



STUDY ON THE THERMAL PERFORMANCE OF A 10W LED FOG LAMP

W. S. Shim and Y. L. Lee

Department of Mechanical Engineering, Kongju National University, Korea

E-Mail: ylee@kongju.ac.kr

ABSTRACT

These days the LED (light emitting diode) is being actively employed in automobiles, due to its wide range of color expressions and excellent durability compared to other conventional light sources. In this study, CFD and other experiments were conducted with the aim of achieving improved thermal performance of 10-Watt grade LED fog lamps. First, three types of heatsink were considered to examine the differences in thermal performances based on the shape of the heatsink. In addition, two PCBs were also compared one with the LED module attached to one side, and other with LED modules on both sides. The analytical result of this study showed that the circular type heatsink with LED modules attached to both sides of the PCB had the highest thermal performance. A prototype of a 10-Watt fog lamp was then produced based on the CFD analysis, and thermal experiments were conducted on the prototype lamp. The results showed that the LED junction temperature of the prototype remained below the marginal junction temperature.

Keywords: light emitting diode, heatsink, fog lamp, heat thermal performance, junction temperature.

1. INTRODUCTION

The LED is capable of expressing diverse colors and has excellent durability when compared to conventional light sources. Its excellent luminance efficiency enables the LED to be the next-generation light sources for automobiles. [1] The LED, however, has some downsides as well. One of the demerits of the LED is its relatively high junction temperature; it converts more than 70 to 80 percent of the input power into thermal energy, and the junction temperature of the LED increases as the amount of power supplied rises. [2] This increased junction temperature may result in the reduction in optical power, and worse yet, a chip-fail can also occur when the temperature exceeds 150 °C, significantly decreasing the life of the LED. [3] To solve these radiation-related problems, cooling fans, heat sinks, heat pipes, etc., have been used. For example, Zhao *et al.* [4] developed a cooling system where the heatsink was attached to conductive heat plates. Sökmen et al. [5] conducted a performance analysis on a heatsink made in the shape of a cylindrical fin. Chen *et al.* [6] studied to enhance cooling performance by ionic wind. Wang *et al.* [7] attempted to enhance thermal performance by developing a cooling system utilizing a TEC (thermoelectric cooler). Unfortunately, the aforementioned systems cannot be fully employed in LED fog lamps for vehicles because of the limited space for the lamps in cars.

Taking this space constraint into account, the heatsink considered in this study is sufficiently small in size so that it can fit into the actual fog lamp for automobiles. In this study, junction temperatures for the proposed approach were first predicted via numerical analysis, based on the shape of the heatsink and its heat-releasing area, and then optimization of the thermal performance by examining the effect of its location on the LED modules was pursued. After that, a prototype of the fog lamp was made and used to conduct thermal management experiments, to verify the thermal performance of the lamp in the suggested shape.

2. NUMERICAL METHODS AND EXPERIMENTS

The LED fog lamps used in this study consist of an LED module, a silicone mold surrounding the module, and a PCB. A steady, 3-dimensional, and laminar flow was used, and the radiation effect was considered in the flow analysis. Catia [8] was used as the geometric modeling for the LED fog lamps, and Fluent [9] was used for the flow analysis.

Figure-1 shows the three-heatsink models employed in this study: Case 1 is circular-fin type, Case 2 cross-fin type, and Case 3 board-fin type heatsink. Although the shapes of the heat sinks are different, the heat releasing areas of Cases 1, 2, and 3 are the same, at around 0.0139 m². In order to examine the thermal performance, two cases were also compared one which had the LED module installed on one side, while the other was installed on both sides. In addition to that, in Case 3, different numbers of fins were applied in order to estimate

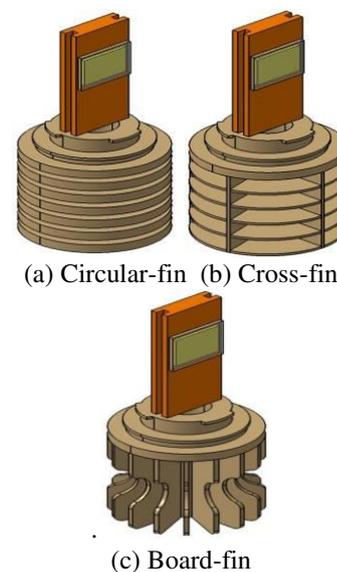


Figure-1. Schematic diagram of LED fog lamps with different kinds of heat sinks installed.

