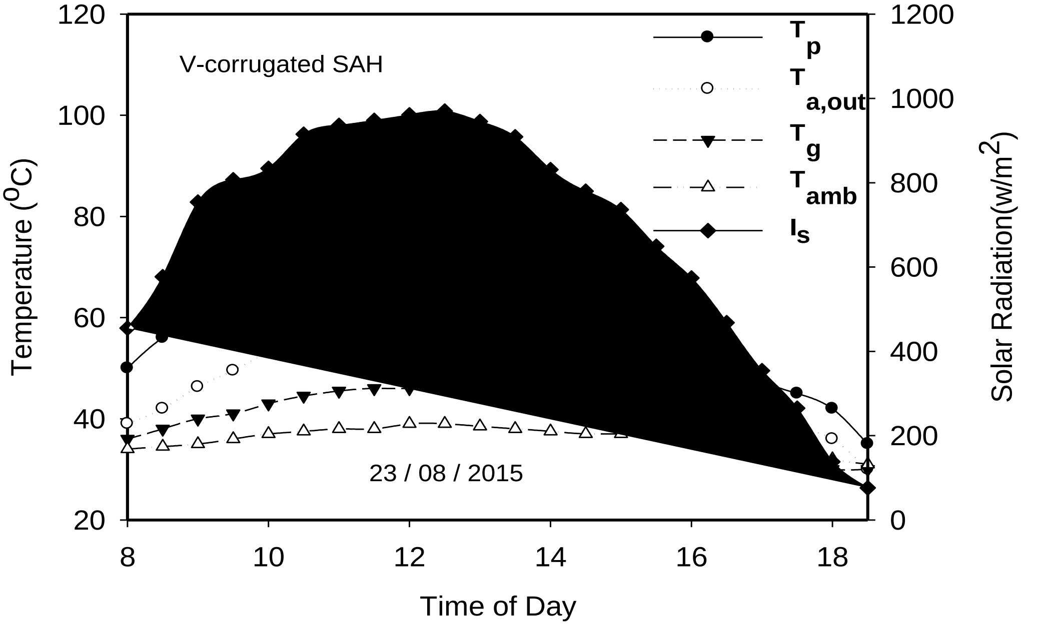


Figure 3. Measured temperatures of the different elements of the v-corrugated heater without PCM, vs. time on 23 th August 2015 when $\dot{m}$ = 0.028 kg/s.

In order to study the effects of using the PCM on the thermal performance of the solar heater, the v-corrugated plate solar air heater is also tested using 4 and 2 cm thicknesses of PCM when the mass flow rates are 0.062, 0.028 and 0.009 kg/s.

Figure 4 exhibits the hourly distribution of measured temperatures of different elements of the v-corrugated plat solar heater implementing 4 cm PCM thickness as well as the measured values of I and T_{amb} on 5th September 2015 when $\dot{m}$= 0.028 kg/s.

From the results of Fig. 4, it is clear that the PCM starts its melting at 1:30 pm then spend 2 hours to completely change its phase at constant melting temperature of 54 ºC. Then, the stored energy is recovered after 4:30 pm when the solar intensity decreases and the average temperature of the PCM is higher than the absorber plate temperature (discharging process). So, the outlet air temperature remains higher than ambient temperature for many hours after sunset. It is also concluded that, the maximum values of $T_{a,out}$ and T_{PCM} are found to be 60.5 ºC and 60 ºC, respectively.

