Paper

Heat-Transfer in Reflector-type Self-Ballasted Compact Fluorescent Lamps

Takeo YASUDA*, Masahiro TODA*, Shinichiro MATSUMOTO* and Yuichiro TAKAHARA*

*Toshiba Lighting & Technology Corp.

Paper originally published in Japanese in J.IELJ, Vol.89-No.2, 2005

A part of this paper was presented as follows: by Matsumoto at Tokyo Branch Meeting of IEE-J in 2001, by Takahara at Annual Conference of IEE-J in 2002, by Yasuda at 16th Seminar on Light Source Property and its Application (2002), and by Toda at Tokyo Branch Meeting of IEE-J in 2002.

ABSTRACT

Self-ballasted compact fluorescent lamps (SBCFL) are widely used to replace incandescent lamps (IL) to save energy. We studied the heat-transfer phenomena of SBCFLs with outer envelopes by measuring the temperatures of the lamp parts, the power consumption, and the luminous output, and by calculating the energy balance. The methods applied were heat-transfer network analysis and computational fluid dynamics (CFD) using FLUENT® software. The heat loss increased in reflector-type SBCFLs as compared to SBCFLs with non-reflective outer envelopes, and was estimated at about 3W when the total lamp power was 22W. This results in a temperature rise of 20 K in the plastic holder, and a maximum rise of 10 K at the electronic components on the circuit board. Accordingly, we have developed a 12W reflector-type SBCFL, which replaces a 60W incandescent, not a 22W SBCFL replacing a 100W incandescent R-lamp, due to the importance of thermal reliability.

KEYWORDS: heat-transfer, self-ballasted, compact fluorescent lamp, network analysis, computational fluid dynamics

1. Introduction

In the recent years, the demand for the self-ballasted compact fluorescent lamps (SBCFL), which have high energy saving effects, has been increasing due to increased concerns for environmental issues. Although almost all self-ballasted compact fluorescent lamps currently being sold in the market contain an electronic circuit, their thermal loading has been increasing due to efforts to reduce their size and increase output¹⁾²⁾ in order to make their sizes closer to those of incandescent lamps. Some of these lamps have an outer envelope of the A-type, G-type, or T-type³⁾ covering the outside of the curved discharge tube for the sake of the appearance of the merchandise, and this structure is one of factors that has caused an increase in the temperature of the electronic circuit. Therefore, it is important to reduce the temperature of the electronic circuit and the surrounding parts in order to improve properties and reliability related to temperature in self-ballasted compact fluorescent lamps, and it is necessary to clearly understand the heat transfer phenomena as a preliminary step.

However, there have been few papers presented on the electrical circuit temperature of the compact fluo-

rescent lamps in the past, and we can list only two: a report on the thermal network analysis of compact fluorescent lamps without outer envelopes⁴⁾, and a report on measuring the results of dimensional design versus electronic parts⁵⁾. Hence, we have implemented a thermal network analysis⁶⁾, which is the same method as was applied in reference (4) on compact fluorescent lamps with envelopes, and also implemented a heat transfer analysis⁸⁾ with FLUENT® thermo-fluid analysis software in the development of compact fluorescent lamps with reflector-type envelopes⁷⁾, and we are going to report these results.

2. Thermal network analysis of 22 W lamp with envelope

2.1 Specification of the SBCFL on which the experiments and analysis were implemented

The lamp that was evaluated in this chapter was a replacement for the 100 W incandescent lamp. Its model name was EFA22EL and had a power consumption of 22W, tri-chromatic warm white color, with a total luminous flux of about 1500 lm²⁾. Fig.1 shows its structure. A hot cathode fluorescent tube, made up of four U-type tubes of 11 mm diameter, is combined with

an electronic circuit that operates the light with a sinusoidal current of about 60 kHz, and can be directly adapted to an E26 socket. The symbol h and the inserted phrases of “reflective film,” “control line,” and “light aperture” are modifications made for the experiment of the reflector-type SBCFL in Chapter 3. In this Chapter 2, experiment and analysis was made on regular product in which a milky white diffusion coating is used so that light transmission be around 95%⁹⁾.

