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NUMERICAL STUDY OF THE EFFECT OF PHASE CHANGE MATERIAL ON THERMAL MANAGEMENT OF ELECTRONIC COMPONENTS

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ABSTRACT

In recent years, the minimization of electronic components, as well as the higher performance of these components, has resulted in the production of compact parts. Therefore, inactive thermal management systems have been widely considered for electronic devices such as mobile phones. In the present study, two types of phase change materials, Heptadecane and Ecosane have been used to design a thermal management model for an electronic component. In order to optimize the model of thermal management of the electronic component, the parameters of the phase change material type, the thickness of the phase change material, the effect of adding the fin on the phase change material side, and also the effect of thermal flux have been investigated. The results show that the Ecosane has a better effect on the temperature control of the electronic component than Heptadecane. Also, by increasing the thickness of the Ecosane phase change material from 1.65 to 2.5 mm, the average temperature of the electronic component decreases by 3.7° C after 30 minutes. Additionally, the addition of a fin at the phase change material side reduces the temperature of the electronic component and increases the thickness of the fin from 2 to 3 mm, increases the temperature of the electronic component. By changing the thermal flux from 3 W to 2 W, the Ecosane phase change material was completely melting after 13.3 minutes later, which resulted in the average temperature of the component after 90 minutes, 6.5 ˚C decrease compared to the thermal flux 3 W.

Keywords: *Thermal Management, Phase Change Material, Heptadecane, Ecosane, Electronic Components*

INTRODUCTION

The advancement of high performance systems and more complexity, results in a sharp increase in the production of heat flux in electronic components. One of the common methods for controlling the temperature of electronic components is the use of a fan for cooling components, which due to fan constraints on some devices such as cell phones and causing high noise and consumption electricity, this method is not desirable at all. Today's the phase change material is widely used in energy storage systems. Inactive thermal management systems that use phase change material are based on three principles of lightness, low ambiguity and high efficiency. The fin is also used to increase the heat transfer rate in the place where the phase change material is located. In recent years, thermal control systems have become increasingly popular with phase change materials. The use of these materials could result in a more uniform temperature for electronic components at peak and low operating temperatures. The phase change materials used in this application typically have a melting temperature of 36°C to 56°C, so that the temperature of the components is well within

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a range below the critical temperature of 85°C that damages the electronic components. On the other hand, the use of these materials in electronic components such as mobile devices should be such as to provide a suitable temperature range for the user at work. Usually, the body temperature of electronic devices that are in contact with the body should not exceed 40-45°C. So far, a lot of researches have been done on the use of phase change materials for thermal management of various systems.

(Tomizawa et al., 2016) are investigated experimentally and numerically the phase change materials for controlling the heat of mobile devices. In order to study the temperature increase in the phase change material, a heater has been used as a simplified mobile device model, and phase change materials have been used for temperature control. The influence of the mass, heat, thermal conductivity, and the geometry of the phase change material sheet on the temperature of the mobile device have been investigated. The results show that the use of phase change materials with higher conduction heat transfer coefficients can have a better effect on the performance of this material in temperature control of the mobile device. (Alshaer et al., 2015) studied laboratory the multiple thermal management systems for electronic devices. Three types of thermal management system have been studied in this research. In the first model, only carbon fiber is used. In the second model, the carbon foam is filled with phase change material, and in the third model, in addition to carbon foam and phase change material, the carbon nanotubes are also used to increase heat transfer. In this study, two types of carbon foam with different conduction heat transfer coefficients have been investigated. The results show that the use of phase change material can postpone the time to reach a steady state. Also, the use of carbon nanotubes can increase the time it reaches the steady state. In the research of (Javani et al., 2014), an inactive thermal management system for an electric vehicle battery has been tested and the phase change material is injected between the battery cells of the li-ion. Due to the working condition of the vehicle's battery, the N-Octadecane phase change material has been selected. Porous foams used to store phase change material have also been selected in laboratory methods. In this research, numerical methods are also used for simulation. The results of the battery drainage process have been compared for a case that has been used with and without a phase change material. The results indicate that the use of phase change material can reduce the maximum temperature to 7.3°C. Also, the use of phase change material makes the distribution of temperature inside the battery more uniform. (Nayak et al., 2006) examined the effect of using the fin on the phase change material to increase the conduction heat transfer within this material. For this purpose, three different geometric structures have been used. The results show that the use of rod fin has more efficiency and more uniform temperature distribution.

(Weng et al., 2011) studied the cooling efficiency of a combined cooling system using simple heat sink and heat sink containing a phase change material. The results show that the use of phase change material can reduce the energy consumption up to 46% in the fan used to cool the system. Gong and Mujumdar (Gong & Mujumdar, 1995; Gong & Mujumdar, 1996; Gong & Mujumdar, 1996) carried out a series of numerical studies on heat transfer during the melting and freezing of single and multiple phase change materials. A new design for thermal storage is proposed by them which using multiple phase change materials to generate power. They then developed their analysis from the single charge (melt) process to a single charge/discharge process (melting/freezing) and by a thermodynamic analysis, found that increasing the thermal efficiency by using multiple phase change material can be doubled or even tripled. (Tan & Tso, 2004) experimentally simulated the cooling of mobile device by using a unit of thermal storage filled with N-Ecosane, and found that the efficiency of the device depending on the amount of the phase change material.

(Gochman et al., 2003) showed that the heat transfer of desktop and mobile processors was 100 watts and 30 watts, respectively. They concluded that heat management in the integrated circuit is an important challenge, and there is a continuing need for developing cooling techniques to disperse this heat. Several researchers have evaluated various cooling techniques for heat dispersion from electronic components to improve the performance of these components. (Alawadhi & Amon, 2003) evaluated thermal energy management issues associated with portable electronic components. The performance of a heat control unit based on phase change material was analyzed for both constant power and variable power utilization. (Lamberg et al., 2004) studied a designed system which store thermal energy when the peak temperature is obtained under the conditions of the operation of a portable electronic device.

(Fok et al., 2010) performed an analysis on a heat sink filled with phase change material for portable electronic devices. They concluded that this solution could increase the heat transfer rate during the charge stage, but does not seem to have a significant effect during the discharge stage. (Wang et al., 2007) evaluated the heat sink with phase change material that contains an extruded aluminum sink located in suitable phase change materials. (Swaminathan & Eswaran, 2016) evaluated numerically the performance of a heat sink with phase change material using porous media as a thermal conductivity enhancer. The results showed that the heat sink with the porous medium had better performance than the heat sink with the phase change material only. (Pakrouh et al., 2015) carried out a numerical evaluation of the geometric optimization of PCM heat sink with fins, and their results showed that a complex relationship between PCM percentages and TCE volumes and optimal PCM percentages were found. (Setoh et al., 2010) experimentally investigated the effect of fin on the performance of phase change material. For this purpose, they examined 8 different cases with different fins (different geometric shapes) and concluded that increasing the number and the length of the fins increases the performance of the phase change material.

