

The Numerical Investigation of the Solar Collector Evacuated Tube Combined With Thermosyphon and Paraffin Wax as PCM

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ABSTRACT:The aim of this study is numerical model of a solar collector, type, evacuated glass tube combined with thermosyphon and using paraffin wax as phase change material SCETHPCM to benefit from the energy stored in this material. Through the use of solar simulator system a different heat is obtained as two values 750 W/m^2 , 1000 W/m^2 have been used, as this heat falls on the SCETHPCM, and collected and then stored in the containers of PCM, as the internal walls of the containers which is surrounded by the water of the tank. Later on the stored heat is transferred to the water. By using computational fluid dynamic CFD and staggered method, the equations are solved through the two periods charging and discharging to represent the model. The results showed that with and without load the thermal performance of the system is higher than without PCM. From this system it is found that water with temperature over $35 \text{ }^\circ\text{C}$ can be supplied during the night or in the absence of heat flux source.

KEYWORDS:Solar collector, evacuated glass tube, phase change material, thermosyphon, paraffin wax, CFD

I. INTRODUCTION

Several arrangements of the solar water heater systems combined with phase change materials have been use as medium storage and then analyzed theoretically, numerically, and experimentally during recent years [1].The PCM can take different shapes but a better performance is either as rectangular or cylindrical[2]. Kousksou et al. [3] used cylindrical container with PCM in storage tank to enhance the performance of solar water heater system. The performance of solar water heater depends on variable factors such as a collector, a storage tank for PCM, and inlet conditions. The pervious literature review showed that the evacuated tube solar collector was better than flat plate solar collector by Zambolin et al. [4]. Different phase change materials were used such as paraffin waxes, fatty acids, and salt hydrates. One of the disadvantageous of PCM is less thermal conductivity so different methods are used to enhance thermal conductivity such as the use of fins, by Seeniraj et al. [5].

Pervious works showed that there were few studied on combination of evacuated solar collector with thermosyphon combined with paraffin wax as PCM which exist on the two sides of the water storage tank ESCTHPCM this work shows the main idea for numerical investigation in this paper.

Nomenclature

As :south direction area m^2
An :north direction area m^2
Ae :east direction area m^2
Aw :west direction area m^2
At :top direction area m^2
Ab :bottom direction area m^2

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Cs :constant
Cn :constant
Ce :constant
Cw :constant
Ct :constant
Cb :constant
C :constant
Cp: specific heat at constant pressure J/kg K
g :acceleration due to gravity m/sec²
h :Heat transfer coefficient W/m² K
hair: heat transfer coefficient of air W/m² K
hw: heat transfer coefficient of water W/m² K
i,j,k: nodes x-,y-,z- direction respectively
kc :thermal conductivity of copper W/m K
kw :thermal conductivity of water W/m K
l :length m
Pr: Prandtl number
qs :south direction heat transfer W
qn :north direction heat transfer W
qe :east direction heat transfer W
qw :west direction heat transfer W
qt :top direction heat transfer W
qb :bottom direction heat transfer W
qsolar: solar flux W/m²
r,θ, z :cylindrical coordinates m, degree, m
t :time sec
T :temperature K
u :velocity of x- component m/sec
v :velocity of y- component m/sec
w :velocity of z- component m/sec
x,y,z: Cartesian coordinate
Δv :volume of element m³
α_ Thermal diffusivity [m²/s]
β :volume coefficient of expansion 1/K
θ: inclination angle degree
PCM: phase change material
T*:Kirchhoff temperature K
□:Dummy variable

II. THE PROPOSED SYSTEM

The suggested evacuated solar collector thermosyphon with phase change materials ESCTHPCM, is shown in Fig. 1.A. It consists of, evacuated tube from type in which there is a thermosyphon. The thermosyphon is a device made of a copper tube divided into two sections a evaporator and a condenser. The evaporator represents the part exposed to heat coming from solar simulator system. The condenser represents the part that is entering into the water tank storage. The vacuum of thermosyphon of air and gases is unpreferable and it is charge with working fluid. The water is used as working fluid with filling ratio FR of 50%.the heat energy is absorbed by evaporator section and transfers to the working fluid in the thermosyphon. The process of evaporation of water takes place and the vapor transfers to condenser section due to the water surrounding the condenser and here the process of condensation happens conveying

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heat to the water in the tank. Then the heat transfers from water to the PCM containers. When the PCM receive the heat it begins to melt during the nine hour of working which are called charge period. After shutting of the solar simulator system the second period begins from 10th hour to 24th hour this period is called discharge period, during this period the process of heat transfer is reversed: from PCM to water. Aluminum foam matrix was used in the PCM containers to enhance thermal conductivity for PCM. The solar simulator system consist of, seven halogen light, variac voltage, measure of current. Variac voltage is used to regulator the required voltage which is specified in the light the required heat flux, also the amount of heat flux can regulated by changing distance between the light of the system and solar collector. Table 1 shows the data of the above mentioned components.

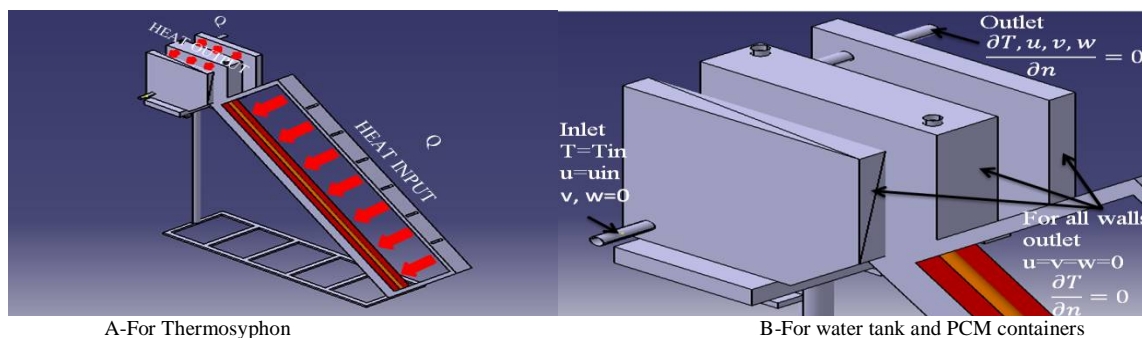


Fig. 1 Schematic diagram of the theoretically test rig

III. NUMERICAL MODEL

The numerical model comprises three parts: a thermosyphon which represented by the energy equation which will be solved, a tank for water storage which is governed by Navier Stocks equations which will be solved by finite volume method, and PCM continuers which is governed by energy equation. All governing equations are solved to determined temperatures distribution, along the surface of thermosyphon, for tank water, and containers of PCM. All These operation can be represented by two main processes: a phase change in the thermosyphon change from water to steam and via verse and a change in the stored PCM form solid to liquid and via versa. Convection process occur in the water of the tank semi-transient condition, and the PCM and thermosyphon by unsteady state conditions. By using program FORTERN 90 to solved and analyze the problem and by using different heat fluxes for nine hour or the charging period. The discharging period begins with the shutting off of solar simulator system, this procedure can be repeated with the other heat flux by using initial condition for pervious run to be use in a new run. In the simulation program, the following procedure is followed:

- 1- Solar flux is applied all along the surface of the evaporator section.
 - 2-The heat transfers through the walls of evaporator section by the conduction process.
 - 3-The heat transfers from the walls of the evaporator to the working fluid inside the thermosyphon by convection process.
 - 4-The evaporation process occurs inside the thermosyphon.
 - 5-After the evaporation occurs in the thermosyphon, the vapor passes to the condenser.
 - 6-The condensation occurs in the walls of the condenser.
 - 7-The heat transfers through the walls of the condenser by the conduction process.
 - 8-The heat transfers from the surface of the condenser to the water of the tank by means of the convection.
 - 9-The heat transfers from the water in the tank to the paraffin wax by conduction process.
 - 10-At the end of the charging period, the discharge period starts and the steps of the procedure above are reversed.
- 3.1 the thermosyphon

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In this part of the system the temperatures distribution is determine by using three dimensions cylindrical coordinate to solve the energy equation by using thermal resistance method. Generally, all nodes in the energy equation can be written as follows [6, 7]:

Energy balance:

$$\sum Q_{in \text{ all sides}} = Q_{storage} \quad (1)$$

$$q_{s-r} + q_{e-\theta} + q_{t-z} + q_{n-r} + q_{w-\theta} + q_{b-z} + q_{solar} = \rho V C_p \frac{T_{(i,j,k)}^{p+1} - T_{(i,j,k)}^p}{\Delta t} \quad (2)$$

$$T_{(i,j,k)}^{p+1} = T_{(i,j,k)}^p + \frac{\alpha \Delta t}{v} [C_s T_{i-1,j,k}^p + C_e T_{i,j+1,k}^p + C_t T_{i,j,k+1}^p + C_n T_{i+1,j,k}^p + C_w T_{i,j-1,k}^p + C_b T_{i,j,k-1}^p - C T_{i,j,k}^p + q_{solar}] \quad (3)$$

