Modeling and Numerical Simulation of Solar Cooker with PCM as Thermal Energy Storage

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***Abstract*—In this article, mathematical modeling and numerical simulation of phase change materials (PCMs) used as latent heat thermal energy storage in a solar cooker have been conducted. The PCM to store thermal energy is packed in many small hollow cylinders and placed in a larger cylinder tank. Heat transfer fluid (HTF) which flows parallel to the PCM cylinder is used to distribute heat from the solar collector to the PCM storage unit and vice versa. A mathematical model describing the behaviour of temperature in the PCM and HTF is used. Numerical solutions are obtained by transforming heat conduction equations of the PCM and HTF into enthalpy equation and solving it by using the Godunov method. Thermal performance during charging and discharging process of several selected PCMs is investigated. The simulation results showed that magnesium chloride hexahydrate has the highest capacity to store solar thermal energy whereas erythritol can achieve the highest temperature history during charging time and at the first 54 minutes of discharging time. The results provide an important information to design a solar cooker prototype equipped with thermal energy storage that has a good thermal performance.**

***Keywords*—Solar cooker; thermal energy storage; phase change material; latent heat; Godunov method; simulation.**

I. INTRODUCTION

Tropical country such as Indonesia is endowed highly abundant solar energy. Sunlight appears throughout the year both in the dry and rainy season. However, the utilization of solar energy is still relatively limited. Heretofore, the solar energy is used for drying agricultural products, power generation, water heater for households and industries, agricultural greenhouses heating, and solar cookers. In the use of the solar cooker, the conventional one works by focusing sunlight through the parabolic mirrors over cooking vessel. The thermal results are quite satisfactory during the sunshine hours. But, several drawbacks appear during the utilization of the convectional solar cooker. One of them is that the cooker can not be used to cook food at the late evening or during the off-sunshine hours [1]. Since the last decades, the idea to use solar thermal energy storage medium has become an interesting topic in thermal engineering. By adding the energy storage in solar cooker design, it is possible that it can be used for cooking at the late evening [2]. The forth issue is to answer what materials which have high thermal performance to be used as thermal energy storage medium.

Phase change material (PCM) is a very promising candidate for consideration as solar energy storage medium due to its heat capacity to store thermal energy. The PCM can store 5-14 times more heat per unit volume than nonPCMs [3]. Hence, PCM can be considered as solar thermal energy storage medium for cooking at late evening or during off-sunshine hours. To choose which PCM that has high thermal performance, the physical properties such as melting point, latent heat, density, toxicity, corrosiveness, and also prices should be considered before conducting experiments or numerical simulations [4].

Some experiments to assess thermal performance of some PCMs were conducted by other researchers. Sharma et al. [4] designed and tested the solar cooker with a PCM storage based on an evacuated tube solar collector. They used commercial PCM erythritol and reported that the evening cooking using erythritol as thermal storage is faster than the noon cooking. Furthermore, Domanski et al. [5] investigated experimentally the possibility of cooking during off-sunshine hours using PCMs (stearic acid or magnesium nitrate hexahydrate) as thermal storage media. From their experimental results, it was found that the cooker performance depends on solar intensity, thermophysical properties of the PCM, and mass of the cooking medium. Buddhi and Sahoo [6] also investigated the use of stearic acid as latent heat storage in box-type solar cooker. Their experimental results were compared with conventional solar cooker having no heat storage. The utilization of cylindrical latent heat storage unit using acetamide and acetanilide for box-type solar cooker used for cooking during the late evening is reported in the literatures [2], [7].

Instead of conducting the expensive experiments, some researchers tested the thermal performance of solar cooker through numerical simulations. Khalifa et al. [8] studied the simulation for predicting thermal performance of the solar cooker where solar energy is supplied by spiral concentrator. Besides, Costa et al. [9] analyzed the thermal performance of a latent heat storage system with and without fins. From their numerical results, it was concluded that the magnitude of the melt fraction with fins is found to be considerable compared with the system without fins. Chen et al. [1] also simulated numerically heat transfer in several PCMs used in box-type solar cooker. They tested four PCMs namely magnesium nitrate hexahydrate, stearic acid, acetamide, acetanilide, and erythritol and they reported that stearic acid and acetamide should be used as a latent heat storage in box-type solar cooker.