In the present study, the process of melting and freezing of a phase change material in an aluminum block, all of which is located in a polycarbonate enclosure, is numerically simulated by Fluent software. Due to the process of producing thermal energy, phase change materials are used in the system in such a way that thermal fluctuations do not have a significant effect on the temperature of the perceptible surface on the contact with the user. The amount of heat production and the period of heat generation fluctuations, the thickness of the phase change material and the type of the phase change material are the variables studied. Thermal boundary conditions are defined in one of the model walls in the form of a steady heat flux and the effects of this heat flux on the surface temperature of the system have been investigated. In order to investigate the thermal control process, different heat fluxes have been applied with different periods of time. Different thicknesses for the phase change material have also been used to study the effect of this parameter on the thermal control process. Correct selection of phase change material is also one of the most important factors affecting the thermal control process. In this study, two Heptadecane and Ecosane phase change materials have been used.

Also, the effects of adding the fin on the phase change material side have been investigated to increase the heat transfer in the temperature control of electronic components.

Problem geometry and numerical simulation

- ### *Geometry and grid generation*

Problem geometry consists of a phase change material sheet with a thickness of 2 mm in an aluminum block with a length of 100 mm, a width of 50 mm and a height of 3 mm. The whole of which is called heat sink and is located in a polycarbonate chamber with a length of 120 mm, a width of 70 mm and a height of 10 mm. The heater which aluminum block is placed on it has a length of 104 mm and a width of 54 mm. This system is designed on the basis of moderate dimensions of portable electronic devices. Figure 1, shows an outline of the geometry of the problem.

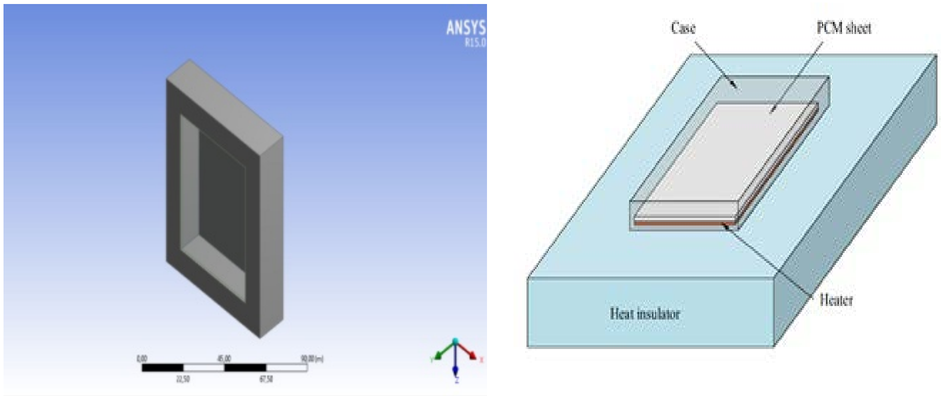

Figure 1. Geometric characteristics of the problem and location of the phase change material in the aluminum block

Grid quality greatly affects the solution convergence process. Finding an optimal grid that answers are independent of that grid is quite experimental and time-consuming. Typically, to find such a grid, the numerical simulation output parameters are mapped according to the number of grid nodes, so that ultimately, with increasing number of nodes, no change in the parameters is obtained. Figure 2, shows the final grid of the problem geometry. Near the boundary, the structure grids have been used to accurately model the effects of the boundary layer.

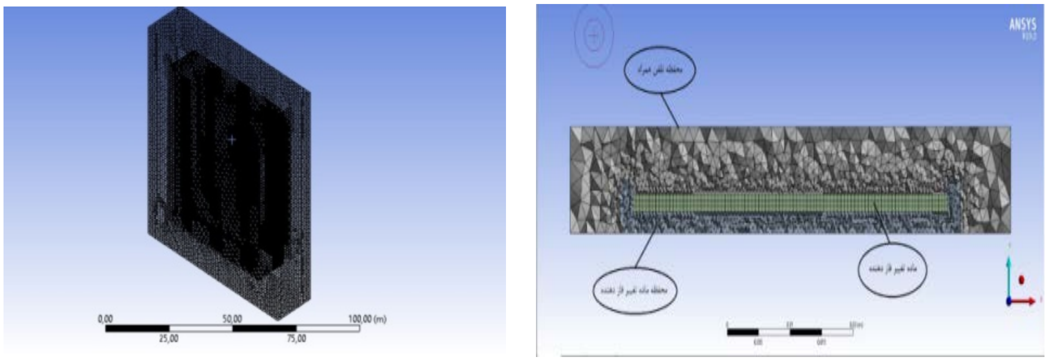

Figure 2. Three-dimensional grid generated of geometry

After adding the fin, the geometry of the problem has been redesigned in the Ansys mesh software. Figure 3 shows the grid generated in the fin mode.

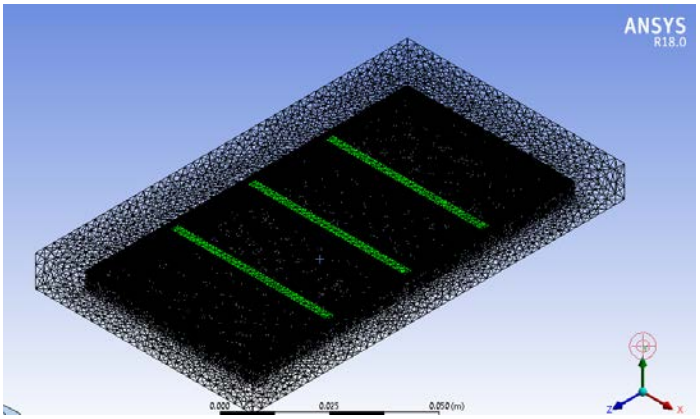

Figure 3. Three-dimensional grid generated of geometry with fin

- ***Governing equations and solving method***

In this study, the enthalpy-porosity technique is used, instead of tracing the common solid-liquid boundary explicitly. The liquid-solid paste region behaves as a porous portion of the fluid fraction, and the components of proper momentum sources are added to the momentum equations for the loss of pressure due to the presence of solids. When using the freezing/melting model in relation to the modeling of the reaction components transfer, there is no mechanism for limiting the reaction in the liquid region, that is, the reactions are solved everywhere. In the enthalpy-porosity technique, the fusion boundary is not explicitly detected. Instead, a value called the volume fraction of the liquid, which represents the fraction of the volume of the cell that is in the form of a liquid, is associated with each cell in the domain of the solution. The liquid fraction is calculated in each repetition based on the enthalpy balance. The paste region is a region in which the liquid fraction is between 0 and 1. The paste region is modeled as a pseudo-porous medium in which porosity decreases from 1 to 0. When a substance becomes solid in a cell, the porosity becomes zero and hence the speed reaches zero.

Relations (1) and (2), show the continuity and momentum equations.

$$\partial_t(\rho) + \partial_i(\rho u_i) = 0 \tag{1}$$

$$\partial_t(\rho u_i) + \partial_i(\rho u_i u_j) = -\partial_i(P) + \rho g_i + \mu \partial_{jj}(u_i) + S_i \tag{2}$$

The component of momentum source resulting from the reduction of porosity in the paste region is obtained from equation (3).

$$S_i = C(1-\beta)^2 \frac{u_i}{\beta^3 + \varepsilon} \tag{3}$$

Where C is a constant for the paste region between 10^4 and 10^7 (Setoh et al., 2010). Also, ε is a small number of 0.001 to avoid dividing by zero.

