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PERFORMANCE OF DUAL SOLAR COLLECTOR WITH SETTING PCM UNDER ABSORBENT PLATE

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Abstract- The dual collector has ability to simultaneously warm up water and air. In this study, firstly the performance of the collector normally and without using PCM (the phase change material) were evaluated, and secondly the efficiency effect of the collector is examined by placing PCM material under absorbent plate. The PCM is the type of paraffin and commercial wax with a melting temperature 54.3 °C. The charge of these materials is obtained from the heat generated by the collision of radiation with absorbent plate. Experiments indicate that charging is taking place in the early hours when the sun's rays is not exist, then the PCM has been discharged that its impact on efficiency became also clear, because it could maintain outlet air temperature significantly above ambient temperature after the sunset for three hours and forty. In these experiments, the flow of water in the form of thermosyphon and active air flow by the fan was in a state of coercion.

Keywords: Dual Collector, Phase Change Material (PCM), Solar Radiation, Efficiency.

I. INTRODUCTION

Since solar radiation is an inherently time-dependent energy resource, the storage of energy is essential if solar radiation is to meet energy needs at night or during daytime periods of cloud cover and makes a significant contribution to total energy needs. Since radiant energy can be converted into a variety of forms and feasible to be stored such as; thermal energy, chemical energy, kinetic energy, or potential energy. Generally, the choice of the storage media is related to the end use of the energy and the process employed to meet this application. The optimum capacity of the storage device for a given solar process depends on the time dependence of the solar availability, the nature of the load, the cost of auxiliary energy, and the price of the process components. These factors must all be weighted carefully for a particular application to arrive at the system design (including storage size), which minimizes the final cost of delivering energy [1, 2].

Storage of solar energy is important for the future success of solar energy utilization. The major problem is the selection of materials having suitable thermophysical characteristics in which solar energy in the form of heat can be stored [3].

II. HISTORIC OVERVIEW FOR USING OF PCM

The design, construction and performance evaluation of a passive solar powered air heating system is presented. The system, which has potential applications in crop drying and poultry egg incubation, consists of a single-glazed flat plate solar collector integrated with a phase change material (PCM) and heat storage system. The PCM is prepared in modules, with the modules equispaced across the absorber plate. The spaces between the module pairs serve as the air heating channels, the channels being connected to common air inlet and discharge headers (Figure 1).

The system was tested experimentally under daytime no-load conditions at Nsukka, Nigeria, over the ambient temperature range of 19-41 °C, and a daily global irradiation range of 4.9-19.9 $MJ.m^{-2}$. Peak temperature rise of the heated air was about 15 K, while the maximum airflow rate and peak cumulative useful efficiency were about 0.058 $Kg.s^{-1}$ and 22%, respectively. These results show that the system can be operated successfully for crop drying applications. With suitable valves to control the working chamber temperature, it can also operate as a poultry egg incubator [4].

Boy and colleagues proposed an integrated collector storage systems based on a salt hydrate phase change materials as an appliance for providing hot water instantaneously. They demonstrated that the thermal efficiency of such systems could be improved significantly by incorporating an appropriate PCM device. However, in their system the salt hydrate PCM was encapsulated in a special corrugated fin heat exchanger, which increased the cost of the system. One of the ways that today in energy systems, especially in solar system has entered is the use of phase change material. Phase change materials can store excess heat and release the heat at the appropriate time [5].

Figure 1. The air heating system: A, collector assembly with energy storage and air-heating subsystems; B, heated space [4]

Compared solar water heating systems with PCMs to conventional solar water heating systems is shown in Figure 2. Polyethylene bottles were filled with a PCM and set into the tank as three rows. The total mass of PCM used in the heat storage tank was approximately 180 Kg. The results indicate that the water temperature has a constant value of 46 °C during the night until sunrise, as the hot water was not consumed. The temperatures between the midpoint of the heat storage tank and the outlet of the collector of the heat storage tank with the PCM is greater than that of the system without a PCM, by an average value of approximately 6 °C. This temperature difference is considerable with exhibiting the high heat storage performance of the heat storage system with a PCM. The storage time of hot water, the mass of hot water produced to use, and the total heat accumulated in the heat storage tank that contains some hydrated salts were approximately 2.59-3.45 times greater than that of conventional solar energy systems with a heat storage tank that does not include a PCM [6].

