Experimental Study of Thermal Performance of a Solar Collector Combined with Paraffin Wax as Phase Change Material PCM

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Abstract- **In this paper, an experimental study has been carried out on the thermal performance of PCM by using it in solar collector. The research was performed in lab condition with different heat flux. The solar collector consists of a unique system. The system consists of evacuated tube ET, thermosyphon TH, water tank with container of phase change material PCM. ET consists of two layers of glass evacuated of air. The TH is copper tube which consists of two parts. The first part is called the evaporator which is set inside evacuated tube. The second part is called the condenser which is put in the water tank. The paraffin wax is used as PCM, located in container which represents interior walls of the water tank. The PCM works in two phases: solid and liquid. The average temperature of the water tank with wax is less than the temperature without wax during the charging and is higher than without wax during the discharge. Water temperature continuous to be high than 35 °C until the next day with a high load conditions. With less drawing of hot water, the temperature will be higher than 35 °C. The temperatures of the thermosyphon and the water tank have increase 10 °C, 6 °C respectively when the heat flux increases 33.3 %. The time of PCM melting has decreases with a rate of 25% with the increases of the heat flux 33.3%.**

Keywords— Solar Collector, Evacuated Glass Tube, Phase Change Material, Thermosyphon , Paraffin Wax

I. INTRODUCTION

The solar energy is considered one of the most importance sources of energy without any pollution in the world. This energy has no negative effect on the human being. Hence the solar energy forms the bases for other renewable energy sources. Researches are non-stop to achieve: the reduction of product cost, and the improvement of performance of the solar energy [1]. The thermal performance and its improvement of solar collector have been studied theoretically and experimentally in different ways. Budihardjo et al. [2] studied a number of solar collectors and found that the best type was glass evacuated tube solar collector especially in the process of water heating. Liang et al. [3] tried to experimentally investigate evacuated tube solar collector with special tube called "U-tube". They found that the thermal performance and exergy are higher than in the evacuated type -copper tube. Azad [4] studied the thermal performance of solar collector with heat pipe under outer condition. The results showed that efficiency of the system increase with the increase of the number of heat pipes. Carlos et al. [5] investigated the effect of hot water in the tank of a solar collector with a heat pipe on the thermal performance in the system. The results showed that the temperature of hot water increases with the decrease of the storage energy of the system. Kavitha and Arumugam [6] tried experimentally to study the PCM with a solar collector. The PCM used was paraffin wax. The PCM was put in Galvanized iron tubes and arranged in especial way criss cross. The results indicated that the thermal efficiency has increased with the PCM and with the increase of the number of tubes. Mettawee et al. [7] tried in experimental wok to use the PCM (paraffin wax) which was used as storage medium with a solar collector. The PCM was combined with the absorber of the system. The results proved that the heat transfer coefficient increases with increase of the thickness melted layers through the time of charging. The gained energy increased with the increase of mass flow rate of water and it decreases in the course of time. Regin et al. [8] studied the behavior of packed bed latent heat thermal energy storage system in which spherical capsule containing on paraffin wax as PCM in addition to system of solar water heating. The thermal performance was also studied and the effects of the capsule radii were considered. The results showed that a suitable PCM temperature for the work of the system should be taken in order to achieve the best performance.

In the present study a glass evacuated tube solar collector, a thermosyphon, a water tank, and two containers of PCM will be used to investigate the thermal performance through the knowledge of temperatures distribution in the components above in the charging and discharging periods.