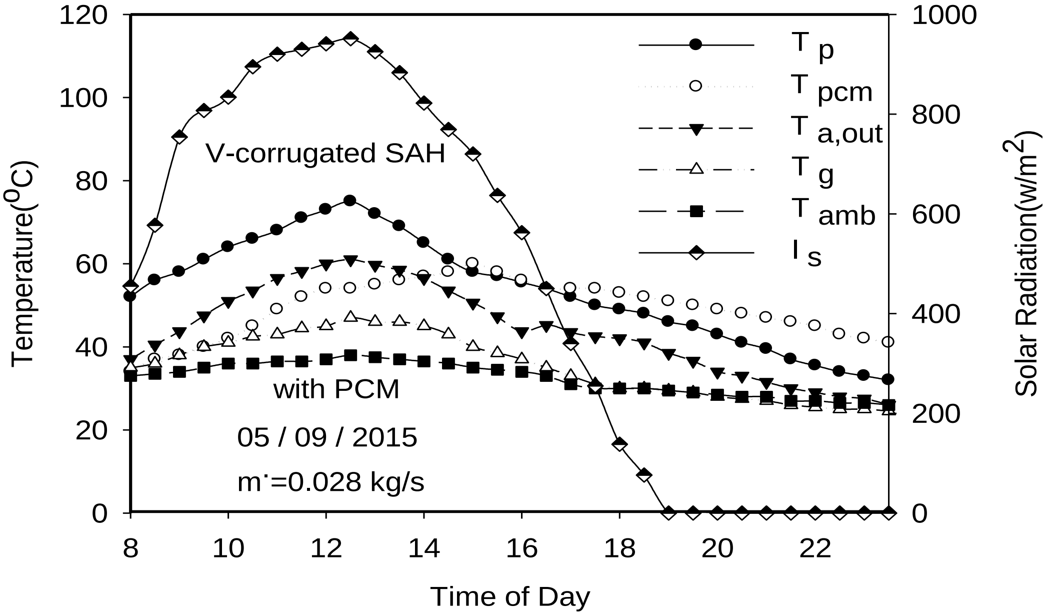


Figure 4. Temperature distribution of the different elements of the v-corrugated plate heater with PCM, vs. time on 5st September 2015 when m· = 0.028 kg/s.

The effect of using the PCM is obviously seen in Fig. 5 as the outlet temperature of air is higher than ambient temperature by 2-10.5 ºC for 5 h after sunset.

A comparison of the temperature difference of air through the v-corrugated plate solar air heater without and with using PCM when the mass flow rate is 0.062 kg/s is presented in Fig. 5. According to the results obtained from Fig. 5, it is observed that, when tested the heater without using PCM the temperature difference of air a cross the heater increases with time as the solar radiation increases reach its peak value at 12:30 PM and then it decreases to be zero at the evening.

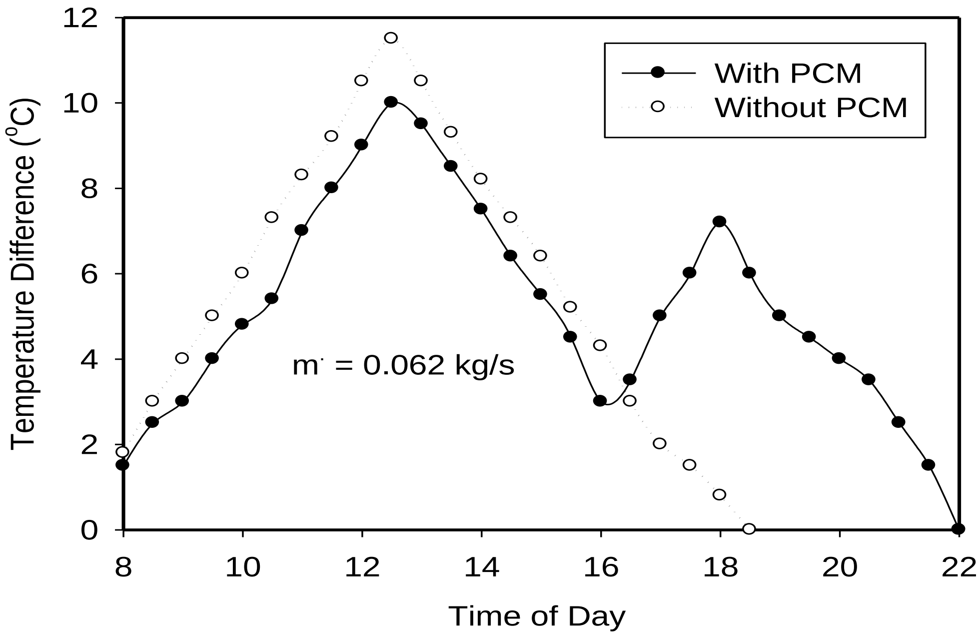


Figure 5. A comparison of the measured temperature difference of the air through v-corrugated plate solar air heater with and without using PCM when m· = 0.062 kg/s

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It is also obviously observed that the air temperature differences across v-corrugated plate solar heater when using PCM are less than that one's without PCM at the period from 8:00 am to 4:30 pm.

