

# UV Lamp Temperature Characteristics

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## INTRODUCTION

The optical and electrical parameters of low-pressure (LP) ultraviolet (UV) lamps are closely related to the mercury vapor pressure in the lamp, which in turn are closely related to the temperature. Thus a temperature change will cause a substantial change in the UV lamp output.

Many LP UV lamps now employ the use of a mercury amalgam, with one or more other elements (e.g., indium), to control the mercury vapor pressure in the lamp. Different amalgams have different characteristics, and the variation of characteristics of some amalgam types is very large; for example, the temperature limits can change by a factor of 5–10, and the UV output can decrease to 50 percent of its normal level. So one should pay more attention to the characteristics of the lamp UV output, which will be a function of different operating temperature circumstances.

## THEORETICAL ANALYSIS

In a LP UV lamp, the mercury vapor pressure  $P_{\text{Hg}}$  is proportional to the mercury atom concentration. When the  $P_{\text{Hg}}$  increases, the probability of impact between the mercury atoms and the electrons increases, and the 253.7 nm UV radiation efficiency  $\eta_{\text{UV}}$  also increases. On the other hand, there is a negative effect on the UV output when the mercury atom concentration increases. That is, the 253.7 nm radiation that is emitted from a given atom can be absorbed by a nearby ground-state atom; this is called *resonance absorption*. When the mercury vapor pressure is low, resonance absorption obviously will not decrease the UV output; however, when the mercury vapor pressure is high enough, the effect of the resonance absorption cannot be neglected.

A 253.7 nm photon, which is emitted from an atom and radiated from the UV lamp will, on average, pass through 100 to 1000 absorption and re-emission pro-

cesses. Because of the very high frequency of these processes, an atom that absorbs a photon has no time to produce radiation and impact with the electrons and other atoms. The atom may be excited to a higher energy level and emit visible light. Or the energy of the atom can be decreased by impact, which causes a reduction of the 253.7 nm UV conversion efficiency.

There is an optimal mercury vapor pressure ( $P_{\text{opt}}$ ) in the LP UV lamp, at which the 253.7 nm UV conversion efficiency is the highest. When the actual mercury vapor pressure deviates from  $P_{\text{opt}}$ , the 253.7 nm UV conversion efficiency will decrease.

The mercury vapor pressure increases with increasing temperature (see Figs. 1 and 2). The  $\eta$  curve of Fig. 1 is characteristic of the UV relative output, which changes as a function of different liquid mercury temperature in the standard T4 ( $\phi = 12$  mm) and T2 ( $\phi = 8$  mm) UV lamps.

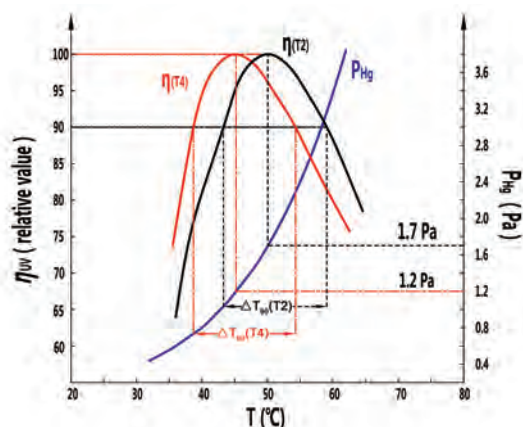


Figure 1. Characteristic curves of standard T4 and T2 UV lamps relative to the liquid mercury vapor pressure.

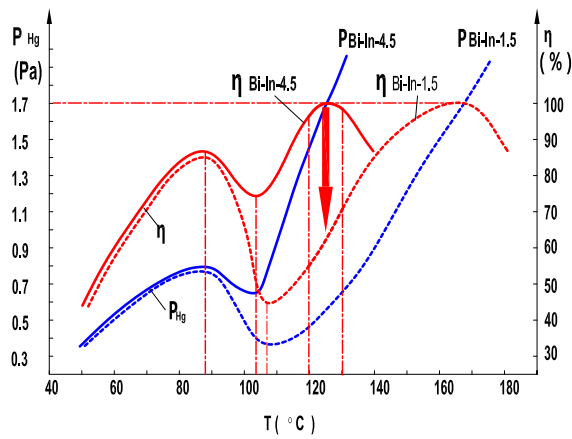


Figure 2. Characteristic curves for the standard T4 UV lamp with either a Bi-In-4.5 or a Bi-In-1.5 amalgam