II. EXPERIMENTAL SET-UP

A. Solar collector

The ETSCTHPCM (evacuated tube solar collector thermosyphon phase change material) has been constructed in the lab in order to protect from the outer environmental conditions. This construction of the system allowed us to use variant heat fluxes (from solar simulator) under similar condition. This construction ESCTHPCM consists of an evacuated tube, a thermosyphon, a water tank, and container of PCM. The evacuated tube solar collector comprises two layers: one external exposed to radiation heat flux that comes from the solar simulator system, and other is internal painted with black color. The two layers are evacuated of air to reduce the lost heat by conduction and convection. The dimensions of the evacuated tube are outer diameter 46 mm, and inner diameter 36 mm, and length 1500 mm. The thermosyphon is made of copper material with diameter 16 mm, the TH consist

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of two parts one with length 1150 mm put in evacuated tube, and the other part with length 200 mm in the water tank . The experimental rig is installed on the floor of the lab. Fig. 1 shows the parts of rig. These are:

(1) Evacuated glass tube, (2) Copper thermosyphon, (3) Water tank storage, (4) Containers of paraffin wax, (5) Solar simulator system (lamp light), (6) Stand steel, (7) Thermocouples type K, (8) Data Acquisition, (9) Personal Computer.

Thermosyphon is a device that transfers heat in two phases with a high thermal conductive efficiency. This device contains an amount of working fluid (water) with a percentage of 50% of the volume evaporator. This amount of is circulation by the force of gravity. The circulation starts from the evaporator when it absorbs the heat from solar simulation (lamp light) which reaches through evacuated tube solar collector, the walls of evaporator transferred the heat by conduction to the working fluid. When the working fluid reaches to saturate of heat absorption it changes from liquid into vapor. The amount of heat is proportional with latent heat of evaporation. The hot vapor moves to condenser section and then gives heat to the water tank through the walls of the condenser. The working fluid turns into liquid phase when it losses is heat in the condenser. This liquid return to evaporator through earth gravity. Fig. 2 illustrates the principle of the working fluid of thermosyphon. TH is used in many engineering application like water heating, cooling, and air condition [9, 10]