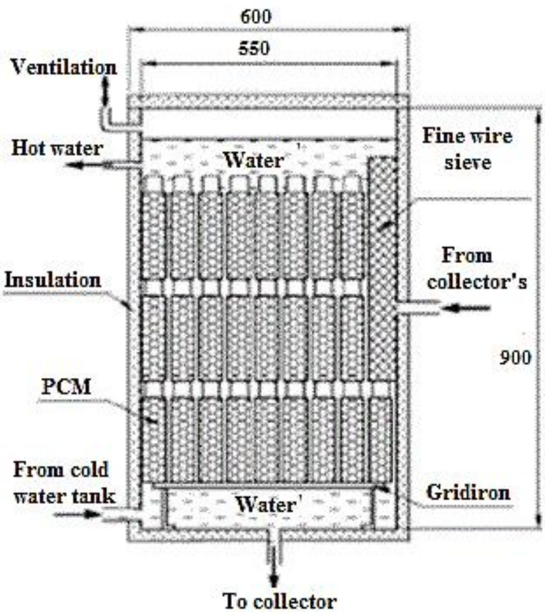

Figure 2. Cross-section of the storage unit designed [6]

III. MATERIALS AND METHODS

A. Designing a Holding Chamber PCM

To store thermal energy in dual collector system two materials were used. One, water absorption of heat in the form of sensible heat storage and the other was commercial paraffin wax as latent heat storage which was responsible for this task in the solar system. Full characteristics of paraffin wax is written in Table 1.

The Paraffin wax is a white (Figure 3) or colorless soft solid derivable from petroleum, coal or oil shale, that consists of a mixture of hydrocarbon molecules containing between twenty and forty carbon atoms. General formula of paraffin is C_nH_{2n-2}.

Table 1. Characteristics of paraffin wax [7, 8]

PCM	Melting temperature °C	Latent heat KJ/Kg	Heat conductivity W/m.K	Density K/m^3
paraffin wax commercial	54.3	243.5	0.16	809

The melting temperature is calculated based on the following experiments:
Some of PCM in a metal container heated gradually until the melting of PCM and this experiment done three times and melting temperatures were save in data logger which were between 54 °C and 55 °C; consequently average melting temperature for PCM was calculated 54.3 °C.

Figure 3. Paraffin wax

Paraffin wax conductivity is around 0.16 W/m.K. To increase the rate of heat transfer to the phase change material, surface area of selective chamber PCM is considered (2×6 cm^2) according to Figure 4, and was used for these lateral Feins made of aluminum with lateral area ((2+2)×200 cm^2) and thickness 2 mm. These Feins were located on the sides of paraffin wax chambers and they transferred heat from the sides to the paraffin chamber (Figure 5). In addition these Feins were the cause of increasing the rate of heat transfer to the air.

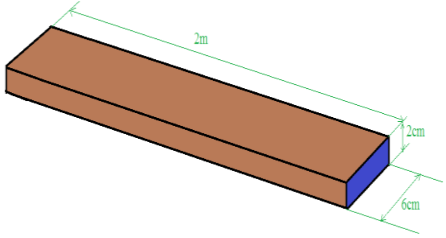

Figure 4. Dimensions of the chamber PCM

B. Characteristics of Collector and Tank

A. The thickness of glass is 6 mm and its surface is 2×1 cm^2,

B. Absorbent plate made of aluminum is with the thickness of 1 mm and the surface in contact is with radiation 0.9×1.9 m^2,

C. The thickness of the underside insulation is 4 cm and the aside insulation is 2 cm,

D. The diameter of the rise pipes is 10 mm and the diameter of the header pipes is 16 mm that both of them were made of copper.

