Experimental Investigation on Phase Change Material Based Circular Pin Fin Heat Sink for Cooling Electronic Equipment

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Abstract

Heat management of electronic device is now rapidly upgrading and considered challenging due to the increase of power and decreasing size of the electronic device. Due to the economic cost, system complexity and operating conditions, the traditional cooling methods are quite impossible. That is the reason why using of phase change material (PCMs) in passive cooling system is considered as a great alternative in recent years. Hydrated salt and Paraffin, which are known as organic phase change material (PCMs), has been greatly recommended in energy storage component due to its high latent heat, non-toxicity and very low melting temperature. Using the PCM energy storage and cooling systems lead to a significant volume reduction to store the same amount of energy compared to sensible heat storages. The experiment attempts to illustrate the difference in heat transfer for a heat sink with and without paraffin wax at different power level.

Keywords
PCM, Heat Sink, Paraffin Wax and Fin

1. Introduction
Effective thermal management holds the key to the fast development and continuous miniaturization of microelectronics. Optimal thermal control is critical to the design and operation of electronic equipment. In several apps such as laptops, cell phones, digital cameras and missile control systems, the thermal management solution requires to be reliable, secure, cheap, light, durable and, more importantly, energy efficient. Equipment's reliability is a quantifier of the expected failure frequency as a function of time. Temperature is one of the most significant variables influencing the reliability of electronic machinery. The need to perform various tasks and the requirements for greater quality of electronic equipment are driving the creation of fresh and innovative thermal management methods According to a US Air Force study, the proportion of temperature-related failures in electronics surpassed 55 percent (Ala-wadhi and Amon 2000).

Electronic manufacturing companies take it for granted that communication devices must have 99.999 percent reliability called 5 9 reliabilities. It means approximately 5 minutes of complete downtime in a year. However, due to the high expectations mentioned above, the conventional cooling meth-odds were inadequate to meet the cooling needs of now - a-day equipment. It has been found that a 1°C decrease in a component temperature can lower its failure rate by as much as 4 percent and a temperature increase of about 10–20 °C can increase its failure rate by 100 percent (Hajmohammadi et al. 2013).

In latest years, the use of PCM is gaining popularity in passive cooling. High latent heat of fusion per unit quantity and tiny volume shift during phase change are the intrinsic characteristics of PCMs. This implies that a high amount of energy can be stored in a fixed amount of PCM during the period of phase change. This can be seen from the abundance of accessible literature. Although most PCMs fulfill these criteria that are used in electronics cooling but unfortunately, nearly all PCMs have unacceptable low heat conductivity, which makes heating and cooling procedures slow during PCM melting and solidification. In order to make PCMs appropriate for cooling applications, it is essential to add material with high thermal conductivity to PCM which will help in heat conduction. So, the impact of PCM based material on a conventional heat sink for electronic devices should be investigated. For this study paraffin wax is the chosen PCM to use in a conventional pin fin heat sink.

1.1 Objectives
The study aims to experimentally differentiate the heat transfer rate using a conventional heat sink (pin fin heat sink) with and without the use of PCM (Paraffin wax) for a varying power input.

2. Literature Review (12 font)
A phase changing material (PCM) is a material that changes its state at a certain temperature, fatted to the application being always constant and reproducible. During the phase change process, a PCM absorbs or release a large amount of heat in order to carry out the transformation. This action is known as the latent heat of fusion or vaporization and through this process energy is stored. Since the nineteenth century, a systematic study of heat storage through latent heat using PCM has been carried out. Telkes and Raymond were the pioneers to investigate PCMs in 1940. However, PCMs were ignored until the energy crisis of late 1970 s and 1980 s, which motivated scientists to explore the usage of PCMs in heat exchanging purpose. Since then a good amount of research has been carried out to assess the thermal performance of PCMs in cooling system. These researches have opened many scopes in the transient behavior, design fundamentals, system optimization and various other fields.

