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Cooling performance of a radial heat sink with triangular fins on a circular base at various installation angles

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ABSTRACT

In this study, a generalized shape of the heat sink for most of the commercial LED light bulbs was considered. The thermal resistance of a radial heat sink with triangular fins on a circular base was investigated at different angles. A numerical model with the consideration of natural convection and radiation was established to investigate the effects of the Rayleigh number, finning factor, porosity factor, installation angle, and radius of the heat sink base. The numerical model was validated through experiment. Then, based on numerical results, a correlation was suggested to estimate the degree of enhancement of cooling performance between the radial heat sinks with and without triangular fins.

1. Introduction

The attention has been drawn to the development of high-efficiency electronic devices. This is due to the fact that the fossil fuel is depleting and the global consumption of energy is growing. Furthermore, approximately 20% of the global energy is consumed to generate light. For these reasons, the conventional lighting devices are being replaced by the light emitting diode (LED) lightings which provide higher efficiency, longer life, and smaller size. As the lighting devices have been rapidly developed for past decades, thermal management, *i.e.*, one of the factors to improve the lifetime of lighting devices, has become more important. Heat sinks have been employed for the purpose of cooling LEDs. In the case of LED light bulbs, the photoelectric conversion efficiency accounts for about one-fifth, and the rest of the input energy is released as heat [1]. Natural convection is recommended for cooling LED lightings, since it does not need extra equipment [2–4]. Without properly designed heat sinks, the LEDs will reach a high temperature and the lifespan of LED lightings will be reduced [5–7]. In addition, LED lightings are utilized in various places and the installation angle of the LED lightings can be different according to the purpose and use. The installation angle is one of the weighty parameters for cooling LED lightings under natural convection. Therefore, it is indispensable to investigate the changes in the cooling performance of heat sinks according to the installation angle with respect to gravity.

Not many studies have been conducted on triangular fins as compared with plate fins or pin fins in the light of fin geometries for radial heat sinks. Iyengar and Bar-Cohen [8] investigated the thermal performance of the heat sinks with vertical pin fins, plate fins, or triangular fins attached to a rectangular base under natural convection through a least-material optimization method. They concluded that the heat sink with triangular fins was thermally superior to pin fins and plate fins at a particular environment. Al-Jamal and Khashashneh [9] experimentally investigated the effects of triangular fins and pin fins attached to a rectangular base at a constant heat flux condition, and a correlation of Nusselt number obtained from their experimental results demonstrated that the Nusselt number for pin fins was higher than that for triangular fins. Dogan et al. [10] considered various fin shapes for a horizontal rectangular base plate through a numerical method, and they found that the optimized fins showed a higher average heat transfer coefficient than the plate fins under the same total area of fins. However, the heat sink geometries of these studies cannot be directly applied to LED light bulbs, since the heat sinks for LED light bulbs, in general, have a circular base with triangular-like shaped fins placed at regular angular intervals.

Recently, many studies have focused on the radial heat sink

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Nomenclature

c_p	specific heat capacity (J/kg)
g	gravitational acceleration (m/s^2)
h	heat transfer coefficient (W/m^2·K)
H	height (m)
k	thermal conductivity (W/m·K)
l	base length of triangular fins (m)
M_w	molecular weight (kg/kmol)
N	number of fins
p	pressure (Pa)
$\dot{q}$	heat flux (W/m^2)
r	radius (m)
R	universal gas constant (J/kmol·K)
R_{th}	thermal resistance (K/W)
Ra	Rayleigh number
S	source term
t	thickness (m)
T	temperature (K)
$\boldsymbol{v}$	velocity vector (m/s)
V	volume (m^3)

Greek symbols

α	thermal diffusivity (m^2/s)
β	volumetric expansion coefficient (1/K)
θ	installation angle (°)
μ	dynamic viscosity (kg/m·s)
υ	kinematic viscosity (m^2/s)
ξ	augmentation factor
ρ	density (kg/m^3)
φ	porosity factor
ψ	finning factor
ε	emissivity

Subscripts

air	air
avg	average
b	base of the heat sink
bottom	bottom
f	fin or finned
hs	heat sink
i	insulator
nf	non-finned
o	operation condition
void	void volume occupied by air
∞	ambient

with a circular base to enhance the heat dissipation due to the increased demand for LED lighting applications. Yu et al. [11] investigated the natural convection on three types of heat sinks, *i.e.*, L, LM and LMS models, and found that the cooling performance of the LM model was superior to the other models. Costa and Lopes [12] presented a methodology to enhance the thermal performance of the radial heat sink with a circular base and a number of spaced rectangular fins having a central core, by using the minimum mass of material. Li and Byon [13] studied the cooling performance of a radial heat sink with rectangular fins on a circular base through experiments and simulations. Jang et al. [14] and Park et al. [15] investigated the cooling performance of a radial heat sink with pin-fins. They revealed that the cooling performance of radial heat sinks was affected by fin-height profile and fin array, and optimized the radial heat sinks by considering the fin-height profile and fin array. Park et al. [16,17] improved the cooling efficiency of radial heat sinks by employing a hollow cylinder or a chimney. However, the heat sink geometries of these studies are applicable to LED downlights which are usually attached to the ceiling horizontally, but not to the LED light bulbs. Lee et al. [18] suggested a correlation to predict the Nusselt number for a heat sink having triangular fins attached to a hollow vertical cylindrical base where heat flux is applied to the inner wall of the vertically oriented hollow cylindrical base. However, the correlation of Lee et al. [18] is not directly applicable to most of commercial LED light bulbs, due to the fact that heat sink geometry considered in Lee et al. [18] is different from those of most of the commercial LED light bulbs having triangular-like shaped fins attached to not only a vertical hollow cylinder but also a horizontal circular base and that heat flux generated by LED chips is in general applied to the circular base in case of the most of the commercial LED light bulbs.

So far, there have been few studies on the cooling performance of heat sink geometries which are appropriate for most of the commercial LED light bulbs, *i.e.*, a heat sink with triangular-like shaped fins installed on a hollow cylinder as well as a circular base, as shown in Fig. 1. Moreover, no studies have considered the orientation effect of the radial heat sink with triangular-like shaped fins attached to a hollow cylinder and a circular base. The purpose of this study, therefore, is to investigate the cooling performance of a radial heat sink with triangular fins on a circular base at various installation angles.

2. Numerical method

The shape of the heat sink considered in this study is shown in Fig. 1. By reflecting the general shape of most of the commercial LED light bulbs, the heat sink was designed to be composed of a circular base, a concentric hollow cylinder, and triangular fins placed at regular angular intervals. As shown in Fig. 2, half of the heat sink was considered for simulation due to the symmetric geometry, and a hemispherical calculation domain was used to investigate the effect of installation angle, θ. The grid independence test was conducted by changing the number of grid cells from approximately 0.6 million to 3.5 million. As a result, the number of grids cells was selected as approximately 2.15 million, and the radius of the hemispherical calculation domain was set to be five times the fin height (H_f). The convergence criteria for relative errors of all dependent variables were less than 10^{-5}.

For simulating the thermal flow around the heat sink, the continuity, momentum, and energy equations were simultaneously solved by using a commercial CFD code, ANSYS FLUENT *Release* 16.1. The flow was assumed to be three-dimensional, steady, laminar, and incompressible. The governing equations in the air side were as follows.

Continuity Equation:

$$\nabla \cdot \mathbf{v} = 0. \quad (1)$$

Momentum Equation: