Research Note

Study of the Halogen Volume on the Tungsten Halogen Lamps

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ABSTRACT

Halide is sealed up inside a tungsten halogen lamp. The action of the halogen allows the lamp to maintain its initial luminous flux without being blackened until the end of its service life. The quantity of halogen, if insufficient, blackens the lamp and shortens its life. If excessive, however, the halogen may affect the lamp's efficacy and service life. Although an appropriate value of quantity is consequently required, this can only be calculated by means of a great number of trial production and life tests, due to the theoretical complexity and associated factors. These tests are time consuming and expensive. The aid value is therefore often determined on the excessive side to simplify experiments, thereby avoiding any risk of blackening. We used theoretical calculation for some success to determine an optimum value. We therefore aim to improve the production technology by applying our theoretical calculations to trial production and life tests.

KEYWORDS: tungsten halogen lamp, evaporation of tungsten, theoretical calculation, proper halogen volume, chemical reaction in tungsten halogen lamps, blacking on tungsten halogen lamps

1. Introduction

Tungsten-halogen lamp was developed by Edward G. Zubler (USA) in 1959. It has a small size, longer life and high efficacy in compared to an incandescent lamp. Also, with improvement of its quality, it is widely being used for various purposes because of its convenience. A bulb of this lamp is usually made from quartz glass, and is pressurized with a high pressure of halide and an inert gas, and it can be used with almost same light speed compared to initial one until its disconnection life without blackening due to "halogen recycle" which means the halogens carry the evaporated tungsten back to the filament instead of allowing it to deposit on the bulb wall.

In case of lack of the halogens, the bulb becomes blacken and then it leads to the end of its life. If excessive, however, there is some possibility to occur "cycle abnormality" which has been empirically reported affects efficacy and its life of bulb. Basic researches about halide movement in lamp[1~4] are considerably being carried out, but there are no reports about production technology that can be used immediately. Therefore, a relatively controversial problem is that "how much amount of halide gas is most suitable for each lamp." Because of this problem is very complicated with many theories and different conditions. Thus, experimental methods are used to solve this problem on this paper. (for example, trial manufacture and life test) However, such means that it takes a lot of time and cost, so generally relatively excess amount of gas is being used, avoiding any risk of blackening. Thus, we tried to find out the appropriate amount of halogen gas while comparing theoretical calculation with the results from experiments which calculated amount of evaporated tungsten under high pressure of an inert gas and then we successfully obtained the appropriate amount of halogen gas from the results.

In our research, the case of the pressurized halogen gas in excess is not discussed. However, we will be able to improve production technology in a different way about these problems which mentioned above by combining experimental methods which is already devised and theoretical methods. And then we hope our all efforts for achievements of high efficiency and long life to be a breakthrough for low cost of halogen lamp.

Note:We used to adopt Torr instead of Pa because of comparing to data of References

2. Summary of Research System

(1) Tungsten, material of a filament, is evaporated and diffused during lamp operation, even through halogen lamp is filled with high pressure of an inert gas. Thus, many data can be obtained from calculated amount of evaporated tungsten.

(2) Small amount of halide in an inert gas is decomposed, and it turns into compounds with halogen and compounds with no halogen. In our research, what we are forcing are halogen molecules coming from the former (compounds with halogen).

(3) A reaction between tungsten which is evaporated and halogen molecules is simplified to find an equivalent relation under some conditions and assumptions.
(4) Concentrations of theoretically required amount of halide in an inert gas were calculated from an equivalent relation.
(5) Trial manufacture and life test were carried out by using many lamps with different concentrations which is theoretically calculated respectively.
(6) Evaluation of theoretically calculated concentrations was carried out from the results of life test while considering next step of this research.

3. About Tungsten-Halogen Lamp

Tungsten-halogen lamp is not only various in types, but also various in lighting voltage, electric power, service life, efficacy and color temperature. In our research, relatively standard type which can be used shop was selected. The characteristics of lamp were shown in Table 1.

Table 1 Characteristics of lamp
Pressure of an inert gas (when operating)
$PV = nRT$ where V is 1.31 cm^3、T is 700 K (at turn on the light)
Gas pressure when pressurized 2100 Torr (20°C)
$R = 62.4 \times 10^3$ (Torr・cm^3/K・mol)
$n = 0.1616^{-3}$ (mol) P = about 5390 (Torr)

Item	Contents
Appearance	One-side pinching seal Infrared ray reflection film courting on lamp surface.
Property	Rated voltage: 110 V power: 85 W Efficacy: 19 lm/w, Life: 2000 h Filament color temperature: 2850 K (measured value)
Material and gauge	Quartz for standard lamps Inner diameter: 8.05 mm, thickness: 1.0 mm Inner volume of lamp: 1.31 cm^3 (measured value)
Filament	Nonsagwire tungsten for halogen lamp Diameter : 6.2×10^{-3} cm, Length: 490 mm (duplex coil) Surface area 0.954 cm^2
Pressure of gas	Ar80%, $N_2$20% (prevention of discharge) Pressured pressure: 2100 Torr (when exhausted, 20°C) Pressure of an inert gas: 5390 Torr (when operating)
Concentration of pressured halogen	0.07% CH_3 Br is diffused in an inert gas uniformly
Gas temperature in lamp	Temperature of gas (when operating with rated voltage) : 427°C (700 K) (Average temperature at upper area of collet under lighting-up condition)

4. Evaporation of Tungsten from Filament

4.1 Evaporation of tungsten in gas

It is well known about that the evaporation of tungsten is more effectively suppressed in an inert gas than in vacuum. Mechanism of evaporation in an inert gas is considered more complicated than in vacuum, but basically most important point is the way tungsten diffuses in an inert gas. It is necessary to use diffusion factor to deal with the mechanism of evaporation quantitatively. Thus it has been considered as an important subject[5),6)]. With an arrangement of diffusion factor, Matsuoka proposed an equation related to evaporation in lamp[7)].

Total amount of evaporation $$m = -\frac{2}{a \ln \frac{b}{a}} \int_{\frac{a}{2}}^{\frac{b}{2}} D\,\mathrm{d}n_w \quad \cdots (1)$$

a : diameter of tungsten filament
b : diameter an inert gas layer around filament (Langmuir Sheath)
D : diffusion factor of tungsten in an inert gas
n_w : molecular density of tungsten which related with vapor pressure of tungsten on a filament

4.2 Calculation on the evaporation amount of tungsten in gas

Some equation that various data can be substituted to calculate the amount of evaporated halogen is necessary. Matsuoka[7)] proposed two way equation which can calculate real value based on combined equation from Langmuir's equation[6)], Fonda's equation[5)] related to evaporation and Jeans, Langevin, Hirschfelder[8)]'s values related to diffusion. Even through many reports have been published on this study of field over a long period of time, we selected Eq.(2) which is one-way equation. Total evaporation amount of halogen, m can be calculated by one-way of calculating equation, and coefficient K_i does not related to temperature but gas diffusion.

$$m = 2.419 \times 10^{-2} \frac{K_i \sqrt{\frac{1}{Mw} + \frac{1}{Mg}}\, Pwa Ta^{\frac{1}{2}}}{a \log \frac{b}{a}\, p\sigma Wg^2} \left(1 - 0.01609 \times 10^{-3} Ta\right) \mathrm{g/cm^2\,sec} \quad \cdots\cdots (2)$$

Mw : molecular weight of tungsten
Mg : molecular weight of an inert gas (Ar)
K_i : coefficient (1.2)
Ta : temperature (K) of a filament

Temperature of tungsten filament (Ta) and color temperature (K)[18)]

Ta	1000	2500	2770*	3000
K	1006	2577	2850	3094

*: Value of calculation

P: pressure of an inert gas (Table 1)
Tb: temperature of gas (Table 1)
Pwa: vapor pressure of tungsten on a filament[7)]

$$\log Pwa = 7.602 - 40500/Ta + 0.51\log Ta$$

$\log\frac{b}{a}$: calculation method[7)]

$$\log b/a = 0.781\log B/a + 0.170$$

$$B = 2.341\times10^3 c_1/c_3 \times T_b^{\frac{1}{2}}/P(1+c_2/T_b)$$

$$c_1(\mathrm{Ar}) = 1.94\times10^{-6} \quad c_2(\mathrm{Ar}) = 130 \quad c_3(\mathrm{Ar}) = 0.17824\times10^{-2}$$

$\sigma Wg^2 = (\sigma_1 + \sigma_2/2)^2$: coefficient related to distance between tungsten and argon

molecular diameter (Å)[7)] Ar: 3.64, W: 2.78

Total evaporation amount of halogen, m can be calculated by substituting all values into Eq. (2).

$$m = 2.976\times10^{-10}\ \mathrm{g/cm^2\,sec} \quad \cdots\cdots (3)$$

Where the amount of an inert gas is argon gas 100%. However, this equation is available for the case of an incandescent lamp (low inside pressure), and the existence of halogen which has strong chemical attraction with tungsten and the case of halogen lamp (higher pressure) were not considered.