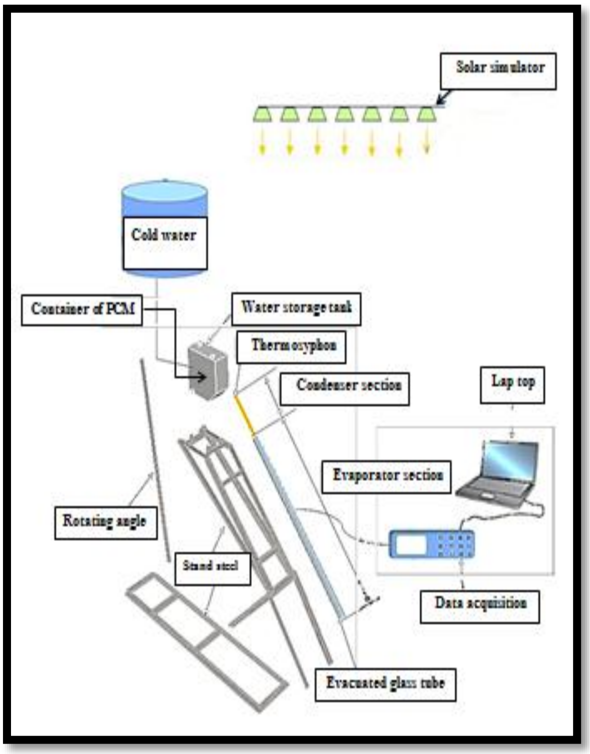

Fig. 1 Schematic diagram of the experimental test rig

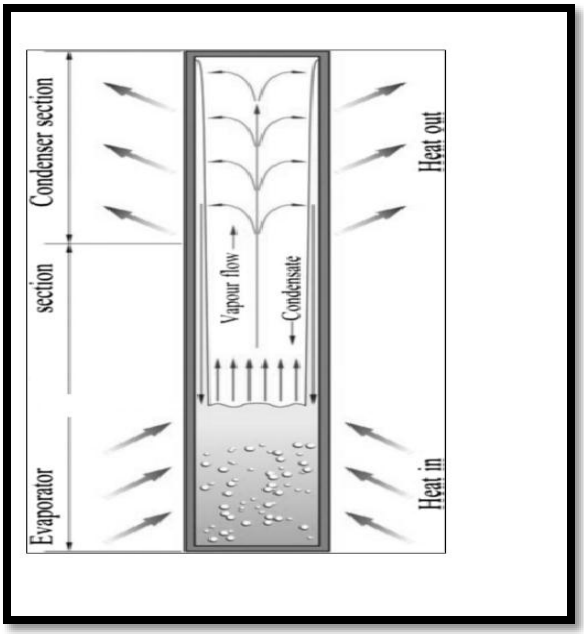

Fig. 2 Schematic of a working of the thermosyphon

B. Main elements of the solar collector

In this experiment, the solar simulator is used to produce constant heat fluxes to the surface using thermoelectric devices and heat sources. Using an artificial lighting can more accurately simulate the influence of solar energy on the thermal performance of collector. The lamp solar simulator has seven halogen lamps; each lamp has power of 500 watt. These lamps are installed in an area of 1400 mm by 150 mm. It is possible to control the heat flux that emerges by varying the voltage and current or by varying the distance between solar simulator and evacuated solar collector. In this study, the paraffin wax is used as PCM with the properties stated in table I. The paraffin wax was in rectangular container in the internal walls of the water tank (70 mm * 275mm * 275 mm). The dimensions of each container are 30 mm depth, 275 mm width, and 275 mm height, and it is filled with 1.8 kg paraffin wax. Each container also contains aluminum foam matrix to enhance the thermal of conductivity of the PCM. The dimensions of aluminum foam matrix are 24 mm thickness, 275mm width, and 275 heights. The outer sides for the water tank and containers are insulated with a 50 mm thickness of glass wood.

C. Instrumentation

To measure the temperature in variant points in the system, K-type thermocouples (Nickel Chrome, Nickel Aluminum) are used. Twenty-four K-type are used in the solar collector: eight are used on the outer side of thermosyphon, five are used inside thermosyphon, three are used inside the water tank, two are used at the inlet and outlet of the water tank, and six are used in one of the PCM container. All thermocouples are calibrated in order to know the precision of reading.

The thermocouples on the surface of thermosyphon are fixed by using high conductivity epoxy after cleaning its surface. In order to fixed the thermocouples in core of thermosyphon wires with the thermocouples bound on them are lowered

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through holes on the surface of thermosyphon, these holes are welding to prevent the escape of working fluid. The thermocouples in the water tank are fixed on a tube with 2 mm diameter (and lowered through the tank) with variant points of the tank height. The thermocouples are fixed in the container of paraffin wax which connected with two tubes of 2 mm diameter, these thermcouples were put in different levels of height and width (and lowered through container). All thermocouples are connected to the Data Acquisition system type LabJack. Fig. 3 shows the sides of thermocouples. All date is collected and transfer to the personal computer PC through the data logger at an interval of 500 ms.

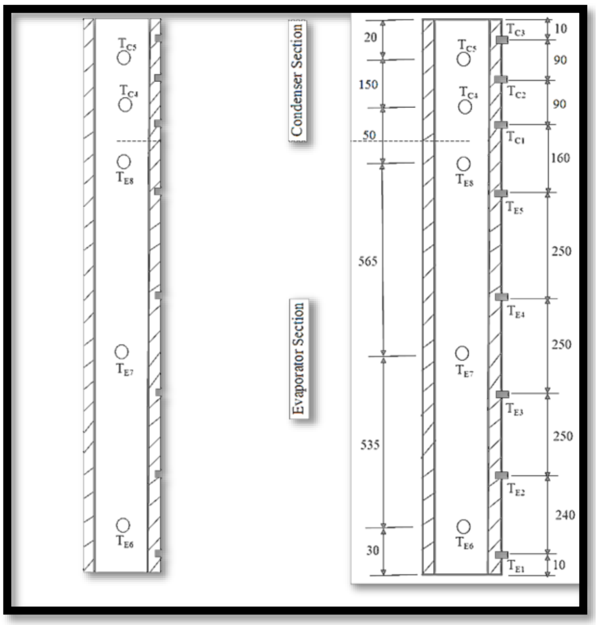

Fig. 3. Thermocouples locations for thermosyphon (all dimensions in mm).

