

Research Article

Thermal Performance of Spiral Heat Sinks for LED Lighting Modules

Sai Sharan Yalamarty[†], Royston Marlon Mendonca[†] and Chandrakant R Kini^{**}

[†]Mechanical and Manufacturing Engineering Department, Manipal University, Manipal Institute of Technology, India

Accepted 12 April 2015, Available online 17 April 2015, Vol.5, No.2 (April 2015)

Abstract

LEDs provide effective lighting solutions. Their main advantages are efficiency, reliability and durability. Although LEDs operate cooler than conventional incandescent bulbs, it is necessary to achieve maximum heat transfer in order to maintain or improve their efficiency and lifespan. Heat sinks in LED modules provide a path for heat to flow from the source to the outside medium. Heat sinks with different fin geometries are analyzed to determine its influence on thermal performance and airflow around the fins. This adds options to the manufacturing field which is also of great importance. The thermal performance determines the effectiveness of different fin geometries for heat sinks to be used in LED lighting modules.

Keywords: Light-emitting diodes, Thermal analysis, Spiral heat sinks, Cooling.

1. Introduction

LEDs have replaced the use of traditional lamps as they provide numerous advantages over them. They are free from mercury, hence they are environmental friendly. LEDs are capable of converting electricity directly to light energy, causing less heat to be generated and minimal waste of energy. They also consume about one-third the power and have a lifespan that is about tenfold. Such advantages make LEDs an attractive option for several applications.

Researchers have reported many cooling techniques, including liquid cooling techniques, for high power LED lighting modules. Wang *et al.* (2010) have developed vapor chamber based plate for 30W high power LEDs. Luo and Liu (2007) have proposed a micro jet array cooling system for a 220W LED lamp. Kim and Bar-Cohen *et al.* (2010) have developed a direct sub-mount cooling technique using FC-72 as a working fluid. Lin *et al.* (2010) have investigated thermal characteristics of aluminum plate oscillating heat pipes. Liu *et al.* (2008) have numerically investigated a micro jet cooling system with three different micro jet structures. Xiang *et al.* (2011) have reported phase change heat sinks fabricated for LED packages cooling. Research for the development of heat sinks with extended surfaces is much less when compared to research work on liquid cooling of heat sinks. Elshafi (2010) proposed a hollow/perforated

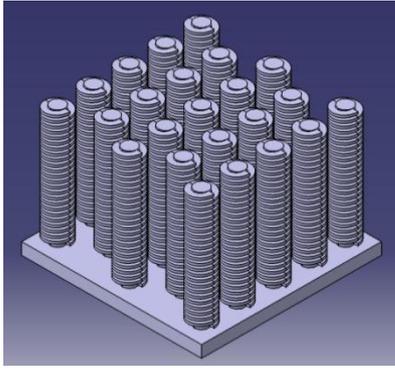
PFH, which when compared to a solid PFH, showed better results in terms of cooling performance. A preliminary study with respect to the thermal behavior of the HFH was reported, proving that the HFH could be lighter and improve cooling performance compared to classical heat sinks such as pin fin heat sinks (PFHs). Kini *et al.* (2015) performed numerical analysis for different shapes of fins to investigate the effect on thermal performance. Airfoil with reverse orientation was found to give the best thermal performance with respect to cooling.

2. Spiral Heat Sink

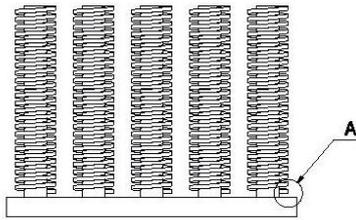
A spiral heat sink consists of a number of cylindrical fins with spirals around them. The model was created to enhance heat transfer by increasing surface area. A total of 23 fins were placed on a base of dimensions 75mm x 75mm x 5mm. Each fin has a height of 50mm and diameter of 6mm. The spiral has a rectangular cross-section with dimensions 2.75mm x 1mm. Figure 1(A) shows the structure of the SHS and Figure 1(B) shows the dimensions of SHS. Fin spacing of 15mm was chosen as it was found to produce the best results (Kim *et al.* 2012). The material used for the heat sink is aluminum 2024 (Kim 2014).

