Proceedings of the 3rd International Conference on Fluid Flow and Thermal Science (ICFFTS'22)
Virtual Conference - October 27 - 29, 2022
Paper No. 125
DOI: 10.11159/icffts22.125

Heat Transfer Enhancement for better Cooling System of Electronic Components

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Abstract **-** The electronic components nowadays require efficient cooling systems compared to that used in the last two decades. The small size of electronic components causes an increase in the heat flux that is dissipated at their surfaces and thus requires thermal management to improve reliability, prevent premature failure as well as keep components within permissible operating temperature limits. Most electronic devices use forced air-cooling which nowadays is somehow not adequate or even enough to keep the system cool. This study is devoted to investigating a passive cooling technique that used RT35HC phase change material (PCM) to absorb the generated heat at the CPU of the personal computer and keep its surface temperature within an acceptable range. To do so, a set of experiments were conducted to examine the CPU surface temperature profile. Four different amounts of the PCM (20, 40, 60, and 80g) were used under the variable level of dissipated heat (10, 20, 30, 40, and 50W). It has been found that, for low levels of dissipated heat (10-20W), the PCM (regardless of its amount) enhanced the thermal performance of the CPU and provided a longer operating period while keeping the CPU surface temperate constant. In the case of increasing the level of the dissipated heat (30-50W), increasing the PCM amount could help in providing better thermal performance in comparison to that without PCM. The optimum amount of the PCM that can be used for passive cooling of the CPU was found to be 60g.

Keywords**:** Passive Cooling, Phase Change Materials, CPU, Thermal Management

1. Introduction

Electronic devices nowadays require efficient cooling systems compared to those used in the last two decades. The small size of electronic components causes an increase in heat flux that is dissipated at their surfaces and thus requires thermal management to improve reliability, prevent premature failure as well as keep components within permissible operating temperature limits [1, 2]. According to a report conducted by the United States Air Force, heat-related electronic failures account for 55% of all electronic failures [3]. With a temperature rise of 10°C to 20°C, component failure increases by 100%, but with a temperature reduction, component failure decreases at a rate of around 4%. Because higher-performance complex electronic devices such as smartphones and laptop computers must be light in weight and small in size, this problem has become much more challenging [4]. The components that can malfunction or suffer from permanent failure if overheated include CPUs (Central Processing Units), chipsets, graphics cards, hard disk drives, etc. Most electronic devices use forced air-cooling to dissipate the dissipated heat, but for some applications that generate excess amounts of heat, air-cooling is somehow not adequate or even enough to keep the system cool [5]. So, liquid cooling might be a better choice to increase the efficiency of the cooling system. This, in fact, belongs to the higher convection heat transfer coefficients associated with liquids that could develop a better heat transfer rate in comparison to that of air-cooling systems. However, this system has a disadvantage associated with the direct contact of the water, in case of leakage, with electronic components which could lead to damage to the CPU and causes corrosion in its components [6]. Accordingly, thermal management is turning into necessary and progressively important to the electronics field and has become a challenging aspect of electronic device design. The task of maintaining an acceptable junction temperature by dissipating heat from the computer circuit chips is a significant challenge for thermal engineers. Yeh [3] showed found that 55% of failures in electronics were due to an increase in the temperature which caused damage or reduce the efficiency of electronic components. In addition, the reliability of a silicon chip has decreased by 10% for every 2°C increase in temperature. So, it is required to keep the temperature at the working level to meet all the consumer’s needs anticipated from the devices.

The huge conventional air-cooled systems are no longer applicable since electronic device packages have become smaller. As a result, new ways for keeping electronic packages within the functioning temperature range are being developed.