In this study, the Godunov method is adopted to simulate thermal performance of several PCMS—i.e. erythritol, magnesium nitrate hexahydrate, RT100, and magnesium chloride hexahydrate. These PCMs were chosen because they have

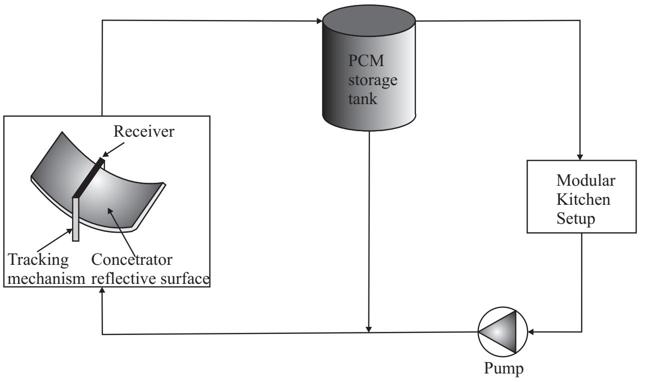

Fig. 1. Configuration of solar cooker equipped with PCM storage tank [10].

melting temperature between 80 °C – 120 °C which are suitable for domestic solar cooker application. These PCMs are then assessed numerically to determine which PCM that has the highest thermal performance. The phase change problem occurring in the PCM is referred to as a Stefan problem. The Godunov method to solve such kind of the Stefan problem is discussed in [11]. More comprehensive review of this method can be found in [12]–[14].

II. MATHEMATICAL MODELING

A solar cooker system equipped with PCM as thermal energy storage is illustrated in Fig. 1. The system consists of solar heat collector, heat transfer fluid (HTF), PCM storage tank, and modular kitchen. One of the important component in the solar cooker system is the PCM storage unit which contains many small PCM cylinders. By this component, the solar cooker can be used for cooking both in the afternoon and even in the late evening.

How the solar cooker works can be described as follows. Firstly, solar heat energy is collected through solar heat collector (receiver), as shown in Fig. 1. Then, heat from the solar collector is flowed through HTF into PCM storage tank. Furthermore, the fluid which brings thermal energy is received by the PCM cylinders which initially in solid phase. As the PCM heated, it starts melting and changing the phase from solid to liquid. At each time, the heat transferred from hot fluid to the PCM is stored as latent heat as well as sensible heat. This process is referred to as the solar thermal energy storage (charging) during sunshine hours. Conversely, when the stored energy will be used for cooking, cold temperature carried by HTF is flowed to the PCM cylinders. As a result, heat from the PCM is transferred to the fluid and distributed to the kitchen modular. Finally, solar heat energy is ready to be used for cooking food at late evening. This conversely process is called discharging process.

Fig. 2(a) shows a PCM storage tank that consists of many hollow PCM cylinders. The configuration of one hollow PCM cylinder is illustrated in Fig. 2(b). Suppose that the cylinder has length l, inner radius r_{in}, and outer radius r_{out}, as shown in Fig. 2(c). Heat collected by solar collector is flowed through the HTF and then passed along the hollow PCM cylinder with velocity v. Heat energy from HTF is transferred to the PCM through the inner wall of hollow PCM cylinder, r_{in}.

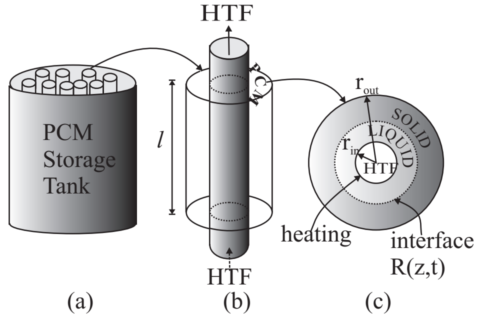

Fig. 2. (a) PCM storage tank. (b) A hollow PCM cylinder with HTF. (c) Sectional view of the PCM with interface separated solid and liquid region.