A fewer study has been reported on parametric investigation of LHTESS (Latent heat transfer energy storage system). Wang et al. (2008) performed the numerical parametric investigation of PCM volume fraction, aspect ratio, temperature difference and PCM properties of PCM-based heat sink. The results demonstrated that a heat sink with PCM achieve better thermal performance and aspect ratio. Qu et al. (2012) performed the experimental work for passive cooling of electronics using parallel hybrid heat sink saturated with solid copper and pure paraffin wax. The outcomes showed that the base temperature of heat sink was lower in case of metal foam-PCM then pure paraffin with a linear trend. Mahrous (2013) conducted an experimental study based on PCM based sink and inquired the fins arrangement and number of fins. Effects of heating rates were observed uisng partially filled heat sinks with paraffin wax. The results showed that both heat rate and peak temperature reduced using PCM based heat sinks. The effect of thermal resistant for heat management of electronics using finite element analysis was reported (Grujicic et al. 2005). The results revealed that the use of thermal interface material lowered the overall base temperature.

Hajmohammadi et al. (2014) conducted the numerical study of Vshaped fins / inserts embedded in a square heat generating cavity .The authors used optimized geometric fins and concluded that V-shaped inserts had the outstanding heat transfer performance and reduced the base heat generating cavity temperature. Hajmohammadi et al. (2016) further, to improve the cooling performance presented the numerical study of forced convection cooling and proposed the correlation between the thick plate and heat source. Authors concluded that at low Reynolds number and low Prandlt number, temperature was reduced with the interface of plate. The authors conducted geometric fins optimization and concluded that V-shaped inserts had the remarkable heat transfer performance and reduced the base heat generating cavity temperature. Hajmohammadi et el. (2012) and Hajmohammadi et el. (2013) presented numerical investigations into laminar forced convection cooling of plate and round pipe under the range of heat sources of varying spacing size.

Najafi et al. (2011) used the genetic algorithm to use air as a working fluid at both ends of the heat exchanger to study the optimization of the plate and fin heat exchanger. Baby and Balaji (2012) carried out an experimental study for PCM-based finned heat sinks for thermal management of electronic devices with a constant volume fraction of 9% of fins. For the pin-fin heat sink, an enhancement ratio of 18 was obtained and it was concluded that the pin-fin heat sink had better efficiency than the PCM-filled plate-fin heat sink. Baby and Balaji (2014) experimentally conducted a transient heating and cooling phase change cooling of electronics using plate-finned PCM filled heat sink.Authors conducted a detailed experimentation on different constant and intermittent heating loads. Sun et al. (2014) proposed a natural cold source with PCMs to cool China's base stations for telecommunications. Mathematical model was developed, followed by prototype of a latent heat storage unit. Authors reported that the latent heat storage unit saved a significant amount of energy to cool the base stations for telecommunications. Alshaer et el. (2015) carried out the numerical study.

Kalbasi and Salimpour (2015) developed and optimized the rectangular enclosures based on PCM by changing the geometric parameters,. Results revealed that it was better to use a wider enclosure than a square and thin enclosure for a rectangular enclosure with vertical fins. Furthermore, authors concluded that the ratio of vertical fin thickness to horizontal fin had no significant effect (Nada and Alshaer 2015). Srikanth et al. (2015) presented an experimental and numerical study of pin-fin heat sink filled with n-eicosane as a PCM with the aim of increasing the loading time during operation and decreasing the discharge time during idle conditions. 40 different geometric settings of heat sinks were taken at steady heat flux and PCM quantity. Authors performed the multi-object. Thermal management of tablet computers conducted experimentally using two PCM. Sahoo et al. (2016) suggested a numerical analysis for the composite fins of the orthotropic framework with PCMs and isotropic fins were compared. The outcome was that orthotropic had better heat efficiency against isotropic fins, and retained reduced base temperature than isotropic fins also had less volume. In continuation of this, numerical inquiry was suggested for present designs of various brands of almost comparable sizes. (Thomas et al. 2016). Authors selected the n-eicosane as a PCM, in natural convection conditions different power levels were provided at the heat sink base, effect of power densities and melt fractions were discussed. Wang et al. (2016) examined a very novel method with PCM-based heat sinks based on porous matrix of copper fibers with extensive antler microstructure on its surface. A composite of MF-PCM (paraffin / PMFSF) was ready and under observation three distinct empty heat sinks were performed with paraffin wax and MF-PCM. The authors found that PMFSF had demonstrated.