Where

$$\alpha = \frac{k}{\rho C_p} \text{m}^2/\text{s} \quad \text{thermal diffusivity}$$

$$A_s = \left(r_i - \frac{\Delta r}{2} \right) \Delta \theta \Delta z$$

$$A_n = \left(r_i + \frac{\Delta r}{2} \right) \Delta \theta \Delta z$$

$$A_e = A_w = \Delta r \Delta z$$

$$A_t = A_b = r_i \Delta r \Delta \theta$$

$$C_s = \frac{A_s}{\Delta r}, C_e = \frac{A_e}{r_i \Delta \theta}, C_t = \frac{A_t}{\Delta z}, C_n = \frac{A_n}{\Delta r}, C_w = \frac{A_w}{r_i \Delta \theta}, C_b = \frac{A_b}{\Delta z}$$

$$C = C_s + C_n + C_e + C_w + C_t + C_b$$

3.2 water storage tank

To analysis the water in the tank NavierStockes equation can be used which consists of: continuity equation, momentum equation, and energy equations with laminar flow for three dimension 3D, and can be solved by finite volume with use of SIMPLE Algorithm method and by using FORTERN 90 for the solution of the problem. The results from the program above are drawn by TECPLOT program. These equations are:

A- Continuity equation:

$$\frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0 \quad (4)$$

B- Momentum equations in u, v, and w direction respectively:

$$\frac{\partial}{\partial x}(uu) + \frac{\partial}{\partial y}(uv) + \frac{\partial}{\partial z}(uw) = -\frac{1}{\rho} \frac{\partial P}{\partial x} + \nu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) \quad (5)$$

$$\frac{\partial}{\partial x}(vu) + \frac{\partial}{\partial y}(vv) + \frac{\partial}{\partial z}(vw) = -\frac{1}{\rho} \frac{\partial P}{\partial y} + \nu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right) + g \beta (T - T_w)$$

$$\frac{\partial}{\partial x}(uw) + \frac{\partial}{\partial y}(vw) + \frac{\partial}{\partial z}(ww) = -\frac{1}{\rho} \frac{\partial P}{\partial z} + \nu \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right)$$

c- Energy equation

$$\frac{\partial}{\partial x}(uT) + \frac{\partial}{\partial y}(vT) + \frac{\partial}{\partial z}(wT) = \frac{k}{\rho C_p} \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) \quad (6)$$

3.3 container PCM

The energy equation with three dimensions was used without viscous dissipation, without convective term and combined with continuity equation in Cartesian coordinate, the equation is [8]:

$$\frac{\partial}{\partial x} \left(k \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(k \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(k \frac{\partial T}{\partial z} \right) + \dot{q} = \rho \frac{\partial E}{\partial t} \quad (7)$$

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Since, state equation

$$\frac{dE}{dT} = C_p$$

Consider the phase change works in same temperature, and with constant specific heat [8]

$$T = \begin{cases} T_m + E / C_{ps} & E \leq 0 \\ T_m & 0 < E < H \\ T_m + (E - H) / C_{pl} & E \geq H \end{cases} \quad \text{Mushy phase} \quad (8)$$

Where

T_m is the melting temperature, and when $E=0$ represent solid phase

The "Kirchhoff" temperature is:

$$T^* = \int_{T_m}^T k(\eta) d\eta = \begin{cases} k_s(T - T_m), & T < T_m \\ 0, & T = T_m \\ k_l(T - T_m), & T > T_m \end{cases} \quad (9)$$

Now, equation 8 is transformed by using the definition equation in 9, to get:

$$T^* = \begin{cases} k_s E / C_{ps}, & E \leq 0 \\ 0, & 0 < E < H \\ k_l (E - H) / C_{pl}, & E \geq H \end{cases} \quad (10)$$

Enthalpy function

$$T^* = \Gamma(E)E + S(E) \quad (11)$$

Where

$$\Gamma(E) = \begin{cases} k_s / C_{ps}, & E \leq 0 \\ 0, & 0 < E < H \\ k_l / C_{pl}, & E \geq H \end{cases}$$

And

$$S(E) = \begin{cases} 0, & E \leq 0 \\ 0, & 0 < E < H \\ -Hk_l / C_{pl}, & E \geq H \end{cases}$$

Now, substitute 11 in 10 get

$$\rho \frac{\partial E}{\partial t} = \frac{\partial}{\partial x} \left(\frac{\partial(\Gamma E)}{\partial x} \right) + \frac{\partial}{\partial y} \left(\frac{\partial(\Gamma E)}{\partial y} \right) + \frac{\partial}{\partial z} \left(\frac{\partial(\Gamma E)}{\partial z} \right) + p + q \quad (12)$$

With

$$p = \frac{\partial}{\partial x} \left(\frac{\partial S}{\partial x} \right) + \frac{\partial}{\partial y} \left(\frac{\partial S}{\partial y} \right) + \frac{\partial}{\partial z} \left(\frac{\partial S}{\partial z} \right)$$

$$\Gamma = \Gamma(E), \quad S = S(E)$$

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So, the energy equation becomes non-linear equation with a single dependent variable E, while in liquid region the above energy becomes linear energy equation, as follows:

$$\rho \frac{\partial E}{\partial t} = \frac{\partial}{\partial x} \left(k_l \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_l \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_l \frac{\partial T}{\partial z} \right) + q \quad (13)$$

