

Tungsten Filament Emissivity Behavior

The emissivity of tungsten wire filaments in incandescent lamps is widely known to change with wavelength. It is not so widely known that lamps initially exhibiting this behavior can change to greybody behavior during their lifetime. This complicates both predicting lamp behavior and measuring filament temperature.

Tungsten wire is arguably the key component of the incandescent lamp business. The emissivity of tungsten wire is therefore important in several ways. First of all, the higher the emissivity of the filament, the better the lamp performs: there is a direct correlation between emissivity and illumination. Second, the life of the filament depends strongly on the burning temperature. The emissivity is key in measuring the filament temperature, since pyrometry is the only practical non-destructive means to make this measurement. Unfortunately, the emissivity of tungsten is problematic, as can be seen in Figure 1.

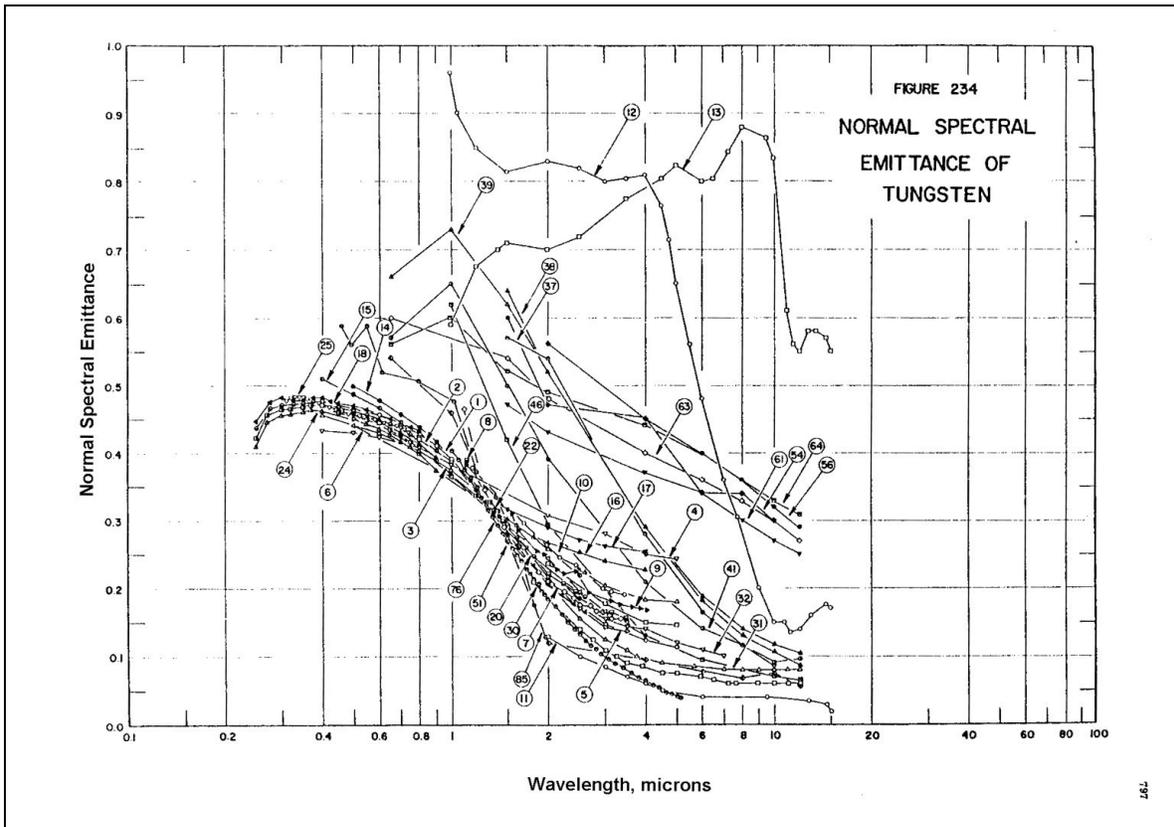


Figure 1. Emissivity of tungsten from *Thermophysical Properties of Matter, Vol. 7 – Thermal Radiative Properties*, IFI/Plenum, New York, 1970

Each numbered curve refers to a series of measurements that may vary from the others by any or all of the following parameters: sample, temperature, surface preparation, atmosphere, and purity. These measurements show that the emissivity of tungsten metal has quite a range. Additionally, it is seen to change with wavelength. The behavior for a particular sample would be difficult to predict from this graph. The problem grows

worse if temperature measurement is the issue, since the emissivity displays temperature dependence.

Temperature dependence of tungsten in the spectral region important to pyrometry is shown in Figure 2. These data are taken from the CRC Handbook of Chemistry and Physics, and are unattributed.

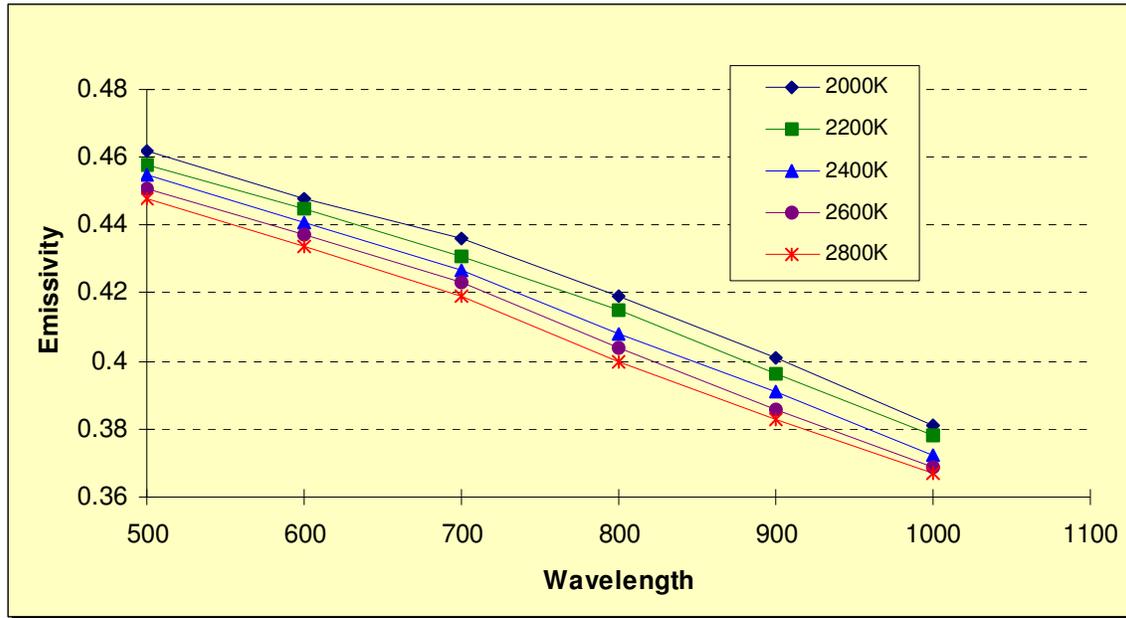


Figure 2. Data taken from CRC Handbook of Chemistry and Physics, 60th Ed., pp. E-381

The uncertainty in the emissivity of tungsten has already been established. Consider now the practice of the lamp industry of coiling, and sometimes re-coiling, the filament to enhance the illumination properties of the lamp by making the resultant assembly operate at a higher temperature than it otherwise would. Another positive effect is to make many small quasi-blackbody cavities so the lamp is more efficient; i.e., so that its emissivity is higher. This adds one more variable to those already ensuring the emissivity of the tungsten filament is impossible to predict.

Fortunately, while it may be impossible to predict the emissivity of a tungsten filament, it is in fact possible to measure it. More precisely, the FAR SpectroPyrometer, an expert-system multi-wavelength pyrometer, has routinely been successful in measuring the temperature of the filament regardless of the behavior of the emissivity. Once the temperature is known, the emissivity may be calculated as a function of wavelength from the temperature and the retained thermal spectrum. Figure 3 shows the result of such a calculation of emissivity taken from data collected on a new 100 Watt, 12 Volt coiled filament (C6) projection lamp that shall here be designated Type A. Color temperature of these lamps is specified to be 3350 Kelvins, and their lifetime 500 hours. The FAR emissivity result was normalized to the 2600 K CRC tungsten emissivity data of Figure 2 at 750 nm. This was done because the filament of the Type A lamp did not fill the instrument's field of view. (Failure to fill the field of view results in the

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SpectroPyrometer reporting a uniform fraction of the emissivity; it does not affect the measured temperature.) As can be seen, the agreement between the slopes of emissivity vs. wavelength is quite good; the emissivity decreases about 17% over the spectral range.