The enthalpy is calculated in terms of the sum of the sensible enthalpy h and the latent heat ΔH from relations (4) and (5).

$$H = h + \Delta H \tag{4}$$

$$h = h_{ref} + \int_{T_{ref}}^{T} C_p dT \tag{5}$$

The value of latent heat can vary between zero (for solids) and L (for liquid). Therefore, ΔH is obtained from relation (6).

$$\Delta H = \beta L \tag{6}$$

For the melting and freezing problems, the energy equation is considered in the form of relation (7).

$$\partial_t(\rho h) + \partial_t(\rho \Delta H) + \partial_i(\rho u_i h) = +\partial_i(k \partial_i T) \tag{7}$$

For natural convection, instead of the density definition, as a function of temperature, one can use the Boussinesq approximation according to equation (8) to achieve faster convergence. This model is accurate when the variation of density is small.

$$\rho = \rho_0(1 - \alpha \Delta T) \tag{8}$$

Using this model, the density is considered constant for all solvable equations, except for the buoyancy term in the momentum equation which obtained from relation (9).

$$(\rho - \rho_0)g \cong -\rho_0 \alpha (T - T_0) g \tag{9}$$

In this research, the Boussinesq approximation is used to calculate the time-dependent natural convection in closed environment.

To freezing and melting a pure material, the phase change occurs at a specific melting temperature T_{melt}. However, for a multi components mixture, there is a freezing/melting paste region between the low temperature of the solidification and the high temperature of liquidation. When a multi components liquid convert to solid, the soluble matter is dispersed from the solid phase to the liquid phase. This effect is determined by the dispersion coefficient of the soluble matter i, which is represented by K_i and is equal to the ratio of solid mass fraction to mass fraction of liquid at the interface.

In the numerical solution method, the solid and liquid temperatures in the multi components mixture are obtained from relationships (10) and (11).

$$T_{solidus} = T_{melt} + \sum_{solutes} \frac{m_i Y_i}{K_i} \tag{10}$$

$$T_{liquidus} = T_{melt} + \sum_{solutes} m_i Y_i \tag{11}$$

The liquidification gradient of the i-th component, which is m_i, is obtained from $T_{eutectic}$ temprature, the lowest melting point of the material in which the frozen crystals and the liquid phase are in equilibrium, and the mass fraction $Y_{i,eutectic}$, according to equation (12).

$$m_i = \frac{T_{eutectic} - T_{melt}}{Y_{i,eutectic}} \tag{12}$$

The volume fraction of the liquid is obtained from equation (13).

$$\beta = \frac{T - T_{solidus}}{T_{liquidus} - T_{solidus}} \tag{13}$$

This relationship is for temperature between $T_{liquidus}$ and $T_{solidus}$. If the temperature is less than $T_{solidus}$, then $\beta = 0$, and if the temperature is greater than $T_{liquidus}$, then $\beta = 1$.

- ***Assumptions and material properties***

For modeling the problem, the following assumptions are considered:

- Properties of material in solid and liquid phases are constant.
- Phase change will occur at constant temperature.
- The boundary condition on one side of the wall is considered as a constant heat flux.
- The problem is considered steady.
- An incompressible fluid is considered.
- Due to the high gradient of temperature, the energy equation is solved.
- Interlayer resistance is considered to be zero.

The thermo physical properties of the phase change materials and the base materials used in this study are presented in Tables 1 and 2, respectively.

Table 1. Thermo physical properties of phase change material

Phase Change Material→	**Heptadecane**	**Ecosane**
Conduction heat coefficient($\frac{W}{m.K}$)	0.21	0.15
Specific heat capacity($\frac{J}{kg.K}$)	2570	2460
Density($\frac{kg}{m^3}$)	778	769
Melting temperature(°C)	23	36.5
Heat of fusion($\frac{kJ}{kg}$)	215	247

Table 2. Thermo physical properties of base materials

Base Material →	Polycarbonate	Aluminum
Conduction heat coefficient($\frac{W}{m.K}$)	0.21	202.4
Specific heat capacity($\frac{J}{kg.K}$)	1170	870
Density($\frac{kg}{m^3}$)	135	660.7

- ***Grid independency***

To ensure that the solutions are independent of the grid (number of nodes), the volume fraction of the liquid (β), which is the most important parameter related to the impact of the use of phase change material, is calculated for several computational grid which are presented in the Table 3 and shown in Figure 4. It should be noted that in all cases, environmental conditions, model geometry and constant thermo physical properties are assumed. According to the results of Table 3 and Figure 4, the grid with the number of elements 1315895 has been used. For this grid, the liquid volume fraction contour is shown in Figure. 5.

Table 3. Liquid volume fractions in 360 seconds for different grids

Number of elements	($\boldsymbol{\beta}$)
111402	0.5422
559989	0.5658
1315895	0.5696
2987344	0.5697

In order to evaluate the quality of the grid, skewness index is used, which means the proximity of the elements created in a balanced manner. The generated grid is acceptable, when the average value of this index is less than 0.95. If the average value of this index is between 0.95 and 1, the generated grid will be unacceptable. The value of this index for the optimal grid used in this study is 0.2, which indicates that the generated grid is very favorable. No matter how close this number is to zero, the better the grid quality.

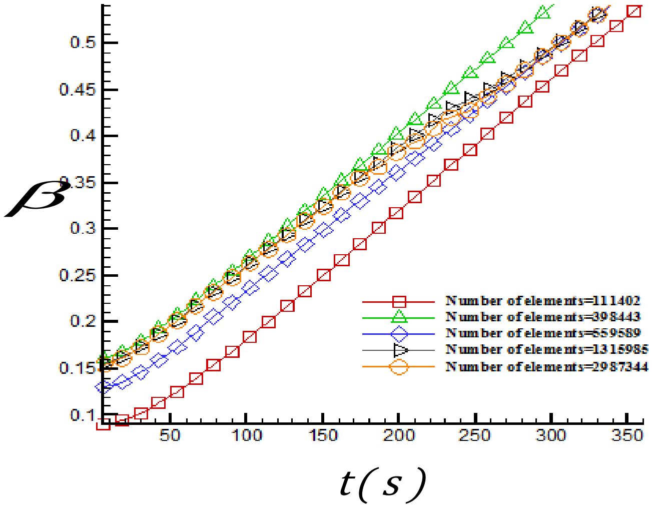

Figure 4. Comparison of liquid volume fractions in 360 seconds for different grids

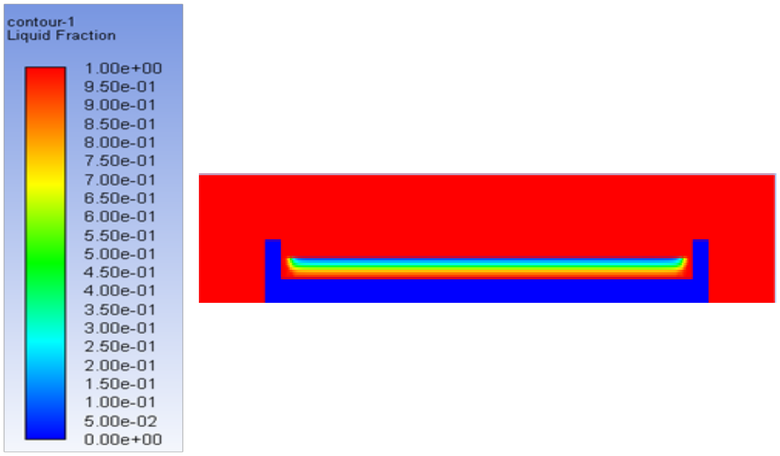

Figure 5. Contour of liquid volume fraction for optimal grid (t=360s)

RESULTS

Validation

In numerical simulations, the results of the work should first be compared with laboratory data or other numerical simulation to ensure the accuracy of the results. One of the most sensitive and important variables in the numerical simulation of the present study is the volume fraction of the liquid (β), since, after obtaining this parameter, it is determined how much of the phase change material is available in liquid form. Also, the volume fraction of a liquid at a time when its value reaches 1, indicates that the total phase change material has melted and if the heat flux continues, the temperature of the object is increased and the selected phase change material is not effective.