And in the solid region as follows:

$$\rho \frac{\partial E}{\partial t} = \frac{\partial}{\partial x} \left(k_s \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(k_s \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(k_s \frac{\partial T}{\partial z} \right) + q \quad (14)$$

For three dimensional in phase change problem the equation 12 can be written thus:

$$\rho \frac{\partial E}{\partial t} = \frac{\partial^2}{\partial x^2} (\Gamma E) + \frac{\partial S^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} (\Gamma E) + \frac{\partial S^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} (\Gamma E) + \frac{\partial S^2}{\partial z^2} \quad (15)$$

Where $\Gamma = \Gamma(E)$ and $S = S(E)$

The discretization of the above equation was used the control volume finite difference approach which described by Patankar 1980. This method was performed through the application of conservation laws over finite size control volume surrounding the grid nodes and integrating with equation over the control volumes, so

$$\begin{aligned} \iiint_{\Delta V} \rho \frac{\partial E}{\partial t} \Delta V &= \iiint_{\Delta V} \frac{\partial}{\partial x} \left(\frac{\partial \Gamma(E)}{\partial x} \right) \Delta V + \iiint_{\Delta V} \frac{\partial}{\partial y} \left(\frac{\partial \Gamma(E)}{\partial y} \right) \Delta V + \iiint_{\Delta V} \frac{\partial}{\partial z} \left(\frac{\partial \Gamma(E)}{\partial z} \right) \Delta V \\ &+ \iiint_{\Delta V} \frac{\partial}{\partial x} \left(\frac{\partial S}{\partial x} \right) \Delta V + \iiint_{\Delta V} \frac{\partial}{\partial y} \left(\frac{\partial S}{\partial y} \right) \Delta V + \iiint_{\Delta V} \frac{\partial}{\partial z} \left(\frac{\partial S}{\partial z} \right) \Delta V + \iiint_{\Delta V} q \Delta V \end{aligned} \quad (16)$$

By using explicit scheme and the left side for above equation becomes

$$\iiint_{\Delta V} \rho \frac{\partial E}{\partial t} \Delta V = \rho \Delta V \left(\frac{E_p - E_p^\circ}{\Delta t} \right) \quad (17)$$

In x-direction for right side from equation 16

$$\begin{aligned} \iiint_{\Delta V} \frac{\partial}{\partial x} \left(\frac{\partial \Gamma(E)}{\partial x} \right) \Delta V &= \left[\left(\frac{\partial \Gamma(E)}{\partial x} \right)_e - \left(\frac{\partial \Gamma(E)}{\partial x} \right)_w \right] \Delta y \Delta z = \\ &\frac{\Delta y \Delta z}{(\delta x)_e} (\Gamma_e E_e - \Gamma_p E_p) - \frac{\Delta y \Delta z}{(\delta x)_w} (\Gamma_p E_p - \Gamma_w E_w) \end{aligned} \quad (18)$$

$$\iiint_{\Delta V} \frac{\partial}{\partial x} \left(\frac{\partial S}{\partial x} \right) \Delta V = \left[\left(\frac{\partial S}{\partial x} \right)_e - \left(\frac{\partial S}{\partial x} \right)_w \right] \Delta y \Delta z = \frac{\Delta y \Delta z}{(\delta x)_e} (S_e - S_p) - \frac{\Delta y \Delta z}{(\delta x)_w} (S_p - S_w)$$

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In y- direction

$$\iiint_{\Delta V} \frac{\partial}{\partial y} \left(\frac{\partial \Gamma(E)}{\partial y} \right) \Delta V = \left[\left(\frac{\partial \Gamma(E)}{\partial y} \right)_n - \left(\frac{\partial \Gamma(E)}{\partial y} \right)_s \right] \Delta x \Delta z$$

$$= \frac{\Delta x \Delta z}{(\delta y)_n} (\Gamma_N E_N - \Gamma_P E_P) - \frac{\Delta x \Delta z}{(\delta y)_s} (\Gamma_P E_P - \Gamma_S E_S) \quad (19)$$

$$\iiint_{\Delta V} \frac{\partial}{\partial y} \left(\frac{\partial S}{\partial y} \right) \Delta V = \left[\left(\frac{\partial S}{\partial y} \right)_n - \left(\frac{\partial S}{\partial y} \right)_s \right] \Delta x \Delta z = \frac{\Delta x \Delta z}{(\delta y)_n} (S_N - S_P) - \frac{\Delta x \Delta z}{(\delta y)_s} (S_P - S_S)$$