Mathematical formulation of heat transfer in the solar cooker system encompasses heat transfer both in the HTF and in the PCM. Suppose that domain of the observation is divided into two regions—i.e. HTF region: $0 \le z \le l$, $0 \le r \le r_{in}$ and PCM region: $0 \le z \le l$, $r_{in} < r \le r_{out}$. Let $T(\mathbf{x}, t)$ represents temperature at position $\mathbf{x} = (r, z) \in \mathbf{R}^2$ and time t. Here, it is assumed that heat from fluid propagates to PCM axially symmetry and the temperature of fluid only depends on z direction. Heat equation for the HTF is given by [15]:

$$\begin{aligned}\rho_F c_F \left(\frac{\partial T^F}{\partial t} + v \frac{\partial T^F}{\partial z} \right) &= \frac{2h}{r_{in}} \left(T^{surf}(z,t) - T^F \right) \\ &+ \frac{\partial}{\partial z} \left(k_F \frac{\partial T^F}{\partial z} \right), \qquad (1)\end{aligned}$$

where $T^F = T^F(\mathbf{x}, t)$ is the fluid temperature, and ρ_F, c_F, h, and k_F are density, specific heat, convective heat transfer coefficient, and thermal conductivity of HTF resepectively. Moreover, $T^{surf} = T(r_{in}, z, t)$ describes temperature of inner wall of PCM cylinder ($r = r_{in}$) which directly contact with fluid flow.

Heat transfer in the PCM is divided into two phase regions—i.e. solid and liquid region. The boundary between the solid and liquid region is referred to as interface. Suppose that $R(z, t)$ is the interface position in radial direction as seen in Fig. 2(c). Thereby, the liquid region is $r_{in} \le r \le R(z, t)$ and the solid region is $R(z, t) \le r \le r_{out}$. The heat conduction equation in the liquid region can be expressed as [16]:

$$\begin{aligned}\rho_L c_L \frac{\partial T^P}{\partial t} &= \frac{1}{r} \frac{\partial}{\partial r} \left(k_L \, r \, \frac{\partial T^P}{\partial r} \right) + \frac{\partial}{\partial z} \left(k_L \frac{\partial T^P}{\partial z} \right), \\ & \quad r_{in} \le r \le R(z,t), \ 0 \le z \le l, \qquad (2)\end{aligned}$$

where $T^P = T(r, z, t)$ is the PCM temperature, and ρ_L, c_L, and k_L are density, specific heat, and thermal conductivity of PCM in liquid phase respectively. Moreover, the heat conduction equation in solid region can be written as

$$\begin{aligned}\rho_L c_S \frac{\partial T^P}{\partial t} &= \frac{1}{r} \frac{\partial}{\partial r} \left(k_S \, r \, \frac{\partial T^P}{\partial r} \right) + \frac{\partial}{\partial z} \left(k_S \frac{\partial T^P}{\partial z} \right), \\ & \quad R(z,t) \le r \le r_{out}, \ 0 \le z \le l, \qquad (3)\end{aligned}$$

where ρ_S, c_S, and k_S are density, specific heat, and thermal conductivity of PCM in solid phase respectively.

The temperature at the interface position should be the transition temperature from solid to liquid or referred to as

TABLE I. PHYSICAL PROPERTIES OF SEVERAL PCMS [1], [4], [16].

Properties	$C_4H_{10}O_4$	$Mg(NO_3)_2\cdot 6H_2O$	RT100	$MgCl_2\cdot 6H_2O$
Density (kg/m^3)	1480	1636	940	1570
Specific heat (kJ/kg °C)				
Solid	1.38	1.84	1.8	2.25
Liquid	2.76	2.51	2.4	2.61
Thermal conductivity (kJ/m s °C)				
Solid	$0.733\cdot 10^{-3}$	$0.611\cdot 10^{-3}$	$0.200\cdot 10^{-3}$	$0.704\cdot 10^{-3}$
Liquid	$0.326\cdot 10^{-3}$	$0.490\cdot 10^{-3}$	$0.200\cdot 10^{-3}$	$0.570\cdot 10^{-3}$
Melting temperature (°C)	118	89	99	116.7
Lantent heat of fusion (kJ/kg)	339.8	162.8	168	168.6

the melting point. Let T_m represents the melting point of the PCM, then the temperature at the interface position is

$$T^P(R(z,t),z,t) = T_m. \tag{4}$$

In addition, energy conservation at the interface position follows

$$\rho L \frac{\partial R}{\partial t} = -k_L \frac{\partial T^P}{\partial r}(R,z,t) + k_S \frac{\partial T^P}{\partial r}(R,z,t), \tag{5}$$

where L is latent heat. Equation (5) is well known as the Stefan condition and it represents energy conservation across the interface $R(z,t)$ in cylindrical coordinate.