This refers to the large amount of stored thermal energy within the PCM from the absorbed heat during the charging process which leads to reduce the heat gain by the flowing air. The stored energy is recovered after 4:30 pm when the solar intensity decreases and the average temperature of the PCM is higher than the absorber plate temperature (discharging process). During the discharging process (after 4:30 pm) the air temperature differences are increased sharply to reach the peak values at 6 pm (close to sunset) then it decreases slowly to become zero at the end of the discharging process.

Figures 6 and 7 also represent a comparison of the temperature difference of air through the v-corrugated plate solar air heater without and with using the PCM when the mass flow rates are 0.028 and 0.009 kg/s, respectively. It is clear that the temperature differences across the heater increases when the mass flow rate decreases as seen in Figs.7 and 8. This attributed to the reduction of $m^{\cdot}$ with the same quantity of solar radiation leads to increase of the air temperature difference across the heater [11,12] .

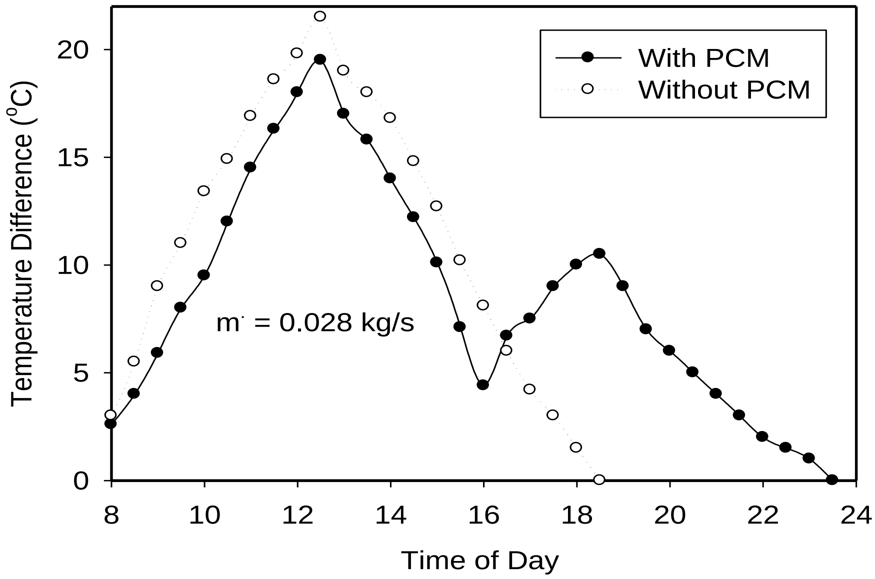

Figure 6. A comparison of the measured temperature difference of the air through v-corrugated plate solar air heater with and without using PCM when $m^{\cdot}$ = 0.028 kg/s.

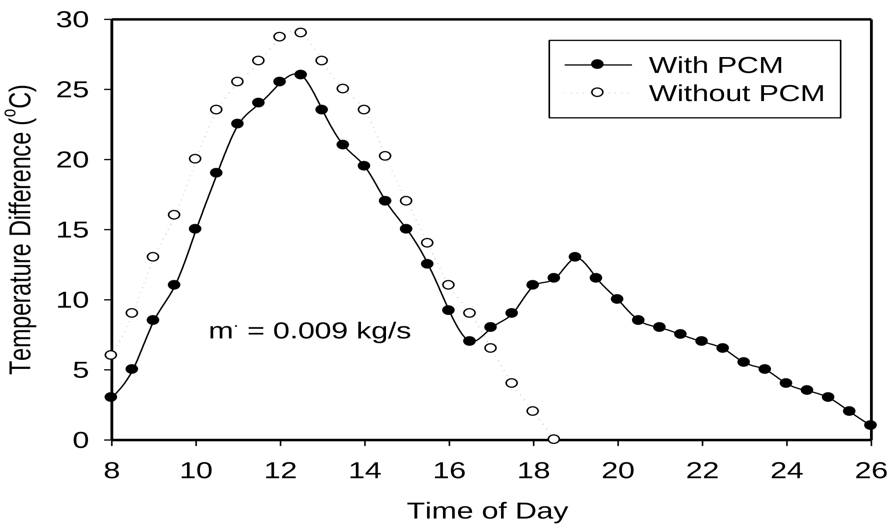

Figure 7. A comparison of the measured temperature difference of the air through v-corrugated plate solar air heater with and without using PCM when $m^{\cdot}$ = 0.009 kg/s.

