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A Considerable Increase in Lifetime of LED Bulbs Using The U-shaped Liquid-Cooled Configuration

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Abstract: *In this study, we present the results obtained in our investigation of the heat dissipation efficiency of the U-shaped liquid-cooled configuration for LED bulbs. Measurement results showed that the U-shaped liquid-cooled configuration did improve heat dissipation efficiency by reducing the temperature of LED chips from 9°C to 12°C compared to conventional heat dissipation without using liquid. In addition to that, our estimated calculation also showed that the U-shaped liquid-cooled configuration helped to increase the chip's lifetime by about 248%, compared to the conventional cooling method without using liquid. At the same time, because of its high transparency, the liquid does not affect the brightness of the bulb at all.Finally, the use of a U-shaped configuration saves liquids and increases the contacted surface areas with the environment, thus greatly improving the heat dissipation efficiency of LED bulbs even more [1].*

Keywords: *Heat dissipation, U-shaped liquid-cooled configuration, LED bulbs, durability, lifetime.*

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I. Introduction

Heat dissipation for LED bulbs play an important role in enhancing their durability and consistency [2-6]. Conventional LED bulbs use the traditional heat dissipation method, in which heat from the LED chips pass through the heat sink, the air layer and the lamp shell to the outside environment. The air layer has low thermal conductivity (0.024 W/mK), and therefore reduces the heat dissipation efficiency of LED bulbs [7], leading to their shorter lifetime. Recently, there have been several other methods of increasing heat dissipation of LED bulbs [8-12]. In this paper, we present the novel solution of filling the air layer with silicone oil, which is a transparent liquid with much higher thermal conductivity (0.15 W/mK). We carried out some experiments to confirm that the liquid could actually increase the heat dissipation, which could potentially lead to a prolonged lifetime for the LED bulb. We also measured the color temperature of the LED chips, the color rendering index, and the luminescence efficiency to see whether the liquid has any negative impacts on the brightness of the LED bulb or not.

II. Experiment

In normal circumstances, a LEB bulb transmits heat through the heat sink, air layer and lamp shell to its surroundings to reduce the heat radiated by the LED. In this experiment, in order to improve heat dissipation, we use silicone oil with thermal conductivity 6 times higher than the air layer inside the bulb. Therefore, the bulb consists of 6 parts, as shown in figure 1:

1) Glass tube
2) Silicone oil
3) Waterproof coating

4) Silicone belt: the belt is opened when liquid is being poured into the glass tube. When the belt is closed, it guarantees that the liquid does not leak out of the glass tube and affects other parts of the bulb.
5) LED chips
6) Lamp cover

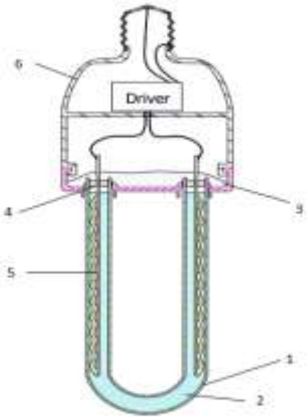

Figure 1: Structure of LED heat dissipation by self-convection

Other specifications of the LED bulb are listed in table 1:

Power	**12 W**
Liquid	**Silicone oil (0.15 W/mK)**
Length of glass-tube	**10 cm**
Diameter of glass-tube	**1 cm**
Power of LED chip	**0.15 W x 80 pcs**

Table 1: The datasheet of LED heat dissipation by self-convection

III. Results

Figure 2:LED bulb using liquid heat dissipation

Figure 2 is the LED bulb that we have manufactured at Institute of Materials Science (IMS), with all 6 components that we previously listed. We waited for about half an hour until the bulb reached its saturation temperature, and then compared this number with that of a bulb using the traditional method.

The temperatures of the LED chip according to its operating time (Figure 3 and Figure 4) showed that:

- The saturation temperature of the LED chip using common heat dissipation method was approximately 76.3℃.
- The saturation temperature of the LED chip using liquid heat dissipation method was approximately 58.3℃.

The saturation temperature of the LED chip using liquid heat dissipation method was 18℃lower than that of the LED chip using common heat dissipation method. This result clearly demonstrates the effectiveness of the silicone oil that we have poured into the glass tube.

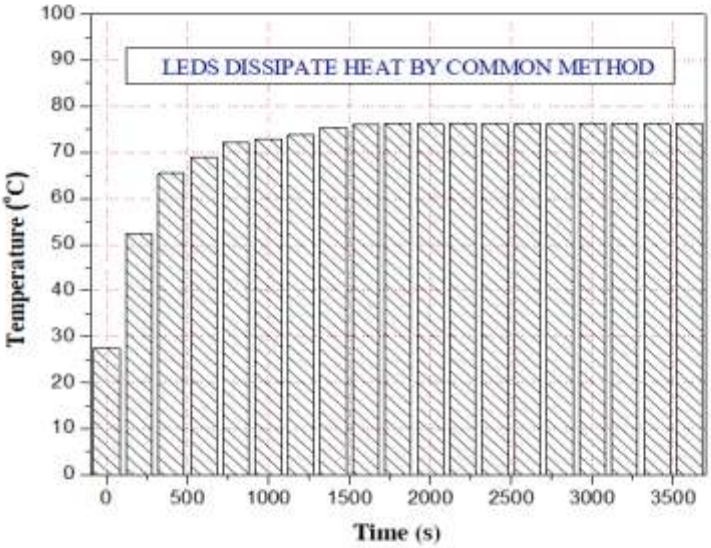

Figure 3: Temperatures of LED chip according to its operating time when using common heat dissipation method