It is assumed that all PCM region in solid form before hot fluid is transferred to it. Let T_0 be the initial temperature of the PCM. Thus, initial conditions for (1) – (5) are given by

$$T(r,z,0) = T_0, \quad R(z,0) = r_{in}. \tag{6}$$

Since at initial the PCM is in solid phase then T_0 must be less than the melting temperature T_m.

Two processes during the utilization of solar cooker are considered. They are charging process (energy storage) and discharging process (energy extraction). During the energy storage, hot fluid is flowed parallel to PCM cylinder. In contrast, during the energy extraction, cold fluid is flowed into the PCM cylinder and take the heat energy from the PCM which then flowed out to the kitchen modular. Therefore, the boundary conditions of the PCM cylinder and HTF can be expressed as [15]:

$$T^F(r,0,t) = T_{ci}, \quad 0 \le r \le r_{in}, \quad \text{(charging)} \tag{7}$$

$$T^F(r,0,t) = T_{di}, \quad 0 \le r \le r_{in}, \quad \text{(discharging)} \tag{8}$$

$$\frac{\partial T^P}{\partial z}(r,0,t) = 0, \quad r_{in} \le r \le r_{out}, \tag{9}$$

$$\frac{\partial T^P}{\partial z}(r,l,t) = 0, \quad r_{in} \le r \le r_{out}, \tag{10}$$

$$h(T^{surf} - T^F) = k_L \frac{\partial T^P}{\partial r}, \quad r = r_{in},\ 0 \le z \le l, \tag{11}$$

$$k_S \frac{\partial T^P}{\partial z}(r_{out},z,t) = 0, \quad 0 \le z \le l, \tag{12}$$

where T_{ci} and T_{di} are inlet temperature during charging and discharging process respectively. Equation (9), (10), and (12) represent no flux at that position (the boundary is insulated). Moreover, equation (11) is convective flux of the boundary condition.

The major advantage of the utilization of the PCM is that thermal energy transferred to the PCM is stored not only in the form of sensible heat but also in the form of latent heat. The energy stored in the hollow cylindrical PCM with length l at time t can be written as

$$\begin{aligned} E_{\text{PCM}}(t) &= \int_0^l \int_{r_{in}}^{R(z,t)} \rho c_L \left[T(r,z,t) - T_m\right] 2\pi r\, dr\, dz \\ &+ \int_0^l \int_{r_{in}}^{R(z,t)} \rho L 2\pi r\, dr\, dz \\ &+ \int_0^l \int_{R(z,t)}^{r_{out}} \rho c_S \left[T(r,z,t) - T_m\right] 2\pi r\, dr\, dz. \end{aligned} \tag{13}$$

The estimated energy stored in the PCM (13) is used to calculate the thermal performance during storage and extraction process.

III. DISCRETIZATION OF ENTHALPY FORMULATION

The emergence of moving boundary (interface) that changes at each time is a major difficulty in solving heat transfer equations represented in (1) – (12). This problem is well-known as a Stefan problem [17]. The standard strategy to solve Stefan problem is by reformulating heat conduction equations in both phases into an enthalpy (energy) form. By applying this strategy, moving boundary is not taken into account in the computation. The transformation from temperature term into enthalpy equation can be described as follows. Let $E(\mathbf{x},t)$ denotes the enthalpy per unit volume at position $\mathbf{x} = (r,z)$ and time t. The sum of sensible and latent heat is given by

$$E(\mathbf{x},t) = \begin{cases} \rho c_S \left(T(\mathbf{x},t) - T_m\right), & T(\mathbf{x},t) < T_m, \\ \rho c_L \left(T(\mathbf{x},t) - T_m\right) + \rho L, & T(\mathbf{x},t) > T_m, \end{cases} \tag{14}$$

where $T(\mathbf{x},t) < T_m$ and $T(\mathbf{x},t) > T_m$ represent temperature at solid and liquid phase respectively.

