An Analytical Study on Lumen Maintenance of the High Pressure Mercury Lamps

K. Shimogaki and B. Kermanshahi

***Abstract*—High-pressure mercury (HPM) lamps use a phosphor on their outer envelope for the sake of improvement of efficacy and color rendition. Although this is basically a rare earth phosphor, if its composition is changed in part, the lumen maintenance ratio of the lamp is improved by about 5% for 8000 hours of lighting. Factors in the lumen maintenance ratio are not the phosphor alone, but the influence of variation in amount on lamp characteristics have not been reported so far. In the current study, we attempted to determine the influence of these phosphors on various characteristics of a standard 400W lamp. With regard to lumen maintenance ratio of a lamp designed for about twice the life, the phosphor involved is identified as one of the components, and the optimum amount of change is verified from the practical application viewpoint. Results obtained indicate that an improvement of as much as about 20% is feasible. This provides a new finding useful for energy saving and reliability improvement.**

***Index Terms*—HPM lamps, phosphors, lumen maintenance, colored body, manageable lamp.**

I. Introduction

THE HPM lamp produces lines of energy in ultraviolet .blue, green and yellow from the mercury arc tube(inner bulb). Because of a lack of radiation in the red portion of the color spectrum, the HPM lamp emits a greenish-blue light. The red deficiency and color rendition are much improved by coating the in-side of the outer envelope with a red-emitting phosphor excited by the ultraviolet energy generated by the mercury arc tube.

Although a variety of phosphors have been developed for HPM lamps, only a few are in practical use, due to the high temperature of the lamp. Among them, manganese-activated magnesium fluorogermanate is a typical one which substantially absorbs visible spectrum since it is a colored body. Its disadvantage is that total luminous flux is reduced by about 15% in comparison to a clear envelope even if red radiation is added by ultraviolet energy. Europium-activated yttrium ortho-vanadate (YVO_4: Eu^{3+}), developed by the color television industry, is a phosphor which has been used continually up to the present. Although it emits red radiation similarly, it has no colored body, so it transmits the visible spectrum, and total luminous flux is eventually increased by about 10%. One report [1] discloses that, if YVO_4: Eu^{3+} is improved to $Y(V, P)O_4$: Eu^{3+} , the lumen maintenance ratio is improved from 80% to 85% with a 400W lamp for 8000 hours of lighting.

Manuscript received July 30, 2007; revised August 19, 2008.

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Publisher Item Identifier S 1682-0053(09)1636

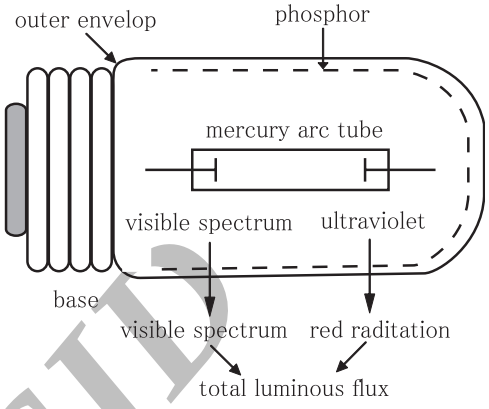

Fig. 1 Sketch of in HPM lamp.

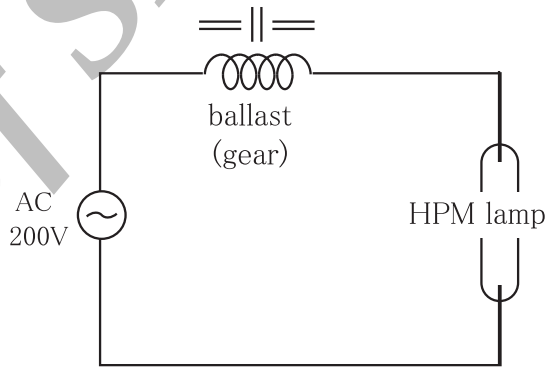

Fig. 2 Operating circuit.

However, the total luminous flux of the HPM lamp consists of the visible spectrum emitted outside through the phosphor plus red radiation by the phosphor, and hence discussion of the lumen maintenance ratio [2] should be analyzed from both viewpoints. Another report [3] states that V is replaced in part with P for improvement of the phosphor, while V/P=1 is the best proportion. However, the influence of the replacement rate on optical characteristics of the phosphor and lamp is not known, nor is the influence on lumen maintenance ratio reported.