The reference model used is a pin fin heat sink with identical base dimensions and material. Figure 2(A) shows the structure of the pin fin heat sink which is used as reference for the hybrid model and Figure 2(B) shows the dimensions of the pin fin heat sink.

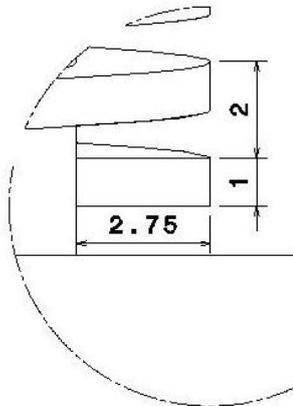
*Corresponding author: Chandrakant R Kini



(A)

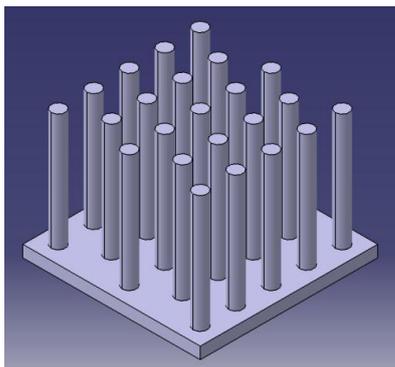


(B)

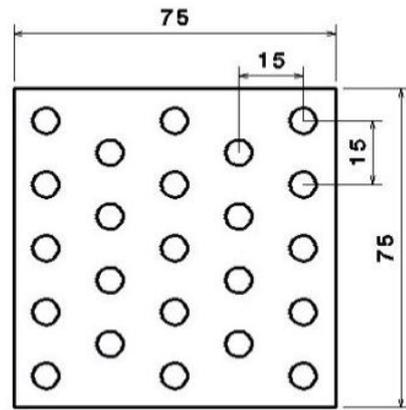
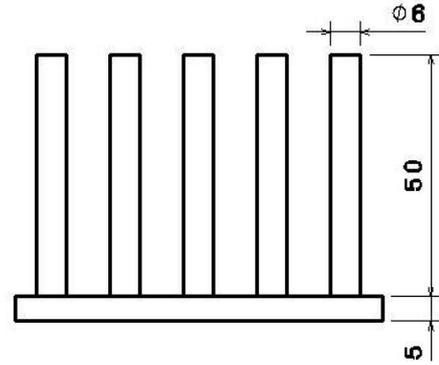


(C)

Fig.1 (A) 3D view of hybrid model, (B) 2D view of hybrid model with dimensions, (C) Enlarged view of the spiral



(A)



(B)

Fig.2 (A) 3D view of pin fin model, (B) 2D view of pin fin model with dimensions

3. Computational Model

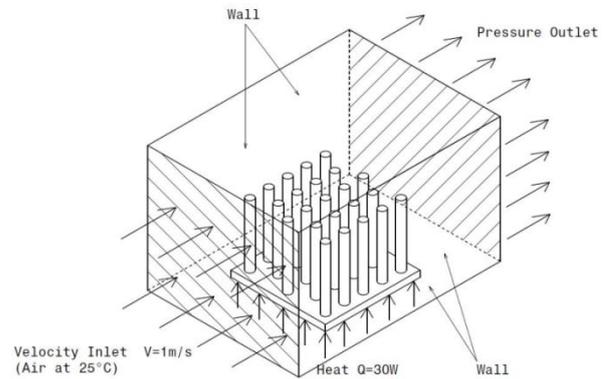


Fig.3 Computational model for the analysis

Thermal performance of the hybrid model was analyzed and compared to the pin fin model using ANSYS Fluent and the mesh was generated on ANSYS Workbench. A uniform heat flux of 30W is applied to the bottom surface of the base. A velocity of 1m/s is given as the inlet boundary condition and atmospheric pressure is given as outlet boundary condition as shown in figure 3. Laminar and steady state conditions are assumed, and the ambient temperature chosen is 25°C (Elshafei 2010).The mesh consists of 3.61 X 10⁵

nodes and 2.11×10^6 elements. Grid dependency test was performed and the appropriate grid size was chosen. The following equations govern the CFD analysis (Hoffmann et. al., 2010).