From the results obtained from Figs.5 -7, it is concluded that when using the PCM, the outlet temperature of the v-corrugated plate solar air heater is higher than ambient temperature by 1 - 7.2 ºC for 3.5 hrs after sunset, 2 – 10.5 ºC for 5 hrs after sunset and 3 –13 ºC for 8 hrs after sunset when the flow rates equals 0.062, 0.028 and 0.009 kg/s, respectively.

The v-corrugated plate solar air heater is tested also when the thickness of the PCM is reduced from 4 to 2 cm. Figure 8 indicates the effect of changing the PCM layer thickness on the air temperature difference across the v-corrugated plat solar heater, when $m^{\cdot}$=0.028 kg/s. It is clearly seen in Fig. 11 that when the PCM layer thickness decreases from 4 cm to 2 cm the air temperature difference across both heaters increases during the melting process period (from 8 am till 4:30 pm), after that it decreases during the discharging process period and extends for several less hours after sunset because of the reduction of thermal energy stored when the mass of the PCM is decreased.

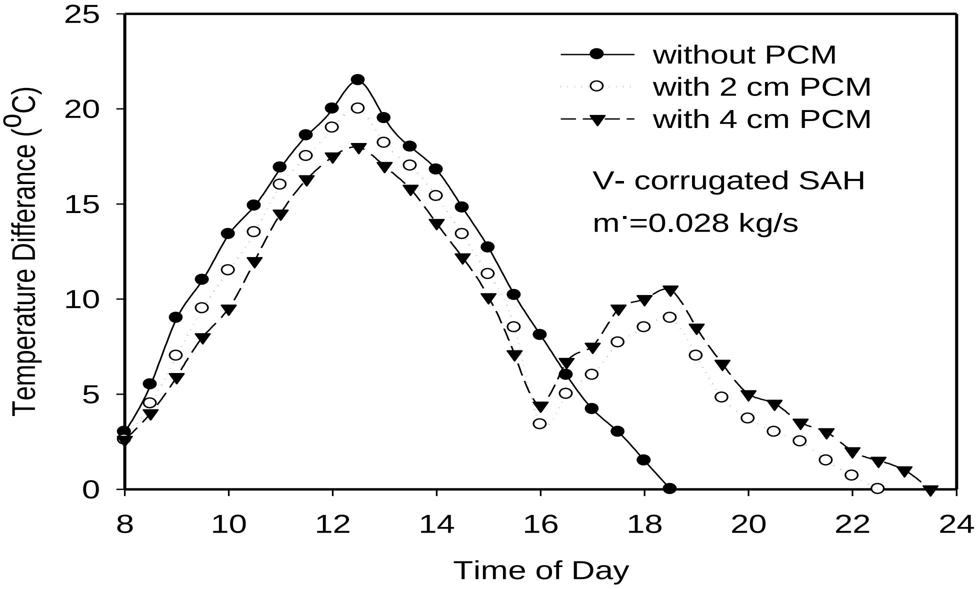

Figure 8 Temperature difference of air across v-corrugated air heater vs. the time with 4 cm, 2 cm PCM thickness and without using the PCM at $m^{\cdot}$=0.028 kg/s.

It is also concluded that when using 2 cm as PCM layer thickness, the outlet temperature of air is higher than ambient temperature by 1.5- 8.3 ºC after sunset for 4 hrs compared with 2-10.5 ºC after sunset for 5 hrs when 4 cm of PCM is used when the mass flow rate is 0.028 kg/s as obtained from the results of Fig.8.

The convective heat transfer coefficient between the v-corrugated plate and the flowing air is calculated from Eq. 5 using the obtained experimental results of the v-corrugated heater with and without using the PCM.

Figures 9-11 refer to the convective heat transfer coefficient of the v-corrugated plate solar heater via time with and without using the PCM when the mass flow rates are 0.062, 0.028 and 0.009 kg/s, respectively.

Clearly, It is seen in Figs. 9-11 that when using PCM the convective heat transfer coefficient increases with time to reach its1st peak at 12:30 pm and then decrease till 4:30 pm then it increases again to reach its 2nd peak at 6 pm at all flow, after that, it decreases slowly to be equal zero after a few hours of sunset. It also observed that the convective heat transfer coefficient with using the PCM is much lower than that one's without using the PCM at the period from 8:00 am to 4:30 pm. Besides, the convection heat transfer coefficient increases as $m^{\cdot}$ increases mainly due to the direct increase of useful heat gain by air as $m^{\cdot}$ increases as seen in Eq. 1.