In order to verify the solution method of present study, the geometry used by (Al-Abidi et al., 2013) has been used. First, this geometry is plotted in the Design Modeler software and then grid generated in Ansys Mesh software. At the final stage, after applying the initial conditions and reference boundary conditions, by using the governing equations of present research, a numerical simulation is done.

In the reference research, in order to investigate the full melting time of the phase change material and its conversion to the liquid, various parameters such as the number of fins, fin length, fin thickness and Stefan number were investigated in seven different modes. In the present study, the specifications of one of these modes, as in Table 4, have been used.

Table 4. Specifications of one of the modes examined in reference (Al-Abidi et al., 2013)

Number of Fins	Fin thickness (mm)	Fin length (mm)
4	1	42

Figure 6, is the reference geometry, which consists of three concentric pipes. In this figure, the radius of the inner tube (r_i) is 25.4 mm with the thickness of 1.2 mm, the radius of the middle tube (r_m) is 75 mm with the thickness of 2 mm and the outer tube radius (r_0) is 100 mm with the thickness of 2 mm. The genus of all tubes is considered to be copper to ensure high conductive heat transfer.

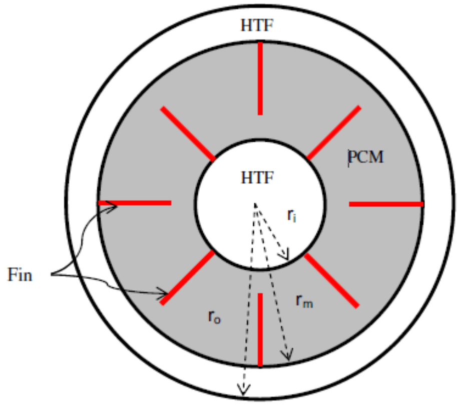

Figure 6. Reference geometry (Al-Abidi et al., 2013)

In Table 5, the thermo physical properties of the reference phase change material (Al-Abidi, et al., 2013), which is RT82, is shown. The heat transfer fluid is also water.

Table 5. Thermo physical properties of phase change material RT82

Phase Change Material →	**RT 82**
Conduction heat coefficient$(\frac{W}{m.K})$	0.2
Specific heat capacity$(\frac{J}{kg.K})$	2000
Solid density$(\frac{kg}{m^3})$	950
Liquid density$(\frac{kg}{m^3})$	770
Melting temperature(°C)	350.15-358.15
Heat of fusion$(\frac{kJ}{kg})$	176
Expansion coefficient$(\frac{1}{K})$	0.001
Dynamical viscosity$(Pa.s)$	0.03499

The geometry shown in Figure 6, in accordance with Figure. 7, is modeled and has a structured grid with the number of elements of 24492.

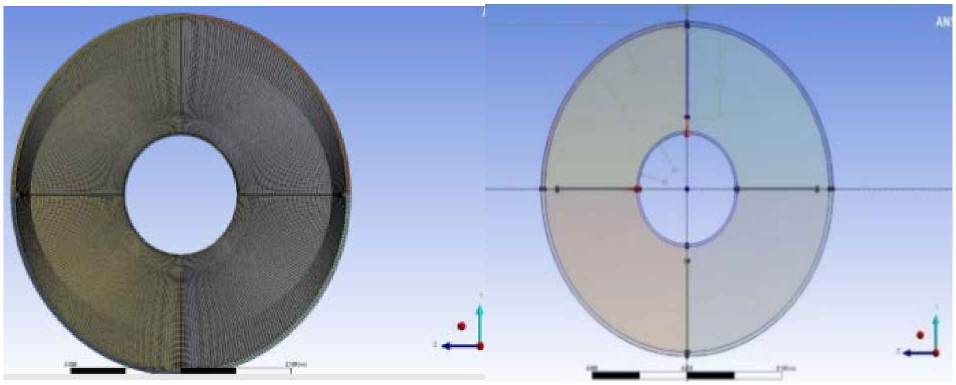

Figure 7. Modeling and grid generation of reference geometry

After grid generation, the governing equations are based on the assumptions of the reference paper, which include the laminar flow, unsteady flow, incompressible flow, considering the convection heat transfer and temperature dependence of the thermo physical properties of the water and the phase change material, is solved numerically and the comparison of the numerical results of this study with reference (Al-Abidi et al., 2013) is shown in Figure. 8. The maximum relative error is 3.39%, which indicates that the results are very consistent.

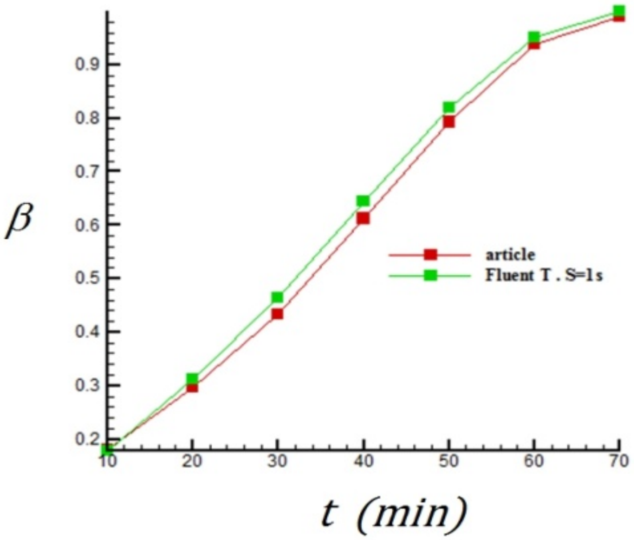

Figure 8. Comparing the results of reference research (Al-Abidi et al., 2013)] with numerical solution method of present study

In Figure 9, the temperature contours derived from the numerical solution method of the present study are compared qualitatively with the reference article, which are highly adapted.