Conservation of mass:

$$\frac{\partial u_k}{\partial x_k} = 0 \tag{1}$$

Conservation of momentum:

$$\frac{\partial}{\partial x_j} (\rho u_j u_i) = \frac{\partial}{\partial x_j} \left[-p \delta_{ij} + \mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right] + \rho g_i \tag{2}$$

Conservation of energy:

$$\frac{\partial}{\partial x_j} \left[\rho u_j \left(h + \frac{1}{2} u_i^2 \right) \right] - \frac{\partial}{\partial x_j} \left(k \frac{\partial T}{\partial x_j} \right) = 0 \tag{3}$$

$u_k \rightarrow$ Velocity, $x_k \rightarrow$ Cartesian coordinate direction, $\rho \rightarrow$ Density, $p \rightarrow$ Pressure, $h \rightarrow$ Enthalpy, $k \rightarrow$ Thermal conductivity and $\delta_y = 1$

4. Validation

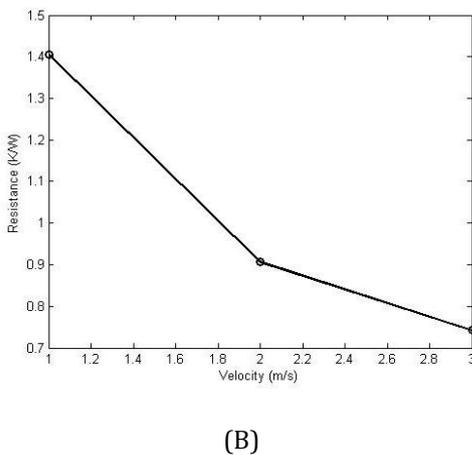
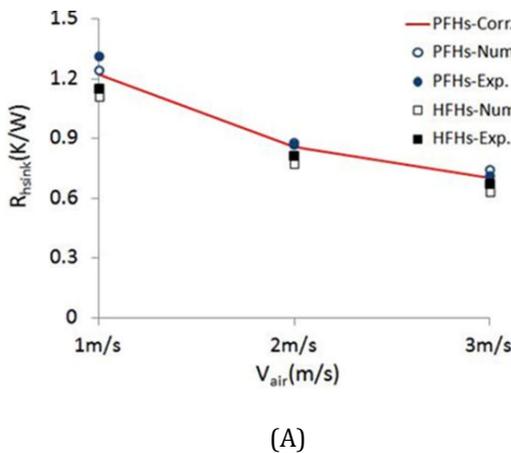


Fig.4 Variation of resistance with air velocity under forced convection with results obtained from (A) Experiment (Kim 2014), (B) CFD analysis

Validation was performed by comparing the experimental results (Kim 2014) of the pin fin model on FLUENT. This involved modeling the pin fin heat sink along with layers of glass (100mm x 100mm x 5mm) and glass fibers (100mm x 100mm x 15mm) beneath it. An air domain with dimensions 620mm x 470mm x 470mm, similar to that of the wind tunnel, was created around the model. A CFD analysis was performed for inlet air velocities 'V'- 1m/s, 2m/s and 3m/s. The results deviated from the experimental results by 6.65%, 4.81% and 4.00% respectively. Figure 3(A) shows the variation of resistance with change in velocity of air for forced convection obtained from the experiment (Kim 2014). Figure 3(B) shows the variation of resistance with velocity of air for forced convection obtained from CFD analysis.