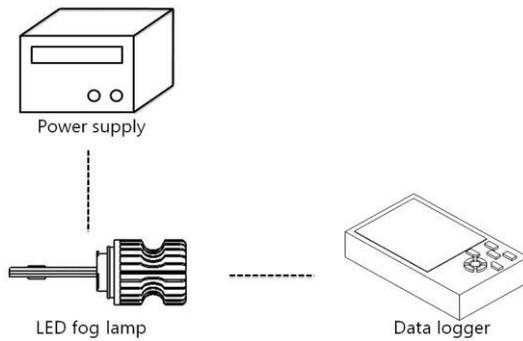


Figure-2. Schematic diagram of thermal performance experiment with LED fog lamps.

the thermal performance based on the heat releasing area. In the final phase of the study, a prototype of the optimized fog lamp was made based on the results of the numerical analysis, and the junction temperature was examined through experiments.

3. RESULTS AND DISCUSSIONS

3.1 Changes in junction temperature by shape of heat sink fin

Figure-3 shows the contours of the junction temperatures by the type of heatsink. The junction temperatures for all three models are presented below the marginal junction temperatures. However, the thermal performance was the highest in Case 1 followed by Case 3 and Case 2, although the differences are not significant. Although Case 1 has the highest thermal performance; its production cost is also higher than that of Case 3 because of the complicated fabrication process needed. Since higher production cost is generally unfavourable in mass production, Case 3 was chosen for this study despite its relatively lower thermal performance, it is easy to fabricate and has better economic feasibility.

3.2 Changes in junction temperature by the number of fins

Figure-4 shows the changes in junction temperature by the number of fins for the Case 3 heatsink. As shown in the graph below, the junction temperature decreases when the number of fins increases.

Examining the graph in more detail, the junction temperature decreases sharply at first when the number of fins increases, but the curve turns to a gradual decline when the number of fins are increased further. The heat releasing area for the 24-fin type, which has the greatest thermal performance, increased by 35 percent when compared to Case 3, while the junction temperature decreased by approximately 3.2°C. In order to secure sufficient thermal performance for the fog lamp, the 24-fin heatsink was chosen for this study.

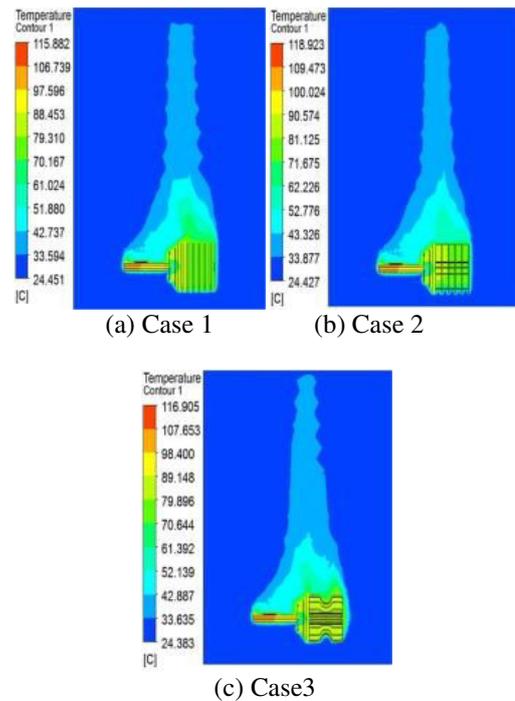


Figure-3. Contours of temperature by shape of heatsink.

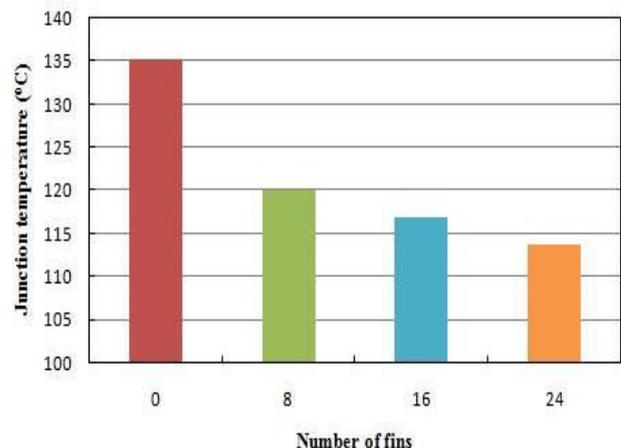


Figure-4. Changes in junction temperature by the number of fins of case 3.

3.3 Changes in junction temperature by the location of LED module

Figure-5 shows two models, one which has the LED module only on one side of the PCB, while other has two LED modules, one on each side of the PCB. This experiment was designed to see how the photometric performance of the fog lamp can be improved depending on the location of the LED module. In this experiment, only the locations of the LED modules were different and the output of the LEDs was kept the same. As shown in Figure 6, the junction temperature of the two-sided model was 108.3°C, lower than that of the one-sided model by approximately 5.4°C. Therefore, the results show that around 11.7°C of margin can be secured below the marginal junction temperature, when the LED modules are installed on both sides of the PCB.