III. RESULTS AND DISCUSSIONS

The experiments have been carried out in order to investigating the thermal performance of the solar collector with the thermosyphon and PCM. These experiments have been performed under the effect of different parameters. These parameters are: different heat flux (750 W/m^2, 1000 W/m^2) with and without paraffin wax as PCM, the angle of incidence of thermosyphon is 90°, and the working fluid is water with filling ratio of 50% of the volume of the evaporator. The experiments were performed with different load conditions. Each experiment lasted for nine hours from 7:00 up to 16:00 (start from temperature of the lab). Then the solar simulator has been operated with a suitable voltage and current to specific the desired heat flux. The solar simulator works for 10 minutes in order that the heat flux be stable. These through reading the heat flux in the power radiation device. Now, the heat flux is directed towards evacuated tube solar collector. The system works for nine continuous hours. The temperature is recorded for each part of the rig. The duration of the work of the system from 7:00 to 16:00 can be called charging time, shut off solar simulator from 17:00 to 6:00 can be called discharging time. During the discharging time the thermal efficiency of PCM on the thermal performance of the system was studied.

The results of this work are stated as follows:

A. Temperatures distribution of the surface of thermosyphon

Fig. 4 shows the average temperatures distribution of the thermosyphon surface, with different cases: the first with heat flux 750 W/m^2-no load, the second with heat flux 1000 W/m^2-no load, the third with heat flux 750 W/m^2 -with load 0.391 L/H, and the fourth with heat flux 1000 W/m^2-with load 0.866 L/H. in all the cases the temperature started high (69.02864°C) and continuous reducing all along the surface. A sharp decline of the temperature occurs at the entrance of the condenser (48.63257°C) section due to the occurrence of the condensation between the surface of the condenser and the water of the tank. Its notice that the curve with heat flux 1000 W/m^2 –no load was higher than the other cases because there is no drawing of hot water and because of the high heat flux. The curve with 750 W/m^2 – load 0.391 L/H was the lowest average temperatures because here is the least heat flux and water drawing. The curve with heat flux 1000 W/m^2-0.866 L/H was lower in average temperatures than the curve with heat flux 750 W/m^2-no load because of the drawing of hot water was high.

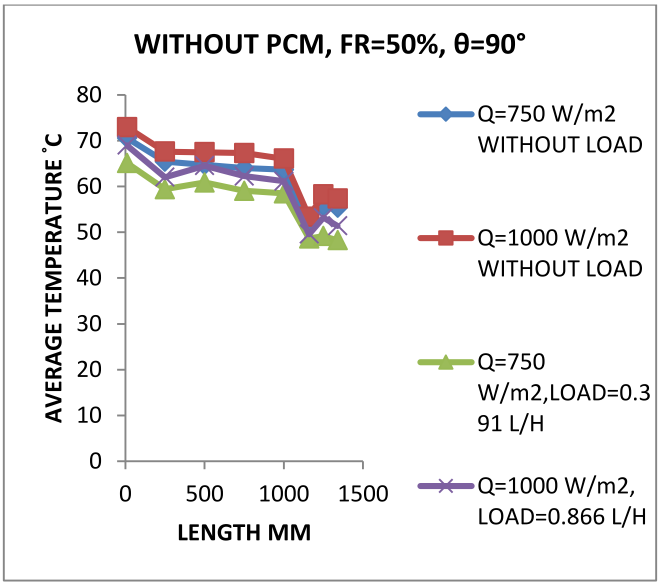

Fig. 4. Variation of average temperature on length surface thermosyphon with different cases

B. Temperatures distribution of the thermosyphon core

Fig. 5 shows the average temperatures distribution in the core of the thermosyphon, with different cases: the first with heat flux 750 W/m^2-no load, the second with heat flux 1000 W/m^2-no load, the third with heat flux 750 W/m^2 -with load 0.391 L/H, and the fourth with heat flux 1000 W/m^2-with load 0.866 L/H. for all cases the temperature started high (59.978°C) and continuous reducing all along the surface. A sharp decline of the temperature occurs at the entrance of the condenser (48.74232°C) section due to the occurrence of the condensation between the surface of the condenser and the water of the tank. Its noticed that the curve with heat flux 1000 W/m^2 –no load shows the highest temperatures because there is no drawing and the heat flux is high. The curve with 750 W/m^2-load 0.391 L/H shows the lowest temperatures because the heat flux was lower and there was water drawing. The curve with 1000 W/m^2-load 0.866 L/H shows higher temperatures than curve with 750 W/m^2-no load because of the high heat flux.