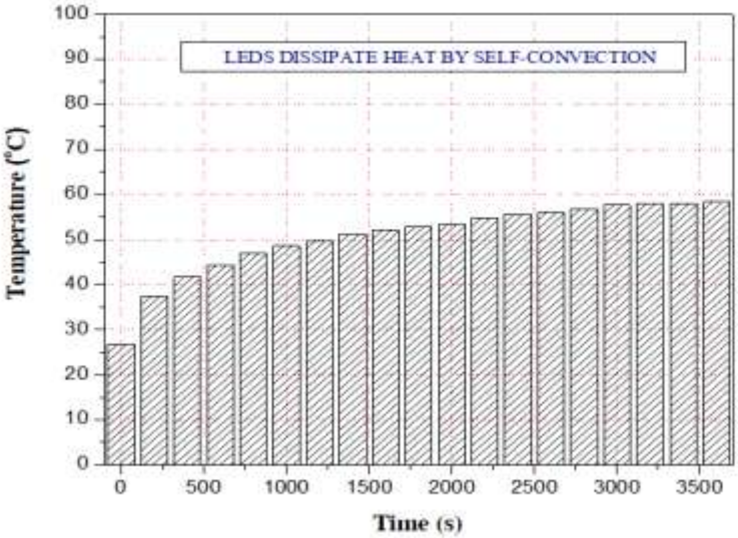

Figure 4: Temperatures of LED chip according to its operating time when using liquid heat dissipation method

IV. Explanation

The increase in the lifetime of the LED bulb when using silicone oil as a medium for heat transmission is calculated by using the Arrhenius equation. The lifetime of an electronic device depends on its operating temperature, and is described in the Arrhenius equation [13,14], which shows the relationship between the probability of failure and the operating temperature. The equation tells us that as the operating temperature of the equipment increases, the probability of it being broken goes up exponentially. The Arrhenius equation is as follows:

$$\mathrm{R} = \frac{\mathrm{D}}{\mathrm{t}} = \mathrm{A}\exp\left(\frac{-\mathrm{E_A}}{\mathrm{kT}}\right)$$

Where: R is the failure level of the equipment (s^{-1}), which is determined by the ratio of the failure rate D (%) to theoperating time t (s).

E_A=0.8 (eV) is activation energy of electronic components.

k=8.617 x 10^{-5} (eV/K) is the Boltzmann constant.

T is the absolute temperature (K) and A is the correlation constant.

From the above equation, the lifetime ratio of the LED bulb when operating at different saturation temperatures can be calculated as follows:

$$AF = \frac{t}{t_0} = \frac{\mathrm{R_0}}{\mathrm{R}} = \frac{\mathrm{A}\exp\left(\frac{-\mathrm{E_A}}{\mathrm{kT}}\right)}{\mathrm{A}\exp\left(\frac{-\mathrm{E_A}}{\mathrm{kT_0}}\right)} = \frac{\exp\left(\frac{-\mathrm{E_A}}{\mathrm{kT_0}}\right)}{\exp\left(\frac{-\mathrm{E_A}}{\mathrm{kT}}\right)} = \exp\left(\frac{E_A}{k}\left(\frac{1}{T} - \frac{1}{T_0}\right)\right)$$

$$AF = \frac{t}{t_0} = \exp\left(\frac{E_A}{k}\left(\frac{T_0 - T}{T.T_0}\right)\right)$$

Where: AF is the ratio of the life of the LED bulb working in two different situations.

t_0 and T_0 are the lifetime and absolute saturation temperature, respectively, in the tradition heat dissipation method.

t and T are the lifetime and the absolute saturation temperature, respectively, when silicone oil is used.

The result of our calculations shows an increase of 248% in lifespan when using heat dissipation by self-convection compared with heat dissipation by common method.

Table 2 shows the color temperature, rendering index and luminescence efficiency of the light bulb in our experiment. It can easily be seen that these figures are not different from those of a normal LED bulb using the traditional heat dissipation method. Therefore, the silicone oil does not affect the brightness of the bulb, which is obviously its most important characteristic.

Color temperature of LED	**6000 K**
Color rendering index	**70**
Luminescence efficiency	**106.9 lm/W**

Table 2: Test measurement results of LEDs dissipate heat by self-convection

V. Conclusion

The U-shaped liquid-cooled configuration for LED bulbs provides excellent heat dissipation. The saturation temperature of LED chip using liquid heat dissipation method was 18 ℃ lower than that of LED chip using common heat dissipation method. According to the Arrhenius equation, the increase in lifespan of LED bulbs using liquid heat dissipation method compared with LED bulbs using common heat dissipation method is 248%. Test results for LED bulbs using liquid heat dissipation method showed that: the colour temperature was 6000 K, the luminescence efficiency was 106.9 lm/W, and the colour rendering index is 70. In addition, the use of U-shaped configuration saves liquids, increases the contacted surface areas with the environment, thus greatly improving the heat dissipation efficiency of LED bulbs.

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