3.4 Prototype production and experiment

Figure-7 shows the LED fog lamp prototype, an optimized model having a board-type heatsink with 24-fins and two-sided PCB, based on the results of the thermal performance analysis. Figure-8 shows the changes in temperature at different parts of the fog lamp by time. The temperature went up sharply for the first 15 minutes after the power was supplied. When the time passed approximately 20 minutes, the fog lamp reached thermal equilibrium, showing little further changes in temperature.

The peak temperature of the LED module was around 113.0°C as shown in Table 1. This is approximately 4.7°C higher than that of the numerical analysis. This difference is thought to have resulted from contact resistance which was produced by the assembly of the parts and components of the fog lamp. However, thermal management was achieved, since the peak temperature was still lower than the marginal junction temperature.

4. CONCLUSIONS

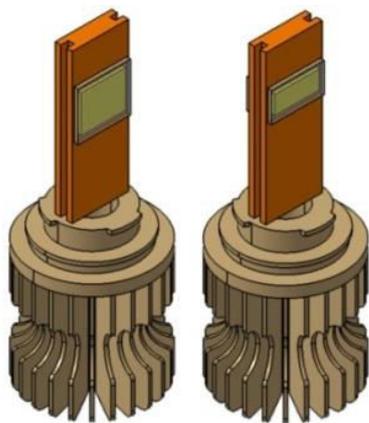
In this study, a thermal performance analysis was conducted considering heatsink shape, heat releasing area,

made and its thermal performance was verified through a series of experiments. The conclusions of this study are as follows:

When the heat releasing areas of the heat sinks are the same, the thermal performance of the circular fin type heatsink is the highest. However, high production costs resulting from more complicated shapes can be a disadvantage in terms of mass production.

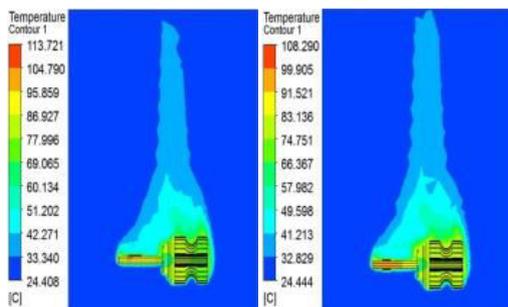
Through the numerical analysis, it was proven that a 24-fin, board fin type heatsink with LED modules installed on both sides of the PCB could secure sufficient thermal performance, and found that the junction temperature for this design was lower than the marginal junction temperature by approximately 11.7°C.

The results of thermal experiments with the prototype showed that the junction temperature of the fog lamp was 113.0°C, which was slightly higher than the numerical



(a) One-sided model (b) Two-sided model

Figure-5. Two models with different LED module location.



One-sided model (b) Two-sided model

Figure-6. Changes in junction temperature by the location of the LED module, number of fins, and location of the LED module. Based on the results, a prototype of the optimized conditions was

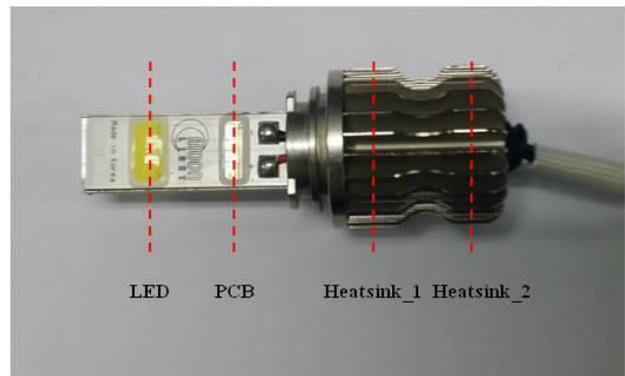


Figure-7. LED fog lamp prototype.

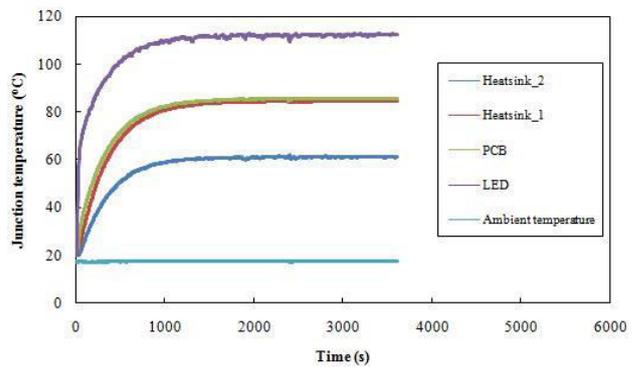


Figure-8. Changes in junction temperature at different parts of the lamp by time.

Table-1. Temperatures measured at different parts of the fog lamp at steady state.

LED module	PCB	Heatsink_1	Heatsink_2
113.0°C	85.8°C	84.7°C	62.1°C

analysis result. However, it was still lower than the marginal junction temperature, signifying that the thermal performance of the prototype had been successfully achieved.



More studies should be conducted on the light distribution performance of the LED fog lamps so as to further improve customer satisfaction going forward.

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