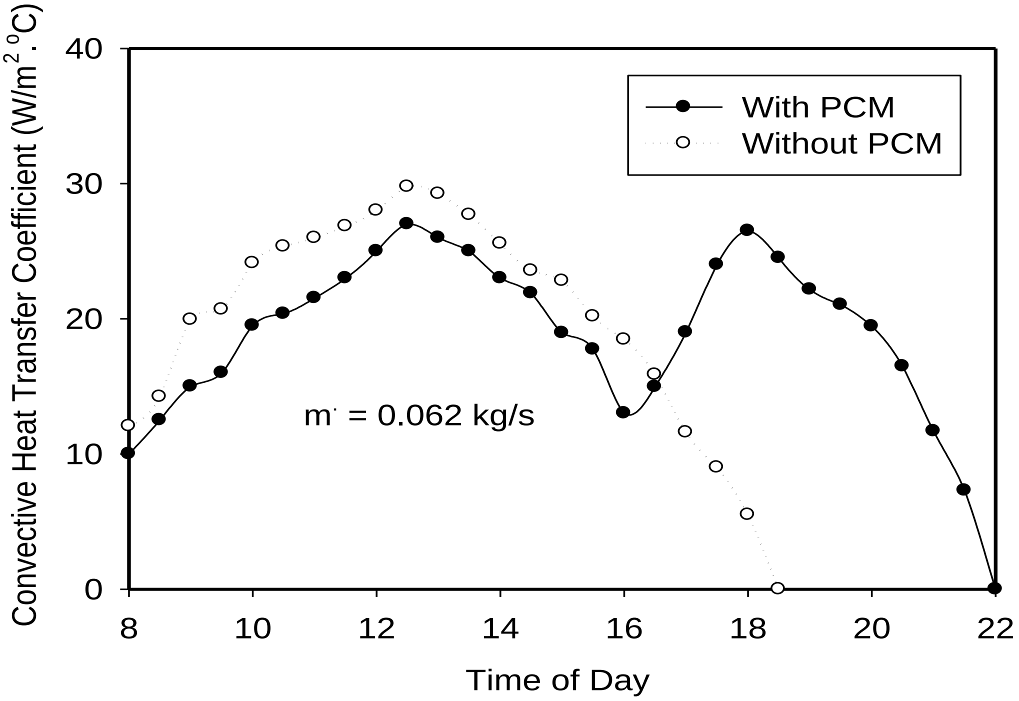

Figure 9. the convective heat transfer coefficient of air through v-corrugated plate solar air heater via time with and without using PCM when m· = 0.062 kg/s.