The use of Phase Change Materials (PCMs) has gotten a lot of interest, because of their high latent heat and low volume change during phase transition, solid-liquid phase change materials are more popular. Organic PCMs are very valuable because of their compatibility with other materials and safety [7]. In general, during a solid-to-liquid phase transition, PCM absorbs thermal energy and stores it. So, this allows the temperature of the electronics to be maintained near the PCM's melting point. PCMs are found to have considerable advantages and disadvantages as compared to other available options for thermal management applications [8]. The use of PCMs for transient thermal management has the benefit of keeping a constant system temperature throughout the melting process, regardless of the heat flux applied. On the other hand, the disadvantages of PCM are low thermal conductivity, super-cooling, and relatively large volume change [9]. Gaikwad and More [10] did an experimental study to compare the cooling process using PCM in microchannel heat sinks and water-cooling systems to cool down computer processors. It has been found that microchannel heat sinks with PCM as coolant is more efficient compared to conventional cooling as well as water cooling system. However, this cooling technique cannot be used in transient operations as the temperature of the CPU may go beyond the limitations of Thermal Design Power. Taremi, [7] found that combining phase change materials and heat sinks is one of the best cooling system solutions. Phase change materials, as previously stated, can absorb a significant amount of overload heat without raising the temperature during peak chip activity. The operational temperature range of a certain electronic package can be modified by selecting the right phase change material. It has been found that the best PCM among all the options was discovered to be RT28HC, which had a lower melting temperature and a larger latent heat. However, the research area of cooling the electronics components, especially the CPUs using the Phase change material (PCM) is still not saturated and required more effort to enrich this area with available scientific experimental data. Accordingly, this study is devoted to developing a practical and feasible solution to improve the thermal performance of the existing cooling system using Phase Change Material type RT35HC as a passive cooling technique to enhance the thermal management of the CPU of the personal computer.

2. Experimental Apparatus and Procedure

The experimental apparatus is shown in Figure 1. It consists of the CPU unit. Due to the difficulty in using a real CPU to conduct the experiments and investigate the performance parameters, a simulated CPU was designed and constructed using a copper plate of size 45 cm x 45 cm x 5 mm which is closer to the real size of the most common CPUs. The dissipated heat in the CPU was simulated using a power source that was able to generate different heat fluxes and reach different surface temperatures. NTC100K thermistors with a resolution of ± 0.01ºC were used to measure the temperatures in different locations, such as the surface temperature of the CPU, the temperature of the PCM, and the ambient temperature. Phase change material type RT35HC was used to perform the passive cooling process. This type of PCM is non-corrosive and has a melting temperature of 35ºC and a heat storage capacity of 240 kJ/kg. This high heat capacity allows to absorb a significant amount of heat when melting while keeping the CPU surface temperature at a constant value. Arduino model ATmega328P was used to record the readings of the thermocouples and the power supplied during the experiments. A power supply was used to serve as a source of electrical power to simulate the dissipated heat at the CPU. The electric power supply was linked to a wire resistance made of Nichrome with a resistance of 12.2 Ohm. The device has a maximum current of 3 amps and a maximum voltage of 30 volts. For better understating the behavior of the PCM, five different quantities of PCM were prepared using a digital scale, i.e., 10g, 20g, 40g, 60g, and 80g. Also, the CPU was subjected to five different levels of dissipated heat, e.g., 10W, 20W, 30W, 40W, and 50W. Each specific amount of the PCM was subjected to the five levels of dissipated heat for a time period of 90 minutes. For the accuracy of the quantitative data, the temperatures were measured every 30 seconds. Also, visual observation was done in order to have a clear picture of the thermal behavior of the PCM during the experiments. At the beginning of each experiment, the specific amount of the PCM was prepared and inserted in the PCM block and covered by a sheet of glass (see Figure 1) that provides the possibility for visual observation. After that, the power source and the PC were both switched on to start the experiments. The current and voltage of the heat source were both set up to provide a specific amount of dissipated heat. The Arduino program was started to record the thermocouples reading with a time interval of 30 seconds. This process was conducted till reached the steady state condition for the CPU surface temperature. Later on, the Arduino program was stopped, and the recordings were saved by using the CoolTerm – Shortcut application. The power source and the PC were both switched off. The PCM was left for a certain time until it solidified again.