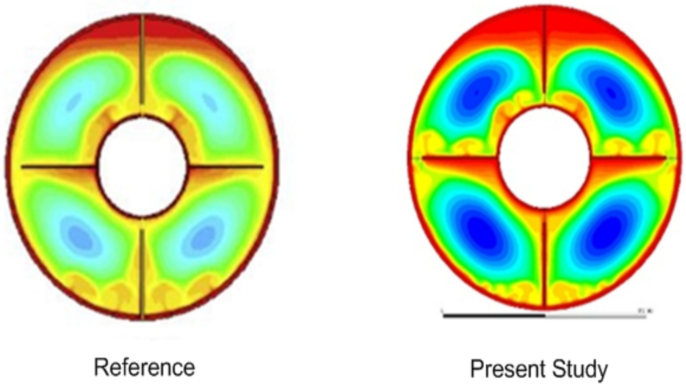

Figure 9. Qualitative comparison of temperature contours

- ***The effect of phase change material type on system performance***

Figure 10, shows the volume fraction of the liquid (β) of the phase change material (Heptadacane and Ecosane) relative to time. It can be seen that the higher the latent heat and the lower the conduction heat transfer coefficient of the phase change material is, the longer it melts (Ecosane). Also, according to this figure, for both phase change material, the volume fraction of the liquid is initially zero and then moves with an almost uniform gradient to 1. The reason of the liquid fraction equal to zero at the initial time, is due to the initial temperature of 20°C (lower than the PCM melting temperature), which by increasing the temperature, when this temperature reaches the melting point of the phase change material, the liquid fraction begins to change.

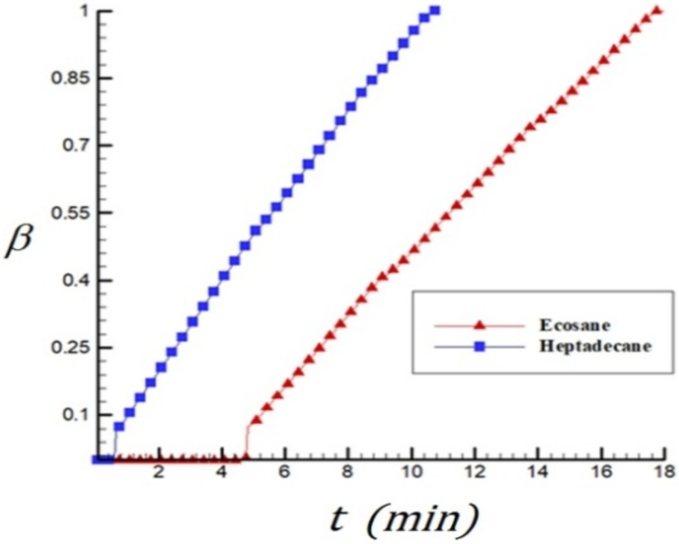

Figure 10. Changes in the volume fraction of the liquid relative to time

Figure 11, shows the average surface temperature of the electronic device in three cases without phase change material and with phase change materials of Ecosane and Heptadecane. According to this figure, it can be seen that, with increasing temperature, the average surface temperature of the electronic component increases, but as soon as the phase change material reaches its melting temperature, it receives all the heat flux generated from the heater to phase change and the rise in the surface temperature stops.

Figure 12, shows the upper surface temperature contours of the electronic component after 10, 20 and 30 minutes in 3 casses, without phase change material and with phase change materials of Ecosane and Heptadecane in the electronic component. As it can be seen, the temperature of the surface of the electronic component during use of the Heptadecane phase change material, at the first 10 minutes is lower than the surface temperature of the electronic component during use of Ecosane, due to the low melting point of the Heptadecane. However, in the 20th and 30th minutes, Ecosane has produced lower temperatures due to the higher latent heat of fusion.

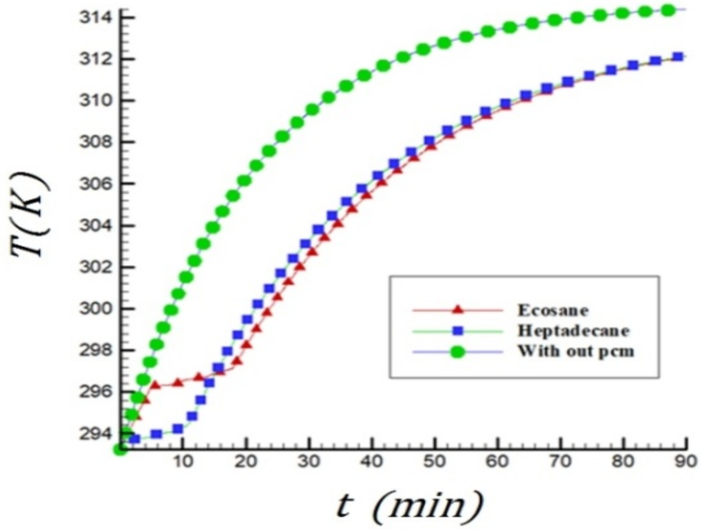

Figure 11. Average variation in the surface temperature of the electronic component relative to time

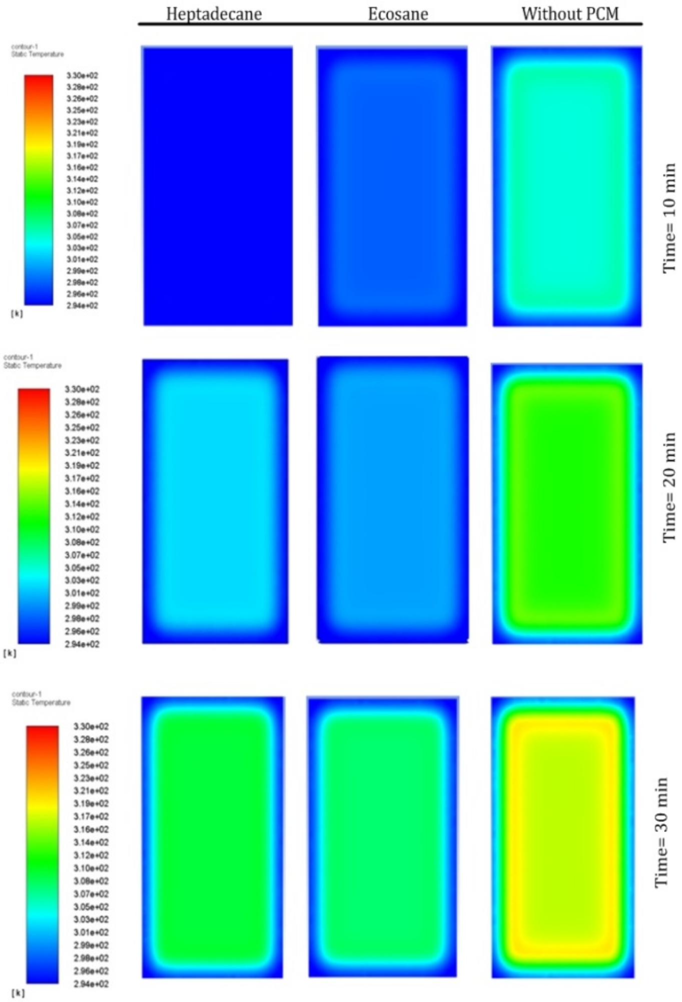

Figure 12. Contours of upper surface temperature of the electronic component at different times for phase change material of Ecosane and Heptadecane

- ***The effect of the thickness of the phase change material on the performance of the system***

Another important parameter in the analysis of the function of the phase change material is the thickness of the material. Figure 13, shows, for example, the variations in the volume fraction of the liquid in time for the Ecosane phase change material with three thicknesses of 1.65, 2.15, and 2.5 mm.