Gharbi et al. (2017) provided a survey of heat sinks filled with PCM (plastic paraffin) in the rectangular enclosure for ongoing and intermittent regimes for discrete heat sources. Authors found that heat sink thermal efficiency relied heavily on the repetition of heat density. Furthermore, a maximum reduced temperature was obtained for the fractionation cycle in intermittent conditions.

The previous all-mentioned studies clearly explain that fewer studies have been reported on round pin-fin heat sinks for passive electronic cooling using PCMs as a material for thermal energy storage, and none have reported any experimental and numerical studies based on parametric investigation with the influence of paraffin wax as PCM. The current study focuses on the parametric study. The authors concluded with statement that PCM sheet with copper sheet as a thermal conductivity enhancer had better thermal management for mobile devices.

3. Methods

Heating and cooling systems still account for a large part of today's energy consumption. In recent days cooling of electronics are very hard due to the small size of electronics. So, thermal conductivity of PCMs must be enhanced by using heat performance enhancer. In this study I will be investigating the effects of circular pin fin as thermal conductivity enhancer.

3.1 Properties Of Materials Used In This Study

- ✓ Paraffin Wax
  - Thermal conductivity 0.167(Liquid) 0.212(Solid) W/m K
  - Specific heat 2.8 kJ/kg K
  - Latent heat 173.6 kJ/kg K
  - Melting point 58-60 °C
  - Density 790(Liquid) 880(Solid) kg/m3
- ✓ Aluminium
  - Thermal conductivity 202.37 W/m K
  - Specific heat 0.871 kJ/KG k
  - Melting point 660.37 °C
  - Density 2719 kg/m3

3.2 Heat Sink Configaration

Heat sinks filled with PCMs will be used in this experiment. A heat sink having constant volume fraction of 9%. Because BABY and BALAJI found out that 9% volume fraction of TCE has the best performance. Paraffin wax will be used as PCM in the base of aluminum with the volume fraction of 0% and100%. The equation that will be using is

$$V = V_{pcm} / V_s - V_f$$

Where,
V = volumetric fraction of PCM
V_{pcm}= specific volume of PCM
V_s = Total volume of heat sink
V_f= Total volume of fins

The dimension of heat sink is 114 × 114 mm^2 and height is 25 mm. Heat sink will be installed from all the sides with rubber pan having low thermal conductivity which will prevent the heat loss to the environment. Top side of the heat sink will be covered with transparent material for observing physical change.

3.3 Design And Fabrication

An experimental setup will be developed to study the effect of Phase Change Material an effect of fin and to achieve our objective. Experimental investigation involves a process in which sample is designed, fabricated and different variables are actively manipulated, controlled, and measured in an effort to gather evidence or data for making proper decision. It is a test under controlled conditions that is made to demonstrate a known truth, to examine the validity of a hypothesis, or to determine the efficacy of something previously untried.

3.3.1 Model of Experimental Setup

First a suitable setup has to be developed for experimental investigation of the performance of heat sink. An experiment is a process carried out to support, or validate a hypothesis. Experiments provide insights into case-and-effect by finding what outcome occurs when a particular factor is varied. An experimental setup is modeled for carrying out the experiment. Figure 1 illustrates the supposed experimental setup