2.2 Heat transfer model and thermal network analysis

The method of thermal network analysis was set as

Figure 1 Structure of EFA22EL

Figure 2 Heat-transfer network model

Table 1 Representative area mentioned by each node

①	Light tube	⑦	Circuit board
②	Air in outer envelope	⑧	Circuit
③	Outer envelope	⑨	Air in case
④	Divider	⑩	Upper part of case
⑤	Air in between divider and circuit board	⑪	Screw base
⑥	Lower part of case		

Table 2 Heat-transfer network equations between nodes

①	$Q1 + Q2 + Q5 + Q24 = 15.8 - Q25$	
②	$-Q2 + Q3 - Q6 = 0$	
③	$-Q1 - Q3 + Q4 + Q22 = 0$	
④	$-Q5 + Q6 + Q7 + Q8 + Q11 = 0$	
⑤	$-Q8 + Q9 - Q12 = 0$	
⑥	$-Q7 - Q9 + Q10 + Q16 - Q22 = 0$	
⑦	$-Q11 + Q12 + Q13 - Q24 = 0$	
⑧	$-Q13 + Q14 + Q20 + Q23 = 2.2$	
⑨	$-Q14 + Q15 - Q18 = 0$	
⑩	$-Q15 - Q16 + Q17 - Q20 = 0$	
⑪	$Q18 + Q19 - Q23 = 0$	
	$Q1 = C1 \times (T1 - T3)$	$Q13 = C13 \times (T7 - T3)$
	$Q2 = C2 \times (T1 - T2)$	$Q14 = C14 \times (T8 - T9)$
	$Q3 = C3 \times (T2 - T3)$	$Q15 = C15 \times (T9 - T10)$
	$Q4 = C4 \times (T3 - T\infty)$	$Q16 = C16 \times (T6 - T10)$
	$Q5 = C5 \times (T1 - T4)$	$Q17 = C17 \times (T10 - T\infty)$
	$Q6 = C6 \times (T4 - T2)$	$Q18 = C18 \times (T11 - T9)$
	$Q7 = C7 \times (T4 - T6)$	$Q19 = C19 \times (T11 - T\infty)$
	$Q8 = C8 \times (T4 - T5)$	$Q20 = C20 \times (T8 - T10)$
	$Q9 = C9 \times (T5 - T6)$	$Q21 = C21 \times (T8 - T6)$
	$Q10 = C10 \times (T6 - T\infty)$	$Q22 = C22 \times (T3 - T6)$
	$Q11 = C11 \times (T4 - T7)$	$Q23 = C23 \times (T8 - T11)$
	$Q12 = C12 \times (T7 - T5)$	$Q24 = C24 \times (T1 - T7)$

sponding to this experiment. Table 1 shows the representative areas mentioned by each node and Table 2 shows the simultaneous equations used to express the relationship between the temperature at each node, the heat conductance (the reciprocal of the heat transfer resistance), and the thermal flow. Here, Q is the heat flow rate (W), C is the heat conductance (W/K), and T is the absolute temperature (K). Regarding the heat transfer vehicles, $C5$, 7, 13, 16, 19, and 22 express heat conduction, $C2$, 3, 6, 8, 9, 12, 14, 15, and 18 express convection, $C1$, 11, 20, 21, 23, and 24 express radiation, and $C4$, 10, and 17 express the sum of the convection and radiation. However, $C21$, which shows a route of radiation connecting the case bottom ⑥ and the circuit ⑧, is not included in Fig. 2 since it was regarded as being unnecessary during evaluation and was disregarded. Although $T \infty$ means an infinite ambient temperature, it is 25°C (298K) here. By the way, each value of C was obtained by approximation based upon the geometric dimensions and the succeeding multiplication by adjusting coefficients to reflect the experimental results of temperature measurement.

The exothermic bodies here are the light tube ① and the circuit ⑧, and each value was obtained as follows. Regarding the heat release value of the circuit, it was known from an experiment with the conditions of an ambient temperature 25°C, the lamp operated with the bare screw base upward, and a rated input of 100V at 50Hz, that the electric power consumption of the whole lamp was around 22.4W, the electric power input to the light tube at around 90% circuit efficiency was around 20.2W, and electric power consumption of the ballast was around 2.2W. Then, in regard to the electric power consumption of the light tube, the visible light of tri-chromatic warm white color, and a total luminous flux of 1500 lm equivalent to around 4.4 W is regarded to have escaped from the thermal network system being studied, and the remaining 15.8W was put as the heat release in the initial calculation. Although there is a heat flow rate Q_{25} to be deducted from 15.8 in item ① in Table 2, this represents a part of heat radiated from light tube that is transmitted through the outer envelope to escape the thermal network system, as was the case with the visible light. This ratio of heat radiation transmitted through the outer envelope TM (%) was obtained by the following Equation (1):

$$TM = \frac{\varepsilon \int_0^{\infty} I(\lambda) M_{e,\lambda}(T) d\lambda}{\varepsilon M_e(T)} \quad (1)$$