Godunov method is a numerical method that easy to apply for energy conservation equation such as enthalpy equation in integral form (15). Numerical solution based on Godunov method begins by dividing the domain $[r_{in}, r_{out}]$ and $[0,l]$ into M_1 and M_2 subintervals respectively. Then, energy conservation equation in each control volume $V_{i,j} = [r_{i-1/2}, r_{i+1/2}] \times [z_{j-1/2}, z_{j+1/2}]$ can be expressed as

$$\int_{V_{i,j}} \left[E(\mathbf{x},t+\Delta t) - E(\mathbf{x},t)\right] \mathrm{d}A = \int_t^{t+\Delta t} \int_{\partial V_{i,j}} -\mathbf{q}\cdot\mathbf{n}\, \mathrm{d}S\, \mathrm{d}t, \tag{15}$$

where $E(\mathbf{x},t)$ is the enthalpy per unit area, and $-\mathbf{q}\cdot\mathbf{n}$ is heat flux into the area $V_{i,j}$ across its boundary $\partial V_{i,j}$, $\mathbf{n}$ being the outgoing unit normal to $\partial V_{i,j}$ [11].

The discretization of the whole domain can be divided into two directions that are axial and radial direction. As illustrated in Fig. 3 and Fig. 4, heat flux across boundary of control volume $V_{i,j}$ are $q_{i,j-1/2}$ and $q_{i,j+1/2}$ (in axial direction) as well as $q_{i-1/2,j}$ and $q_{i+1/2,j}$ (in radial direction). The heat flux is calculated by using Fourier law for heat conduction equation: $q = -kT_x$. Numerical solutions of (1) – (12) using Godunov method in explicit scheme are then obtained from (15). The discrete solution of enthalpy equation in cylindrical coordinate can be written as

$$E_{i,j}^{n+1} = E_{i,j}^{n} + \frac{\Delta t}{r_{i,j}\Delta r}\left[q_{i-1/2,j}^{n} r_{i-1/2,j} - q_{i+1/2,j}^{n} r_{i+1/2,j}\right] + \frac{\Delta t}{r_{i,j}\Delta z}\left[q_{i,j-1/2}^{n} r_{i,j-1/2} - q_{i,j+1/2}^{n} r_{i,j+1/2}\right], \quad (16)$$

where

$$r_{i-1/2,j} = r_{in} + (i-1)\Delta r, \quad r_{i,j-1/2} = (j-1)\Delta z,$$

$$q_{i-1/2,j} = \frac{T_{i-1,j} - T_{i,j}}{R_{i-1/2,j}},\ R_{i-1/2,j} = \frac{\Delta r}{2}\left(\frac{1}{k_{i-1,j}} + \frac{1}{k_{i,j}}\right),$$

$$q_{i,j-1/2} = \frac{T_{i,j-1} - T_{i,j}}{R_{i,j-1/2}},\ R_{i,j-1/2} = \frac{\Delta z}{2}\left(\frac{1}{k_{i,j-1}} + \frac{1}{k_{i,j}}\right).$$

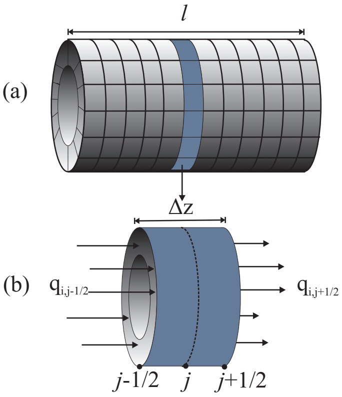

Fig. 3. (a) Discretization of the domain in axial direction of the PCM cylinder. (b) Heat flux into the area of control volume $V_{i,j} = [r_{i-1/2}, r_{i+1/2}] \times [z_{j-1/2}, z_{j+1/2}]$ across its boundary, $z_{j-1/2}$ and $z_{j+1/2}$.