E. The number of rise pipes used is 7.

G. There are 14 Fein to storage and transfer heat to paraffin chamber as sown in Figure 5.

H. Used tank has a volume of 84 liter with the diameter of 34 cm and height of 98 cm.

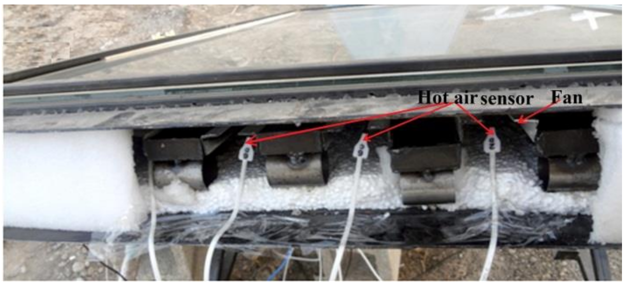

Figure 5. The hot air sensors and Feins in dual collector

All experiments were performed in Dezful city (Iran) with latitude of 48.2 degree and longitude of 32.3 degree in smooth air which the collector angle was 20 degrees. In calculating the efficiency of water temperature was considered equal to the average temperature of the tank and temperature for the outlet air temperature was medium.

Figure 6 shows that air flow with use of fan (active) through a channel enter under absorbent plate with PCM and absorb the heat from absorbent plate and hot PCM, then exit from end of the collector. Water closed cycle which work in thermosiphon (inactive) condition flow from tank to under the absorbent plate which is include two independent pipe line and absorb heat from absorbent plate and hot PCM, eventually exit from end of collector and pour into tank. The 9 sensors are on the absorbent plate, 4 sensors are in the hot outlet air direction, there is one sensor in the environment and also there are 26 sensors in the water tank for evaluate the temperature and all of these sensors informations saved in a data logger.

IV. EXPERIMENTAL RESULTS

The first experiment had been done without using PCM in dual collector which in that system, water heater in the form of thermosyphon and air heater with Debbie (0.034 Kg/s) connected to the fan according to Figure 7.

The test started at 8:40 am and lasted until 19:40. Maximum average temperature in the tank at 17:00 pm obtained to the amount of 57.8 °C and maximum average temperature of absorbent plate at 13:00 was 75.8 °C.The second experiment was performed by using PCM in dual collector.

The chamber of PCM is as shown in Figure 4 and was connected below the absorbent plate. In all compartments PCM were placed 15 Kg. Phase-change material made of paraffin wax with a melting temperature of 54.3 °C. The experiment was continued 20:20 pm to 21:00 pm. After 17:00 radiation decreased but until 21:00 the outlet temperature of air heater was higher than ambient temperature, which shows well the effect of using PCM in this test.

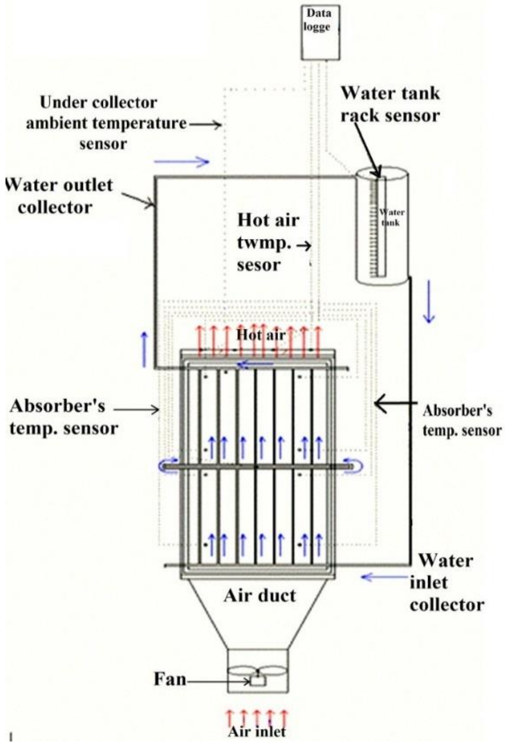

Figure 6. Schematic diagram of the experimental set-up in dual collector and thermosyphon condition