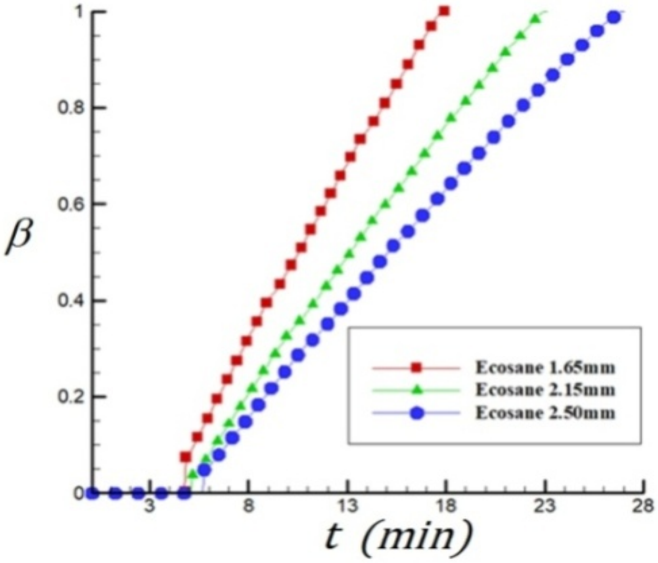

Figure 13. Changes in the volume fraction of the liquid relative to time in different thicknesses for the Ecosane

According to this figure, for all three thicknesses, the volume fraction of the liquid is initially zero and then goes to 1 with an almost uniform gradient. The reason of the liquid fraction equal to zero at the initial time, is due to the initial temperature of 20°C (lower than the PCM melting temperature), which by increasing the temperature, when this temperature reaches the melting point of the phase change material, the liquid fraction begins to increase. Also, by increasing the thickness of the phase change material, the volume fraction of the liquid decreases. The reason for this is that by increasing the thickness of the phase change material, the mass increases and for a constant heat flux, the time it takes for the volume fraction of the liquid reaches to 1, is increased and as a result the gradient of the chart is reduced. Figure. 14, shows the variation of the average total temperature of the electronic device relative to time. According to this figure, it can be seen that by increasing the thickness of the phase change material, the average total temperature of the unit decreases.

As it can be seen, increasing the thickness of the phase change material, the time required to completely melt the material increases. The reason for this is that by increasing the thickness in the constant heat flux, the amount of energy received by the material increases and the volume fraction of the liquid reaches 1. (full melt)

Figure 15, shows the upper surface temperature contours of the electronic component after 10, 20 and 30 minutes in 3 thicknesses of 1.65, 2.15, 2.50 mm for the Ecosane phase change material.

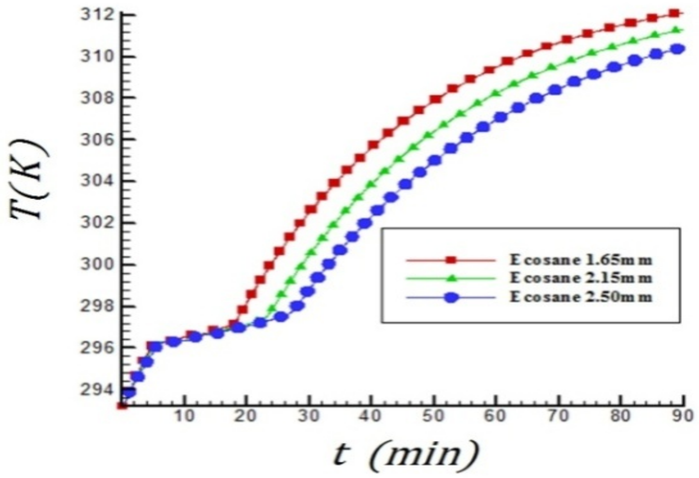

Figure 14. Average variation in the surface temperature of the electronic component relative to time in different thicknesses for the Ecosane

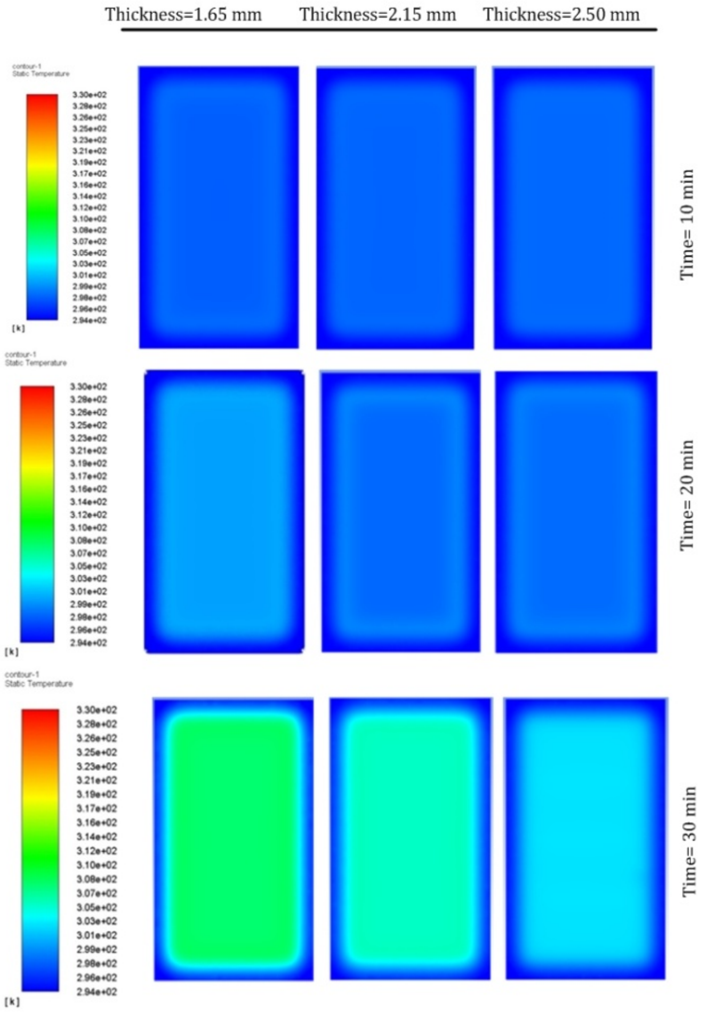

Figure 15. Contours of upper surface temperature of electronic components at different times and different thicknesses for Ecosane

- ***The effect of adding the fin to the phase change material on the performance of the system***

One of the thermo physical problems of phase change materials is that it has a very low thermal conductivity coefficient, which can be compensated by adding the fin in the phase change material side. For this purpose, two cases of the phase change material are as follows: a) 9.6125 gr of Ecosane without fin b) 9.6125 gr of Ecosane with three rectangular fins of 2 mm in thickness and 50 mm in length is considered. For example, the volume fraction of liquid diagram for state (b) is shown in Figure 16.

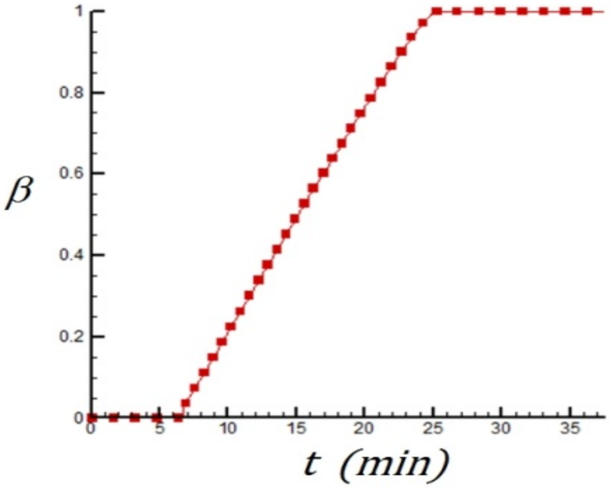

Figure16. Variation of volume fraction of liquid relative to time in Ecosane with three rectangular fins

In both cases (a) and (b), the heat flux of 3 W is considered. The result is shown in Figure 17.