In this study, we attempted to identify these areas and to confirm the roles of the phosphor related to the lumen maintenance ratio through long-life testing.

The authors have examined the results of the experiments [4] and wish to present them as data on production techniques for the HPM lamp. We include a sketch of the HPM lamp (Fig. 1).

On the lamp, important components are the mercury arc tube made of quartz and the outer envelope made of clear glass. The outer envelope is useful for protecting the mercury arc tube and phosphor coating.

The HPM lamp operates with ballast (Fig. 2). The ballast limits the electric current through the operating circuit, shown in Fig. 2.

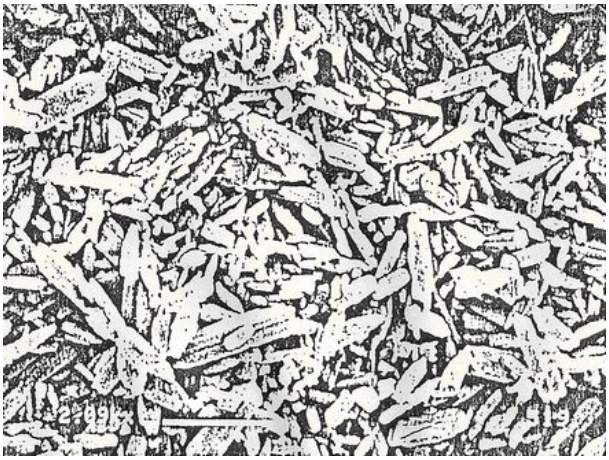

Fig. 3. Phosphor photo P=0.3 (1.2 μ).

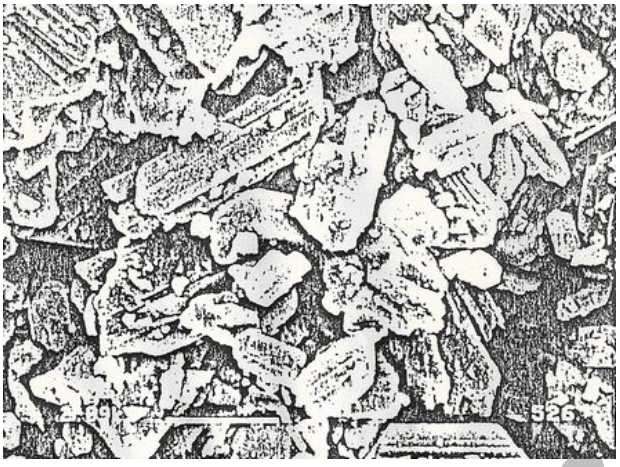

Fig. 4. Phosphor photo P=1.0 (3.9 μ).

II. Characteristics of Phosphors and Their Manufacture

A. Manufacturing of Phosphors (Dry Type)

The original materials used Y_2O_3, Eu_2O_3, NH_4VO_3, $(NH_4)_2HPO_3$. The flux is H_3BO_3. The molar ratio of Eu to Y is 5% (on activator). Therefore, (Y_{1-x} Eux) is ($Y_{0.95}$ $Eu_{0.05}$).

On YVO_4, V is replaced with P in part or as a whole in Eu^{3+}. It is expressed as $Y(V_{1-X}$ Px)O_4: Eu^{3+}, where the x-value represents the conversion rate to P, and in total 11 types are prepared, P = 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 (P-value is used hereafter for the designation of types of phosphors).

B. Images of Phosphors (SEM)

Magnification is ×2000, those in ( ) are average particle size, and there is a tendency toward the greater the P-value, the greater the particle size.

C. Emission Spectrum (Room Temperature, Excitation Spectrum: 365 nm)

Effective red radiations are 619 nm and 615 nm. When the P-value becomes larger, the ratio of strength, 615 nm to 619 nm, becomes smaller (Fig. 5) [4]. However, when the P-value becomes larger, the effective red radiation gets smaller and the emission of shorter wave lengths (around 590 nm) becomes larger (Figs. 6, 7).

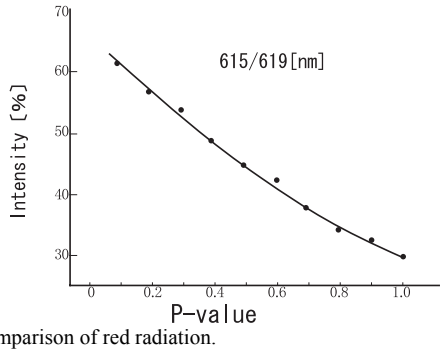

Fig. 5. Comparison of red radiation.