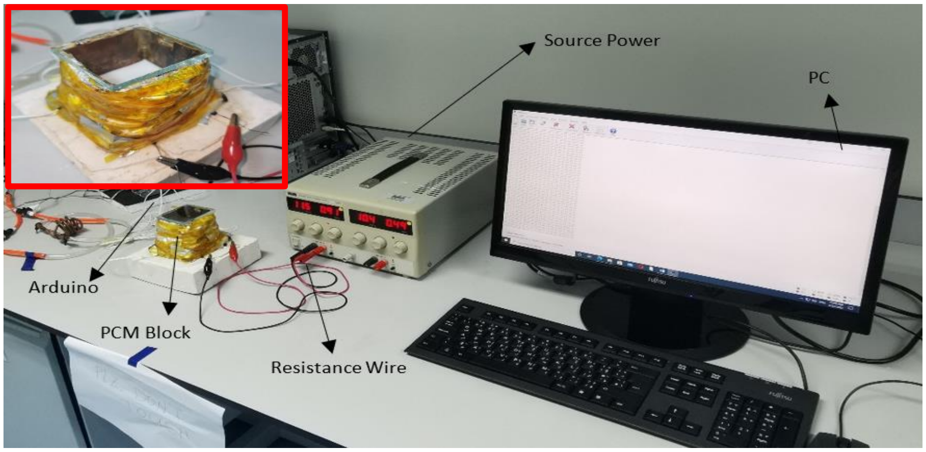

Fig. 1: Experiment apparatus

3. Results Analysis and Discussion

This section is devoted to analyzing the experimental data in terms of CPU surface temperature profile and the PCM temperature profile in order to come up with behavior explanations, parameter effects, findings, and future suggestions.

3.1 Thermal Performance of CPU without Cooling

The surface temperature of the CPU was monitored while various amounts of power were supplied (dissipated heat) without cooling (which means without using the PCM nor the water cycle for cooling). Figure 2 shows the temperature profile of the CPU as a function of time at a different level of dissipated heat.

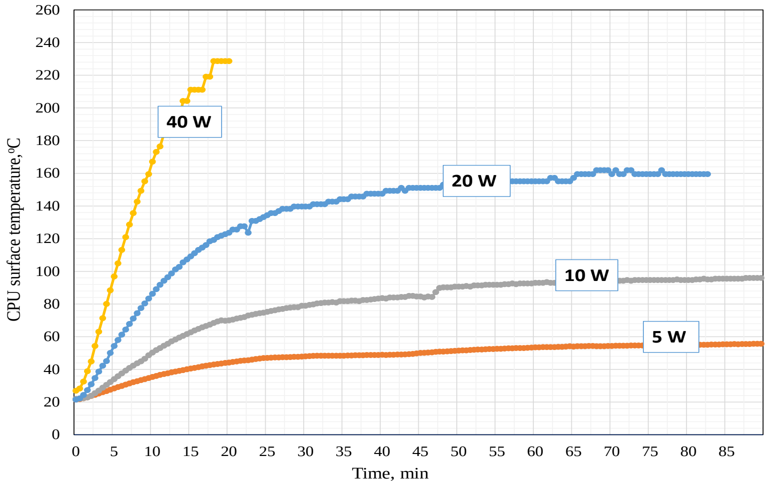

Fig. 2: CPU surface temperature profile as a function of time without using a cooling system

The temperature profile for each amount of dissipated heat started with a sharp increase in the CPU surface temperature which has relatively a linear slope. After a specific period of time, the CPU surface temperature reached asymptotic behavior where the temperature remained almost constant. However, the slope of the sharp increase and the level of asymptotic temperature increase with increasing the dissipated heat value. Table 1 shows some characteristic values extracted from Figure 2. Without using a cooling system, the CPU surface temperature reached values above 100ºC (The most common thermal design temperature of the CPUs), especially with dissipated heat above 20W. For safety conditions related to the simulated CPU, the experiment under 40W was turned off at 20 minutes as the surface temperature reached approximately 230ºC. Based on these observations, without a cooling system, the surface temperature of the CPU reached to level which is extremely harmful to any sort of electrical device, not just the CPU, because increased temperature reduces reliability, resulting in poor performance. In the case of the CPU, this might result in slower clocking speeds and, eventually, the system burning, potentially resulting in fires. A suitable cooling system is required to avoid these incidents.