5 Geometric Testing

5.1 Pitch Variation

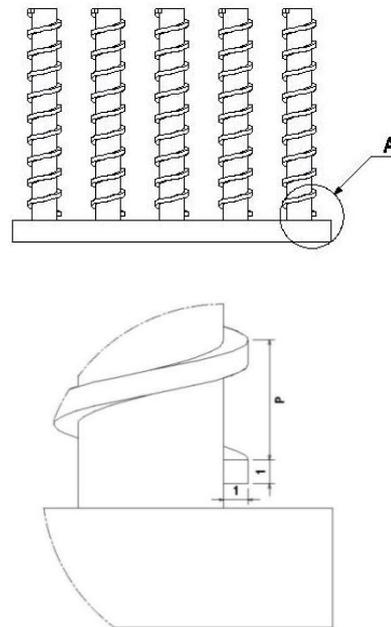
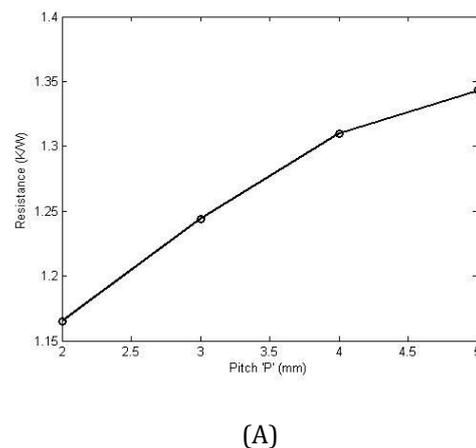
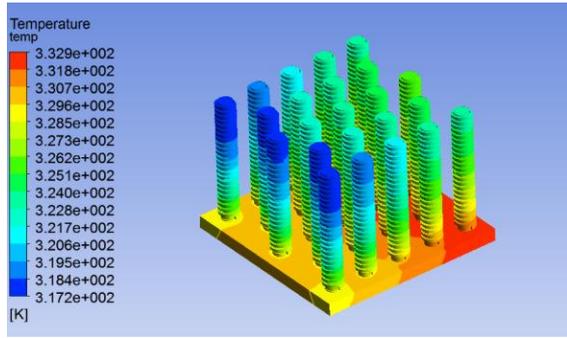


Fig.5 Enlarged view of a section of the spiral with pitch variation





(B)

Fig.6 (A) Graph of Resistance versus Pitch 'P', (B) Temperature distribution of SHS with a spiral of pitch 2mm

Spirals were added along the entire length of the fins to increase surface area, hence improving heat transfer. A pitch of 5mm was initially used which showed improved results as compared to the pin fin model. The resistance offered by the pin fin model is 1.406 K/W. By the addition of spirals, of 5mm pitch, the resistance decreased to 1.343 K/W. The pitch 'P' was then varied between 2mm and 5mm. As the pitch was varied to 4mm, 3mm and 2mm it resulted in resistances of 1.310 K/W, 1.244 K/W and 1.165 K/W respectively. A pitch of 1mm was not possible since it would lead to contact between the spirals. A pitch of 2mm was thus chosen since it was found to offer the least resistance. Figure 5 shows an enlarged view of the spiral with 'P' as the pitch of the spiral. Figure 6(A) shows the plot between resistance and the pitch 'P' of the spiral. Figure 6(B) shows the temperature distribution in a SHS with a spiral of pitch 2mm.