In z-direction

$$\iiint_{\Delta V} \frac{\partial}{\partial z} \left(\frac{\partial \Gamma(E)}{\partial z} \right) \Delta V = \left[\left(\frac{\partial \Gamma(E)}{\partial z} \right)_t - \left(\frac{\partial \Gamma(E)}{\partial z} \right)_b \right] \Delta x \Delta y$$

$$= \frac{\Delta x \Delta y}{(\delta z)_t} (\Gamma_T E_T - \Gamma_P E_P) - \frac{\Delta x \Delta y}{(\delta z)_b} (\Gamma_P E_P - \Gamma_B E_B) \quad (20)$$

$$\iiint_{\Delta V} \frac{\partial}{\partial z} \left(\frac{\partial S}{\partial z} \right) \Delta V = \left[\left(\frac{\partial S}{\partial z} \right)_t - \left(\frac{\partial S}{\partial z} \right)_b \right] \Delta x \Delta y$$

$$= \frac{\Delta x \Delta y}{(\delta z)_t} (S_T - S_P) - \frac{\Delta x \Delta y}{(\delta z)_b} (S_P - S_B)$$

The last term from equation 16

$$\iiint_{\Delta V} q \Delta V = \bar{q} \Delta V$$

Now, the equation 17 becomes as down with coefficients E_N, E_S, E_E, E_W, E_T and E_B as a_N, a_S, a_E, a_W, a_T and a_B :

$$a_P E_P = a_N E_N + a_S E_S + a_E E_E + a_W E_W + a_T E_T + a_B E_B + b \quad (21)$$

The E_p° represent the old value of E at grid point p. the values of coefficient are:

$$a_p = a_N + a_S + a_E + a_W + a_T + a_B$$

$$a_E = \frac{\Delta t}{\rho \Delta V} \frac{\Gamma_E A_x}{\delta x_e}, \quad a_W = \frac{\Delta t}{\rho \Delta V} \frac{\Gamma_W A_x}{\delta x_w}, \quad A_x = \Delta y \Delta z, \quad \Delta V = \Delta x \Delta y \Delta z$$

$$a_N = \frac{\Delta t}{\rho \Delta V} \frac{\Gamma_N A_y}{\delta y_n}, \quad a_S = \frac{\Delta t}{\rho \Delta V} \frac{\Gamma_S A_y}{\delta y_s}, \quad A_y = \Delta x \Delta z$$

$$a_T = \frac{\Delta t}{\rho \Delta V} \frac{\Gamma_T A_z}{\delta z_t}, \quad a_B = \frac{\Delta t}{\rho \Delta V} \frac{\Gamma_B A_z}{\delta z_b}, \quad A_z = \Delta x \Delta y$$

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And

$$b = -[a_N + a_S + a_E + a_W + a_T + a_B - 1]E_P^\circ + b_N S_N + b_S S_S + b_E S_E + b_W S_W + b_T S_T + b_B S_B - b_P S_P + \frac{dt}{\rho} q \Delta V$$

Where

$$b_P = b_E + b_W + b_N + b_S + b_T + b_B$$

$$b_E = \frac{\Delta t}{\rho \Delta V} \frac{A_x}{\delta x_e}, \quad b_W = \frac{\Delta t}{\rho \Delta V} \frac{A_x}{\delta x_w}$$

$$b_N = \frac{\Delta t}{\rho \Delta V} \frac{A_y}{\delta y_n}, \quad b_S = \frac{\Delta t}{\rho \Delta V} \frac{A_y}{\delta y_s}$$

The discretization equations for liquid and solid regions are:

$$\rho \frac{\partial E}{\partial t} = \frac{\partial}{\partial x} \left(k \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(k \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(k \frac{\partial T}{\partial z} \right) \quad (22)$$

$$\iiint_{\Delta V} \rho \frac{\partial E}{\partial t} dV = \iiint_{\Delta V} \frac{\partial}{\partial x} \left(k \frac{\partial T}{\partial x} \right) dV + \iiint_{\Delta V} \frac{\partial}{\partial y} \left(k \frac{\partial T}{\partial y} \right) dV + \iiint_{\Delta V} \frac{\partial}{\partial z} \left(k \frac{\partial T}{\partial z} \right) dV \quad (23)$$

$$\iiint_{\Delta V} \rho \frac{\partial E}{\partial t} \Delta V = \rho \Delta V \left(\frac{E_P - E_P^\circ}{\Delta t} \right)$$

$$\iiint_{\Delta V} \frac{\partial}{\partial x} \left(k \frac{\partial T}{\partial x} \right) dV = \left(k_e A_x \frac{T_E - T_P}{(\delta x)_e} \right) - \left(k_w A_x \frac{T_P - T_W}{(\delta x)_w} \right)$$