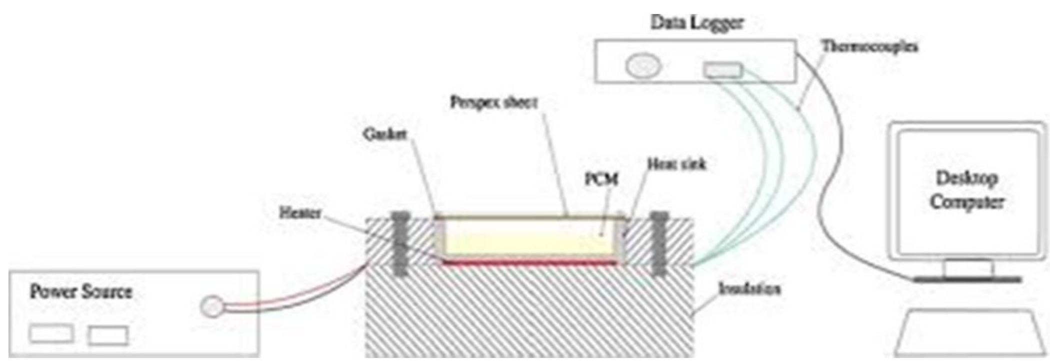

Figure 1. A model of experimental setup

3.3.2 Design of Heat Sink

Heat sink is properly designed using design software. The overall dimension of the heat sink is 116mm*116mm and height is 35mm, radius of fin is 6mm. Figure 2 shows the detailed dimensions of the heat sink.

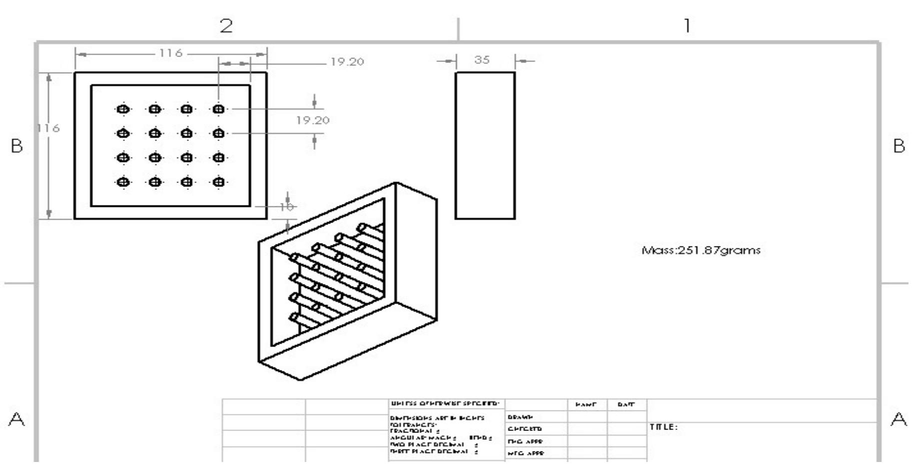

Figure 2. Dimension of 6mm diameter pin fin heat sink

3.3.3 Fabrication of Heat Sink

Heat sink is fabricated by using sand casting. Casting is a simple, inexpensive and versatile way of forming aluminum into a wide array of products. The most versatile method for producing aluminum products is sand casting. Virtually any pattern can be pressed into a fine sand mixture to form into which the aluminum is poured. The process started with a pattern of the heat sink that is a replica of the finished casting. The pattern is made slightly larger than the part to be made, to allow for aluminum shrinkage during solidification and cooling. After making final cast product, by proper matching process the fabrication of heat sink is completed. Figure 3 illustrates the heat sink with and without paraffin wax.

Figure 3. Fabricated heat sink without and with paraffin wax

3.4 Experimental Setup

An experimental is set up to taste the effect of a variable on an outcome. This variable that the experimenter manipulates is known as the independent variable. If some alternate occurs as a result of the independent variable, this change is the dependent variable. Figure 4 is an image of actual experimental setup.

Figure 4. Photograph of experimental setup

In this experimental all the equipment is assembled to accomplish the desired setup for finding out dependent variable or time required to reach set point temperature. Studies is conducted for heat sinks on which a uniform heat load is applied for the without finned and finned cases.