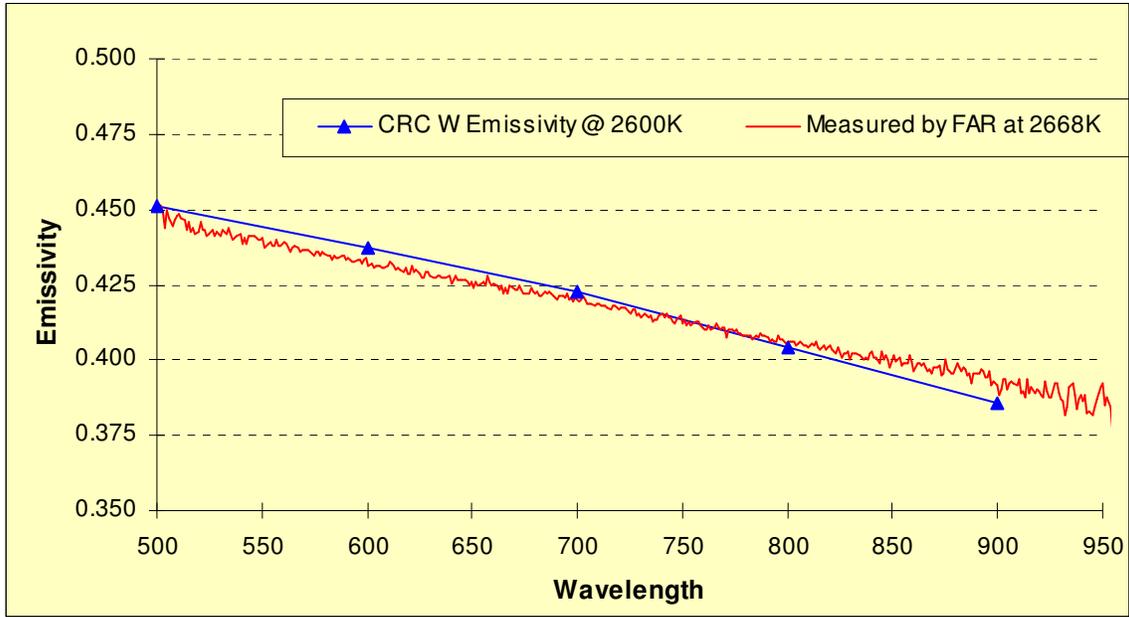


Figure 3. Emissivity as measured by a FAR SpectroPyrometer on a new Type A tungsten halogen projection lamp graphed on the same axes with one of the traces of Figure 2. FAR data normalized to CRC data at 750 nm.

However, this does not mean that the emissivity of a tungsten filament will always exhibit both this spectral dependence and agreement with published data. In fact, a Type A lamp was again measured with a FAR SpectroPyrometer after years of intermittent service. The emissivity was found to be uniform to better than 1.5% across the spectrum, exhibiting graybody behavior. These data are plotted in Figure 4.

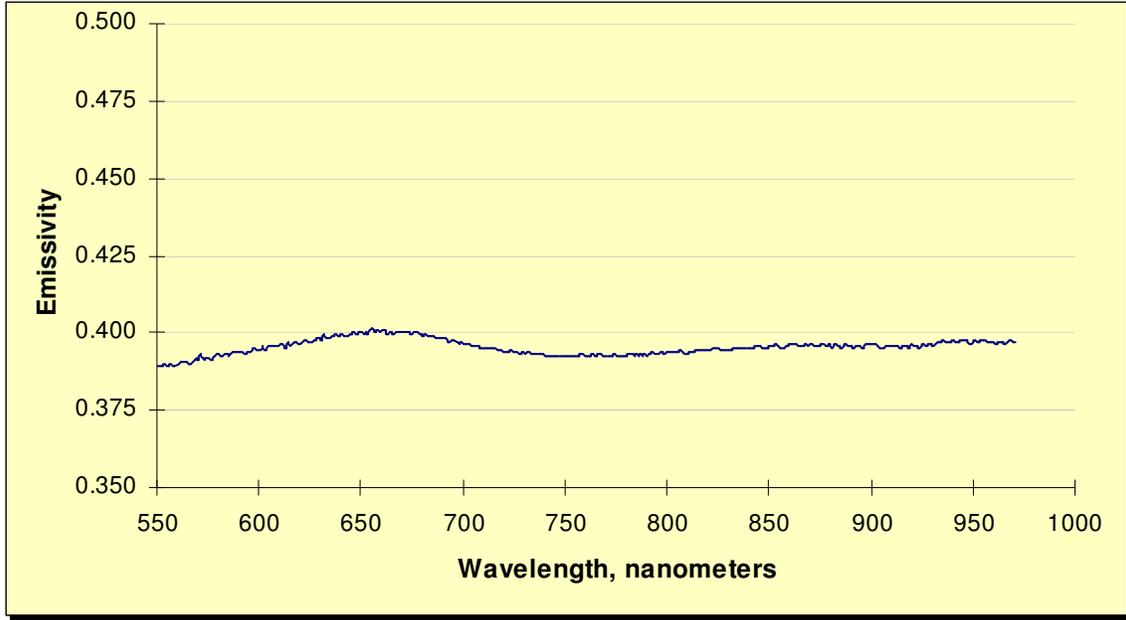


Figure 4. This Type A lamp had years of service; contrast this spectral emissivity plot with that of Figure 3.

Interestingly, the lamp characteristic curves of temperature as a function of current, Figure 5, remained quite similar, even though the emissivity was very different.

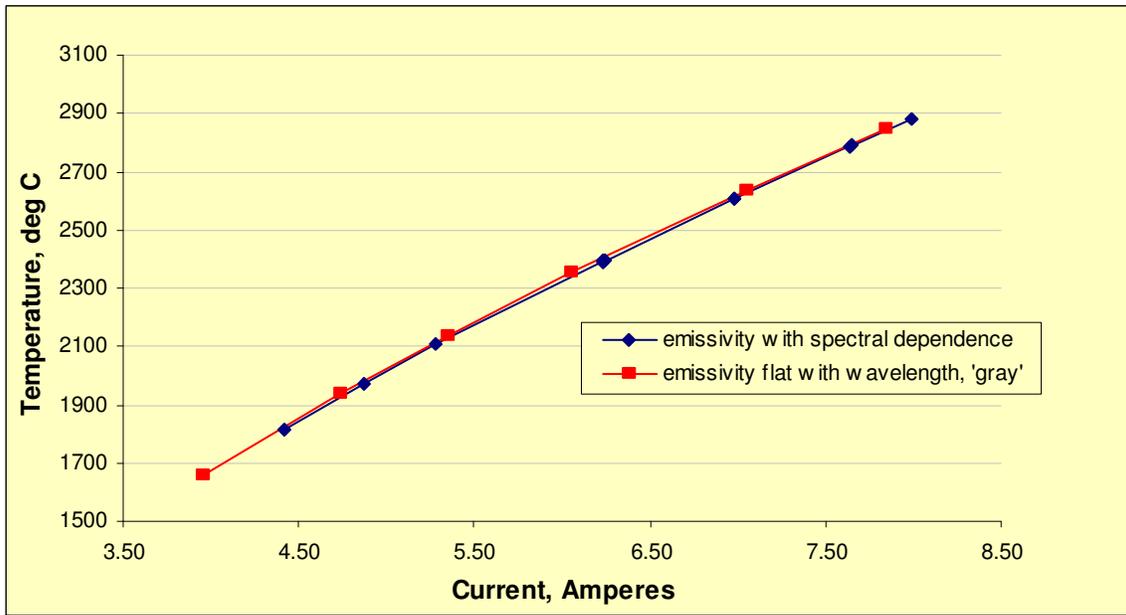


Figure 5. Temperature vs. current for Type A projection lamps. The one exhibiting spectral dependence was relatively new; the other lamp which exhibited greybody behavior had been in intermittent service for several years.

This can be explained by noting that the electrical characteristics are determined by the bulk of the material, specifically the cross-sectional area and length of the wire, while the emissivity is a surface phenomenon.

If we extrapolate the data of Figure 5 to the design current, 8.33 Amperes, we find the temperature is approximately 3250 Kelvins. The color temperature for this lamp, 3350 Kelvins, converts to an actual temperature of 3236 K. Clearly 3250 K determined above is in excellent agreement with the 3236 Kelvins specified.

There is no obvious visual difference between the new and used filaments that would give an indication of which emissivity behavior to expect. The filaments are shown below in Figure 6 and Figure 7.



Figure 6. New lamp of Type A. Grid is ¼ inch square.

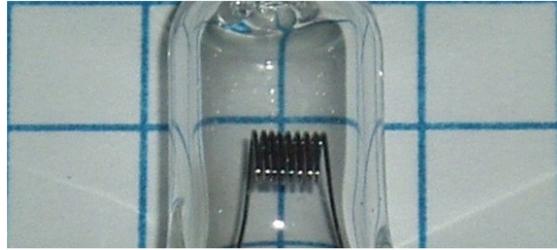


Figure 7. Lamp of Type A after years of intermittent service.

Greybody behavior has been observed in some coiled filament lamps as received. There does not seem to be a way to predict the emissivity behavior before measurement, except that it appears to be consistent within a particular lamp type. The filaments of the lamps that exhibited spectral dependence of emissivity were not very different visibly (other than length) from those that were gray. The filament of a lamp whose emissivity was measured to be gray as received, here designated Type B, is shown below in Figure 8. This filament is also specified as C6.



Figure 8. Filament of Type B lamp on a ¼ inch grid. These have been seen to behave as graybodies on first use.

Summary

Because it governs the amount and color of the light given off, the emissivity of the tungsten filament is the most important parameter in a lamp. We've seen that it is difficult to predict the emissivity's value, and that filaments of the same specifications can have very different emissivity behavior. Some exhibit emissivity changing with wavelength, while others are gray. Some change behavior during their lifetime. This uncertainty makes the illumination behavior of the lamp hard to predict, and the burning temperature unknown to conventional pyrometry.

Fortunately, the FAR SpectroPyrometer has been successful in measuring both the true temperature and the spectral emissivity of the filament no matter which behavior is manifested.

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