5.2 Cross-section Variation

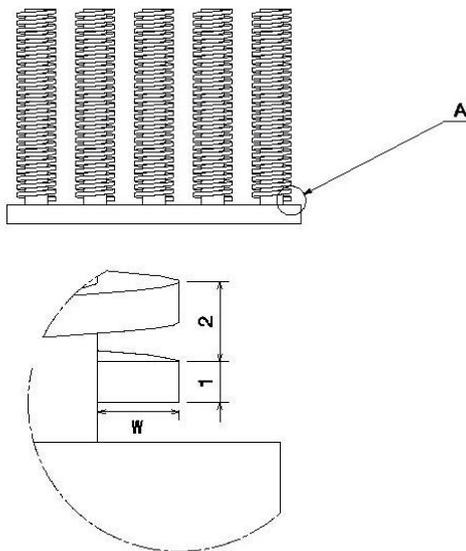


Fig.7 Enlarged view of a section of the spiral with width variation

The cross-sectional area of the spiral was also varied to increase surface area. The width 'W' of the cross-section was varied from 1mm to 4mm. However, with increased width, there was a reduction in air flow over the fins, resulting in a higher base temperature. Resistances offered were 1.165K/W, 1.056K/W, 1.080K/W and 1.126K/W for 1mm, 2mm, 3mm and 4mm respectively. The results followed a trend where the resistance first reduced to a minimum at 2mm, and then increased. To find the minima, multiple tests were performed with values of width in the neighborhood of 2mm i.e. 1.5mm, 1.75mm, 2.25mm, 2.5mm and 2.75mm which offered resistances of 1.115K/W, 1.084K/W, 1.043K/W, 1.023K/W and 1.013K/W respectively. A 2.75mm width was found to give the best thermal performance, combining the effects of increased surface area and sufficient air flow. Figure 7 shows an enlarged view of the cross-section of the spiral with 'W' as the width of the cross-section. Figure 8 shows the plot between resistance and Width 'W'.

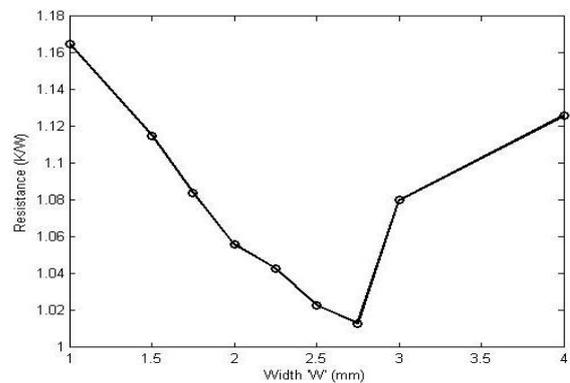


Fig.8 Graph of Resistance versus Width 'W'

6. Thermal Performance

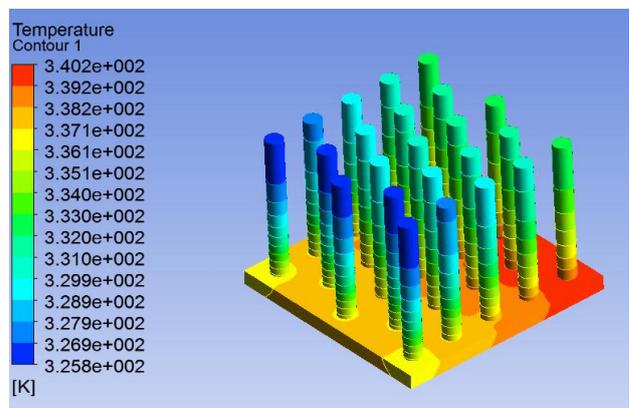


Fig.9 (A) Temperature plot of pin fin model

Earlier, it was seen that the resistance of the pin fin model is 1.406 K/W. After varying the pitch and cross-section, a combination of 2mm pitch and 2.75mm width produced the best thermal performance. The

resistance offered by this combination is 1.013 K/W. The overall thermal performance was found to be 28% better than the pin fin model. Figure 9(A) shows the temperature distribution in a pin fin heat sink. Figure 9(B) shows the temperature distribution in spiral heat sink with pitch 2mm and width 2.75mm.