After the enthalpy at position $\mathbf{x}_{ij}$ is obtained using (16), temperature at that position and time t^{n+1} is calculated by reformulating (14) into temperature term—viz.

$$T_{i,j}^{n+1} = \begin{cases} T_m + \dfrac{E_{i,j}^{n+1}}{\rho c_S}, & E_{i,j}^{n+1} \leq 0 \quad \text{(solid)}, \\ T_m, & 0 < E_{i,j}^{n+1} < \rho L \quad \text{(interface)}, \\ T_m + \dfrac{E_{i,j}^{n+1} - \rho L}{\rho c_L}, & E_{i,j}^{n+1} \geq \rho L \quad \text{(liquid)}. \end{cases} \quad (17)$$

IV. RESULT AND DISCUSSION

The selected PCMs: erythritol ($C_4H_{10}O_4$), magnesium nitrate hexahydrate ($Mg(NO_3)_2{\cdot}6H_2O$), RT100, and magnesium chloride hexahydrate ($MgCl_2{\cdot}6H_2O$) are tested numerically to asses its thermal performance. These PCMs are chosen because their melting point are suitable for cooking food. In addition, the selected PCMs have high latent heat of fusion so that it is expected that they can store more heat in the storage unit. Physical properties of the four selected PCMs are listed in Table I. By calculating the temperature and stored energy in the PCMs, it will be determined which PCM that has the highest thermal performance so that it can be used as thermal energy storage in solar cooker.

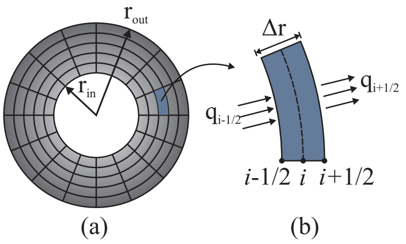

Fig. 4. (a) Discretization of the domain in radial direction of the PCM cylinder. (b) Heat flux into the area of control volume $V_{i,j} = [r_{i-1/2}, r_{i+1/2}] \times [z_{j-1/2}, z_{j+1/2}]$ across its boundary, $r_{i-1/2}$ and $r_{i+1/2}$.

TABLE II. OTHER PARAMETERS OF THE SIMULATION [15], [18].

Parameter	value	unit
Initial temperature of the PCM	30	°C
Heat transfer fluid (HTF)		
Density	1000	kg/m^3
Specific heat	4.2	kJ/kg °C
Thermal conductivity	$0.6{\cdot}10^{-3}$	kJ/m h °C
Average velocity inside annulus	0.5	m/s
Inlet temperature during storage	140	°C
Inlet temperature during extraction	40	°C
Cylinder tank		
Inner radius	0.0125	m
Outer radius	0.025	m
Length	1.5	m
Convective heat transfer coefficient	37.81	$kJ/(m^2\ s\ °C)$

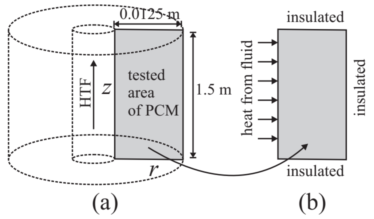

Fig. 5. (a) Sectional view of the tested area of PCM cylinder. (b) Two-dimensional view and illustration of boundary conditions.

Sectional view of the domain to assess the thermal performance of the selected PCMs is shown in Fig. 5(a). Since the heat transfer in the PCM cylinder is assumed as axially symmetric, then the tested area can be considered as two-dimensional domain, as illustrated in Fig. 5(b). Suppose that the storage tank has 20 PCM cylinders with length 1.5 m, inner radius 0.0125 m, and outer radius 0.025 m. The heat carried by the fluid is transferred at constant temperature 140 °C. But, when the fluid enters the wall of PCM, its temperature values depend on its position in the cylinder. Further, the boundary conditions of the PCM are described in Fig. 5(b). The other parameters of the simulation are summarized in Table II.