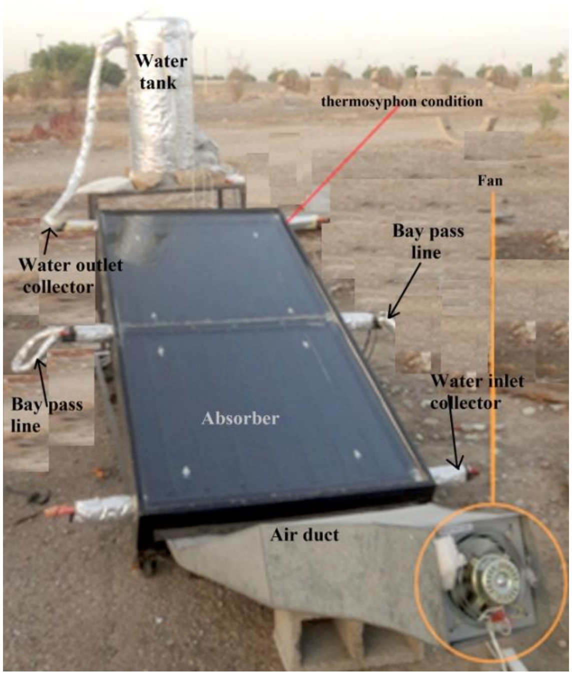

Figure 7. The set-up of dual collector in thermosyphon condition

By comparing the temperature of the absorbent plate in two tests during the day in the two states, with and without using PCM (Figure 9), it is evident that the case of using PCM average temperature of absorbing until about 18:20 is less than the state of without using PCM, thus, the case of using PCM thermal dissipation is less than without it, and air heater outlet temperature in the case of without using PCM until 17:00 is approximately more than case of using PCM. This reduction is due to the heat that is storing in the PCM.

The heat stored in the PCM from 17:00 onwards showed its impact. The efficiency of the system in Equation (4) with unused PMC except in 14:00 and 18: 00 was reported more than the state of using PCM as shown in Figure 10. The system equation are as the following [4]:

$$\dot{Q}_{u.w} = \dot{m}_w c_{water} \Delta T \quad (1)$$

$$\dot{Q}_{u.a} = \dot{m}_a c_{air} \Delta T \quad (2)$$

$$\dot{Q}_{u.t} = \dot{Q}_{u.w} + \dot{Q}_{u.a} \quad (3)$$

$$\eta = \frac{\dot{Q}_{u.t}}{A_c \times G} \quad (4)$$

where,

$\Delta T = T_{out} - T_{in}$

$c_{air} = 1004$ J/Kg.K

$c_{water} = 4180$ J/Kg

$A_c = 1.9 \times 0.9$ cm

The radiation area of absorbent plate is described in Equation (2).

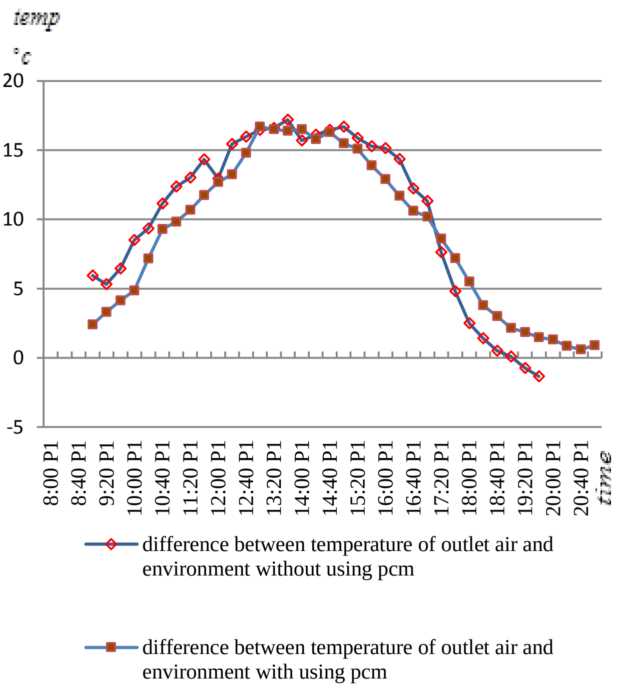

Figure 8. Comparison between temperature of air heater's outlet and environment in the two state of with and without using PCM, Temperatures recorded in certain hours by data logger