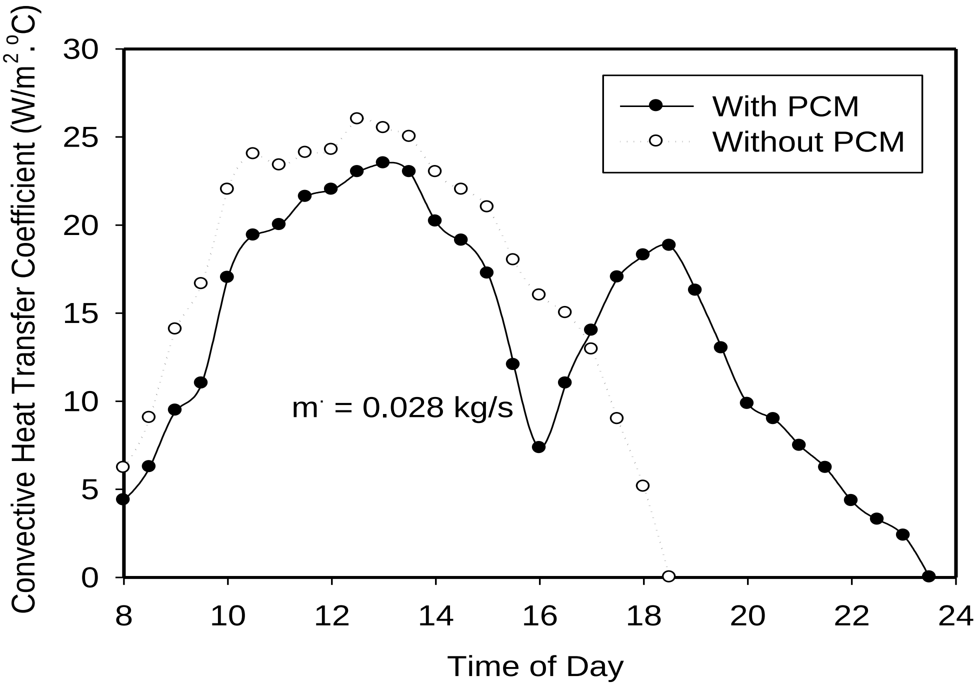

Figure 10. the convective heat transfer coefficient of air through v-corrugated plate solar air heater via time with and without using PCM when m· = 0.028 kg/s.

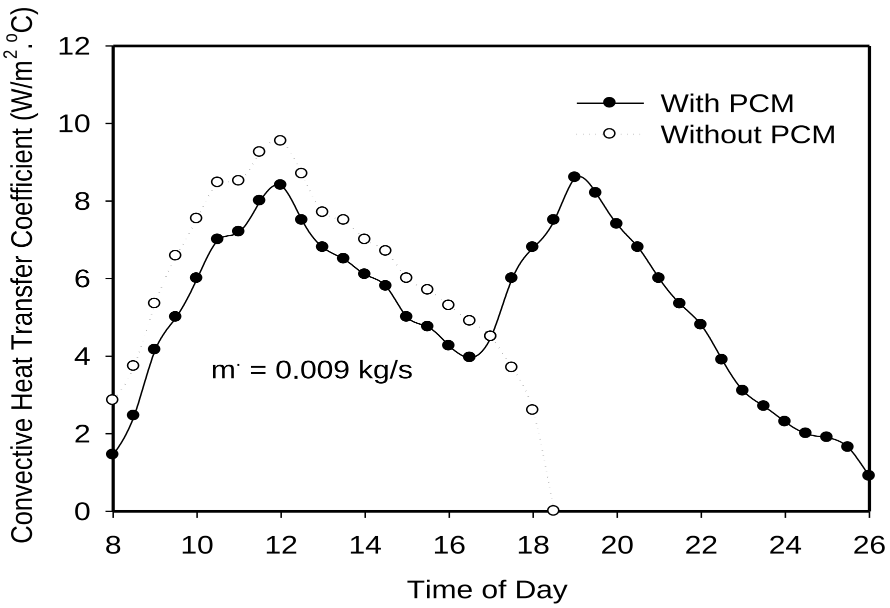

Figure 11. the convective heat transfer coefficient of air through v-corrugated plate solar air heater via time with and without using PCM when m· = 0.009 kg/s.

In order to note the improvement of using the PCM on the thermal performance of the v-corrugated heater; it is important to compare the daily average efficiency of the v-corrugated solar air heater with and without using the PCM. Figure 12 illustrate a comparison of the daily average efficiency of the v-corrugated plate solar air heater with respect to Reynolds number with and without using the PCM.

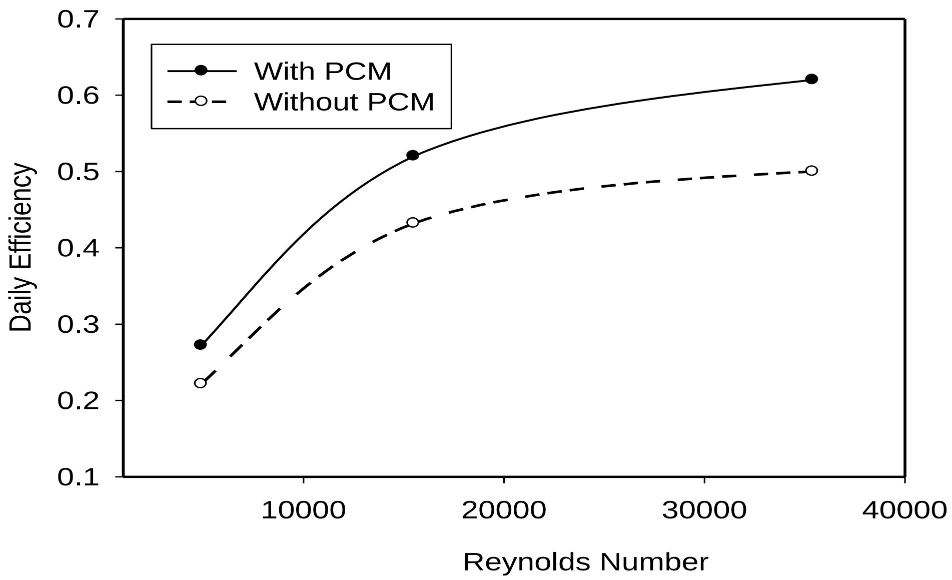

Figure 12. A comparison of the daily average efficiency of the v-corrugated plate solar air heater with respect to Reynolds number with and without using the PCM