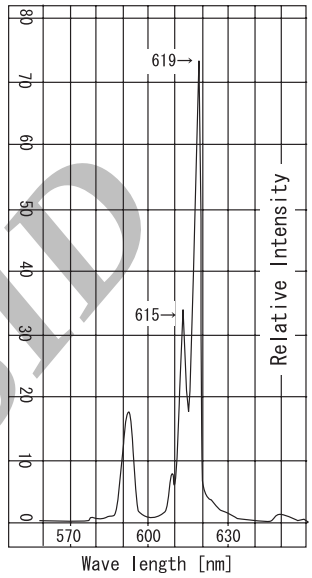

Fig. 6. Red radiation P=0.5.

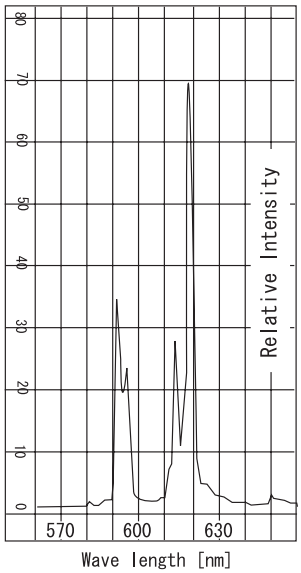

Fig. 7. Red radiation P=0.8.

III. Characteristics of Lamps and Their Manufacture

A. Manufacturing of Lamp (Lamp Power: 400 W)

The wet method is used for coating phosphors on the inside of the outer envelope and three lamps each are prepared using a total of 11 types of phosphors. (From $P = 0$ to $P = 1$).

Uniform mercury arc tubes each having a luminous flux of 21,000 lm [4] and lamp voltage of 130 V are prepared.

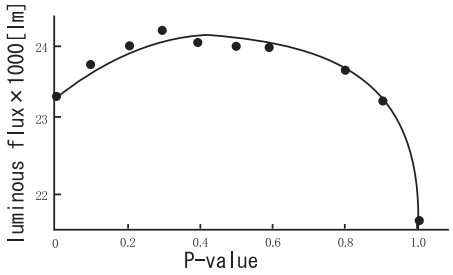

Fig. 8. Total luminous flux.

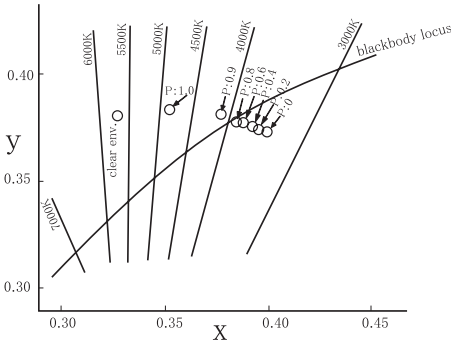

Fig. 9. Variation in correlated color temperature.

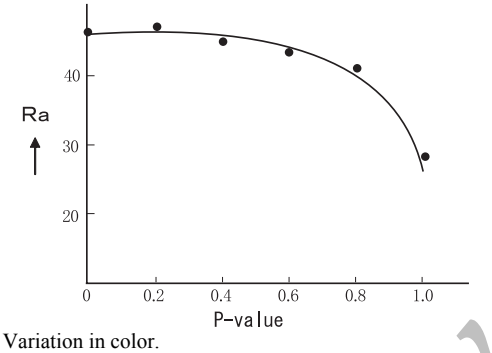

Fig. 10. Variation in color.

B. Initial Characteristics of Lamps (Aging: 1 Hour)

(1) Total lumen flux of the lamps become maximum around $P = 0.4$ (Fig. 8).

(2) Correlated color temperature of the lamp becomes gradually higher from $P = 0$ to $P = 0.8$. When it reaches $P = 1.0$, it is close to that of the lamp using a clear envelope (Fig. 9).

(3) Color rendition is expressed by a general color rendering index (Ra) which is gradually lowered from $P = 0$. When the value of P reaches to about 1.0, general utilization is not possible (Fig. 10).

IV. Analysis of Lumen Maintenance Ratio

The term " lumen maintenance ratio" is normally used. Here, it is expressed as lumen decrease ratio due to data arrangement [4].

A. Analysis System

(1) L_1 is the lumen flux value of the visible spectrum emitted by the mercury arc tube. A clear envelope is mounted for measurement.