$$\iiint_{\Delta V} \frac{\partial}{\partial y} \left(k \frac{\partial T}{\partial y} \right) dV = \left(k_n A_y \frac{T_N - T_P}{(\delta y)_n} \right) - \left(k_s A_y \frac{T_P - T_S}{(\delta y)_s} \right) \quad \iiint_{\Delta V} \frac{\partial}{\partial z} \left(k \frac{\partial T}{\partial z} \right) dV =$$

$$\left(k_t A_z \frac{T_T - T_P}{(\delta z)_t} \right) - \left(k_b A_z \frac{T_P - T_B}{(\delta z)_{z,b}} \right)$$

$$a_P E_P = E_P^\circ + a_E T_E + a_W T_W + a_N T_N + a_S T_S + a_T T_T + a_B T_B - T_P \quad (24)$$

$$a_P = a_E + a_W + a_N + a_S + a_T + a_B$$

$$a_E = \frac{\Delta t}{\rho \Delta V} \frac{k_e A_x}{\delta x_e}, \quad a_W = \frac{\Delta t}{\rho \Delta V} \frac{k_w A_x}{\delta x_w}, \quad A_x = \Delta y \Delta z, \quad \Delta V = \Delta x \Delta y \Delta z$$

$$a_N = \frac{\Delta t}{\rho \Delta V} \frac{k_n A_y}{\delta y_n}, \quad a_S = \frac{\Delta t}{\rho \Delta V} \frac{k_s A_y}{\delta y_s}, \quad A_y = \Delta x \Delta z$$

$$a_T = \frac{\Delta t}{\rho \Delta V} \frac{k_t A_z}{\delta z_t}, \quad a_B = \frac{\Delta t}{\rho \Delta V} \frac{k_B A_z}{\delta z_b}, \quad A_z = \Delta x \Delta y$$

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3.5 BOUNDARY CONDITIONS

The boundary conditions for the whole system which consist of a thermosyphon, a water storage tank and paraffin wax containers are shown in Fig.1 as follows:

1-For thermosyphon:

Evaporator	q_{in} (solar)
Condenser	$q_{out,c}$ (convection heat transfer)

2-For water tank:

Variable	Wall	Inlet	Outlet
Velocity	$u, v, w = 0$	$u = u_{in}, v = w = 0$	$\left[\frac{\partial u, v, w}{\partial n} = 0 \right]$
Temperature	$\left[\frac{\partial T}{\partial n} = 0 \right]$	$T = T_{in}$	$\left[\frac{\partial T}{\partial n} = 0 \right]$

3-For containers paraffin wax:

Initial Conditions	At time=0, $T_{PCM} = T_{WATER}$
Boundary Conditions	At out walls, $\left[\frac{\partial T}{\partial n} = 0 \right]$ At internal walls, convection and conduction heat transfers

IV. RESULTS AND DISCUSSIONS

Figure 2 shows the average of temperatures distribution along the surface of thermosyphon and variant cases. It is noticed from the figures that with the heat flux 1000 W/m^2 and load 0.866 L/H the values of temperatures are higher because of the absence of PCM which draws some heat, with heat flux 750 W/m^2 and load 0.27 L/H the temperatures are the lowest due to the existence of PCM, with heat flux 1000 W/m^2 and load 0.8 L/H the tempers in this case is lower than the highest tempers due to the use of PCM, and with 750 W/m^2 and load 0.39 L/H the temperatures in this case is a bit higher than the lowest temperatures because of the exclusion of PCM.

Figure 3 shows the average of temperatures distribution of the storage water in the tank during charging-discharging periods with different cases. from the figure it is noticed that the highest temperatures during charging period is with high heat flux 1000 W/m^2 and without PCM. the discharge period the average of temperatures are higher with heat flux 750 W/m^2 and load condition 0.27 L/H due to the PCM which emits the stored heat. the stored heat is collected during the charging period which transforms the PCM from solid into liquid. the amount of drawn hot water(load) has an effect on maintaining high temperatures. It is noticed that with PCM and load 0.27 L/H the temperatures is over $40 \text{ }^\circ\text{C}$ all night long.

Fig. 4 shows the average temperatures distribution in the containers of PCM during the charge and discharge periods. It is notice that the case two is higher than the first case due to the high heat flux and that the PCM at the beginning in solid phase which requires heat to overcome latent and sensible heat and the melting process start with temperature $38 \text{ }^\circ\text{C}$. in the discharging period the first case is higher than the second case because of less load condition this state begins at hour 17^{th} , with temperature over $35 \text{ }^\circ\text{C}$ until the hour 20 this is because of high load condition in case two.