Obviously, it is observed that the daily efficiency of the v-corrugated plate solar air heater with using PCM is much better than that one's without using the PCM due to the fact that the accumulative useful heat gain by air for several hours after sunset in the absence of the solar radiation when using the PCM at all flow rates. Also, it is noticed also that, the daily efficiency of the heater increases when Reynolds number increases, as $\dot{m}$ is increased, due to high useful heat gain by air and low heat losses. From the results of Fig.15, it is concluded that when using the PCM, the daily efficiency of the v-corrugated solar heater are 62, 52 and 27 % compared with 50, 43.2 and 22.2 % for the same plate heater but, without using PCM at flow rates 0.062, 0.028 and 0.009 kg/s, respectively.

Comparison between the current obtained results with those due to Fath [19], Shalaby and Bek [20] and Esakkimuthu et al. [27] are summarized in Table 3.

5 CONCLUSIONS

The v-corrugated plate solar air heater with PCM (paraffin wax) as latent heat thermal energy storage material was experimentally investigated The integrated solar air heater uses paraffin wax with melting temperature 54 ^{o}C as PCM as latent heat thermal energy storage material.

The study is adopted to investigate the influences of the main parameters on system performance. In conclusion, the main results from this paper are summarized below:

- The outlet temperature of air is significantly affected when the PCM is used the solar air heater especially during night (after sunset).
- The outlet hot temperature of the v-corrugated plate solar air heater is higher than ambient temperature by 1.5 – 7 ºC for 3.5 hr, 2- 10.5 ºC for 5 hrs and 3-13 ºC for 8 hr after sunset when the mass flow rates are 0.062, 0.028 and 0.009 kg/s, respectively.
- When using the PCM, the daily efficiency of the v-corrugated solar heater are 62, 52 and 27 % compared with 50, 43.2 and 22.2 % for the same plate heater but, without using PCM at flow rates 0.062, 0.028 and 0.009 kg/s, respectively.
- As the mass flow rate increases, the daily and instantaneous thermal efficiency increase with and without using PCM. However, the air temperature difference across the heater, the amount of heat stored and the PCM freezing time decrease.
- When the PCM layer thickness decreases to 2 cm , the air temperature difference across the heater slightly increases during the PCM melting process (8:00 am to 4:30 pm) and it slightly decreases during PCM discharging process that it extends for several less hours comparing with the case where the thickness of the PCM layer is 4 cm.
- Finally, it is recommended when using the PCM, the v-corrugated plate solar air heater is an effective way to improve the thermal performance of the solar air heater which considered predominantly useful for drying and desalination applications.

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Table 3. Comparison between the current study and similar studies

Ref.	Absorber Type	PCM Type	m· per unit area (kg/s.m^2)	Melting temperature (^{o}C)	PCM Mass (kg)	Heater area (m^2)	($T_{a,o}$ –T_{amb}) After sunset (^{o}C)	PCM Freezing time (h)
[19]	Set of staggered cylinders	Paraffin wax	0.03	50	Not mentioned	1	5	1.5
			0.02				7	4
			.01				5-12	9
	Flat plate	Paraffin wax	0.03	50	Not mentioned	1	Not mentioned	Not mentioned
			0.02				3	1.5
			0.01				3 - 6	6
[21]	Flat plate	Paraffin wax	0.037	49	12	3.32	2.5 – 7.5	7
[28]	Flat capsulated with PCM balls	HS-(58)	0.0185	58	125	6	5-11	6
Current Study	V-corrugated plate	Paraffin wax	0.062	54	38	1	1.5- 7	3.5
			0.028				2- 10.5	5
			0.009				3 - 13	8
	V-corrugated plate	Paraffin	0.028	54	19	1	1.5- 8.3	4