1. A plate heater is used to mimic the heat generation in electronic chips in the base of the heat sink as a heating source. Power is used from an AC source of 220 volt and it is regulated by using voltage regulator. This type of heater is very used full to generate uniform heating.
2. An insulation box is used to minimize the heat loss from heater so that all the time the condition remains the same. It consists of wooden frame the gap between heat sink and box is filled with aluminum foil as it conceals heat inside.
3. A glass plate is placed above the sink for monitoring the melting phase of paraffin wax time to time for better understanding of phase change phenomenon during heating period and cooling.
4. A voltage regulator is used to regulate voltage so that the required power can be obtained by the heater.
5. Thermocouples (k-type) and temperature controller is used to measuring the temperature time to time at different position.

The effect of different types of fins for different power level (18 watts to 36 watts with equal interval of 6) in enhancing the operating time for different set point temperatures and on the duration of lantern heating phase is explode in this study. Experimental setup consists of heat sinks having pin fin configurations filled with PCM, insulated with aluminum foil which prevents heat loss. Temperatures at different point of the heat sink are measured with high precision K-type thermocouples.

3.5 Thermocouples Position

To realize the melting and solidification of paraffin wax calibrated K-type thermocouples is used at different position. Calibration is done by talking values with respect to ice and steam. Two thermocouples are placed at the base of the heat sink between plate heater and base of heat sink. Thermocouples are also fixed at the heat sink side wall surface.

3.7 Experimental Procedure

The experiment is performed by following some procedure so that desired output can be found. Experimental procedures are given below:

1. The setup consists of aluminum heat sink with pin fins. Different volume fraction is used to find suitable volume fraction. First a comparison of base temperature with and without PCM. Also the time measured for consonant heat input for investigation the effect of paraffin wax.
2. Then for constant input heat base temperature and time have been measured with and without using paraffin wax. This is done for heat sinks with fin for investigating the effect of paraffin wax in the heat sink.
3. Operational time for various PCM based heat sinks have been investigated for three different critical set point temperature (55c, 60c, 65c) and the value of base thermocouples is record to investigate time to reach the set point temperature.
4. Enhancement of operation time for different configuration of heat sink have been investigated to find the effect of paraffin wax and pin fin in the performance of heat sink
5. Enhancement ration has also calculated for different power input.

By comparing these values investigation of the performance of the heat sink are completed.

4. Data Collection

Temperature data for the heat sink was collected for various power inputs (18 Watts, 24 Watts, 30 Watts, 36 Watts). Table 1 lists the temperature values after every minute for the heat sink. The heat sink experiences large difference in temperature when it is filled with paraffin wax and without paraffin wax.

Table 1. Time taken to reach different temperature (°C) at 18-watt, 24-watt, 30-watt and 36-watt power inputs

Time (Minutes)	Temperature							
	18 Watts		24 Watts		30 Watts		36 Watts	
	Without Wax	With Wax	Without Wax	With Wax	Without Wax	With Wax	Without Wax	With Wax

1	33	33	34	33	35	34	38	34
2	38	37	40	37	41	39	45	40
3	43	40	45	40	46	43	50	45
4	45	43	49	43	50	46	54	48
5	48	45	52	45	55	49	60	51
6	50	47	55	47	58	52	65	54
7	52	49	57	49	61	54		56
8	54	52	60	52	65	55		58
9	55	53	62	53		56		60
10	57	54	65	54		57		61
11	59	55		55		58		62
12	61	56		55		59		63
13	63	57		56		60		63
14	65	58		57		61		64
15		58		59		61		64
16		59		60		63		65
17		60		61		63		
18		60		61		63		
19		61		62		64		
20		61		62		65		
21		62		63				
22		62		64				
23		62		65				
24		63						
25		63						
26		63						
27		64						
28		64						
29		65						

5. Results and Discussion

In this experiment baseline temperature has been taken with respect to time for different heat input i.e.18 watts, 24 watts, 30 watts &36 watts. The temperature has been taken every one minute interval to investigate temperature variation for different heat sink configuration. Temperature increases rapidly for heat sink without paraffin wax because there was no other way to absorb the heat generated by the base. It has been clearly observed that heat sink with paraffin wax and fin gives better result in all power input.