(2) L_2 is the total luminous flux of the lamp with phosphor coated outer envelope. Visible spectrum of (1) passes through the phosphor layer and appears outside the lamp. Ultraviolet light emitted from the mercury arc tube is converted to red radiation in the phosphor layer and appears outside the lamp. The total of these two types of light is measured as the total luminous flux.

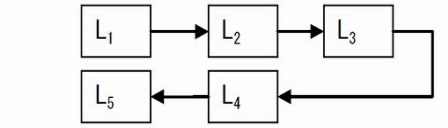

Fig. 11. Diagram of measurement.

TABLE I
LUMINOUS FLUX X100 LM

	L_1	L_2	L_3	L_4	L_5
$P = 0$	210	234	159	190	208
$P = 0.2$	210	239	198	188	214
$P = 0.4$	210	239	204	189	214
$P = 0.6$	210	238	206	191	218
$P = 0.8$	210	237	203	190	214
$P = 1.0$	210	216	189	191	194

TABLE II
LUMEN DECREASE RATIO (%)

	Dt	*Dc*	*Df*
$P = 0$	32.1	9.5	23.9
$P = 0.2$	17.2	10.5	7.5
$P = 0.4$	14.6	10.0	4.7
$P = 0.6$	13.6	9.1	5.5
$P = 0.8$	14.2	9.5	5.2
$P = 1.0$	12.5	9.1	2.6

(3) L_3 is the total lumen flux value after completion of life test (about 16,000 hours) of the lamp in (2). $L_3 / L_2 \times 100\%$ normally represents the lumen maintenance ratio. However, both the mercury arc tube and the phosphor exhibit reduction in their performances, and therefore, assessment by lumen maintenance ratio alone are insufficient.

(4) L_4 is the luminous flux value when the outer envelope of the lamp that completed its life test is replaced with a clear envelope, and from this, changes in the visible spectrum of the mercury arc tube can be determined

(5) L_5 is the total luminous flux value when the outer envelope of the lamp in (4) is replaced with a new phosphor coated outer envelope.

(6) Fig. 11 shows the order of measurements from L_1 to L_5.

(7) *Dt*, *Dc*, and *Df* are the calculated lumen decrease ratios from values L_1 through L_5 by the following method.

$$Dt: \frac{L_2 - L_3}{L_2} \times 100\% \text{ (total lumen)}$$

$$Dc: \frac{L_1 - L_4}{L_1} \times 100\% \text{ (by arc tube)}$$

$$Df: \frac{L_5 - L_3}{L_5} \times 100\% \text{ (by phosphor)}$$

B. Results

Table I shows measurement values of L_1 through L_5 for six types of lamps $P = 0$, $P = 0.2$, $P = 0.4$, $P = 0.6$, $P = 0.8$, $P = 1.0$. Table II shows each lumen decrease ratio.

V. CONCLUSIONS

(1) The lumen decrease ratio of the visible spectrum emitted from the mercury arc tube is about 9.1 to 10.5% and there is no significant difference.
(2) The lumen decrease ratio of the phosphor is within a range of about 5 % to 24 % and there is a significant difference. Compared to $P = 0$, about 20 % improvement has been attained with $P = 0.4$ to 0.8.
(3) The phosphors of $P = 0$ are colored after the life test, and this resulted in lower transmittance of the visible spectrum from the mercury arc tube.
(4) If the initial characteristics of the lamp are taken into consideration, from $P = 0.4$ to 0.6 is considered appropriate.
(5) If P-level is selected appropriately, it is possible to maintain a total luminous flux of about 20,500 lm with a 400 W lamp even for extended lighting.
(6) As for the initial luminous flux (after 100 hours of aging) of a 400 W lamp, about 22,000 lm [5], [6] has been reported. The fact that 20,500 lm can be secured even after extended lighting means that a high quality lamp having a lumen maintenance ratio of more than 90% is obtained. Although efficacy is slightly low, this is a manageable lamp.

VI. POSTSCRIPT

A high-pressure mercury lamp, together with high-pressure sodium lamp and metal halide lamp belong to high-intensity discharge lamps, are the lamps which are mainly used for wide-area illumination. However, these lamps have not achieved demercurization yet. At present, as for practical discharge lamps including a fluorescent lamp, studies on mercury reduction techniques are being conducted. In addition, efforts for protecting environment through collecting the used lamps and other methods are being made.

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