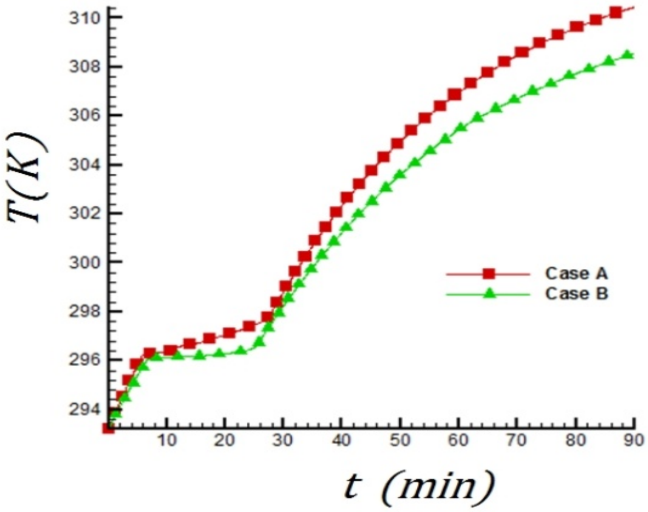

Figure 17. Average variation in the surface temperature of the electronic component relative to time in Ecosane with and without the fin

With regard to this figure, it is clear that, when using the fin, the conduction heat transfer coefficient of the Ecosae is increased, and therefore it melts sooner. The rapid melting of the material causes more heat to be absorbed by the phase change material, resulting in a decrease in the average total temperature of the electronic component.

Figure. 18, shows the average variation in the all surfaces temperature of the electronic components in time in different thicknesses of the fin for the Ecosane phase change material. As it can be seen, with an increase in the thickness of the fin from 2 to 3 mm, the average total temperature of the electronic component increases. The reason for this increase in temperature is that, with increasing the thickness of the fin, the thermal dissipation of the fins increases and this thermal loss causes the heat transfer between the air inside the chamber from polycarbonate and fins increases and hence increase the temperature of the electronic component. Also, it is observed that the increase in the thickness of the fins does not have any effect on the volume fractional changes of the liquid, and the phase change material of Ecsane in each of the thicknesses of 2 and 3 mm of the fin, melts at the same time.

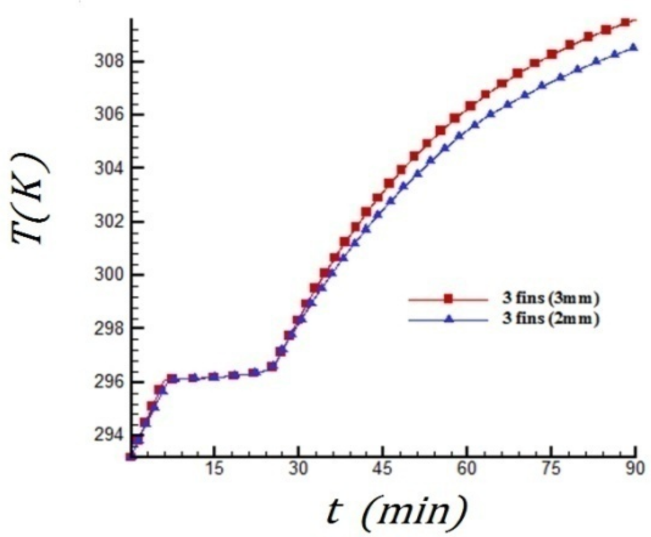

Figure 18. Average variation in surface temperature of the electronic component relative to time in two different fin thicknesses for Ecosane

- *The effect of the variation of heat flux on system performance*

In this section, the phase change material of Ecosane with an optimum thickness of 2.5 mm, once affected by the heat flux of 2 W and again influenced by the high flux of 3 W. Figure. 19, shows the variations in the volume fraction of the liquid for the 2 and 3 watt heat fluxes. As it can be seen in this figure, with the decrease of heat flux, the phase change material is melted later, as well as the start of the phase change process is also delayed.

Figure 20, shows the variation of the average total temperature of the electronic component relative to time for Ecosane with a thickness of 2.5 mm, once affected by the heat flux 2 W and again influenced by the heat flux of 3 W. It is clear that, with the decrease of heat flux, the average total temperature of the electronic component was significantly reduced.

Figure. 21, shows the upper surface temperature contours of the electronic component after 10, 30 and 90 minutes. It can be seen that the upper surface temperature of the electronic component in the heat flux of 2 W is not very different from the heat flux of 3 W in 10 minutes. The reason is that when the heat flux of 3 W is applied to the electronic component, the phase change material melts sooner with respect to the heat flux 2 W and this causes the effect of the difference in heat flux is neutralized. But at 30 and 90 minutes, the high temperature of the electronic component in the heat flux 2 W is much lower than the heat flux of 3 W. For this reason, the phase change material has been melted in the longer time in heat flux of 2 W, therefore, with the decrease of the heat flux, more time is needed to completely melt the material, and the surface temperature of the electronic component is lower than the heat flux of 3 W.

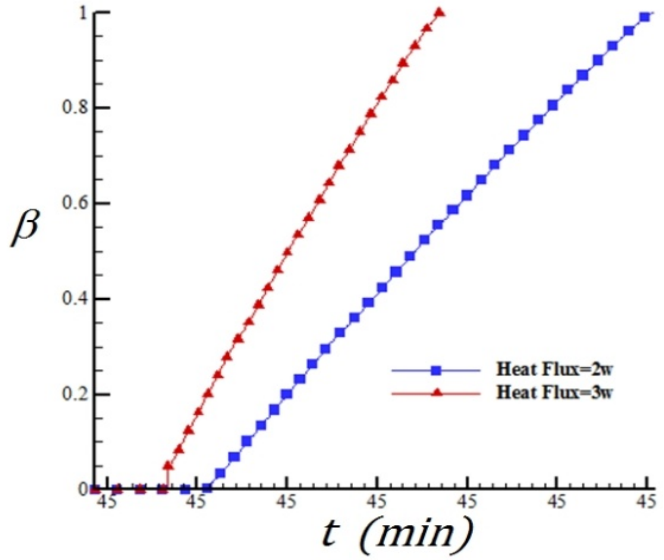

Figure 19. Variation of the volume fraction of the liquid relative to the time in the Ecosane with a thickness of 2.5 mm in two different heat fluxes