Table 1: CPU temperature profile characteristics without a cooling system

Parameters	**Dissipated heat (W)**			
	05	**10**	**20**	**40**
T_{max}, (ºC)	55.7	95.97	161.88	228.67
Constant temperature period, (min)	30-50	30-40	25-40	--
The linear part slope, (°C/min)	3.54	5.03	8.63	16.71
T_s at the end of the linear part, (ºC)	36.62	53.09	91.79	135.64

3.2. Thermal Performance of CPU with Cooling using PCM

In this section, the thermal performance of the CPU subjected to a passive cooling system using the PCM was discussed. The behavior of temperatures at the previously mentioned locations were discussed in detail in this section. The temperature profile of the CPU and the PCM was discussed and explained. Each quantity of PCM was tested five times (20g, 40g, 60g, 80g) at different heat sources (10W, 20W, 30W, 40W, 50W) in a total of 20 experiments. For these experiments, the readings of each thermocouple were gathered and explained as follows:

3.2.1. CPU Surface Temperature Profile

Figure 3 shows the profile of the CPU surface temperature subjected to variable levels of the dissipated heat using four different amounts of PCM. In general, the temperature profile using PCM has a different trend than that without cooling. It started with an almost linear increase in temperature with time followed by a constant surface temperature for a specific period of time, after that starting again to increase till reaching the asymptotic profile in some cases. It is worth mentioning that the period of constant surface temperature is referred to the melting region of the PCM where the dissipated heat was observed to change the PCM from the solid phase to the liquid phase. The length of this period was strongly affected by the amount of dissipated heat and the amount of the utilized PCM. It has been found that at a very low level of dissipated heat (10-20W) longer time was required for the melting region when a larger amount of PCM was used. This indicated that the dissipated heat was not enough to melt the whole amount of the PCM. For 80g, the PCM required 70 minutes to complete the melting process, and the maximum temperature after 90 minutes was 48ºC. Such thermal performance is suitable for personal computer applications. In the case of considering the maximum working temperature of the CPU to be 100ºC, the results presented in Figure 2 showed that the PCM of 60g and 80 provide better cooling in terms of a longer period of constant surface temperature that was below the maximum design limits of the CPU surface temperature.