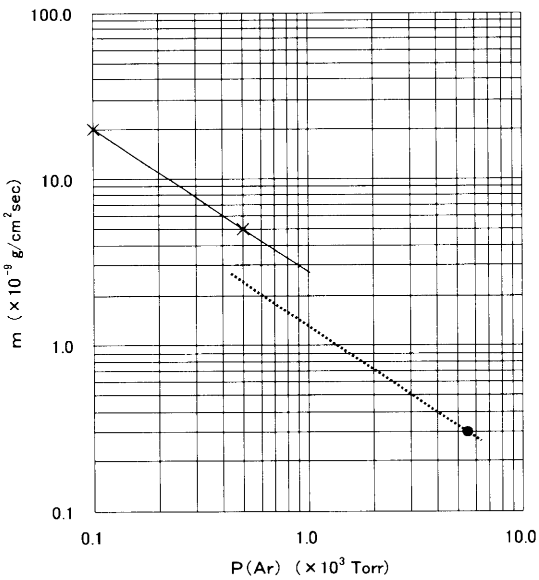

Figure 1 Evaporation of tungsten in argon gas
● : value of calculation.
- - - - : extended line.
$a = 6.2\times10^{-3}$ cm
$Ta = 2770$ K $Tb = 700$ K $K_i = 1.2$
× : value of calculation by Matsuoka[7)] (appropriate value by Fonda[5)])
$a = 9.78\times10^{-3}$ cm $Ta = 2870$ K $Tb = 360$ K $Ki = 1.2$

5. The Amount of Halogen Which Reacts with Tungsten

5.1 Decomposition of halide after turning off

The result of FT-IR showed[11),12)] the result of lamp heat causes decomposition of CH_3Br[10)] which leads to produce CH_4, C_2H_2 and HBr. Further, the result of GC showed existence of C_2H_2, H_2, Br_2[13)]. Therefore, these results support assumption that CH_3Br is thermally decomposed as follows (trace amount of H_2 and Br_2 is caused by decomposition of HBr).

$$CH_3Br \rightarrow HBr + (CH_4, C_2H_2, C_2H_4, \text{etc.}) \quad \cdots\cdots (4)$$

We also confirmed HBr as the same mole as CH_3Br by using FT-IR. Decomposition and interaction of some other molecules caused by decomposition of CH_3Br also can be considered, but the amount of HBr was used for calculation except other molecules due to its difficulty of quantitative calculation.

5.2 The amount of halogen sealed in trial manufacture lamp

The amount (μg) of halide can be calculated by using ideal gas state equation.

$$PV = nRT$$

P: pressure of pressurized inert gas (2100 Torr) at temperature 293 K
V: volume of lamp
n: mole number
R: constant
T: temperature of gas (when pressurized)

Constant R can be calculated by 1 mol of gas volume at standard state.

$$R = \frac{PV}{nT} = 62.4\times10^3\left(\mathrm{Torr\cdot cm^3/K\cdot mol}\right)$$

Pressurized amount of CH_3Br (μg) M is given by,

$$M = nm = 0.052 P\alpha V = 10.0\,\mu g$$

where m is molecular weight and α is concentration of CH_3Br.

Thus, amount of HBr (M') decomposed from CH_3Br is to be (5).

$$M' = 8.52\mu g \quad \cdots\cdots (5)$$

This value (4) is fitting well with calculated by an ion-electrode method.

5.3 Equilibrium on decomposition of HBr

Decomposition of HBr inside lamp is favorable at a high temperature rather that room temperature[14]. When the lamp operated, small amount of HBr is decomposed and reached equilibrium with H_2 and Br_2 near the gas temperature.

$$2HBr \Leftrightarrow H_2 + Br_2 - 24.5\,Kcal$$ [14]

At equilibrium, is HBr coexists with H_2, Br_2 inside lamp. Temperature has a large effect on equilibrium, and equilibrium coefficient K_p is to be as the followings.

(1) Calculation by experimental equation[14] $K_p = 3.63 \times 10^{-9}$

$$\log K_p = -5244 / T_b + 0.00043 T_b - 1.25$$

(2) Theoretical calculation (thermodynamics)[15] $K_p = 2.37 \times 10^{-9}$
Nernst equation

$$\log K_p = Q_p / 4.75 T_b + \sum n 1.75 \log T_b + \sum ni$$

Even through there is some difference between (1) and (2), we choose calculated value from Eq. (1).

5.4 Calculation of ratio of decomposing HBr

By using value of 5.3, decomposition ratio K_p is to be as the following.

$$K_p = \frac{[H_2][Br_2]}{[HBr]^2} = \frac{X^2}{4(1-X)^2} = 3.63 \times 10^{-9}$$

Dissociation ratio X is to be value (6)

$$X = 9.93 \times 10^{-5} \quad \cdots\cdots (6)$$

When operating temperature increase up to 700 K, real amount of Br_2 calculated from value (5) and (6).