Fig. 6 depicts the temperature contours of the tested PCMs at $t = 6, t = 8$, and $t = 10$ hours during the charging process. From the figure, it can be seen that erythritol has

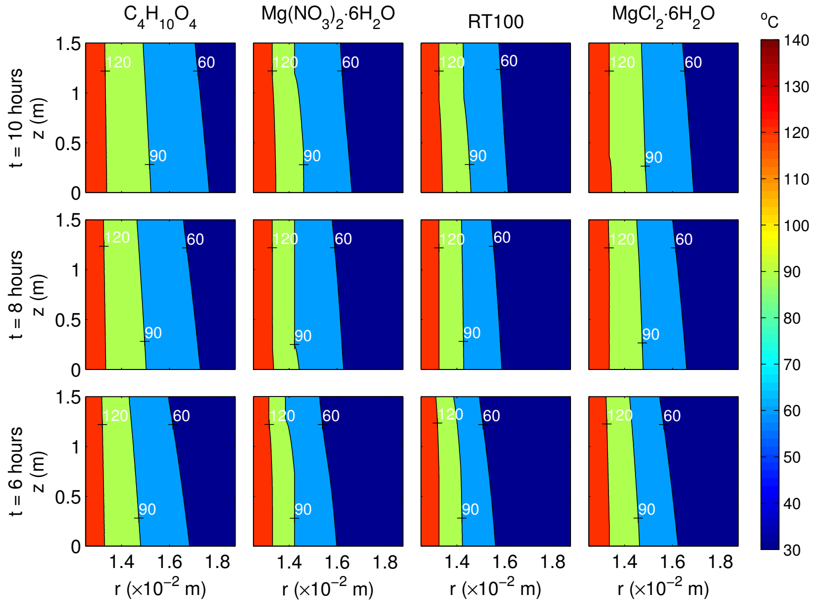

Fig. 6. Temperature contours during charging process at $t = 6$, $t = 8$, $t = 10$ hours of PCMs: erythritol ($C_4H_{10}O_4$), magnesium nitrate hexahydrate ($Mg(NO_3)_2{\cdot}6H_2O$), RT100, and magnesium chloride hexahydrate ($MgCl_2{\cdot}6H_2O$).

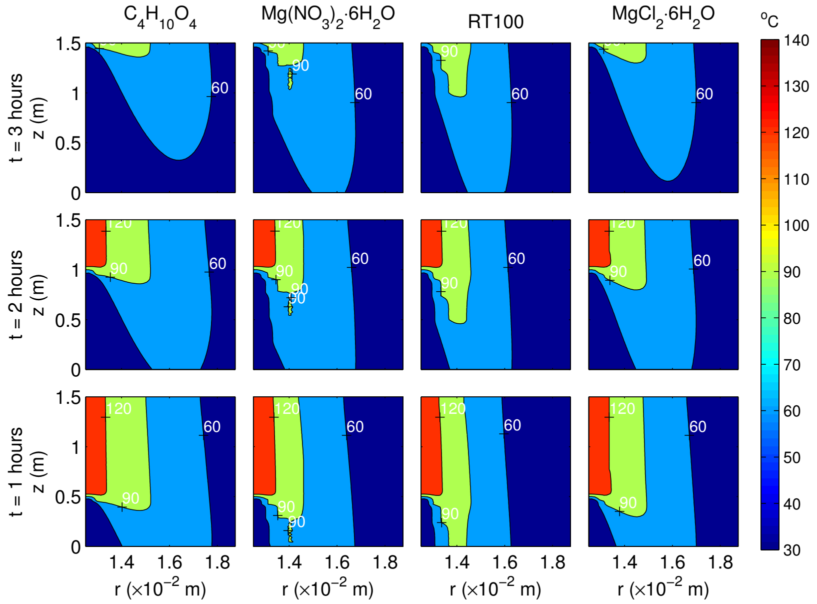

Fig. 7. Temperature contours during discharging process at $t = 1$, $t = 2$, and $t = 3$ hours of PCMs: erythritol ($C_4H_{10}O_4$), magnesium nitrate hexahydrate ($Mg(NO_3)_2{\cdot}6H_2O$), RT100, and magnesium chloride hexahydrate ($MgCl_2{\cdot}6H_2O$).

the highest heat propagating rate. The magnesium chloride hexahydrate has heat propagating rate only lower than erythritol, while the magnesium nitrate hexahydrate and RT100 have relatively equal heat propagating rate. In addition, the temperature contours of the tested PCMs for $t = 1, t = 2$, and $t = 3$ hours during the discharging process are presented in Fig. 7. As can be seen that, although erythritol has the fastest heat propagating rate during the charging time, its rate occurs also during the discharging time which is not good result in the use of solar cooker. The different results are shown by RT100 and magnesium nitrate hexahydrate which can maintain heat longer than erythritol and magnesium chloride hexahydrate.