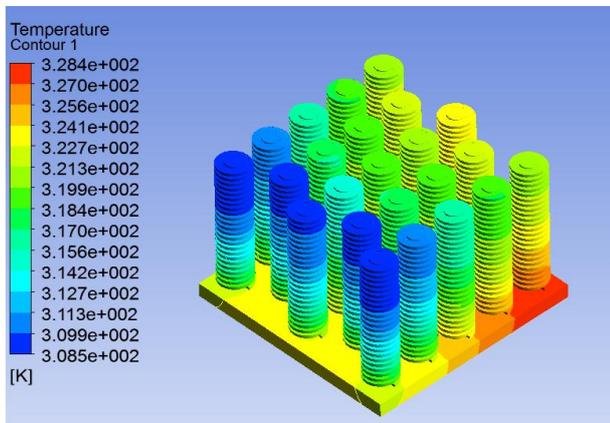


Fig.9 (B) Temperature plot of spiral heat sink with 2mm pitch and 2.75mm width

Conclusion

A spiral heat sink is introduced in order to improve thermal performance. The model was designed and tested with different geometric variations. A pitch variation test was conducted followed by a width variation test. The optimal model obtained has a spiral of pitch 2mm and the width of the cross-section of the spiral is 2.75mm. The thermal performance of this optimal model was compared with that of the pin fin model. The thermal performance was found to be 28% better than the pin fin model. Therefore, it can be concluded that it acts as an effective heat sink for LED modules, resulting in a cooler operation and increasing their lifespan.

Nomenclature

P Pitch of spiral 'mm'
 W Width of cross-section of spiral 'mm'
 V Velocity of inlet air 'm/s'
 R Resistance 'K/W'
 SHS Spiral heat sink
 PFH Pin fin heat sink
 HFH Hybrid fin heat sink

References

- Wang, J.-C., Wang, R.-T., Chang, T.-L., and Hwang, D.-S., 2010, Development of 30 Watt High Power LEDs Vapor Chamber Based Plate, *Int. J. Heat Mass Transfer*, 53(19), pp. 3990–4001.
- Luo, X., and Liu, S., (2007), A Micro jet Array Cooling System for Thermal Management of High-Brightness LEDs, *IEEE Trans. Adv. Packag. Technol.*, 30(3), pp. 475–484.
- Kim, D.-W., Rahim, E., Bar-Cohen, A., and Han, B., (2010), Direct Sub mount Cooling of High-Power LEDs, *IEEE Trans. Compon. Packag. Technol.*, 33(4), pp. 698–712.
- Lin, Z., Wang, S., Huo, J., Hu, Y., Chen, J., Zhang, W., and Lee, E., (2011), Heat Transfer Characteristics and LED Heat Sink Application of Aluminum Plate Oscillating Heat Pipes, *Appl. Therm. Eng.*, 31(14), pp. 2221–2229.
- Liu, S., Yang, J., Gan, Z., and Luo, X., (2008), Structural Optimization of Micro jet Based Cooling System for High Power LEDs, *Int. J. Therm. Sci.*, 47, pp. 1086–1095.
- Xiang, J.-H., Zhang, C.-L., Jiang, F., Liu, X.-C., and Tang, Y., (2011), Fabrication and Testing of Phase Change Heat Sink for High Power LED, *Trans. Nonferrous Met. Soc. China* 21, pp. 2066–2071.
- Elshafei, E. A. M., (2010), Natural Convection Heat Transfer from a Heat Sink with Hollow/Perforated Circular Pin Fins, *Energy*, 35(7), pp. 2870–2877.
- Kim, H., Kim, K. J., and Lee, Y., (2012), Thermal Performance of Smart Heat Sinks for Cooling High Power LED Modules, *13th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm)*, San Diego, CA, May 30–June 1, pp. 962–967.
- Kyoung Joon Kim.,(2014), Performance of Hybrid Fin Heat Sinks for Thermal Control of Light Emitting Diode Lighting Modules, *Journal of Electronic Packaging*, Vol. 136, pp. 011002-1 - 011002-6
- Sai S. Y., Royston M. M., Chandrakant R Kini, (2015), Numerical Analysis of Heat Sinks for LED Lighting Modules, *International Journal of Research in Engineering and Technology*, Vol. 4(3), pp. 142–150.
- Hoffmann, K. A. and Chiang, S. T., (1998), *Computational Fluid Dynamics*, Vol. I, 3rd ed., Engineering Education System, Wichita, KS.