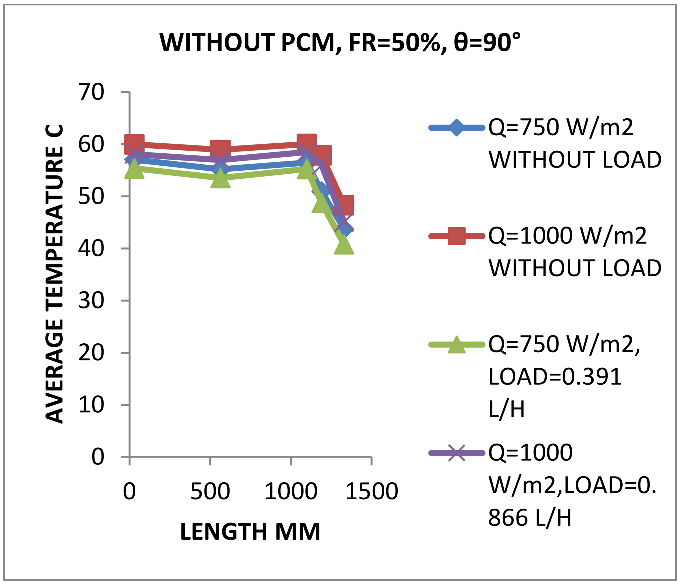

Fig. 5.Variation of average temperature in core thermosyphon with different cases

C. Temperatures distribution of the water tank

Fig.6 shows the average temperatures distribution of the tank water for different cases. It is noticed that the temperatures increase with the increase of the heat flux. The temperatures of the tank water decrease with the increase of the volumetric flow rate of the hot drawn water, this leads to a decrease of the temperatures of the condenser section in thermosyphon.

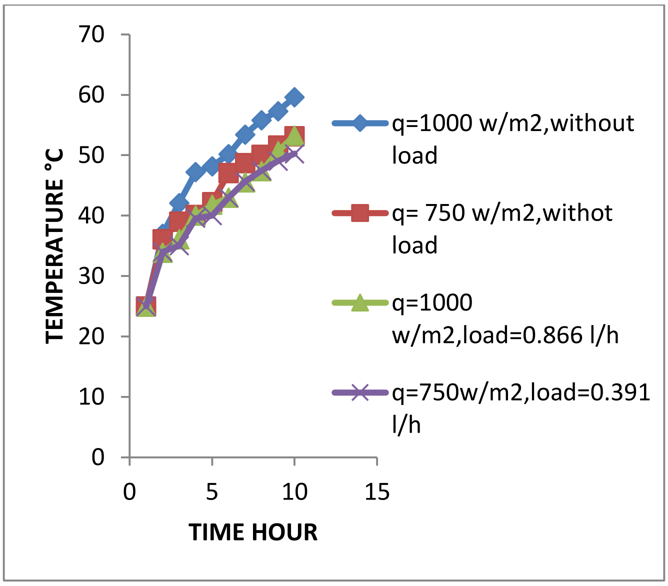

Fig. 6.Variation of temperature with time in tank for water with different cases

D. Temperatures distribution of the PCM

Fig.7 shows the variation of temperatures of the tank water during the charging and discharging periods. The heat flux with 750 W/m^2 and load condition of 0.39 h. During the charging period one notices increase of temperatures with time and the temperatures of water without PCM is higher because only water takes in the heat. During the period of restoring (discharging) energy a decrease of water temperature with and without PCM occurs because of the sensible heat vanishing then the water with PCM remains higher in temp because of the effect of latent heat and continuous to be higher than 40 °C until the time 18:00. At the end of the time 24:00, the temperature fills to less than 38 °C and this temperature represent the turning point between the start of melting and freezing of the PCM.