Fig. 8 displays the temperature history of the tested PCMs during 10 hours of charging time and 6 hours of discharging time. It is shown that erythritol has the highest temperature history compared with magnesium chloride hexahydrate, magnesium nitrate hexahydrate, and RT100. However, it occurs only for the first 54 minutes of the discharging time and it decreases drastically after that. Similarly, magnesium chloride hexahydrate has a better performance than RT100 and magnesium nitrate hexahydrate although it occurs only for the first 66 minutes of the discharging time. Furthermore, for whole discharging time, in this simulation is 6 hours, RT100 has temperature history above three other selected PCMs. But

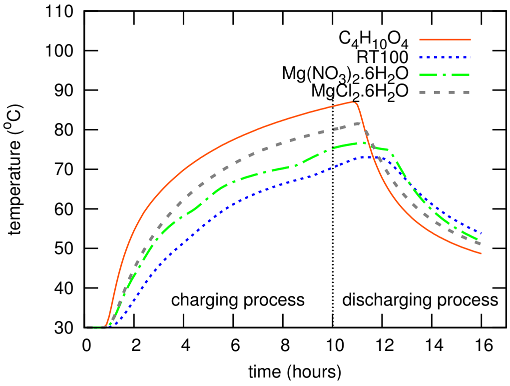

Fig. 8. Temperature history of PCMs: erythritol ($C_4H_{10}O_4$), magnesium nitrate hexahydrate ($Mg(NO_3)_2{\cdot}6H_2O$), RT100, and magnesium chloride hexahydrate ($MgCl_2{\cdot}6H_2O$) at $(r, z) = (0.015625, 0.3745)$ for a cycle of charging and discharging.

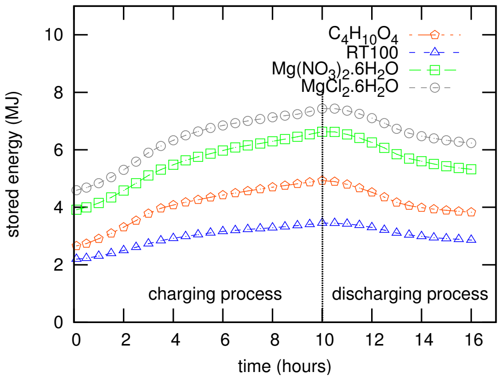

Fig. 9. Stored energy of PCMs: erythritol ($C_4H_{10}O_4$), magnesium nitrate hexahydrate ($Mg(NO_3)_2{\cdot}6H_2O$), RT100, and magnesium chloride hexahydrate ($MgCl_2{\cdot}6H_2O$) in megajoule (MJ) with respect to time using 20 cylinders PCM for a cycle of charging and discharging.

unfortunately, its temperature history is below 70 °C which is not suitable for cooking such as rice.

Total stored energy of the tested PCMs is approximated by using (13). Fig. 9 depicts stored energy of the selected PCMs for a cycle of charging and discharging. As can be seen from the figure, magnesium chloride hexahydrate has the highest capacity to store solar thermal energy while RT100 is poor in storing thermal energy compared with erythritol and magnesium nitrate hexahydrate. Moreover, total stored energy of erythritol is lower than magnesium chloride hexahydrate and magnesium nitrate hexahydrate whereas erythritol has the best performance in heat propagating rate.

V. CONCLUSION

The mathematical model and numerical simulation of solar cooker with thermal energy storage were studied to assess thermal performance of PCMs—i.e. erythritol, magnesium nitrate hexahydrate, RT100, and magnesium chloride hexahydrate. From the obtained simulation results, it can be concluded that magnesium chloride hexahydrate has the highest capacity to store solar thermal energy whereas erythritol can achieve the highest temperature history during charging time and at the first 54 minutes of discharging time. It means that the erythritol as heat storage medium is good for cooking only for short time after charging time terminated while the magnesium chloride hexahydrate can be used for cooking until late evening. Some developments are currently being made such as analyzing the stored energy in HTF, simulating the influence of various HTF velocity to heat transfer in PCM, and using periodic boundary conditions for heat transfer from HTF to PCM.

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