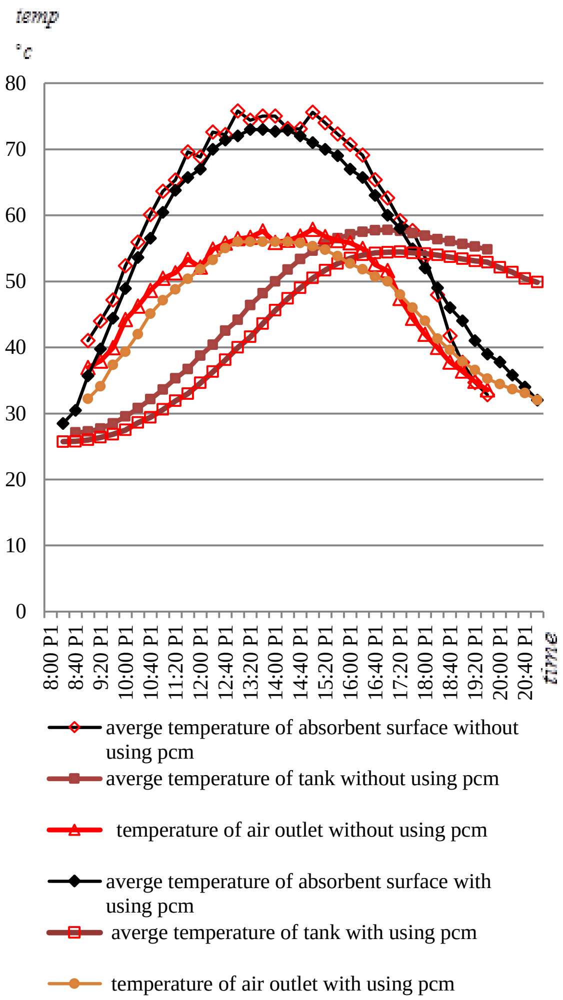

Figure 9. Comparison between the two state of with and without using PCM in thermosyphon condation. Temperatures recorded in certain hours by data logger

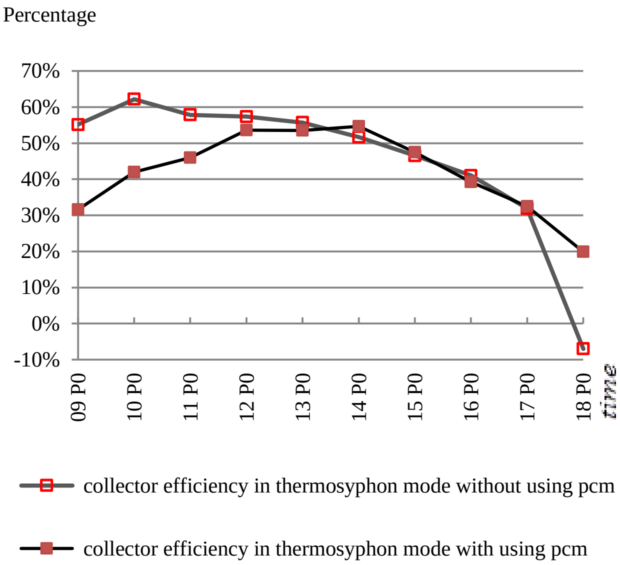

Figure 10. Comparison of the collector efficiency in thermosyphon mode with and without using PCM

Figure 10 illustrates comparison between efficiency of collector with and without using PCM. This line graph is drawn according to calculation of Equation (1), Equation (2) and consequently efficiency in Equation (4).

V. CONCLUSION

In calculation of the collector efficiency using the phase change material, the rate of absorbed energy absorption was not entered because the amount of energy absorbed by the PCM and percentage melting of the material was unknown. But, it is possible to detect the times that phase change material melted more or less. On this basis, in the water heater operated as a thermosyphon, paraffin more rapidly began to melt at the beginning of the radiation because the efficiency extremely decreased at 9:00 in the morning that was because of the extreme heat absorbed by the PCM at that time.

The process of melting PCM has probably ended at 13:00 because decrease of efficiency did not happen anymore and at 14:00 onwards the collector efficiency is increased by using PCM, which is because of releasing energy by PCM, after 17: 00 radiation was reduced but until 21:00, air heater outlet temperature was more than ambient air (Figure 8), which well shows the effect of using PCM.

NOMENCLATURES

$\dot{Q}_{u.t}$: Total useful heat

$\dot{Q}_{u.w}$: Useful water heat

$\dot{Q}_{u.a}$: Useful air heat

ΔT : Difference of temperatures, °C

T_{out} : Outlet temperature, °C

T_{in} : Inlet temperature, °C

C: Specific heat, J/Kg.K

A_c : Area, m^2

η : Efficiency, %

G: Solar irradiance, $W.m^2$

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