Here, ε is the emissivity of glass, $M_e(T)$ is the radiant emittance (W/m^2), λ is the wavelength (μm), $M_{e,\lambda}(T)$ is

Figure 3 Relation between the temperature of light tube and transmitted radiation

Figure 4 Relation between the temperature of light tube and the transmitted rate

the spectral radiant emittance ($W/(m^2 \cdot \mu m)$), T is the absolute temperature (K), and $I(\lambda)$ is the spectral transmittance of the outer envelope. Although there is no data on $I(\lambda)$ for a milky white diffusion envelope, we have assumed that below 2.9 μm is 95%, above 4.8 μm is 0%, and the transmittance is reduced linearly in the range from 2.9 μm to 4.8 μm , using the data for the spectral transmittance for soda lime glass as a reference. Fig. 3 shows the calculated results of the spectral distribution of the thermal radiation at light tube temperatures of 25°C, 100°C, and 200°C, as well as the spectral distribution of the thermal radiation transmitting through the outer envelope. Fig. 4 shows the relationship between the surface temperature of the light tube and the rate of thermal radiation transmission. The temperature of an SBCFL is roughly in the range from 100°C to 200°C, although it varies by brand, and the transmitted thermal radiation is only in the range from 1% to 5%, so there is no significant error, even if it is assumed that the outer envelope is opaque to thermal radiation.

2.3 Analysis of results

Table 3 compares the calculated and measured values of the temperature and electric power for major parts of the lamp, and the differences in temperatures for each

Table 3 Comparison between calculation results and measured data

Position of parts	Measured value	Calculated value
Globe (°C)	89	89
Divider (°C)	152	152
Upper part of case (°C)	76	72
Lower part of case (°C)	82	76
Average of circuit (°C)	119	123
Screw base (°C)	62	63
Electric power at light tube (W)	20.2	20.2
Consumption power at circuit (W)	2.2	2.2

Figure 5 Calculated result on the heat-transfer of EFA22EL

part is within 10°C. Temperature measurements were made using a copper-constantan thermocouple with a 0.2mm wire diameter ϕ . By the way, it is not surprising that the calculated temperature value matched the measured values well because adjusting coefficients were applied, and, instead, the more valuable result obtained by the calculations was the status of the thermal flow, as shown in Fig. 5. The temperature of the light tube reached approximately 180°C and the thermal radiation transmitted through the outer envelope as obtained per the description in paragraph 2.2 was 0.3W, which is equivalent to around 4%.

Among the heat out of the light tube, the heat flow rate to the circuit via the board was 1.16W, which was an unexpectedly low level. However, the surface area of the case surrounding the circuit is small compared to the outer envelope that covers the light tube, and the channels to allow the escape of the generated heat are fundamentally limited, so the temperature of the circuit is considered to be easily increased even by small heat generation.

Figure 6 Relation between the temperature of lamp part and the height of control line

3. Heat analysis of SBCFL with a reflector envelope

3.1 Temperature measurement of a 22 W lamp with envelope

As suggested by the reflector-type incandescent lamps already on the market, there is a market need for SBCFLs with high directional luminance for downlight applications even with a somewhat reduced total luminous flux. Hence, a lamp with a structure as shown in Fig. 1 was produced experimentally for the purpose of basic testing and its properties were evaluated. The symbol h in the figure indicates the height of the control line for the aluminum reflective film formed on the inside surface of the envelope by means of vacuum vapor deposition. Fig. 6 shows the temperature increase of parts of the lamp with varied values of h against the temperature of the parts in the regular product. Here, the regular product is a lamp without a reflective film but with a milky white diffusive film formed in its inside. Parts 1, 2, 3, and 4 correspond to the partition plate, the narrow tube tip, parts on the lower surface of the circuit board, and parts on the upper surface of the circuit board, respectively. It is known from Fig. 6 that the temperature of each part increased in parallel with an increase in the control level and that especially the temperature of the divider, which is close to the light tube, increased remarkably. In view of the results in the previous Chapter 2, it is assessed that, a portion of around 7.8W of the heat radiated from the light tube to

Table 4 Specifications of the developed reflector-type SBCFL
Each lamp color is tri-chromatic warm white (2800K)

	SBCFL with reflector-type envelope (newly developed)	SBCFL with milky white diffusion film A type (existing line)
Rated input power (V)	100	100
Rated consumption power (W)	12	12
Total light flux (lm)	560	810
Central luminance (cd)	115	72
Maximum luminance (cd)	135	79

Figure 7 Dimensions of the developed lamp with reflector-type envelope

Figure 9 Meshes of 2D-model

Figure 8 2D-Model of the lamp

the outer envelope was reflected by the aluminum film and also a portion of the visible light equivalent to 4.4W was reflected by the same, they were not used effectively and, as a result, were transferred in the form of heat throughout the inside of the system. For example, the total luminous flux with a control line height of 56 mm was around 75% of the flux in the regular product

when comparative photometry was done using and integrating sphere of ϕ 3 mm, and it is considered that approximately 3W, or around 25% of the 12.2W total radiated heat and visible light, became heat and caused the temperature increase in the parts.

An increase in temperature of the circuit parts shortens the life of the lamp, and also it is undesirable because a more expensive resin with higher heat resistance has to be used for the partition plate, a part made of resin, in parallel with an increase in the operating temperature.

3.2 Example of two-dimensional thermal flow analysis using FLUENT®

Table 4 and Fig. 7 show the final specification of the developed product, which was designed to achieve 560 lm total luminous flux, which is equivalent to 60W reflector-type incandescent lamp, and as a result realized a 12W power consumption. Compared to an A-shaped SBCFL of 12W with 810lm¹²⁾, the center beam candle-power is about 1.6times higher. A thermal flow analysis of a two-dimensional model of this reflector-type lamp was implemented.

Fig. 8 and Fig. 9 show diagrams of the model and the mesh formation. Although there is no wall to block convection, as shown in Fig. 8, in the actual product, it was set in the model in order to check its effect on tempera

Table 5 Conditions of calculation

	Reflective film on envelope	Envelope side wall angle θ	Wall to block convection	Heat release value
Condition (1)	No	10 deg.	Without wall	Equivalent to product of 22 W
Condition (2)	Yes	10 deg.	Without wall	Equivalent to product of 22 W
Condition (3)	Yes	20 deg.	Without wall	Equivalent to product of 22 W
Condition (4)	Yes	10 deg.	With wall	Equivalent to product of 22 W
Condition (5)	Yes	10 deg.	Without wall	Equivalent to product of 12 W

Table 6 Calculated temperatures at each position (°C)

	Center of divider	Circuit part a	Circuit part b
Condition (1)	164	137.5	69
Condition (2)	172	167.5	77.5
Condition (3)	167.5	152.5	73
Condition (4)	177.5	137	70
Condition (5)	138	120	62

Figure 10 Positions of the lamp temperature indicated

Figure 12 Results on the calculated temperature distribution under the condition

Figure 11 Result on the calculated convection under the condition

ture reduction. Table 5 shows the conditions set for the calculation. In this section, the circuit parts were not regarded as exothermic bodies, and it was assumed that only the surface of the light tube generates heat in order to calculate its influence on the temperature of the circuit parts. The density of heat generation was put as 900 W/m^2 for a product equivalent to a lamp input power of 22 W and as 450 W/m^2 , or half of the former, for 12 W equivalence. An emissivity of 0.04 was assumed for the aluminum reflective film of the outer envelope, and an emissivity of 0.89 was assumed for the soda lime glass in the case of no reflective film¹³⁾. Thicknesses of screw base, case, outer envelope, and wall for blocking

were assumed as 0.5 mm, 1 mm, 1 mm, and 1 mm, respectively. Circuit parts were assumed to be of thermal insulating material, and the overall heat transfer coefficient by natural convection from the screw base, case, and envelope to the outside was set at $5 \text{ W}/(\text{m}^2 \cdot \text{K})$.