5.1 Numerical Results

There is a huge difference in heat absorption for the heat sink with and without paraffin wax. The absorption rate increases when paraffin wax is applied for 18 watts, 24 watts, 30 watts, 36 watts are 107%, 130%, 150% and 166.67% sequentially.

5.2Graphical Results

Effect of only fin and paraffin wax in the heat sink is investigated by taking three different temperatures for 18 watts, 24 watts, 30, watts and 36 watts, power inputs. By comparing the corresponding values of different time and temperature can be found. Among all the different input of power the highest input shows the most promising outcome and better heat absorption than the rest of them.

- For 36-watt input

  From Figure 5, it is clearly seen that when we used the only fins temperature rises rapidly in a short time of period. But when paraffin wax is used as a heat medium the time to reach same temperature increases. The volume fraction of PCM is V=0, V=1.

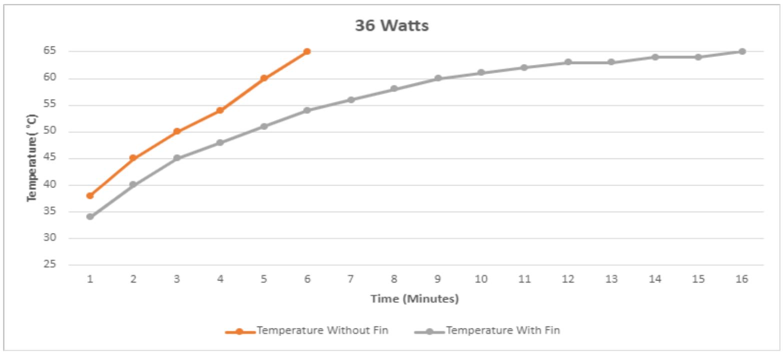

Figure 5. Temperature vs time for two conditions at 36 watts.

➢ For 30-watt input

In Figure 6, the time difference between the two conditions increases as the power supply changes. The volume fraction of PCM is V=0, V=1. At the point of eight minutes the temperature of only fin increased far more than fin with paraffin wax.

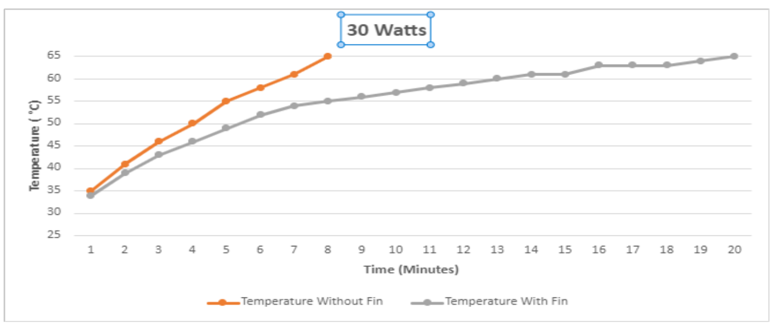

Figure 6. Temperature vs time for two conditions at 30 watts.

➢ For 24-watt input

In Figure 7, as the time difference increases it also shows this difference is incrementally increasing from the previous graphs. The volume fraction of PCM is V=0, V=1.

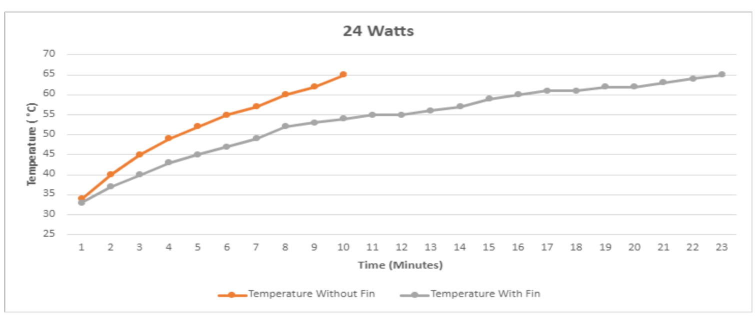

Figure 7. Temperature vs time for two conditions at 24 watts.