In Fig. 2, when the Bi-In-Hg4.5% amalgam temperature is 105 °C, the mercury vapor pressure is at a minimum, and the relative UV output is only 78 percent. As the lamp burns, the mercury content of the amalgam Bi-In-Hg3.5 percent decreases from 3.5 percent to 1.5 percent because the mercury is lost (e.g., by reaction with the impurities from the lamp) in the process of lamp burning. At this time, the temperature of the Bi-In-Hg1.5 percent amalgam for minimum mercury

vapor pressure is 107 °C. Hence, the mercury vapor pressure will be lower, and the relative UV output drops to about 40 percent. So it is obvious that any change of the mercury vapor pressure will influence significantly the UV output.

## CHARACTERISTICS OF UV RELATIVE OUTPUT AS A FUNCTION OF WATER TEMPERATURE

1. The UV output (UV intensity) should maintain a high level and have small fluctuations over the actual operating temperature range. Figs. 3a-d show the relative UV output characteristics as a function of water temperature for several typical UV lamps. Fig. 3d shows a high UV output and small fluctuation over the operating water temperature range.

2. In water disinfection applications, one should ensure at any time that a good disinfection effect is obtained for various operating temperature circumstances. So one should pay more attention to the relative UV output characteristics as a function of water temperature at the beginning of the lamp lifetime. At the same time, the relative UV output characteristics as a function of water temperature near the end of the lamp life is also important. In order to get a good disinfection effect for