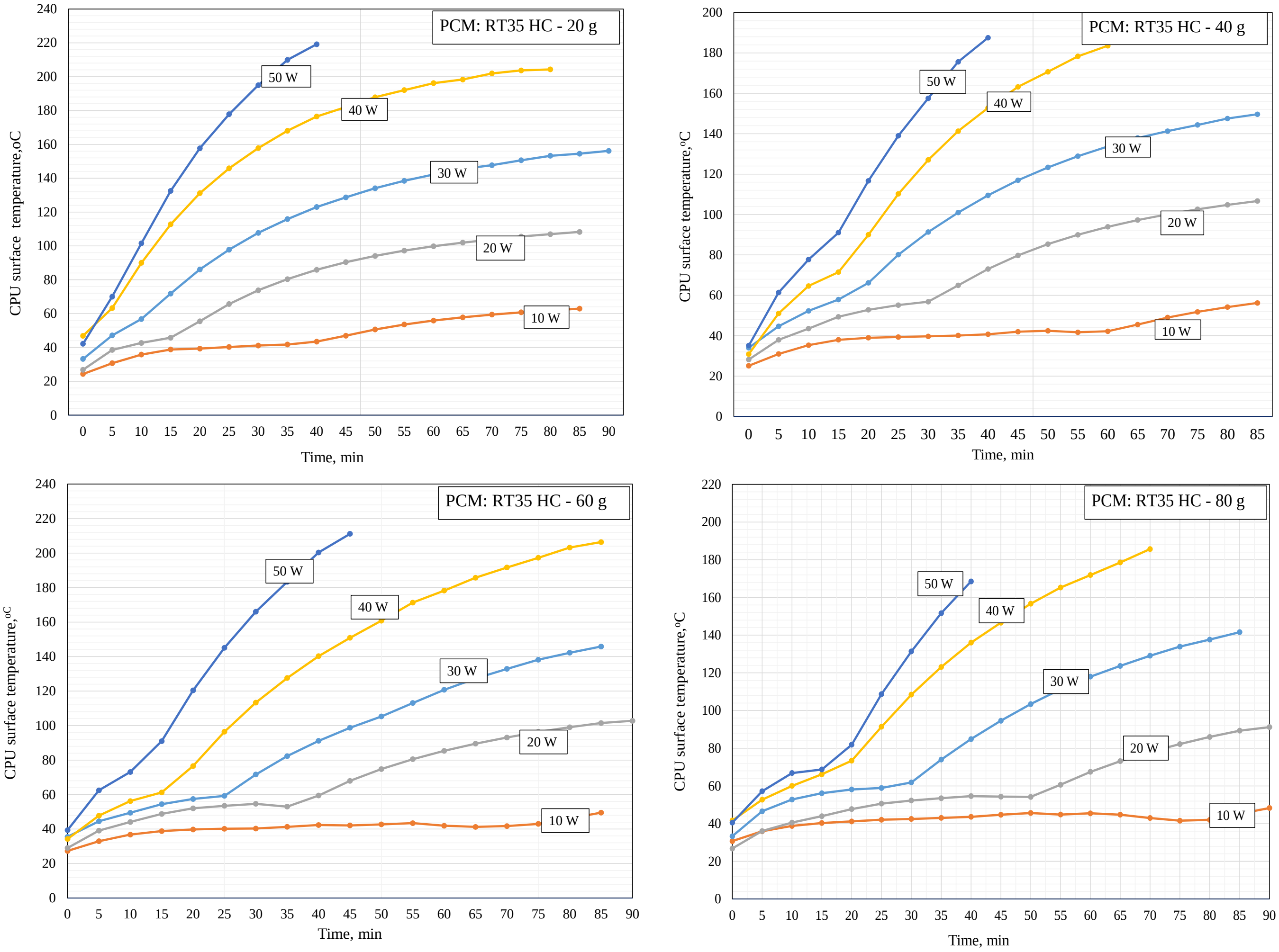

Fig. 3: CPU surface temperature profile as a function of time under passive cooling using the PCM

3.2.2. PCM temperature profile (T_{pcm})

The temperature profiles of the PCM at 10W, 20W, 30W, 40W, and 50W are shown in Figure 4. No matter how much PCM was used, the PCM temperature increased as the dissipated heat were raised. Additionally, for each particular quantity of dissipated heat, the PCM has a better temperature profile as the PCM amount increases. In conclusion, the PCM temperature profile has a reverse relationship to the PCM quantity but a proportional relationship to the dissipated heat. The PCM temperature profiles for 10W and 20W were less time-sensitive to the dissipated heat than 40W and 50W at any PCM quantity. For instance, the temperature profile at 80g PCM was almost linear at 10W of dissipated heat, however, it showed different behavior at 50W. At 10W, the PCM was still in the sensible heat region and did not melt. But at 50W, the PCM melted and moved into the latent heat region. It is evident that the PCM temperature remained constant for a while before once more entering the range of sensible heat of the liquid phase. The PCM reached the latent heat region at different periods depending on its quantity and the level of the dissipated heat. The maximum temperature that the CPU could reach increased as the level of dissipated heat or the PCM amount increased. However, the increase in the temperature was more sensitive to the changes in heat that is dissipated from the CPU than to the changes in the amount of PCM. For instance, if the PCM amount changes from 20g to 80g while the dissipated heat remains constant at 10W, the temperature decreases from 60°C to 41°C, whereas it increases to 211°C when the supplied heat is changed from 20W to 50W while the PCM amount remains constant at 20g. The PCM can reach a maximum temperature of 211°C at 20g and 50W, and a minimum temperature is 41°C at 80g and 10W.