➢ For 24-watt input

Figure 8 shows that the time variation in this power input is maximum. The volume fraction of PCM is V=0, V=1.

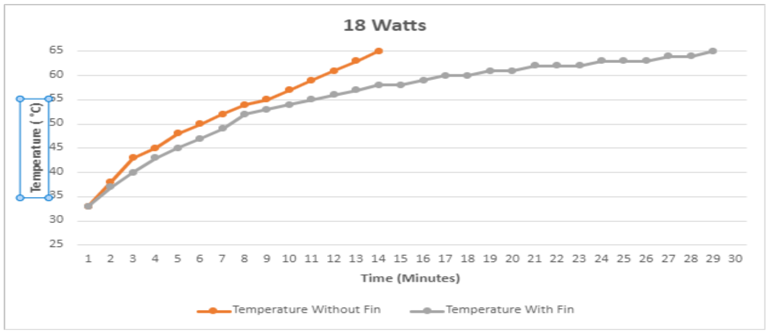

Figure 8. Temperature vs time for two conditions at 18 watts.

5.3 Enhancement Of Operation Time For Two Different Configuration OF PCM Based Heat Sink

Total operation time for different power configuration for the set point temperature (55°C, 60°C, 65°C for different configuration of PCM V=0 V=1) can be compared by charts which shows the different points and heights in the study. These temperatures are the critical breakdown or damage point for many electronic equipment.

- 18 Watts

Time measured with respect to reach heat sink temperature 55°C, 60°C, 65°C for 18 watts power input of different configuration of heat sink. It can be seen from the Figure 9 that time the time difference to reach higher temperatures increases as the paraffin wax starts melting and absorbing more latent heat.

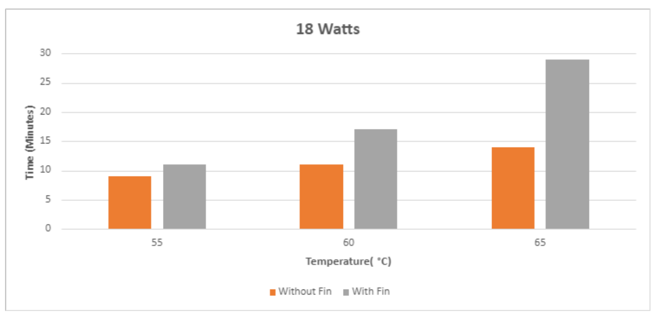

Figure 9. Time to reach SPT 55°C, 60°C, 65°C at power input 18 watts for only fin and fin with paraffin wax heat sink.

- 24 Watts

Time to reach SPT 55°C, 60°C, 65°C at power input 24 watts for only fin and fin with paraffin wax heat sink. Figure 10 also shows the same trend as the previous one, with the temperature increasing the time difference intensifies.

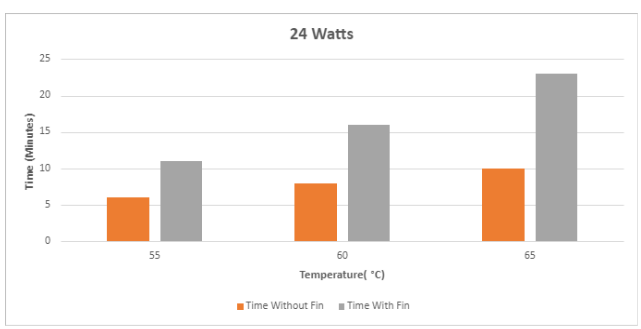

Figure 10. Time to reach SPT 55°C, 60°C, 65°C at power input 24 watts for only fin and fin with paraffin wax heat sink.

❖ SPT 30 Watts

Time to reach SPT 55°C, 60°C, 65°C at power input 30 watts for only fin and fin with paraffin wax heat sink illustrated in Figure 11.