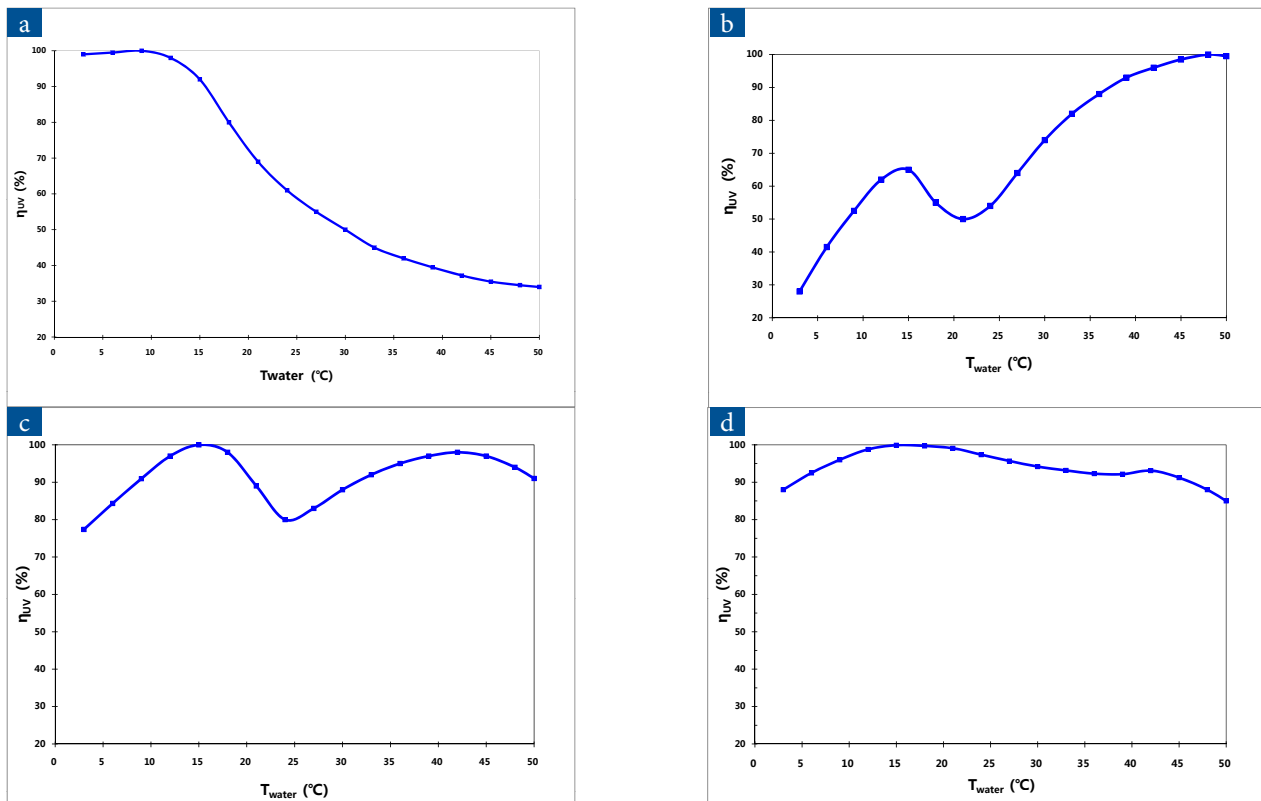


Figure 3. Characteristic curves of the UV lamp output versus temperature for several amalgams: (a) amalgam 1; (b) amalgam 2; (c) amalgam 3; (d) amalgam 4

the water disinfection equipment, one should use the minimum UV output value as a function of temperature to calculate the UV dose.

Figs. 4a-d show the relative UV output characteristics as a function of water temperature at the beginning of the lamp lifetime (0 h) and near the end of the lifetime (12,000 h) for a 320 W UV lamp from several typical UV lamp manufactures,

Some water disinfection equipment designers do not pay attention to the lamp characteristics when calculating the UV dose. Normally, they multiply the UV data by an aging factor to calculate UV dose, using data supplied by the lamp manufacturer. Generally, the UV output data is the maximum UV output value of the lamp.

In Fig. 4a, the maximum UV irradiance is 2,600  $\mu\text{W}/\text{cm}^2$ ; if one multiplies 2,600  $\mu\text{W}/\text{cm}^2$  by an aging factor of 0.80, one obtains the revised UV output value 2,080  $\mu\text{W}/\text{cm}^2$ ; this value is only slightly larger than the actual UV output minimum value of 2,040  $\mu\text{W}/\text{cm}^2$  (over the 5-40 operating temperature range). Table 1 summarizes similar calculations for the various lamps.

Table 1. Calculation of UV dose for various lamps  
UV Irradiance<sup>a</sup> /  $\mu\text{W cm}^{-2}$

Lamp in Fig.	UV Irradiance <sup>a</sup> / $\mu\text{W cm}^{-2}$			
	Max. over temp. range <sup>b</sup>	with aging factor 0.8	min. over temp. range <sup>b</sup>	Revised aging factor K over temp. range <sup>c</sup>
4a	2,600	2,080	2,040	0.850
4b	2,550	2,040	1,400	0.686
4c	2,580	2,064	1,340	0.632
4d	2,240	1,792	880	0.746

- Note:
- Measurement in the temperature-controlled special designed testing unit, tested with 320 W lamp and matched electronic ballast.
  - Temperature range is set from 5 to 40 °C in these applications
  - Revised aging factor  $k = E_{nmin} / E_{0min}$ . here,  $E_{nmin}$  is the minimum UV output of the UV lamp which was burned for 12,000 h over the temperature range,  $E_{0min}$  is the minimum UV output of the UV lamp which was burned for 100 h over the temperature range.