The calculation results are shown in Table 6, in which the temperature is shown at three positions or, as shown in Fig. 10, the center of the divider, the circuit part a on the lower surface of the board, and the circuit part b on the upper surface of the board. By the way, measurement increment is 0.5°C . The following was clarified: (a) through comparison of Conditions (1) and (2), it was found that an increase in temperature of the parts is caused by the formation of the reflective film on the outer envelope; (b) although we obtained a result that heat reduction effect in the case of Condition (5), a reduced heat release value, was apparently large, we noted that, when Conditions (2) and (3) were compared, there was another heat reduction effect in the case of an enlarged envelope side wall angle and a resulting enlarged surface area, (c) in view of the data for Condition (4), when convection between the divider and the board is blocked, the temperature of the circuit parts is reduced but the temperature of the divider is increased, and, although there is a blocking effect, the total effect seems to depend upon the design. Fig. 11 and Fig. 12 show examples of calculations under condition (3). The results show that convection is developed in a space between the light tube and the outer envelope as well as in a space between the divider and the board, as described above.

3.3 Example of three-dimensional thermal flow analysis using FLUENT®

Although it is possible to investigate the qualitative changes in lamp temperature by the two-dimensional model per the previous Section 3.2, there were the flaws that the heat release of the circuit was neglected and that the inside space of a U-type light tube is assumed as homogeneous because it is closed except bottom surface. Hence, we developed a three-dimensional model of a 22W reflector-type SBCFL and added the heat release values of each part of the electronic circuit as obtained by experiments in the setup conditions. Fig. 13 shows the shape of the model. Circuit parts a, b, c, d, and e are an electric-field-effect transistor (MOS-FET, regarded two pieces as one package), a wire-wound ballast, an aluminum electrolytic capacitor for ripple filtering, a rectifier (REC), and a resonant capacitor respectively, and parts a and d are surface-mount parts on the back of the board. Their heat release values are 0.18 W, 0.41 W, 0.14 W, 0.32 W, and 0.44 W respectively, which were obtained by electrical or thermal measuring. These five values add up to around 1.5 W, which can represent

Figure 13 3D-analysis model

Figure 14 Result of 3D-analysis for example

around 70% of the 2.2 W of the circuit loss. Six parts of five categories built into this model are the main heat releasing parts in the half-bridge circuit¹⁴⁾. If all the parts are taken into consideration, the modeling will be complicated and the calculation time will be enormous. Also, if the whole circuit loss of 2.2 W is allocated to parts a through e, the heat release values per surface area of each part is assumed to increase resulting in a local elevation of temperature. Therefore, the circuit loss was put as around 1.5 W for the main parts alone for this study. Regarding the electric power to be consumed as the heat of the light tube, it is necessary to add around 3 W due to a reason as explained in paragraph 3.1 on top of the 15.5 W as shown in Fig. 5, and thus it was put as 18 W in this study. The heat transfer coefficient due to natural convection was set at $5 \text{ W}/(\text{m}^2 \cdot \text{K})$, similar to the previous section, and it was assumed that a reflective film was formed on the inside surface of

the conic portion of the outer envelope.

The temperature distribution is shown in the left side of Fig. 14, and the status of the convection is shown in the right side. In the three-dimensional model, as compared to the two-dimensional model, it was shown that convection is developed in the interstices of the light tubes and that there are thermal gradients in the top and bottom and the inside and outside in the envelope and heat transfer by natural convection is actively made. On the other hand, regarding the electronic circuit section above the board, although there is an up-draft of high temperature air between part c and part e, it was shown that, in general, the temperature is reduced flatly toward the upper side and a comparatively low temperature portion is formed in the vicinity of the inside of the screw base. However, there was a trend noted that the absolute values of the calculated temperatures are higher than the measured levels in the high temperature section and they are lower than the measured levels in low temperature section. In order to increase the precision of the calculation in the future, it is necessary to re-examine the boundary conditions, since, although the calculation with this model assumed a constant heat transfer coefficient irrespective of location, the heat transfer coefficient is assessed to be lower toward the upper side of the lamp taking into consideration the fact that the air outside the lamp causes natural convection.