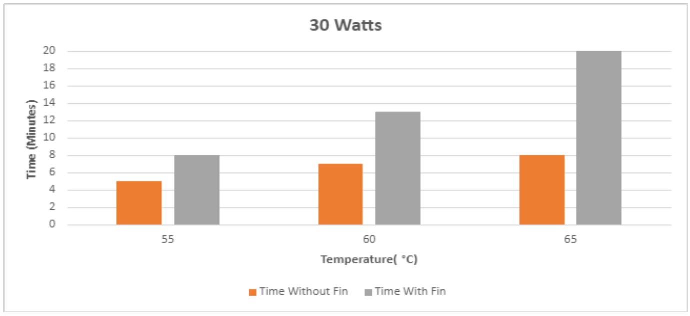

Figure 11. Time to reach SPT 55°C, 60°C, 65°C at power input 30 watts for only fin and fin with paraffin wax heat sink.

❖ SPT 36 Watts

Time to reach SPT 55°C, 60°C, 65°C at power input 36 watts for only fin and fin with paraffin wax heat sink represented in Figure 12.

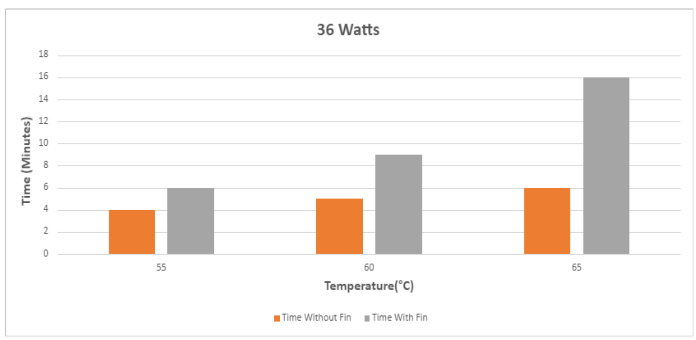

Figure 12. Time to reach SPT 55°C, 60°C, 65°C at power input 36 watts for only fin and fin with paraffin wax heat sink.

From the above figures it is very clear that pin fin is very effective for better performance of PCM based heat sink as in every configuration and different power inputs. Fin with paraffin wax shows much more heat absorptive capacity than only fin. Among all the different output the lowest power (18 watt) shows the best possible outcome (largest time difference) of the broad study. The more power we provide the faster the process operates. For that the sink gets less time to absorb heat from the fins and the paraffin wax. So, we can say that the slower we provide heat the faster and greater the absorption process occurs.

5.4 Limitations

The experiment was conducted using a heater and power was controlled using a voltage regulator. An actual electronic equipment as the heat source would provide more substantial and accurate data to work with in the future.

Also, a sounder insulation would make the data more accurate. For some electronic devices like mobile phones, an external cooling system using PCM material may not be a practical solution and a more practical design/method should be investigated.

6. Conclusion

The experimental investigation performed aimed to investigate the effect of paraffin wax also evaluate the effect of paraffin wax also evaluate the of volume fraction of paraffin wax and pin fin of PCM based heat sinks for heat input of 18watts, 24watts, 30watts and 36watts. The performance of the heat sink was evaluated for several minutes for each temperature outcome. As thermal conductivity of paraffin wax is low, this experimental study presents the effect of pin fin, keeping the volume fraction 10% constant of thermal conductivity enhancer for different heat sinks tested with volume fraction V=0, V=1. Taking temperatures with respect to time, evaluation of the important data resultants of this study are given below:

- As the heat sink provides completely passive techniques for cooling electronic devices as it is cost efficient and reliable.
- It is concluded that inclusion of paraffin wax helps to keep the base temperature lower.
- It also concludes that a heat sink with a volumetric fraction of V=1 means fully filled with PCM is more effective to keep the base temperature lower than that of V=0.
- In this experiment conclude that combine effect of paraffin wax and fin is more effective than only fin.
- Effectiveness (Time to reach a certain temperature) increases as the power input decreases.
- Enhancement ratio is larger for 36-watts power input for all different SPT temperatures.

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