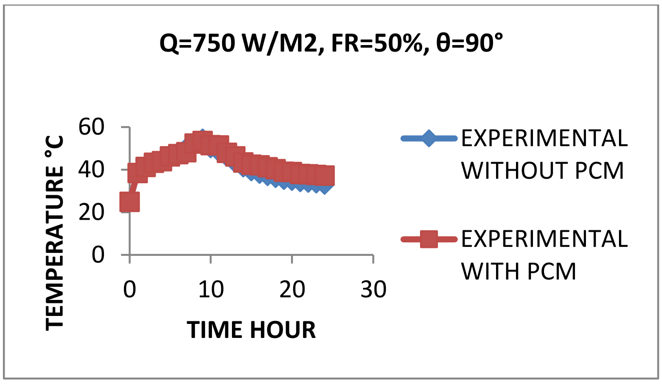

Fig. 7.Temperature variations of the water during charging and discharging (750 W/m^2)

Fig.8 shows the variation of temperatures of the tank water during the charging and discharging periods. The heat flux with 1000 W/m^2 and load condition of 0.866 h. During the charging period one notices increase of temperatures with time and the temperatures of water without PCM is higher because only water takes in the heat. During the period of restoring (discharging) energy a decrease of water temperature with and without PCM occurs because of the sensible heat vanishing then the water with PCM remains higher in temperature because of the effect of latent heat and continuous to be higher than 40 °C until the time 17. At the end of the time 20:00, the temperature fills to less than 38 °C. This high decrease was because of the high load condition.

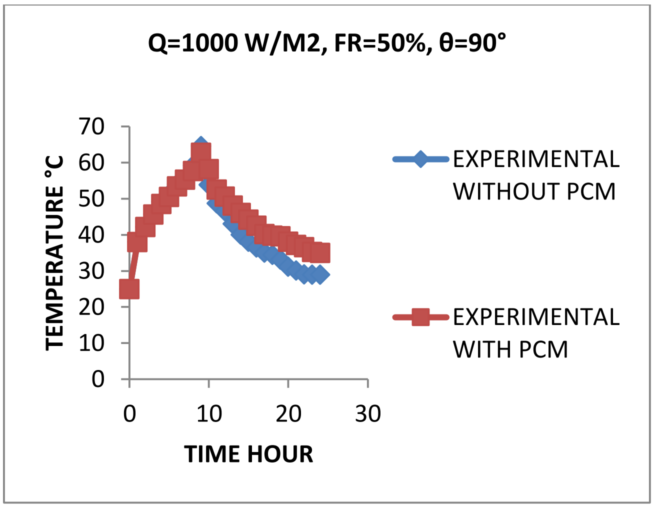

Fig. 8.Temperature variations of the water during charging and discharging (1000 W/m^2)

Fig. 9 illustrates temperatures in the water tank and in the paraffin wax containers during the period of charging and discharging with a heat flux of 750 W/m^2 with load condition 0.39 h. It is noticed that the temperature of water without PCM during the period of charging is higher than the temperature of water with PCM and with the temperature of PCM, that is because at the beginning of charging the PCM is solid (occur pure conduction). After 2-6 hours of work all the PCM melts. It is noticed that the heat transfer by convection increase with the increase of PCM melting. At the beginning of discharging time the temperature of the PCM is at acme, then this temperature begins to fill down as a result of transferring the heat to the water until the temperature reaches (36.9 °C). The temperature of water remains above 39 °C until 19:00.