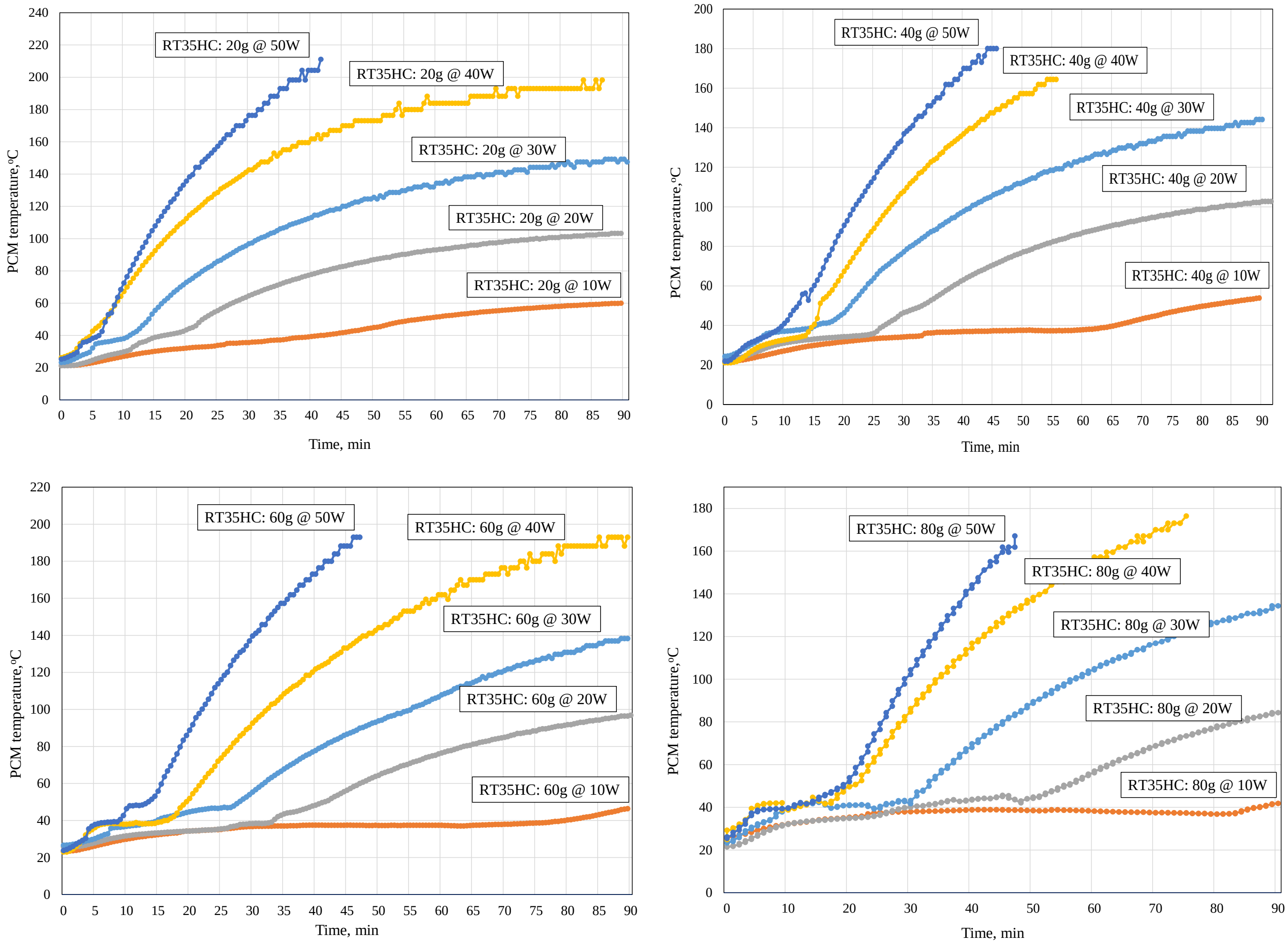

Fig. 4: PCM temperature profile as a function of time

Figure 5 shows a comparison between the real and the theoretical behavior of the PCM temperature profile for 80g at 50W of the dissipated heat. The real temperature profile was closer to that of the theoretical one with some deviations. The PCM was firstly subjected to an increase in its temperature till reaching the melting temperature of 34-35ºC. This region is called the solid sensible region which required 15 minutes to reach this point. After that, between 15 to 40 minutes, the PCM started to melt, which corresponds to the latent heat region. Until the entire solid was converted to liquid in the next 25 minutes, the temperature profile remained essentially constant. The PCM entered the liquid sensible heat region after 15 minutes from leaving the melting region. In this region, the PCM temperature increased rapidly and the PCM melted completely.

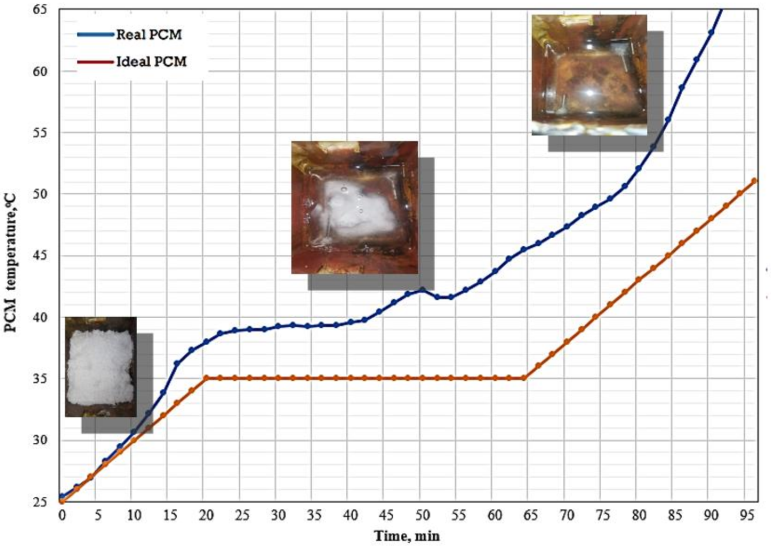

Fig. 5: Real and theoretical temperature profile of the PCM of 80g at 50W

4. Conclusion

As electronic devices are subjected to continuous development, they are getting smaller, and therefore the generated heat flux from them increases rapidly. Hence, an efficient cooling system is needed. A passive cooling technique using the PCM was investigated in this study with the aim of achieving the better thermal performance of the CPU of personal computers. To do so, various scenarios were evaluated in order to look into how well the cooling system performed. Four amounts of PCM: 20g, 40g, 60g, and 80g were used to monitor the effects of the amount and select the best value for large-scale application. These amounts were subjected to five levels of dissipated heat i.e., 10W, 20W, 30W, 40W, and 50W, that simulated the heat flux produced by a real CPU. The typical usage (20W and 30W) and heavy use were represented by these values (40W and 50W). The results demonstrated a considerable variation in CPU surface temperature when subjected to passive cooling compared to that without cooling. It has been found that using the PCM type RT35HC provide better thermal management (even with a low amount) for the CPUs that are dissipating lower level of heat while in process. The high heat capacity value of the PCM allowed the CPU to work probably without facing a significant increase in its surface temperature. However, once the level of the dissipated heat increases, the low amount of the PCM was no longer enough to absorb the generated heat from the CPU. However, increasing the amount of PCM could enhance the performance of the CPU. It has been found that 60-80g of PCM developed an optimum thermal performance for the CPU at a low level of dissipated heat and an acceptable working performance at a high level of dissipated heat.

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