Fig. 5 shows a comparison between the results of the experimental [9] and numerical results for the average of temperatures of the tank water with different conditions, without PCM, heat flux 750 W/m^2 , filling ratio 50%, incidence angle $\theta=90^\circ$, and load condition 0.39 L/H . From a comparison of temperatures there is a good agreement during the charge-discharge periods, but there is difference 6°C during the first hour of work due to different operation of work at the beginning.

Figure 6 shows the temperatures contour of the water in the tank with different conditions, filling ratio $FR=50\%$, incidence angle 90° , with-without PCM, different load conditions, and different heat fluxes. From the figures stated it is noticed that there is a cut in the right lower angle to ease the process of assemble the thermosyphon and the water tank the cut is with an angle of 45° .the temperatures raise in the course of the charge period and reach the highest value at

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the end of the ninth hour, noticing that the highest temperatures are in the top area of the tank due to the effect of natural convection. Water with lowest temperature acquires heat and so circulate to the higher layers in the tank due to the effect of bouncy force. The temperatures noticed over 35°C with PCM.

Fig. 7 shows the velocity contour of water flowing in the water tank with different conditions, filling ratio FR=50%, incidence angle 90°, with-without PCM, different load conditions, and take sample 1000 W/m² as heat flux. These figures have been taken in the middle of the tank thickness where the thermosyphon passes. The velocity is higher in the thermosyphon site and it is lowest in areas under the thermosyphon due to natural convection. The direction of velocity near the walls of the tank are straight and circulate at corner of the tank, while the areas nearer to the thermosyphon, these direction are vertical and pointing upwards on the thermosyphon.

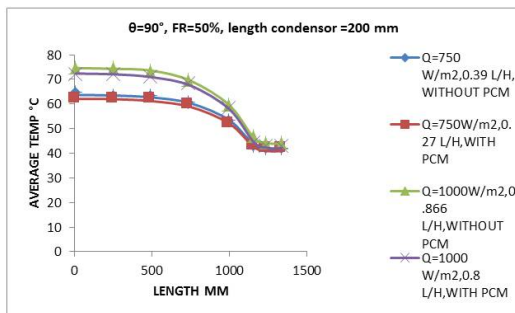


Fig. 2 Variation of average temperature on length surface thermosyphon with different cases

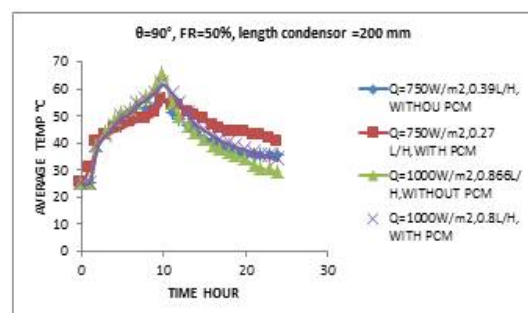


Fig. 3 Variation of average temperatures distribution for water in tank with time