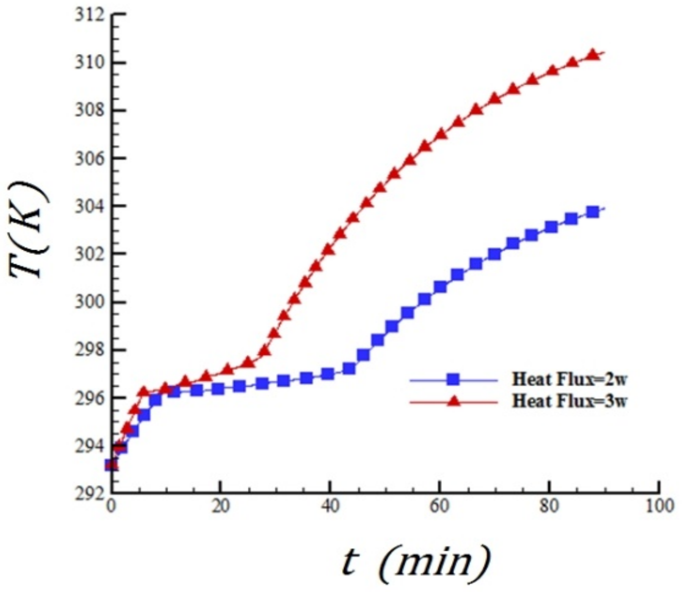

Figure 20. The average variation in surface temperature of the electronic component relative to the time in the Ecosane with a thickness of 2.5 mm in two different heat fluxes

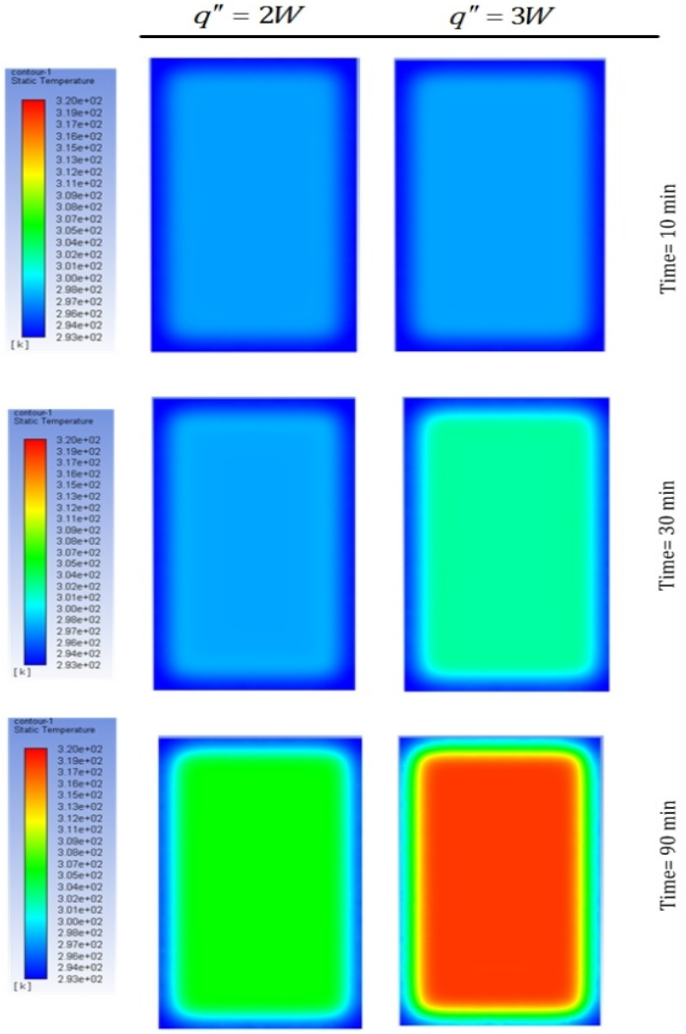

Figure 21. Electronic upper surface temperature contours at different times for Ecosane with a thickness of 2.5 mm in two different heat fluxes

CONCLUSION

In this research, for the first time, two different phase change materials have been used for thermal management of portable electronic components. In this regard, this electronic component is modeled and simulated numerically, and then the parametric analysis of the phase change material functions on the heat management of the piece is discussed. The results of this research can be summarized as follows:

- By adding the Heptadecane phase change material to the electronic component, the average total temperature of electronic components as well as the average surface temperature, after 20 minutes decreased by 6.9°C and 9°C, respectively. Also, after 90 minutes, the average temperature of the electronic component decreased by 2°C.
- By adding the Ecosane phase change material to the electronic component, the average surfaces temperature of the electronic component as well as the average upper surface

temperature, after 20 minutes decreased by 8°C and 11°C, respectively. Also, after 90 minutes, the average surfaces temperature of the electronic component decreased by 2.2°C.

- The addition of both the phase change material of Ecosane and Heptadecane also greatly increased the time to reach the equilibrium temperature.
- Comparison of the results obtained at different times for both Ecosane and Heptadecane phase change materials, showed that the Ecosane was more effective in the thermal management of the electronic component.
- For better thermal management, various thicknesses of phase change material were used. The results indicated that when the thickness of the Ecosane rises from 1.65 mm to 2.50 mm, the average surfaces temperature of the electronic component as well as the average upper surface temperature, after 30 minutes is reduced to 3.7°C and 5°C, respectively. Also, the results after 90 minutes show that when the Ecosane phase change material with a thickness of 2.50 mm was used, the average surfaces temperature of electronic components as well as the average upper surface temperature, were respectively 1.6°C and 1.1°C decrease.
- By changing the heat flux from 3 W to 2 W, the phase change material of Ecosane is thoroughly melted 13.3 minutes later. This causes the average temperature of the upper surface of the electronic component as well as the average surfaces temperature of the unit, after 90 minutes, decrease 9.7°C and 6.5°C, respectively, relative to the heat flux of 3 W.
- One of the weaknesses of phase change material is the low thermal conductivity coefficient. In this study, in order to reduce this weakness, as well as better thermal management, the fin is used in the phase change material side. For this purpose, 3 fins were added once with a thickness of 2 mm and again with a thickness of 3 mm under the heat flux of 3 W to the phase change material. The results indicated that after adding fin with thickness of 2 mm, the average total temperature of the electronic components as well as the average surface temperature, decreased. However, with increasing fin thickness, the average total temperature of the electronic component as well as the average surface temperature, increases. As a result, the optimum fin thickness was 2 mm.
- The addition of a fin with a thickness of 2 mm at the heat flux of 3 W on the side of the phase change material, caused the material to start the phase change process 4.5 minutes earlier and thus, at equal times, a volume fraction of the liquid when the fin is used, is higher and more energy absorbed by the phase change material over time. This also reduces the average total temperature of the electronic component as well as the average surface temperature, relative to the non-fin mode.
- Considering the importance of designing the thermal management model for the electronic component, in this study, according to the results obtained, the Ecosane phase change material with thickness of 2.5 millimeters and using 3 rectangular fins with thickness of 2 mm is the best mode for thermal management of electronic components.

Nomenclature

u_i	Flow velocity
P	Pressure
g_i	Acceleration of gravity
S_i	Momentum source
C	Constant Coefficient
H	Enthalpy
ΔH	Latent heat
h	Sensible enthalpy
C_p	Specific heat capacity
T	Temprature
L	Latent heat of liquid
k	Conduction heat coefficient
K_i	Dispersion coefficient of the soluble matter
Y_i	Mass fraction of the soluble matter
m_i	liquidification gradient of the i-th component
Greek	
ρ	Density
μ	Dynamical viscosity
β	Volume fraction of liquid
ε	Constant number
α	Thermal expansion coefficient
Subscripts	
ref	Reference
0	Base value

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