Decomposition equation is to be assumed because there is HBr (4) in lamp.

$$8.52 \times 10^{-6} \times \frac{160}{162} \times 9.93 \times 10^{-5} = 8.36 \times 10^{-10}\,g \quad \cdots\cdots (7)$$

In addition, it is assumed that this Br_2 reacts with tungsten repeatedly.

6. Reaction between Tungsten and Halogen near the Bulb Wall

Even if there are much impurities and molecules produced by decomposition in lamp[16], we assumed one of reactions model in lamp as follows.

$$WBr_2 + Br_2 \Leftrightarrow WBr_4$$
$$\uparrow\downarrow$$
$$WBr + Br \Leftrightarrow WBr_2$$
$$\downarrow\uparrow$$
$$W + Br \Leftrightarrow WBr$$

It is based on the assumption that reactions can be formula (8) after simplifying and summarizing the left and right side to calculate.

$$W + 2Br_2 = WBr_4 \quad \cdots\cdots (8)$$

7. Evaluation of Sealed CH_3Br Concentration

Some fixed space near the bulb wall is assumed. It shall be assumed that tungsten gas evaporate from the filament in 1 sec, corresponds well with calculated halogen amount (7). Here, we assumed non-succession 1 sec cycle model which carries out "halogen recycle" which means tungsten from the filament is evaporated into the gas of the bulb and deposited on the bulb wall and then the halogen gas carries tungsten particles back to the filament and re-deposits them for 1 sec. The amount of tungsten related to reaction m' is given by value of Eq. (3), surface area and 1 sec.

$$m' = 2.976 \times 10^{-10}[g/cm^2 \cdot sec] \times 0.954[cm^2] \times 1[sec] = 2.84 \times 10^{-10}[g]$$

Where h is a halogen amount for reaction, and it becomes value (9) in the aspect of an equivalent.

$$h = 2.84 \times 10^{-10}[g] \times 320/184 = 4.94 \times 10^{-10}[g] \quad \cdots\cdots (9)$$

Value (7) is amount of Br_2 composed from halide sealed in trial manufacture lamp, while value (9) is calculated necessary amount. Thus, the amount of a trial manufacture lamp becomes 1.7 times more than calculated value.

8. Evaluation of Necessary Amounts of Halogen for Life Test

8.1 Trial manufacture

In our study we prepared 5 trial manufacture lamps of 0.07%, 0.15% CH_3Br and 0.04% CH_3Br, respectively.

Table 2 Result of life test

Item \ Pressured gas %	0.04	0.07	0.15
Life (h) Mean $n = 5$	1320	2650	2280
Range of life	880～1450	2420～2810	1980～2480
Luminous flux At 1080 h lm	$n = 4$ 980	$n = 5$ 1620	$n = 5$ 1560
Appearance (End of life)	About 50% of inside surface of bulb was covered with black spots	No prominent change	Some parts of bulb: Yellow The tip of filament: needle crystals

8.2 Life test and results

Table 2 shows the results of life test which is carried out under rated voltage, 6 h cycle (1 h turning off) and by using 15 lamps.

8.3 Evaluation of life test

In case of 0.04% showed blackening and 60% of life compared to normal case which may be caused by lack of halogen. Furthermore, the case of 0.15% (4 times more than calculated value) showed tendency to have relatively shorter life than the trial manufacture case of 0.07% (2 times more than calculated value) which is made for our study.

9. Discussion

About trial manufacture lamp, we suspect of the half amount of halogen amount considered as necessary amount to be necessary amount. Even if this result can be considered great difference, adsorption of halogen[17] and relationship with impurities also must be considered. In addition, these results will be changed depending on conditions like assumptions and values. Therefore, to get the scientific rationalization and more accurate results, these results not only require further examination but also investigation of calculation methods. Also, it should be established that possible system for an estimate of necessary halogen amount of lamp which differs from various conditions. These all efforts will suggest a way to develop new type lamp and find most appropriate halogen volume.

10. Conclusion

Since finding appropriate halogen volume for halogen lamp requires a lot of efforts and money, main objective of this study is to calculate appropriate halogen volume not by experimental method but by theoretical method. In particular, some attempts revealed that trial manufacture lamp had a possibility of practicality. Furthermore, universality and accuracy about various types of lamp and using conditions is worthwhile subject to investigate. Problems of adsorption and impurities on lamp also should be considered related to influence of excess halogen volume on its characteristics.

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