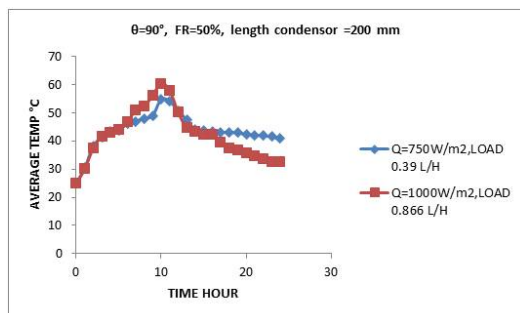


Fig. 4. Variation of average the temperatures distribution in PCM

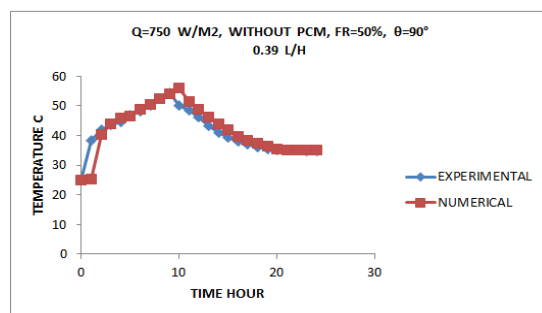


Fig.5 Comparison temperatures for water during charge-discharge periods

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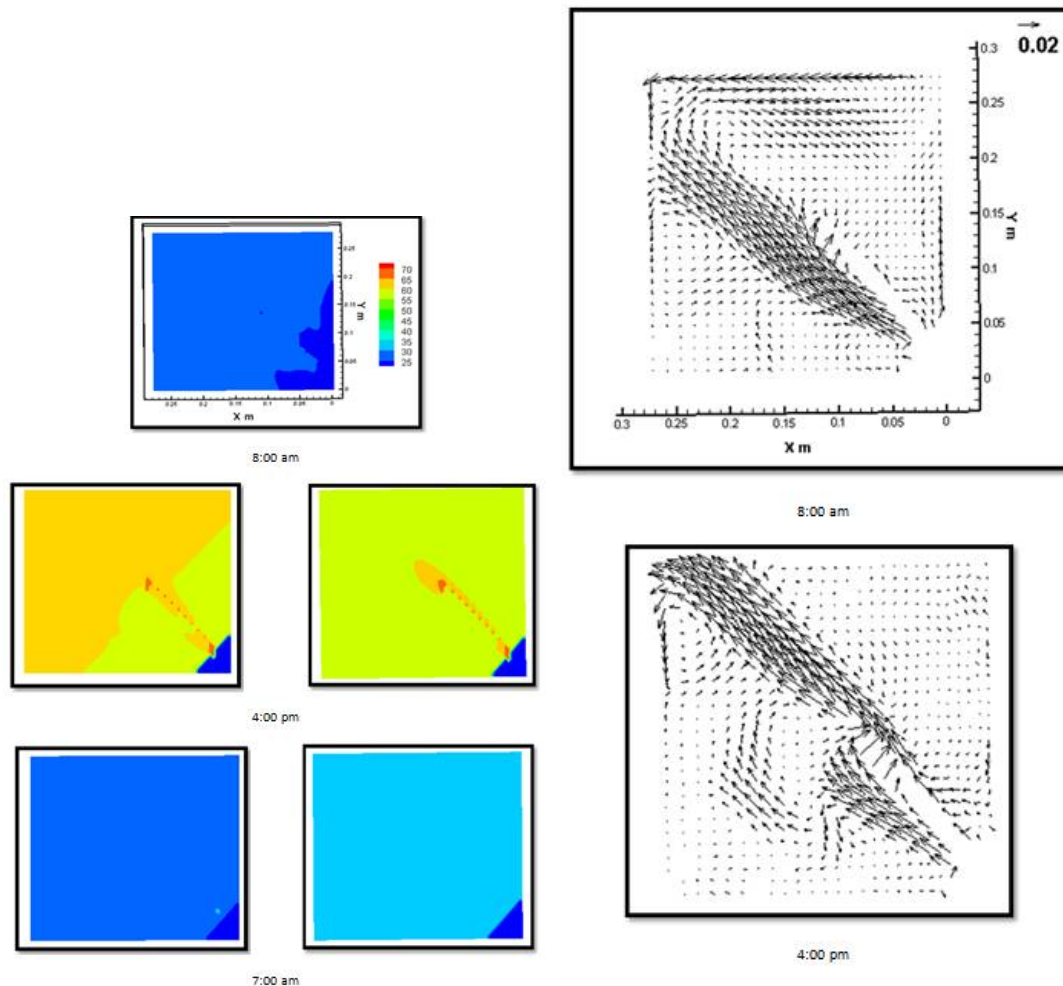


Fig. 6 Temperature contours of water in tank $FR=50\%$, $\theta=90^\circ$, $q=750 \text{ W/m}^2$, $Z=35 \text{ mm}$ (middle), and a)left side without PCM ,load 0.866 L/H, b)right side with PCM, load 0.866 L/H

Fig. 7 Velocity contours of water in tank, $FR=50\%$, $\theta=90^\circ$, $q=1000 \text{ W/m}^2$, $Z=35 \text{ mm}$ (middle), with-without PCM , and load 0.866 L/H

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Table I
DATA FOR ALL SYSTEM

Item	value
Evaporator length (mm)	1150
Condenser length (mm)	200
Evaporator and condenser outer diameter (mm)	16
Evacuated glass tube outer diameter (mm)	46
Evacuated glass tube inner diameter (mm)	36
Storage tank water height (mm)	275
Storage tank water length (mm)	275
Storage tank water width (mm)	70
container of PCM height (mm)	275
container of PCM length (mm)	275
container of PCM width (mm)	30
Aluminum foam matrix height (mm)	275
Aluminum foam matrix length (mm)	275
Aluminum foam matrix width (mm)	24
Porosity for Aluminum foam matrix (%)	96
Glass emittance	0.94
Thermal conductivity for water (W/m k)	0.6
Thermal conductivity for copper (W/m k)	383

V. CONCLUSION

The solar collector combined with thermosyphon and the use of paraffin wax as PCM has been studied theatrically. The analysis of SCETH with PCM was taken during the charge–discharge periods. Through the staggered method with CFD and by using FORTERN 90 program to perform the analysis for the part of the system: thermosyphon, tank, and PCM the distribution of temperatures was found. The behavior of velocity of water in the tank was also found. The results showed that the temperatures with PCM are higher for a longer time with a value over 35 °C during the night. The temperatures of the hot water in the tank depend on drawn load condition, this means that the use of PCM improve thermal performance of the system by SCETHPCM is better than the thermal performance of the system without PCM.

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