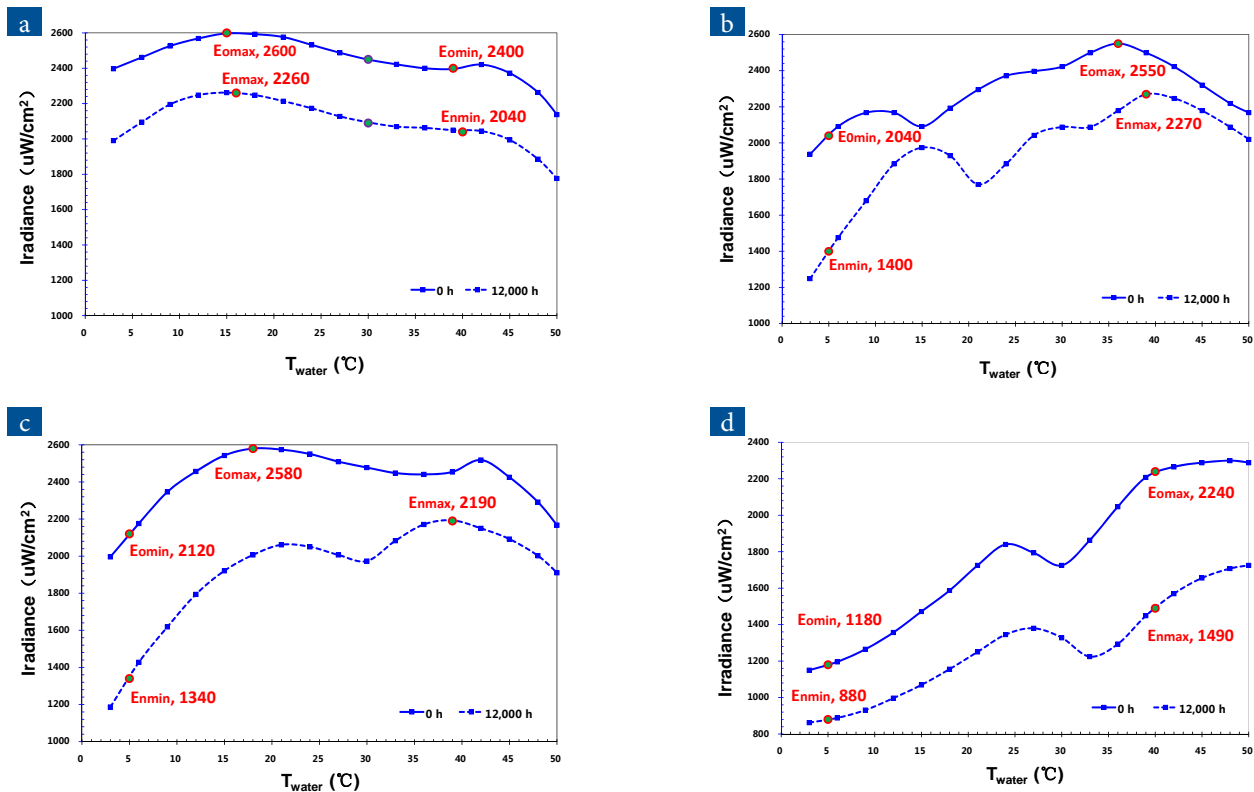


Figure 4. Characteristic curves versus water temperature for 320 W UV lamps from several manufacturers: (a) manufacturer A; (b) manufacturer B; (c) manufacturer C; (d) manufacturer D

Note that for Figs. 4b-4d, the UV output after the aging factor is applied is far larger than the minimum UV output over the temperature range.

According to the above data, if one multiplies the maximum value by the aging factor to revise the UV output value and use these data to calculate the UV dose, then one would obtain a far larger UV dose than the actual UV dose. If one designs the water disinfection equipment based on these data, the UV dose would not be sufficient to obtain a good disinfection effect over some period of lifetime and over the water temperature operating range.

Now the UV output value and aging factor value are supplied by the lamp manufacturer, but some values lack strict and specific data to support them. The lamp manufacturer should supply accurate UV output characteristics, which change as a function of water temperature at the beginning of the lamp lifetime and near the end of the lamp lifetime to support the calculation of UV dose and the design of water disinfection equipment. The equipment designers should select good quality low-pressure, high-intensity UV lamps (to cover different lamp operating temperature conditions) to make sure of a good disinfection effect and lowest cost of the equipment.

*REMINDER: UV EQUIPMENT DESIGNERS NEED TO PAY MORE ATTENTION TO THE UV LAMP OUTPUT CHARACTERISTICS AS A FUNCTION OF DIFFERENT OPERATING TEMPERATURE CIRCUMSTANCES.*

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