INVESTIGATION OF HEAT DISSIPATION EFFICIENCY OF THE LIQUID-COOLED SPRING LAMP

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ABSTRACT

In this article, the results that we have obtained from our experiments with the heat dissipation process of the liquid-cooled spring lamp are presented. Our measurements clearly demonstrated that using liquid as a coolant did enhance the efficiency of the heat dissipation process, as the temperatures of the LED chips reduced by 16 degrees compared with normal spring lamps, which do not use coolant. Because of this decline in temperature, the average lifetime of the chips is increased by approximately 367%. In addition to that, the liquid that we used in our experiments (silicone oil) has high transparency and thus does not have any negative impacts on the brightness of the LED chips.

Keywords: Spring lamp, coolant, lifetime, LED chips, durability

1. INTRODUCTION

In order to increase durability and consistency for LED bulbs, we need to improve their heat dissipation [1-5]. Normally, heat from the LED chips consecutively go through the heat sink, the air layer and the lamp shell and radiates to the outside environment. However, due to the relatively low thermal conductivity of the air layer (0.024 W/mK), the efficiency of the process remains insignificant, resulting in their shorter lifespan [6]. Over the past several years, some companies have developed different ways of improving the efficiency [7-11]. In this article, we set out the details of a new way in which the problem can be solved: filling the air layer with silicone oil, a transparent liquid with much higher thermal conductivity (0.15 W/mK). In order to make sure that the silicone oil could actually improve heat dissipation, we conducted experiments to measure the temperature differences between the two methods of temperation reduction. In addition to that, other important aspects like colour rendering index, colour temperature, and luminescence efficiency are also checked to reaffirm that the silicone oil does not have any negative impacts on the brightness of the chips.

2. MATERIAL

In our experiment, we pour silicone oil into the glass tube so that it could cool all the LED chips. Therefore, the spring lamp consists of 6 parts, as shown in figure 1:

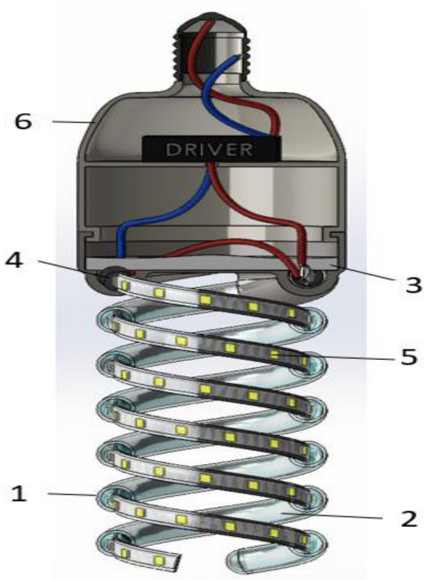

Figure 1: Structure of a spring lamp using the self-convection heat dissipation

1) Glass tube: does not react chemically with silicone oil, and has high transmission efficiency.
2) Silicone oil: the thermal conductivity of the oil (0.15 W/mK) is 6.25 times higher than the normal air layer (0.024 W/mK).
3) Waterproof coating: elastic, heat resistant, heat resistant, does not react chemically with silicone oil, and adhere properly to other materials in the LED bulb. The waterproof coating also fills all the small gaps to make sure that the silicone oil cannot leak into other parts of the LED bulb.
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: when the chips are arranged in this configuration, their contact area with the cooling liquid increases significantly compared with other kinds of LED bulbs, leading to a considerable decrease in the average temperature of the LED bulb.
6) Lamp cover.

Table 1 sets out several important specifications of the LED bulb:

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

3. RESULTS AND DISCUSSION

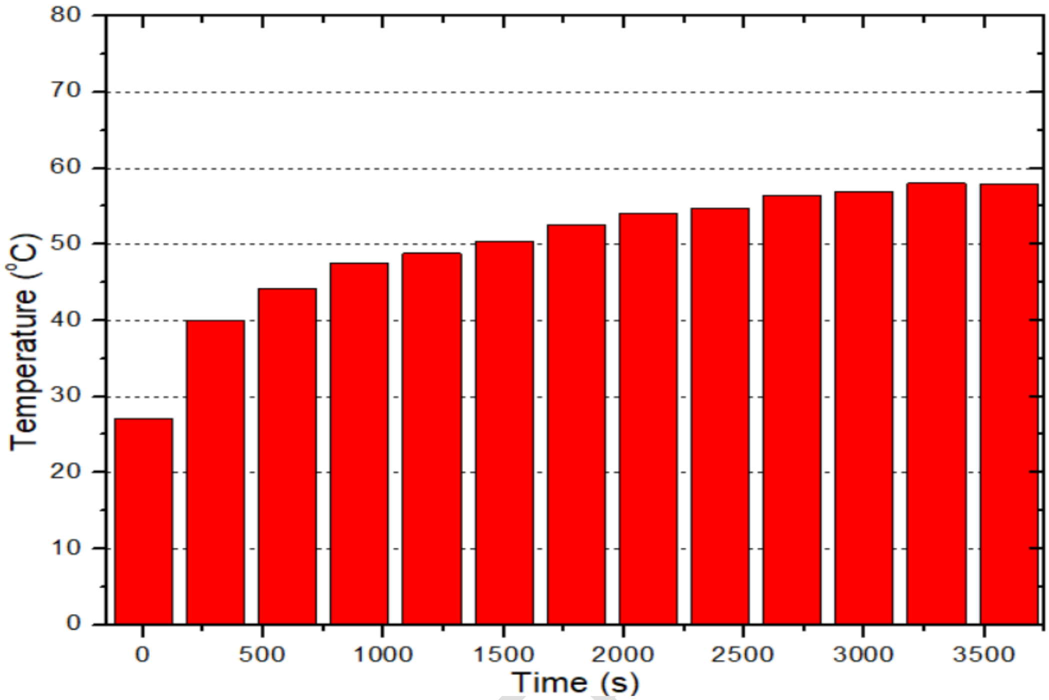

Figure 2: Temperatures of LED chip according to its operating time when using liquid heat dissipation method

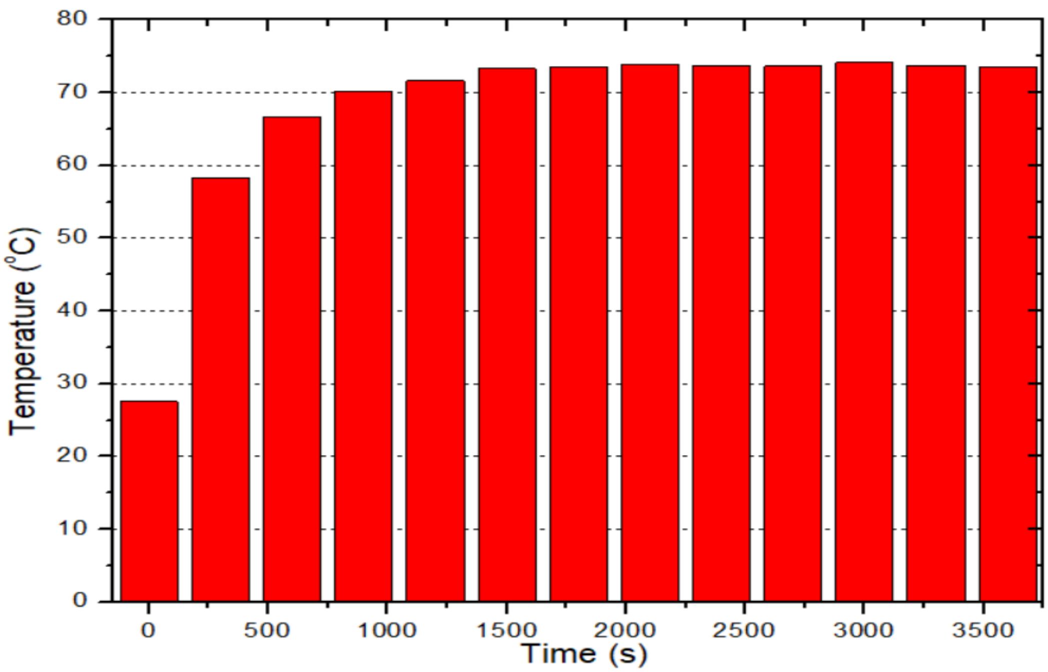

Figure 3: Temperatures of LED chip according to its operating time when using common heat dissipation method

In this article, we use the Arrhenus life-stress relationship, which is the most common model used in calculating the realiability of an electronic device, depending on its operating

temperature [12,13]. The model was derived from the reaction rate equation of Arrhenis, a Swedish chemist in 1887.
The Arrhenius reaction rate equation is given by:

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

Where:

R: the failure level (s^{-1}), is defined as the ratio of the failure rate D (%) to the operating time of the device (s).

E_A: thermal activation energy of the device (0.8 eV).

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

A: correlation constant.

T: absolute temperature (K).

Based on the original equation, we can calculate the lifetime ratio of a LED bulb working at different operating temperatures:

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

$$X = \frac{t}{t_0} = \exp\left(\frac{E_A}{k}\left(\frac{T_0 - T}{T.T_0}\right)\right) \qquad (1)$$

Where: X is the lifetime ratio of two LED bulbs operating in two different temperatures.

t_0 is the lifetime of the LED using the traditional heat dissipation method.

t is the lifetime of the LED when silicone oil is used.

T_0 is the absolute saturation temperature of the LED using the traditional heat dissipation method (347^{o}K).

T is the absolute saturation temperature of the LED when silicone oil is used (331^{o}K).

Replace all the known numbers into equation (1), we have:

$$X = \exp\left(\frac{0.8}{k}\left(\frac{347-331}{347.331}\right)\right) = 3.67$$

The result shows a lifetime increase of 367% 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. All the three numbers are the same with those of a LED bulb using the traditional method of heat dissipation. Because of that, the brightness of the bulb is not affected when the silicone oil is used for heat dissipation.

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

Table 2: Colour characteristics and luminescence of the LED bulb

4. CONCLUSION

The results of our calculations and experiments all show that the liquid-coolded spring lamp shows great heat dissipation efficiency. The saturation temperature of the chips reduced by 16oC, compared with the traditional temperature reduction method. Using the Arrhenius equation, we also calculated that the lifetime of the chips increased by as much as 367%. In our experiments, we also measured the colour temperature (6000K), the luminescence efficiency (106.9 lm/W), and the colour rendering index (70).

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