4. Summary

In regard to the SBCFL with an outer envelope, the status of the heat transfer was studied applying two methods, heat-transfer network analysis and analysis using FLUENT® thermo-fluid software. As a result of the heat-transfer network analysis, we have obtained the calculation result that the heat flow rate from the light tube to the circuit in 22 W lamp is around 1.2 W, which was unexpectedly small. However, it was found that designing a reflector-type SBCFL with a power consumption of 22 W will increase the thermal loading for the lighting circuit parts and the divider made of resin, since the sum of the heat of the visible light and the heat radiated from the surface of the light tube is estimated at around 12.2 W and around 3 W, or around 25% of the 12.2 W is assessed to be the source of heat generation in the lamp system. Based upon the analysis results with the two-dimensional model using FLUENT®, it was clarified that (1) convection developed between the outer envelope and the light tube as well as between the divider and the circuit board, and (2) enlargement of the surface area of the outer envelope by enlargement of its opening angle or reduction in the consumed power of the lamp itself contribute to a temperature reduction in the parts. Also, in the calculation

with the three-dimensional model, it was shown that convection is developed in the interstices of the light tubes and that a low temperature space is formed in the vicinity of the inside of the screw base. These analysis results were applied for our development of an SBCFL with reflector-type envelope with a rated power of 12 W. Topics for future study are to confirm the heat flow rate as assessed in this study by actual measuring using heat flux sensors and so on and to reexamine the setting of the boundary conditions for thermo-fluid analysis.

References

- (1) T. Yasuda, K. Nishio, Y. Shibahara and S. Hakuta: The Self-Ballasted Compact Fluorescent Lamp of an A60 Bulb Shape, *J. Light & Vis. Env.*, 24-2, pp.1-7(2000).
- (2) Shibahara, Nishio and Shiota: Study on Down Sizing of Self-ballasted Compact Fluorescent Lamp for High Lumen Output, *Proc. 2000 Annual Conf. IEI Jpn.*, No.9 (2000)(in Japanese).
- (3) Edition by IEI-J: Lighting Handbook 2nd Edition, OHM Sha, p.110(2003)(in Japanese).
- (4) Honda, Yuge, Itoh, Ishizuka and Sasaki: Thermal Simulation of Compact Self-ballasted Fluorescent Lamp, *J. Illum. Engng. Jpn.*, 73-2, pp.46-51(1989)(in Japanese).
- (5) A.W. Serres: Reducing the Length of an Integrated Compact Fluorescent Lamp, *J. Illum. Engng. Soc.*, 23-2, pp. 26-30(1994).
- (6) Matsumoto and Yasuda: NETSUKAIRO KAISEKI-WO MOTII-TA DENKYUGATA KEIKO Lamp-NO NETU-KAISEKI (Study on Heat Release of Self-Ballasted Compact Fluorescent Lamp Using Heat-Transfer Network Analysis), *Proc. the 27th Tokyo Branch Meet. IEI Jpn.*, No.12 (2001)(in Japanese).
- (7) Takahara, Ikeda and Yasuda: Development of Self-ballasted compact fluorescent lamp with reflector globe, *Proc. 2002 Annual Conf. of IEI Jpn.*, No.5(2002)(in Japanese).
- (8) Toda, Yasuda and Takahara: RYUTAI KAISEKI Soft-wo MOCHIITA DENKYUGATA KEIKO Lamp-NO NETSUKAISEKI (Heat Analysis of Self-Ballasted Compact Fluorescent Lamp Using Software for Fluid Analysis), *Proc. the 28th Tokyo Branch Meet. IEI Jpn.*, No.4(2002)(in Japanese).
- (9) T. Yasuda, T. Tanaka, K. Nishio and M. Izumi: Technical Issues on the Electronic Compact Fluorescent Lamp Covered with a Diffusive Globe, *J. Light & Vis. Env.*, 23-2, pp.10-15(1999).
- (10) Ishizuka: DENSHIKIKI-NO NETSUSEKKEI-TO NETSUKAIROMOUHOU-NO OUYOU (Thermal Design of Electronic Appliances and Application of

- Heat-Transfer Network Method), DENSHI GI-JUTSU (Electronic Engng). 2002-No.11, pp.12-15(2002)(in Japanese).
- (11) Kunimine: Electronics-NO TAMENO NETSUSEK-KEI KANZEN NYUUMON (Complete Introduction to Heat Design for Electronics), Nikkan Kogyo Shinbun-sha, p.36(1997)(in Japanese).
- (12) Toshiba Lighting & Technology Corp.: Lamp General Catalogue(2003)(in Japanese).
- (13) J.P. Holman (Author), K. Hirata (Translation Supervisor): DENNETSU KOUGAKU (Heat Transfer), Maruzen, p. 268 (1982)(in Japanese).
- (14) Japan Electric Lamp Manufacturers Association: NIHON DENKYU KOUGYO-SHI DAI 4 TSUIHOBAN (History of Electric Lamp Manufacturing in Japan, Supplement No.4), p.55(2003)(in Japanese).