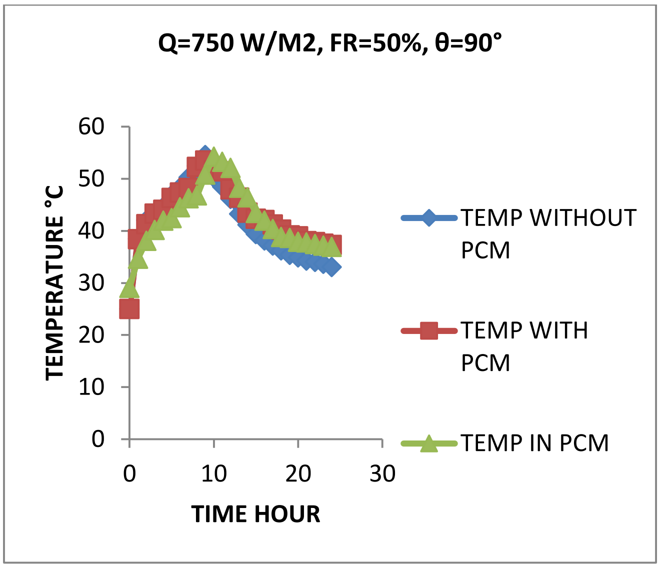

Fig. 9 Temperature variations of the water and PCM during charging and discharging (750 W/m^2)

Fig. 10 illustrates temperatures in the water tank and in the paraffin wax containers during the period of charging and discharging with a heat flux of 1000 W/m^2 with load condition 0.866 h. It is noticed that the temperature of water without PCM during the period of charging is higher than the temperature of water with PCM and with the temperature of PCM, that is because at the beginning of charging the PCM is solid (occur pure conduction). After 2-4 hours of work all the PCM melts. It is noticed that the heat transfer by convection increase with the increase of PCM melting. At the beginning of discharging time the temperature of the PCM is at acme, then this temperature begins to fill down as a result of transferring the heat to the water until the temperature reaches (32.4 °C). The temp of water remains above 39 °C until 19:00.

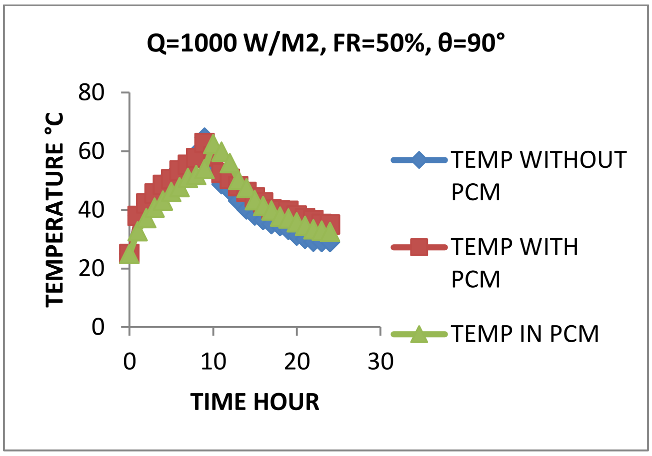

Fig. 10.Temperature variations of the water and PCM during charging and discharging (1000 W/m^2)

TABLE I
THERMO PHYSICAL PROPERTIES FOR PARAFFIN WAX

Melting range (°C)	38-43
Thermal Conductivity k (W/m °C)	Solid=0.2 Liquid=0.2
Latent Heat (kJ/kg)	165
Density (kg/m3)	Solid=880 Liquid=760
Specific Heat (kJ/kg °C)	Solid=2.0 Liquid=2.0

IV. CONCLUSIONS

The phase change material PCM has been taken with solar collector system ESCTHPCM in order to make use of its large capacity to store heat with small volume. The main conclusion of this study is that it was possible to have continues hot water supply all during the day and night time. Water temperature continuous to be high than 35 °C until the next day with a high load conditions. With less drawing of hot water, the temperature will be higher than 35 °C. The temperatures of the thermosyphon and the water tank have increase 10 °C, 6 °C respectively when the heat flux increases 33.3 %. The time of PCM melting has decreases with a rate of 25 % with the increases of the heat flux 33.3%. From these results, it appears that the thermal performance of the system ESCTHPCM is better than the thermal performance of the system without PCM.

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